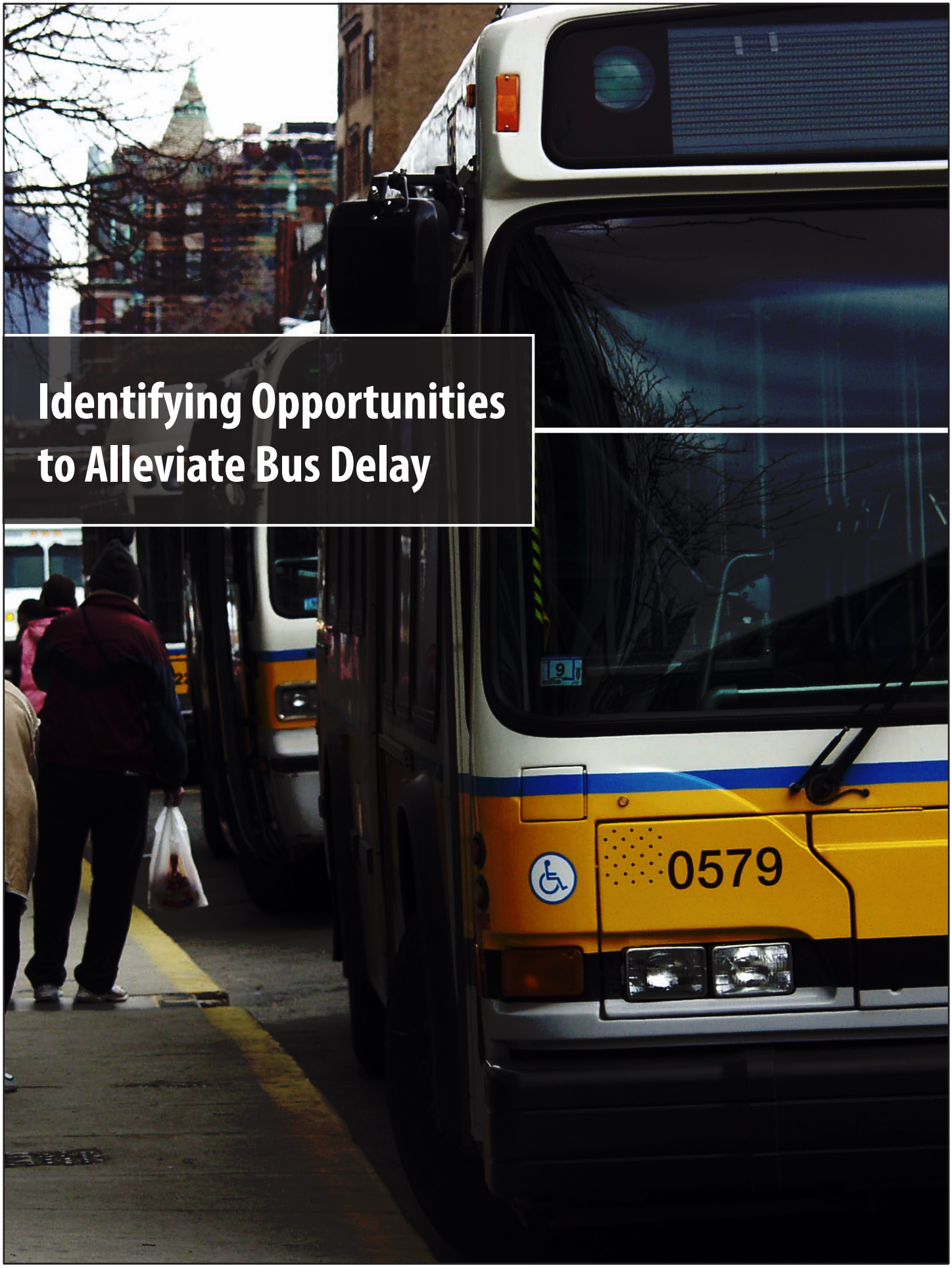

Identifying Opportunities to Alleviate Bus Delay

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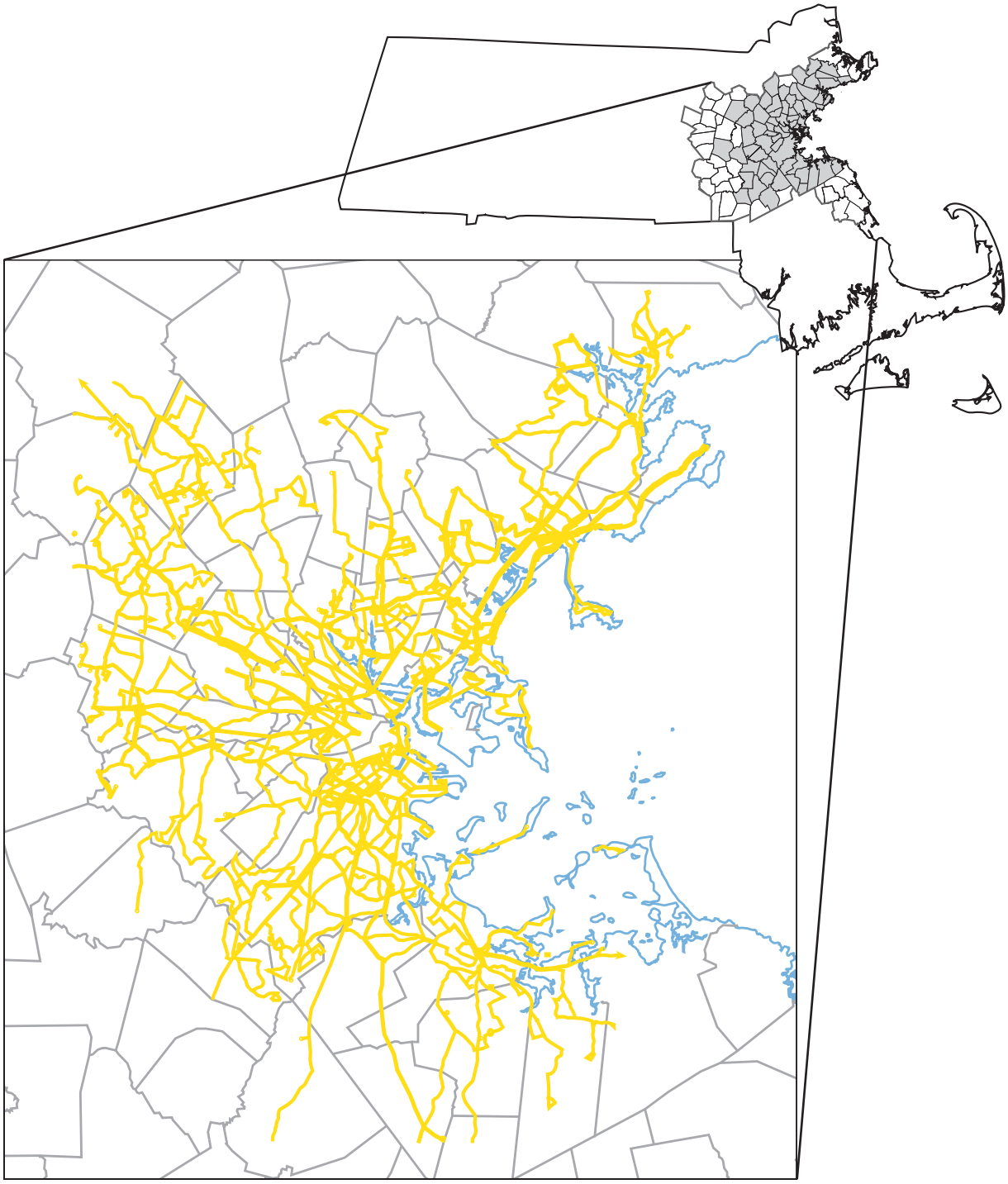

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Abstract

Reliable bus transportation offers mobility, access, and livability benefits to residents throughout the region. However, delays in bus service diminish these benefits. This study seeks to identify opportunities to alleviate existing delays in bus service. To this end, MPO staff 1) examined factors that lead to increased dwell time at bus stops. This included estimating the amount of time contributed by passengers' use of each fare payment type, as well as the time added by boardings of baby carriages, wheeled mobility devices, and portable shopping carts—along with any delay caused by the on-board presence of such items. In addition, staff 2) assessed delay caused by operational and scheduling practices—such as, the scheduling of interlines, scheduling of deadhead movements, on-time performance of garage pull-outs, scheduling of supplemental bus trips, scheduling of bus operator swing-ons, and non-utilization of early pull-up opportunity at trip origins.

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Chapter 1—Executive Summary

Reliable bus transportation offers mobility, access, and livability benefits to residents throughout the region. However, delays in bus service diminish these benefits. Upgrades to infrastructure, such as more efficient fare-collection equipment, as well as operational improvements, such as increasing the effectiveness of scheduling practices, could decrease bus delay, which in turn would improve on-time performance, reduce travel times for transit passengers, and make transit a more attractive travel mode. Using a variety of data sources, the Central Transportation Planning Staff (CTPS) to the Boston Region Metropolitan Planning Organization (MPO) analyzed these factors, and developed solutions to address the specific causes of delay.

Chapter 2 of this report investigates factors that lead to increased dwell time at bus stops by estimating the amount of time contributed by using each fare payment type, and by the boardings and on-board presence of baby carriages, wheeled mobility devices, and portable shopping carts, using observations from a sample of Route 116 and 117 trips. The results from the regression analysis estimate that the baseline boarding time (for a passenger paying with a CharlieCard or CharlieTicket) is about 3.3 seconds. An additional 9.4 seconds is added (12.7 seconds of total boarding time) if the passenger pays with cash, and an additional 6.3 seconds is added (9.6 seconds of total boarding time) if the passenger adds value to their CharlieCard. These results suggest that overall dwell time for the observed trips would be reduced by an estimated 11.3 percent if cash transactions were not permitted and by an approximate 2.6 percent if baby carriages had not boarded. Dwell time accounted for 14.4 percent of total run time. Therefore, staff estimate that total run time for the observed trips would be reduced by only 1.6 percent if cash transactions were not permitted and by 0.4 percent if baby carriages had not boarded.

Chapter 3 of this report assesses delay caused by a series of operational and scheduling practices; the scheduling of interlines, scheduling of deadhead movements, on-time performance of garage pull-outs, scheduling of supplemental trips, scheduling of bus operator swing-ons, and non-utilization of early pull-up opportunity at trip origins.

In analyzing interlines and deadhead movements, CTPS found that 193 of the 364 scheduled weekday interlines from the Charlestown bus district might be considered for de-interlining based on their run time variability observed in fall 2015. In addition, 41 of the 437 scheduled weekday deadhead movements systemwide had median run times greater than their scheduled run times in spring 2016.

In analyzing on-time performance of garage pull-outs, CTPS found that in spring 2016, 31 percent of pull-out trips departed more than three minutes late from the garage; and of these trips, 70 percent of them arrived at the start point of their first vehicle-revenue trip after the scheduled departure time, with an average arrival lateness of 3.9 minutes per trip.

For the analysis of supplemental trips, CTPS provided summaries of origin departure lateness, end-point arrival lateness, and run times, and identified how each trip might be scheduled more effectively. It is important that these trips run as scheduled, as many of them start a string of trips that provide service throughout the PM peak period.

In analyzing bus operator swing-ons, CTPS estimated that swing-ons added an extra 59 seconds to each trip where a swing-on occurred. Staff also found that 24 percent of scheduled swing-ons occurred on trips where the bus arrived at the swing-on location already behind schedule.

In analyzing early pull-up opportunity at trip origins, CTPS found that earlier pull-ups at origins would not contribute to a significant reduction in departure lateness on the routes that staff studied. Of the 25,169 minutes of observed departure lateness, staff estimated that only 1,441 minutes (5.7 percent) would have been saved if buses, that had the opportunity to do so, had pulled up earlier.

Chapter 2—Investigating Factors that Lead to Increased Dwell Time

2.1 DATA COLLECTION—MBTA ROUTES 116 AND 117

MPO field staff (CTPS) conducted manual observations of baby carriage boardings, wheeled mobility device boardings, and portable shopping cart boardings on sample trips of MBTA bus Routes 116 and 117 from January 12, 2016 to January 21, 2016. These observations were paired with dwell times, boarding and alighting counts from on-board Automatic Passenger Counters (APCs), and counts by fare transaction type from the MBTA Automatic Fare Collection (AFC) database. A total of 97 trips of usable data was collected from 23 Route 116 inbound trips, 24 Route 116 outbound trips, 23 Route 117 inbound trips, and 27 Route 117 outbound trips. Appendix A provides a summary of boarding observations for each trip; Table 1 displays a summary of all boarding observations; and Table 2 displays a summary of all load-at-stop observations.

Table 1
Summary of Bus Routes 116 and 117 Boarding Observations
(Sampled Trips from January 12, 2016 to January 21, 2016)

Boarding Type	Total Observations	Percentage of AFC Transactions
CharlieCard	2,253	72.6%
CharlieTicket	673	21.7%
Add-Value	265	8.5%
Pay Cash	178	5.7%
Baby Carriage	42	1.4%
Shopping Cart	7	0.2%
Wheeled Mobility Device	3	0.1%

AFC = Automatic fare collection.

Note: Counts do not include activity at first and last stop of a trip. Add-value transactions are also counted as CharlieCard transactions.

Table 2
Summary of Bus Routes 116 and 117 Load-at-Stop Observations
(Sampled Trips from January 12, 2016 to January 21, 2016)

Load Type	Total Observations	Percentage of Stops
One Baby Carriage on-board	344	11.5%
Two Baby Carriages on-board	89	3.0%
Three Baby Carriages on-board	10	0.3%
One Shopping Cart on-board	95	3.2%
One Wheeled Mobility Device on-board	32	1.1%

Note: Counts do not include activity at first and last stop of a trip.

2.2 Estimating a Dwell Time Regression Model

Using the APC data, AFC data, and data collected from manual observations on sample trips of MBTA Routes 116 and 117, CTPS conducted a regression analysis to estimate the amount of dwell time contributed by a set of variables. Table 3 displays a list of variables that were tested.

Table 3
Variables Tested for the Estimation of a Dwell Time Regression Model

Variable	Definition	Range of Observed Values
APC Dwell	Dwell time in seconds, calculated from APC data as the amount of time between the doors opening and doors closing	3 to 152
AFC Ons	Number of boardings, calculated as the number of AFC transactions	0 to 18
AFC Ticket	Number of CharlieTicket transactions	0 to 5
AFC Cash	Number of cash only transactions	0 to 5
AFC Add-Value	Number of add value to CharlieCard transactions	0 to 4
AFC Noninteraction	Number of APC boardings minus the number of AFC transactions, only when more APC boardings than AFC transactions are recorded	0 to 7
Load Over 30	Number of additional passengers greater than 30 on-board the bus	0 to 36
APC Offs Front	Number of front door alightings	0 to 20
Extra Rear	Extra rear door activity calculated as the number of rear door offs minus the total number of AFC transactions, AFC noninteraction, and front door offs	0 to 10
Carriage Ons	Number of baby carriage boardings	0 to 2
Carriage Offs	Number of baby carriage alightings	0 to 2
Cart Ons	Number of portable shopping cart boardings	0 to 1
Cart Offs	Number of portable shopping cart alightings	0 to 1
Carriage On-board	Number of baby carriages on-board the bus when it leaves the stop	0 to 3
Cart On-board	Number of personal shopping carts on-board the bus when it leaves the stop	0 to 1
WMD On-board	Number of wheeled mobility devices on-board the bus when it leaves the stop	0 to 1

AFC = Automatic fare collection. APC = Automatic passenger counters. WMD = Wheeled mobility devices.

CTPS estimated an ordinary least squares linear regression model[1]. The first and last stop of each trip and stops that included a wheeled mobility device boarding or alighting were removed from the regression analysis, as bus doors are often left open for a longer period of time than is required to board and alight passengers at the first and last stop, and the procedure to board or alight a wheeled mobility device may alter the typical manner in which additional

[1] Ordinary least squares is a method for estimating the unknown parameters in a linear regression model.

customers at the stop board and alight. The functional form of the model is shown below, and its coefficients are shown in Table 4.

$$APC\ Dwell = \beta_0 + \beta_i(AFC\ Ons) + \beta_i(AFC\ Cash) + \beta_i(AFC\ Add) + \beta_i(AFC\ Noninteraction) + \beta_i(APC\ Offs\ Front) + \beta_i(Load\ Over\ 30) + \beta_i(Extra\ Rear) + \beta_i(Carriage\ Ons) + \beta_i(Carriage\ Offs)$$

Table 4
Coefficients of the Dwell Time Regression Model

Variable	Estimate	Standard Error	p-value
Intercept	3.70	0.35	< 2.0E-16
AFC Ons	3.32	0.14	< 2.0E-16
AFC Cash	9.38	0.64	< 2.0E-16
AFC Add-Value	6.29	0.59	< 2.0E-16
AFC Noninteraction	3.23	0.31	< 2.0E-16
Load Over 30	0.30	0.06	1.7E-07
APC Offs Front	2.82	0.17	< 2.0E-16
Extra Rear	1.34	0.25	1.2E-07
Carriage Ons	9.63	1.45	4.1E-11
Carriage Offs	7.18	1.32	6.1E-08

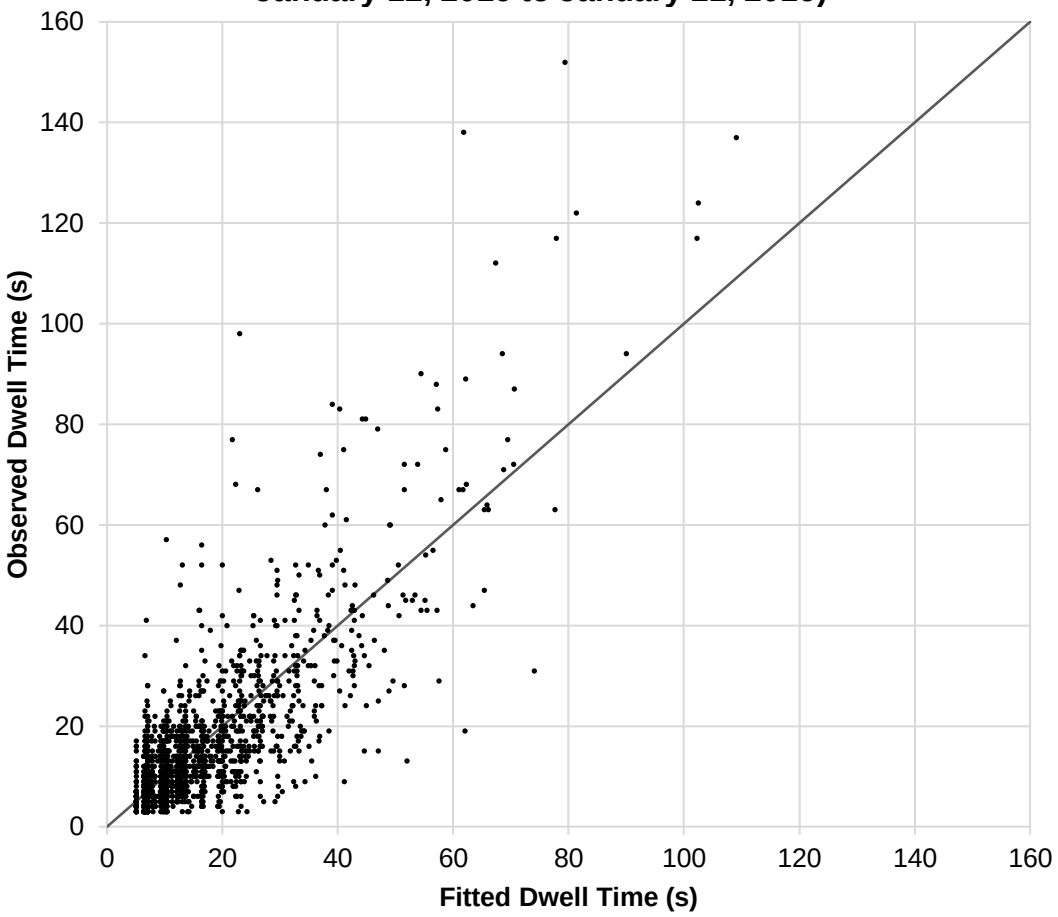
AFC = Automatic fare collection. APC = Automatic passenger counters.
Note: Multiple R-squared = 0.641, degrees of freedom = 1,785.

The results from the regression analysis estimate that the baseline boarding time (for a passenger paying with a CharlieCard or CharlieTicket) is about 3.3 seconds. An additional 9.4 seconds is added (12.7 seconds of total boarding time) if the passenger pays with cash, and an additional 6.3 seconds is added (9.6 seconds of total boarding time) if the passenger adds value to their CharlieCard. When the variable representing the number of CharlieTicket transactions was included in the model, it was well outside of a five percent confidence level, suggesting that CharlieCard and CharlieTicket transactions take a similar amount of time to complete. Furthermore, the model estimates that dwell times increase as passenger loads increase, once loads are greater than 30 passengers[2], at a rate of about 0.3 seconds per additional passenger, and that baby carriages contribute 9.6 seconds when boarding and 7.2 seconds when alighting.

[2] CTPS chose a load of 30 passengers to represent the point at which standees might typically start to form on-board a bus, thus impeding boarding and alighting passengers. However, a regression tree analysis, and the testing of multiple load variables at different break points did not find any one break point to be conclusively significant over another. CTPS hypothesize that this may be a result of low sampling at certain ranges of passenger load.

Figure 1 displays the relationship between observed dwell time and fitted dwell time. From Figure 1 it appears that the model tends to underestimate when observed dwell times are long. This is because observations with long dwell times are more likely to include additional delay factors that were not specified in the model.

Figure 1
Observed and Fitted Dwell Time
(Sampled Trips from Bus Routes 116 and 117, January 12, 2016 to January 21, 2016)



The coefficients estimated by the dwell time regression model were applied to the dataset to estimate the total contribution to dwell time and run time[3] for each variable, shown in Table 5[4]. The results estimate that overall dwell time for the observed trips would be reduced by 11.4 percent if cash transactions (pay cash and add-value) were not permitted and by 1.5 percent if baby carriages had not boarded. Dwell time accounted for 15.6 percent of total run time. Therefore, it is estimated that total run time for the observed trips would be reduced by 1.8 percent if cash transactions were not permitted and by 0.2 percent if baby carriages had not boarded.

Table 5
Estimation of Total Dwell Time and Run Time Contribution
(Sampled Trips from Bus Routes 116 and 117, January 12, 2016 to January 21, 2016)

	Total Dwell Contribution (seconds)	Percentage of Total Dwell Time	Percentage of Total Run Time
Intercept	6,763	21.3%	3.3%
AFC Ons	12,685	40.0%	6.2%
AFC Cash	1,762	5.6%	0.9%
AFC Add-Value	1,834	5.8%	0.9%
AFC Noninteraction	1,798	5.7%	0.9%
Load Over 30	842	2.7%	0.4%
APC Offs Front	4,483	14.1%	2.2%
Extra Rear	709	2.2%	0.3%
Carriage Ons	477	1.5%	0.2%
Carriage Offs	352	1.1%	0.2%

AFC = Automatic fare collection. APC = Automatic passenger counters.
Note: Three boardings and three alightings of wheeled mobility devices were observed. The combined dwell time for these observations was 502 seconds, accounting for 1.6 percent of total observed dwell time (0.2 percent of total run time).

The relatively small impact of cash transactions on total run time suggests that fare system upgrades that eliminate on-board cash transactions may improve reliability for specific trips or during certain time periods that experience relatively high cash usage. However, these upgrades likely would not reduce run times on the observed trips to a degree that allows service to be scheduled more frequently with the same amount of resources (unless significant time savings are achieved through all-door boarding). Figure 2 shows that the estimated amount of time added by pay cash and add value transactions was less than two minutes for all observed trips, with the largest estimated amount of time added for a single trip being 2.0 minutes (4.7 percent of that trip's total run time). Figure 2 also shows that trips with relatively larger estimated amounts of time added

[3] Total run time for the trips that were observed may have been increased by buses waiting for the Andrew McArdle Bridge to reopen when allowing commercial maritime vessels to pass.
[4] Activity at the first stop of each trip was included if it occurred after the trip's scheduled departure time, and excluded if the trip left before or at its scheduled departure time.

because of pay cash and add value transactions tended to occur during the midday period of service, with less of an effect during the AM peak and PM peak periods of service.

Figure 3 shows that the estimated amount of time added by baby carriage boardings and alightings was less than one minute for all observed trips, with the largest estimated amount of time added for a single trip being 0.8 minutes (1.2 percent of that trip's total run time). Figure 3 also shows that, as with trips that have relatively larger estimated amounts of time added because of pay cash and add value transactions, trips with relatively larger amounts of time added because of baby carriage boardings and alightings tended to occur during the midday period of service, with less of an effect during the AM peak and PM peak periods of service. Figure 4 shows that the estimated amount of time added by pay cash and add value transactions and baby carriage boardings and alightings combined was less than 2.5 minutes for all observed trips, with the largest estimated amount of time added for a single trip being 2.3 minutes (5.4 percent of that trip's total run time).

The variables representing shopping cart boardings and alightings, baby carriages on-board, shopping carts on-board, and wheeled mobility devices on-board were not significant at a five percent confidence level when included in the model; however, this does not necessarily mean that these variables are not significant contributors to dwell time in the real world. It is possible that the dataset did not contain enough observations of these variables to estimate their effects5. Because the on-board presence of baby carriages, shopping carts, and wheeled mobility devices were not significant contributors to the model, no conclusions on their effect on dwell time can be drawn, and it remains unclear whether a seating arrangement designed to provide more room for these devices might produce an overall decrease in dwell time.

The results of this analysis are contingent on the observations of only two bus routes, and a short observation period of seven weekdays6. Therefore, these results are not meant to reflect the MBTA system as a whole, as the effect and rate at which the variables in the model occur likely would vary geographically and temporally.

[5] An analysis of variance was performed between the chosen model and a set of nested models containing each of the variables that were excluded. A nested model containing both the Cart Ons and Cart Offs variables was shown to have a significant reduction in the residual sum of squares at a five percent confidence level, and a nested model containing the Carriage On-board variable was shown to have a significant reduction in the residual sum of squares at a ten percent confidence level.

[6] Observations from 97 bus trips were used for this analysis. The MBTA runs approximately 4 million bus trips annually.

Figure 2
Estimated Delay from Pay Cash and Add Value Transactions by Trip
(Sampled Trips from Bus Routes 116 and 117,
January 12, 2016 to January 21, 2016)

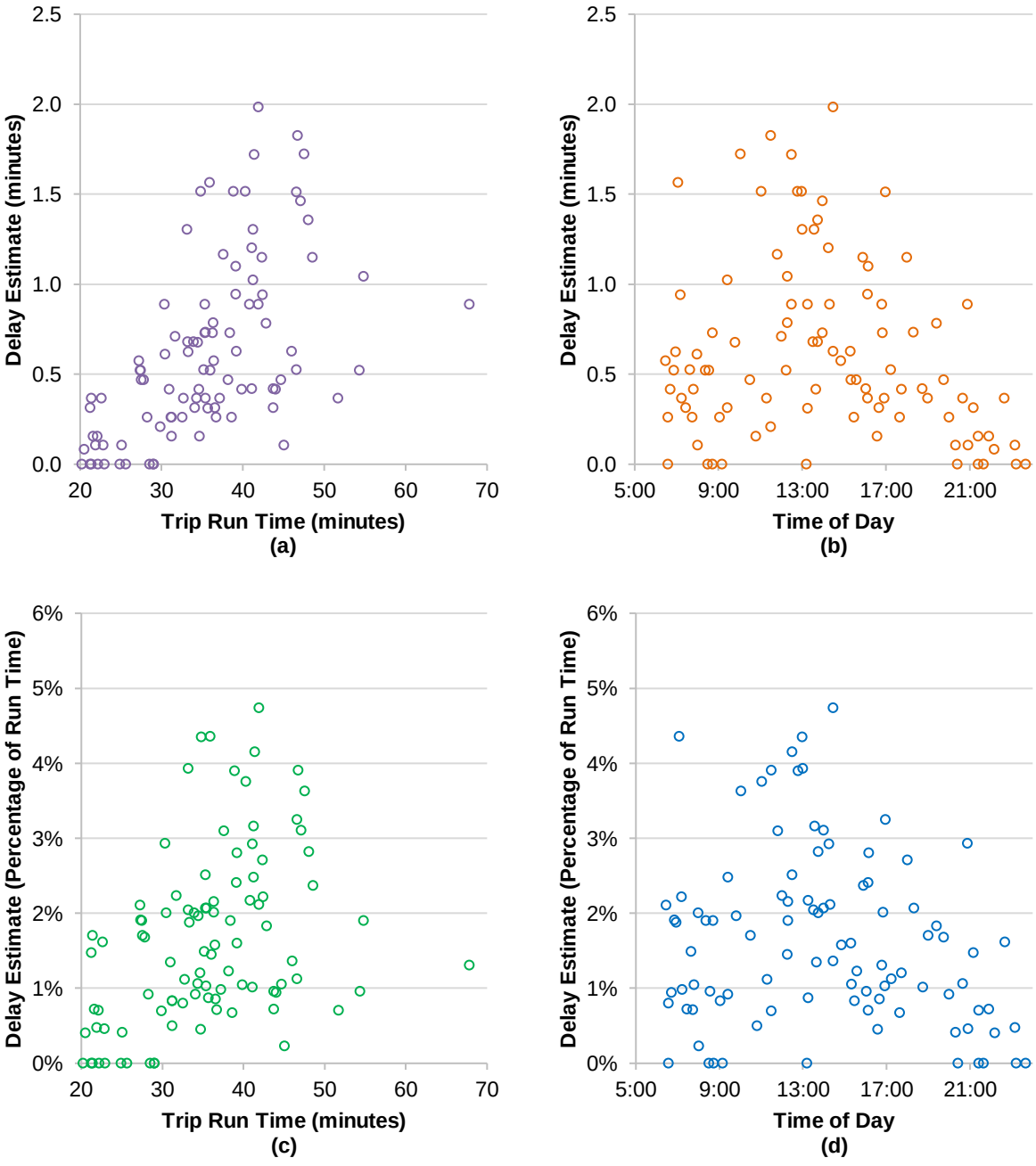


Figure 3
Estimated Delay from Baby Carriage Boardings and Alightings by Trip
(Sampled Trips from Bus Routes 116 and 117,
January 12, 2016 to January 21, 2016)

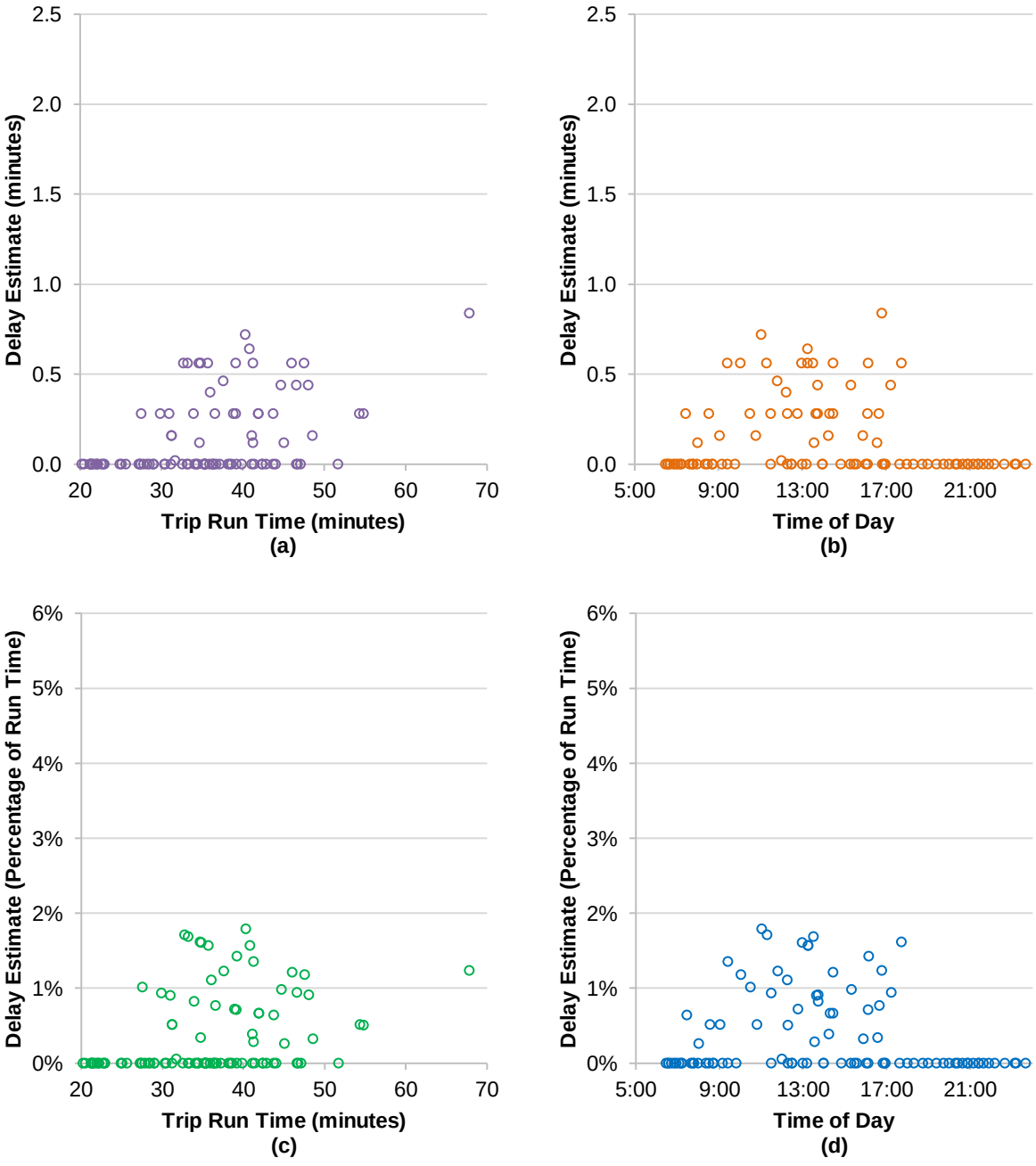
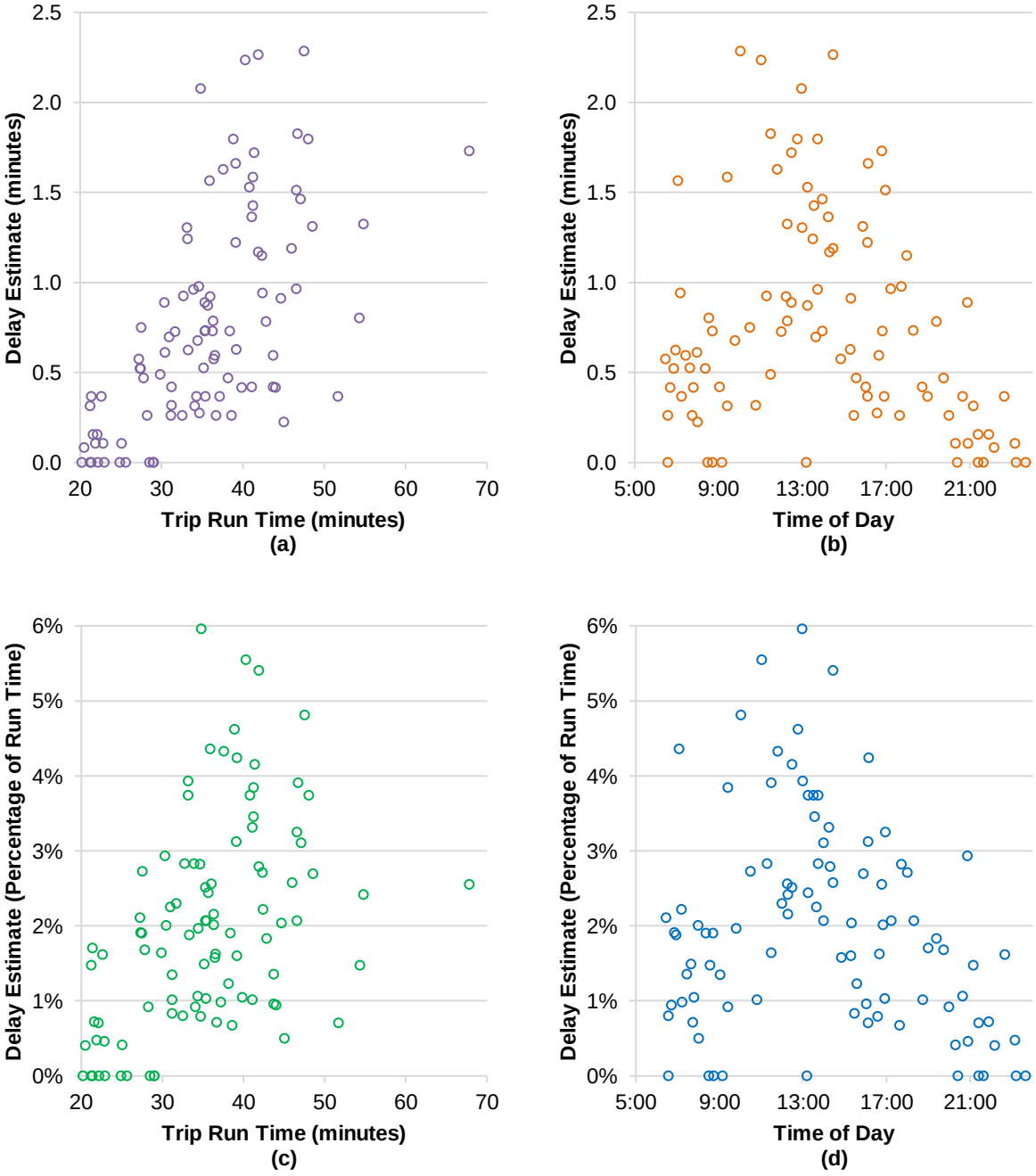


Figure 4
Estimated Delay from Pay Cash and Add Value Transactions and Baby Carriage Boardings and Alightings by Trip
(Sampled Trips from Bus Routes 116 and 117, January 12, 2016 to January 21, 2016)



Chapter 3—Assessing Operational and Scheduling Improvements to Alleviate Bus Delay

CTPS assessed areas where improvements to operational and scheduling practices can be made to alleviate bus delay, including (3.1) interlines, (3.2) deadhead movements, (3.3) garage pull-outs, (3.4) supplemental trips, (3.5) bus operator swing-ons, and (3.6) early pull-up opportunity.

3.1 INTERLINES

An interline is when a vehicle is scheduled to complete a trip on one route and conduct its next trip on another route, either between two routes that share a common start/end point or through a deadhead movement. The benefit of interlining is that it allows resources to be utilized more efficiently, with less vehicle movements to and from the garage. A negative effect of interlining is the possibility that a route/corridor with normally reliable service can take on the delay from a route/corridor with poor on-time performance. From a customer-experience perspective, it is generally preferred that customers on one route/corridor are not negatively impacted by recurring delay from another route/corridor, and that routes with poor reliability are self-contained.

The MBTA uses the Horaires et Assignments pour Systems de Transport Urban et Semi-Urban (HASTUS) scheduling software to automatically block (form the string of trips that is assigned to an individual bus) and assign runs (the string of trips that is assigned to an individual operator) to build bus schedules for each bus district. The automatic blocking capabilities of HASTUS provide an opportunity to automatically schedule interlines into each garage's schedule. CTPS was tasked with assessing run-time variability of trips to provide a list of suggested trips that should not be coded for interlining (assuming that proper run times, recovery times, and other factors are programmed into HASTUS for each trip). CTPS assessed the run-time variability of trips from the Charlestown bus district using fall 2015 Automatic Vehicle Location (AVL) data provided by the MBTA.

Staff utilized two thresholds to assess run-time variability; the 80 percentile run time compared to 120 percent of the scheduled run time if a trip is to be interlined at its end point, and the 90 percentile run time compared to 120 percent of the scheduled run time if a trip is to be interlined with a deadhead movement, to account for additional variability in the deadhead run time. Trips that do not pass these thresholds are not meant to form a definitive list of trips that should not be

interlined, as there are scheduling techniques that may reduce the impact of run-time variability, such as increasing the scheduled recovery time. At most, the summary of trips based on these thresholds should be used to identify trips, routes, locations, and times of day where extra attention might be warranted.

Table 6 provides a summary of run-time variability by route; Table 7 provides a summary of run-time variability by trip end point; and Table 8 provides a summary of run-time variability by trip end time for trips from the Charlestown bus district.

Table 6
Run-Time Variability by Route—Charlestown District, Fall 2015

Route	Dir.	Scheduled Weekday Trips	Number of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Number of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time
89	In	33	18	25	55%	76%
89	Out	28	14	18	50%	64%
89-2	In	32	27	29	84%	91%
89-2	Out	32	2	3	6%	9%
89-4	Out	1	0	0	0%	0%
90	In	19	1	3	5%	16%
90	Out	19	2	8	11%	42%
91	In	36	24	30	67%	83%
91	Out	35	27	32	77%	91%
91-7	In	6	3	5	50%	83%
91-7	Out	7	4	4	57%	57%
92-1	In	15	3	8	20%	53%
92-1	Out	13	6	9	46%	69%
92-3	In	22	13	16	59%	73%
92-3	Out	24	11	16	46%	67%
92-7	In	3	0	1	0%	33%
92-7	Out	2	0	1	0%	50%
93	Out	2	1	1	50%	50%
93-1	In	56	28	41	50%	73%
93-1	Out	55	24	42	44%	76%
93-2	In	12	9	12	75%	100%
93-2	Out	13	12	13	92%	100%
93-7	In	8	1	3	13%	38%
93-7	Out	8	1	5	13%	63%
94-1	In	11	2	3	18%	27%
94-1	Out	10	8	9	80%	90%
95	In	8	0	2	0%	25%
95	Out	9	2	4	22%	44%
95-5	Out	1	1	1	100%	100%
96	In	14	11	13	79%	93%

Route	Dir.	Scheduled Weekday Trips	Number of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Number of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time
96	Out	14	3	5	21%	36%
99-7	In	6	2	5	33%	83%
99-7	Out	7	0	1	0%	14%
100-3	In	9	1	3	11%	33%
100-3	Out	8	1	3	13%	38%
101-1	In	4	2	2	50%	50%
101-1	Out	2	2	2	100%	100%
101-2	Out	4	3	3	75%	75%
101-3	In	39	32	36	82%	92%
101-3	Out	32	15	19	47%	59%
101-4	In	13	7	9	54%	69%
101-4	Out	18	9	12	50%	67%
104	In	48	25	30	52%	63%
104	Out	45	18	26	40%	58%
105-1	In	1	0	0	0%	0%
105-1	Out	1	0	0	0%	0%
106	In	7	0	4	0%	57%
106	Out	24	9	11	38%	46%
106-3	In	19	11	13	58%	68%
106-4	In	1	1	1	100%	100%
106-4	Out	1	0	0	0%	0%
106-6	Out	1	0	0	0%	0%
106-7	In	11	8	11	73%	100%
106-7	Out	10	2	5	20%	50%
108-6	In	7	3	3	43%	43%
108-6	Out	8	2	3	25%	38%
109	In	52	19	35	37%	67%
109	Out	48	34	38	71%	79%
109-1	In	2	1	1	50%	50%
109-1	Out	8	0	1	0%	13%
110	In	36	19	23	53%	64%
110	Out	35	7	11	20%	31%
110-2	Out	2	1	1	50%	50%
110-4	In	13	9	11	69%	85%
110-4	Out	11	9	10	82%	91%
111-2	In	66	36	46	55%	70%
111-2	Out	72	45	52	63%	72%
111-5	In	88	61	69	69%	78%
111-5	Out	78	27	41	35%	53%
111-6	In	27	22	26	81%	96%
111-8	In	19	1	5	5%	26%
111-8	Out	24	11	14	46%	58%
112	In	20	7	10	35%	50%
112	Out	21	5	11	24%	52%
112-3	Out	1	0	0	0%	0%

Route	Dir.	Scheduled Weekday Trips	Number of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Number of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time
132	In	1	0	0	0%	0%
132	Out	1	1	1	100%	100%
134-5	In	3	1	2	33%	67%
134-5	Out	3	0	1	0%	33%
134-6	In	1	1	1	100%	100%
134-7	In	5	3	4	60%	80%
134-7	Out	7	1	1	14%	14%
136-4	In	2	1	2	50%	100%
136-4	Out	2	0	0	0%	0%
136-5	In	1	0	0	0%	0%
136-5	Out	1	0	0	0%	0%
137-3	In	2	0	0	0%	0%
137-3	Out	2	0	1	0%	50%
194	In	1	0	0	0%	0%
325	In	7	2	3	29%	43%
325	Out	7	7	7	100%	100%
325-1	In	9	7	7	78%	78%
325-1	Out	6	0	1	0%	17%
325-2	Out	3	3	3	100%	100%
326	In	6	0	0	0%	0%
326	Out	11	11	11	100%	100%
326-1	In	12	12	12	100%	100%
326-1	Out	5	2	4	40%	80%
326-2	Out	1	0	1	0%	100%
352	In	9	5	5	56%	56%
352	Out	8	7	8	88%	100%
354-4	Out	1	0	0	0%	0%
411-1	In	1	1	1	100%	100%
411-1	Out	1	1	1	100%	100%
411-8	In	1	0	0	0%	0%
411-8	Out	1	0	0	0%	0%
430-1	In	1	1	1	100%	100%
430-1	Out	1	1	1	100%	100%
430-2	In	2	2	2	100%	100%
430-2	Out	2	1	2	50%	100%
608	In	60	1	1	2%	2%
Total		**1,684**	**797**	**1,053**	**47%**	**63%**

Table 7
Run-Time Variability by Trip End Point—Charlestown District, Fall 2015

Trip End Point	Scheduled Weekday Trips	Number of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Number of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time
sull	378	211	283	56%	75%
hayms	246	142	172	58%	70%
welst	158	64	94	41%	59%
malst	108	48	64	44%	59%
milk	105	53	77	50%	73%
woodc	80	28	42	35%	53%
wacry	72	45	52	63%	72%
davis	62	6	14	10%	23%
haymg	60	1	1	2%	2%
lindn	56	36	41	64%	73%
cntsq	42	27	35	64%	83%
wondw	35	7	11	20%	31%
bwypk	35	20	24	57%	69%
medfd	34	14	18	41%	53%
clarh	29	14	18	48%	62%
plast	25	15	19	60%	76%
leban	25	9	11	36%	44%
elm	21	8	11	38%	52%
woodi	20	7	10	35%	50%
bally	14	11	13	79%	93%
amall	13	6	9	46%	69%
fklin	10	2	5	20%	50%
statx	9	5	5	56%	56%
chnut	9	7	8	78%	89%
glndl	8	0	1	0%	13%
uphgh	7	0	1	0%	14%
wnbrk	5	4	4	80%	80%
nwobn	3	0	1	0%	33%
saug	3	2	3	67%	100%
readc	3	0	1	0%	33%
rosec	3	3	3	100%	100%
wakef	2	0	0	0%	0%
rdstn	1	1	1	100%	100%
grana	1	1	1	100%	100%
lwdly	1	0	0	0%	0%
revhs	1	0	0	0%	0%
Total	**1,684**	**797**	**1,053**	**47%**	**63%**

Table 8
Run-Time Variability by Trip End Time—Charlestown District, Fall 2015

Trip End Time	Scheduled Weekday Trips	Number of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Number of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 80 Percentile Run Time Greater than 120 Percent of Scheduled Run Time	Percentage of Trips with 90 Percentile Run Time Greater than 120 Percent of Scheduled Run Time
4:00-4:59	2	0	0	0%	0%
5:00-5:59	71	21	35	30%	49%
6:00-6:59	96	45	56	47%	58%
7:00-7:59	121	81	95	67%	79%
8:00-8:59	128	81	96	63%	75%
9:00-9:59	101	40	61	40%	60%
10:00-10:59	55	16	28	29%	51%
11:00-11:59	58	16	30	28%	52%
12:00-12:59	55	14	25	25%	45%
13:00-13:59	54	8	15	15%	28%
14:00-14:59	66	28	41	42%	62%
15:00-15:59	91	53	73	58%	80%
16:00-16:59	123	89	100	72%	81%
17:00-17:59	140	109	118	78%	84%
18:00-18:59	127	81	96	64%	76%
19:00-19:59	92	31	53	34%	58%
20:00-20:59	71	20	34	28%	48%
21:00-21:59	61	18	33	30%	54%
22:00-22:59	58	19	27	33%	47%
23:00-23:59	50	14	21	28%	42%
24:00-24:59	46	10	11	22%	24%
25:00-25:59	18	3	5	17%	28%
Total	**1,684**	**797**	**1,053**	**47%**	**63%**

Table 9 provides a list of fall 2015 trips that were scheduled as a lead in to a non-deadhead interline that did not pass the 80 percentile run-time comparison to the 120 percent of the scheduled run-time threshold (147 out of 290 such trips).

Table 9
Trips Leading into Non-Deadhead Interlines that Do Not Pass the Run-Time Variability Threshold—Charlestown District, Fall 2015

Route	Dir.	Start Time	Number of Obs.	80 Percentile Run Time (min.)	120 Percent of Scheduled Run Time (min.)	80 Percentile Run Time Minus 120 Percent of Scheduled Run Time (min.)
101-3	In	7:23	31	46.9	31.2	15.7
101-3	In	7:10	57	46.8	31.2	15.6
104	In	24:41	57	38.3	22.8	15.5
93-2	In	15:58	44	33.9	20.4	13.5
101-3	Out	14:07	5	61.1	48	13.1
106-3	In	7:33	54	52.6	40.8	11.8
89	In	7:45	59	35.8	25.2	10.6
101-3	In	6:50	41	41.5	31.2	10.3
101-3	In	7:42	55	44.7	34.8	9.9
89-2	In	7:39	55	29.5	20.4	9.1
101-3	In	8:18	56	48.1	39.6	8.5
101-3	In	16:32	43	39.6	31.2	8.4
110	In	7:18	55	45.5	37.2	8.3
106-3	In	7:10	59	51.4	43.2	8.2
101-3	In	8:30	52	44.0	36	8.0
89-2	In	8:15	51	28.2	20.4	7.8
101-3	In	7:54	53	47.1	39.6	7.5
89	In	7:27	57	31.1	24	7.1
93-1	In	7:19	39	28.4	21.6	6.8
101-3	In	15:35	50	37.6	31.2	6.4
104	In	16:44	51	37.6	31.2	6.4
91	Out	16:05	47	29.1	22.8	6.3
89	In	16:55	46	29.0	22.8	6.2
325	In	16:15	49	33.8	27.6	6.2
106-3	In	7:57	55	43.3	37.2	6.1
101-3	In	15:05	54	36.6	31.2	5.4
93-1	In	15:30	54	25.7	20.4	5.3
89	In	14:43	56	26.7	21.6	5.1
89-2	In	18:04	55	23.1	18	5.1
89	In	7:09	55	27.9	22.8	5.1
101-4	Out	8:40	5	48.3	43.2	5.1
101-3	In	6:30	57	32.5	27.6	4.9
91	Out	14:45	43	27.6	22.8	4.8
93-1	Out	7:53	43	26.4	21.6	4.8
112	Out	7:20	55	58.6	54	4.6
89-2	In	17:28	54	25.9	21.6	4.3

Route	Dir.	Start Time	Number of Obs.	80 Percentile Run Time (min.)	120 Percent of Scheduled Run Time (min.)	80 Percentile Run Time Minus 120 Percent of Scheduled Run Time (min.)
91	Out	17:35	55	28.2	24	4.2
104	In	17:44	37	31.8	27.6	4.2
134-5	In	6:10	47	49.6	45.6	4.0
110	In	16:44	56	38.8	34.8	4.0
104	In	16:05	17	35.1	31.2	3.9
109	In	16:45	34	30.0	26.4	3.6
106-3	In	5:30	57	30.0	26.4	3.6
92-3	Out	16:24	43	27.6	24	3.6
92-3	Out	16:09	42	24.0	20.4	3.6
101-3	In	6:40	9	31.1	27.6	3.5
89-2	In	15:13	56	25.0	21.6	3.4
104	In	14:00	57	40.6	37.2	3.4
110	In	18:25	56	33.3	30	3.3
430-2	In	22:25	54	30.9	27.6	3.3
92-1	In	15:26	54	34.5	31.2	3.3
104	In	20:40	53	25.9	22.8	3.1
93-2	Out	8:38	51	24.6	21.6	3.0
109	In	14:55	54	31.8	28.8	3.0
91	Out	13:45	53	23.4	20.4	3.0
93-1	Out	16:45	54	28.2	25.2	3.0
91	Out	18:05	39	26.8	24	2.8
91-7	Out	19:45	53	19.5	16.8	2.7
92-3	Out	8:32	27	21.9	19.2	2.7
93-1	Out	7:10	50	21.9	19.2	2.7
111-2	In	16:31	51	21.8	19.2	2.6
92-3	Out	17:39	55	27.8	25.2	2.6
104	In	18:15	44	27.8	25.2	2.6
93-1	Out	19:05	55	25.4	22.8	2.6
92-3	Out	15:54	54	23.0	20.4	2.6
109	In	5:21	53	25.3	22.8	2.5
93-2	Out	18:05	56	28.9	26.4	2.5
91	Out	18:30	51	25.3	22.8	2.5
92-3	In	7:35	43	26.4	24	2.4
93-1	In	15:45	43	22.8	20.4	2.4
89-2	In	21:25	56	19.2	16.8	2.4
109	In	13:40	38	31.2	28.8	2.4
92-3	Out	16:39	55	27.5	25.2	2.3
93-1	Out	17:10	46	31.0	28.8	2.2
101-4	In	13:06	54	33.4	31.2	2.2
89-2	In	13:30	54	20.1	18	2.1
89-2	In	16:30	52	23.7	21.6	2.1
91-7	Out	22:15	56	16.5	14.4	2.1
93-2	Out	14:25	56	27.2	25.2	2.0
89	In	16:36	45	27.2	25.2	2.0

Route	Dir.	Start Time	Number of Obs.	80 Percentile Run Time (min.)	120 Percent of Scheduled Run Time (min.)	80 Percentile Run Time Minus 120 Percent of Scheduled Run Time (min.)
91	Out	7:15	49	19.9	18	1.9
101-3	In	17:08	4	33.1	31.2	1.9
104	Out	17:52	46	35.5	33.6	1.9
91	Out	7:45	59	19.9	18	1.9
104	In	5:11	50	23.5	21.6	1.9
93-1	Out	6:56	49	21.0	19.2	1.8
93-1	Out	17:17	53	29.4	27.6	1.8
89	In	11:52	55	23.4	21.6	1.8
91	Out	8:15	54	19.8	18	1.8
93-2	Out	13:25	55	25.8	24	1.8
89-2	In	16:07	56	23.3	21.6	1.7
93-1	Out	8:08	53	23.3	21.6	1.7
89	In	18:56	50	24.5	22.8	1.7
110-4	In	5:36	48	22.0	20.4	1.6
93	Out	5:03	51	11.2	9.6	1.6
110-4	In	17:48	56	23.2	21.6	1.6
430-2	In	21:00	57	37.5	36	1.5
93-1	Out	8:15	49	23.1	21.6	1.5
411-1	In	18:25	56	18.3	16.8	1.5
104	In	19:45	57	24.3	22.8	1.5
91	Out	8:40	53	19.5	18	1.5
109	In	7:16	42	42.3	40.8	1.4
89	In	8:40	55	26.6	25.2	1.4
91	Out	12:35	55	21.8	20.4	1.4
106-3	In	6:30	56	35.0	33.6	1.4
110-2	Out	14:17	18	27.8	26.4	1.4
89-2	In	19:55	56	18.1	16.8	1.3
93-1	Out	17:01	52	30.1	28.8	1.3
92-3	Out	8:47	46	20.5	19.2	1.3
93-2	Out	7:28	54	22.8	21.6	1.2
104	In	15:05	33	32.4	31.2	1.2
112	Out	18:00	55	51.6	50.4	1.2
93-1	Out	17:49	47	27.5	26.4	1.1
134-7	In	21:15	56	13.0	12	1.0
94-1	In	21:15	54	17.8	16.8	1.0
134-7	In	20:15	56	12.9	12	0.9
110	In	7:48	55	38.1	37.2	0.9
92-3	Out	16:54	37	29.7	28.8	0.9
109	In	21:10	56	22.5	21.6	0.9
109	In	18:15	48	22.4	21.6	0.8
93-1	In	7:33	45	26.0	25.2	0.8
91	Out	9:00	15	20.0	19.2	0.8
134-7	In	23:15	59	11.5	10.8	0.7
104	In	6:55	13	39.1	38.4	0.7

Route	Dir.	Start Time	Number of Obs.	80 Percentile Run Time (min.)	120 Percent of Scheduled Run Time (min.)	80 Percentile Run Time Minus 120 Percent of Scheduled Run Time (min.)
89-2	In	6:03	51	16.3	15.6	0.6
110-4	In	6:12	57	25.8	25.2	0.6
93-7	Out	23:25	51	13.8	13.2	0.6
104	Out	14:50	50	37.8	37.2	0.6
104	In	19:20	49	24.6	24	0.6
93-1	Out	16:37	59	24.5	24	0.5
92-1	In	15:38	43	31.7	31.2	0.5
92-1	In	16:10	50	31.7	31.2	0.5
91	Out	6:50	56	13.7	13.2	0.5
93-1	Out	17:33	55	26.9	26.4	0.5
101-4	In	9:44	52	36.4	36	0.4
94-1	Out	5:39	30	13.6	13.2	0.4
101-1	Out	18:53	13	20.8	20.4	0.4
100-3	In	6:00	52	14.7	14.4	0.3
94-1	Out	24:10	47	17.1	16.8	0.3
93-1	Out	15:40	55	24.3	24	0.3
93-1	Out	16:04	52	24.3	24	0.3
111-5	In	18:25	40	25.5	25.2	0.3
325	In	16:35	54	27.9	27.6	0.3
92-3	Out	17:09	43	30.2	30	0.2
89-2	In	10:17	57	19.4	19.2	0.2
93-1	Out	18:35	49	23.0	22.8	0.2
104	Out	15:10	45	34.9	34.8	0.1

Table 10 provides a list of fall 2015 trips that were scheduled as a lead-in to an interline that required a deadhead movement that did not pass the 90 percentile run-time comparison to the120 percent of the scheduled run-time threshold (46 out of 74 such trips).

Table 10
Trips Leading into Deadhead Interlines that Do Not Pass the Run-Time Variability Threshold—Charlestown District, Fall 2015

Route	Dir.	Start Time	Number of Obs.	90 Percentile Run Time (min.)	120 Percent of Scheduled Run Time (min.)	90 Percentile Run Time Minus 120 Percent of Scheduled Run Time (min.)
326	Out	18:35	50	39.8	19.2	20.6
352	Out	15:20	50	53.6	38.4	15.2
134-6	In	7:25	44	40.5	27.6	12.9
110	In	7:08	56	49.5	37.2	12.3
352	In	8:30	46	58.7	46.8	11.9
101-4	Out	21:30	9	43.1	32.4	10.7
111-5	In	6:37	53	41.8	31.2	10.6
326	Out	17:53	48	30.6	20.4	10.2
91	Out	15:05	47	32.7	22.8	9.9
110	In	7:28	56	46.1	37.2	8.9
325-2	Out	18:10	43	30.5	22.8	7.7
109	In	14:15	54	36.0	28.8	7.2
101-3	In	14:35	56	41.8	34.8	7.0
352	Out	17:35	51	51.4	44.4	7.0
111-2	In	15:50	50	25.5	19.2	6.3
101-2	Out	7:10	52	24.2	18	6.2
101-2	Out	7:20	53	24.1	18	6.1
101-3	In	8:06	4	44.3	38.4	5.9
101-3	In	14:50	17	38.0	32.4	5.6
91	Out	11:50	53	25.4	20.4	5.0
101-3	In	15:50	44	36.2	31.2	5.0
326-1	In	7:20	54	32.5	27.6	4.9
136-4	In	6:00	33	33.5	28.8	4.7
93-2	Out	8:48	40	25.8	21.6	4.2
136-4	In	5:30	52	32.9	28.8	4.0
106-7	In	10:15	42	49.4	45.6	3.8
106-3	In	17:16	55	39.7	36	3.7
104	Out	16:22	56	42.1	38.4	3.7
111-6	In	6:23	57	24.0	20.4	3.6
91	Out	13:20	54	23.9	20.4	3.5
111-5	Out	18:55	9	30.8	27.6	3.2
95-5	Out	7:00	43	17.6	14.4	3.2
110-4	In	6:30	57	28.3	25.2	3.1
104	Out	22:15	56	25.6	22.8	2.8
101-3	In	14:09	56	38.7	36	2.7
111-6	In	6:06	56	22.9	20.4	2.4
111-6	In	6:13	48	22.8	20.4	2.4
112	Out	8:40	48	56.2	54	2.2
101-4	In	12:33	48	36.8	34.8	2.0
104	Out	19:20	44	30.5	28.8	1.7
89	In	15:25	56	26.7	25.2	1.5
104	In	17:14	48	32.3	31.2	1.1
93-1	Out	6:36	55	20.2	19.2	1.0
104	In	14:45	57	34.6	33.6	1.0
326-1	In	6:25	59	25.0	24	1.0
106-4	In	18:33	45	11.2	10.8	0.4

3.2 DEADHEAD MOVEMENTS

Unlike vehicle-revenue trips, HASTUS does not allow schedule makers to attach recovery time to deadhead movements. Therefore, it is especially important that programmed run times for deadhead movements are not undervalued. CTPS assessed deadhead run times using AVL observations from spring 2016. Table 11 provides a list of 41 (out of 437) scheduled weekday deadhead movements that had median run times greater than scheduled run times.

Table 11
Deadhead Movements with Median Run Times Greater than Scheduled Run Times, Spring 2016

District	Start Point	End Point	Start Time	Number of Obs.	Scheduled Run Time (min.)	Median Run Time (min.)	Median Run Time - Scheduled Run Time (min.)
Cabot	jasst	Dudly	14:52	47	41	54.8	13.8
Cabot	cntsq	brway	17:22	32	28	38.8	10.8
Quincy	qnctr	nwbhl	14:07	63	28	35.3	7.3
Cabot	fhill	jqnsb	14:40	50	20	27.1	7.1
Quincy	newbl	qnctr	15:08	61	17	23.2	6.2
Cabot	rugg	jqnsb	10:18	10	12	17.2	5.2
Charlestown	hayms	warbp	6:08	48	20	24.6	4.6
Charlestown	malst	uphgh	7:50	60	10	14.6	4.6
Bennett	clarh	arlht	15:09	47	26	30.5	4.5
Charlestown	hayms	wacry	9:05	9	12	16.4	4.4
Charlestown	malst	medfd	8:43	63	17	21.4	4.4
Arborway	fhill	louis	13:53	23	22	25.5	3.5
Charlestown	mdlsc	sull	15:08	49	27	30.4	3.4
Bennett	rindg	alewf	15:12	64	18	21.1	3.1
Quincy	nqncy	fldcr	15:03	22	17	19.8	2.8
Charlestown	fells	sull	14:54	45	16	18.5	2.5
Charlestown	sull	davis	18:33	22	17	19.4	2.4
Bennett	alewf	rindg	19:02	19	13	15.1	2.1
Cabot	bumed	andrw	8:14	28	11	13.1	2.1
Arborway	matpn	fhill	18:37	18	23	25.0	2.0
Cabot	matpn	kenbs	14:25	33	41	43.0	2.0
Cabot	conat	ctypt	8:27	61	8	9.5	1.5
Bennett	alewf	bdfwd	17:12	57	68	69.4	1.4
Arborway	ashmt	matpn	14:54	12	16	17.3	1.3
Arborway	louis	fhill	7:17	13	22	23.1	1.1
Bennett	cntsq	alewf	17:31	50	34	35.1	1.1
Cabot	bumed	andrw	8:34	9	11	12.1	1.1
Arborway	Dudly	jpctr	6:59	58	14	15.1	1.1
Charlestown	woodc	welst	14:39	61	16	16.9	0.9
Arborway	louis	fhill	7:06	57	22	22.9	0.9
Cabot	ashmt	Dudly	16:14	48	29	29.8	0.8
Arborway	fhill	cloop	15:59	57	27	27.8	0.8
Cabot	conat	ctypt	8:34	58	8	8.7	0.7

District	Start Point	End Point	Start Time	Number of Obs.	Scheduled Run Time (min.)	Median Run Time (min.)	Median Run Time - Scheduled Run Time (min.)
Bennett	bally	sull	18:47	50	21	21.7	0.7
Cabot	conat	ctypt	7:57	48	8	8.6	0.6
Charlestown	hayms	warbp	5:37	59	21	21.4	0.4
Lynn	wlynn	mavck	15:01	49	19	19.4	0.4
Cabot	conat	ctypt	8:06	61	9	9.2	0.2
Cabot	andrw	bumed	15:16	58	10	10.2	0.2
Charlestown	sull	davis	19:19	54	16	16.1	0.1
Cabot	andrw	bumed	15:36	54	10	10.1	0.1

3.3 Garage Pull-Outs

Unlike vehicle-revenue trips and deadhead movements between two vehicle-revenue trips, assessing delay caused by pull-out movements from the garage as a function of observed run time would be misleading, as operators are permitted to leave the garage as much as 20 minutes early to pick up items such as coffee and water on the way to their first in-service trip. Without knowing which AVL observations contain such a stop along the way, assessing delay is limited to investigating how often operators leave the garage on time, and how late operators arrive at the start point of their first vehicle-revenue trip when they do not leave the garage on time.

Figure 5 provides a summary of departure time from the garage for all pull-out trips with AVL observations from spring 2016.

Figure 5
Departure Lateness from Garage—Systemwide Observations, Spring 2016

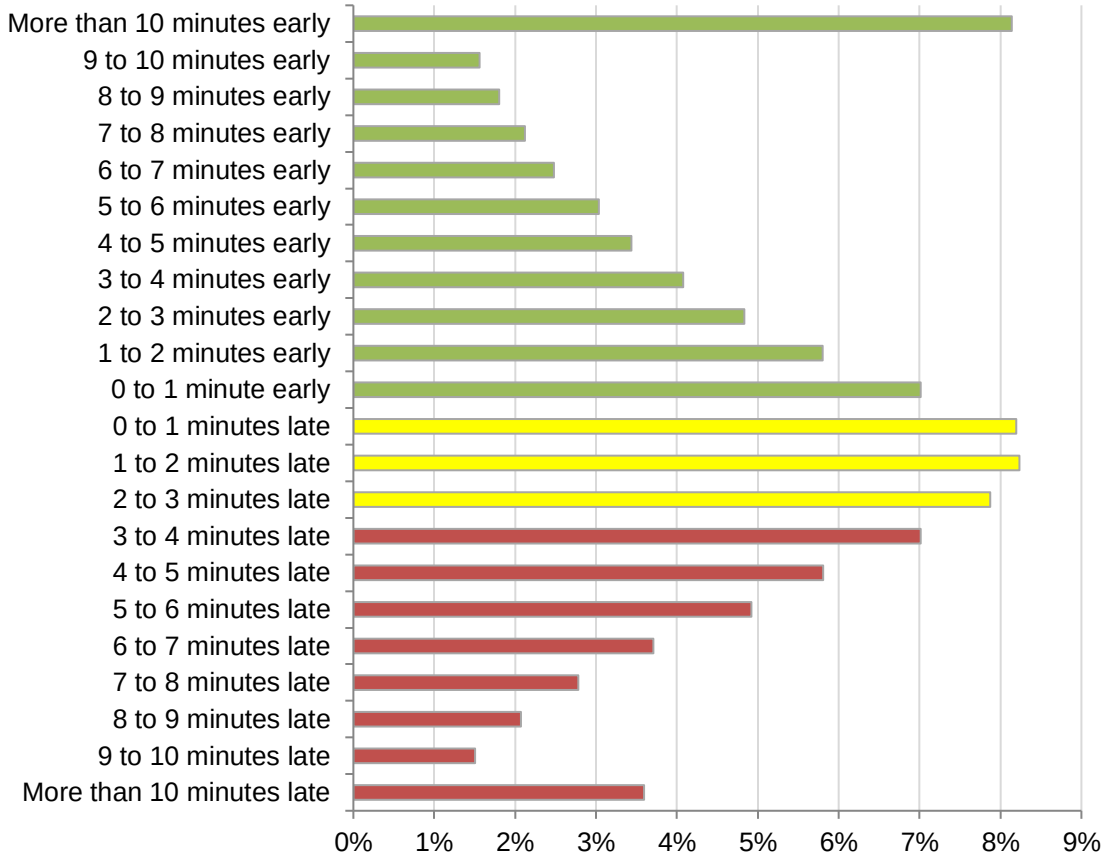


Table 12 provides a summary of the number of pull-out trips that departed the garage more than three minutes late, delineated by garage.

Table 13 provides a summary of how late trips arrived at the start point of their first vehicle-revenue trip when they departed more than three minutes late from the garage, delineated by garage.

Table 12
Summary of Departure Lateness from Garage, Spring 2016

Garage	Spring 2016 Observations	Number of Observations that Departed Garage More than Three Minutes Late	Percentage of Observations that Departed Garage More than Three Minutes Late	Percentage of all Observations that Departed Garage More than Three Minutes Late and Arrived for First Trip After Scheduled Departure
Albany	7,775	2,814	36.2%	18.9%
Arborway	14,787	6,099	41.2%	33.0%
Cabot	12,439	4,035	32.4%	25.7%
Charlestown	11,254	3,111	27.6%	20.1%
Fellsway	5,271	1,489	28.2%	17.3%
Lynn	6,841	1,401	20.5%	12.6%
North Cambridge	782	338	43.2%	29.5%
Quincy	7,308	1,961	26.8%	21.8%
Southampton	3,207	934	29.1%	15.4%
Somerville	9,558	2,694	28.2%	17.0%
Total	**79,222**	**24,876**	**31.4%**	**22.1%**

Table 13
Summary of First Trip Arrival Lateness of Pull-Outs that Depart more than Three Minutes Late from the Garage, Spring 2016

Garage	Number of Observations that Arrived for First Trip After Scheduled Departure	Percentage of Observations that Arrived for First Trip After Scheduled Departure	Arrival Lateness per Trip of Observations that Arrived for First Trip After Scheduled Departure (min.)
Albany	1,472	52.3%	3.6
Arborway	4,876	79.9%	3.8
Cabot	3,202	79.4%	4.5
Charlestown	2,260	72.6%	3.9
Fellsway	914	61.4%	3.0
Lynn	859	61.3%	3.9
North Cambridge	231	68.3%	2.7
Quincy	1,591	81.1%	3.0
Southampton	493	52.8%	4.0
Somerville	1,621	60.2%	4.4
Total	**17,519**	**70.4%**	**3.9**

Of the 79,222 observations in the spring 2016 dataset, 24,876 (31.4 percent) of pull-out trips departed more than three minutes late from the garage. Of these, 17,519 (22.1 percent of all pull-outs, and 70.4 percent of pull-outs that departed more than three minutes late) arrived at the start point of their first vehicle-revenue trip after the scheduled departure time, with an average arrival lateness of 3.9 minutes per trip.

3.4 Supplemental MBTA Bus Trips

On weekdays throughout the midafternoon and early PM peak periods, the MBTA operates a series of supplemental bus trips; these are different from typical scheduled bus service as they traverse along a unique route variation and hold at their origin point until bus operations field staff release them for departure. The time of day that bus operations field staff release each supplemental trip often can change without notice, presenting a challenge when building them into a schedule each quarter. Because supplemental trips are typically scheduled following a pull-out from the garage, arriving on time for departure is generally not an issue from a scheduling perspective. However, when bus operations field staff adjust when a supplemental trip is released it affects when the bus arrives to start its next trip, which may cause that trip to depart late. Such delay has the potential to resonate throughout the remainder of the block heading into the PM peak period.

With the use of automatic blocking software, it has become increasingly important that scheduled departure times and run times for supplemental trips reflect the reality of what is being operated. To assess supplemental bus trips, CTPS used fall 2015 AVL data provided by the MBTA. Summaries of origin departure lateness, end-point arrival lateness, and run times for supplemental trips based on the fall 2015 AVL observations are provided in Appendix B along with a summary of suggested scheduling adjustments. The summaries provided in Appendix B are not intended to reflect the current state of these supplemental trips, as the MBTA makes constant schedule adjustments, but rather to highlight the importance of closely monitoring them.

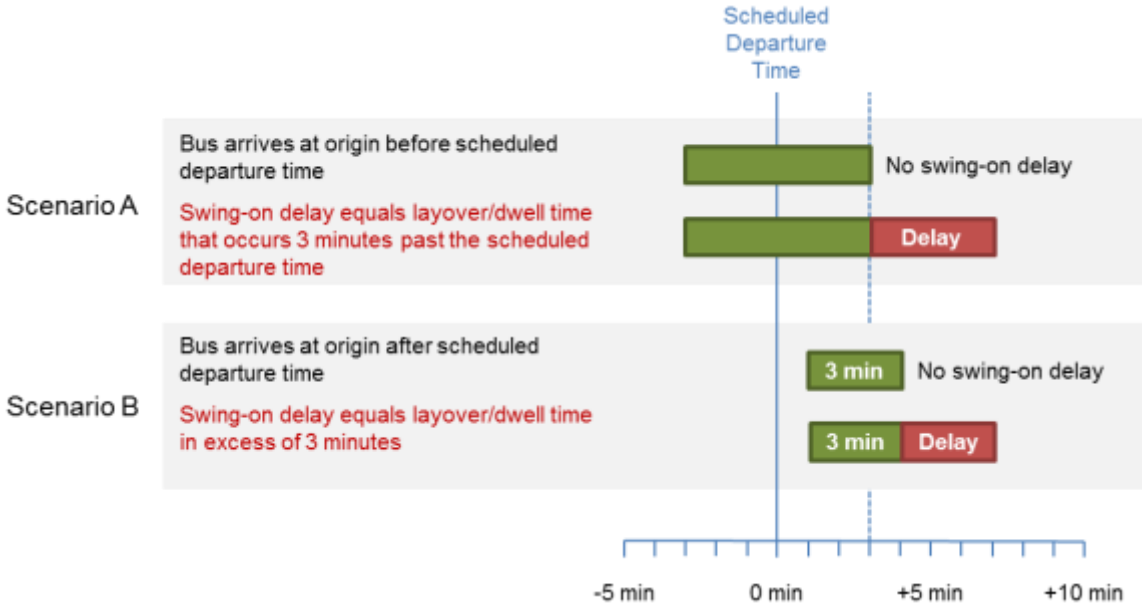
3.5 Bus Operator Swing-Ons

A bus operator swing-on occurs when there is a scheduled change in operators while a bus is in service, usually at the start or end point of a trip. In general, the operator stepping off the bus ends their assignment while the other operator starts theirs. A swing-on provides the benefit of reducing the total number of non-revenue vehicle-hours when compared to the alternative option of pulling a vehicle in and out of service to change operators at the garage. The potential burdens of scheduling swing-ons include the extra time it takes for an operator

switch to occur and delays caused by operators showing up late to the swing-on location. In addition, swing-ons increase the number of trips in a row a vehicle is scheduled to complete, which can perpetuate delay that occurs early on in the block. For blocks containing trips with poor on-time performance, a scheduled trip back to the garage for an operator change may be utilized as a layover to recover from delay that occurred on previous trips.

CTPS used fall 2015 AVL data provided by the MBTA to assess swing-on delay under two scenarios, as outlined in Figure 6.

Figure 6
Procedure for Assessing Swing-On Delay



As shown in the figure above, scenario A reflects a situation where the bus arrives for its swing-on before its scheduled departure time. Swing-on delay for a trip under this condition is assessed as the amount of time that passes from three minutes past the scheduled departure time to when the trip departs. Three minutes past a trip's scheduled departure time was selected as a threshold because it is similar to the MBTA's definition of a late departing trip.

Scenario B reflects a situation where the bus arrives for its swing-on after its scheduled departure time. Swing-on delay that occurs under this condition is assessed as the amount of time between arrival and departure that is in excess of three minutes, under the assumption that three minutes is a reasonable amount of time for an operator switch to be completed and all passengers to be loaded. The frequency at which scenario B occurs is important, as a trip where scenario B occurs frequently might benefit from a schedule adjustment that assigns the operator change back at the garage with a hook to a different trip or deadhead movement in order to minimize delay in the system.

Appendix C provides swing-on delay summaries by route, start-point location, and time of day. In the fall 2015 schedule, there were 720 scheduled swing-ons each weekday.

In scenario A, 28,077 AVL observations were recorded, with total assessed swing-on delay of 414 hours (53 seconds of delay per swing-on). In scenario B, 9,077 AVL observations were recorded, with total assessed swing-on delay of

195 hours (77 seconds of delay per swing-on) in addition to any amount of delay from a late arrival. Scenarios A and B combined yield an average of 59 seconds of delay per swing-on. Scenario B accounted for 24.4 percent of all observations (that is, at least 24.4 percent of swing-ons begin after their scheduled departure time). Staff recommend that the MBTA review specific trips, locations, and times of day where scenario B is a common occurrence.

3.6 Early Pull-Up Opportunity

CTPS was tasked with assessing the amount of time that departure lateness at origins could be reduced if operators who have time to lay over are held to a higher standard of on-time departure performance by pulling up early to load passengers so that all passengers are boarded no later than the scheduled departure time.

CTPS used fall 2015 AVL data and fall 2015 APC data provided by the MBTA to assess early pull-up opportunity for four high-frequency routes at four locations; Route 28 at Ruggles, Route 32 at Forest Hills, Route 57 at Kenmore, and Route 111 at Haymarket. Early pull-up opportunity is categorized by the four scenarios (A, B, C, and D) outlined in Figure 7. An arrival time at the terminal was assigned using the AVL data, and door open and door close time was assigned using the APC data. Layover time was assessed as the time between buses' arrival at the terminal (using AVL data) and doors opening (using APC data). Dwell time was assessed as the time between the doors opening and doors closing (using APC data).

Scenario A occurs when the bus arrives at the origin after its scheduled departure time. Because the bus arrives late, there is no opportunity to achieve any time savings by cutting the layover short, and the missed opportunity for time savings is zero. Departure lateness is equal to the time when the doors close minus the scheduled departure time.

Scenario B occurs when the bus arrives at the origin before its scheduled departure time, but the doors do not open until after the scheduled departure time. The missed opportunity for time savings is equal to the time when the doors close minus the scheduled departure time, or the time when the doors open minus the time when the bus arrives, whichever is least. Departure lateness is equal to the time when the doors close minus the scheduled departure time.

Scenario C occurs when the bus arrives at the origin and opens its doors before its scheduled departure time, but the doors do not close until after the scheduled departure time. As with scenario B, the missed opportunity for time savings is equal to the time when the doors close minus the scheduled departure time, or

the time when the doors open minus the time when the bus arrives, whichever is least. Departure lateness is equal to the time when the doors close minus the scheduled departure time.

Scenario D is the preferred scenario, where the operator has pulled up early enough to load all passengers before the scheduled departure time. All opportunity for time savings has been utilized, and there is zero departure lateness.

Figure 7
Procedure for Assessing Early Pull-Up Opportunity

Table 14 provides a summary of early pull-up opportunity for each route; Table 15 provides a summary of all observations combined; and Appendix D provides a summary by trip. The number of observations for each route is limited by the number of APC observations, as the percentage of buses equipped with APC devices varies by garage.

Table 14
Summary of Early Pull-Up Opportunity by Route

Route - Location	Scenario	Number of Obs.	Total Departure Lateness (min.)	Total Missed Opportunity for Savings (min.)	Departure Lateness per Trip (min.)	Missed Opportunity for Savings per Trip (min.)
28 - Ruggles	A	1,015	8,644	N/A	8.5	N/A
	B	110	259	134	2.4	1.2
	C	744	1,369	336	1.8	0.5
	D	1,137	N/A	N/A	N/A	N/A
	Total	**3,006**	**10,271**	**469**	**3.4**	**0.2**
32 - Forest Hills	A	116	1,190	N/A	10.3	N/A
	B	25	70	23	2.8	0.9
	C	122	246	68	2.0	0.6
	D	90	N/A	N/A	N/A	N/A
	Total	**353**	**1,506**	**91**	**4.3**	**0.3**
57 - Kenmore	A	86	698	N/A	8.1	N/A
	B	8	38	28	4.7	3.5
	C	190	277	51	1.5	0.3
	D	246	N/A	N/A	N/A	N/A
	Total	**530**	**1,013**	**79**	**1.9**	**0.1**
111 - Haymarket	A	943	10,132	N/A	10.7	N/A
	B	96	404	176	4.2	1.8
	C	955	1,842	626	1.9	0.7
	D	723	N/A	N/A	N/A	N/A
	Total	**2,717**	**12,378**	**802**	**4.6**	**0.3**

Table 15
Summary of Early Pull-Up Opportunity—All Observations

Scenario	Number of Obs.	Total Departure Lateness (min.)	Total Missed Opportunity for Savings (min.)	Departure Lateness per Trip (min.)	Missed Opportunity for Savings per Trip (min.)
A	2,160	20,664	N/A	9.6	N/A
B	239	770	360	3.2	1.5
C	2,011	3,734	1,081	1.9	0.5
D	2,196	N/A	N/A	N/A	N/A
Total	**6,606**	**25,168**	**1,441**	**3.8**	**0.2**

Staff formed 6,606 observations from AVL and APC data for the four routes combined. Of these observations, 33.7 percent were categorized under scenario A, where the bus arrived at its origin after its scheduled departure time, leaving no opportunity to achieve any time savings by reducing the layover. Staff categorized 33.2 percent of all observations under scenario D, where the bus closed its doors before the scheduled departure time, utilizing all opportunity for time savings.

The remaining 33.1 percent of observations were categorized under scenarios B and C, where a potential for time savings exists. For these 2,250 observations, there were 4,504 minutes of departure lateness (2.0 minutes per trip) and 1,441 minutes of missed opportunity for savings (0.6 minutes per trip). However, the amount of missed opportunity for time savings is likely less than reported, as this methodology did not account for any required travel time between the location of the AVL time point and the passenger pickup location.

A comparison of the total amount of departure lateness (25,169 minutes) to the total missed opportunity for savings (1,441 minutes) suggests that earlier pull-ups at origins would not contribute to a significant reduction in departure lateness along these routes.

Appendix A:
Summary of Data Collected on MBTA Bus Routes 116 and 117

Table A-1
Route 116 Inbound Boarding Observations

Trip	Date	Total Dwell Time (min)	Total APC Boardings	Total AFC Boardings	CharlieCard Transactions	CharlieTicket Transactions	Cash Transactions	Add Value Transactions	Baby Carriage	Shopping Cart	Wheeled Mobility Device
6:42	1/21/16	4.5	41	38	28	8	2	1	0	0	0
7:11	1/20/16	7.2	74	81	55	24	2	6	0	0	0
8:01	1/20/16	6.4	62	54	41	13	0	1	1	0	0
8:33	1/14/16	9.0	78	73	50	21	2	2	1	0	0
10:03	1/12/16	13.6	80	78	52	21	5	6	2	1	0
11:03	1/14/16	9.1	62	64	46	13	5	8	3	0	0
12:59	1/12/16	7.3	69	56	42	8	6	7	2	0	0
13:15	1/12/16	6.7	34	31	27	1	3	4	2	0	0
13:15	1/14/16	3.7	24	24	14	8	2	0	2	0	0
13:34	1/14/16	11.9	73	83	58	20	5	7	1	0	1
14:16	1/13/16	7.5	49	59	42	14	3	7	1	0	0
15:19	1/14/16	5.3	40	37	25	10	2	3	0	0	0
15:54	1/13/16	12.9	52	52	38	12	2	8	1	0	1
16:10	1/12/16	5.7	48	48	43	4	1	9	2	0	0
16:58	1/14/16	8.8	50	56	35	14	7	3	0	0	0
17:14	1/12/16	4.7	41	38	30	8	0	4	2	0	0
17:39	1/21/16	1.8	16	15	10	5	0	1	0	0	0
18:19	1/13/16	5.0	30	38	26	12	0	7	0	0	0
18:45	1/12/16	5.5	50	46	34	12	0	4	0	1	0
19:45	1/13/16	3.4	19	17	10	4	3	0	0	0	0
20:19	1/19/16	1.3	5	5	3	2	0	1	0	0	0
20:53	1/13/16	7.1	34	42	32	9	1	8	0	0	0
21:25	1/19/16	1.2	6	7	3	4	0	0	0	0	0
Total		**149.6**	**1,037**	**1,042**	**744**	**247**	**51**	**97**	**20**	**2**	**2**

AFC = Automatic fare collection. APC = Automatic passenger counters.

Note: Counts do not include activity at first and last stop of the trip. Add value transactions are also counted as CharlieCard transactions. One additional Route 116 Inbound trip (8:53 on 1/12/16) was observed by CTPS staff, but did not have functioning APC equipment on-board.

Table A-2
Route 116 Outbound Boarding Observations

Trip	Date	Total Dwell Time (min.)	Total APC Boardings	Total AFC Boardings	CharlieCard Transactions	CharlieTicket Transactions	Cash Transactions	Add Value Transactions	Baby Carriage	Shopping Cart	Wheeled Mobility Device
6:28	1/14/16	3.8	27	30	22	7	1	4	0	0	0
6:57	1/13/16	7.0	30	22	13	6	3	0	0	0	0
7:14	1/20/16	3.9	27	25	17	7	1	1	0	0	0
7:48	1/14/16	3.3	20	17	9	6	2	1	0	0	0
8:22	1/12/16	2.5	14	13	10	1	2	2	0	0	0
9:25	1/20/16	3.4	29	32	24	8	0	3	0	0	0
9:25	1/21/16	8.5	63	59	44	13	2	6	3	0	0
10:30	1/14/16	3.2	18	19	17	1	1	2	1	0	0
11:30	1/12/16	9.4	57	50	35	8	7	3	0	0	0
11:30	1/14/16	5.4	19	21	18	3	0	2	0	0	0
12:00	1/14/16	4.9	33	33	20	10	3	2	0	0	1
12:30	1/12/16	5.9	31	33	27	2	4	5	0	1	0
12:30	1/14/16	10.4	42	45	29	8	8	3	0	0	0
13:00	1/14/16	7.5	36	33	21	7	5	1	0	0	0
13:40	1/12/16	3.3	27	26	16	8	2	1	1	0	0
13:59	1/12/16	6.5	33	33	30	1	2	4	0	0	0
13:59	1/14/16	6.0	44	47	33	10	4	8	0	0	0
14:18	1/14/16	7.9	55	55	43	10	2	5	1	0	0
16:48	1/21/16	10.0	35	32	26	5	1	6	2	0	0
20:40	1/12/16	4.2	23	23	18	4	1	2	0	0	0
21:40	1/12/16	2.9	9	7	5	2	0	0	0	0	0
22:40	1/12/16	1.6	5	6	5	1	0	2	0	0	0
23:10	1/13/16	3.1	8	7	5	2	0	1	0	0	0
23:40	1/12/16	2.1	6	5	2	3	0	0	0	0	0
Total		**126.6**	**691**	**673**	**489**	**133**	**51**	**64**	**8**	**1**	**1**

AFC = Automatic fare collection. APC = Automatic passenger counters.

Note: Counts do not include activity at first and last stop of the trip. Add value transactions are also counted as CharlieCard transactions. Eleven additional Route 116 outbound trips (8:05, 9:35, 11:00, 17:36 on 1/12/16; 8:36, 21:10, 22:10 on 1/13/16; 17:04, 18:30 on 1/14/16; 15:46, 17:20 on 1/14/16) were observed by CTPS staff, but did not have functioning APC equipment on-board.

Table A-3
Route 117 Inbound Boarding Observations

Trip	Date	Total Dwell Time (min)	Total APC Boardings	Total AFC Boardings	CharlieCard Transactions	CharlieTicket Transactions	Cash Transactions	Add Value Transactions	Baby Carriage	Shopping Cart	Wheeled Mobility Device
6:35	1/20/16	4.9	51	45	33	12	0	0	0	0	0
7:05	1/14/16	7.0	66	68	40	20	8	3	0	0	0
7:39	1/12/16	5.7	50	53	41	12	0	5	0	0	0
8:43	1/20/16	7.3	62	64	41	19	4	1	0	0	0
9:03	1/12/16	3.5	24	22	14	7	1	1	1	0	0
9:48	1/14/16	4.8	47	49	33	13	3	2	0	0	0
10:48	1/12/16	5.5	33	29	19	8	2	0	1	0	0
11:18	1/14/16	5.3	36	34	25	8	1	2	2	0	0
11:48	1/12/16	5.8	49	41	32	4	5	4	1	0	0
12:18	1/12/16	7.7	45	48	39	8	1	6	0	0	0
12:18	1/14/16	9.1	53	50	38	8	4	4	1	0	0
12:47	1/13/16	7.9	51	62	44	13	5	7	1	0	0
13:45	1/12/16	10.2	75	74	48	20	6	4	2	0	0
13:45	1/14/16	5.3	54	51	36	14	1	5	1	0	0
14:51	1/12/16	6.2	37	38	32	5	1	5	0	1	0
15:29	1/12/16	2.5	25	22	19	2	1	2	0	0	0
16:03	1/21/16	4.6	27	26	22	4	0	4	0	0	0
16:35	1/20/16	4.9	56	36	25	10	1	0	1	0	0
16:51	1/13/16	4.3	37	40	31	7	2	4	0	0	0
20:00	1/12/16	2.5	16	15	5	9	1	1	0	0	0
21:10	1/12/16	2.6	13	15	13	2	0	3	0	1	0
22:11	1/12/16	1.8	9	10	3	7	0	0	0	0	0
23:13	1/12/16	0.5	4	4	2	2	0	0	0	0	0
Total		**119.9**	**920**	**896**	**635**	**214**	**47**	**63**	**11**	**2**	**0**

AFC = Automatic fare collection. APC = Automatic passenger counters.

Note: Counts do not include activity at first and last stop of the trip. Add value transactions are also counted as CharlieCard transactions. Nine additional Route 117 inbound trips (10:18 on 1/12/16; 9:23, 20:34, 21:41, 22:43 on 1/13/16; 8:11, 8:26, 16:19, 17:51 on 1/14/16) were observed by CTPS staff, but did not have functioning APC equipment on-board.

Table A-4
Route 117 Outbound Boarding Observations

Trip	Date	Total Dwell Time (min)	Total APC Boardings	Total AFC Boardings	CharlieCard Transactions	CharlieTicket Transactions	Cash Transactions	Add Value Transactions	Baby Carriage	Shopping Cart	Wheeled Mobility Device
6:35	1/20/16	1.9	17	19	11	7	1	1	0	0	0
6:52	1/12/16	2.8	28	21	14	6	1	0	0	0	0
7:27	1/21/16	3.2	25	22	21	1	0	1	1	0	0
7:45	1/14/16	3.1	23	22	19	2	1	1	0	0	0
7:59	1/20/16	2.7	25	24	16	7	1	1	0	0	0
8:30	1/13/16	4.4	19	19	17	2	0	0	0	0	0
8:44	1/20/16	1.3	7	7	3	4	0	0	0	0	0
9:10	1/14/16	1.0	4	3	1	2	0	0	0	0	0
12:15	1/12/16	4.9	29	27	23	2	2	2	1	1	0
13:12	1/12/16	2.8	20	18	12	6	0	0	0	0	0
13:31	1/13/16	5.2	40	39	32	6	1	2	2	0	0
14:28	1/12/16	6.2	23	29	23	2	4	2	0	0	0
14:28	1/14/16	9.3	51	57	42	9	6	9	0	1	0
15:20	1/12/16	3.5	35	26	23	3	0	3	1	0	0
15:36	1/12/16	4.5	19	17	16	0	1	3	0	0	0
16:08	1/12/16	4.2	15	16	15	1	0	2	0	0	0
16:08	1/14/16	7.0	40	36	33	3	0	8	1	0	0
16:40	1/13/16	6.4	24	23	20	3	0	3	1	0	0
16:56	1/12/16	2.7	11	10	7	3	0	1	0	0	0
17:44	1/14/16	4.7	27	22	16	4	2	1	1	0	0
18:00	1/12/16	7.8	37	39	22	14	3	4	0	0	0
19:00	1/13/16	1.7	7	8	7	0	1	1	0	0	0
19:25	1/12/16	4.2	27	28	19	6	3	2	0	0	0
20:25	1/13/16	2.9	14	14	10	4	0	0	0	0	0
20:55	1/19/16	2.4	10	13	11	2	0	1	0	0	0
21:25	1/13/16	3.2	14	14	6	7	1	0	0	0	0
21:55	1/19/16	1.9	4	4	3	0	1	0	0	0	0
Total		**105.8**	**595**	**577**	**442**	**106**	**29**	**48**	**8**	**2**	**0**

AFC = Automatic fare collection. APC = Automatic passenger counters.

Note: Counts do not include activity at first and last stop of the trip. Add value transactions are also counted as CharlieCard transactions. One additional Route 117 outbound trip (15:05 on 1/13/16) was observed by CTPS staff, but did not have functioning APC equipment on-board.

Appendix B:
Summary of MBTA Supplemental Bus Trip Observations

Table B-1
MBTA Supplemental Bus Trips Delay Summary, Fall 2015

Route	Dir.	Scheduled Start Time	Scheduled Run Time (min.)	Number of Obs.	Median Departure Lateness (min.)	90 Percentile Departure Lateness (min.)	Median Run-Time Difference (min.)	90 Percentile Run-Time Difference (min.)	20 Percent of Scheduled Run Time (min.)	Median Endpoint Lateness (min.)	90 Percentile Endpoint Lateness (min.)	Endpoint Late?
36-9	Out	13:35	38	52	17.3	21.7	-3.1	3.5	7.6	15.5	21.5	Median Late
19-5	Out	13:40	20	53	10.5	13.4	1.6	6.5	4	12.7	18.1	Median Late
44-2	Out	13:40	9	54	12.0	13.8	0.4	2.2	1.8	12.5	14.9	Median Late
22-3	Out	13:40	17	57	9.3	10.2	2.9	7.4	3.4	12.4	15.1	Median Late
436-8	In	14:27	31	51	13.3	14.4	0.1	9.4	6.2	11.6	22.0	Median Late
10-8	Out	13:40	31	42	9.9	12.7	1.0	7.4	6.2	11.2	18.9	Median Late
23-6	In	13:40	4	51	10.2	16.2	-0.3	1.1	0.8	11.0	17.0	Median Late
10-8	Out	13:40	31	33	11.4	14.6	-1.5	4.7	6.2	10.2	13.4	Median Late
19-5	Out	13:40	20	52	9.6	11.6	0.4	5.3	4	10.0	14.3	Median Late
22-1	Out	14:05	33	52	7.3	8.4	2.1	8.1	6.6	9.6	15.0	Median Late
429-3	In	14:20	20	46	6.4	12.6	3.3	8.4	4	9.0	19.4	Median Late
101-8	In	14:30	31	49	2.4	7.5	6.7	14.8	6.2	8.0	17.4	Median Late
101-8	In	14:25	31	45	-0.6	4.9	8.4	16.3	6.2	7.0	17.9	Median Late
426-3	Out	14:20	15	49	3.5	9.1	1.7	8.2	3	6.8	14.9	Median Late
101-8	In	14:35	31	53	-1.1	6.8	7.0	15.8	6.2	6.8	14.9	Median Late
37-3	Out	14:56	27	45	5.7	12.4	1.0	2.4	5.4	6.0	11.9	Median Late
79-1	In	14:45	20	39	3.9	10.6	2.4	8.0	4	5.8	13.8	Median Late
430-7	Out	14:20	18	26	3.2	5.4	2.0	4.8	3.6	5.7	8.3	Median Late
101-8	In	14:40	31	51	0.1	3.8	6.4	13.4	6.2	5.4	13.2	Median Late
240-G	In	14:30	32	49	2.4	6.6	1.6	4.6	6.4	5.2	9.8	Median Late
57-8	Out	14:15	43	55	10.4	12.9	-5.1	-0.6	8.6	5.0	9.4	Median Late
108-2	Out	14:20	12	56	3.4	6.4	1.6	3.7	2.4	5.0	9.0	Median Late
35-3	Out	14:18	61	41	-2.9	15.3	5.1	15.9	12.2	4.9	14.3	90 Percentile Late
429-4	In	14:35	25	54	-0.2	8.6	1.4	18.8	5	4.9	10.8	90 Percentile Late
429-3	In	14:25	22	56	2.5	8.2	1.7	6.0	4.4	4.5	11.1	Median Late
429-4	In	14:35	25	53	7.4	12.4	-2.8	7.9	5	4.3	9.8	90 Percentile Late
89-1	In	14:30	17	51	0.1	2.4	4.7	20.5	3.4	4.3	12.4	Median Late
426-3	Out	14:25	15	40	1.3	4.9	3.1	6.5	3	4.3	10.3	Median Late
431	In	14:35	3	53	3.7	5.6	0.3	1.6	0.6	4.1	6.3	Median Late
436-9	In	14:35	21	47	3.8	5.5	0.0	2.6	4.2	3.4	7.6	90 Percentile Late
431	In	14:35	3	55	2.4	6.1	-0.1	10.4	0.6	3.2	7.6	Median Late
429-3	In	14:40	24	52	0.9	6.2	0.5	5.4	4.8	3.2	10.7	90 Percentile Late
28-9	Out	14:15	66	42	11.0	13.1	-8.5	6.9	13.2	2.4	18.9	90 Percentile Late
436-2	Out	14:46	28	30	0.3	2.8	0.2	4.8	5.6	2.4	7.1	90 Percentile Late

Route	Dir.	Scheduled Start Time	Scheduled Run Time (min.)	Number of Obs.	Median Departure Lateness (min.)	90 Percentile Departure Lateness (min.)	Median Run-Time Difference (min.)	90 Percentile Run-Time Difference (min.)	20 Percent of Scheduled Run Time (min.)	Median Endpoint Lateness (min.)	90 Percentile Endpoint Lateness (min.)	Endpoint Late?
39-9	Out	14:15	41	52	11.7	12.6	-9.6	-3.6	8.2	2.3	6.5	90 Percentile Late
120-5	Out	14:20	19	55	0.6	5.4	0.2	4.7	3.8	2.3	7.4	90 Percentile Late
79-1	In	14:35	20	53	1.0	4.7	1.2	4.6	4	1.9	9.3	90 Percentile Late
66-7	In	14:10	36	48	-1.9	3.3	4.4	12.6	7.2	1.8	11.2	90 Percentile Late
93-4	In	13:50	27	26	1.2	5.7	-1.2	2.7	5.4	1.7	4.5	90 Percentile Not Late
39-9	Out	14:15	41	50	11.9	18.8	-11.9	-5.1	8.2	1.7	11.1	Median Late
39-9	Out	14:15	41	2	3.2	9.6	-1.8	6.8	8.2	1.4	3.6	90 Percentile Not Late
57-8	Out	14:25	43	39	6.0	13.1	-6.2	3.3	8.6	1.2	7.9	90 Percentile Late
216-1	Out	14:40	12	55	1.2	5.2	0.5	7.0	2.4	1.1	5.5	90 Percentile Late
217-2	In	14:35	21	48	2.3	5.1	-2.1	2.0	4.2	1.0	5.1	90 Percentile Late
36-7	In	14:40	16	15	4.1	8.6	-3.4	-1.3	3.2	0.9	5.9	90 Percentile Late
39-9	Out	14:15	41	55	11.2	15.0	-12.0	-5.0	8.2	0.9	6.9	90 Percentile Late
39-9	Out	14:15	41	56	11.4	13.7	-11.3	-5.0	8.2	0.8	6.4	90 Percentile Late
34-K	Out	13:35	55	51	17.2	19.0	-17.4	-7.7	11	0.6	10.0	90 Percentile Late
38-1	Out	13:35	51	55	16.9	18.7	-16.2	-13.0	10.2	0.5	3.8	90 Percentile Not Late
211-3	In	14:40	10	49	0.9	3.0	-0.5	0.6	2	0.5	2.9	90 Percentile Late
79-1	In	14:55	20	46	0.5	3.9	-1.5	4.9	4	-0.2	7.2	90 Percentile Late
51-1	In	15:05	58	51	3.8	8.1	-3.9	3.8	11.6	-0.3	9.4	90 Percentile Late
429-3	Out	14:46	21	46	-3.2	-0.9	1.9	5.0	4.2	-1.1	2.2	90 Percentile Not Late
22-2	Out	14:15	53	52	-2.2	6.0	1.7	9.6	10.6	-1.3	7.6	90 Percentile Late
23-1	Out	13:40	33	57	10.2	14.2	-12.5	-3.9	6.6	-1.3	5.5	90 Percentile Late
51-9	In	15:15	57	49	0.4	0.7	-1.9	4.0	11.4	-1.5	4.5	90 Percentile Not Late
88-1	Out	14:50	19	52	2.1	8.9	-4.9	-2.5	3.8	-1.8	4.4	90 Percentile Late
426-2	Out	14:35	28	53	2.9	7.1	-5.2	9.2	5.6	-1.9	3.4	90 Percentile Not Late
19-4	Out	14:15	61	51	2.4	10.6	-4.0	4.2	12.2	-2.4	3.9	90 Percentile Not Late
19-1	Out	14:05	32	49	6.7	7.5	-9.2	-4.3	6.4	-2.7	1.3	90 Percentile Not Late
39-9	Out	14:15	41	56	10.7	12.8	-13.7	-7.0	8.2	-2.8	3.6	90 Percentile Not Late
211-9	In	14:45	29	49	-3.0	0.6	-0.8	2.5	5.8	-3.0	1.5	90 Percentile Not Late
28-5	In	13:55	14	49	-3.4	7.2	-0.2	1.7	2.8	-3.1	6.2	90 Percentile Late
57-4	In	13:55	27	53	9.6	11.0	-13.0	3.1	5.4	-3.2	-0.3	90 Percentile Not Late
9702	In	14:05	34	40	1.9	5.9	-6.4	6.9	6.8	-3.3	6.6	90 Percentile Late
28-3	Out	14:00	25	43	-4.4	2.0	1.0	6.9	5	-3.3	4.4	90 Percentile Not Late
455-3	In	14:35	26	3	5.1	5.9	-7.9	-7.8	5.2	-3.4	-2.9	90 Percentile Not Late
88-1	Out	14:40	19	55	0.9	7.2	-4.8	-2.8	3.8	-3.4	3.8	90 Percentile Not Late
15-5	Out	14:05	26	39	4.4	10.8	-8.8	8.6	5.2	-3.6	5.7	90 Percentile Late
245-5	In	14:40	28	51	0.3	4.6	-4.1	-0.5	5.6	-4.2	0.7	90 Percentile Not Late
66-7	In	14:10	36	57	-4.0	-0.7	0.3	10.8	7.2	-4.2	3.9	90 Percentile Not Late

Route	Dir.	Scheduled Start Time	Scheduled Run Time (min.)	Number of Obs.	Median Departure Lateness (min.)	90 Percentile Departure Lateness (min.)	Median Run-Time Difference (min.)	90 Percentile Run-Time Difference (min.)	20 Percent of Scheduled Run Time (min.)	Median Endpoint Lateness (min.)	90 Percentile Endpoint Lateness (min.)	Endpoint Late?
216-3	Out	14:40	19	48	-0.5	3.8	-3.0	0.4	3.8	-4.4	0.5	90 Percentile Not Late
9701	In	14:10	21	1	-4.0	-4.0	-0.7	-0.7	4.2	-4.6	-4.6	90 Percentile Not Late
28-6	Out	14:08	43	23	-2.6	8.3	-4.7	6.5	8.6	-4.9	3.9	90 Percentile Not Late
214-4	Out	14:40	17	11	-4.3	-3.1	-0.6	1.8	3.4	-5.3	-3.7	90 Percentile Not Late
15-6	Out	14:05	35	43	-1.4	4.0	-4.3	2.3	7	-5.6	-1.7	90 Percentile Not Late
23-3	Out	14:05	41	49	0.4	4.5	-5.8	4.1	8.2	-5.7	-0.7	90 Percentile Not Late
134-4	In	14:30	28	48	2.8	4.4	-8.2	1.8	5.6	-5.8	-2.8	90 Percentile Not Late
95-5	In	14:30	24	51	1.7	4.5	-7.8	0.1	4.8	-6.3	-0.9	90 Percentile Not Late
32-9	Out	13:35	58	56	17.0	18.7	-23.0	-18.5	11.6	-6.6	-1.6	90 Percentile Not Late
134-4	In	14:25	29	51	3.3	4.2	-10.4	6.8	5.8	-6.8	-2.3	90 Percentile Not Late
95-5	In	14:40	24	50	2.4	6.0	-10.5	-4.7	4.8	-7.4	-2.9	90 Percentile Not Late
134-4	In	14:40	28	51	2.0	3.5	-10.2	-3.8	5.6	-8.2	-3.3	90 Percentile Not Late
211-1	In	14:35	24	51	2.1	4.7	-10.8	-8.7	4.8	-8.5	-4.6	90 Percentile Not Late
426-2	Out	14:40	28	53	0.3	3.4	-9.7	1.5	5.6	-8.9	-1.6	90 Percentile Not Late
212-5	In	14:40	23	16	1.2	2.1	-11.7	-10.6	4.6	-11.2	-8.9	90 Percentile Not Late
69-1	In	14:34	28	47	1.7	7.4	-13.5	-8.9	5.6	-11.7	-4.3	90 Percentile Not Late
69-1	In	14:47	28	46	0.7	10.1	-13.2	-6.8	5.6	-12.2	2.8	90 Percentile Not Late
214-3	Out	14:40	22	47	3.0	5.6	-15.9	-2.5	4.4	-12.5	-10.3	90 Percentile Not Late
214-3	Out	14:40	22	41	1.0	4.7	-15.3	2.0	4.4	-13.5	-10.5	90 Percentile Not Late
83-2	Out	14:40	32	40	1.2	10.4	-16.7	-13.6	6.4	-15.4	-5.4	90 Percentile Not Late
09-5	Out	14:15	65	40	-10.0	3.9	-3.7	3.6	13	-15.6	-6.3	90 Percentile Not Late
350-9	Out	14:25	42	51	-0.3	6.9	-16.8	-12.3	8.4	-16.8	-4.4	90 Percentile Not Late
83-2	Out	14:40	32	54	-0.7	5.3	-16.6	12.3	6.4	-17.2	11.6	90 Percentile Not Late
39-7	Out	14:28	26	0	.	.	.	.	5.2	.	.	N/A
88-1	Out	14:35	19	0	.	.	.	.	3.8	.	.	N/A
9701	In	14:05	21	0	.	.	.	.	4.2	.	.	N/A
9703	In	14:10	68	0	.	.	.	.	13.6	.	.	N/A

Table B-2
MBTA Supplemental Bus Trips Suggested Scheduling Adjustments

Route	Dir.	Start Time	Start-Time Adjustment	Run-Time Increase	Run-Time Decrease
36-9	Out	13:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
19-5	Out	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
44-2	Out	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
22-3	Out	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
436-8	In	14:27	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
10-8	Out	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
23-6	In	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
10-8	Out	13:40	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
19-5	Out	13:40	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
22-1	Out	14:05	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
429-3	In	14:20	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
101-8	In	14:30	Maybe, 90% is more than 3 minutes late	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
101-8	In	14:25	Maybe, 90% is more than 3 minutes late	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
426-3	Out	14:20	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
101-8	In	14:35	Maybe, 90% is more than 3 minutes late	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
37-3	Out	14:56	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
79-1	In	14:45	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
430-7	Out	14:20	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
101-8	In	14:40	Maybe, 90% is more than 3 minutes late	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
240-G	In	14:30	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
57-8	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
108-2	Out	14:20	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
35-3	Out	14:18	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
429-4	In	14:35	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
429-3	In	14:25	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
429-4	In	14:35	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
89-1	In	14:30	No, 90% is less than 3 minutes	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
426-3	Out	14:25	Maybe, 90% is more than 3 minutes late	Yes, median is more than 120% of scheduled	No, median is more than 80% of scheduled
431	In	14:35	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
436-9	In	14:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
431	In	14:35	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
429-3	In	14:40	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
28-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
436-2	Out	14:46	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
120-5	Out	14:20	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
79-1	In	14:35	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
66-7	In	14:10	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled

Route	Dir.	Start Time	Start-Time Adjustment	Run-Time Increase	Run-Time Decrease
93-4	In	13:50	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
57-8	Out	14:25	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
216-1	Out	14:40	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
217-2	In	14:35	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
36-7	In	14:40	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
34-K	Out	13:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
38-1	Out	13:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
211-3	In	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
79-1	In	14:55	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
51-1	In	15:05	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
429-3	Out	14:46	No, 90% is less than 3 minutes	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
22-2	Out	14:15	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
23-1	Out	13:40	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
51-9	In	15:15	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
88-1	Out	14:50	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
426-2	Out	14:35	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
19-4	Out	14:15	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
19-1	Out	14:05	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
39-9	Out	14:15	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
211-9	In	14:45	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
28-5	In	13:55	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
57-4	In	13:55	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
9702	In	14:05	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
28-3	Out	14:00	No, 90% is less than 3 minutes	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
455-3	In	14:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
88-1	Out	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
15-5	Out	14:05	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	Maybe, median is less than 80% of scheduled
245-5	In	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
66-7	In	14:10	No, 90% is less than 3 minutes	Maybe, 90% is more than 120% of scheduled	No, median is more than 80% of scheduled
216-3	Out	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
9701	In	14:10	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
28-6	Out	14:08	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
214-4	Out	14:40	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
15-6	Out	14:05	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
23-3	Out	14:05	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
134-4	In	14:30	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled

Route	Dir.	Start Time	Start-Time Adjustment	Run-Time Increase	Run-Time Decrease
95-5	In	14:30	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
32-9	Out	13:35	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
134-4	In	14:25	Yes, median is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	Maybe, median is less than 80% of scheduled
95-5	In	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
134-4	In	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
211-1	In	14:35	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
426-2	Out	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
212-5	In	14:40	No, 90% is less than 3 minutes	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
69-1	In	14:34	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
69-1	In	14:47	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
214-3	Out	14:40	Yes, median is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
214-3	Out	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Maybe, median is less than 80% of scheduled
83-2	Out	14:40	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
09-5	Out	14:15	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	No, median is more than 80% of scheduled
350-9	Out	14:25	Maybe, 90% is more than 3 minutes late	No, 90% is less than 120% of scheduled	Yes, 90% is less than 80% of scheduled
83-2	Out	14:40	Maybe, 90% is more than 3 minutes late	Maybe, 90% is more than 120% of scheduled	Maybe, median is less than 80% of scheduled
39-7	Out	14:28	N/A	N/A	N/A
88-1	Out	14:35	N/A	N/A	N/A
9701	In	14:05	N/A	N/A	N/A
9703	In	14:10	N/A	N/A	N/A

Figure B-1
Start Point Departure Time of MBTA Supplemental Bus Trips, Fall 2015

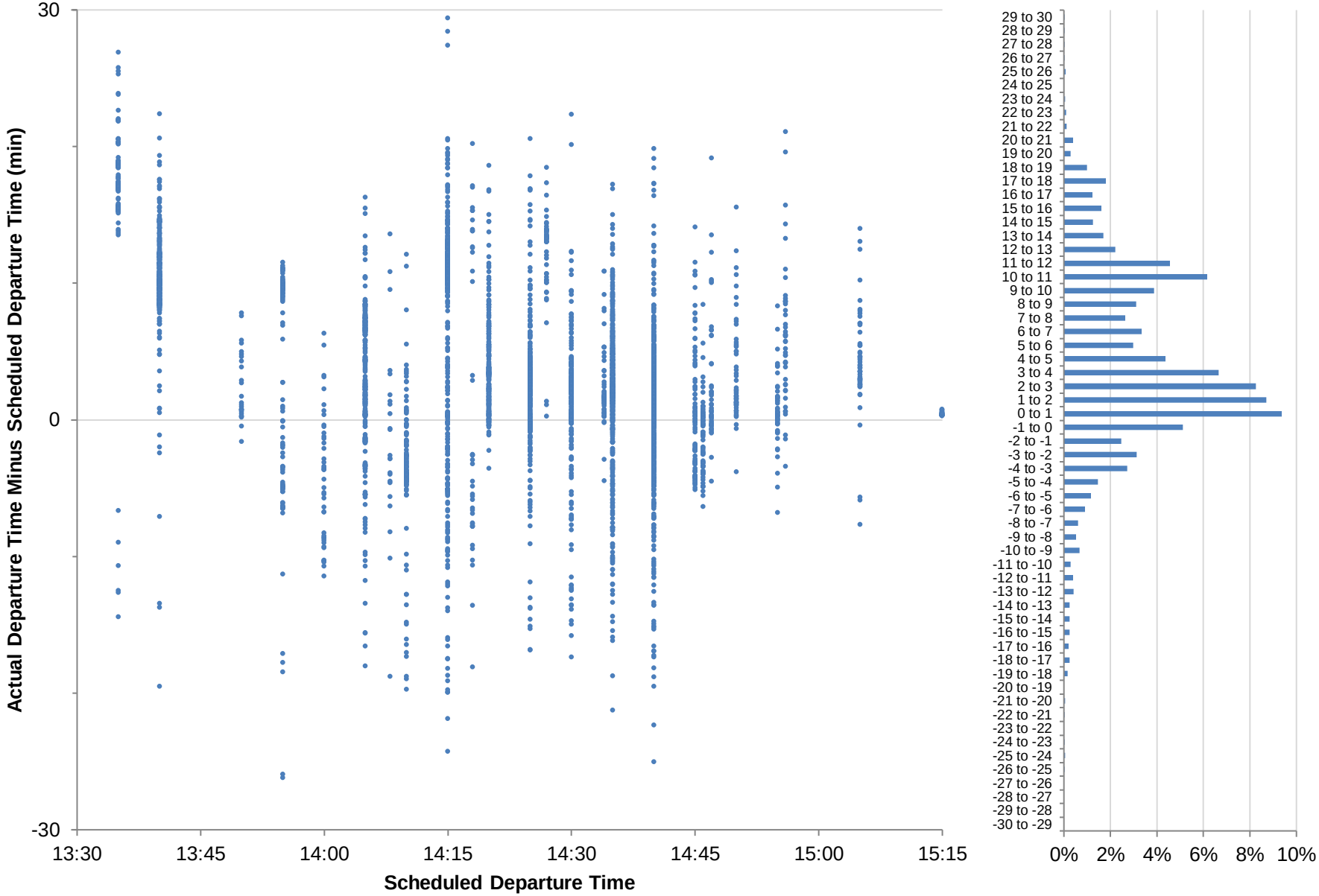


Figure B-2
End Point Arrival Time of MBTA Supplemental Bus Trips, Fall 2015

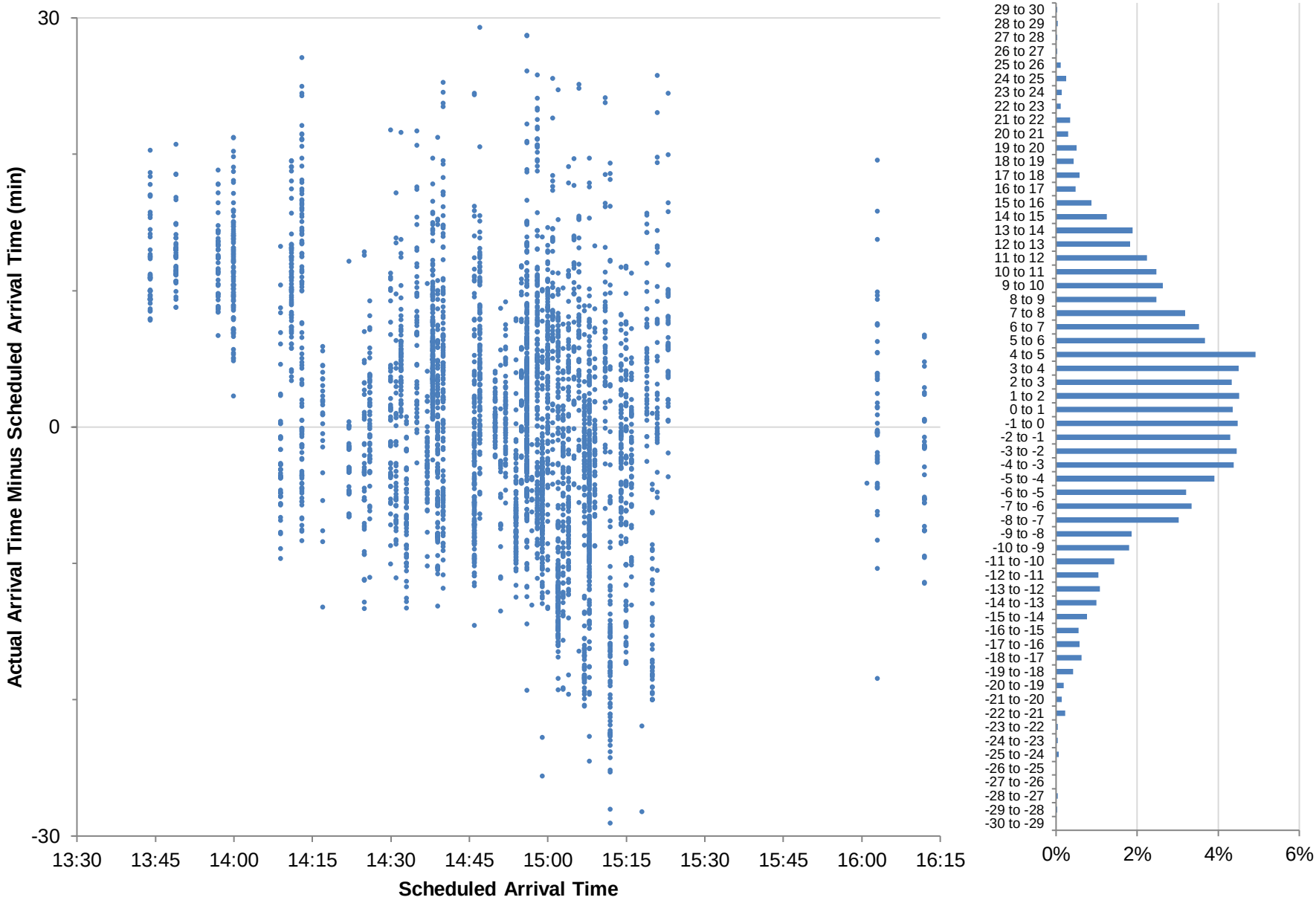


Figure B-3
Run Time of MBTA Supplemental Bus Trips, Fall 2015

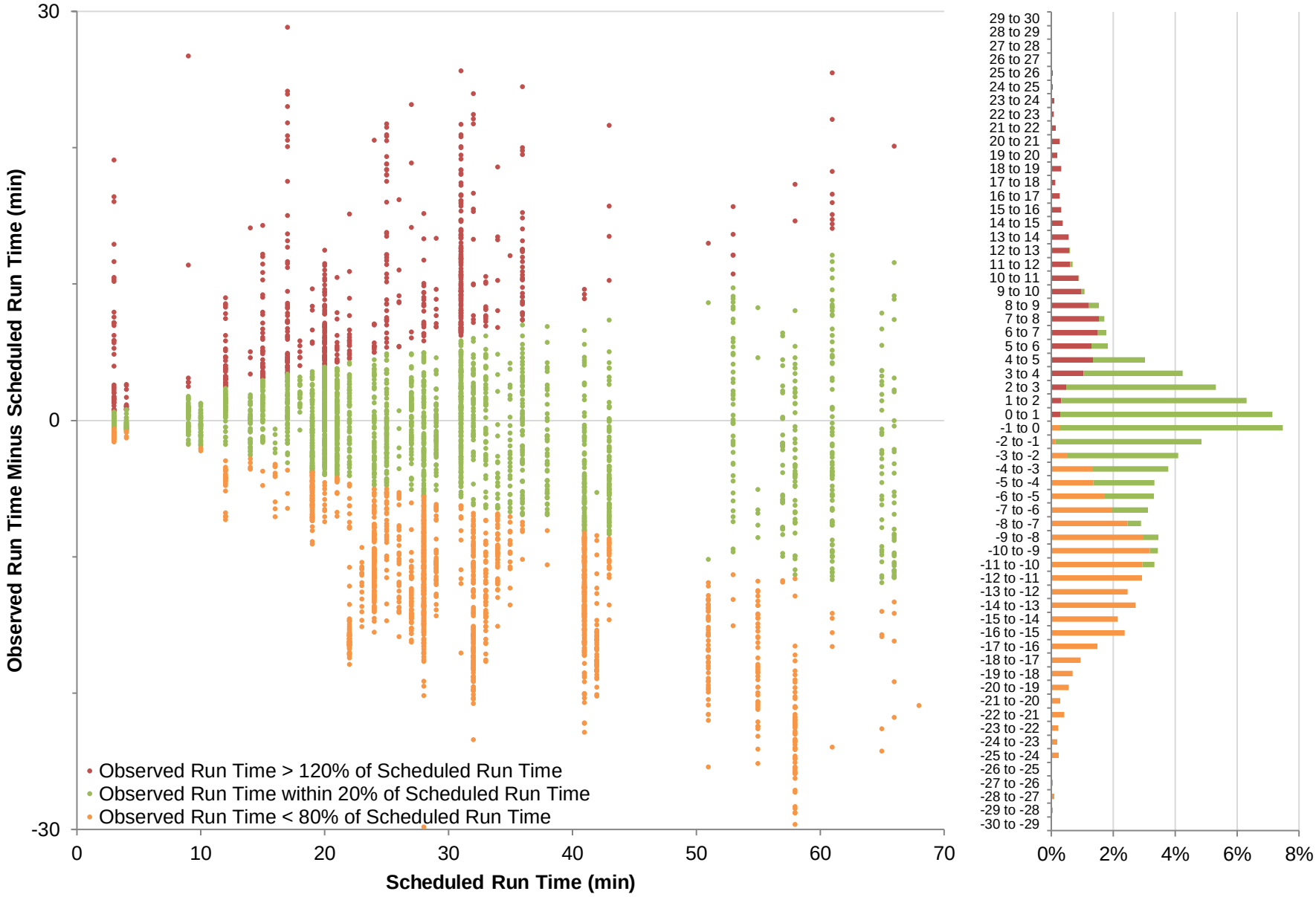


Figure B-4
Arborway District Supplemental Bus Trip Observations, Fall 2015

Startpoint Departure Lateness

Variation	Trip	Run	Median	90 Percent
28-9 Out	14:15	1092	11.0	12.7
32-9 Out	13:35	1033	17.0	18.7
34-K Out	13:35	1023	17.3	19.3
35-3 Out	14:18	1045	0.1	15.7
36-7 In	14:40	1036	4.1	8.6
36-9 Out	13:35	1043	17.3	21.9
37-3 Out	14:56	1059	5.9	13.8
38-1 Out	13:35	1037	16.9	18.7
39-9 Out	14:15	1032	11.4	14.2
39-9 Out	14:15	1040	11.9	18.5
39-9 Out	14:15	1055	3.2	9.6
39-9 Out	14:15	1059	11.7	12.6
39-9 Out	14:15	1061	10.7	12.9
39-9 Out	14:15	1086	11.2	15.9
51-1 In	15:05	1454	3.8	8.6
51-9 In	15:15	9001	0.4	0.7

>3 min
2 min
1 min
0 min
-1 min
-2 min
< -3 min
n/a

Endpoint Arrival Lateness Expressed as Percentage of Scheduled Layover (Scheduled Layover = 20 Percent of Scheduled Run Time)

Variation	Trip	Run	Median	90 Percent
28-9 Out	14:15	1092	18%	143%
32-9 Out	13:35	1033	-57%	-14%
34-K Out	13:35	1023	5%	91%
35-3 Out	14:18	1045	40%	117%
36-7 In	14:40	1036	28%	184%
36-9 Out	13:35	1043	204%	283%
37-3 Out	14:56	1059	110%	220%
38-1 Out	13:35	1037	5%	38%
39-9 Out	14:15	1032	9%	78%
39-9 Out	14:15	1040	20%	136%
39-9 Out	14:15	1055	17%	44%
39-9 Out	14:15	1059	28%	79%
39-9 Out	14:15	1061	-34%	44%
39-9 Out	14:15	1086	11%	84%
51-1 In	15:05	1454	-2%	81%
51-9 In	15:15	9001	-13%	39%

> 100%
50%
0%
-50%
< -100%
n/a

Run Time Expressed as Percentage of Scheduled Run Time

Variation	Trip	Run	Median	90 Percent
28-9 Out	14:15	1092	87%	111%
32-9 Out	13:35	1033	60%	68%
34-K Out	13:35	1023	68%	86%
35-3 Out	14:18	1045	108%	126%
36-7 In	14:40	1036	79%	92%
36-9 Out	13:35	1043	92%	109%
37-3 Out	14:56	1059	104%	109%
38-1 Out	13:35	1037	68%	75%
39-9 Out	14:15	1032	72%	88%
39-9 Out	14:15	1040	71%	88%
39-9 Out	14:15	1055	96%	117%
39-9 Out	14:15	1059	77%	91%
39-9 Out	14:15	1061	67%	83%
39-9 Out	14:15	1086	71%	88%
51-1 In	15:05	1454	93%	107%
51-9 In	15:15	9001	97%	107%

>120%
110%
100%
90%
< 80%
n/a

09-08 09-09 09-10 09-14 09-15 09-16 09-17 09-21 09-22 09-23 09-24 09-28 09-29 09-30 10-01 10-05 10-06 10-07 10-08 10-15 10-19 10-20 10-21 10-22 10-26 10-27 10-28 10-29 11-02 11-03 11-04 11-05 11-09 11-10 11-12 11-16 11-17 11-18 11-19 11-23 11-24 11-25 11-30 12-01 12-02 12-03 12-07 12-08 12-09 12-10 12-14 12-15 12-16 12-17 12-21 12-22 12-23

Figure B-5
Bennett District Supplemental Bus Trip Observations, Fall 2015

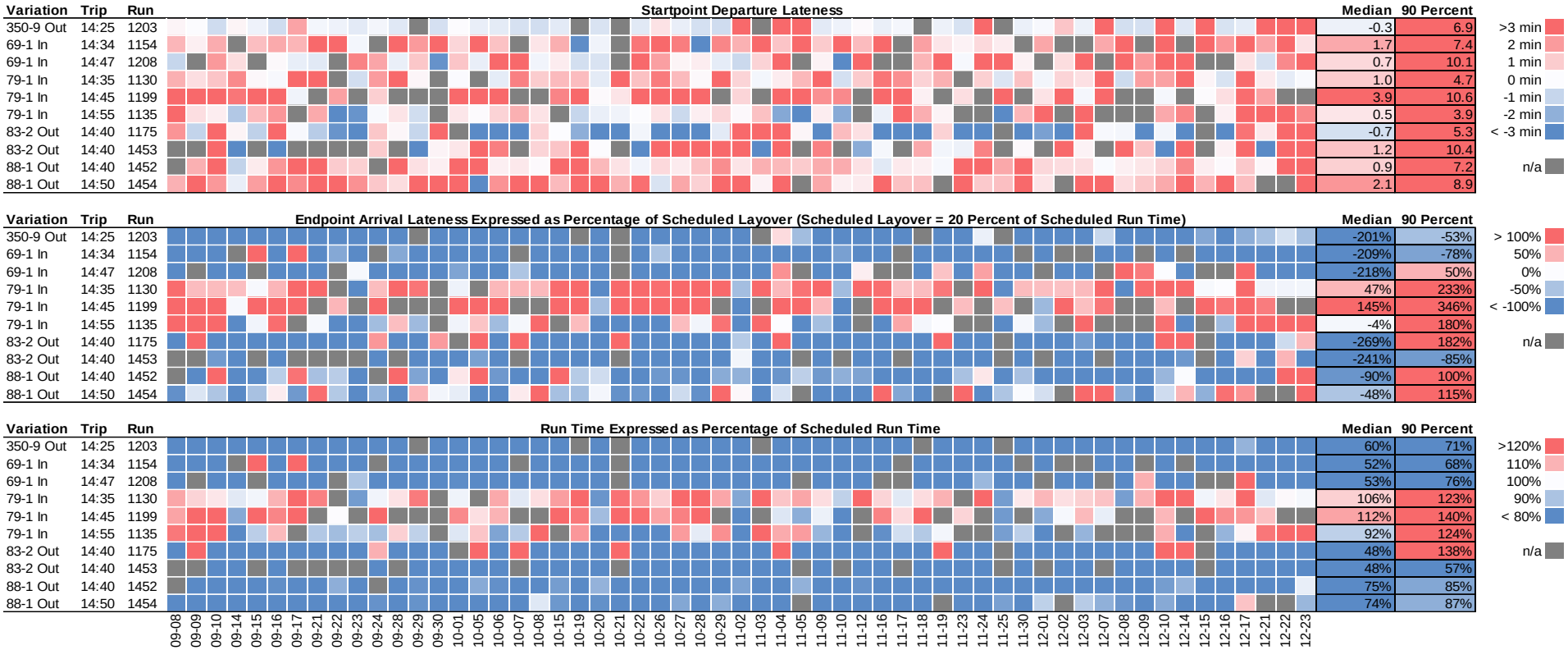


Figure B-6
Cabot District Supplemental Bus Trip Observations, Fall 2015

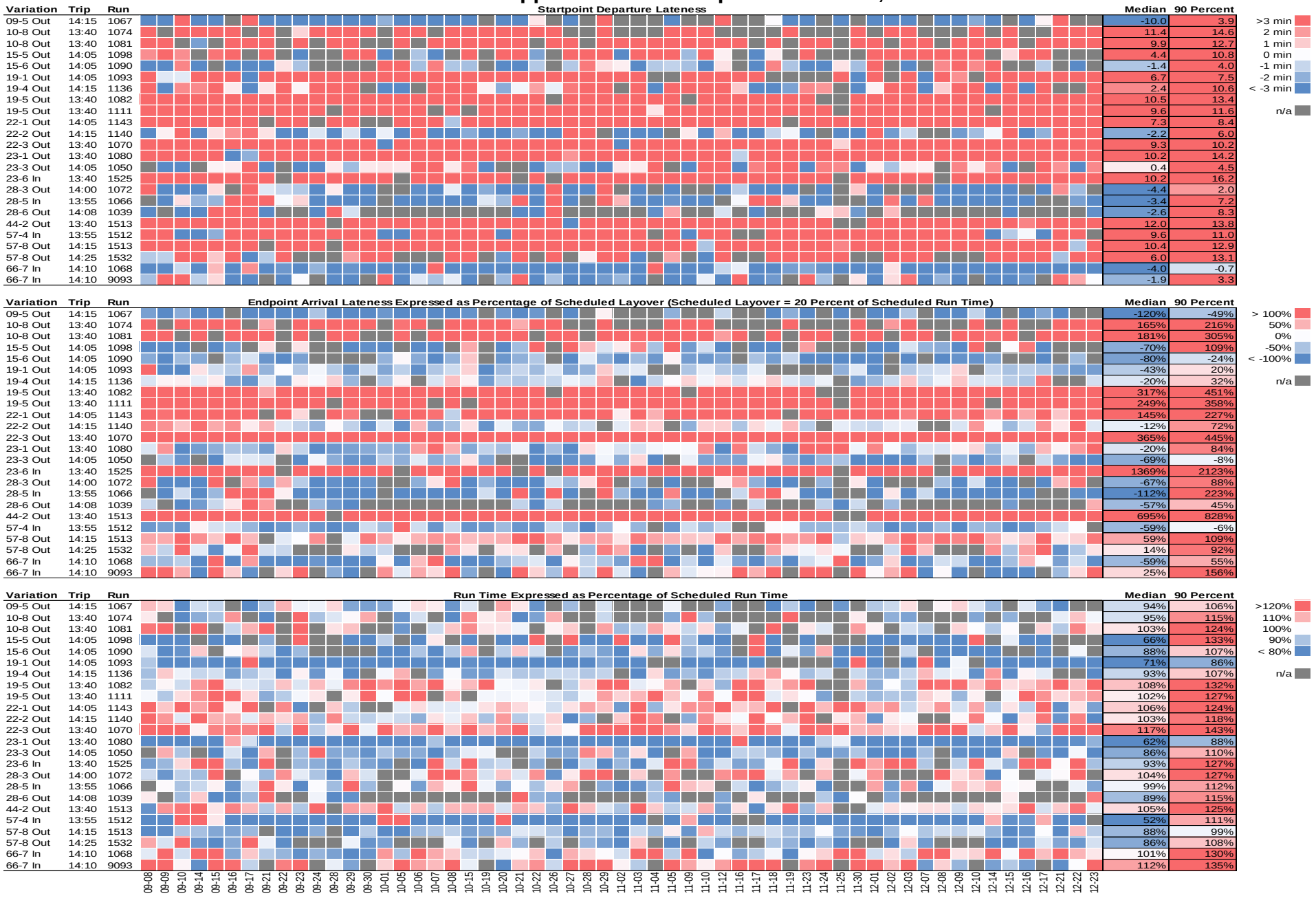


Figure B-7
Charlestown District Supplemental Bus Trip Observations, Fall 2015

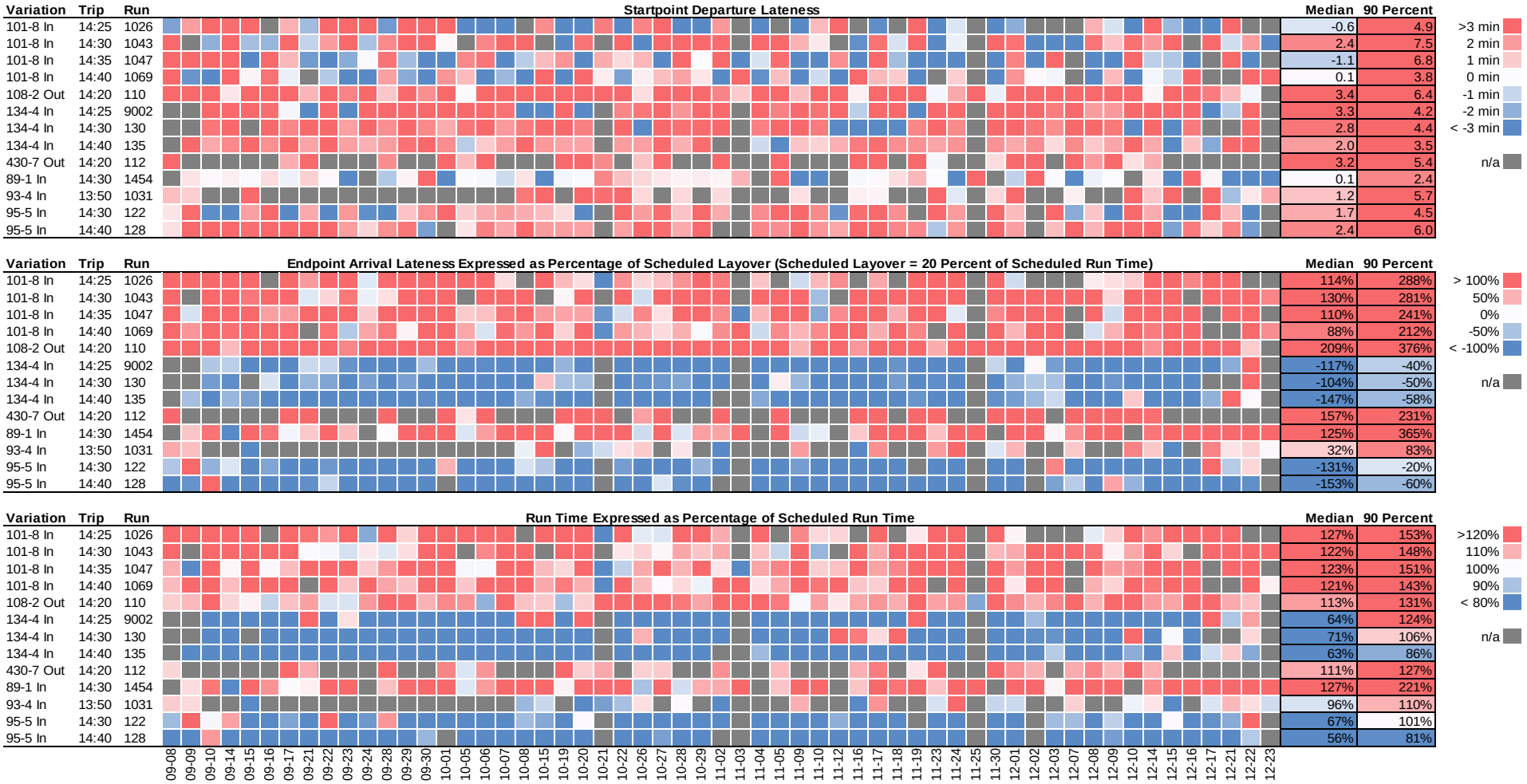


Figure B-8
Lynn District Supplemental Bus Trip Observations, Fall 2015

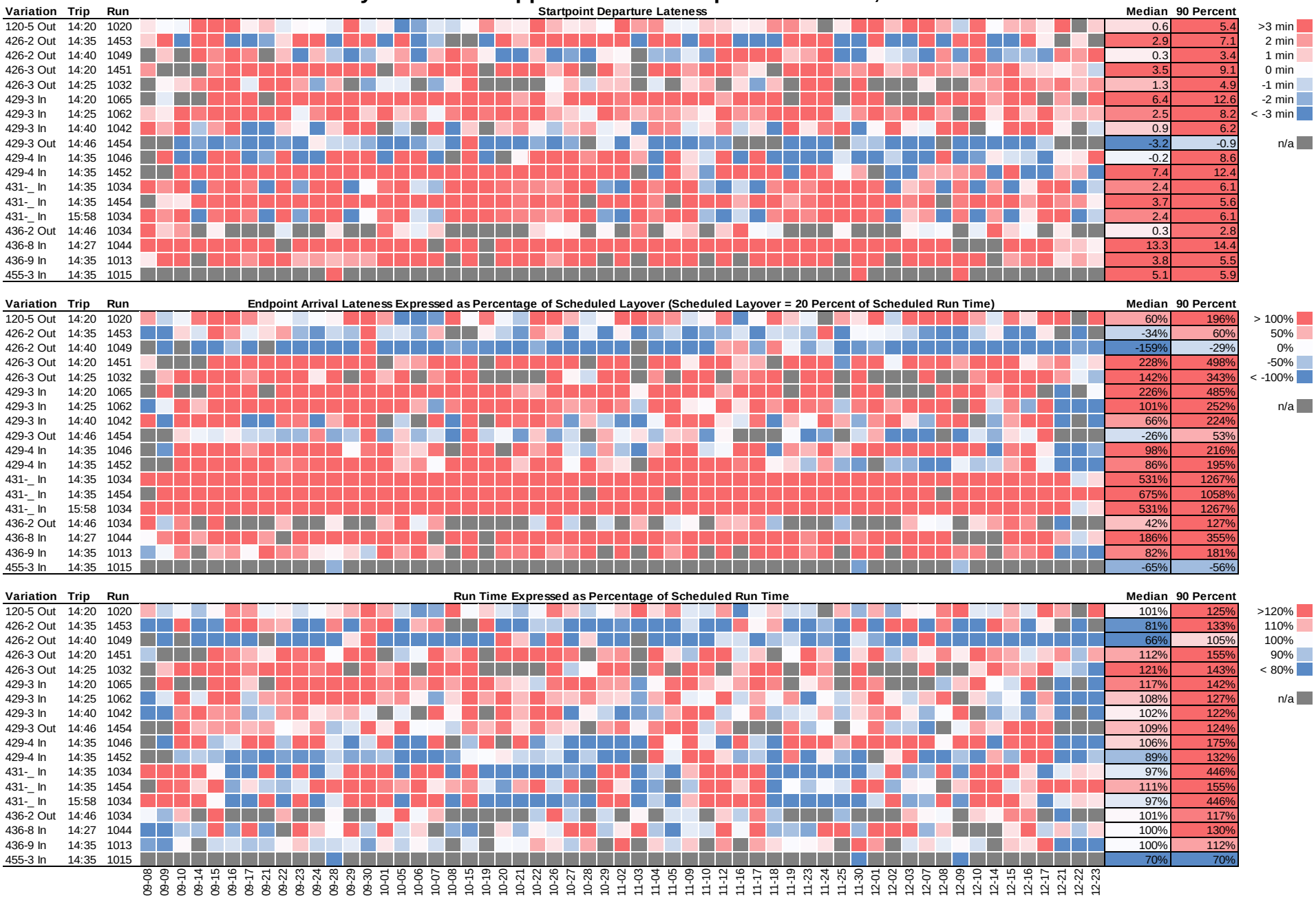
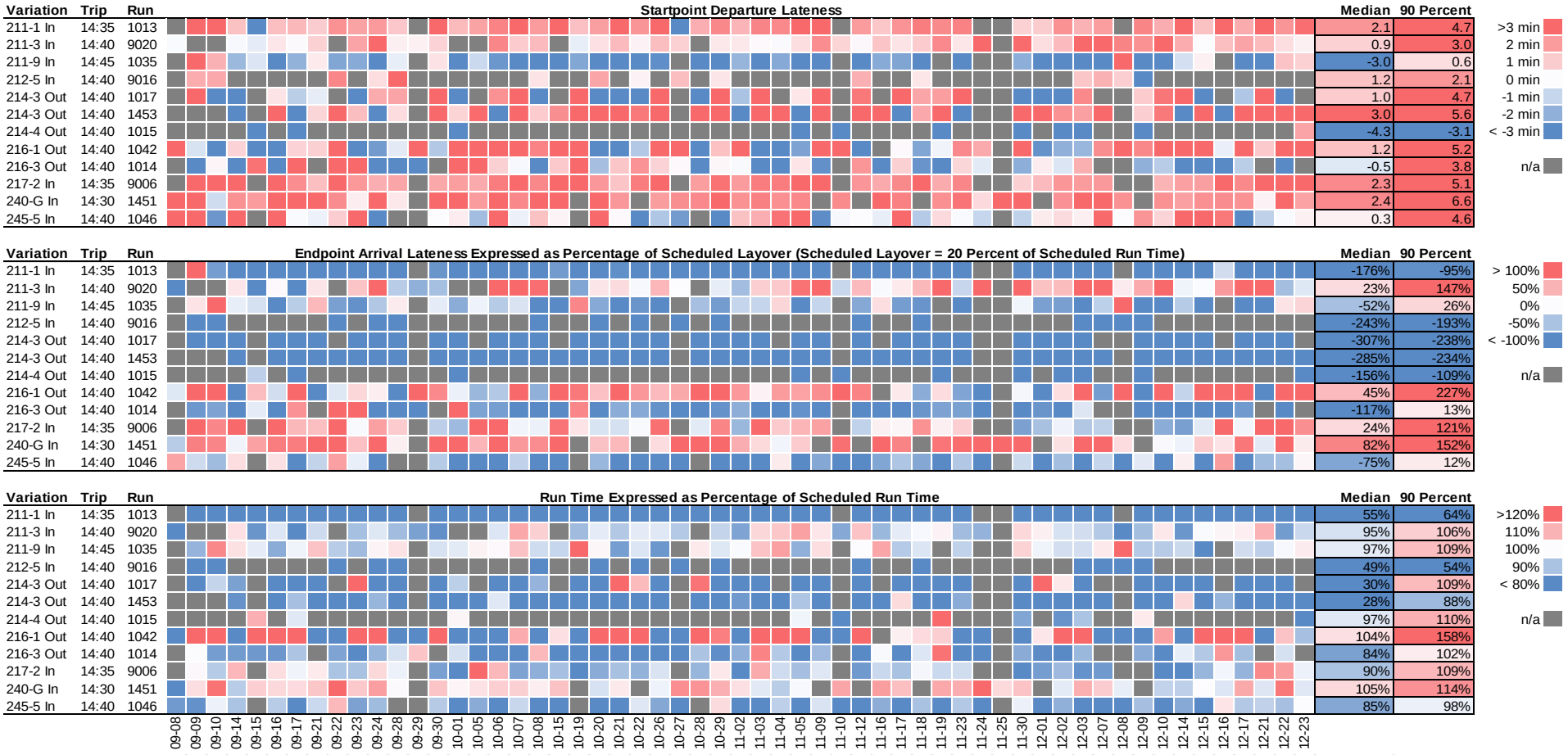


Figure B-9
Quincy District Supplemental Bus Trip Observations, Fall 2015



Appendix C:
Summary of MBTA Swing-On Delay Observations

Table C-1
Summary of Swing-On Delay by Route, Fall 2015

			Scenario A			Scenario B			All Trips		
Route	Dir.	Sched. Swing-Ons	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip
29-5	In	1	10	75.2	7.5	43	230.6	5.4	53	305.8	5.8
29-1	Out	1	8	65.6	8.2	36	139.9	3.9	44	205.4	4.7
62-8	Out	1	29	93.6	3.2	6	31.5	5.3	35	125.2	3.6
78-1	Out	4	165	437.0	2.6	46	191.3	4.2	211	628.3	3.0
78-2	Out	2	64	160.9	2.5	37	129.7	3.5	101	290.6	2.9
111-5	Out	2	67	153.5	2.3	34	134.8	4.0	101	288.3	2.9
465	Out	5	262	765.0	2.9	20	35.1	1.8	282	800.1	2.8
608	In	4	187	421.6	2.3	17	44.6	2.6	204	466.2	2.3
75	Out	3	139	317.4	2.3	18	29.3	1.6	157	346.6	2.2
450-8	In	6	248	323.5	1.3	87	371.6	4.3	335	695.1	2.1
19	Out	3	84	136.0	1.6	66	167.8	2.5	150	303.8	2.0
77	Out	24	877	1494.5	1.7	247	780.0	3.2	1,124	2274.5	2.0
746	Out	1	22	35.7	1.6	8	24.7	3.1	30	60.4	2.0
76-3	Out	2	83	166.3	2.0	9	14.1	1.6	92	180.5	2.0
29-1	In	2	47	94.3	2.0	28	52.5	1.9	75	146.9	2.0
120	Out	12	582	1019.0	1.8	90	229.1	2.5	672	1248.1	1.9
39-3	In	19	709	825.6	1.2	305	1038.2	3.4	1,014	1863.7	1.8
44-1	In	3	78	98.6	1.3	87	201.9	2.3	165	300.6	1.8
79	Out	7	315	547.2	1.7	17	26.0	1.5	332	573.2	1.7
106-6	Out	1	48	81.1	1.7	9	13.0	1.4	57	94.2	1.7
33-6	Out	2	58	161.7	2.8	49	9.0	0.2	107	170.7	1.6
111-2	Out	8	308	324.1	1.1	113	341.6	3.0	421	665.8	1.6
131-1	Out	1	22	16.4	0.7	31	66.9	2.2	53	83.3	1.6
17	Out	8	209	116.2	0.6	168	460.8	2.7	377	577.1	1.5
72	Out	6	187	173.7	0.9	116	290.0	2.5	303	463.7	1.5
742-3	Out	2	47	91.6	1.9	14	1.7	0.1	61	93.3	1.5
66-6	Out	30	1,162	1615.7	1.4	446	824.4	1.8	1,608	2440.1	1.5
430-1	Out	4	199	319.6	1.6	23	14.5	0.6	222	334.1	1.5
350-4	Out	1	32	51.3	1.6	18	21.9	1.2	50	73.2	1.5
24	Out	4	218	317.3	1.5	8	10.4	1.3	226	327.7	1.5
74	Out	4	219	298.8	1.4	4	12.1	3.0	223	310.9	1.4
106	Out	4	155	150.5	1.0	55	140.3	2.6	210	290.8	1.4
67-4	Out	3	120	159.2	1.3	18	30.9	1.7	138	190.1	1.4
16-9	Out	6	264	369.0	1.4	29	34.5	1.2	293	403.6	1.4
459	In	6	304	355.2	1.2	36	112.4	3.1	340	467.6	1.4
44-3	Out	2	53	55.8	1.1	52	84.1	1.6	105	139.9	1.3
19-3	In	1	46	41.3	0.9	10	32.9	3.3	56	74.2	1.3
01	Out	26	1,191	1426.8	1.2	198	357.5	1.8	1,389	1784.4	1.3
747	Out	8	175	279.9	1.6	239	248.3	1.0	414	528.1	1.3
751	In	6	217	203.0	0.9	96	191.1	2.0	313	394.1	1.3
62-3	Out	2	78	103.6	1.3	8	3.4	0.4	86	107.0	1.2
97-5	Out	2	83	108.7	1.3	31	32.7	1.1	114	141.4	1.2
114-1	Out	3	102	57.6	0.6	67	150.7	2.2	169	208.3	1.2

			Scenario A			Scenario B			All Trips		
Route	Dir.	Sched. Swing-Ons	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip
134-3	Out	2	105	120.2	1.1	3	11.4	3.8	108	131.5	1.2
112	In	7	325	333.4	1.0	64	138.7	2.2	389	472.1	1.2
751	Out	6	176	122.8	0.7	144	262.3	1.8	320	385.1	1.2
455-6	In	7	344	295.2	0.9	51	176.0	3.5	395	471.2	1.2
15	Out	7	186	289.7	1.6	167	128.6	0.8	353	418.3	1.2
106-7	Out	5	246	275.1	1.1	29	47.1	1.6	275	322.1	1.2
134-6	Out	3	147	173.9	1.2	16	17.0	1.1	163	190.9	1.2
350-5	Out	5	209	195.7	0.9	34	82.5	2.4	243	278.2	1.1
23	Out	26	736	1090.8	1.5	573	360.2	0.6	1,309	1451.1	1.1
108-1	Out	2	94	100.2	1.1	9	13.8	1.5	103	114.0	1.1
749	In	16	662	536.6	0.8	182	392.3	2.2	844	928.8	1.1
742	Out	7	187	136.6	0.7	56	129.7	2.3	243	266.3	1.1
18	Out	2	90	45.6	0.5	19	72.9	3.8	109	118.5	1.1
110-4	Out	2	91	79.4	0.9	21	35.7	1.7	112	115.1	1.0
105-1	In	4	90	31.4	0.3	133	196.1	1.5	223	227.5	1.0
110	Out	5	251	239.0	1.0	22	31.5	1.4	273	270.5	1.0
65	Out	7	345	338.6	1.0	48	40.1	0.8	393	378.6	1.0
43	In	5	175	224.4	1.3	95	34.4	0.4	270	258.8	1.0
742-1	Out	3	77	81.2	1.1	26	15.8	0.6	103	97.0	0.9
97-5	In	2	94	56.5	0.6	19	47.3	2.5	113	103.8	0.9
111-8	Out	2	92	78.4	0.9	9	12.3	1.4	101	90.7	0.9
45-3	Out	2	68	62.2	0.9	35	30.0	0.9	103	92.2	0.9
442-1	Out	3	93	47.5	0.5	81	106.4	1.3	174	153.9	0.9
45	Out	8	270	324.4	1.2	151	46.8	0.3	421	371.3	0.9
90	Out	5	231	189.3	0.8	31	38.6	1.2	262	227.9	0.9
459	Out	2	77	32.8	0.4	31	58.2	1.9	108	91.0	0.8
22	Out	16	549	608.5	1.1	252	65.2	0.3	801	673.6	0.8
441-7	Out	5	231	128.0	0.6	48	101.0	2.1	279	229.0	0.8
60-2	Out	3	114	74.9	0.7	53	57.2	1.1	167	132.1	0.8
60	Out	5	263	204.3	0.8	17	11.9	0.7	280	216.2	0.8
84-1	Out	3	128	97.7	0.8	19	13.5	0.7	147	111.3	0.8
435	Out	5	228	168.4	0.7	44	32.4	0.7	272	200.8	0.7
741	Out	20	539	422.4	0.8	111	23.2	0.2	650	445.5	0.7
15-2	Out	6	198	182.6	0.9	101	22.0	0.2	299	204.6	0.7
80	Out	3	162	106.6	0.7	1	0.0	0.0	163	106.6	0.7
708-1	Out	3	139	27.8	0.2	16	73.0	4.6	155	100.9	0.7
27	In	4	184	94.4	0.5	37	48.2	1.3	221	142.6	0.6
70A-1	Out	6	282	193.2	0.7	42	11.8	0.3	324	205.0	0.6
456	Out	1	49	32.6	0.7	5	0.7	0.1	54	33.3	0.6
87-2	Out	6	304	142.3	0.5	32	64.7	2.0	336	206.9	0.6
44-1	Out	7	231	157.1	0.7	135	67.6	0.5	366	224.7	0.6
68	In	3	94	53.9	0.6	53	35.5	0.7	147	89.4	0.6
76	Out	2	78	44.1	0.6	6	5.3	0.9	84	49.4	0.6
99-7	Out	6	275	140.9	0.5	62	57.0	0.9	337	197.8	0.6
70-5	Out	13	525	320.7	0.6	99	37.5	0.4	624	358.2	0.6

			Scenario A			Scenario B			All Trips		
Route	Dir.	Sched. Swing-Ons	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip
83-1	Out	3	125	39.8	0.3	27	45.5	1.7	152	85.3	0.6
07-1	In	5	172	62.7	0.4	87	79.8	0.9	259	142.5	0.6
08-9	Out	1	36	17.8	0.5	20	11.0	0.5	56	28.8	0.5
88	Out	7	336	131.2	0.4	44	62.5	1.4	380	193.8	0.5
100-3	Out	4	163	65.7	0.4	51	42.2	0.8	214	108.0	0.5
442-7	Out	3	153	48.5	0.3	16	36.4	2.3	169	84.9	0.5
69	In	2	96	47.5	0.5	10	5.3	0.5	106	52.8	0.5
69	Out	6	283	123.0	0.4	28	31.3	1.1	311	154.3	0.5
09	In	9	244	131.2	0.5	200	82.5	0.4	444	213.7	0.5
426	Out	2	104	38.1	0.4	11	16.2	1.5	115	54.3	0.5
64	Out	5	219	114.0	0.5	46	11.0	0.2	265	125.0	0.5
11-3	In	6	224	81.0	0.4	90	62.7	0.7	314	143.7	0.5
70A-4	Out	3	102	42.9	0.4	54	28.4	0.5	156	71.3	0.5
411-8	Out	3	103	24.2	0.2	12	27.1	2.3	115	51.3	0.4
57	Out	22	1,108	417.9	0.4	115	121.3	1.1	1,223	539.2	0.4
136-5	Out	4	200	70.9	0.4	20	22.8	1.1	220	93.7	0.4
137-3	Out	3	148	34.5	0.2	18	34.0	1.9	166	68.5	0.4
33-5	Out	2	110	41.4	0.4	4	0.9	0.2	114	42.4	0.4
117-5	In	1	57	19.0	0.3	1	1.0	1.0	58	20.0	0.3
41	In	6	191	46.2	0.2	137	66.3	0.5	328	112.5	0.3
436	Out	5	247	60.0	0.2	29	32.7	1.1	276	92.8	0.3
106-5	Out	1	55	18.4	0.3	0	0.0	N/A	55	18.4	0.3
15-1	Out	2	59	18.5	0.3	45	11.8	0.3	104	30.3	0.3
435-4	Out	1	8	3.1	0.4	28	6.5	0.2	36	9.6	0.3
70-8	Out	2	90	25.4	0.3	6	0.0	0.0	96	25.4	0.3
450-8	Out	4	218	44.3	0.2	6	5.9	1.0	224	50.2	0.2
426	In	6	202	43.7	0.2	100	13.9	0.1	302	57.6	0.2
119-1	In	1	15	1.3	0.1	41	9.3	0.2	56	10.5	0.2
108-6	Out	2	103	7.2	0.1	9	12.4	1.4	112	19.6	0.2
134-2	Out	1	54	9.4	0.2	0	0.0	N/A	54	9.4	0.2
10-9	Out	3	142	23.8	0.2	24	0.4	0.0	166	24.3	0.1
71	In	16	658	54.9	0.1	203	67.6	0.3	861	122.5	0.1
450-9	In	1	57	7.5	0.1	1	0.0	0.0	58	7.5	0.1
108-1	In	2	95	13.8	0.1	17	0.0	0.0	112	13.8	0.1
116-4	In	2	100	4.5	0.0	9	7.3	0.8	109	11.8	0.1
11-3	Out	12	434	25.5	0.1	211	44.0	0.2	645	69.5	0.1
07-1	Out	3	120	3.4	0.0	43	14.2	0.3	163	17.5	0.1
708-1	In	1	14	2.6	0.2	39	2.8	0.1	53	5.5	0.1
429	In	2	93	1.6	0.0	22	9.8	0.4	115	11.4	0.1
08-9	In	8	125	4.1	0.0	239	26.5	0.1	364	30.6	0.1
55-1	Out	3	41	11.5	0.3	112	0.0	0.0	153	11.5	0.1
10-9	In	1	37	0.0	0.0	6	2.6	0.4	43	2.6	0.1
429	Out	3	129	6.3	0.0	35	3.7	0.1	164	10.0	0.1
73	In	15	565	20.1	0.0	180	20.1	0.1	745	40.2	0.1
92-1	In	1	46	2.2	0.0	10	0.0	0.0	56	2.2	0.0

			Scenario A			Scenario B			All Trips		
Route	Dir.	Sched. Swing-Ons	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip	Number of Obs.	Swing Delay	Swing Delay per Trip
99-7	In	2	114	4.4	0.0	0	0.0	N/A	114	4.4	0.0
100-3	In	1	25	0.0	0.0	28	1.9	0.1	53	1.9	0.0
132	Out	2	75	0.8	0.0	38	1.7	0.0	113	2.5	0.0
92-1	Out	1	18	0.0	0.0	33	1.1	0.0	51	1.1	0.0
441-7	In	2	107	0.7	0.0	1	0.0	0.0	108	0.7	0.0
108-6	In	2	86	0.0	0.0	27	0.5	0.0	113	0.5	0.0
09	Out	3	113	0.0	0.0	53	0.6	0.0	166	0.6	0.0
43	Out	4	10	0.0	0.0	200	0.2	0.0	210	0.2	0.0
442-7	In	1	55	0.0	0.0	0	0.0	N/A	55	0.0	0.0
16-2	Out	1	2	0.0	0.0	44	0.0	0.0	46	0.0	0.0
708	In	1	33	0.0	0.0	22	0.0	0.0	55	0.0	0.0
92-3	Out	1	51	0.0	0.0	4	0.0	0.0	55	0.0	0.0

Table C-2
Summary of Swing-On Delay by Start-Point Location, Fall 2015

		Scenario A			Scenario B			All Trips		
Location	Sched. Swing-Ons	Obs.	Swing Delay	Swing Delay per Trip	Obs.	Swing Delay	Swing Delay per Trip	Obs.	Swing Delay	Swing Delay per Trip
jasst	4	86	164	1.9	123	342	2.8	209	506	2.4
bally	43	1,651	2,882	1.7	468	1,432	3.1	2,119	4,315	2.0
fhill	19	709	826	1.2	305	1,038	3.4	1,014	1,864	1.8
mavck	15	684	1,077	1.6	157	380	2.4	841	1,456	1.7
salem	25	1,215	1,746	1.4	195	695	3.6	1,410	2,442	1.7
matpn	15	627	784	1.3	169	352	2.1	796	1,136	1.4
alewf	26	1,072	1,459	1.4	135	229	1.7	1,207	1,688	1.4
hayms	22	976	1,060	1.1	190	555	2.9	1,166	1,615	1.4
dudly	78	3,232	3,782	1.2	922	1,765	1.9	4,154	5,547	1.3
fldcr	1	46	41	0.9	10	33	3.3	56	74	1.3
andrw	19	702	559	0.8	232	641	2.8	934	1,200	1.3
esxat	6	176	123	0.7	144	262	1.8	320	385	1.2
rugg	92	2,784	3,430	1.2	1,911	1,267	0.7	4,695	4,697	1.0
welst	51	2,371	2,074	0.9	412	631	1.5	2,783	2,705	1.0
soust	33	872	768	0.9	215	195	0.9	1,087	963	0.9
malst	24	986	573	0.6	294	410	1.4	1,280	983	0.8
wondw	14	634	248	0.4	155	252	1.6	789	500	0.6
kenbs	38	1,866	1,053	0.6	253	242	1.0	2,119	1,295	0.6
hhgat	5	190	101	0.5	63	41	0.6	253	142	0.6
cntsq	3	125	40	0.3	27	46	1.7	152	85	0.6
lchmr	22	1,085	503	0.5	105	159	1.5	1,190	662	0.6
unvpk	29	1,218	696	0.6	247	89	0.4	1,465	785	0.5
ctypt	21	677	275	0.4	383	228	0.6	1,060	503	0.5
censq	18	734	308	0.4	206	86	0.4	940	394	0.4
otsum	5	197	36	0.2	74	72	1.0	271	108	0.4
jpctr	6	191	46	0.2	137	66	0.5	328	113	0.3
stjim	3	142	24	0.2	24	0	0.0	166	24	0.1
wtrsq	16	658	55	0.1	203	68	0.3	861	122	0.1
ngate	3	108	3	0.0	63	19	0.3	171	22	0.1
bdfch	12	434	26	0.1	211	44	0.2	645	70	0.1
louis	1	14	3	0.2	39	3	0.1	53	5	0.1
umass	9	127	4	0.0	283	26	0.1	410	31	0.1
lindn	4	181	14	0.1	44	0	0.0	225	14	0.1
silmt	3	129	6	0.0	35	4	0.1	164	10	0.1
wavsq	15	565	20	0.0	180	20	0.1	745	40	0.1
amall	1	46	2	0.0	10	0	0.0	56	2	0.0
uphgh	2	114	4	0.0	0	0	N/A	114	4	0.0
elm	1	25	0	0.0	28	2	0.1	53	2	0.0
pktrm	7	51	11	0.2	312	0	0.0	363	12	0.0
milk	2	69	0	0.0	37	1	0.0	106	1	0.0
marbl	3	162	1	0.0	1	0	0.0	163	1	0.0
copst	3	113	0	0.0	53	1	0.0	166	1	0.0
bethi	1	33	0	0.0	22	0	0.0	55	0	0.0

Table C-3
Summary of Swing-On Delay by Time of Day, Fall 2015

		Scenario A			Scenario B			All Trips		
Time of Day	Sched. Swing-Ons	Obs.	Swing Delay	Swing Delay per Trip	Obs.	Swing Delay	Swing Delay per Trip	Obs.	Swing Delay	Swing Delay per Trip
8:00-8:59	10	230	365	1.6	259	699	2.7	489	1,064	2.2
9:00-9:59	31	1,233	1,626	1.3	387	662	1.7	1,620	2,288	1.4
10:00-10:59	63	2,726	2,490	0.9	596	859	1.4	3,322	3,350	1.0
11:00-11:59	79	3,516	2,418	0.7	622	405	0.7	4,138	2,823	0.7
12:00-12:59	49	2,135	1,872	0.9	437	628	1.4	2,572	2,500	1.0
13:00-13:59	66	2,835	2,315	0.8	615	572	0.9	3,450	2,887	0.8
14:00-14:59	61	2,641	2,389	0.9	492	419	0.9	3,133	2,809	0.9
15:00-15:59	79	2,960	2,826	1.0	996	1,138	1.1	3,956	3,964	1.0
16:00-16:59	126	4,425	3,953	0.9	2,143	3,117	1.5	6,568	7,070	1.1
17:00-17:59	67	2,113	1,990	0.9	1,260	2,106	1.7	3,373	4,096	1.2
18:00-18:59	20	604	461	0.8	395	215	0.5	999	676	0.7
19:00-19:59	13	412	410	1.0	231	341	1.5	643	752	1.2
20:00-20:59	19	739	910	1.2	257	263	1.0	996	1,173	1.2
21:00-21:59	27	1,053	554	0.5	291	261	0.9	1,344	815	0.6
22:00-22:59	8	340	199	0.6	95	10	0.1	435	209	0.5
23:00-23:59	2	115	46	0.4	1	0	0.0	116	46	0.4

Appendix D:
Summary of Early Pull-Up Opportunity

Figure D-1
Average Span of Layover and Dwell for Observed Route 28 Outbound Trips, Fall 2015

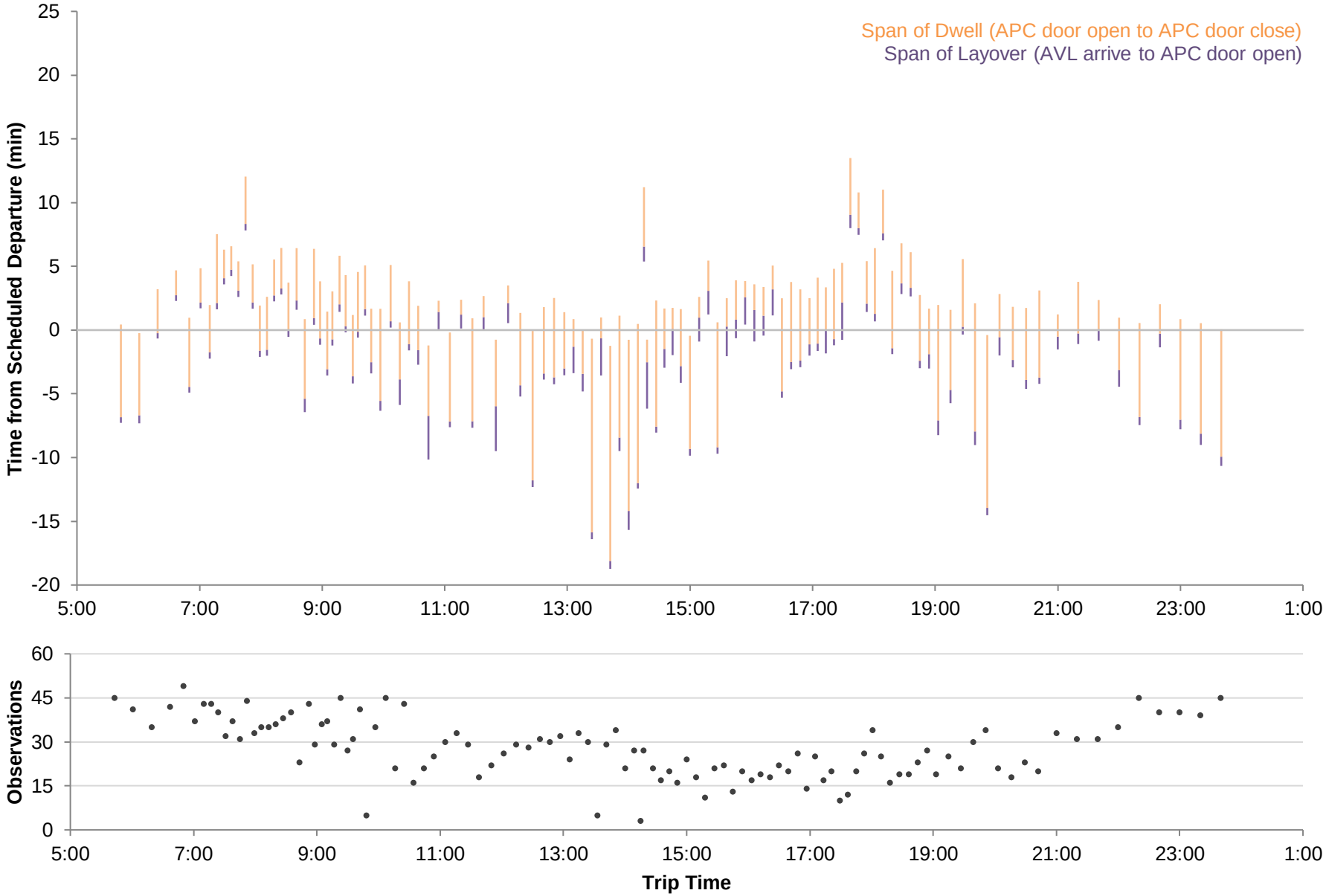


Figure D-2
Average Span of Layover and Dwell for Observed Route 32 Outbound Trips, Fall 2015

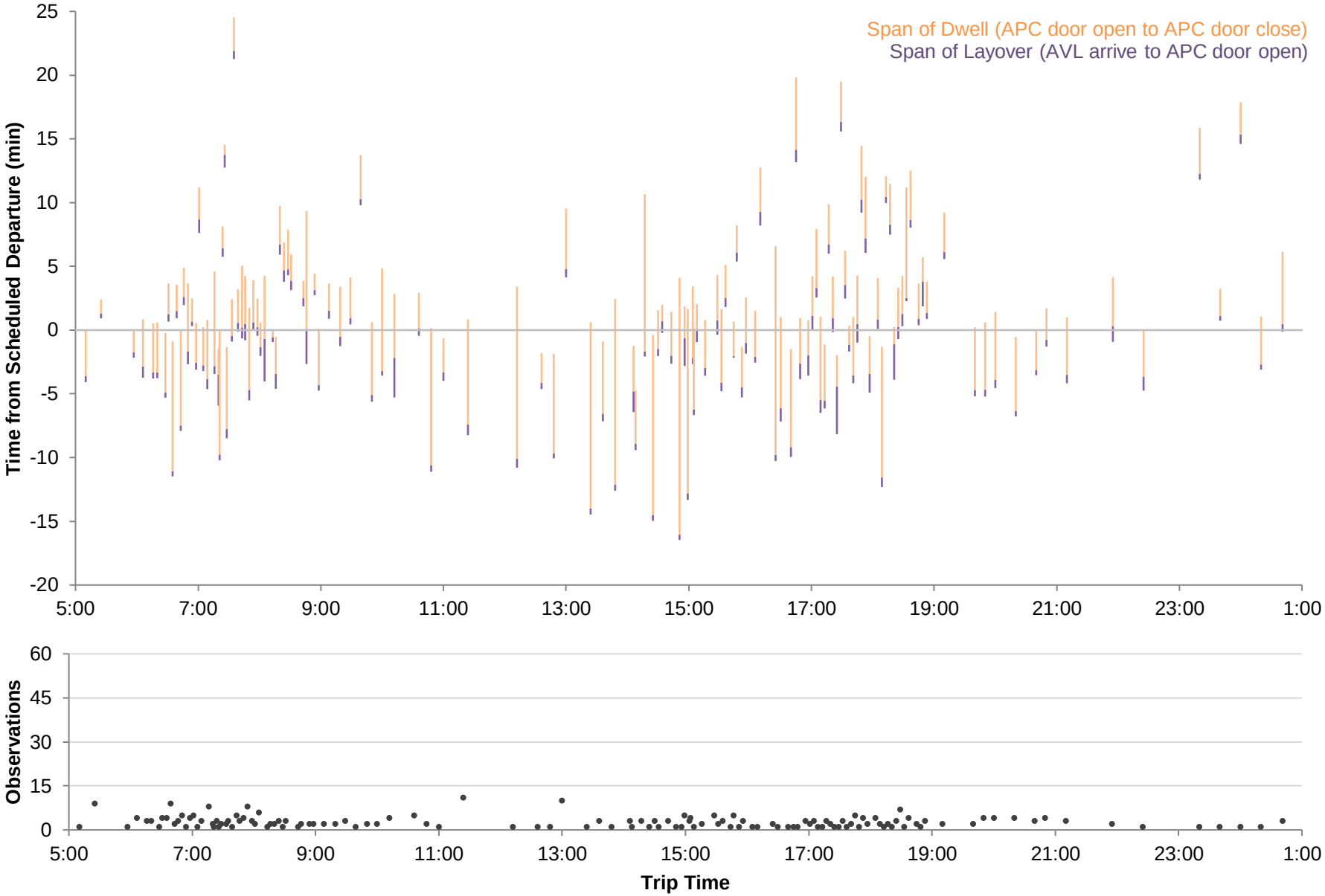


Figure D-3
Average Span of Layover and Dwell for Observed Route 57 Outbound Trips, Fall 2015

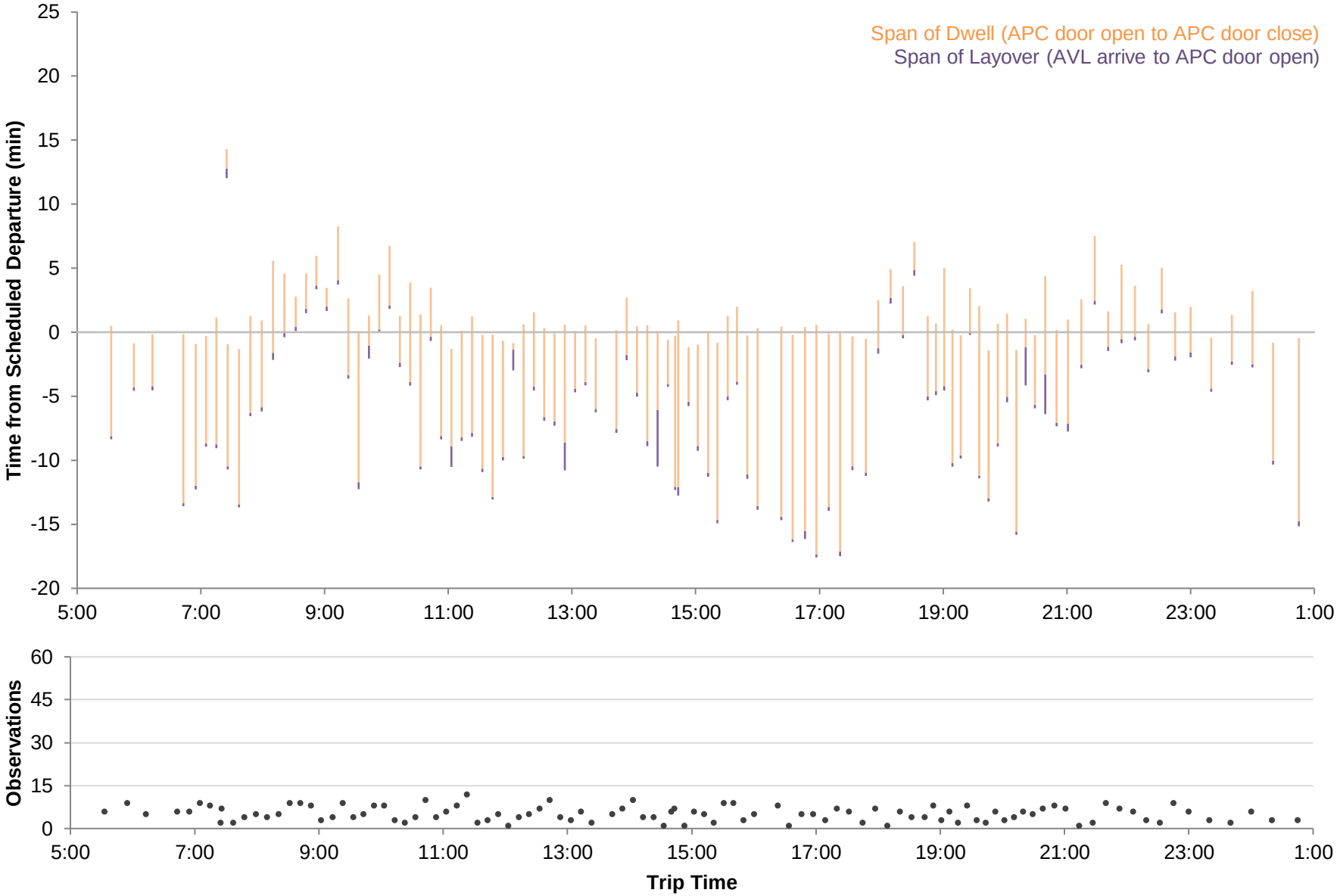


Figure D-4
Average Span of Layover and Dwell for Observed Route 111 Outbound Trips, Fall 2015