TECHNICAL MEMORANDUM

DATE: **December 21, 2017**
TO: **CMP Committee**
FROM: **Ryan Hicks, CMP Manager**
RE: **Fall 2016 Monitoring of MBTA Bus Performance Measures**

1 INTRODUCTION AND BACKGROUND

1.1 Introduction

The purpose of this memorandum is to identify congested or inefficiently operated locations within the Massachusetts Bay Transportation Authority (MBTA) bus network. The Boston Region Metropolitan Planning Organization (MPO) staff performed this specific task in response to a verbal recommendation at the MPO's Federal Recertification Review in 2014. The recommendation—made by the Federal Transit Administration (FTA)—was that MPOs, in general, should incorporate transit performance measures into their congestion management processes (CMP).

1.2 Background

Congestion monitoring is performed though a CMP—a federally mandated program that requires all MPOs to review alternatives to expand roadway capacity to relieve congestion. The CMP identify and document congested locations in the transportation network. Once staff discerns congested locations, the CMP then recommends low-cost non-capital strategies for implementation. The congestion management process is multi-modal; it monitors roadways, transit, high-occupancy-vehicle (HOV) lanes, and bicycle/pedestrian and park and ride facilities. MPO staff gathers data about these facilities, and employs performance measures to gauge the transportation network's efficiency. The collected data could be used to inform planners and engineers as they make decisions about congestion-mitigation strategies. This task relates directly to the capacity management/mobility and preservation goals stated in the Boston Region MPO's Long- Range Transportation Planning (LRTP).

The MBTA system includes a total of 9 heavy rail rapid transit lines and light rail lines, 13 commuter rail lines, and 3 ferry lines. The CMP last monitored the MBTA transit system in 2013, using two performance measures—on-time performance and load factor. However, this study focused initially on buses because the MBTA bus system has the newest and most reliable automatic

vehicle location (AVL) data available. Thus, staff analyzed only the 171 (340 bi-directional) bus routes, which include five Silver Line bus rapid transit routes, three crosstown routes and 23 express bus routes. For this analysis, staff used the following three factors:

- Bus travel time
- Bus on-time performance
- Bus passenger crowding

2 DESCRIPTION OF TRANSIT DATA

2.1 Data Collection

Data for this project came from multiple sources including existing MBTA data (see Table 1). For the purpose of this analysis, staff collected data from September, October, and November 2016; from Monday through Friday; with an AM peak period of between 7:00 AM and 9:00 AM, and a PM peak period of between 4:00 PM and 6:30 PM. The major data sources used for this project are as follows:

- Timepoint data was provided for each bus trip that took place during the three-month period in 2016. The timepoint data showed variables such as average run time and scheduled run time.
- Data to measure on-time performance was downloaded from the MBTA Back on Track website.
- Maximum and median bus loads were provided via MBTA automatic passenger counters (APC), which are installed on the buses.
- Bus fleet information and capacities were provided by the MBTA.

2.2 Data Processing

In this study, staff used eight performance measures altogether to gauge congestion on the bus network. In order to calculate the performance measures, staff collected MBTA timepoint data. Table 1 lists the performance measures that were used for this study along with the data components that were needed to compute each performance measure.

Table 1
Performance Measures and Data Sources

Performance Measure	Data Needed/Source
On-time performance	Timepoints; number of stops where buses arrive late
Transit time index	Average bus run time; scheduled bus run time
Person hours of delay	Bus run delay; average number of people on bus run
Bus run delay	Average bus run time; scheduled bus run time; departure delay time
Passenger crowding/ load factor	Maximum number of people on bus run; number of bus seats
Pass-up standard	Maximum number of people on bus run; number of bus seats; total number of bus runs; number of bus runs that fail pass-up standard
Person-hours of delay per bus run	Total person-hours of delay, total number of bus runs
Percent of delay during peak periods	Total person hours of delay for peak period; total person-hours of delay for the entire day

The data provided was originally separated by bus line, bus run, and time of day (AM peak, PM peak, or off-peak period). Staff executed an analysis using RStudio[1] to transform data that was collected from the MBTA into data that is averaged for each bus route for each time period. The criteria listed in Table 1 are used as the attributes and are sorted by bus route for each time period. A table that has the above attributes for every bus route is displayed in Appendix B. In addition, this table was joined to a bus network shapefile, which was used to create the maps in Appendix A.

3 PERFORMANCE MEASURES DESCRIPTION

To monitor performance on a transportation network properly, it is important to measure congestion in each of the following four categories: duration, extent, intensity, and reliability. Each performance measure is designed to measure one of these categories, descriptions of which are listed below.

3.1 Performance Measure Categories

Duration

Duration performance measures gauge how long a bus route is congested during the peak period, or the length of delay that occurs as a result of congestion.

Extent

Extent performance measures estimate the number of passengers or buses that are affected by congestion, and the geographic distribution of congestion.

[1] RStudio is an open-source integrated development that facilitates statistical analysis via the "R" programming language.

Intensity

Intensity performance measures show the severity of congestion and typically differentiate between the levels of congestion on different bus lines.

Reliability

Reliability is the variation in the first three performance measure categories between peak-period and off-peak-period time. Reliability performance measures indicate how a trip may be affected by nonrecurring congestion as well as by recurring congestion.

3.2 Performance Measures

On-Time Performance—Reliability

Historically, the MBTA's on-time performance measure has been used for CMP monitoring; and will be reported according to the MBTA's definition of reliability. Data from this performance measure is available on the MBTA Back on Track dashboard. Bus service is measured at both terminuses of the route and at midpoints.

- For buses that have headway of 15 minutes or less, an on-time trip is defined as a trip that departs a timepoint no more than three minutes later than the scheduled time.
- For buses scheduled less frequently than every 15 minutes, a bus that leaves a timepoint between less that one or as much as six minutes earlier than the scheduled time is considered to be on time.

The peak periods are slightly different[2] from those used in the other performance measures. For the purpose of this study, the CMP threshold of 60 percent of timepoints that experience on-time performance is used as a parameter to determine on-time performance.

Transit Time Index—Reliability

Transit time index compares the average travel time of buses through a route during a given time period with the scheduled travel time during that time period. This measure can be used to calculate delay along a bus route. Routes that have a transit time index of more than 1.3 are considered to be congested. This data was provided by the MBTA, via the crossing summary/timepoint data. Unlike person-hours of delay, this measure does not factor in late departure time, thus

[2] http://www.mbtabackontrack.com/performance/index.html#/detail/reliability/// Peak period for this measure is 6:30 to 9:30 AM and 3:30 to 6:30 PM.

making it the best measure to determine if there is a roadway congestion problem along a bus line.

Transit Time Index = Average Travel Time / Scheduled Travel Time

Transit Time Index Threshold = Greater than 1.3

Person-Hours of Delay—Extent; Bus Run Delay—Intensity

This performance measure combines ridership numbers with the travel time delay of the buses. Late origin-departure is also included in determining person-hours of delay (late departure time is capped at 15 minutes). The delay for each run can be multiplied by the average ridership for that run. The hours of delay can be calculated for the peak period, entire day, or entire year.

Bus Run Delay = (Actual Travel Time for Bus Run + Departure Delay Time) - Scheduled Travel Time

*Person Hours of Delay per Run = Bus Run Delay * Average Number of People on Bus Run*

Passenger Crowding/Load Factor—Intensity

Passenger crowding is measured as the ratio of the number of passengers on a vehicle at the maximum load point to the number of seats on the vehicle. For CMP purposes, MBTA thresholds for passenger crowding are used in this performance measure. If the ratio of passengers to seats is more than 1.4 at any point during a specific trip, then the route is considered to be crowded. Data will be available from either APC or ridecheck data.

Passenger Crowding Threshold = Maximum Load of More than 1.40 Passengers per Seat

Pass-Up Standard—Intensity

Pass-up standard estimates the number of trips on a bus route that leave passengers at a stop. It is assumed that if the maximum passenger load on a bus is more than 1.50 times the number of seats, then the bus is likely leaving passengers at stops because of lack of capacity.

Steps for Calculating Pass-Up Standard:

1. Analyze APC or ridecheck data for each trip.
2. If the number of passengers on a bus trip at any time exceeds 1.5 times the number of seats, then that trip fails the pass-up standard. Each of the daily bus trips in each peak period is labeled as either pass or fail for this standard

3. A bus route fails the pass-up standard if 1) more than five percent of all trips have failed the pass-up standard test at all times, and/or 2) more than five percent of trips fail during either the AM or PM peak period.

Percent of Delay during Peak Periods—Duration

Person-hours of delay are calculated for each peak period and for the entire service day. If more than 60 percent of the total daily person-hours of delay occur during a single peak period, then the bus route is flagged as having a high directional travel split, which means that the route has a high incidence of delay in one direction and little or no travel delay in the opposite travel direction. If delays are concentrated during certain times of day, schedule adjustments may be necessary.

Percent of Delay during Peak Periods = Total Person-Hours of Delay for Each Peak Period / Total Person-Hours of Delay for Entire Day

Percent of Delay during Peak Periods Threshold = More than 60 Percent during a Single Peak Period

Person Hours of Delay per Bus Trip—Extent

This performance measure shows the average person-hours of delay per trip for each bus route regardless of service frequency. (Use of absolute person-hours of delay per route could overstate the impact to individual passengers on high-frequency routes.)

Person Hours of Delay per Bus Trip = Daily Total Person Delay / Total Number of Bus Trips

Person-Hours of Delay per Bus Trip = Five Hours

4 PERFORMANCE MEASURES ANALYSIS

4.1 Regional Overview

Table 2 displays a systemwide overview of the MBTA bus system in terms of performance measures for transit time index, delay, passenger crowding, and the percentage of delay occurring during the peak periods.

- As indicated by the transit time index performance measure, actual trip times average 15 percent longer than scheduled times in the AM peak period and 16 percent longer than the scheduled trip times in the PM peak period.
- The systemwide average load factor for buses is 0.76 during the AM peak period, and 0.75 during the PM peak period. For example, for a bus with 39 seats the maximum load per trip would average 30 passengers. However, this overview does not highlight problem areas on the bus

system where buses have a load factor of 1.40 or greater. Table 4 cites individual routes that experience extreme overcrowding.

- According to MBTA standards for on-time arrival, 55 percent of weekday peak-period bus trips arrive on time. The CMP goal for this performance measure is that 60 percent of all buses arrive on time, and the MBTA goal is that 70 percent of all buses arrive on time. Out of 340 directional bus routes, 217 routes failed to meet the CMP threshold for this performance measure.
- Sixteen directional routes fail the pass-up standard at some point during a typical weekday, which means that buses on these routes will be overcrowded to the point that the buses are bypassing stops, leaving passengers waiting.
- There are 4,782 person-hours of delay in the AM peak and 6,345 person-hours of delay in the PM peak period on a typical weekday. The AM and PM person-hours of delay represent 20.6 percent and 27.4 percent, respectively, of the total daily person-hours of delay. The person-hours of delay per bus trip is greater in the PM peak than in the AM peak period, so the greater PM peak person-hour total is attributable to greater delay intensity as well as to the longer PM peak span defined by the MBTA (2.5 hours compared with 2.0 hours in the AM peak period).

Table 2
Systemwide Overview of the MBTA Bus System, Fall 2016

Performance Measure	Fall 2016 Result
AM transit time index	1.15
PM transit time index	1.16
AM total bus trip delay	339.1 hours
PM total bus trip delay	428 hours
Total daily bus trip delay	1,655.5 hours
AM load factor	0.76
PM load factor	0.75
Daily load factor	0.49
Weekday peak period on-time performance	55%
Directional routes that fail pass-up standard at any time	15 out of 340 routes
Person-hours of delay in AM peak	4,782 hours
Person-hours of delay in PM Peak	6,345.1 hours
Total person-hours of delay per day	23,188.7 hours
Percentage of person-hours of delay in AM peak	20.60%
Percentage of person-hours of delay in PM peak	27.40%
AM person-hours of delay per bus trip	2.1 hours
PM person-hours of delay per bus trip	2.5 hours
Total daily person-hours of delay per bus trip	1.7 hours

4.2 Individual Bus Routes

This section analyzes performance monitoring results for individual bus routes and identifies problem areas in the bus network based on the performance measures for duration, extent, intensity, and reliability.

Duration

Percent of person-hours of delay during peak period

Table 3 shows the routes that have the highest percentage of person-hours of delay during a specific peak period. Most of the routes that are listed in this table are express bus routes.

Table 3
Percent of Delay during Designated Peak Period

Bus Route	Direction	Percentage Delay	Time Period
439	Outbound	95%	PM
SLW	Inbound	85%	PM
57A	Outbound	85%	PM
326	Inbound	84%	AM
352	Outbound	84%	PM
448	Outbound	83%	PM
325	Outbound	83%	PM
351	Outbound	82%	AM
7	Inbound	81%	AM
326	Outbound	81%	PM

Extent

Bus Routes with the most total person hours of delay per day

Figures 1, 2 and 3 display the routes with the most total person-hours of delay for the AM peak period, PM peak period, and all day. Figure A-3 in Appendix A shows a detailed map that displays all MBTA bus routes based on amount of person-hours of delay. Most of the routes that have a large number of person hours of delay per day are among those with the greatest number of bus trips per day. With the exception of route 240 outbound in the PM peak period, every route displayed in these figures is in the top-40 group of total bus trips in the displayed peak period. Figure A-5 displays the person-hours of delay by bus route.

Figure 1
Routes with the Most Total Person-Hours of Delay per Day, AM Peak Period

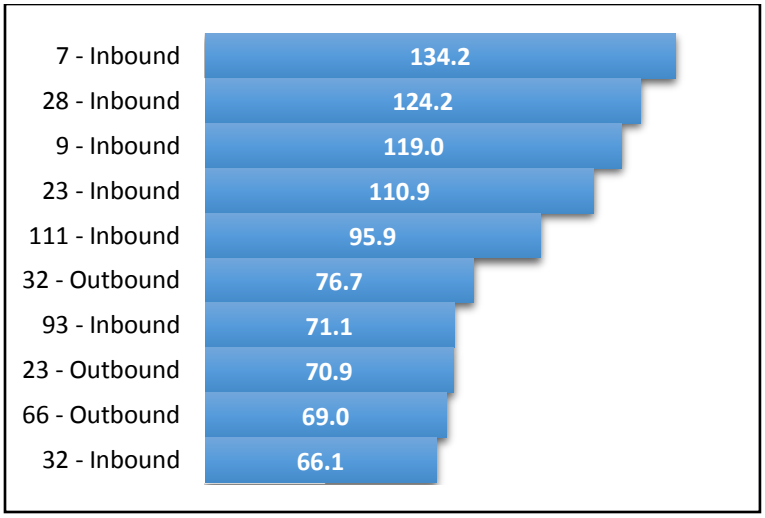


Figure 2
Routes with the Most Total Person-Hours of Delay per Day, PM Peak Period

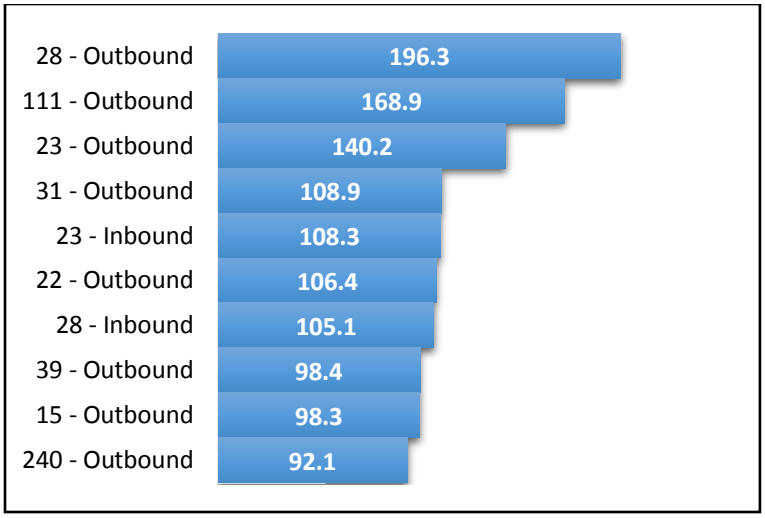
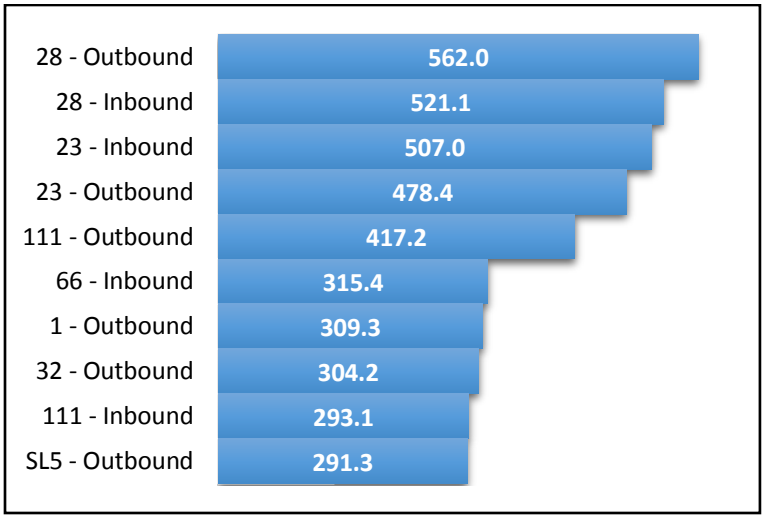


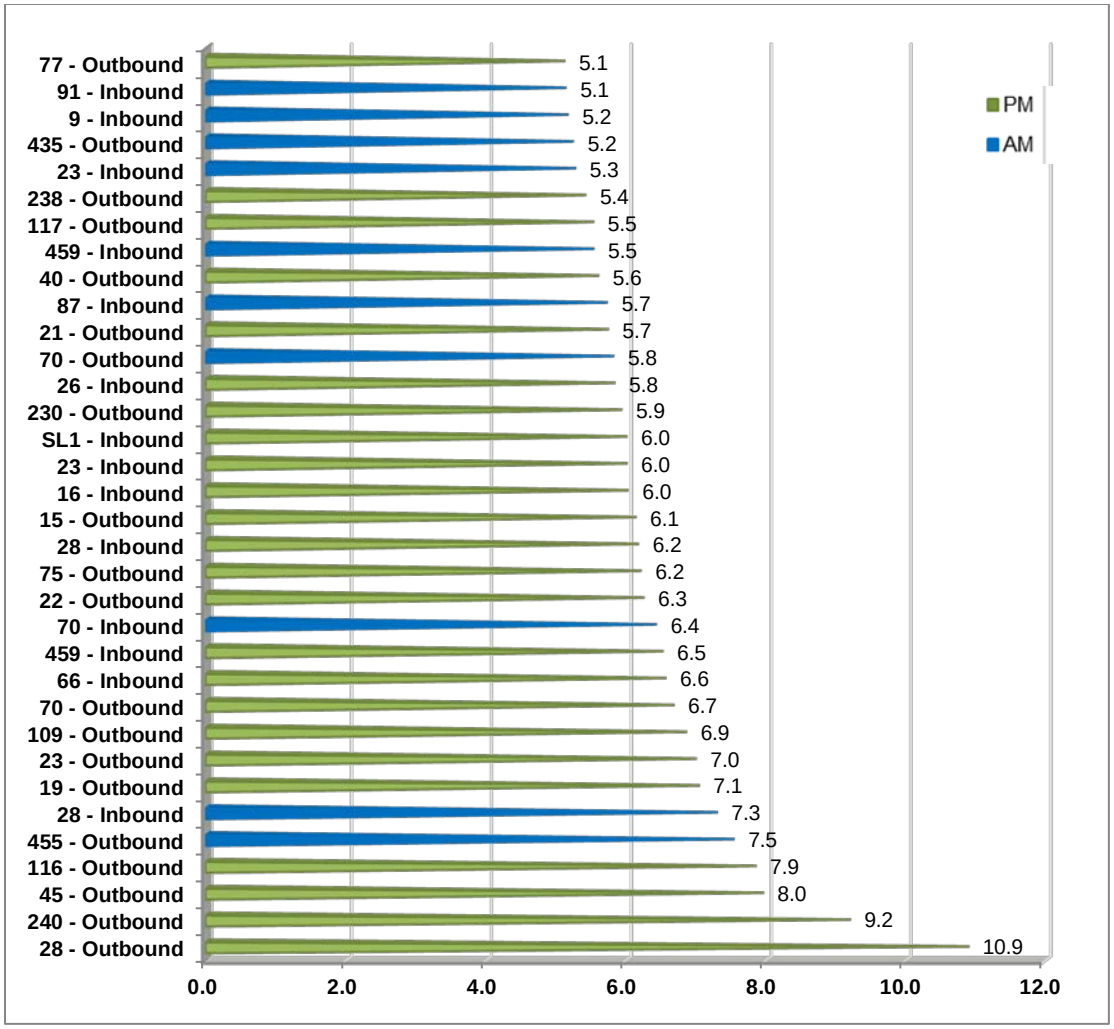
Figure 3
Routes with the Most Total Person-Hours of Delay per Day, Entire Day



Person-hours of delay by bus trip

To illustrate the extent of congestion by bus route further, another approach is to display the average person-hours of delay per trip during the AM or PM peak period. This shows the intensity of the delay on the route, regardless of the number of trips in the time period. Figure 4 shows the bus routes, by peak period and direction that average more than five person-hours of delay per bus trip. This data is also displayed in Figure A-5 in the appendix, which shows this performance measure for all bus routes on a map. Most of the bus routes that have the highest amount person-hours of delay per bus trip occur in the PM peak period.

Figure 4
Total Daily Person Hours of Delay per Bus Run
Bus Routes with More than Five Person-Hours of Delay per Bus Run



Intensity

Load factor/passenger crowding

Table 4 lists the bus routes with the highest maximum load factor in fall 2016. Bus Routes 71 and 73 both have vehicle fleets that have fewer seats than the fleets on other routes. Many of the bus routes with a very high load factor traverse the near-west portion of the MPO region.

Table 4
Bus Routes with the Highest Load Factor, Fall 2016

Route	Direction	Peak Period	Greatest Load Factor
73	Inbound	AM	2.23
73	Outbound	PM	2.19
71	Inbound	AM	1.94
70	Outbound	PM	1.85
71	Outbound	Both	1.81
57	Outbound	PM	1.79
57	Inbound	AM	1.69
87	Outbound	PM	1.59
101	Inbound	AM	1.56
65	Inbound	AM	1.54

Bus routes that failed pass-up standard

Table 5 lists the bus routes that failed the pass-up standard, meaning that passengers who ride these routes during the specified period may have to wait for one or more buses to pass before one with available capacity stops. Most of the non-Silver Line routes that fail the pass-up standard are located in the near-west section of the MPO region.

Table 5
Bus Routes that Failed Pass-Up Standard, Fall 2016

Route	Direction	Time Period
11	Inbound	AM
57	Inbound	AM
57	Outbound	PM
57A	Inbound	AM, All Day
57A	Outbound	PM, All Day
65	Inbound	AM
66	Inbound	AM
70	Outbound	PM
70A	Outbound	PM, All Day
71	Inbound	AM, All Day
71	Outbound	AM, PM
73	Inbound	AM, All Day
73	Outbound	PM
87	Outbound	PM
101	Inbound	AM

Reliability

Bus routes with the lowest rate of on-time performance

Table 6 lists 14 routes that have the lowest on-time performance rate. Note that most routes failed the on-time performance standard of 60 percent. Please see Figure A-1 for a full map of the on-time performance standard.

Table 6
Bus Routes with Lowest On-Time Performance Rate, Fall 2016

Route	On-Time Performance
137	30%
459	30%
14	31%
112	31%
411	31%
41	33%
52	34%
215	35%
105	35%
240	35%
29	36%
91	36%
448	36%
40	36%

Bus routes with the highest transit time index greater than 1.3

Table 7 lists the bus routes with the highest transit time index in fall 2016. Routes that have a very high transit time index probably have roadway congestion issues, which might not be directly related to MBTA operations. Figure A-2 displays the bus routes a transit time index of more than 1.30 during either of the peak periods.

Table 7
Bus Routes with Highest Transit Time Index, Fall 2016

Route	Direction	Transit Time Index	Time Period
109	Outbound	1.56	PM
326	Outbound	1.54	PM
72	Outbound	1.50	PM
100	Inbound	1.46	AM
68	Inbound	1.44	AM
134	Inbound	1.44	AM
217	Outbound	1.43	PM
26	Both	1.42	PM
75	Outbound	1.41	PM
88	Inbound	1.41	AM
101	Inbound	1.40	AM
95	Inbound	1.39	AM, PM
85	Inbound	1.38	AM
99	Inbound	1.38	PM
354	Inbound	1.38	PM

5 CONCLUSION AND NEXT STEPS

5.1 General Conclusions

- Regardless of the longer PM peak period (two hours in the AM peak period versus 2.5 hours in the PM peak period) congestion is clearly more intense in the PM peak period.
- Compared to the AM peak period, the PM peak period contains a significantly higher percentage of person-hours of delay. In addition, several bus routes that have a high percentage of person-hours of delay in the AM or PM peak periods are express bus routes.
- Person-hours of delay per route correlate with ridership and service frequency. In general, routes with the most amount of ridership have the most service, and factors that contribute to delay on one trip also likely would impact the preceding and succeeding trips.
- The on-time performance for the MBTA bus system either needs to improve dramatically, or the on-time performance metric needs to be altered. The on-time performance for more than half of the bus system fails to meet the CMP or MBTA standards during the weekday peak period.
- Several routes that have passenger crowding or fail the pass-up standard are located in the near-west section of the Boston MPO region.

5.2 Recommendations and Next Steps

This analysis should be shared with the MBTA. Moreover, this data should be formally analyzed by the MBTA; and the MBTA should recommend improvements to the bus system based on this study.

The MPO should continue monitoring the MBTA bus system. The monitoring should be conducted annually, as staff time permits. The results should be displayed in a very brief report card, which would contain numerous visuals and maps. Trends should be tracked via the annual report card to see if congestion on the bus network is increasing or decreasing. If funding permits, an interactive dashboard would be created to show the yearly results of these performance measures. If created, the dashboard will be displayed on the CMP section of the Boston Region MPO website, along with the report card.

MPO staff should continue to look at other sources that would provide additional travel time data for other transit modes including rapid transit and commuter rail. MPO staff should also continue to keep up with trends in big data to see if there are better emerging methods for monitoring congestion in the MBTA bus system.

Lastly, routes that have a high transit time index may experience roadway congestion. These routes should be evaluated for roadway congestion through the CMP.

RH/rh