MINETA NATIONAL TRANSIT RESEARCH CONSORTIUM

# Evaluation of Bus Transit Reliability in the District of Columbia


MNTRC Report 12-14

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REPORT 12-14

# EVALUATION OF BUS TRANSIT RELIABILITY IN THE DISTRICT OF COLUMBIA

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November 2013

A publication of
**Mineta National Transit Research Consortium**

College of Business
San José State University
San José, CA 95192-0219

# TECHNICAL REPORT DOCUMENTATION PAGE

| 1. Report No. | 2. Government Acession No. | 3. Recipient's Catalog No. |
|---|---|---|
| CA-MNTRC-13-1139 | | |

| | |
|---|---|
| **4. Title and Subtitle**<br>Evaluation of Bus Transit Reliability in the District of Columbia | **5. Report Date**<br>November 2013<br>**6. Performing Organization Code** |
| **7. Authors**<br>Stephen Arhin, Ph.D., P.E., PTOE and Errol C. Noel, Ph.D., P.E. | **8. Performing Organization Report**<br>MNTRC Report 12-14 |
| **9. Performing Organization Name and Address**<br>Mineta National Transit Research Consortium<br>College of Business<br>San José State University<br>San José, CA 95192-0219 | **10. Work Unit No.**<br>**11. Contract or Grant No.**<br>DTRT12-G-UTC21 |
| **12. Sponsoring Agency Name and Address**<br>U.S. Department of Transportation<br>Research & Innovative Technology Admin.<br>400 Seventh Street, SW<br>Washington, DC 20590 | **13. Type of Report and Period Covered**<br>Final Report<br>**14. Sponsoring Agency Code** |

**15. Supplemental Notes**

**16. Abstract**

Several performance metrics can be used to assess the reliability of a transit system. These include on-time arrivals, travel-time adherence, run-time adherence, and customer satisfaction, among others. On-time arrival at bus stops is one of the performance metrics of the Washington Metropolitan Transit Authority (WMATA). A bus is considered to be on time by WMATA if it arrives at most two minutes earlier or seven minutes later than the scheduled arrival times, with a performance goal of 78%. Most regional transit agencies consider arrivals that fall within one minute earlier or five minutes later than the scheduled arrival times as being on time. The goal of this project was to determine the on-time performance and their statistical significance based on WMATA's advertised threshold and the industry standard for on-time arrivals. Fifteen bus routes in Washington DC with several stops were studied in this research. WMATA's published bus schedules provided expected arrival times. An on-board manual survey was conducted from June 2012 through June 2013 for peak morning and afternoon travel on those routes during which the actual arrival times at the bus stops were noted and compared with the scheduled arrival times. For WMATA's two-minutes-early and seven-minutes-late arrival threshold, the buses were found to be on time approximately 82% of the time, on average, during the morning. In the evening, for the same threshold, only 68% of the buses on average were considered to be on time. This results in an overall on-time performance of 75%, which is a modest improvement over the 2010 on-time performance of 74%. Based on the one-minute-early and five-minutes-late arrival threshold used by several regional transit agencies, the buses were found to be on time approximately 67% of the time during the morning and 55% in the evening, resulting in an overall performance of 61%.

| 17. Key Words | 18. Distribution Statement | | |
|---|---|---|---|
| Bus arrival reliability; Bus arrival deviations; On-time arrival; Transit performance goal; Transit reliability indicators | No restrictions. This document is available to the public through<br>The National Technical Information Service, Springfield, VA 22161 | | |
| **19. Security Classif. (of this report)** | **20. Security Classif. (of this page)** | **21. No. of Pages** | **22. Price** |
| Unclassified | Unclassified | 52 | $15.00 |

Form DOT F 1700.7 (8-72)

Library of Congress Catalog Card Number:
2013953829

**To order this publication, please contact:**

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# ACKNOWLEDGMENTS

This material is based upon work supported by the U.S. Department of Transportation's University Transportation Centers Program under Grant Number DTRT12-G-UTC21.

The authors and students at the Howard University Transportation Research and Data Center would like to thank MTI staff, particularly the Deputy Executive Director and Director of Research Karen Philbrick, Ph.D.; Director of Communications and Technology Transfer Donna Maurillo; Research Support Manager Joseph Mercado; and Webmaster Frances Cherman who also provided additional editorial and publication support.

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# EXECUTIVE SUMMARY

Transit reliability is a critical measure of performance since it is a major factor used by customers in making transit decisions on travel by rail and bus systems, especially in urban areas. Transit agencies across the world are striving to improve the reliability of their systems in order to satisfy their customers. Several performance metrics are used to assess the reliability of a transit system; these include on-time arrivals (or on-time performance), travel time adherence, run time adherence and customer satisfaction. Washington Metropolitan Transit Authority (WMATA) has established an arrival threshold of two minutes earlier and seven minutes later than the advertised scheduled arrivals at bus stops as the boundary for on-time performance; that is, buses are considered to be on time when they arrive no more than two minutes earlier or seven minutes later than the scheduled arrival times at each bus stop. Most regional transit agencies, however, use a one-minute-early and five-minutes-late arrival outside the advertised scheduled arrivals at bus stops as their thresholds.

This research determined the extent to which WMATA's individual and grouped bus lines satisfy the performance goal of 78% for on-time arrivals. The arrivals were compared using the one-minute-early and five-minutes-late arrival threshold used by several regional transit agencies across the United States. Other metrics for measuring the reliability of bus arrivals at bus stops were also identified. Fifteen (15) bus routes were selected from bus stop arrival schedules obtained from WMATA. The routes varied from 6-15 miles and involved at least 125 bus stops. An onboard manual survey was conducted for peak morning and afternoon travel on the selected routes during which the actual arrival times at bus stops were recorded. The survey was conducted from June 2012 through June 2013.

The percentages of arrivals within WMATA's on-time threshold and the average deviation from the scheduled arrival times at each bus stop were computed. The mean deviations from the scheduled arrival times for all the bus routes selected for the study were computed for the morning and evening peak travel. The following tables present the summary of the analyses.

**Table 1. Overall Performance Based on WMATA's Threshold**

| PERIOD | Percent On-Time Arrival | Average* |
|---|---|---|
| Morning | 82% | 75% |
| Evening | 68% | |

**Performance goal = 78%*

**Table 2. Overall Performance Based on Standard Threshold**

| PERIOD | Percent On-Time Arrival | Average |
|---|---|---|
| Morning | 67% | 61% |
| Evening | 55% | |

The results of the analyses showed that WMATA exceeded its on-time bus arrival criterion by 4% during morning trips and fell 10% below the criterion during evening service. From a systems perspective and based on the 15 lines studied, WMATA missed its on-time performance goal by 3%. Using the on-time arrival standard adopted by most bus transit agencies across the United States, the overall arrival performance for WMATA's buses was 17% lower than expected, few of them being statistically significant. For the morning travel, the average deviation from the scheduled arrivals was 2 minutes for early arrivals and 3.8 minutes for late arrivals. During the evening travel, the average deviations were determined to be 2.4 minutes for early arrivals and 5.1 minutes for late arrivals.

In addition to the on-time arrival metric at bus stops, the literature recommended that travel time, dwell time at stops, run time and transit level of service should also be considered in evaluating schedule performance. These additional factors should be included in making decisions regarding improvement of the evening service to meet or exceed the performance criterion. It is therefore recommended that data should be routinely compiled and analyzed for these performance or reliability indicators, on 3-5 year cycles, because characteristics of routes (e.g., land-use patterns) could change over time.

# I. INTRODUCTION

Transit reliability has become a critical measure of performance in recent years as communities weigh the value of using alternative modes for urban travel. Increasing congestion on America's roadways and the need for a cleaner environment have stimulated the increased use of mass transit systems for public transportation. Although commuters consider numerous factors in making urban commute decisions, access, cost, safety and reliability are the more dominant concerns. Transit provides mobility to those who cannot or prefer not to drive, and it offers access to jobs, education and medical services. Transit reduces congestion, gasoline consumption and the nation's carbon footprint.[1] In 1997, public transportation saved 646 million hours of travel delay and 398 million gallons of fuel in the U.S., saving $13.7 billion in congestion costs.[2] It has been estimated that the use of public transportation reduced carbon dioxide (CO2) emissions by 6.9 million metric tons in 2004.[3] Communities can reduce traffic congestion and the adverse environmental impact of transportation by improving travelers' confidence in the reliability of transit systems. Operators of urban transit make major investments to achieve reliability goals. Transit reliability management strategies could lead to better evaluation of changes that can improve ridership and load factors.[4]

Public transit agencies have developed multiple indicators to measure quality of service. On-time performance, headway adherence (the time between two vehicles passing the same point traveling in the same direction on a given route), and run-time adherence are some of the statistics commonly monitored by transit agencies.[5,6,7] Unreliable service significantly impacts transit agencies, passengers and potential passengers, and is therefore a major concern to transit managers. The degree of adherence to advertised schedule times and headways can significantly affect customer satisfaction and perception of service quality. If buses do not run on schedule, service could be perceived as unreliable, with long waiting times and random crowding. Poor service translates to a decrease in ridership and revenue as well as potentially higher costs for overtime and use of extra buses to provide backup capacity.

The Washington Metropolitan Transit Authority (WMATA) provides regional rail and bus transit service to the District of Columbia and its neighboring counties in Virginia and Maryland. Several WMATA bus routes utilize arterial highways in the city. This research investigated schedule adherence and variability for the regional bus transit service in the District of Columbia. Arrival times of buses on a selection of bus routes were observed in the field and used to compute deviations from scheduled arrival times. WMATA has established a performance goal of 78% for on-time arrivals. This research explores the extent to which WMATA's buses achieved the performance goal.

# II. RESEARCH OBJECTIVES

1. To analyze the arrival patterns of bus transit at bus stops along selected busy corridors in the District of Columbia.

2. To determine the level of achievement of the two-minutes-early and seven-minutes-late arrival thresholds for the bus stops, and to assess other performance criteria set by WMATA.

3. To assess the on-time performance of WMATA's buses using the standard arrival thresholds of one minute early and five minutes late used by broader industry.

WMATA has posted bus schedule arrivals at each bus stop along transit routes. WMATA considers a bus to be on-time when the bus arrives not more than two minutes earlier or seven minutes later than the scheduled arrival time. This research tested the hypothesis that the deviation beyond WMATA's two-minutes-early and seven-minutes-late arrival threshold would be consistent along the corridors studied. The overall on-time reliability on selected bus routes was also evaluated. The general literature showed that the most common industry standard for on-time performance was one minute early to five minutes late.

# III. LITERATURE REVIEW

Providing a reliable transit service has been a basic objective of the public transit industry. Transit reliability is determined from the collection, monitoring and analyses of data to establish the accomplishment of pre-determined goals and objectives. For each specific objective, measures can be established for monitoring performance. Reliability measures may relate to en route travel time goals, information systems, vehicle systems, and passenger expectations. Both passengers and operators focus on success in achieving an expected level of compliance with advertised schedules, although patrons also may be interested in seat availability, crowding, ticketing convenience, and cost. This research is concerned with on-time service reliability and is limited to bus compliance with pre-scheduled arrival and travel times.

Service reliability is a growing priority for transit agencies struggling to provide service that is both high quality and cost-effective.[8] A high level of compliance is essential for attracting and retaining riders, particularly in areas where patrons have access to alternative modes of transportation.[9] Efficient scheduling and utilization of vehicle capacity increases the reliability of service and provides significant benefits to transit agencies and passengers alike.[8] In addition to containing operating costs, improved reliability lowers average passenger wait times, reduces bus crowding, and ensures greater predictability.

The factors relevant to each reliability measure depend largely on service frequency, whether or not timed transfers are involved, and the functional purpose(s) of travel.[10] Some of the key measures of transit reliability for all occasional transit users (especially infrequent users) are schedule adherence and timed transfers. When vehicles conform to schedule, passengers are better able to coordinate their arrivals with other modes of transportation, resulting in average wait times that are generally less than the scheduled headway. In addition, headway delay is one of the most important indicators of reliability. In high-frequency service transit systems, headway delays of ten minutes or less is deemed acceptable.[11] Extreme variation in headway delay could result in bus bunching and the use of more vehicles to serve the same number of passengers.

The variability of service attributes and its effects on traveler behavior and agency performance could also be used to define service reliability.[12] In order to provide reliable service, transit vehicles need to be on schedule while maintaining pre-determined headways and minimizing the variance of passenger loads.[13] Adding complexity to the measurement of reliability and the impact of any improvements, there are differences in the perceptions of reliability by travelers and operators. Several studies have explored the effects of transit reliability from the perspective of both transit customers and transit operators.[13] Transit providers must generally make decisions on the threshold values or ranges of values for classifying a service as reliable or unreliable. These threshold values should be based on the level of service the transit operator can cost-effectively deliver, in addition to customer expectations, which are generally expected to vary by type of route and time of day. Patrons on low-frequency service routes often use posted schedules and personal experience at the stops to plan their arrival time at the stops and determine their expected wait time. Passengers on high-frequency routes are assumed to arrive at random times, since they typically have little confidence in the posted schedule but know their waiting time should be low. Therefore, the threshold values of deviations at stop locations should be different for low-frequency and high-frequency routes.

## THRESHOLDS OF RELIABILITY INDICATORS

### On-time Performance

Transit providers, sometimes with input from the public or government agency, often provide a range around the scheduled time within which the transit bus is considered on-time. Generally, the on-time threshold values depend on the type of route, scheduling practices and location on the route. For low-frequency service routes, where on on-time performance is critical to patrons, schedule deviations should be minimized, since they affect passenger wait times. Early arrivals and departures could cause passengers to miss their scheduled trips and force them to wait a full headway for the next bus, while late departures simply increase the wait time of all passengers at the stop. Concerned about the negative impacts on patrons, transit providers generally strive to avoid early departures while keeping late arrivals to a minimum. In some cases, transit providers may implement a “no early departure” policy and instruct operators to stay at selected time points until their scheduled time, at the expense of increased travel times for passengers already onboard. Thus, transit service providers often specify the deviation in minutes from scheduled arrival time. Arrivals within the deviation limits are considered “on-time.” The extent of the deviation standard is determined by scheduling practices, travel time variability, and customer expectations.[14] The main concern of passengers on high-frequency routes is headway regularity; however, minimizing schedule deviations is the preferred practice since headways could be adjusted to maintain schedules. The same criterion for low-frequency routes could be applied, but with less concern about early departures.

With regard to scheduling practices and travel time variability, the threshold limits for on-time arrivals depend on how scheduled arrival times at various time points are set and managed. Scheduled arrival times are typically based on average run times. Some slack could be built into the arrival times to account for run time variability. The general literature reviewed showed that the most common current practice was to set a one-minute-early to five-minutes-late range for on-time performance.[15] This threshold is used for regional bus service in Seattle, San Mateo, Oakland, BART, Portland, and Connecticut. One of the strictest on-time metrics is used by San Francisco’s Muni. It requires all vehicles to arrive no earlier than one minute before and no later than four minutes after the scheduled arrival time, with a voter-mandated on-time performance goal of 85%. The larger metropolitan bus transit systems have established on-time performance goals that are based on specific on-time thresholds. WMATA’s on-time performance goal is at least 78% for on-time arrivals at bus stops.

### Headways

Headway values are typically used for high-frequency routes. Transit providers use either an absolute value or a relative value to evaluate actual headways. Relative values of headways are considered when bunching buses with an actual headway that is less than or equal to a portion of a fixed headway, for example, 0.30 of the scheduled headway. In general, relative values are preferred for routes on which consecutive headways are not equal; they range from three to five minutes.[16]

## Passenger Loads

Threshold values for overcrowding are based on seating capacity, travel demand, headway, and an acceptable maximum number of standees. Overcrowding thresholds also vary by length of route, frequency of service and time of day. For long routes, the overcrowding threshold value could be lowered to ensure that passengers would not feel crowded and would have a seat available during a trip. During peak hours, threshold values for overcrowding tend to be set higher, reflecting the higher cost of providing peak-hour service.[14,15] Overcrowding threshold values may be set as the average maximum load over a specific time period, or they could be set as a specific number of trips with loads exceeding a certain value.

## Percent of Trips

Another common threshold used to measure service quality is the percentage of on-time trips during daily time periods. The value varies depending on frequency of service and time of day. For low-frequency bus routes and periods of low demand, performance standards may be lower, with specified schedule deviations by time of day. For example, a criterion for schedule adherence may state that 75% of all trips should be completed within a schedule deviation of zero to five minutes for each time period. The range for schedule deviation is an acknowledgement that variability in departure times is inevitable. Schedule deviations on low-frequency routes impact passenger wait times but do not impact operations as much as they do on high-frequency routes. For high-frequency routes and time periods, transit agencies should be more aggressive in maintaining schedules or headways because of the higher levels of passenger demand and stronger tendency for problems to propagate. Typical percent threshold values that describe on-time performance and promised level of service follow those presented by the Transit Capacity and Quality of Service Manual.[12]

## Run Time

The performance report should summarize the distribution of trip run times for each time period, with the average, percentile, and, for comparison, coefficient of variation (or standard deviation) of observed and scheduled values. Actual run times should be compared with scheduled run times, based on the current timetable, to determine whether schedule adjustments are needed. Evaluations may include the average (or percentile value) run-time-per-period to assess on-time performance. In addition, the run times could be used to identify appropriate time periods for the development of a new timetable that reflects current conditions, thereby minimizing variability.[15] Variation in run time is recognized in the general literature as an indicator of deteriorating transit service.[13] Data for establishing variability is quite vast since there are numerous contributing factors relating to vehicles, passengers, routes, and traffic. Data collected via automatic vehicle location (AVC) and automatic passenger counting (APC) systems is critical for use of computer models for measuring variability.[16]

### Schedule Deviations

Reports on schedule deviations are used to evaluate on-time performance of buses by focusing on their distribution, along with the averages and coefficient of variations based on specific time-periods for terminals and/or time points on a route. Service providers aim to achieve trip times that closely follow the scheduled times, with small positive or negative deviations. Large schedule deviations indicate problems such as inadequate run times, abnormal boardings, etc.[12,14,15,17]

### Probability of Delay

Schedule deviations could also be used to analyze the probability of delays at a specific time point given a time deviation on departure from a terminal. For trips with on-time departure at locations or stops, the schedule deviation could be calculated. A schedule deviation distribution could be determined using a sufficient number of trips to support the level of data aggregation. From the schedule deviation distribution, the probability of on-time arrival at the location or stop could be calculated. The same distributions could be generated for each location based on its departure deviation data. The distributions of trips with on-time departures also provide insight into the adequacy of the scheduled run time between two stops on a route. If the probability of arriving at a stop within an "on-time" range is low, it can be deduced that the scheduled times are unrealistic and may need adjustment.[13,14,15]

## ISSUES WITH RELIABILITY INDICATORS

Three problems have been identified in setting realistic threshold values for measuring service reliability. The first is the infrequent monitoring and collection of field data. Automated collection of transit service data has increased the accuracy of records and eliminated the need for some manual inventory.[5] In-vehicle information management systems linked to centralized data management systems are increasingly used for automatic compilation of service data.

The second issue is the reliability and cost of analyzing multiple performance indicators. A single, comprehensive service reliability indicator would make it much easier and less expensive to quickly identify the routes most in need of intervention or improvement. With multiple indicators, it is difficult to determine which routes have the overall worst performance because routes can show high or low performance depending on the measures used. This problem is exacerbated when quick decisions are needed.[7] It is difficult to determine from the reliability indicators whether a route's declining service is the result of a new, systemic problem or mere chance. Transit providers should avoid wasting time on "improvements" to routes whose reported declines are simply random variations.[9]

Data and results from several onboard surveys were reviewed in this research. Onboard surveys provided a customer satisfaction element (including reliability). In some surveys, respondents were simply asked to rate their level of satisfaction with transit reliability and/or travel time. Overall, riders' ratings of various attributes, including reliability, are specific to the operations at each transit agency. For some of the transit systems, schedule reliability was rated very highly while at other agencies it was rated relatively lower. Transit operators use the survey results to track customer satisfaction over time.[8]

The results from WMATA's onboard survey conducted in 2001 as part of its Regional Bus Study showed that approximately 50% of respondents indicated their most-wanted improvement was in on-time arrival/reliability. This was true across all demographics surveyed, regardless of the time of day or the day of the week. Young riders in particular (66% of riders aged 15-18 and 79% of riders under age 15) rated on-time arrival/reliability most important.[16]

A non-rider survey was conducted as part of WMATA's survey in 2001. Sixty-eight percent (68%) of the respondents in this survey indicated that they had used the bus in the past. However, when asked why they had stopped using the bus services, approximately 44% indicated that they gained access to a car. Seventeen percent (17%) of the respondents said they stopped using the bus due to a lifestyle change, such as a change in residence or work location. Only 6% of the respondents indicated that the service was not "reliable enough." Respondents were also asked to name the biggest drawback to using the bus in this survey. Only 3% of the respondents indicated that low reliability was the biggest drawback of the service. Thirty-one percent (31%) indicated that the bus was "inconvenient," followed by 15% who indicated that the bus "takes too long." Of the six specific potential improvements presented to the respondents to attract their patronage, the most common responses were "nothing" and "stop closer to home/destination" (each 18%).[16]

Asked how often the bus picked them up and dropped them off on-time according to the system's pocket schedule, the majority of the respondents (approximately 56%) in a Dallas survey said "almost always" or "always." On the other hand, 29% indicated "sometimes" while 15% indicated "never." A follow-up question targeted to those who answered "sometimes" or "never" asked why the bus was not on-time. Thirty-four percent (34%) of the respondents to the follow-up question indicated the delays were due to "people boarding" the bus. Other perceived causes included "heavy traffic" (23%), "weather" (14%), "schedule needs more time" (11%), "routing" (8%) and "other" (18%).[17]

In a 2006 survey conducted by the Sacramento Regional Transit, the attribute for buses and trains "running when schedule says" (on-time performance) ranked second in importance out of 29 attributes presented. However, this attribute ranked 12th in the percentage of users who were satisfied (as indicated by a rating of "excellent") with the service as delivered. It was noted that only 22% and 24% of the respondents, respectively, rated the transit system's fulfillment of the highly valued attributes "running when schedule says" and "travel time" as "excellent."[18]

In Cleveland, a telephone survey was conducted of those considered to be familiar with, but not regular users of, the transit authority. These survey participants were considered potential users. Respondents were asked to rate the same service attributes as in the onboard survey. This group of infrequent users and non-users generally rated service attributes worse than regular riders, including schedule reliability and travel time.[12]

The reliability surveys showed a variety of reliability indicators that could be used to gauge the performance of a transit system. Notable indicators include adherence to scheduled times, headway, and travel or run times. The results of the surveys of bus patrons conducted across the United States confirm existing hypotheses that transit riders are concerned about service reliability. Information about perceptions and attitudes among non-users could be used to improve travel time reliability or on-time performance.

# IV. RESEARCH METHODOLOGY

## CORRIDORS SELECTED FOR THE STUDY

Fifteen transit bus corridors in the District of Columbia metropolitan area were selected for this study. The selection was based on published bus stop arrival times, and on routes with adequate gaps for onboard data collection. The corridors were as follows:

1. *Ballston-Farragut Square (Line 38B):* This bus route runs in the east-west direction and connects Georgetown in the District of Columbia to Arlington, Virginia. The origin of this bus line is in close proximity to the White House and travels through the Central Business District (CBD) of the District of Columbia. Average weekday ridership on this bus line in FY 2012 was approximately 3,760. Eight bus stops each were selected for the eastbound and westbound travel on this route.

2. *Rhode Island Avenue-New Carrollton (Line 84):* This route is oriented in the east-west direction with an average weekday ridership of 2,215 in FY 2012. The route starts at the Rhode Island Metro Station and ends in Maryland's New Carrollton Metro Station. Sections of the route include non-CBD neighborhoods, with several business and residential neighborhoods along the way. Nine bus stops each were selected for the eastbound and westbound routes along the route.

3. *Brookland Potomac Park (Line H1):* This bus route runs in the north-south direction and connects Catholic University to George Washington University and Potomac Park. Portions of the route run through the CBD. The average weekday ridership on this bus line in FY 2012 was approximately 714. Eight bus stops each were selected for the northbound and southbound travel on this route.

4. *Garfield Anacostia Loop (Line W6):* This bus route is considered a "loop" route since it starts and ends at the origin (Anacostia Metro Station). According to data compiled by WMATA in FY 2012, the average weekday ridership was 2,170. This bus line serves primarily residential neighborhoods in the District of Columbia. Eight bus stops on this route were selected for this study.

5. *14th Street (Line 53):* This route is oriented in the north-south direction with an average weekday ridership of 14,803 in FY 2012. The route starts at the Tacoma Metro Station and travels through the CBD, with the final destination at the L'Enfant Plaza Metro Station. This is one of the routes that has access to other major Metrorail Stations, especially those in the CBD area. Seven bus stops each were selected for the northbound and southbound routes along the route.

6. *Sheriff Road-Capitol Heights (Line F14):* The average weekday ridership of this bus line was 2,384 in FY 2012. The route runs in the north-south direction from Naylor Road Metro Station to the New Carrollton Metro Station, both in Maryland. The route traverses several residential neighborhoods. Thirteen bus stops each were selected for both northbound and southbound routes along the route.

7. *Mayfair-Marshall Heights (Line U6):* This bus route is also considered a “loop” route since it starts and ends at the origin (Minnesota Metro Station). The FY 2012 average weekday ridership was 2,170. This bus line serves primarily residential neighborhoods in The District of Columbia. A total of ten bus stops on this route were selected for this study.

8. *North Capitol Street (Line 80):* The average weekday ridership on this bus line in FY 2012, which runs the north-south direction, was 7,758. This bus route serves the CBD, several metro rail stations and a heavily traveled corridor. Ten bus stops each were selected for the northbound and southbound travel on this route.

9. *Rhode Island Avenue (Line G8):* This route is oriented in the east-west direction with an average weekday ridership of 3,919 in FY 2012. The bus route travels through non-CBD and provides access to Howard University, Rhode Island Shopping Mall and Catholic University of America in the District of Columbia. Seven bus stops each were selected for the northbound and southbound routes along the route.

10. *Capitol Heights-Benning Road (Line U8):* This “loop” bus route also starts and ends at Minnesota Metro Station and serves residential neighborhoods primarily in the District of Columbia. The FY 2012 average weekday ridership was 3,323. A total of twelve bus stops on this route were selected for this study.

11. *Pennsylvania Avenue (Line 36):* The average weekday ridership on this bus line in FY 2012 was 13,283. This bus route serves the CBD, several metro rail stations and runs on heavily traveled corridors in the east-west direction. Ten bus stops each were selected for the northbound and southbound travel on this route.

12. *Crosstown (Line H4):* The average weekday ridership of this bus line was 3,919 in FY 2012. The route runs in the east-west direction, travels through non-CBD and provides access to American University, the National Zoo and Catholic University of America. Seven bus stops each were selected for both northbound and southbound routes along the route.

13. *Connecticut Avenue (Line L2):* The average weekday ridership of this bus line was 3,562 in FY 2012. The route runs in the north-south direction and serves four metro rail stations, one of which is near the University of the District of Columbia. The route traverses both commercial and residential neighborhoods. Seven bus stops each were selected for both northbound and southbound routes along the route.

14. *16th Street Limited (Line S9):* This route is oriented in the north-south direction and recorded an average weekday ridership of 2,713 in FY 2012. The route starts at the McPherson Square Metro rail station and travels through the CBD in the District of Columbia to the Silver Spring Metro rail station in Maryland. Eight bus stops were selected for the northbound route and six were selected for the southbound route.

15. *Benning Road H Street Express (Line X9):* This bus route recorded an average weekday ridership of 1,598 passengers in FY 2012. It runs in the east-west

direction. Eight bus stops were selected for both eastbound and westbound travel on this route, which traverses the CBD in the District of Columbia and ends at the Capitol Heights Metro rail station in Maryland.

## DATA COLLECTION

Bus arrival time data at each bus stop were obtained by manual onboard recording at the selected bus stops on weekdays from June 2012 through June 2013. The selected weeks and weekdays were organized to achieve a robust sample, while enabling student workers to maintain academic responsibilities. Prior to the commencement of the data collection effort, several preliminary runs were conducted for to familiarize the research team with the routes and bus stops selected for the study. A prepared data recording sheet was used, which contained the route name, name of bus stops, date, time, scheduled arrival times, blank spaces for entering actual arrival times at bus stops, the name of the recorder, and the start and end times of the observations. The data collection students also noted the start and end locations of the survey for each route.

For each route, the inbound and outbound arrival times at each bus stop were recorded while on board the bus for morning (7:00 am to 9:30 am) and evening (4:00 pm to 6:00 pm). Thus, each data collection technician rode the bus inbound, recording the actual arrival times for the selected bus route, and did the same for the outbound route. The data for each route were compiled for 15 days by different field data collection staff for the morning and evening peak periods. Each field technician gathered data on each route only once in order to eliminate bias in the data, and only on weekdays. The data collection effort was aborted or canceled in cases of traffic accidents or incidents, adverse weather conditions, or other unforeseen circumstances that could result in excessive delays. In all, 2,220 arrival times of buses at 148 bus stops were documented. The survey forms were returned and reviewed, after which the data was extracted for analysis using Microsoft Excel.

## DATA REDUCTION, STATISTICAL ANALYSES AND HYPOTHESIS

The arrival times were compared with the scheduled arrival times at each bus stop for each route. Bus arrivals between two minutes early and seven minutes late (according to the advertised scheduled arrival times) were considered “on time.” Actual deviations from the advertised scheduled arrival times were computed for each bus stop and classified as either “on time” or “not on time.” The mean deviation of observed arrival from the scheduled arrival time was computed and used to determine the reliability of the measured bus arrival times, using a 95% confidence level. General trends in scheduled arrival times at each bus stop for both inbound and outbound routes in each corridor were also analyzed.

If the early arrival time of Bus Y on corridor A at bus stop #1 is $T_1$ (and $T_2$ is the scheduled arrival time) then the deviation in early arrival time, $\Delta T_Y x_{Early}$, (where X=1, 2, 3,…n, denote the bus stop numbers) at station X can be calculated by:

$$\Delta T_Y x_{Early} = T_1 - T_2$$

For the entire period of the data collection, *n* data points of the parameter $\Delta T_Y x_{Early}$ were deduced for the same corridor Y from which the average for "early" arrivals was computed. For each bus, the following information was then determined for each corridor:

**Table 3. Typical Data Summary for Early Arrivals for Bus Y on Corridor A**

| Station | Time Difference $\Delta T_{YXEarly}$, where X= station # |
|---|---|
| | Early |
| 1 | |
| 2 | |
| n | |
| **Route Average** | $\Delta t^*_{A(early)}$ |

Similarly, the same data was compiled for "late" arrivals outside of the advertised scheduled arrival times, the sample of which is presented in the following:

**Table 4. Typical Data Summary for Late Arrivals for Bus Y on Corridor A**

| Station | Time Difference $\Delta T_{YXLate}$, where X= station # |
|---|---|
| | Late |
| 1 | |
| 2 | |
| n | |
| **Route Average** | $\Delta t^*_{A(late)}$ |

It must be noted that although a negative $\Delta T_Y x_{Early}$ denotes an "early" arrival and a positive $\Delta T_{YXLate}$ indicates a "late" arrival, the absolute values were used in the analyses. WMATA has published a bus arrival schedule for each bus stop along each corridor. WMATA considers a bus to be on-time if the bus arrives between two minutes earlier and seven minutes later than the scheduled arrival time. Therefore, a bus will be considered "not on time" when it arrives earlier than two minutes before the scheduled time or later than seven minutes after the scheduled arrival time. These can be expressed mathematically as:

$$\{H_o: \Delta t_E \leq 2$$

$$\{H_1: \Delta t_E > 2$$

$$\{H_o: \Delta t_L \leq 7$$

$$\{H_1: \Delta t_L > 7$$

where $\Delta t_E$ and $\Delta t_L$ are the respective average early and late deviation times from the advertised schedules. Due to the small sample points of the data compiled ($n < 30$), the students' *t*-test was used to test the above hypotheses at 5% level of significance, with the assumption that the sample is normally distributed. The test was conducted for both the inbound and outbound routes of the same corridors. A *p*-value is the probability that a given random variable of a summary statistic is larger in magnitude than an observed value of that statistic. Based on a one-tailed test at 5% significance level, the null hypothesis ($H_o$) was rejected if the associated *p*-value of the computed students' *t*-statistic was less than 0.05. Similar analyses were conducted based on the popular industry standard for on-time arrivals of one minute early to five minutes late. The hypothesis for that is expressed mathematically as follows:

$$\{H_o: \Delta t_E \leq 1 \qquad \{H_o: \Delta t_L \leq 5$$

$$\{H_1: \Delta t_E > 1 \qquad \{H_1: \Delta t_L > 5$$

# V. RESULTS

## FREQUENCY/PERCENT OF ON-TIME ARRIVALS AT BUS STOPS

The summary of the frequency of on-time arrivals at each bus stop for each bus route was tallied and summarized as a percentage of the total number of arrivals in Table 5 (AM travel) and Table 6 (PM travel). The results are based on the two criteria: 1) two-minutes early to seven-minutes late and 2) one minute early to five minutes late.

For the two-minutes-early to seven-minutes-late window of the scheduled arrival times, overall, the mean on-time arrival at the bus stops on the selected routes was 82% in the morning and 68% during the afternoon travel periods. The 16th Street route (Line S9) recorded the highest percentage of on-time arrivals in the morning and evening (94% and 90%, respectively). The lowest rate of on-time arrivals in the morning was determined to occur on the North Capitol Street route (Line 80). In the evening, the lowest rate of on-time arrivals occurred on the Brookland Potomac Park route (Line H1). WMATA's goal of achieving at least 78% on-time bus arrivals was met during morning transit service, generally, but was woefully lacking during evening operation. Overall, the on-time performance for the buses was determined to be 75%, on average. As previously discussed, weather, accidents, and other factors potentially may have impacted the evening on-time performance of the buses.

**Table 5. Percent of On-time Arrivals for AM Travel on Routes**

| Bus Route | WMATA On time Threshold | | Industry On time Threshold | |
|---|---|---|---|---|
| | On time | Not On time | On time | Not On time |
| Ballston-Farragut Square Line (Line 38B) | 93% | 7% | 88% | 12% |
| Rhode Island Avenue-New Carrollton (Line 84) | 96% | 4% | 88% | 12% |
| Brookland Potomac Park (Line H1) | 55% | 45% | 46% | 54% |
| Garfield Anacostia Loop (Line W6) | 81% | 19% | 70% | 30% |
| 14th Street (Line 53) | 73% | 27% | 64% | 36% |
| Sheriff Road-Capitol Heights (Line F14) | 87% | 13% | 75% | 25% |
| Mayfair-Marshall Heights (Line U6) | 84% | 16% | 48% | 52% |
| North Capitol Street (Line 80) | 49% | 51% | 39% | 61% |
| Rhode Island Avenue (Line G8) | 87% | 13% | 72% | 28% |
| Capitol Heights-Benning Road (Line U8) | 87% | 13% | 65% | 35% |
| Pennsylvania Avenue (Line 36) | 82% | 18% | 62% | 38% |
| Benning Street Express (Line X9) | 81% | 19% | 70% | 30% |
| Crosstown (Line H4) | 94% | 6% | 81% | 19% |
| Connecticut (Line L2) | 81% | 19% | 54% | 46% |
| 16th Street Limited (Line S9) | 94% | 6% | 86% | 14% |
| **AVERAGE** | **82%** | **18%** | **67%** | **33%** |

When considering the one-minute-early-to-five-minutes-late window of the scheduled arrival times, overall, the mean on-time arrival at the bus stops on the selected routes was

67% in the morning and 55% during the afternoon travel periods. Overall, the average on-time performance was 61%. The highest percentage of on-time arrivals in the morning occurred on both the Ballston-Farragut Square Line (Line 38B) and Rhode Island Avenue-New Carrollton (Line 84) routes. The lowest on-time arrival rates in the morning occurred on the Brookland Potomac Park (Line H1), while Sheriff Road-Capitol Heights (Line F14) recorded the lowest rates during the evening travel. Only five of the fifteen routes satisfied WMATA's on-time bus performance goal, and only during the morning operations.

**Table 6. Percentage of On-time Arrivals for PM Travel on Routes**

| Bus Route | WMATA On time Threshold | | Industry On time Threshold | |
|---|---|---|---|---|
| | On time | Not On time | On time | Not On time |
| Ballston-Farragut Square Line (Line 38B) | 69% | 31% | 54% | 46% |
| Rhode Island Avenue-New Carrollton (Line 84) | 81% | 19% | 72% | 28% |
| Brookland Potomac Park (Line H1) | 46% | 54% | 39% | 61% |
| Garfield Anacostia Loop (Line W6) | 63% | 38% | 56% | 44% |
| 14th Street (Line 53) | 88% | 12% | 72% | 28% |
| Sheriff Road-Capitol Heights (Line F14) | 45% | 55% | 32% | 68% |
| Mayfair-Marshall Heights (Line U6) | 86% | 14% | 69% | 31% |
| North Capitol Street (Line 80) | 68% | 32% | 52% | 48% |
| Rhode Island Avenue (Line G8) | 86% | 14% | 68% | 32% |
| Capitol Heights-Benning Road (Line U8) | 68% | 32% | 50% | 50% |
| Pennsylvania Avenue (Line 36) | 67% | 33% | 49% | 51% |
| Benning Street Express (Line X9) | 54% | 46% | 38% | 62% |
| Crosstown (Line H4) | 49% | 51% | 37% | 63% |
| Connecticut (Line L2) | 66% | 34% | 53% | 47% |
| 16th Street Limited (Line S9) | 90% | 10% | 83% | 17% |
| **AVERAGE** | **68%** | **32%** | **55%** | **45%** |

Summaries of the performance, expressed as percentage, for each of the 15 bus lines studied, are presented in Figures 1 through 15, based on WMATA's and industry on-time threshold.

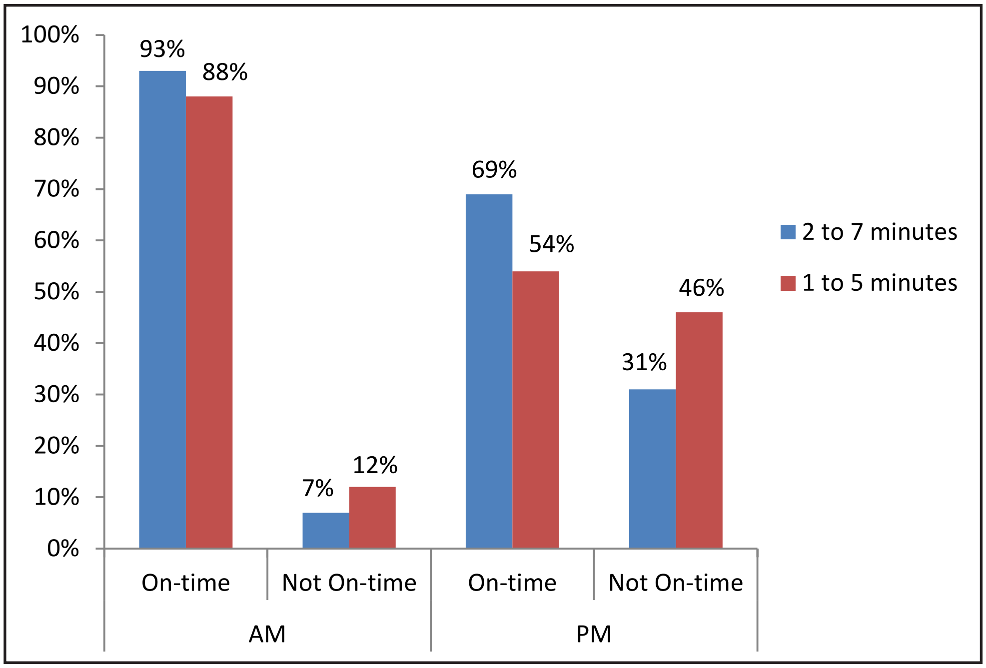


**Figure 1. Ballston-Farragut Square Line (Line 38B) On-time Performance**

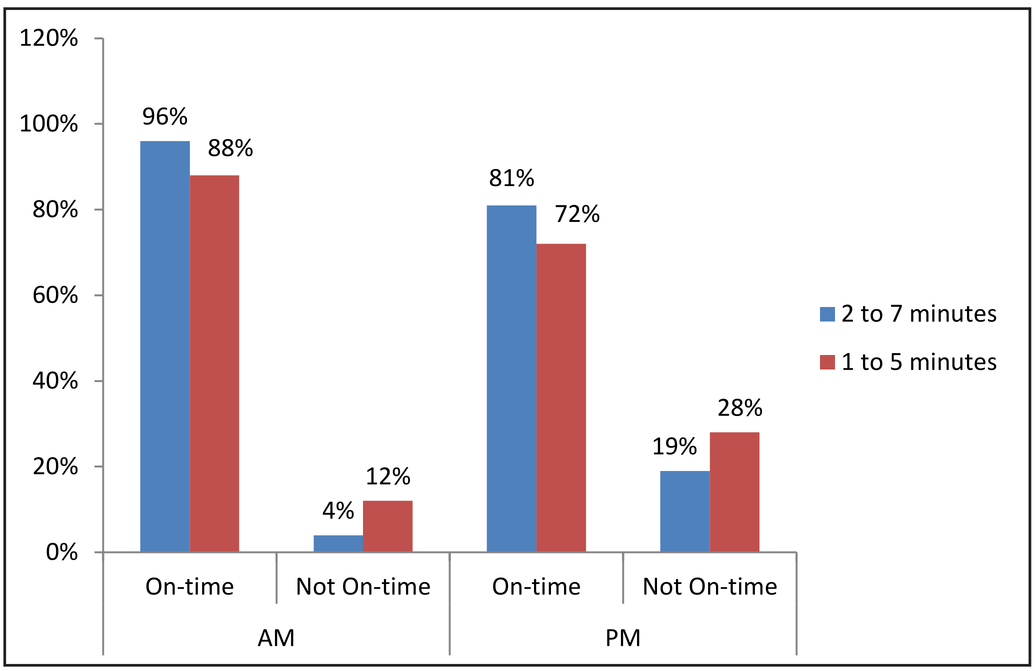


**Figure 2. Rhode Island Avenue-New Carrollton (Line 84) On-time Performance**

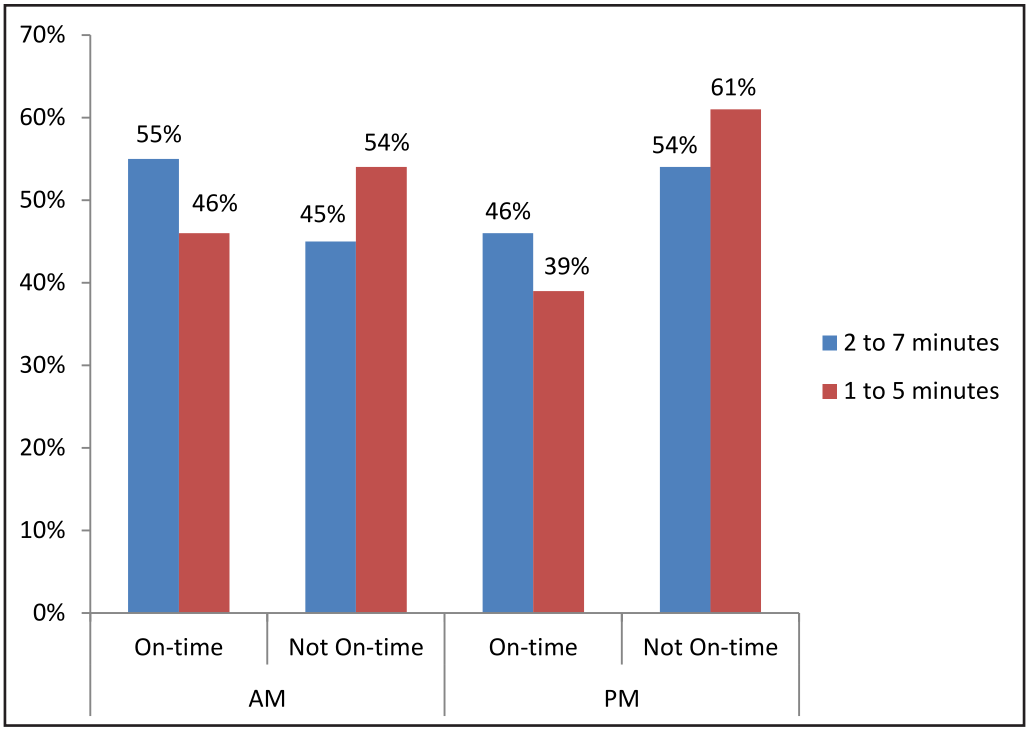


**Figure 3. Brookland Potomac Park (Line H-1) On-time Performance**

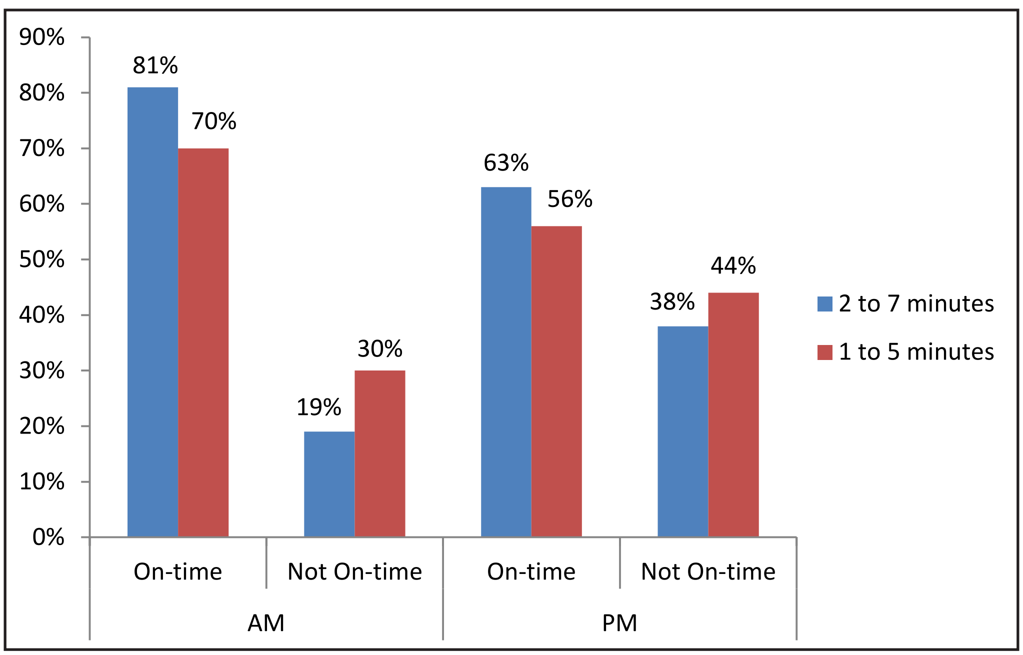


**Figure 4. Garfield Anacostia Loop (Line W6) On-time Performance**

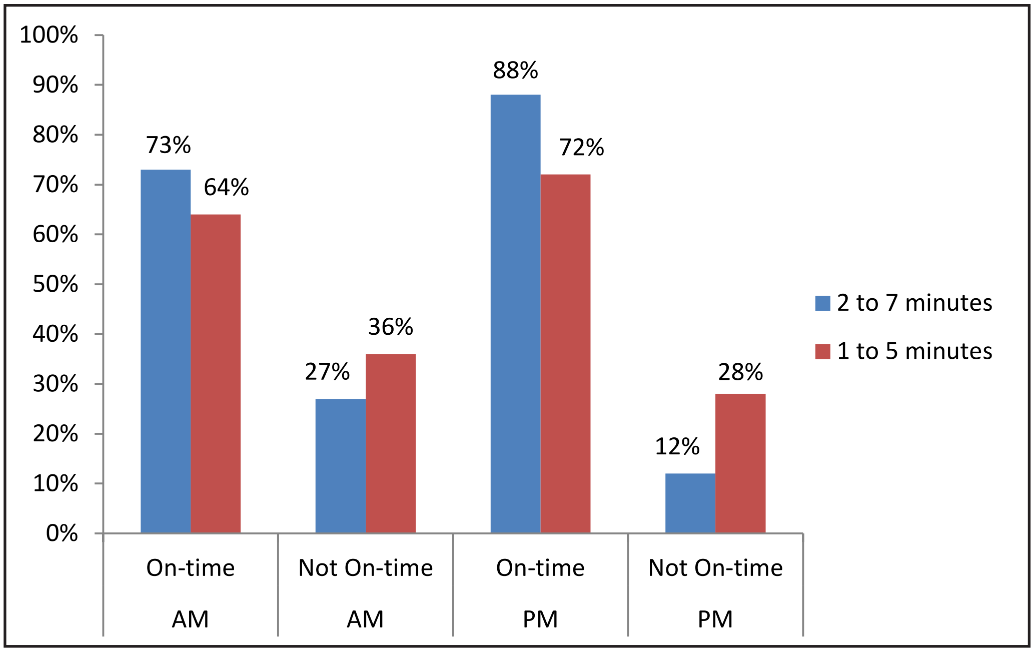


**Figure 5. 14th Street (Line 53) On-time Performance**

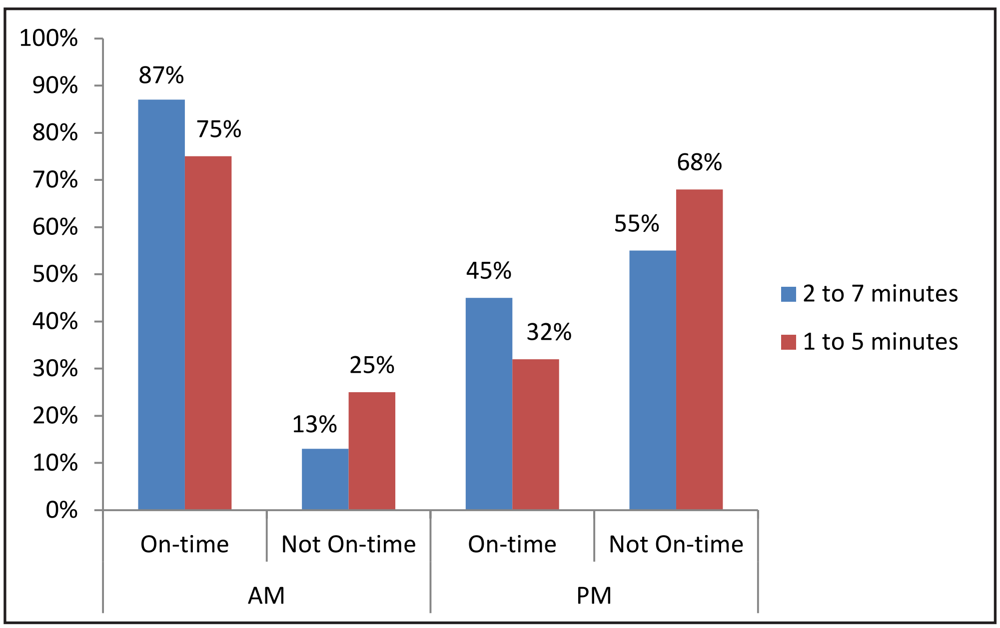


**Figure 6. Sheriff Road-Capitol Heights (Line F-14) On-time Performance**

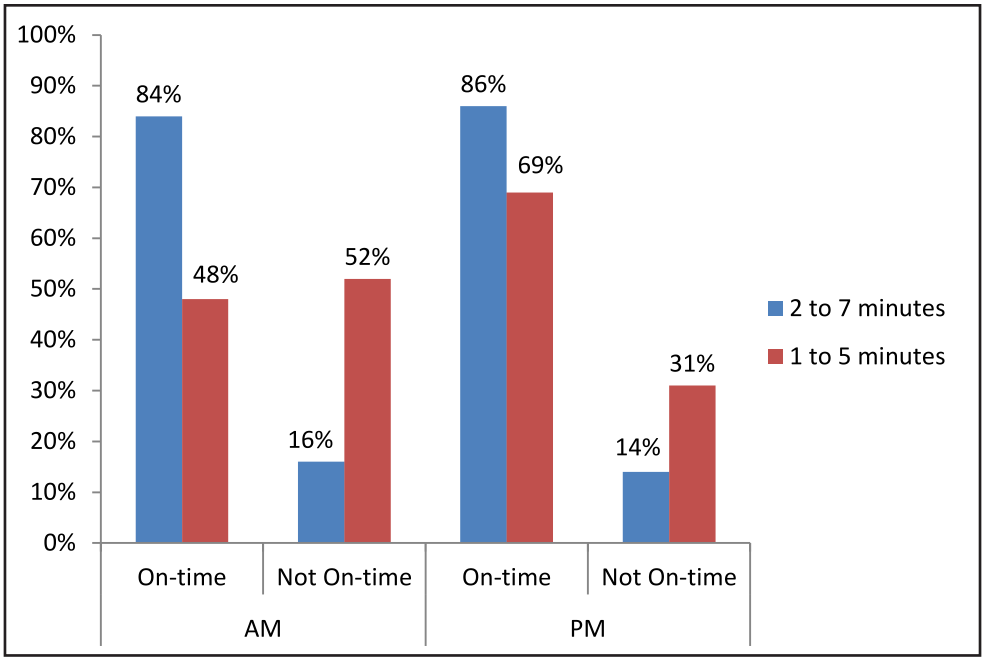


**Figure 7. Mayfair-Marshall Heights (Line U6) On-time Performance**

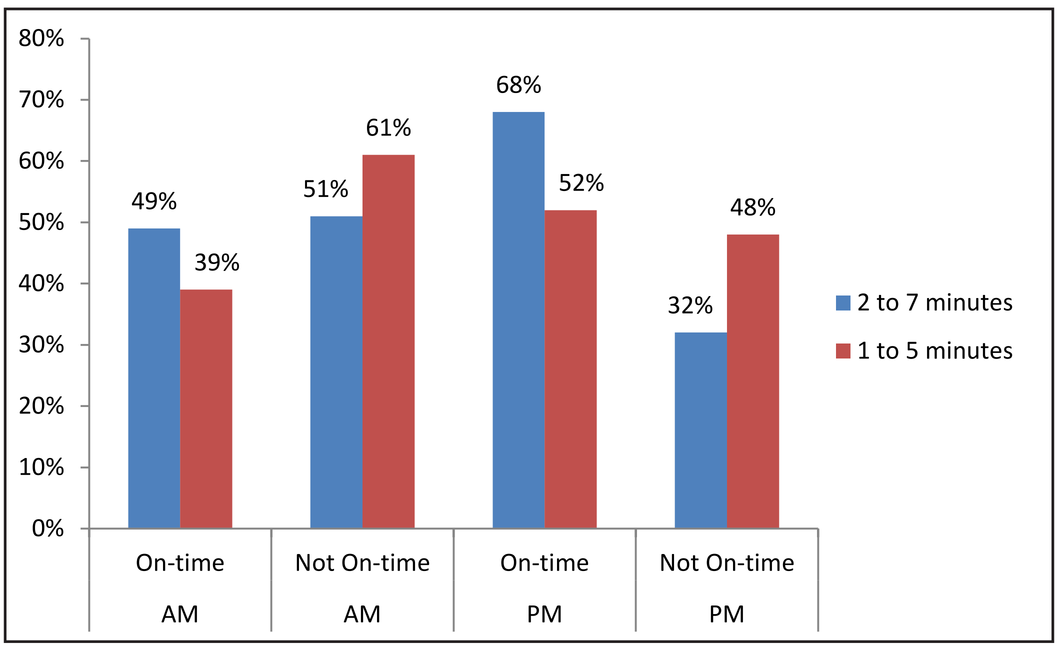


**Figure 8. North Capitol Street (Line 80) On-time Performance**

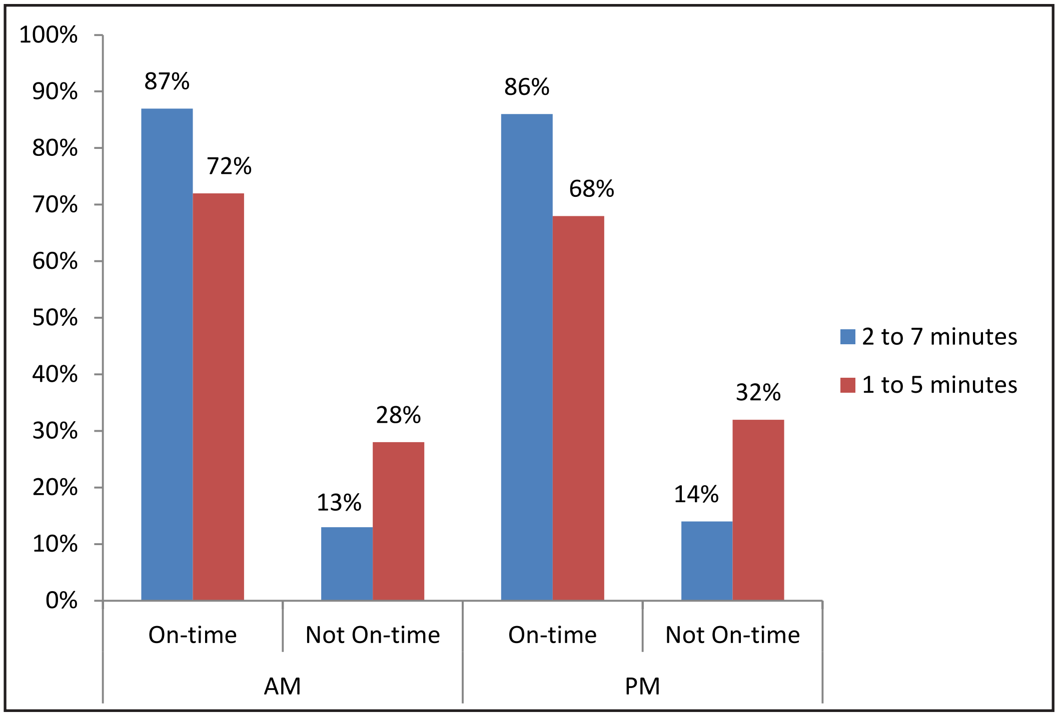


**Figure 9. Rhode Island Avenue (Line G8) On-time Performance**

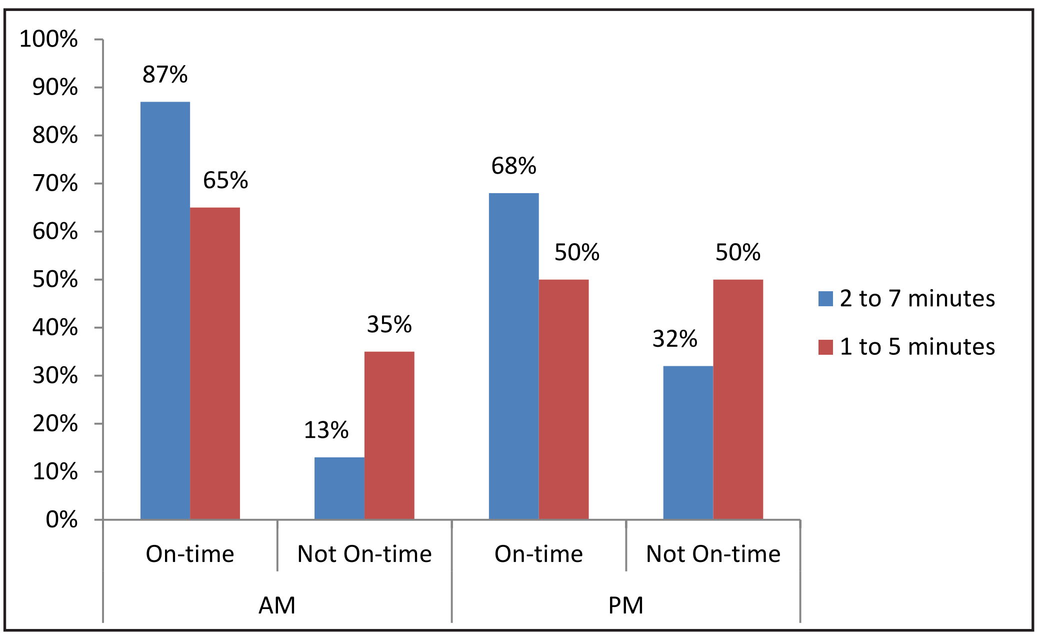


**Figure 10. Capitol Heights-Benning Road (Line U8) On-time Performance**

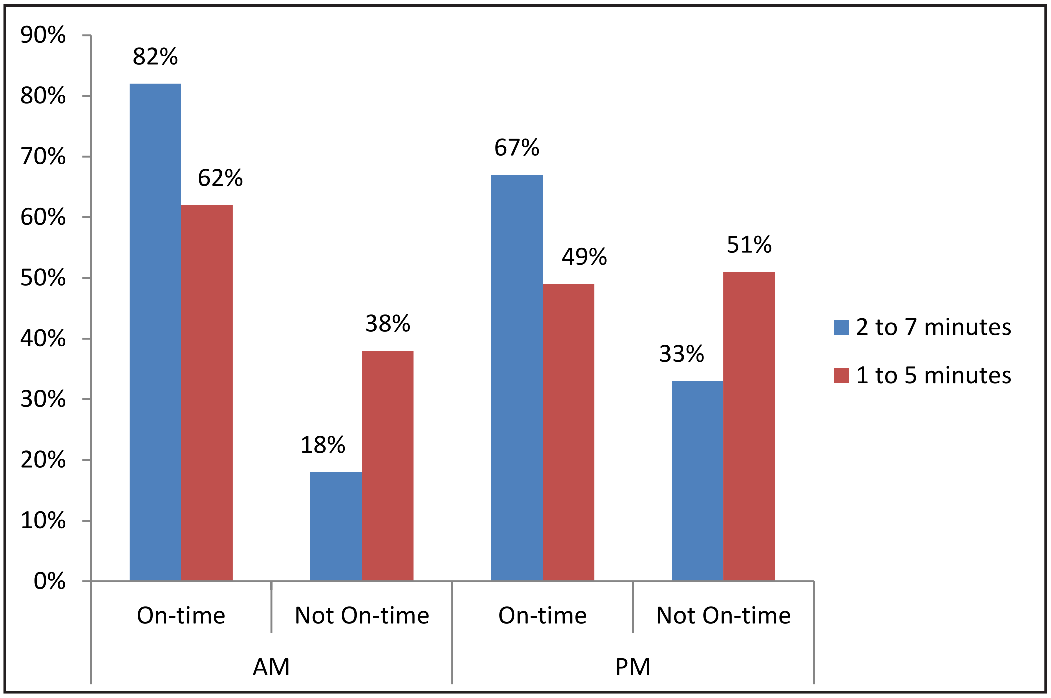


**Figure 11. Pennsylvania Avenue (Line 36) On-time Performance**

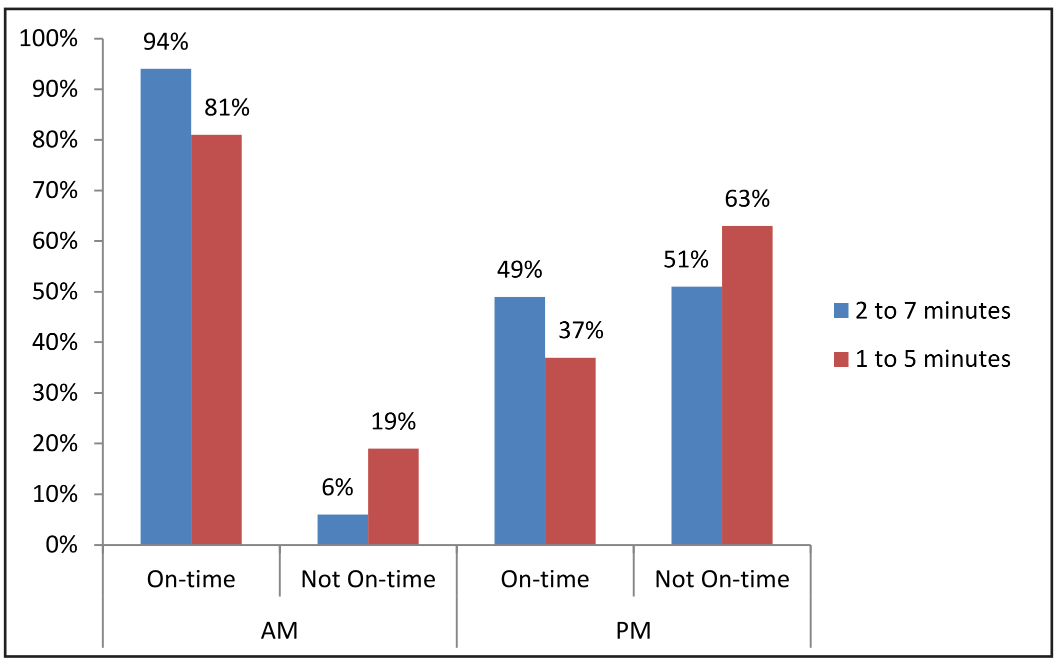


**Figure 12. Crosstown (Line H4) On-time Performance**

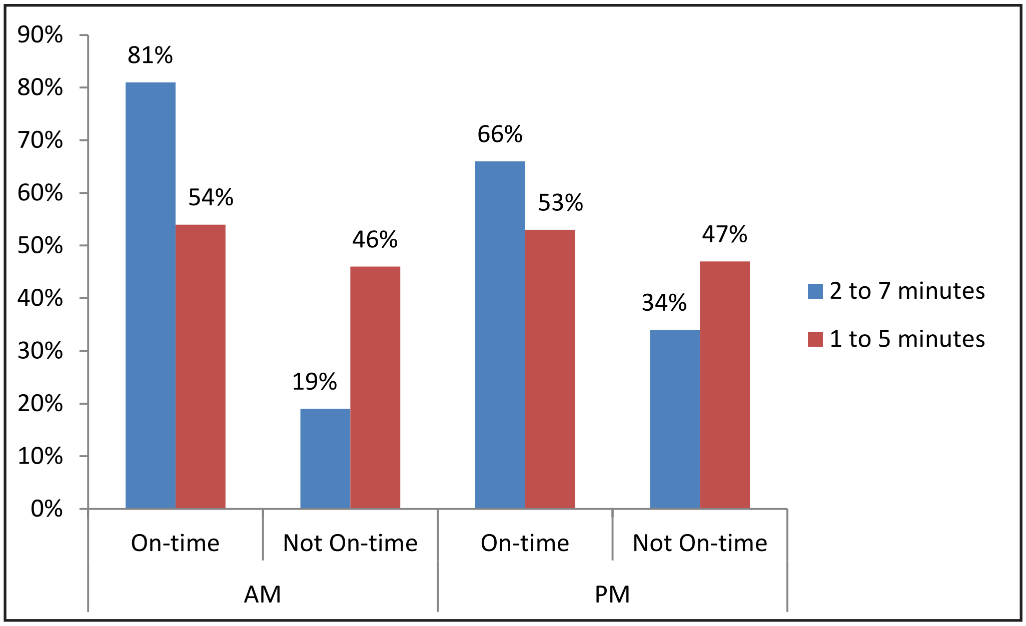


**Figure 13. Connecticut (Line L2) On-time Performance**

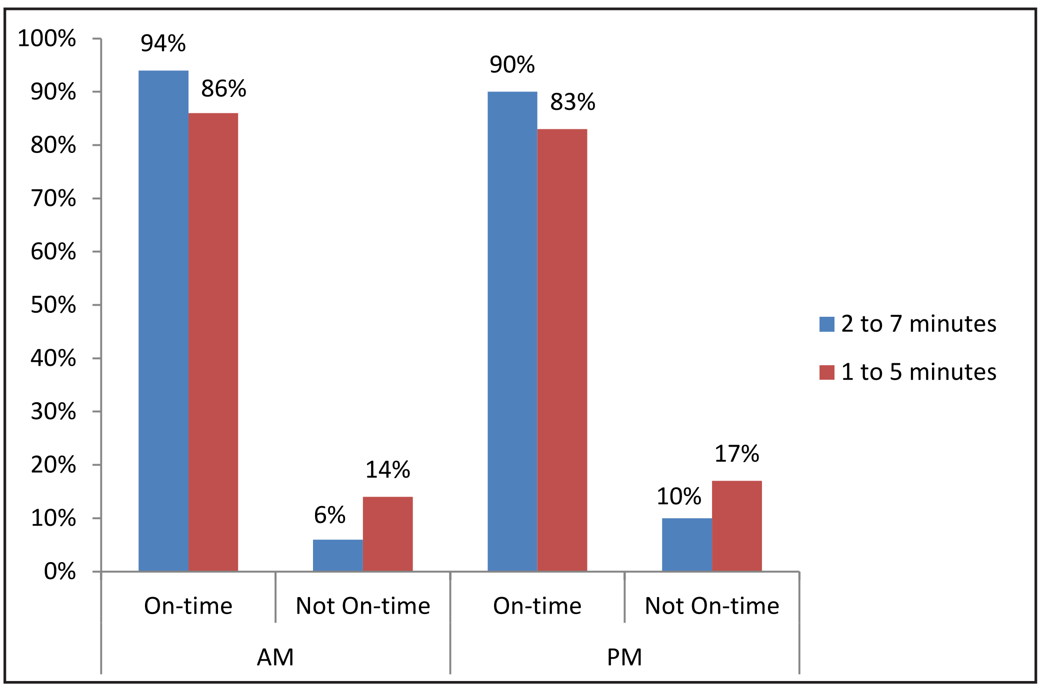


**Figure 14. 16th Street Limited (Line S9) On-time Performance**

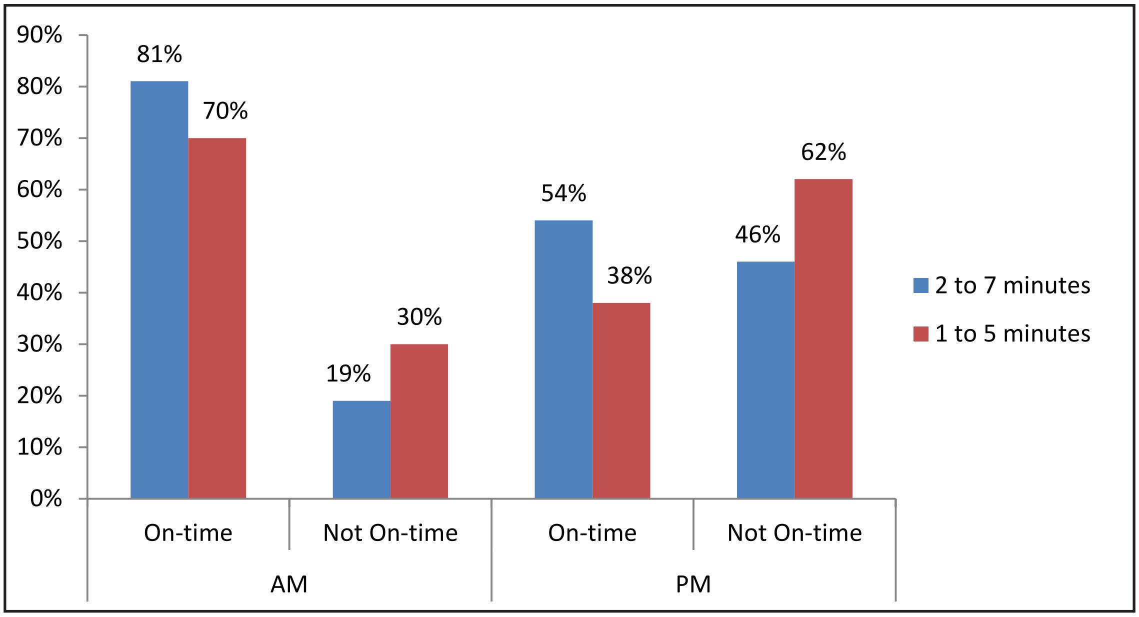


**Figure 15. Benning Street Express (Line X9) On-time Performance**

## AVERAGE DEVIATION-TIMES FROM SCHEDULE ARRIVAL TIMES

Table 7 shows the summary of the average deviation (in minutes) of arrivals before and after the scheduled arrival times along each route for the inbound and outbound travel for both the morning (AM) and evening (PM) travel. These deviations represented the difference between the actual and scheduled arrival times. The early arrival time differences were separated from the late arrival times after which the mean for each group was computed.

**Table 7. Mean Deviations (Minutes) from Scheduled Arrivals at Bus Stops**

| Bus Lines | AM | | PM | |
|---|---|---|---|---|
| | Early | Late | Early | Late |
| Ballston-Farragut Square Line (Line 38B) | 1.27 | 3.17 | 0.88 | 4.96 |
| Rhode Island Avenue-New Carrollton (Line 84) | 1.35 | 2.82 | 2.55 | 2.98 |
| Brookland Potomac Park (Line H-1) | 1.00 | 7.40 | 2.62 | 10.20 |
| Garfield Anacostia Loop (Line W6) | 2.40 | 1.80 | 1.33 | 7.29 |
| 14th Street (Line 53) | 2.96 | 6.00 | 1.83 | 3.72 |
| Sheriff Road-Capitol Heights (Line F-14) | 1.91 | 2.98 | 3.38 | 2.61 |
| Mayfair-Marshall Heights (Line U6) | 2.27 | 2.38 | 1.46 | 4.55 |
| North Capitol Street (Line 80) | 2.69 | 7.59 | 2.27 | 5.48 |
| Rhode Island Avenue (Line G8) | 2.22 | 3.59 | 2.28 | 3.76 |
| Capitol Heights-Benning Road (Line U8) | 2.65 | 1.77 | 3.37 | 4.14 |
| Pennsylvania Avenue (Line 36) | 2.10 | 5.13 | 3.21 | 5.34 |
| Benning Street Express (Line X9) | 1.55 | 4.92 | 4.46 | 6.98 |
| Crosstown (Line H4) | 1.88 | 2.43 | 1.00 | 7.96 |
| Connecticut (Line L2) | 2.01 | 2.45 | 2.69 | 3.89 |
| 16th Street Limited (Line S9) | 1.60 | 1.82 | 1.89 | 1.65 |
| **OVERALL AVERAGE** | **1.99** | **3.75** | **2.35** | **5.03** |

Table 7 shows that the overall mean early arrival deviation times for the morning and afternoon travel were respectively 1.99 and 2.35 minutes while those for the late arrivals at the bus stops were found to be 3.75 and 5.03 minutes. These results are also presented graphically in Figures 16 through 19 for the morning and evening travel periods. The results show that the overall average deviation of arrivals does not exceed the two-minutes-early and seven-minutes-late arrival thresholds on the bus routes studied for both the morning and afternoon travels. However, for the Brookland Potomac Park, Garfield Anacostia Loop and the Crosstown lines or routes showed an average late arrival exceeding the seven-minute threshold while several bus lines also showed early arrivals of more than two minutes. In addition, the overall averages fall outside the one-minute-early and five-minutes-late window for the PM travel and for the early arrivals during the morning travel.

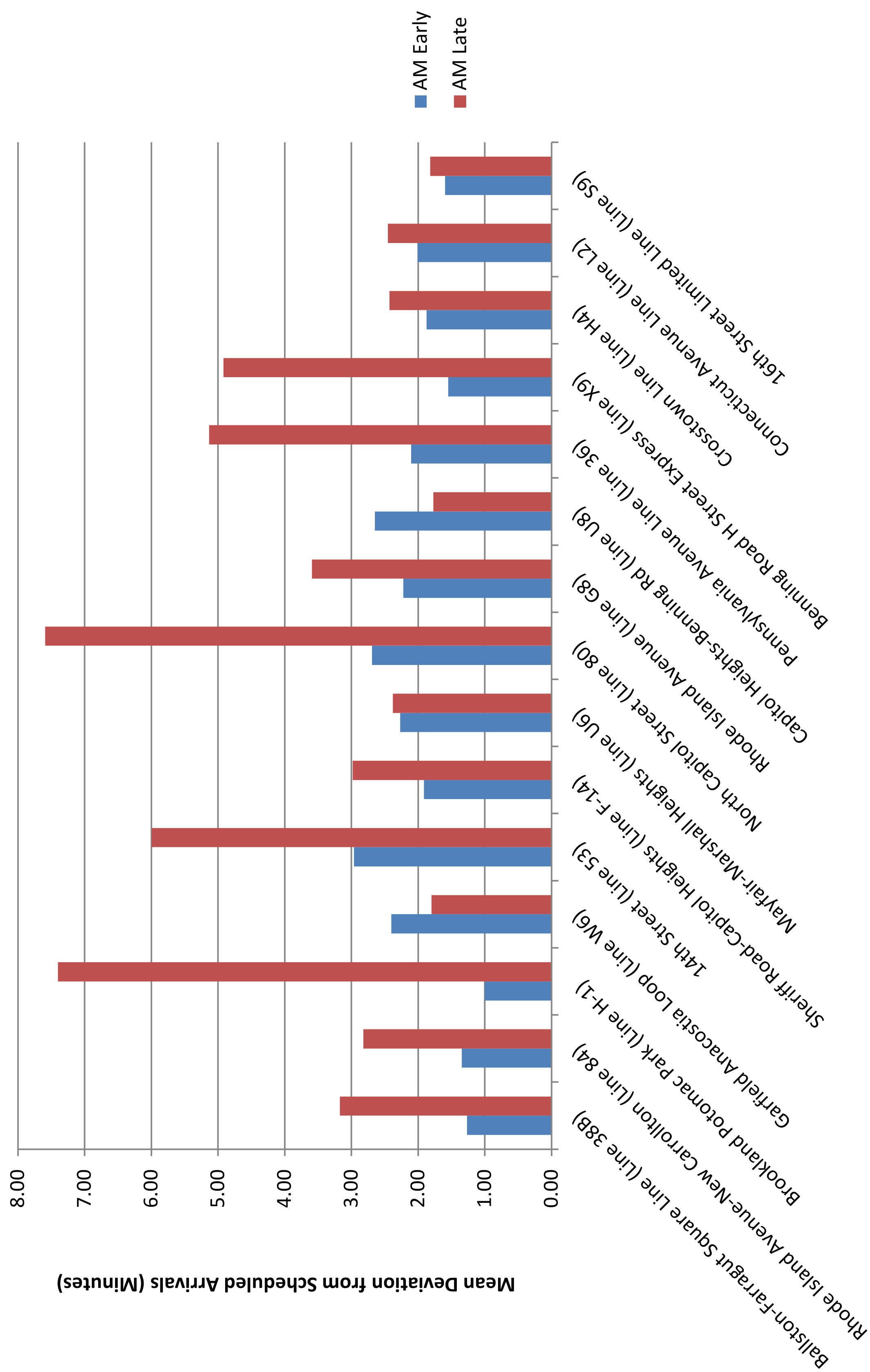


**Figure 16. Mean Deviation from Scheduled Arrivals at Bus Stops During Morning Travel and a Two to Seven Minute Threshold**

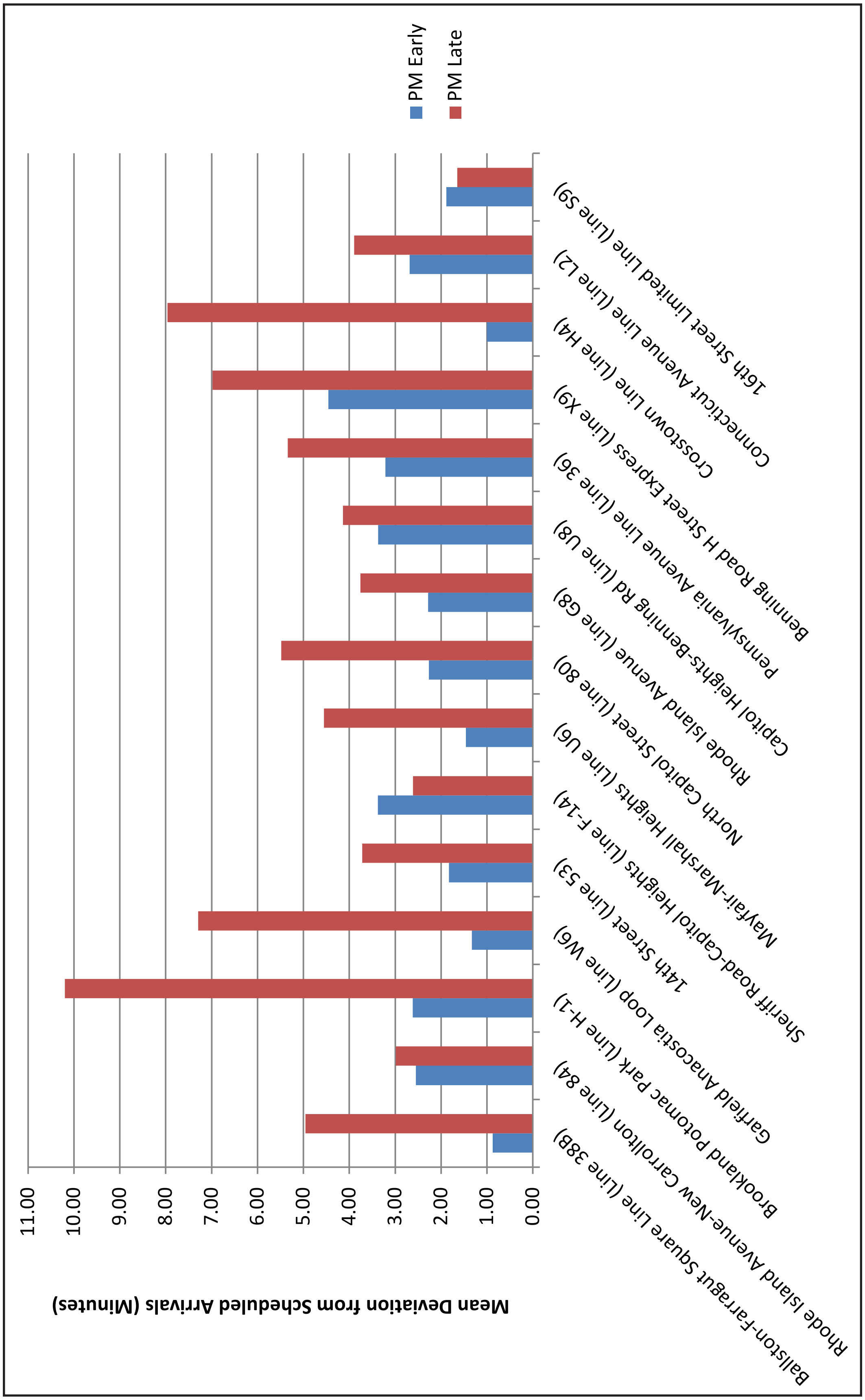


**Figure 17. Mean Deviation from Scheduled Arrivals at Bus Stops During Afternoon Travel and a Two to Seven Minute Threshold**

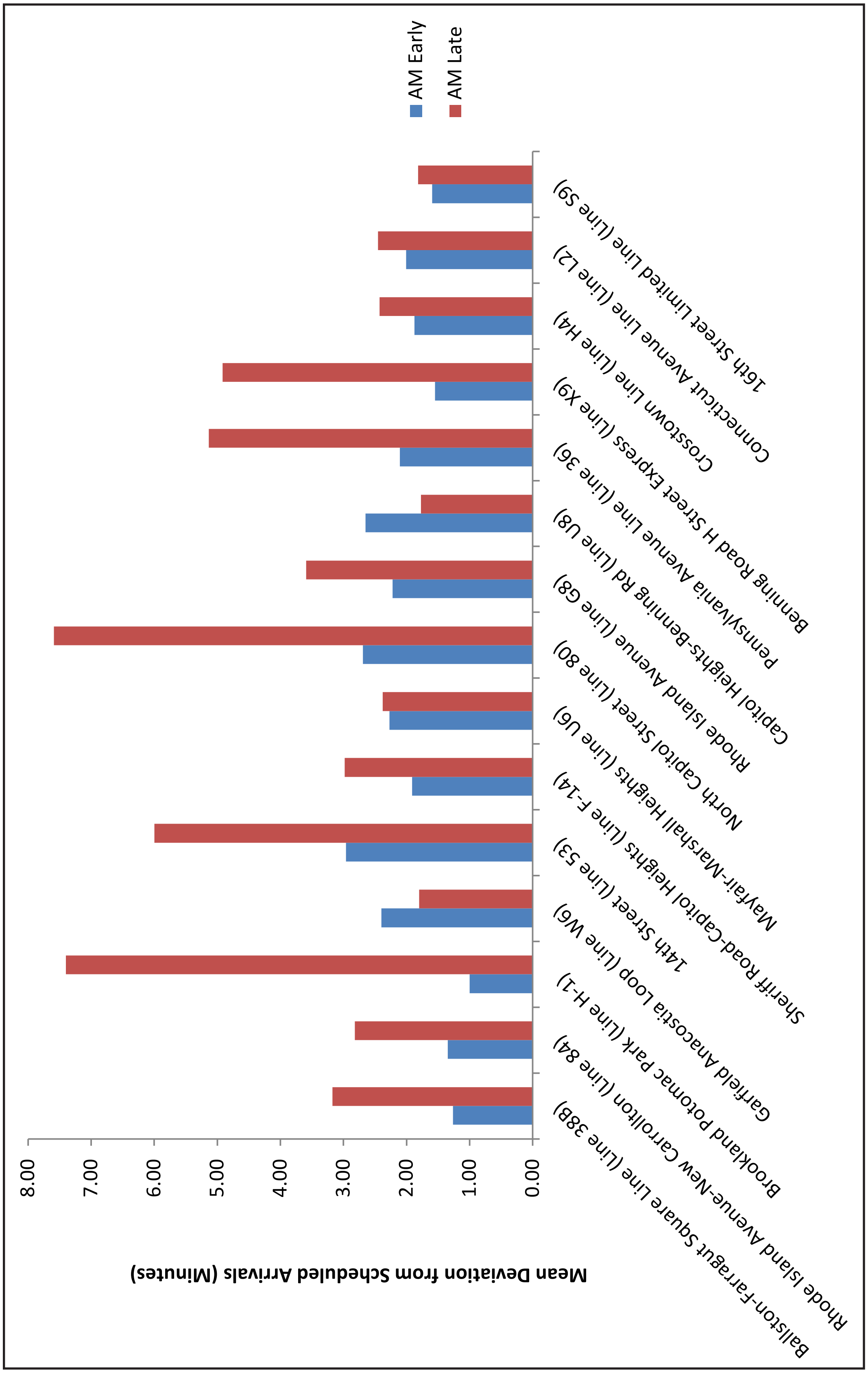


**Figure 18. Mean Deviation from Scheduled Arrivals at Bus Stops During Morning Travel and a One to Five Minute Threshold**

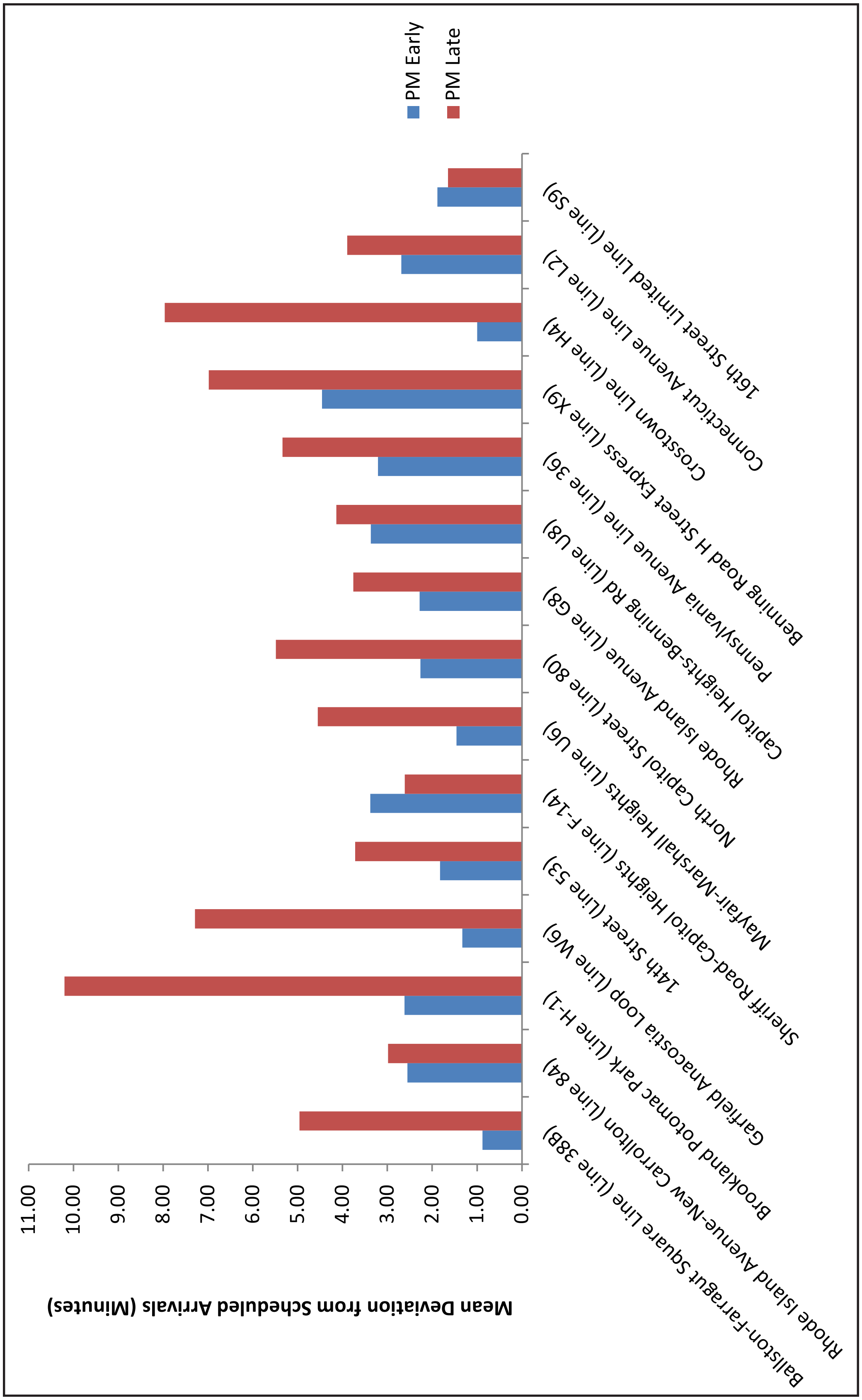


**Figure 19. Mean Deviation from Scheduled Arrivals at Bus stops During Afternoon Travel and a One to Five Minute Threshold**

## RESULTS OF TESTS OF HYPOTHESIS

Using Microsoft Excel, the standard error of mean, Student's *t*-statistic and associated *p*-values were computed based on the one-tail hypothesis test based on a sample size of 15 data points. The summary of the results of the hypothesis tests are presented in Table 8 for two-minutes-early arrival, Table 9 for seven-minutes-late arrival, Table 10 for one-minute-early arrival and finally Table 11 for five-minutes-late arrival.

### Table 8. Results of Tests of Hypothesis for Two-Minutes-Early Arrival

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Early | Early | Early | Early |
| Ballston-Farragut Square Line (Line 38B) | -7.332 | -7.155 | 0.000 | 0.000 |
| Rhode Island Avenue-New Carrollton (Line 84) | -4.232 | 2.260 | 0.001 | 0.022 |
| Brookland Potomac Park (Line H-1) | - | 2.372 | - | 0.025 |
| Garfield Anacostia Loop (Line W6) | 3.128 | -2.490 | 0.008 | 0.021 |
| 14th Street (Line 53) | 1.992 | -0.745 | 0.035 | 0.236 |
| Sheriff Road-Capitol Heights (Line F-14) | -0.746 | 5.285 | 0.233 | 0.000 |
| Mayfair-Marshall Heights (Line U6) | 1.184 | -3.304 | 0.135 | 0.005 |
| North Capitol Street (Line 80) | 2.261 | 0.902 | 0.025 | 0.192 |
| Rhode Island Avenue (Line G8) | 1.285 | 0.867 | 0.113 | 0.202 |
| Capitol Heights-Benning Road (Line U8) | 3.392 | 3.464 | 0.003 | 0.003 |
| Pennsylvania Avenue Line (Line 36) | 0.599 | 3.319 | 0.283 | 0.003 |
| Benning Road H Street Express (Line X9) | -1.089 | 6.336 | 0.163 | 0.000 |
| Crosstown Line (Line H4) | -0.674 | - | 0.260 | - |
| Connecticut Avenue Line (Line L2) | 0.035 | 1.997 | 0.486 | 0.036 |
| 16th Street Limited Line (Line S9) | -2.068 | -0.352 | 0.032 | 0.365 |

### Table 9. Results of Tests of Hypothesis for Seven-Minutes-Late Arrival

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Late | Late | Late | Late |
| Ballston-Farragut Square Line (Line 38B) | -40.060 | -5.134 | 0.000 | 0.000 |
| Rhode Island Avenue-New Carrollton (Line 84) | -11.702 | -14.57 | 0.000 | 0.000 |
| Brookland Potomac Park (Line H-1) | 0.286 | 2.759 | 0.391 | 0.014 |
| Garfield Anacostia Loop (Line W6) | -18.504 | 0.555 | 0.000 | 0.298 |
| 14th Street (Line 53) | -0.763 | -9.304 | 0.230 | 0.000 |
| Sheriff Road-Capitol Heights (Line F-14) | -15.016 | -7.737 | 0.000 | 0.000 |
| Mayfair-Marshall Heights (Line U6) | -17.336 | -2.635 | 0.000 | 0.014 |
| North Capitol Street (Line 80) | 0.332 | -1.747 | 0.373 | 0.049 |
| Rhode Island Avenue (Line G8) | -6.354 | -6.776 | 0.000 | 0.000 |
| Capitol Heights-Benning Road (Line U8) | -16.841 | -6.259 | 0.000 | 0.000 |
| Pennsylvania Avenue Line (Line 36) | -5.678 | -4.985 | 0.000 | 0.000 |
| Benning Road H Street Express (Line X9) | -10.637 | -0.033 | 0.000 | 0.487 |

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Late | Late | Late | Late |
| Crosstown Line (Line H4) | -18.985 | 0.912 | 0.000 | 0.190 |
| Connecticut Avenue Line (Line L2) | -4.746 | -6.788 | 0.001 | 0.000 |
| 16th Street Limited Line (Line S9) | -24.863 | -17.79 | 0.000 | 0.000 |

## Table 10. Results of Tests of Hypothesis for One-Minute-Early Arrival

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Early | Early | Early | Early |
| Ballston-Farragut Square Line (Line 38B) | 2.655 | -0.784 | 0.010 | 0.225 |
| Rhode Island Avenue-New Carrollton (Line 84) | 2.231 | 6.367 | 0.023 | 0.000 |
| Brookland Potomac Park (Line H-1) | - | 6.324 | - | 0.000 |
| Garfield Anacostia Loop (Line W6) | 10.947 | 1.226 | 0.000 | 0.130 |
| 14th Street (Line 53) | 4.063 | 3.559 | 0.001 | 0.002 |
| Sheriff Road-Capitol Heights (Line F-14) | 7.662 | 9.120 | 0.000 | 0.000 |
| Mayfair-Marshall Heights (Line U6) | 5.571 | 2.815 | 0.000 | 0.011 |
| North Capitol Street (Line 80) | 5.522 | 4.298 | 0.000 | 0.000 |
| Rhode Island Avenue (Line G8) | 7.126 | 3.963 | 0.000 | 0.001 |
| Capitol Heights-Benning Road (Line U8) | 8.610 | 5.993 | 0.000 | 0.000 |
| Pennsylvania Avenue Line (Line 36) | 6.346 | 6.057 | 0.000 | 0.000 |
| Benning Road H Street Express (Line X9) | 1.324 | 8.913 | 0.121 | 0.000 |
| Crosstown Line (Line H4) | 4.715 | - | 0.001 | - |
| Connecticut Avenue Line (Line L2) | 4.236 | 4.902 | 0.001 | 0.000 |
| 16th Street Limited Line (Line S9) | 3.041 | 2.720 | 0.006 | 0.009 |

## Table 11. Results of Tests of Hypothesis for Five-Minutes-Late Arrival

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Late | Late | Late | Late |
| Ballston-Farragut Square Line (Line 38B) | -19.11 | -0.107 | 0.000 | 0.458 |
| Rhode Island Avenue-New Carrollton (Line 84) | -6.104 | -7.318 | 0.000 | 0.000 |
| Brookland Potomac Park (Line H-1) | 1.718 | 4.484 | 0.065 | 0.001 |
| Garfield Anacostia Loop (Line W6) | -11.387 | 4.386 | 0.000 | 0.002 |
| 14th Street (Line 53) | 0.756 | -3.638 | 0.232 | 0.002 |
| Sheriff Road-Capitol Heights (Line F-14) | -7.542 | -4.211 | 0.000 | 0.000 |
| Mayfair-Marshall Heights (Line U6) | -9.831 | -0.484 | 0.000 | 0.320 |
| North Capitol Street (Line 80) | 1.456 | 0.556 | 0.085 | 0.293 |
| Rhode Island Avenue (Line G8) | -2.627 | -2.593 | 0.011 | 0.012 |
| Capitol Heights-Benning Road (Line U8) | -10.401 | -1.882 | 0.000 | 0.043 |
| Pennsylvania Avenue Line (Line 36) | 0.410 | 1.015 | 0.344 | 0.162 |

| Bus Route | AM *t*-stat | PM *t*-stat | AM *p*-value | PM *p*-value |
|---|---|---|---|---|
| | Late | Late | Late | Late |
| Benning Road H Street Express (Line X9) | -0.420 | 3.481 | 0.340 | 0.002 |
| Crosstown Line (Line H4) | -10.68 | 2.81 | 0.000 | 0.008 |
| Connecticut Avenue Line (Line L2) | -2.66 | -2.42 | 0.016 | 0.019 |
| 16th Street Limited Line (Line S9) | -15.27 | -11.15 | 0.000 | 0.000 |

Based on the one-tailed test at 5% significance level, we reject the null hypothesis ($H_o$) if the associated *p*-value of the computed Students' *t*-statistic is less than 0.05.

### *Two-Minutes-Early Arrivals*

From Table 8, the null hypothesis that the buses arrive at the bus stops within the two-minutes-early of the scheduled arrival times is rejected for the morning travel for 7 out of the 14 bus lines (50%). This implies that the mean deviation of the early arrival times of the buses within the two-minute timeframe was not necessarily true for 47% of the bus lines (at 5% level of significance). In the evening travel, the null hypothesis was rejected for 10 out of the 14 (71%) at 5% level of significance. Only 14 bus routes were considered because one bus line (for am and pm each) recorded an average of one-minute deviation from scheduled arrival time on the basis of which the standard error was undefined.

### *Seven-Minutes-Late Arrivals*

The null hypothesis that the buses arrive at the bus stops within the seven-minutes-late window of the scheduled arrival times is rejected for the morning travel for 12 out of the 15 bus routes (80%) as shown in Table 9. The same percentage of bus lines was obtained for the evening late arrivals.

### *One-Minute-Early Arrivals*

From Table 10, the null hypothesis that the buses arrive at the bus stops no more than one minute before the scheduled arrival times is rejected for the morning travel for 11 out of the 14 bus lines (~93%). Thus, the mean deviation of the early arrival times of the buses within the one-minute timeframe was not necessarily true for 93% of the bus lines (at 5% level of significance). Similarly, the null hypothesis was rejected for 12 out of the 14 (~86%) at 5% level of significance for the evening travel. Only 14 bus routes were considered because one bus line (for AM and PM each) recorded an average of one-minute deviation from scheduled arrival time on the basis of which the standard error was undefined.

### *Five-Minutes-Late Arrivals*

The null hypothesis that the buses arrive at the bus stops within the five-minutes-late window of the scheduled arrival times is rejected for the morning travel for 11 out of the 15 bus routes (~73%) as shown in Table 11. The same percentage of bus lines was obtained for the evening late arrivals.

*Summary of Hypothesis Tests*

The summary of the statistical analyses is presented in Table 12. From the table, during the morning travel, on average, 65% of the buses did not statistically meet the threshold WMATA's bus stop arrival performance goal, while approximately 76% did not for the evening travel using WMATA's standards. When the industry standard thresholds were considered, a higher percentage of 83%, on average, did not statistically meet the standard during the morning travel. Similarly, 80% on average did not statistically meet the criteria during the evening travel. This resulted in overall averages of 71% and 82% respectively for WMATA's threshold and the general transit industry threshold.

**Table 12. Summary of Statistical Significance of Mean Arrival Deviation — Percentage of Bus Routes that Did Not Satisfy the Null Hypothesis**

| ARRIVAL THRESHOLDS | | Percentage of Bus Routes That Did Not Satisfy the Null Hypothesis | | Averages | | Overall Averages |
|---|---|---|---|---|---|---|
| | | AM | PM | AM | PM | |
| 2 to 7 Minutes | 2 minutes | 50% | 71% | 65% | 76% | **71%** |
| | 7 minutes | 80% | 80% | | | |
| 1 to 5 minutes | 1 minute | 93% | 86% | 83% | 80% | **82%** |
| | 5 minutes | 73% | 73% | | | |

# VI. DISCUSSION OF RESULTS

Passengers generally tend to gauge the reliability of buses using scheduled arrival times at bus stop. When considering WMATA's "on-time" arrival threshold of two-minutes-early and seven-minutes-late within the advertised scheduled arrival times, the results of the analysis showed that, on average, the buses arrived on time at the bus stops on the routes selected approximately 82% of the time in the morning and 68% during the afternoon travel periods. Thus the overall average of on-time performance was determined to be 75%, which does not meet the goal of 78%. On the other hand, these on-time percentages decreased to 67% and 55%, respectively, for the am and pm travel when the general standard of one-minute-before-to-five-minutes-after the advertised scheduled arrival times is taken into consideration. This resulted in an average of 61% on-time performance when the industry standard threshold is considered, which also falls below WMATA's performance goal.

Each route showed a combination of early and late arrival percentages that were not consistent. The results presented in this report showed that the routes exhibited a combination of higher or lower early or late arrivals. The potential for late or early arrival of buses could be attributed to several factors discussed in the literature, which may include spillover traffic due to a crash or incident on adjacent corridor. Thus, this largely could be attributed to chance.

The mean arrival deviations from the scheduled arrival times were aggregated for all 15 bus routes. From the results, the overall mean early arrivals for both morning and evening travel periods were determined to be 1.99 and 2.35 minutes, respectively. This shows that WMATA's threshold of the two-minutes-early arrival is satisfied only during the morning travel. In considering the one-minute-early arrival threshold, neither the morning nor evening travel meets the standard. Similarly, the mean late arrival deviations, on average, were found to be 3.75 and 5.03 minutes for the morning and evening travel periods, respectively. Although these average deviations meet WMATA's seven-minutes-late arrival threshold, they do not meet the standard five-minutes-late threshold used by most transit agencies.

The statistical significance of the mean arrival deviations was also tested at 5% level of significance. This study tested the significance of the hypothesis that the buses will arrive within WMATA's two-minutes-early and seven-minutes-late window. Using a one-tailed test at 5% significance level, this assertion was rejected for 65% (on average) of the routes in the morning and 76% for the evening travel. The rejection rates of the assertion for the buses were higher (83% for AM and 80% for PM) when the one-minute-early and five-minutes-late arrival window was considered. Overall, 71% of the bus routes failed to meet the statistical test based on WMATA's arrival goal, while 82% of those bus routes did not statistically meet the industry standard, at the selected significance level.

# VII. CONCLUSIONS

Only one of the three primary factors used to measure reliability was tested. It has been recognized that transit on-time arrival performance and travel time reliability may have a significant impact on the attractiveness of transit to many current and prospective riders. In addition, transit agencies are continually working to keep the riders they have and attract new riders to their services. From the results, considering WMATA's window of two-minutes-early and seven-minutes-late arrival, the buses were found to be on time an average of 75% of the time during the morning and evening travel. However, on average, 65% failed to meet the statistical test (using 5% level of significance) during the morning travel, and 76% failed during the evening travel. When the one-minute-early-to-five-minutes-late arrival threshold used by several transit agencies was considered, the buses were found to be on time 61% of the time, on average, for both morning and evening travel, of which only 17% (on average) statistically met the criteria in the morning. In the evening, 55% of the buses were considered on-time; however, only 20% of those (on average) statistically met the criteria (using 5% level of significance). Overall, on average, 71% of the buses failed to statistically meet WMATA's threshold, and an even higher percentage (82%) did not meet the general transit industry threshold.

Based on the 15 bus lines studied, the deviation observed for arriving before the scheduled times averaged 1.99 to 2.35 minutes (2.17 minutes on average). The equivalent deviation for arriving late ranged from 3.75 to 5.12 minutes (4.52 minutes on average). Based on these results, it would appear that WMATA's performance is close to the transit industry threshold that should be considered.

# VIII. RECOMMENDATIONS

Service reliability is one of the attributes most important to transit customers, while service quality and customer satisfaction have been linked to higher levels of retention and possibly even ridership gain. Reliability can be measured by several characteristics mentioned in this report, including scheduled arrival patterns, travel time, run time, and transit level of service, among other metrics. Several of these performance metrics must be analyzed simultaneously to arrive at a definitive plan of action to improve reliability, thereby improving ridership and customer satisfaction. Based on the literature reviewed and the analysis in this report, the following recommendations are made for WMATA's consideration:

- Consider adopting the one-minute-early-to-five-minutes-late arrival window of the advertised schedules to bring WMATA's transit system in line with several other transit agencies. This is based on the fact that WMATA's average deviations for early and late arrivals of 2.17 and 4.52 minutes, respectively, are close to the industry standard.

- Scheduled arrival studies should be conducted periodically on several representative WMATA bus lines and routes. Results should be used for schedule adjustment and monitoring progress toward the industry arrival threshold.

- Conduct a travel and run-time study using automated data collection to gauge the efficiency of bus travel on heavily traveled/patronized routes.

In addition, it is recommended that reliability performance metrics and studies be conducted comprehensively and periodically—perhaps every three to five years—to identify areas for improvement. Finally, because WMATA has the capability to obtain data automatically through its vehicle location and passenger counting system, it is highly recommended that consideration be given to providing access to the data for educational institutions.

# ENDNOTES


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Funded by U.S. Department of Transportation