Task J: Aircraft Arrival Management Systems (AAMS) Demonstration Project

Final Delta Data Collection and Analysis Report

OTA DTFAWA-08-A-00001

Task J Document Number: Item 28

August 31, 2012

Version 1.0

Status: Draft

Prepared by: Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd. Daytona Beach, FL 32114-3900

MCR, LLC
2010 Corporate Ridge, Suite 350
McLean, VA 22102

Version Control

Version #	Description of Change	Date
1.0	Initial Release	August 31, 2012

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1 EXECUTIVE SUMMARY

1.1 Purpose

The purpose of the Aircraft Arrival Management System (AAMS) Next Generation Air Transportation System (NextGen) Task J project is to demonstrate the feasibility and benefits of a time-based aircraft flow management system to precondition the arrival traffic at a single airport and to quantify the benefits of the system. The demonstration at Minneapolis-St. Paul International Airport (MSP) is designed to identify the feasibility, efficacy, and benefits of a single-user, Airline Operation Center (AOC) based system. The commercially available ATH Group Inc. Airline Attila™ system was installed as the flow management system to coordinate and combine the business needs of Delta Air Lines and provide a Delta-centric Required Time of Arrival (RTA) to inbound aircraft. The MSP element of this project is an expansion of the initial operational and benefit-cost analysis performed at the Charlotte-Douglas International Airport (CLT) with US Airways. The project provides evidence of system-wide and airline-specific benefits that can be attributed to the assessed systems.

1.2 Project Document Overview

This project document summarizes all the information, analysis and conclusions obtained during the Delta/MSP phase of the AAMS Project. The AAMS is an airline-centric, business rule and time based flow management system developed to pre-condition the aircraft arrivals into Minneapolis-St. Paul International Airport (MSP). In commissioning this research project, the FAA desired an independent benefits and costs determination that an AAMS does not require expensive development or installation of aircraft or ground technologies, or expensive changes to the Air Traffic Control (ATC) system, or substantial changes in airline or ATC operating procedures to achieve measurable benefits. In performing this independent analysis, ERAU and MCR were also commissioned to measure real-time operational benefits to the National Airspace System (NAS) and cost savings to the airlines from the AAMS while controlling for environmental and other system conditions over two phases: baseline (pre – AAMS installation), and single-user AAMS operations.

The **General Information** section includes the project methodology (test plan), AAMS system description, and deviations from the test plan which occurred during the project. Details of the testing procedures are contained in the **Test Description** section. The **Airport Characterization** section includes descriptive data of the airports usual traffic patterns, arrival rates and time lines, airline/aircraft demographics, and dwell time statistics. This data was primarily compiled using the AAMS system by its vendor.

The **Performance Analysis** section contains the descriptive statistics and regression analysis performed by ERAU for the baseline (Passive Operation) and AAMS operation period (Active Phase). Based on the comparison of the benefits with and without the AAMS operation, the **Cost – Benefit Analysis** section quantifies the direct (primary) and indirect (secondary) benefits observed during the project.

The last two sections (**Issues** and **Conclusions – Recommendations**) provide other observations by the research team outside the analysis contained in the Cost – Benefit Analysis.

1.3 Operational Analysis Summary

Traffic flows east or west over six corner posts into MSP in seven arrival banks that have a tendency to approach or exceed the FAA called arrival rate. These banks are primarily driven by the schedule of the airport's largest tenant, Delta Air Lines.

It has also been noted in the course of the operational analysis that the weather during the second phase of the project was unseasonably mild.

1.4 Benefits Analysis

The Cost Benefit Analysis (CBA) quantifies the costs (primarily incurred by the airlines) for implementation of the AAMS system and compares those costs to the benefits to the participating carrier, Delta Air Lines (only mainline), and non-participating airlines and the National Airspace System (NAS) identified through pre- and post AAMS implementation operation analysis. Overall, the AAMS demonstration project confirms the viability of the AAMS concept and provides an evidence of measurable benefits, including monetized benefits summarized in Table 1 that can be attributed to the AAMS.

Table 1. Monetized Benefits Summary (for first year of operation)

	MSP All Observations	*MSP Rep. Days*
Total System Costs	$1,553,530	$1,553,530
Total System Monetized Benefits	$12,328,152	$5,242,340
System Benefit/Cost Ratio	7.94	3.37
Total Costs (Delta Air Lines mainline)	$1,553,530	$1,553,530
Total Monetized Benefits (Delta mainline)	$3,330,214	$1,373,975
Benefit Cost Ratio (Delta mainline)	2.16	0.88

The CBA further confirms the viability of the AAMS concept and suggests that if implemented, the AAMS will generate considerable benefits to participating airlines as well as overall AAMS airport operations. The AAMS system worked as designed as it operated under and produced the following during the six months of the Active Phase (November 1, 2011 through April 30, 2012):

- MSP arrivals - 96,330 total air carrier, 27,438 Delta Mainline, 2,293 air taxi, and 3,021 general aviation during the six month of active AAMS;

- Daily average flights - 532 total air carrier, 151 Delta mainline;
- Average of 124 Delta mainline RTAs sent per day, no Delta Connection RTAs sent;
- 50 seconds per flight shorter dwell time for all MSP arrivals;
- 29 seconds further dwell time reduction for optimized flights that moved forward;
- All flights had a significant on-time performance improvement, while complied flights have even better on-time performance improvement;
- On average each flight saved 66 pounds of fuel, and in total arriving flights saved 4,109,401 pounds of fuel (613,343 gallons) between the cornerpost and landing;
- 12,873,488-pound reduction in CO_2 emissions;
- 7.7% RTA compliance based on all MSP arrivals, and
- More optimized and complied flights will improve benefits.

1.5 Conclusions—Recommendations

The AAMS-MSP demonstration project confirms the viability of the AAMS concept and suggests that if implemented, the AAMS will generate considerable benefits to participating airlines as well as the overall AAMS airport operations.

2 GENERAL INFORMATION

2.1 Purpose

The purpose of the Aircraft Arrival Management System (AAMS) Next Generation Air Transportation System (NextGen) Task J project is to demonstrate the feasibility and benefits of a time-based aircraft flow management system to precondition the arrival traffic at a single airport and to quantify the benefits of the system. The demonstration at Minneapolis-St. Paul International Airport (MSP) is designed to identify the feasibility, efficacy, and benefits of a single-user, Airline Operation Center (AOC) based system. Embry-Riddle Aeronautical University, in partnership with ATH Group, Delta Air Lines, and MCR, LLC examined the installation of the commercially available ATH Group Inc Airline Attila™ system. The installed system acted as the flow management system to coordinate and combine the business needs of Delta Air Lines and provide a Delta-centric Required Time of Arrival (RTA) to inbound aircraft.

The primary objectives of this AAMS Project are to:

- Investigate how AOC-based metering tools may support NextGen time-based metering concepts.
- Demonstrate that a single user AAMS does not require expensive development or installation of aircraft or ground technologies, or expensive changes to the Air Traffic Control (ATC) system or substantial changes in airline or ATC operating procedures.

- Confirm that a single user AAMS system provides real-time operational benefits to the National Airspace System (NAS) and cost savings to the airlines.

From November 1, 2010 to April 30, 2011, (the Passive Phase) the AAMS was running on recorded data and the system did not distribute the calculated RTAs. The Passive Phase provides a statistical baseline with which to compare the operational results. The Active Phase, where RTA messages were issued based on live data, ran November 1, 2011 to April 30, 2012.

2.2 Scope

Testing the AAMS operations involved two phases of data collection which make up the foundation for the operational and statistical analyses:

1. AAMS Passive Operation Phase (Passive Phase): During the initial phase of six months, input messages were processed and RTA calculations were made; however, the RTAs were not sent to the participating aircraft. The benefits obtained in the Passive Phase were measured to create the “statistically zero” baseline scenario that is compared with the benefits obtained during the latter two phases of testing.
2. AAMS Active Operation Phase (Active Phase): In this phase, the system operated with the same configuration for an additional six months. RTA messages are computed and sent to the Delta Air Lines aircraft. The benefits are estimated by comparing the “dwell” times and fuel burned recorded during the AAMS Active Phase with those of the Passive Phase.

DELTA/Minneapolis Airport Characterization – Passive Data Collection Report (Deliverable 26) provided a detailed analysis of the airport and its airspace in operation. This report also included analysis of the AAMS Passive Phase data that would serve as the base upon which to estimate the AAMS benefits. The data analyzed came from November 1, 2010 to April 30, 2011. This report was accepted by the FAA on February 24, 2012.

DELTA/MSP Quick Look Report: Three Months Active Phase Data (Deliverable 27) provided the analysis of the AAMS performance and benefits used the full Passive Phase data set with the first three months of Active Phase data (November 1, 2011-January 31, 2012) to provide an overview of the demonstration’s progress that was accepted by the FAA on April 10, 2012.

FINAL - DELTA Data Collection and Analysis Report – Active (Deliverable 28 – this report) reports the findings of the performance and benefits analysis for the Delta/MSP AAMS demonstration. The results were calculated using the full Passive Phase and Active Phase (November 1, 2011-April 30, 2011) data sets.

2.3 Project Methodology

2.3.1 Aggregate Benefits Analysis

In the aggregate benefit analysis the statistically significant differences between two samples of data (passive/baseline, active/single-user AAMS periods) are examined. In particular, the following variables are analyzed:

- Average "dwell times" for different corner posts and arrival configurations
- Average "dwell times" with and without Traffic Management Advisor (TMA) metering
- Average "dwell times" with and without runway closures
- Average "dwell" fuel consumption
- Average times en route per flight
- Average fuel consumption per flight
- Number of flights that arrived as scheduled (A0)
- Number of flights that arrived within 15 minutes of schedule (A14)
- Average actual taxi-in times
- Average actual taxi-out times

While the data carries a considerable amount of noise due to potential changes in the environment, the analysis of statistically significant differences in these variables between the two data collection periods shows the "big picture" of AAMS benefits.

Prior to the analysis, ATH's .atx file arrival data was validated using actual departure and arrival data from Delta Air Lines' Aircraft Communications Addressing and Reporting System (ACARS) equipped aircraft's Out, Off, On and In (OOOI) electronically generated data. Actual fuel consumption for both data collection periods for Delta flights was provided by Delta Air Lines. For "dwell" fuel consumption for each type of arriving aircraft the Base of Aircraft Data (BADA) from EUROCONTROL were used.

2.3.2 "Representative Days" Analysis

To reduce the amount of noise in the data and make a more robust comparison between the baseline and active AAMS periods, a subsample of "representative days" was used. To be considered as "representative", a day should have A14 performance of at least70%. Having been first used in the CLT AAMS Demonstration, it was determined by a US Airways and research team consensus that when more than 70% of flights at the study airport on a particular day arrive within 15 minutes of schedule, it indicates that there were no major weather or other disruptive events that significantly affected airline and airport operations. Thus, such days better reflect undisrupted operations of the airline with and without the AAMS. The "representative days" analysis included the same variables as the aggregate benefit analysis.

2.3.3 Multiple Regression Analysis

Multiple regression analysis has been employed to avoid aggregation biases and provide parameter estimates that can be attributed solely to the variable under investigation. This analysis therefore controls for multiple environmental and operational conditions to identify the AAMS impact on participating and non-participating traffic. Before regressions were performed, multicollinearity and heteroscedasticity tests were run to ensure that the data conformed to classical regression assumptions. The regression model is presented below and was performed with all data, data filtered for the participating carrier (Delta), data for traffic on representative days, and data for Delta flights on representative days. The parameters of the regression are designed to mirror the regressions used for CLT.

$$\begin{aligned} DTime_i = {} & a + b_1 ACT_i + b_2 OPTC_i + b_3 OPTF_i + b_4 OPTS_i + b_5 TMA_i + b_6 TMA_i * MOV_i + b_7 RWCL_i \\ & + b_8 SHONNE_i + b_9 OLLEEW_i + b_{10} OLLEEE_i + b_{11} DELZYW_i + b_{12} DELZYE + b_{13} TRGETW_i \\ & + b_{14} TRGETE_i + b_{15} TWINZW_i + b_{16} TWINZE_i + b_{17} BITLRW_i + b_{18} BITLRE_i + e_i \end{aligned}$$

Where:

- *DTime* is "dwell time" for flight *i.*
- *a* is constant.
- *ACT* is the dummy variable that becomes "1" if an arrival was performed during Active Operation Phase and "0" otherwise.
- *OPTC* is the dummy variable that becomes "1" if an arriving flight was optimized and complied (received an RTA and passed a corner post within 60 seconds of the RTA).
- *OPTF* and *OPTS* are the dummy variables that become "1" when an arriving flight received an RTA and moved in its direction and "0" otherwise. *OPTF* indicates that the RTA prescribed the flight to expedite and it did, but did not pass the corner post within 60 seconds of the RTA. *OPTS* indicates that the RTA required the flight to slow down and flight attempted to comply, but did not pass the corner post within 60 seconds of the RTA.
- *TMA* is the dummy variable that becomes "1" if TMA was operational and "0" otherwise.
- *TMA*MOV* is the dummy variable that becomes "1" when an arrival was performed when TMA was operational and the flight received an RTA and moved in its direction within 15 minutes of receiving the RTA, and "0" otherwise.
- *RWCL* is the dummy variable that becomes "1" if an arrival was performed when at least one of the runways at MSP was closed and "0" otherwise.
- *SHONNE* is the dummy variable that indicates that an arrival was performed through SHONN corner post and East arrival configuration.
- *OLLEEW* is the dummy variable that indicates that an arrival was performed through OLLEE corner post and West arrival configuration.

- *OLLEEE* is the dummy variable that indicates that an arrival was performed through OLLEE corner post and East arrival configuration.
- *DELZYW* is the dummy variable that indicates that an arrival was performed through DELZY corner post and West arrival configuration.
- *DELZYE* is the dummy variable that indicates that an arrival was performed through DELZY corner post and East arrival configuration.
- *TRGETW* is the dummy variable that indicates that an arrival was performed through TRGET corner post and West arrival configuration.
- *TRGETE* is the dummy variable that indicates that an arrival was performed through TRGET corner post and East arrival configuration.
- *BITLRW* is the dummy variable that indicates that an arrival was performed through BITLR corner post and West arrival configuration.
- *BITLRE* is the dummy variable that indicates that an arrival was performed through BITLR corner post and East arrival configuration.
- e is the error term.

SHONN West variable is not included to the equation to be used as a reference. The coefficients of interest are b_1 through b_6. The remaining regression terms are used to control for factors that may influence the "dwell time" and are not managed by the AAMS.

2.4 AAMS System Description

2.4.1 Overview

The AAMS is a ground based aircraft time based metering system that uses derived RTA messages, electronically sent to the aircraft, to manage corner post arrival times to improve the sequencing of arriving aircraft. In the case of the Task J MSP AAMS Program, the RTAs are derived internally by Delta Air Lines, while the Task J Charlotte Douglas (CLT) AAMS Program added the additional approval step of real time coordination with a second AAMS Exchange server.

The Task J MSP AAMS operation utilizes a commercially available time based aircraft metering system, ATH Group's Attila™ Managed Arrivals System, which has been in use by Delta Air Lines at Atlanta Hartsfield International Airport (ATL) since 2006, as well as Minneapolis-St. Paul International Airport (MSP) and Detroit Metropolitan Wayne County Airport (DTW) since 2011. The system has also been in use at Charlotte Douglas International Airport (CLT) since 2010. The system adjusts the arrival time (increases or decreases the speed of the aircraft), based on the airline's business needs, airport capacity and other factors, with the purpose of managing the arrival flow more efficiently. Figure 1 outlines the conceptual relationships between these components of the AAMS demonstration at MSP.

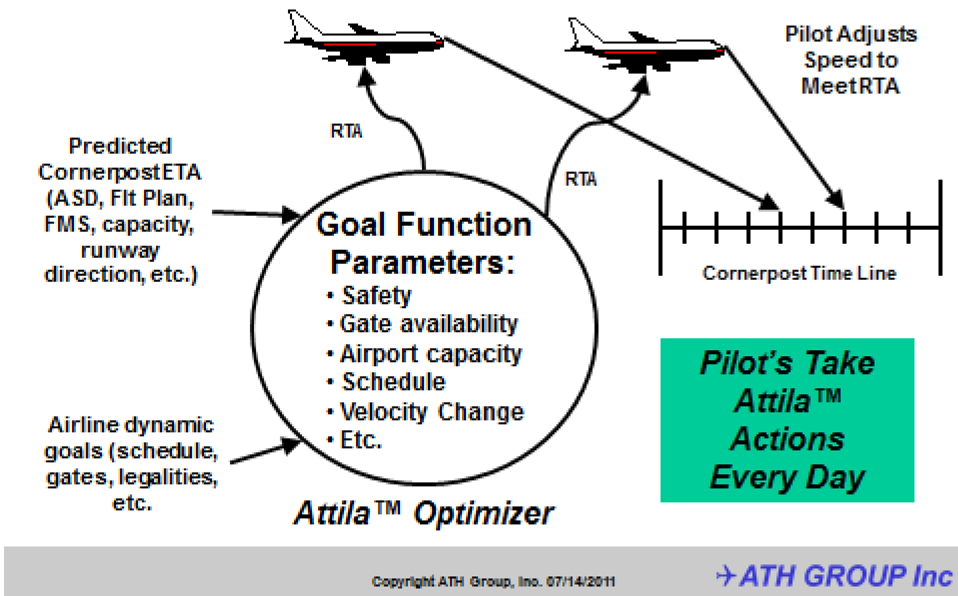

Figure 1. MSP AAMS's Attila™ Operational Concept

2.4.2 Test Environment

The AAMS MSP Data Collection Program is an operational, time based metering system that runs in an operational airline environment and works to apply an airline's business needs to the airport arrival flow 24-hours a day. This operational evaluation is for a period of 12 months (6 months passive and 6 months active).

The objective of the first part of the operational evaluation was to run the system on a recorded MSP data set covering a period of six months. This offline passive data analysis, completed in the fall/winter of 2011, used data collected by Delta and ATH Group from November 1, 2010 through April 30, 2011. During these data runs input messages were processed and Required Time of Arrival (RTA) calculated, however, since this was an offline analysis, RTAs were not uplinked to the participating aircraft. The results of these passive runs were used by ATH to measure the calculated benefits in order to create a "statistically zero" baseline scenario. The results of this baseline analysis were compiled in the Delta - MSP Airport Characterization Report (Deliverable 26).

With the passive runs completed, the AAMS system computed and sent RTAs to Delta flights in full operational mode with the same configuration as the passive runs over an additional six month period (November 1, 2011 through April 30, 2012). This period is called the AAMS MSP Active Phase.

Once the RTA is calculated, Delta Air Lines aircraft received RTA messages via their onboard Aircraft Communications Addressing and Reporting System (ACARS) system with the goal of preconditioning the MSP arrival flow using RTA times at the aircraft's arrival fix (TWINZ, BITLR, DELZY, TRGET, SHONN, and OLLEE) into MSP.

As part of both the Passive and Active Phases, the AAMS application generated Time Event (ATX) files, aircraft four dimensional trajectories, and airport configuration files. These files form the primary data source for system evaluation in the Final - Delta Data Collection and Analysis Report - Active (Deliverable 28).

By comparing the benefit measured during the active operation with that of the passive operation, the net AAMS benefit at MSP could be determined. The research team will also perform a comparative analysis of Delta Air Lines and US Airways AAMS operations in Deliverable 29.

The operational environment involved the operational airline (Delta), the airline's operation center, the Delta Air Lines aircraft inbound to MSP, and the ATH Group data center in Lanham, MD.

2.4.2.1 Test System

The Delta Air Lines airline-centric AAMS system was evaluated individually to determine that it does generate benefit when run as a standalone system in MSP. No other AAMS components are part of this demonstration.

2.4.2.2 Locations

The operational evaluation location consisted of several sites:

- ERAU College of Business
- FAA Headquarters in Washington DC
- Delta Air Lines's Information Technology facility in Atlanta, Georgia
- Delta Air Lines's Operations Control Center in Atlanta, Georgia
- ATH Group's software and data center and facility in Lanham, Maryland.

Data was shared between Delta Air Lines and ATH Group using a secure Virtual Private Network (VPN) tunnel. ATH Group in turn made operational data files available in the project library on a secure FTP site. Files were made available to ERAU within two to three days of the operational evaluation.

2.4.2.3 Description

The operational system at Delta Air Lines's facility in Atlanta generated target times and RTA messages. These and other data were collected and archived for analysis.

This system also generated:

- *.trj trajectory files for all aircraft operation into MSP
- *.atx files with time events for Delta Air Lines aircraft
- *.stl files that record certain important aspects of airport operation such as called rates and arrival directions.

2.4.2.4 System Context

The AAMS analysis suite connected to the project libraries in the ATH Group data center FTP site. This allowed all the tools in the suite next day access to data about all flights operating into MSP. Figure 2 outlines this AAMS test system context.

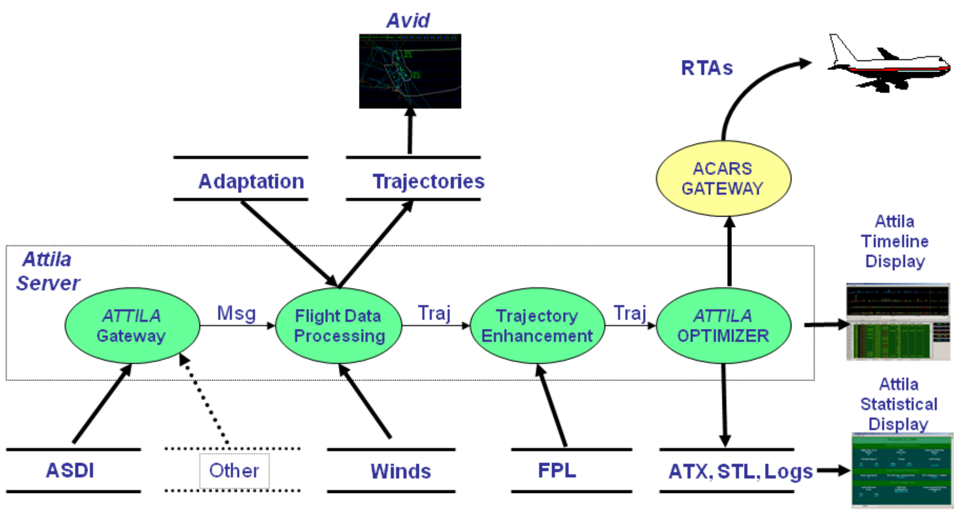

Figure 2. AAMS Test System Context

2.4.3 Test Failure and Prevention Procedures

2.4.3.1 AAMS Software Application

The AAMS and associated software applications were installed and underwent a calibration and validation process performed during the Passive Phase.

Both the passive and active data collection periods are large enough to minimize any potential risk regarding installation and validation process. If problems presented in either the passive or active data collection periods, the amount of data collected over the 12 month period should have been sufficient to mitigate any noise appearing in the data due to data collection delays.

2.4.3.2 Data Collection Information

The following is the list of risks that were identified that could have impacted the data collection process and the actions taken to prevent or mitigate them:

- Lack of connectivity from the information sources
  - The data collection period will be long enough to avoid or reduce the risk of not collecting the amount of data needed to calibrate and evaluate the AAMS concept and AAMS operation.
- Server failure
  - Delta has already installed a Fail Active Attila™ software (2 MSP Attila™ systems running simultaneously), with automatic fail over capability.
  - Backup data storage has been installed at Lanham, MD, and will be used to store the information on a routine basis in case of failure of the main servers.
- Weather: Weather factors could impact the developing of the normal air traffic operations at Minneapolis airport and cause loss of data.
  - The active data collection period has been selected over the same months of the year as the Passive data collection to minimize weather and environmental differences.
  - In addition, the 12 month period (6 months passive, 6 months active) for the data collection process reduced the potential risk of not collecting information needed for developing the statistical analysis due to weather conditions. The problems caused by weather conditions should not be statistical significant to impact the results obtained from the operational evaluation.

2.4.3.3 Operational Procedures

The following is the list of potential risks that could have influenced in the data collection process as well as the actions taken to prevent or mitigate the event:

- Airline operational procedures: Airline operational procedures could cause an inability to perform specific procedures that are necessary to achieve RTAs, thus, some aircrew members may choose not to participate in the operational evaluation.
  - Coordination with Delta Air Lines to mitigate operational conflicts between the AAMS operational evaluation flights and the airline's procedures.
  - Coordination between the airline's operational departments to assure the privacy of information and safety of the operations during the operational evaluation.
- Airline Fleet: Delta's fleet is composed of mainline aircraft which have the

performance (FMS) and communications (ACARS) capability to meet the RTA generated by the airline's AOC, however, some aircraft might not be able to meet the RTAs.

- ATH and Delta ensured that proper operational information was sent to the aircraft and also ensured that the participating aircraft were capable (from the performance point of view) of meeting the RTAs generate by the AAMS demo system software.

- ATC operations:
  - AAMS operations should be completely transparent to ATC operations.
  - Coordination with Minneapolis Center and Minneapolis tower to inform them about the AAMS operational evaluation. Close monitoring of the ATC activities was performed with the input and information collected from the aircrew member in order to mitigate any potential conflict between the AAMS activities and the ATC operations.

2.5 Deviations from Test Plan

2.5.1 Software – Performance Enhancements

Over the course of the demonstration the software behind the AAMS has been modified to improve performance and correct any issues that arose. These adjustments are described in Table 22.

Table 2. Delta Air Lines Attila™ Software Revision Log

Implemented	Version	Description	Notes
11/2/2011	603-u12	ASD updated for a problem with coordination point latitude/longitude conversion	
11/17/2011	603-u13	FDP maintenance update (bad DEP caused pos reports to be rejected), AFD maintenance to protect against rare case when a large RTA change can get generated, ARC to correct archiving upon restart, GSR update for MVT output for long international flights and a new filter to block MVT for specified flights.	Taxi tables updated
11/29/2011	603-u14	Updated dwell times and slow down parameters for all 3 installs. Slow down parameters take advantage of arrival direction specific capability.	Prelim update was made on 11/23/11 for MSP and DTW

Implemented	Version	Description	Notes
12/8/2011	603-u15	FDP maintenance update (bad position data problem, multiple sources issue, arrival time), GSR recompile, ADX restructuring for messages.ini, SGI addition of time stamp data	Corrects problem with arrival time when SMA data was being received.
12/16/2011	603-u16	Changed SanityCheckThresholdMinutes setting to 6645 in *.ath.ini files (corrects rare case of a bad MVT being generated)	
1/6/2012	Stats-5-6 u2	update of aircraft types data used by the stats package	
2/14/2012	603-u17	GSR update to eliminate delay in MVT output, OGI parameter change to not send no change RTAs and AFD updates for additional output in .ath	AFD change is for upcoming ACI change
2/28/2012	603-u18	Increased time for GSR to stop	Changes to atl_proc, msp_proc, dtw_proc services
3/20/2012	603-u19	GSR updates for file naming, gate availability corrections, FTE update for updating GSR generated AUX data, minor ATD update.	Taxi tables updated, IATA-ICAO codes updated. Opt Mach updated for MD8x, MD90
3/27/2012	603-u20	Updated MSP & DTW goal functions (DTW same as ATL, MSP slightly different in Time in Queue and Queued Advisory components)	Taxi tables updated

2.5.2 Other Deviations

The design of the Passive and Active Phase dates was initially intended to act as a control and minimize variations outside of experimental control. In particular, it should be noted that the MSP is known to have severe winters and did experience considerable winter weather in the Passive Phase. The experienced weather in the Active Phase has been unseasonably mild. This variance on the weather conditions can also be seen in the Passive and Active Phase data where 18% of passive traffic occurred on non-representative days while only 1% did so during the Active Phase.

Also during the demonstration, Delta introduced and adjusted initiatives to improve its operational performance. The majority of these initiatives was in place for Passive and Active Phases and should not provide a source for excessive variation.

The AAMS itself experienced operational interrupts during the Active Phase. A summary of operational interrupt events is disclosed in Table 3. The majority of the status notations cite weather conditions while a few lack a reason for disconnect.

Table 3. AAMS Operation Interruptions (all times local)

Date	Hours Operational	Comments
1/13/2012	6.25	Off at 09:54 (reason N/A)
1/17/2012	2.88	Off at 04:52 (no reason given; VFR)
1/18/2012	8.82	On at 05:11
2/21/2012	3.78	Off at 05:46 due to weather (snow and fog)
2/22/2012	-	Off (no reason given; VFR)
2/23/2012	-	Off (haze)
2/24/2012	-	Off (snow and fog)
2/25/2012	-	Off (snow)
2/26/2012	-	Off (snow, fog, and haze)
2/27/2012	0.81	On at 05:11
2/28/2012	2.76	Off at 04:45 (snow and haze)
2/29/2012	-	Off (rain, sleet, snow, and fog)
3/1/2012	-	Off (snow and fog)
3/2/2012	9.67	On at 06:18

3 Airport Characterization Findings

3.1 Airport Characteristics

The airport characteristics for MSP are based on the Passive Data collected November 1, 2010 to April 30, 2011.

3.1.1 Arrival Rate

Minneapolis-St. Paul International Airport (MSP) has a maximum called arrival rate of 90 flights per hour (per FAA Called Arrival Rate) in ideal weather conditions. This rate decreases when weather, runway closures, noise and/or fire-rescue restrictions limit the runways utilization.

Figure 3 shows FAA's Airport Arrival Demand Chart on December 7, 2011 at MSP. The white horizontal line represents the FAA Called Arrival Rate (90 arrivals per hour).

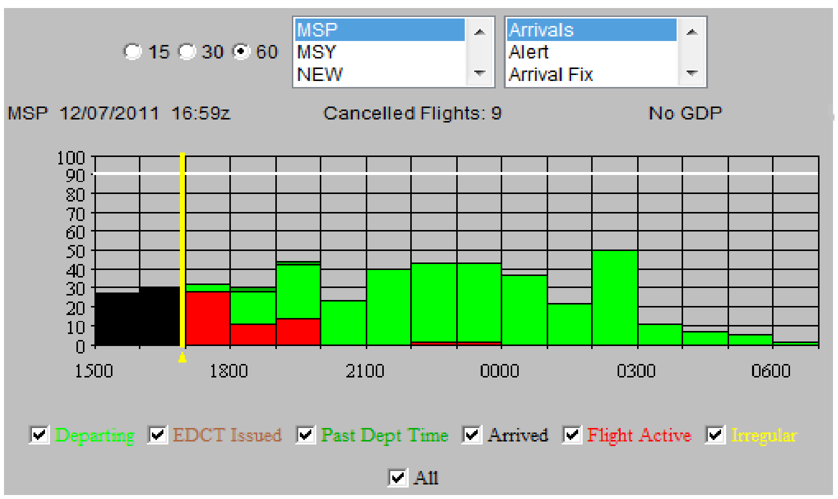

Figure 3. FAA's Airport Arrival Demand Chart (times are GMT)

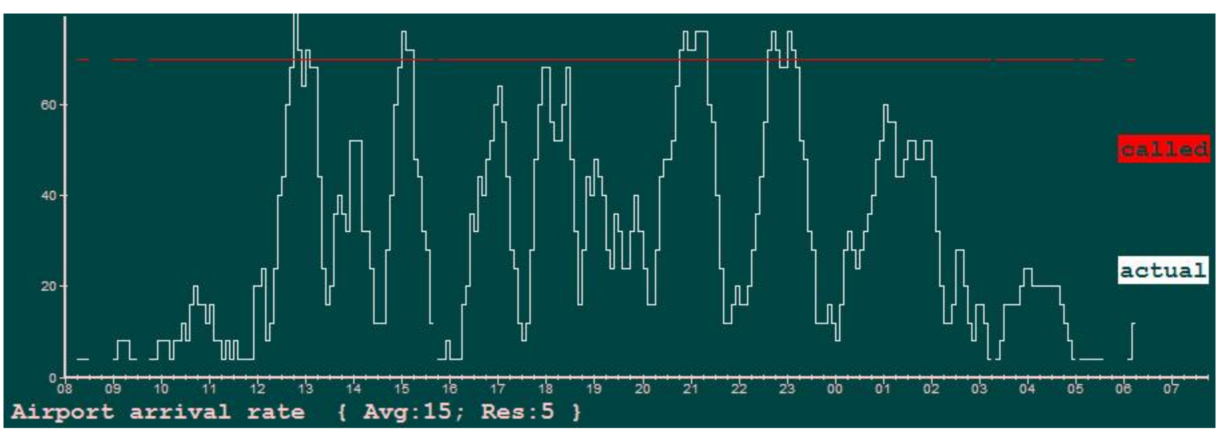

Figure 4. MSP Arrival Rate for a Typical Day

Figure 4provides a plot of MSP's actual arrival by time of day for a "typical" single day. The plot (white line), seen in Figure 4, represents the measured arrival rate. It can be clearly seen that MSP has seven distinct arrival banks distributed throughout the day. The Called Rate, represented by the red line, is also shown in the preceding diagram. Note that the actual arrival rate does occasionally rise higher than the called rate during the arrival banks.

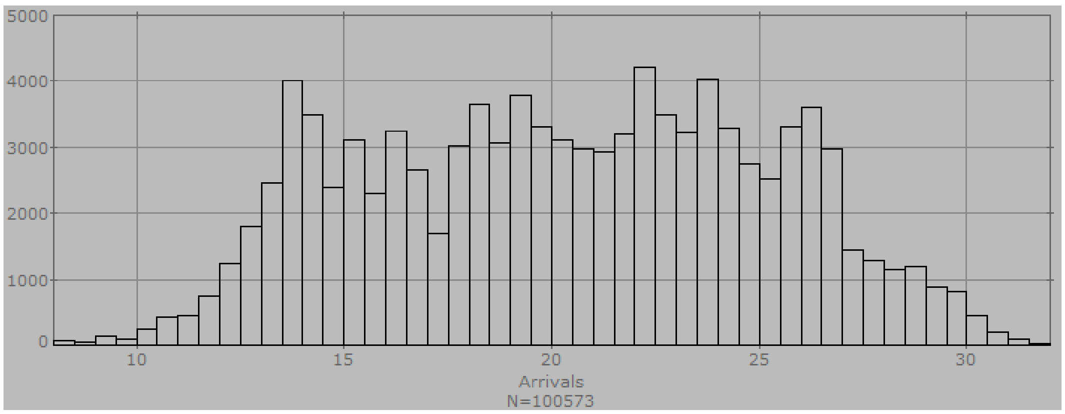

Figure 5. MSP Arrival Timeline for the six month Passive Analysis Period

Figure 5 illustrates the arrival timeline for the entire six-month analysis period. This represents approximately 100,573 arrivals to MSP during the passive analysis period. It shows multiple arrival-banks (i.e., the peaks). Note, however, that the bank structure is not quite as defined as can be seen in Figure 4. This is to be expected, since there is some variation in the time of day when each individual flight arrives and the dataset includes a shift in traffic due to daylight savings time. In other words, when the data set is increased from one day to six months; the variation of the actual arrival time of the individual flight lowers the peaks and increases the valleys.

As concluded in the CLT AAMS Program, the accuracy of the FAA Called Arrival Rate to the actual arrival rate was not quite accurate enough to calculate arrival queues and will not be used in the MSP AAMS Program. As such, as was the case for Delta's ATL AAMS operation, Delta's ATC desk has the responsibility to input the Called Arrival Rate for MSP.

3.1.2 Airport Orientation

The orientation of an airport principally refers to the orientation of the primary runways, which is an important factor during airport planning and design. Ideally, all aircraft operations should be conducted into the wind; however, wind conditions vary with time, thus requiring careful examination of prevailing wind conditions at the airport. This section will provide an overview of the airport configuration, with respect to the airport-centric and airspace-centric variables that plays a role in the analysis of the MSP arrivals.

3.1.3 Direction of Operation

As seen in the Figures 7 and 8 below, the landing direction of the airport's operation is not a constant. The operational landing direction is dependent upon weather events (e.g., wind pattern and storms) that influence which arrival direction air traffic control will use.

For example, Figure 7 provides an example of a day when the airport had an East-arrival flow, and where the two primary East runways (12L and 12R) were used for arrival traffic into the airport.

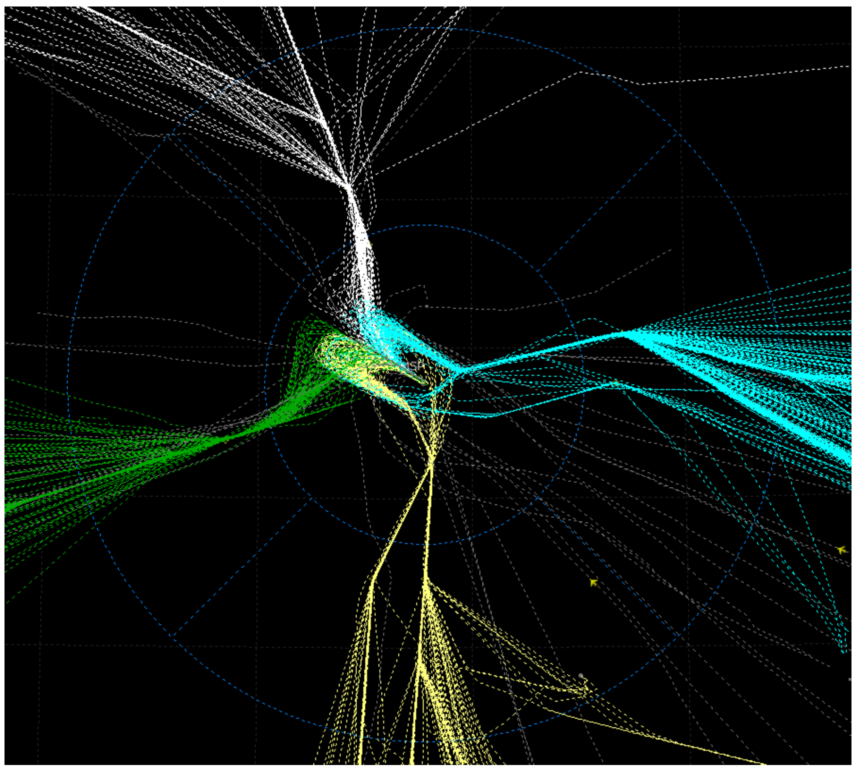

Figure 6. Example of East-Arrival Flow into MSP

Figure 8 provides an example of a day when the airport had a West-arrival flow, and where all west runways (30R, 30L and 35) were used for the arrivals to the airport.

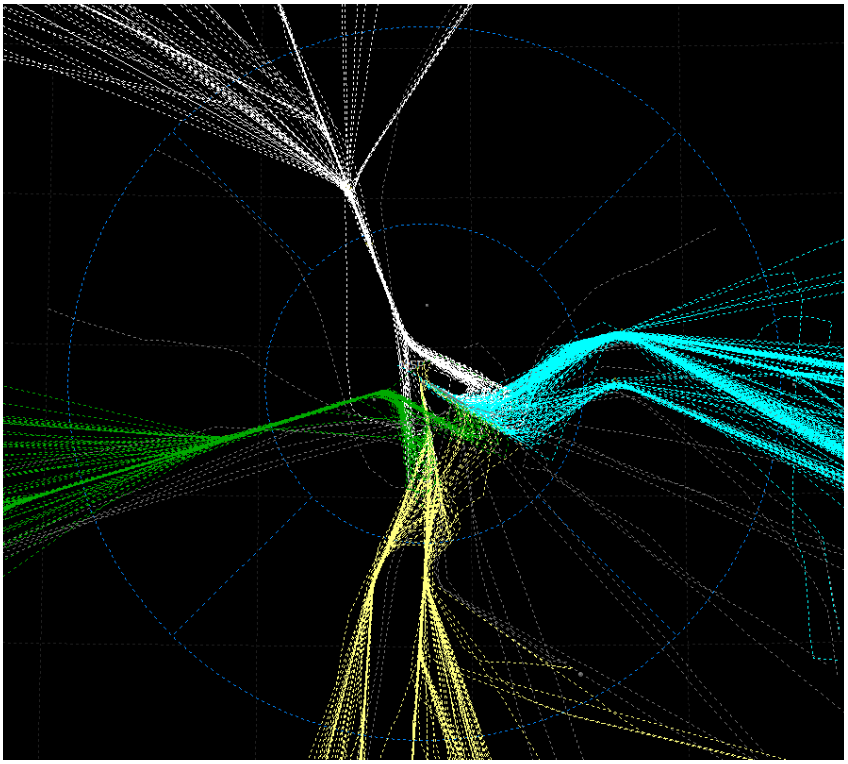

Figure 7. Example of a West-Arrival Flow into MSP

3.1.3.1 Daily Arrival Patterns

As described above, the MSP has primarily an East/West arrival flow.   Figure 8 provides the daily arrival patterns for MSP over the six-month analysis period.

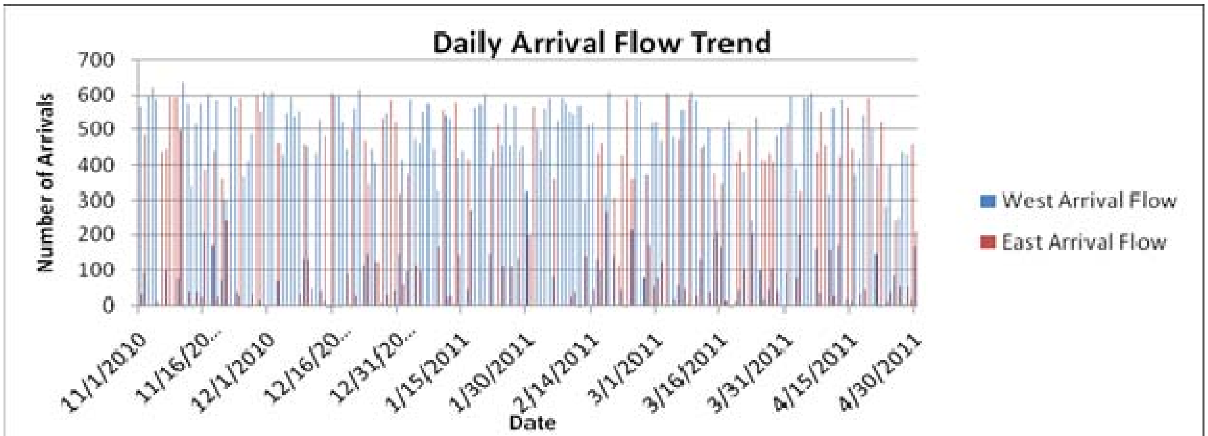

Figure 8. Daily Trends of Arrival Flow Direction

Based on the sample provided in Figure 8, it can be determined that the primary arrival direction of operations is the West orientation. (*Note: Days where there are no East or West arrivals indicate a missing day of data*).

Figure 8 above also shows that for some days the direction of air traffic operation changed during the day, meaning the arrival flow switched from one direction to another, primarily due to a change in the weather pattern.

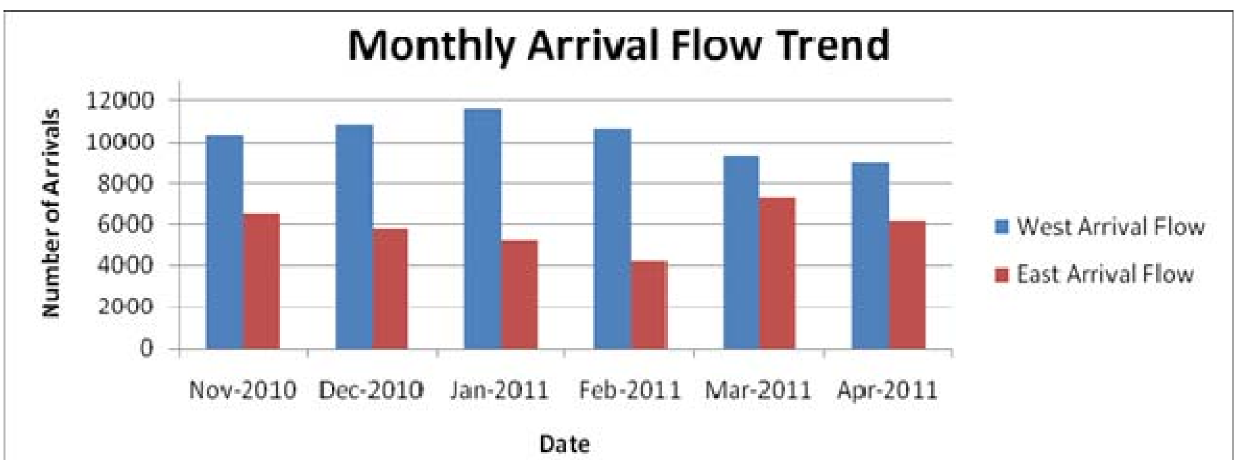

Figure 9. Monthly Trend of Arrival Flow Direction

Figure 9 shows a clearer trend of arrival orientation, when the arrival flow is categorized monthly and plotted respectively. The dominance of the West-arrival flow is more evident in Figure 9 above than from the daily breakdown of the arrival flow direction displayed in Figure 8.

3.1.3.2 Dominant Operation

The results obtained from the six-month analysis of arrivals to the MSP indicated that, despite the fact that the airport has both East and West arrivals; the dominant direction of arrivals to the airport favors the West arrival flow. From the six-month analysis, approximately 64% of arrivals (or 61,539 flights) approached the airport using the West arrival flow.

It is understood that weather is a primary driver in the arrival direction, which can result in a changing operation for a period of time. Figure 10 shows the timeline (throughout a day) of the arrival flow into the MSP (for the entire analysis period), which further demonstrates that the West arrival flow was the dominant operation pattern for the airport during this time period.

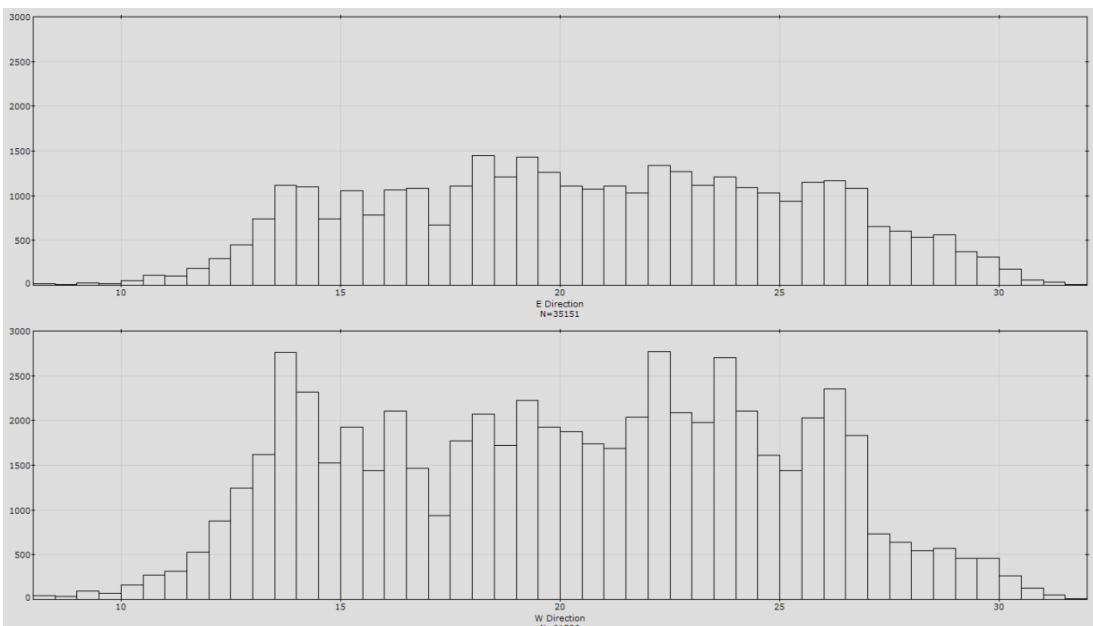

Figure 10. Timeline of Arrival Flow (Top - East arrivals, Bottom - West arrivals)

3.1.4 Arrival Flow Quadrant Definition

The adaptation data of the MSP and airspace characteristics was incorporated into ATH Group's analysis suite. This included the adaptation of the runways, the Standard Instrument Departure (SID) procedures, the Standard Terminal Arrival Routes (STAR), and arrival fixes for the airport.

The airspace around the MSP, shown in Figure 11, was divided into sections known as the inner circle (IN) and the outer circle (OU). The OU was further divided equally into four (4) quadrants, whose areas (for each quadrant) equaled the area occupied by the inner circle (useful for analyzing traffic density). Each of the quadrants roughly captures one of the arrival flows into the airport. The OU's quadrants were labeled N, S, E and W; the quadrants were designed such that each arrival fix was well encapsulated within a quadrant, and each arrival flow did not encroach on an adjacent quadrant.

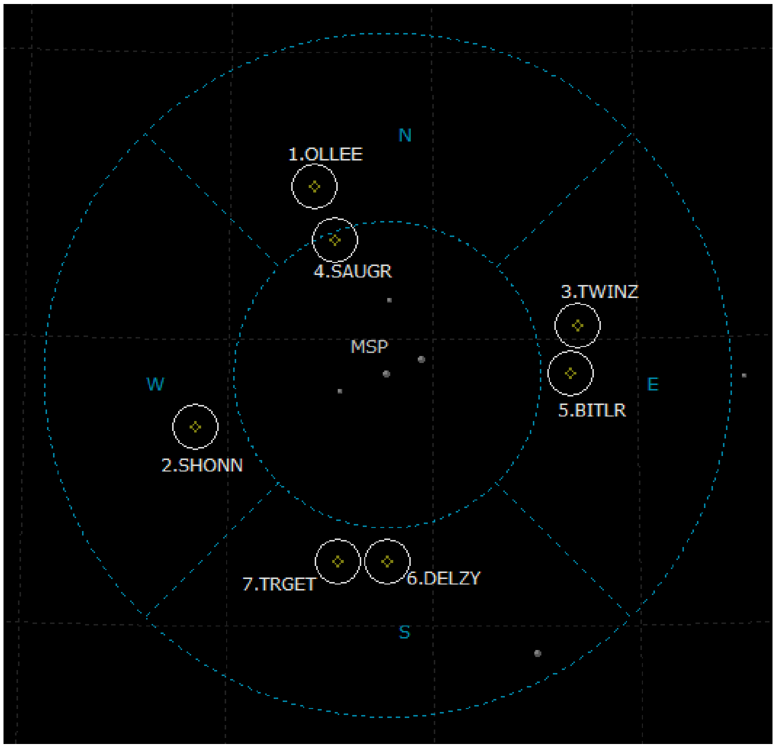

Figure 11. MSP Airspace Quadrants

3.2 Arrival Aircraft Population Breakdown

Once the adaptation was completed, a customized configuration of AwSim™ was setup for the MSP AAMS analysis. This included the definition of metrics that would assist in analyzing the arrival flow into the airport, creating statistics, and analyzing correlations of some of the results.

The metrics defined were divided into two categories: airport centric and airspace centric. These metrics were intended to provide a measurement of how the arrival traffic to MSP flowed on any given day with details for each arrival stream. FAA's ASDI messages were used by ATH's AwTrak™ program to generate flight trajectories. These trajectories were then used by the customized AwSim™ application to perform analysis of the airport's arrival flow.

3.2.1 Airlines

While the MSP serves as a hub for Delta Air Lines and its regional carriers, other airlines also operate at the airport. Table 4 shows the population breakdown of the airlines that operate into MSP.

Table 4. Breakdown of Airline Flights Arriving into MSP

Airline	Count	Share
Delta Air Lines	29,634	27.8%
Mesaba Airlines	17,440	16.4%
Compass Airlines	10,414	9.8%
Pinnacle Airlines	10,357	9.7%
SkyWest Airlines	8,229	7.7%
Southwest Airlines	2,830	2.7%
Sun Country Airlines	2,801	2.6%
Comair	2,113	2.0%
American Airlines	1,751	1.6%
Bemidji Airlines	1,713	1.6%
Express Jet	1,700	1.6%
Shuttle America	1,607	1.5%
United Airlines	1,582	1.5%
US Airways	1,510	1.4%
General Aviation	2,912	2.7%
Other	9,859	9.3%
Total	**106,452**	**100%**

For the six-month passive analysis period, it is clear that Delta Air Lines is the largest carrier of the arrival population into the MSP. This is an important statistic as it shows that Delta Air Lines will provide a significant population to conduct the AAMS operation in MSP.

3.2.2 Aircraft Types

In addition to analyzing the airline population breakdown for arrivals to MSP, the population breakdown of the aircraft types used by Delta Air Lines are summarized in Table 3.

The "Aircraft Type" column gives the indicated International Civil Aviation Organization (ICAO) Type Identifier for the aircraft. From the table, it is again clear that Delta Air Lines uses large jets (with 38% being Airbus, 31% Boeing and 31% McDonnell-Douglas aircraft).

Table 5. Aircraft Type Population Breakdown for Delta Air Lines

Aircraft Type	Count	%
A319	4,772	16.10%
A320	5,847	19.73%
A332	35	0.12%
A333	460	1.55%
DC94	49	0.17%
DC95	2,381	8.03%
MD88	2,110	7.12%
MD90	4,726	15.95%
B737	3	0.01%
B738	2,376	8.02%
B752	4,108	13.86%
B753	2,049	6.91%
B757	1	0.00%
B763	349	1.18%
B764	180	0.61%
B767	1	0.00%
B744	187	0.63%
Delta Total	**29,634**	**100%**

3.2.3 Flight Duration

Flight Duration, one of the airport-centric metrics, provides insight about the duration of flights arriving into MSP. From Figure 11, it is seen that the average flight duration for flights arriving to MSP is approximately 103 minutes. Figure 13 compares the flight durations for all MSP arrivals against those for Delta arrivals.

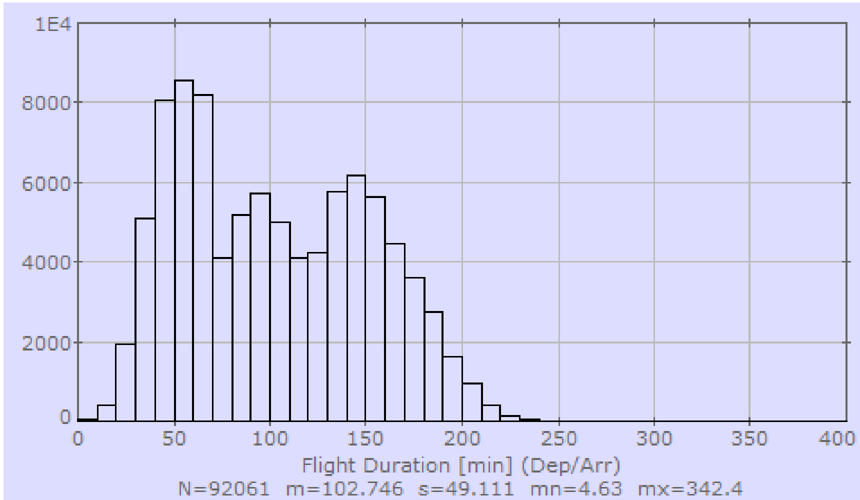

Figure 12. Flight Duration Statistics for Arrivals into MSP

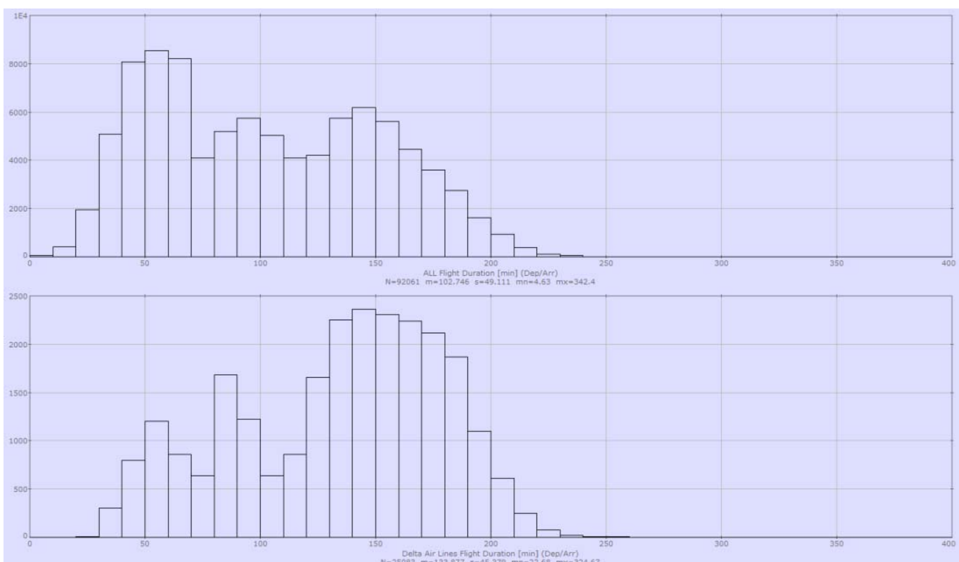

Figure 13. Flight Duration for All arrivals (top) and Delta Air Lines (bottom)

3.3 MSP Dwell Times (Corner post to Touchdown)

"Dwell Time" is a key parameter in configuring the AAMS operation. Dwell time is defined in this study as the flight times from the corner post (arrival fix) to the arrival runway.

3.3.1 Average (Nominal) Corner post to Runway Times for Each Geometry

The average dwell times were calculated for all arrivals into MSP. Figure 14 presents the breakdown of the dwell times, with respect to each corner post through which the aircraft arrival flows approach MSP.

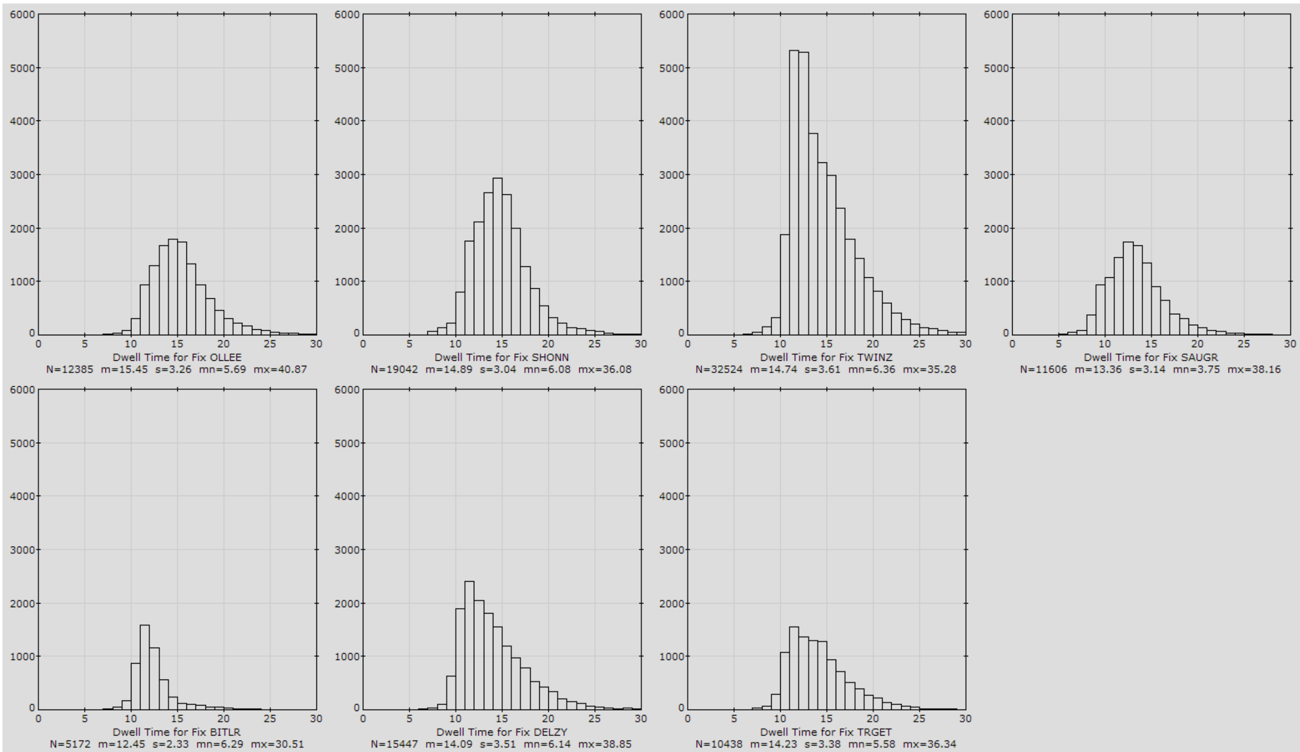

Figure 14 Average Corner Post to Runway Dwell Times

Figure 14 shows that the arrival fixes SHONN (top row, second graph) and TWINZ (top row, third graph) hosts the largest share of the traffic flow to the airport, whereas the arrival fix BITLR (bottom row, first graph) hosts the smallest share of that traffic flow.

The average dwell times from these corner posts are shown in Table 6 while the average dwell times are further divided into East and West arrivals of Delta Air Lines as shown in Table 7 below.

Table 6 Average (Nominal) Dwell Times for Arrivals from Individual Corner Post

Fix Name	Traffic Count for Fix Pass	Average Dwell Time to Arrival (minutes)
TWINZ	31,799	14.76
BITLR	4,644	12.47
DELZY	15,161	14.10
TRGET	10,232	14.24
SHONN	18,706	14.91
OLLEE	11,922	15.42

Table 7. Nominal Corner post to Landing Dwell Times for East/West Arrivals (minutes)

Fix	Traffic count for Fix Pass	Nominal Dwell Time to Arrival	Delta Air Lines	
			Nominal Dwell time (E Arrivals)	Nominal Dwell time (W Arrivals)
TWINZ	31,799	14.76	17.0	13.2
BITLR	4,644	12.47	15.4	12.0
DELZY	15,161	14.10	16.3	12.7
TRGET	10,232	14.24	16.6	13.1
SHONN	18,706	14.91	13.7	15.7
OLLEE	11,922	15.42	14.4	16.3

3.4 Airspace Events

Airspace centric metrics of events that occurred around the airport and surrounding airspaces were also identified.

Figure 15 provides an illustration of the following generated events for the airspace around MSP:

- Airspace Enter events (lime green color) - triggered when aircraft cross a defined airspace boundary, which in this case was either the outer-circle airspace or the inner-circle airspace,
- Cruise End events (gray color) - triggered when the cruise phase of the aircraft ends,
- Arrival Fix Pass events (light green) - triggered when aircraft cross a defined Fix point, which in this case were the arrival fixes defined for the airport,
- Hold Start events (yellow color) - triggered when aircraft vector away from the anticipated travel route, and travel in a defined pattern that categorize the maneuver as Hold,
- Arrivals (cyan color) - triggered when aircraft arrive at the airport.

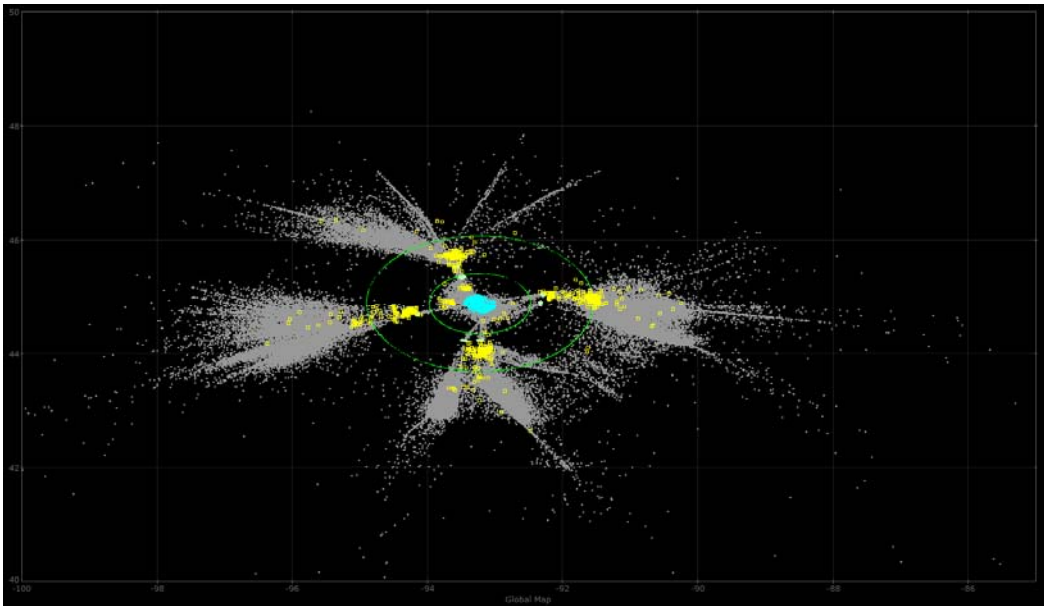

Figure 15. Map of Airspace Events Generated around MSP

From this illustration, it is noted that the majority of the Cruise-End events occur outside of the outer-circle airspace. Furthermore, the majority of the Hold events occur between the outer and inner-circle airspaces, closer to the arrival fixes.

Figure 16 presents a timeline of the events shown in the preceding illustration, color-coded respectively to the corresponding event. Each chart in Figure 17 shows the number of flights (vertical axis) in each hour of the day over a 30 hour period (horizontal axis). The data set is for the period between November 7, 2010 and March 13, 2011.

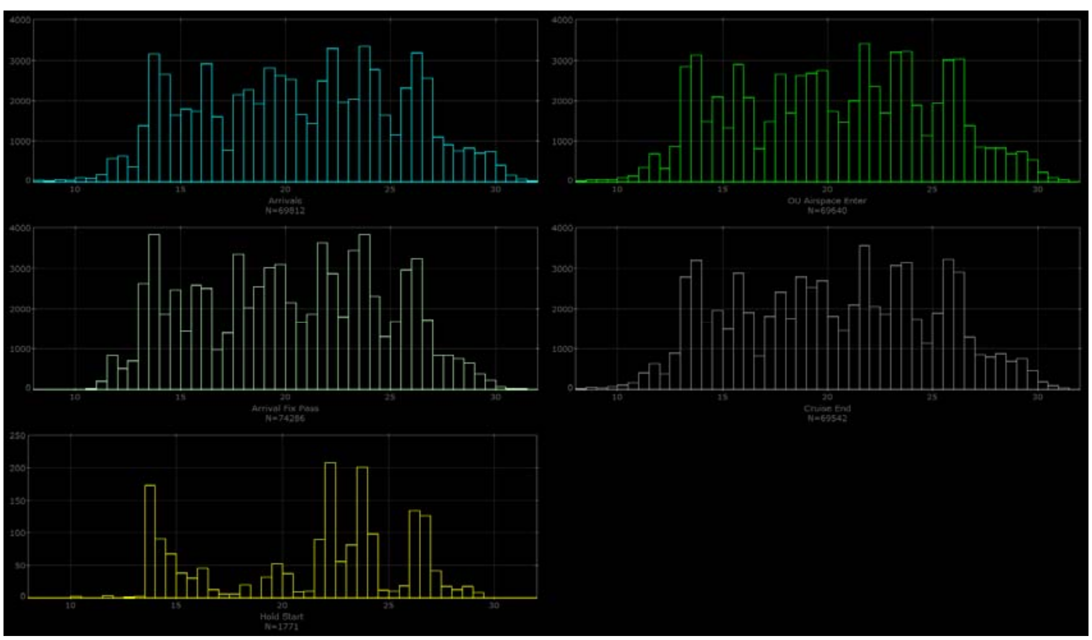

Figure 16. Timeline of Airspace Events Generated around MSP

The previous illustration highlights some important observations about the events generated during the analysis of the MSP, including:

- There are two distinct peaks of holds (yellow chart, bottom left) that occur for the arrival flow: one during the morning rush hour, and the other during the evening rush hour, as shown in Figure 16 above.
- The Arrival Fix Pass events (light green, middle left) occur in waves, spaced out every 90 - 120 minutes.
- The Outer Airspace Entry event (lime green, top right) almost follows the same pattern as the Arrival events. This is because most of the flights that enter the outer airspace, after a given period of time, arrive at the airport thus generating an Arrival event.

3.4.1 Arrival Event Timelines

Figure 17 describes the arrival events that are generated once a trajectory has ended at the arrival airport, or close to the airport (within a given tolerance). Each chart shows the number of flights (vertical axis) in each hour of the day over a 30 hour period (horizontal axis). The figure shows the arrival timelines of all arrivals (top), and Delta Air Lines (bottom).

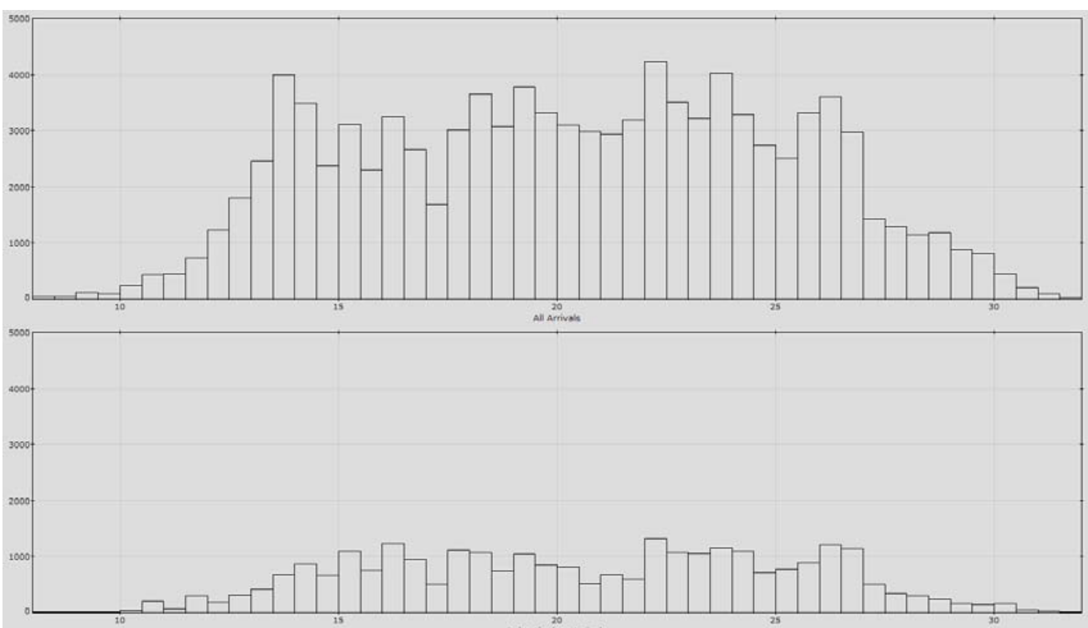

Figure 17. Arrival Timelines for MSP

3.5 Data Correlations

3.5.1 Arrival Rate vs. Dwell Time Correlation

The relationship of the arrival rate to the dwell time for each corner post is shown in the Figures 18 through 25. For each figure, the horizontal axis is the arrival rate, while the vertical axis is the dwell time (time from corner post to landing).

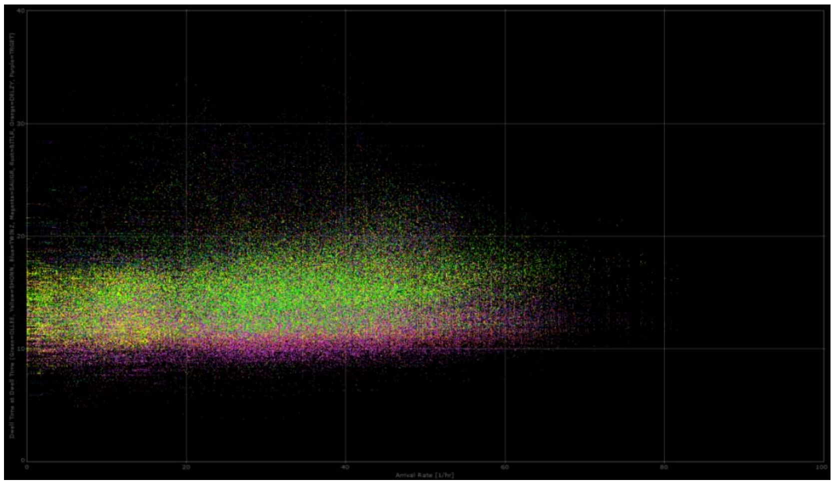

Figure 18. Correlation of Arrival Rate to Fix-Pass Dwell Time (Color Legend: Green=OLLEE, Yellow=SHONN, Blue=TWINZ, Magenta=SAUGR, Rust=BITLR, Orange=DELZY, Purple=TRGET)

In Figure 18 it appears that as the rate increases the dwell time also increases. This can be seen more clearly by observing the individual trend lines for each corner post. The subsequent figures show that all of the corner posts have relatively strong correlations between the arrival rate and the dwell time.

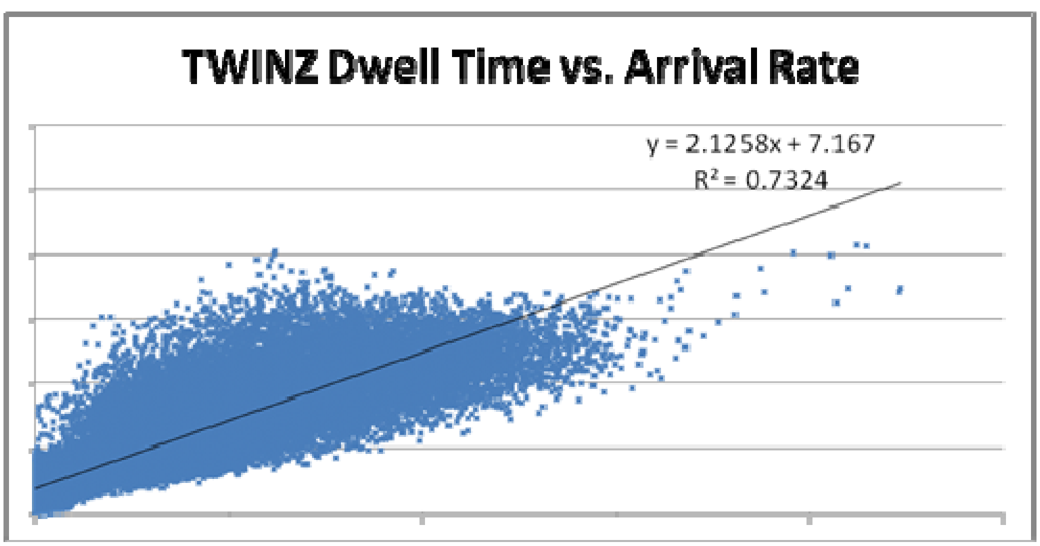

Figure 19. Correlation of Arrival Rate to TWINZ Dwell Time

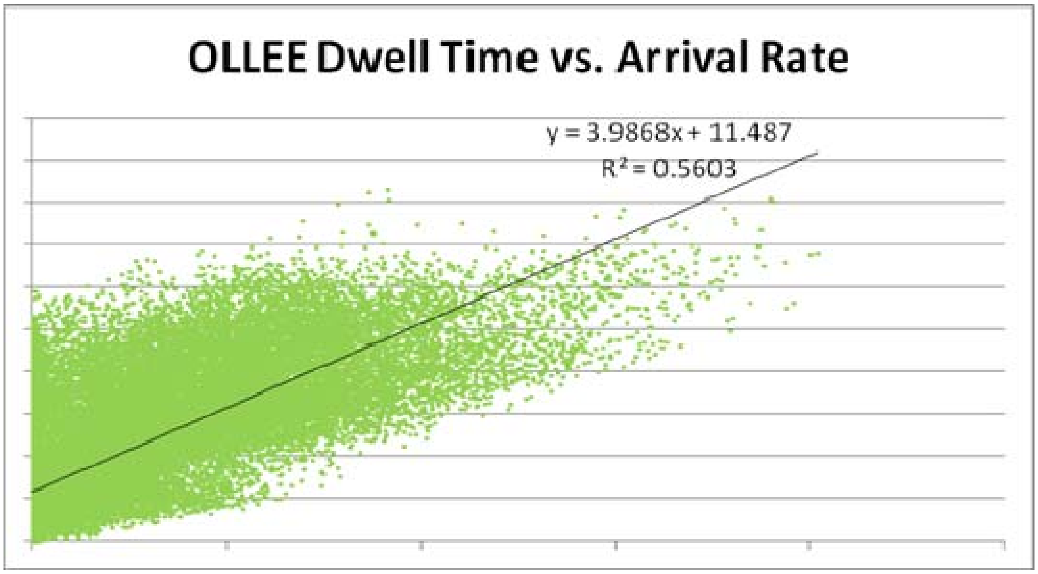

Figure 20. Correlation of Arrival Rate to OLLEE Dwell Time

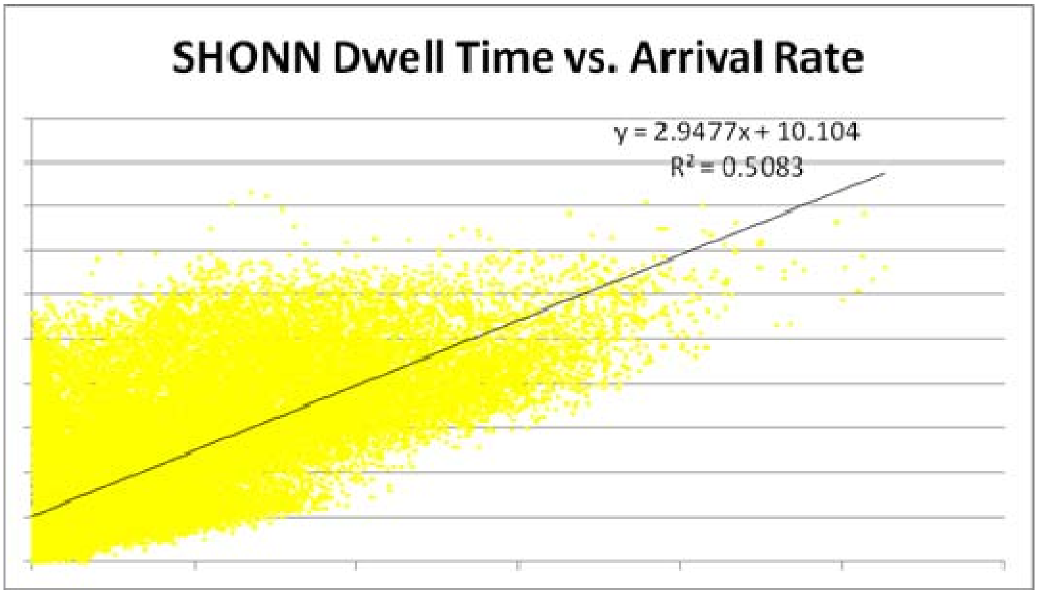

Figure 21. Correlation of Arrival rate to SHONN Dwell Time

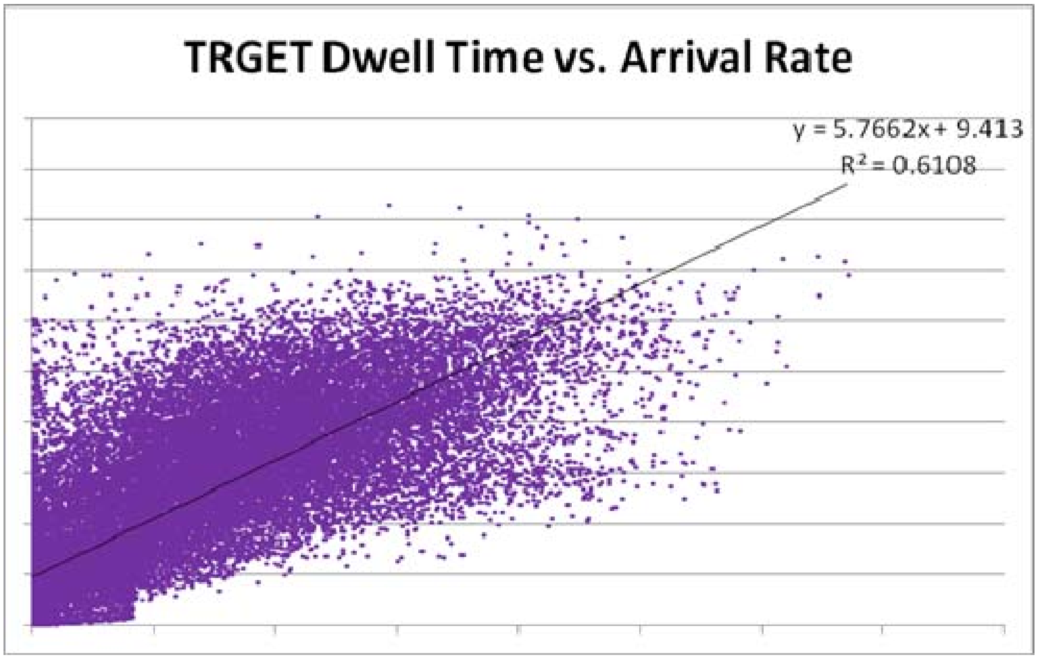

Figure 22. Correlation of Arrival Rate to TRGET Dwell Time

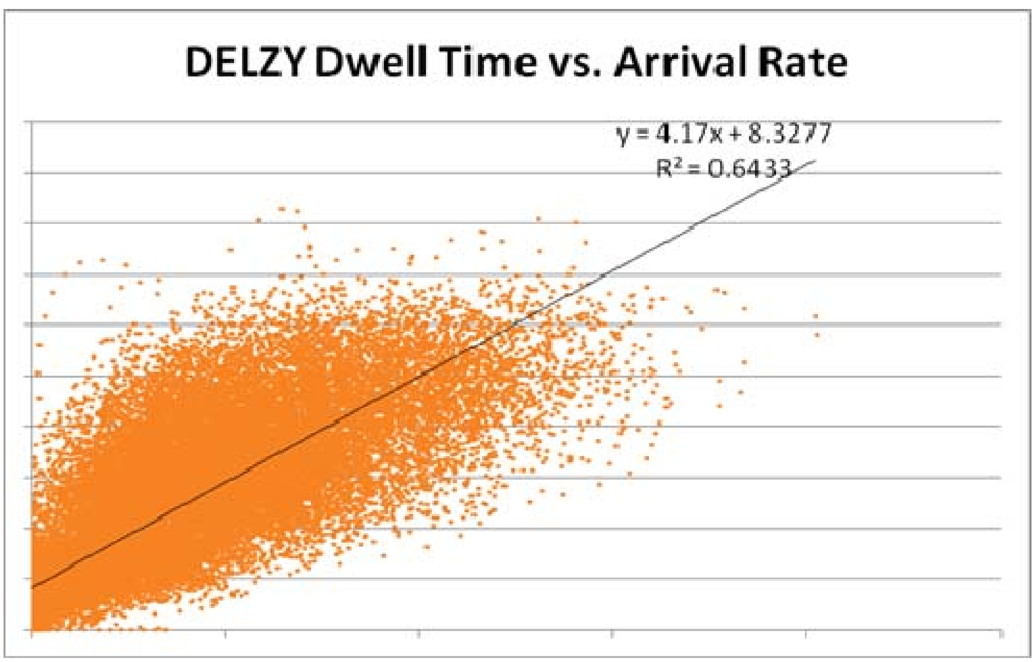

Figure 23. Correlation of Arrival Rate to DELZY Dwell Time

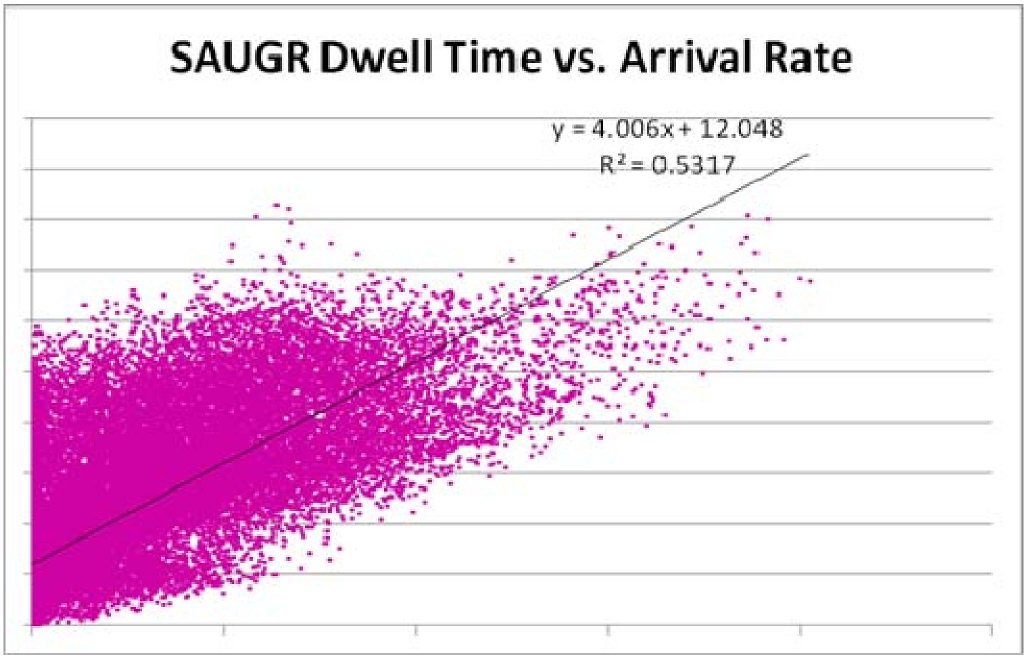

Figure 24. Correlation of Arrival Rate to SAUGR Dwell Time

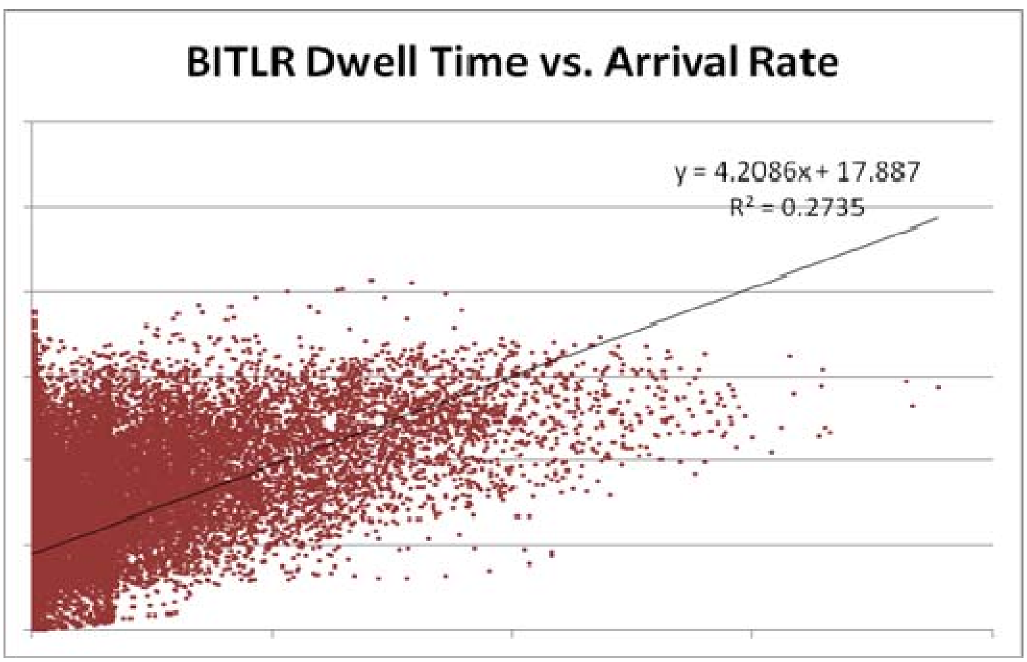

Figure 25. Correlation of Arrival Rate to BITLR Dwell Time

3.5.2 Correlations to Outer Ring (OU) Entry Time

The following set of four timeline charts in Figure 28 indicates the following:

- The outer ring (OU) entry rate against the outer ring entry time (top), which clearly shows the seven distinct arrivals banks. There are two separate datasets observed, one during daylight savings time (November 1-6, 2010 and March 13-April 30, 2011), and another (the majority) period when daylight savings time ended (November 7, 2010 to March 12, 2011).
- The arrival fix pass rate against the entry time (second), which shows some distinct arrival banks but more importantly, shows a uniform conformance followed by the majority of the population. As with the earlier case, there are two separate datasets observed, one during daylight savings time (November 1-6, 2010 and March 13-April 30, 2011), and another (the majority) period when daylight savings time ended (November 7, 2010 to March 12, 2011).
- The runway arrival rate as it relates to the OU entry time (third), and
- The excess distance (NM) within the OU as it relates to the OU entry time.

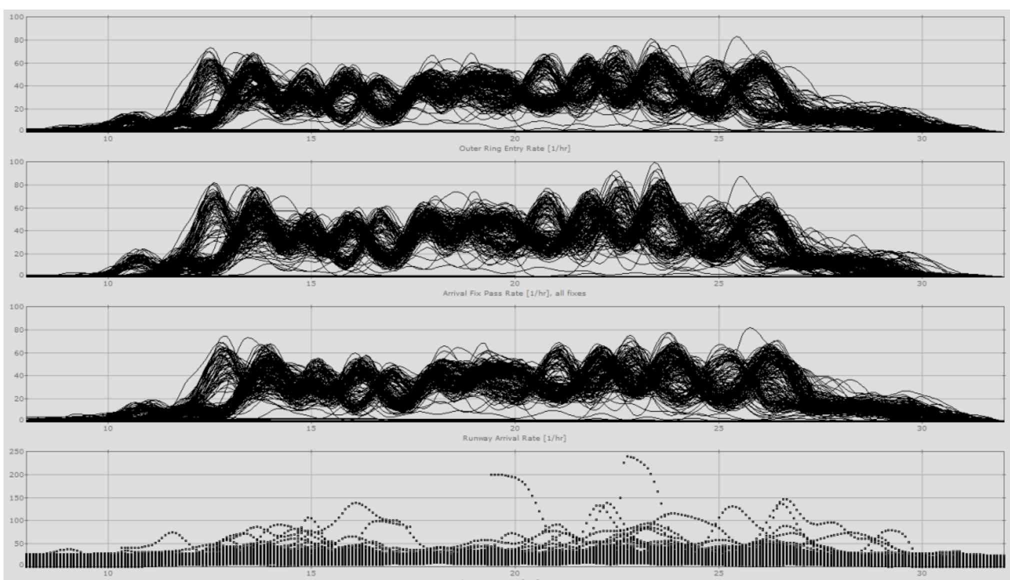

Figure 26. Correlation of the OU Entry Rate, Arrival Fix Pass Rate, Runway Arrival Rate and Excess Distance to the OU Entry Time (for the entire Passive-period)

When looking at just one period or the other (i.e., when DST has ended or started) a more uniform pattern amongst daily operation is noticed, as depicted in Figure 27.

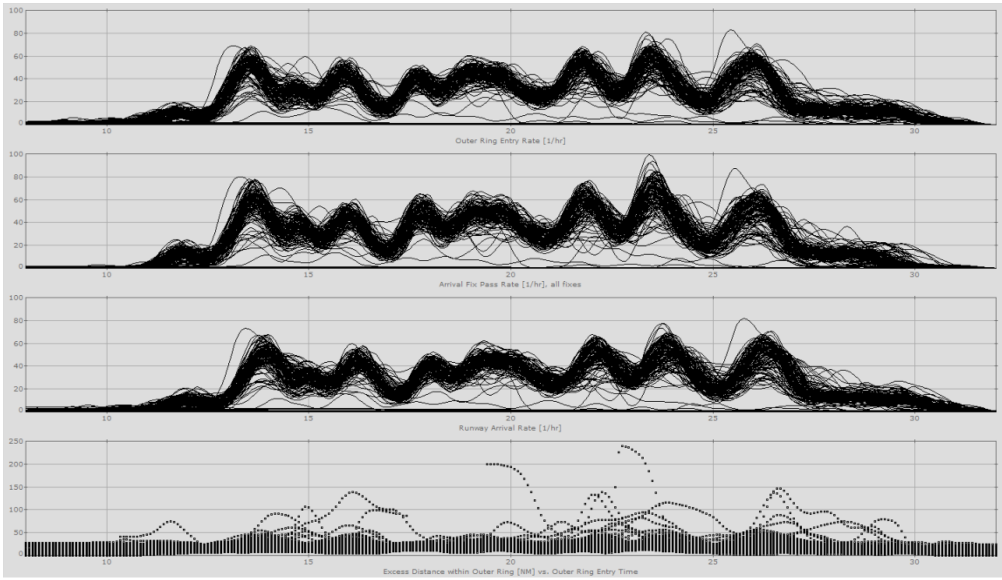

Figure 27. Correlation of the OU Entry Rate, Arrival Fix Pass Rate, Runway Arrival Rate and Excess Distance to the OU Entry Time (for period when DST ended: Nov.7, 2010 - Mar.12, 2011)

Figures 28 and 29 provide the following:

- The excess distance within the outer-ring against the outer-ring entry time (below)
- The outer ring entry rate (page 43).

Examining the two timelines, a clear relationship exists between entry rate and excess distance. One interesting exception is in the first bank which has a relatively low entry rate but has the highest excess distance. This is a result of noise and runway restrictions during the early morning hours.

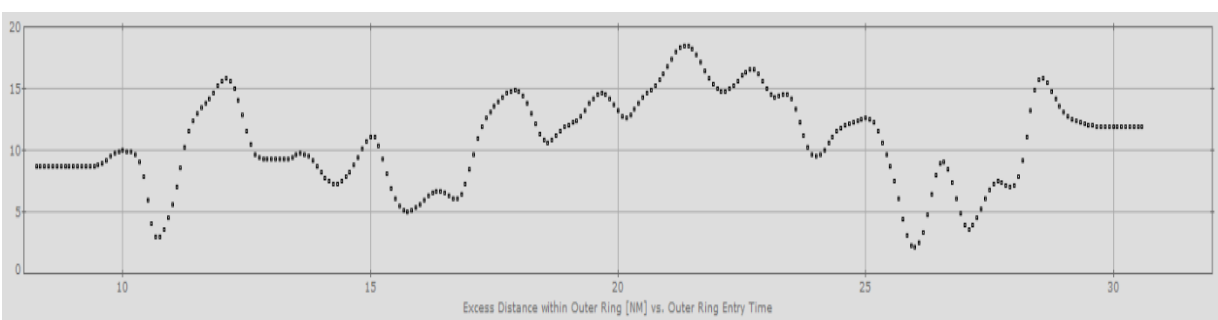

Figure 28. Correlation of Excess Distance within the Outer-Ring to the OU Entry Time (for a single day)

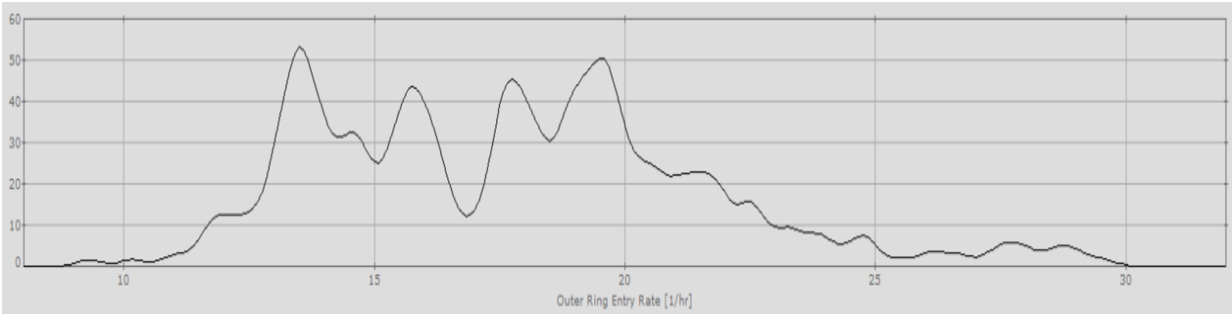

Figure 29. OU Entry Rate (for a single day)

4 TEST DESCRIPTION

4.1.1 AAMS Data

There are three main types of data files generated by the AAMS operational software that are used for statistical purposes:

- .atx - this file contains a record for each completed flight containing event time and other data on the flight. The file is a text file that can be imported into a spreadsheet or database.
- .stl - this file contains a status log of AAMS operations, it records when RTA generation was on or off, changes in airport arrival rate and in airport configuration.
- .trj - this file contains the as flown trajectories, recorded when the flight has been completed.

The .atx and .stl file are used by the AAMS statistic program to generate the daily statistics. The definition of the data fields in these two files are provided in this document.

The .trj file is used by AViD to visualize the flown traffic for a day and also by FlightScope™ in doing -day analysis. The .trj content is defined in the AwSim™ Data File Standards (A-REF-046) document.

Each of the files is written as a serial numbered file, with the file closed out at the end of the day (this is defined by an initialization parameter as eight hours after midnight GMT). Until the file is closed out, the file type has an underscore character (_) appended to it to indicate it is still an open file.

After the day is closed out, the archiving program runs and merges (if there are multiple files in the day due to a restart) and puts the files into a daily directory with the file name for each of the files being YYMMDD.

Additional Information about the AAMS data can be found in the AAMS MSP Data Collection and Test Plan document.

4.1.2 Non-AAMS Data

In addition to the data collected through the AAMS the following have also contributed to the analysis:

- TMA operation status records from the FAA to allow an analysis of any conflicts or synergies between TMA and AAMS system operations
- NOTAM data concerning runway closures obtained from Minneapolis St. Paul Metropolitan Airports Commission (MSP MAC)
- Trip Fuel consumption provided by Delta Air Lines
- A log of software, goal function, or any other system related changes implemented during the Active and Passive Periods provisioned by ATH
- Scheduled and Actual Departure and Arrival Times furnished by Delta Air Lines
- Scheduled and Actual Taxi-In and Taxi-Out Times provided by Delta Air Lines

The MSP Runway NOTAMs and TMA records were used to partition the AAMS data sets for more thorough analysis of the interactions of AAMS with these related events.

4.2 Passive Phase

In the Passive Phase, the optimal RTAs were calculated by the AAMS application. However, since the Passive Phase was an offline analysis using recorded data, the calculated RTAs were not sent to the aircraft. This was to ensure that the system algorithm is properly calibrated for MSP's operations.

Once the system was properly calibrated, the benefits measured during the system's passive evaluation are near zero on average over the six-month Passive Phase from November 1, 2010 through April 30, 2011.

The purpose of collecting the data in the passive mode was to provide the information necessary to create the baseline model for MSP. The Passive Phase data was to be compiled and made available to ERAU by November 30, 2011.

The steps to accomplish this included:

1. Importing the necessary data into the system software (Class I or II ASDI data, winds, schedule, runway direction, FAA called landing rate, Delta Air Lines Goal Function),
2. Calculating the RTA,
3. Not sending the RTA to the aircraft,
4. Measuring the benefits using AST.

A graphical overview of the data capture in the AAMS is provided in Figure 30.

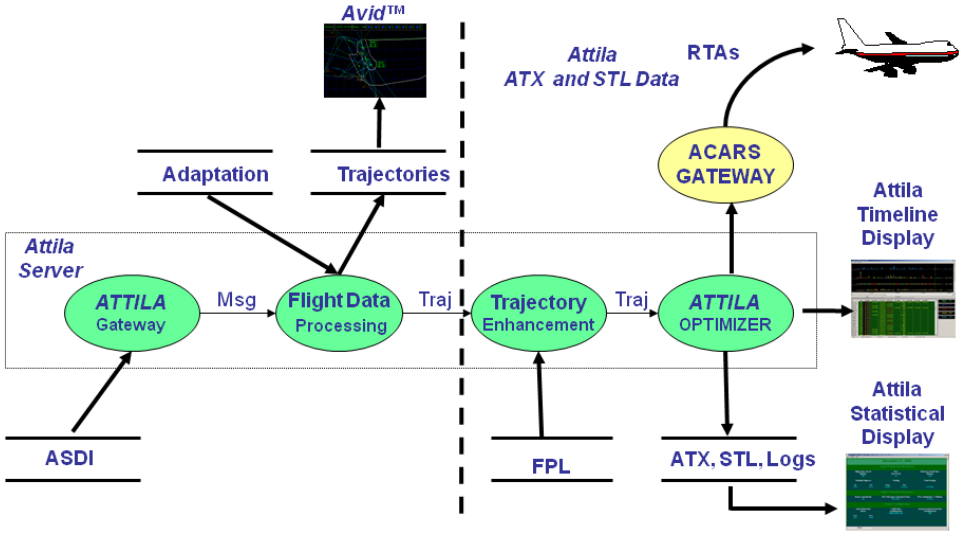

Figure 30. AAMS Data Capture Partition

4.3 Active Phase

During the Active Phase the AAMS software calculated the optimal RTAs. Differing from the Passive Phase, in the Active Phase RTAs were uplinked to the participating Delta aircraft. The designation of the aircraft (tail number) and the ACARS messaging capability was provided by Delta. The Active Phase operation was November 1, 2011 to April 30, 2012.

It is expected that if the system worked as designed and the pilots met the assigned RTAs, then the AAMS benefits should become apparent when compared to the Passive Phase.

The steps to accomplish this included:

1. Importing the necessary data into the system software (Class I ASDI data, winds, schedule, runway direction, FAA called landing rate, Delta Air Lines Goal Function),
2. Calculating the RTA,
3. Sending the RTA to the aircraft,
4. Measuring benefits using the AST.

5 PERFORMANCE ANALYSIS

5.1 AAMS Passive Period Performance

This section describes the results of the statistical analysis of the data collected during the passive period at MSP, and thereby establishes the baseline for future benefit calculations. Data from the implementation of active AAMS was benchmarked against this baseline.

The baseline statistical information is presented in the following sections. Each variable is presented with an actual distribution histogram as well as a best-fit theoretical distribution. Along with the histograms, mean, standard deviation, range, and other descriptive statistical information are provided. Changes to the distributions would afford further insights into the impact of AAMS in the data.

5.1.1 Data Collection Time Frame

The Passive Phase data collection occurred between November 1, 2010 and April 30, 2011. Recorded data for this period was processed by the AAMS; however, RTA messages were not issued as part of the Passive Phase benchmarking.

5.1.2 Descriptive Statistics of the Sample

Figure 32 provides a visual overview of the data used in the analysis. In the 105,630 arriving flight records 73% belong to Delta Air Lines flights and 27% represent flights by non-participating carriers and general aviation activity. Additionally, this traffic was distributed across six corner posts at MSP: SHONN, OLLEE, DELZY, TRGET, TWINZ, and BITLR with 20%, 13%, 16%, 11%, 35%, and 5% of the recordings, respectively. The arrivals were also configured from the East in 38% of the records and 62% from the West. TMA metering is indicated as having been active for 96% of the recorded flights. Eighty-one percent (81%) of flights arrived while all runways were open. Representative days where 70% or more of arriving participating carrier flights were completed within 15 minutes of their scheduled arrival time (A14) comprise 82% of the flights in the data.

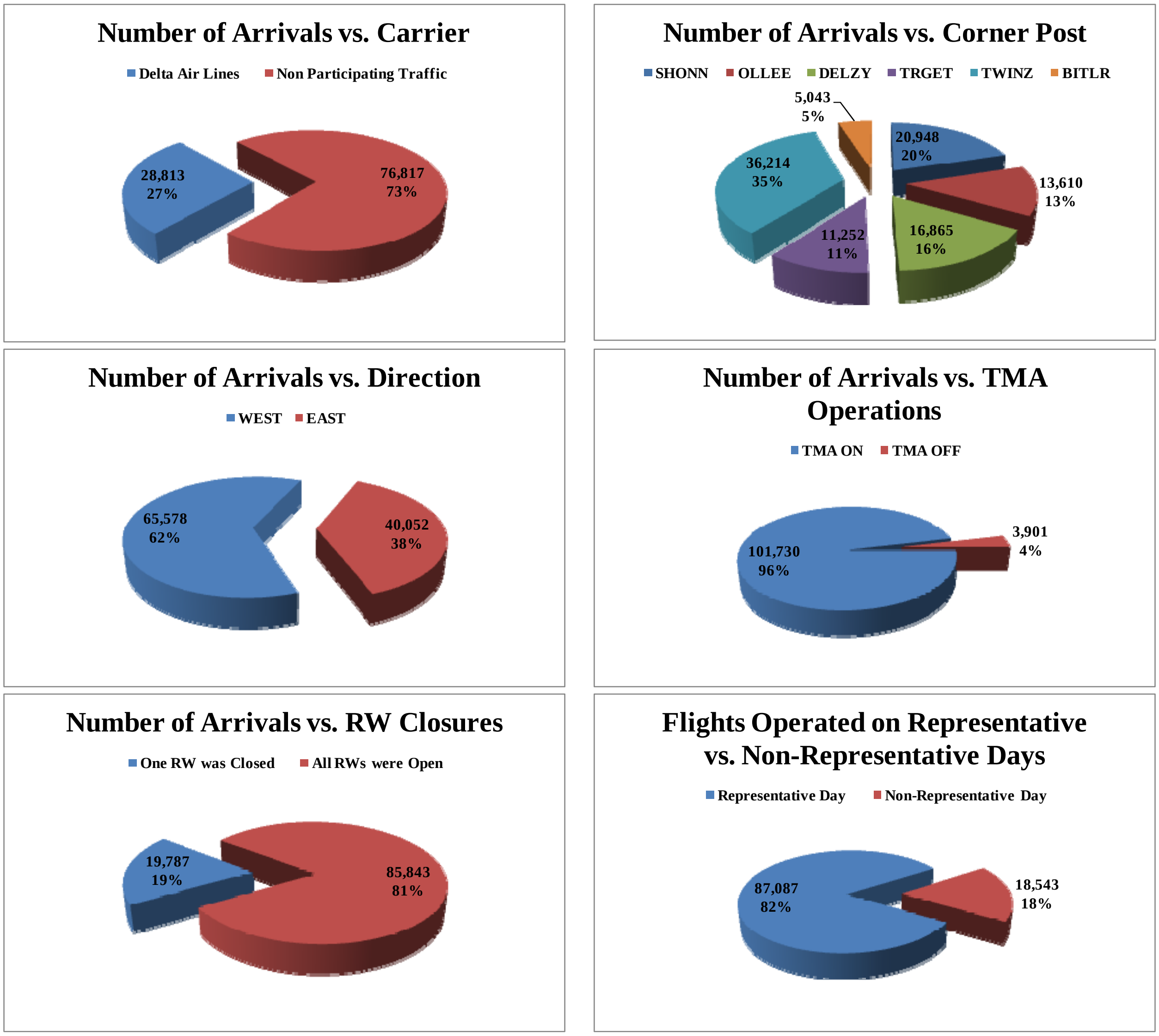

Figure 31. Passive Phase Data Description and Distribution

5.1.3 Data Summary

5.1.3.1 Validation of ATH data

The data sets from Delta and ATH were matched and compared for verification. Figure 32 provides the distribution of the differences between the two sources for wheels-off times. This shows that on average Delta's timestamps were 33 seconds earlier than ATH's. Ninety-percent (90%) of the differences were ATH lagging behind Delta's times by zero to 60 seconds.

Similarly, Figure 33 gives the average difference as Delta's wheels-on times being 30 seconds earlier than ATH's times. For this set, 90% of the differences were between Delta being ahead of ATH by 61 seconds and ATH being ahead by 2 seconds.

The "lag" in the ATH values attributable to Delta's numbers being captured by Aircraft Communications Addressing and Reporting System (ACARS) messages while ATH uses the Aircraft situational Display to Industry (ASDI) feed for its data.

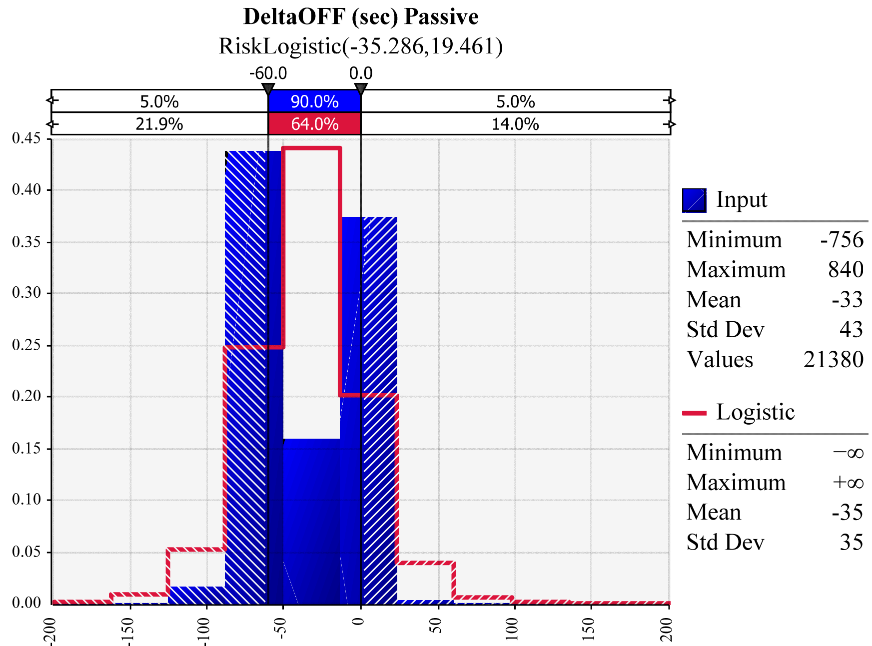

Figure 32. Distribution of the difference between wheels-off times of Delta and ATH (seconds)

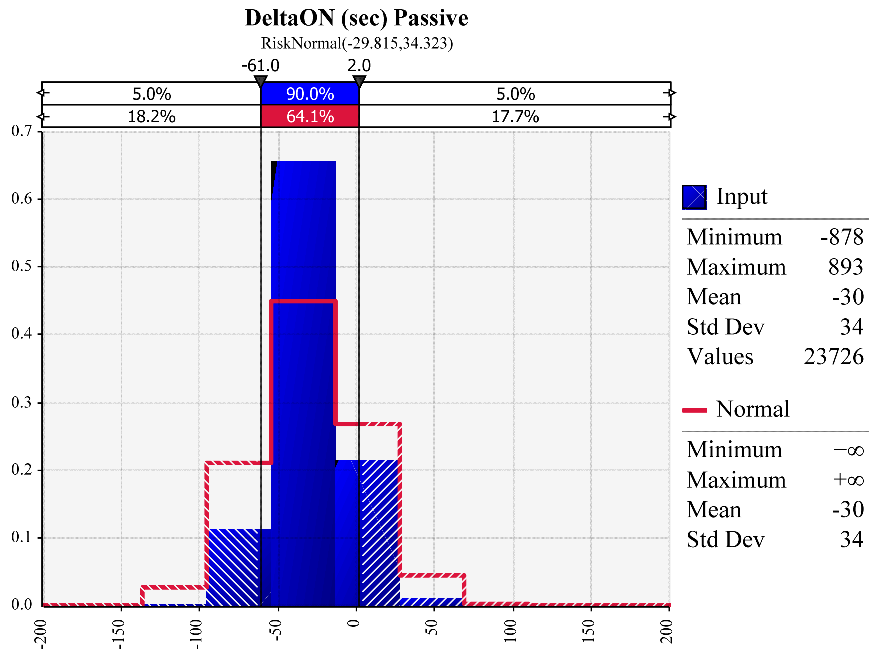

Figure 33. Distribution of the difference between the wheels-on time between Delta and ATH (seconds)

5.1.3.2 On-Time Arrival Performance

Figures 34 and 35 provide the distributions of the differences between the observed and scheduled arrival times for Delta Air Lines flights against zero- and fourteen-minute tolerances (A0 and A14, respectively).

During the passive observation period Delta flights were observed to have operated 64.9% A0 on-time and 86.8% A14 on-time. The arrival schedule performance was also evaluated using data provided by ATH in Figures 36 and 37.

In the ATH data set the performance numbers are observed to be very similar to Delta's with 59.5% of flights arriving on or before schedule with zero-minute tolerance and 79.5% arriving with a 14-minute tolerance.

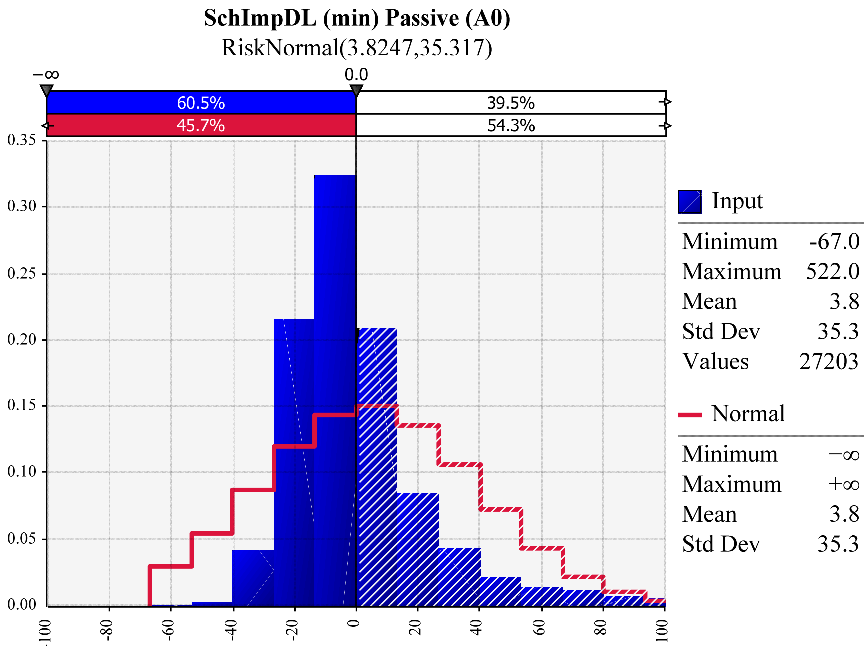

Figure 34. Distribution of the difference between actual and scheduled arrival times for Delta flights (0 minutes tolerance)

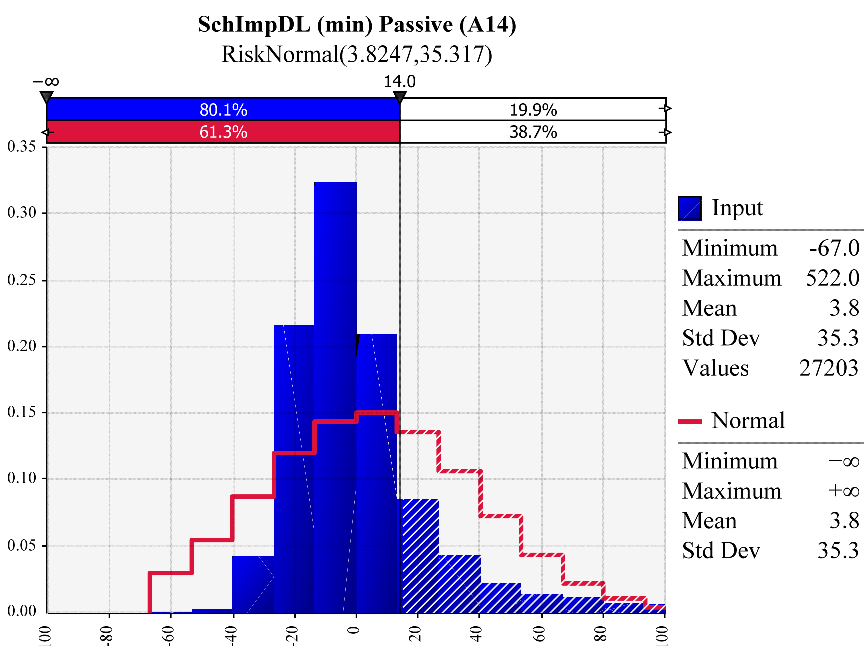

Figure 35. Distribution of the difference between the actual and scheduled arrival times for Delta flights (14 minutes tolerance)

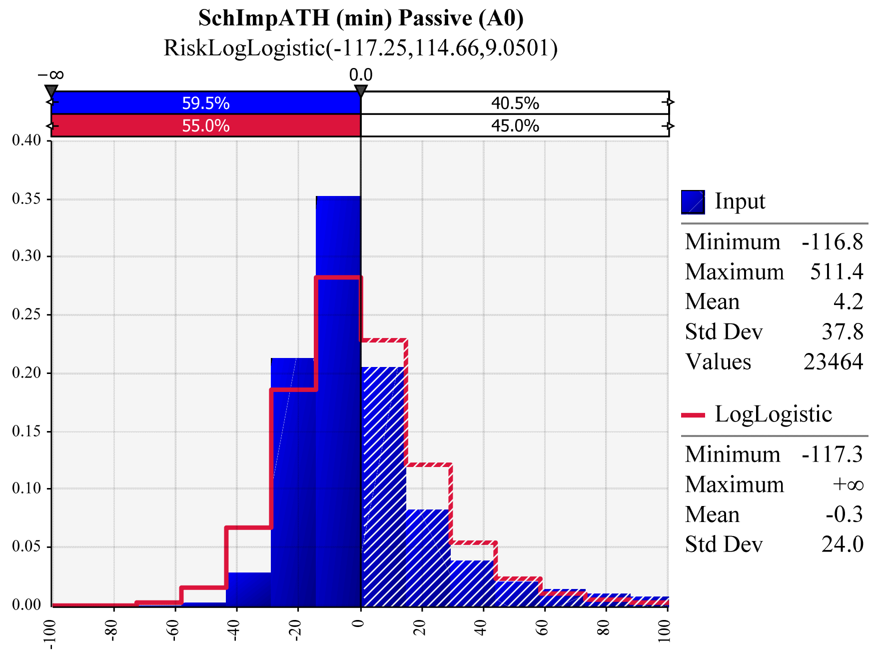

Figure 36. Distribution of the difference between the actual and scheduled arrival times for ATH data (0 minutes tolerance)

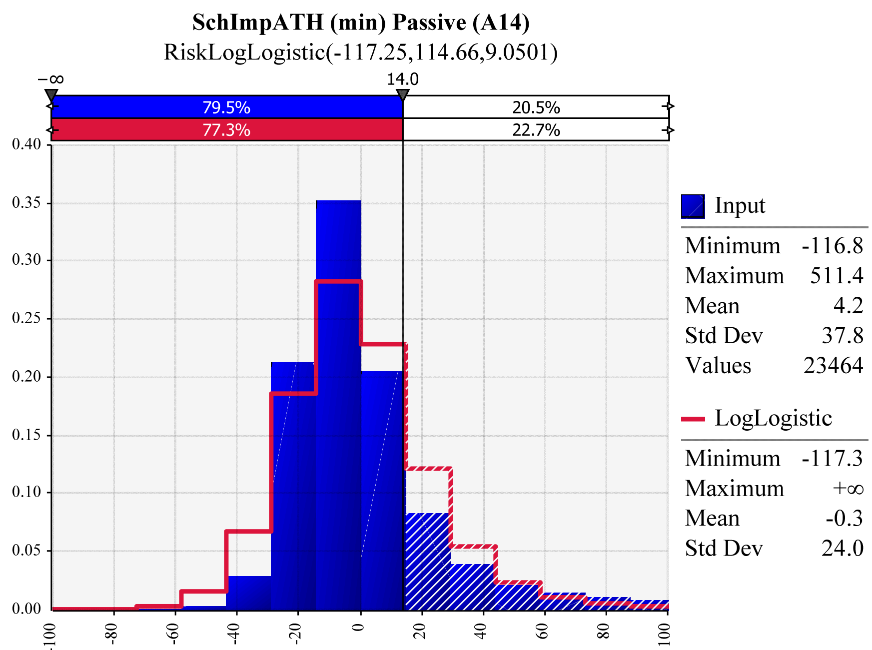

Figure 37. Distribution of the difference between the actual and scheduled arrival times for ATH data (14 minutes tolerance)

5.1.3.3 Taxi-In and Taxi-Out Performance

In order to facilitate future assessments of AAMS impact on taxi times, actual taxi-in and taxi-out times have been compared to scheduled times. Figure 38 and Figure 39 provide the distributions for these two comparisons. In these data sets, only participating carrier (Delta Air Lines) flights are available and show actual taxi-in times were within scheduled times in 68.5% of cases while actual taxi-out times within scheduled times in 71.9% of cases.

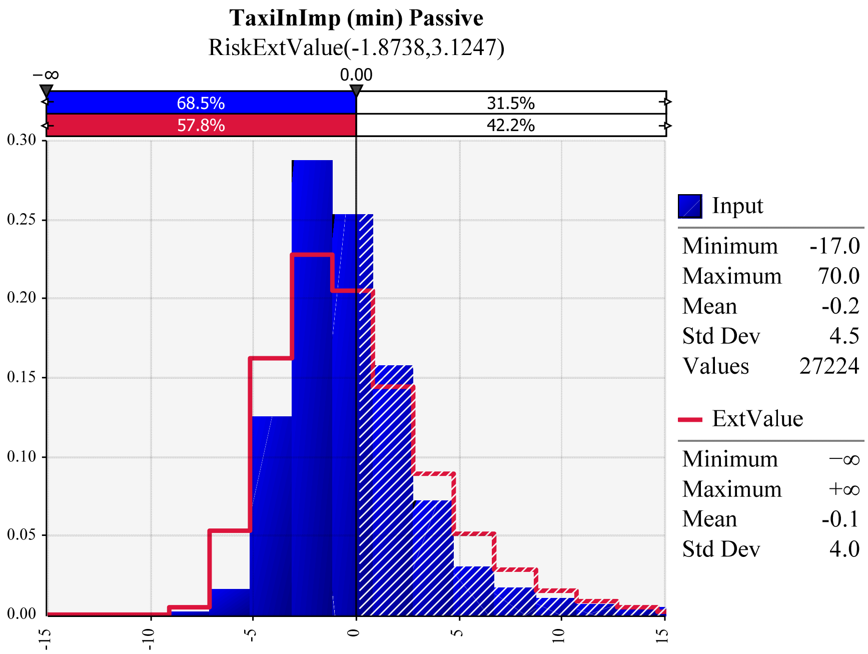

Figure 38. Distribution of the difference between actual and scheduled taxi-in time (minutes)

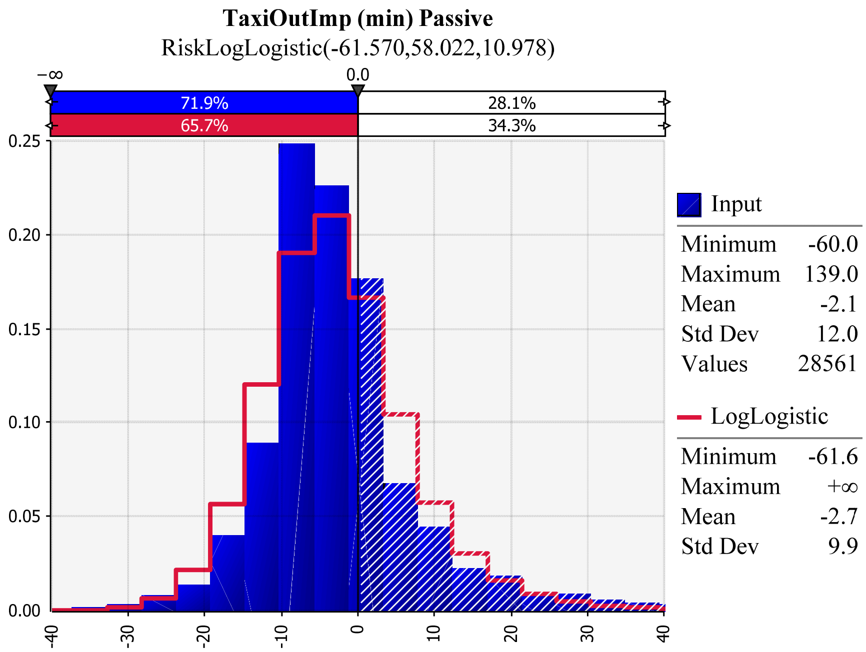

Figure 39. Distribution of the difference between actual and scheduled taxi-out time (minutes)

5.1.3.4 Total Flight Times and Total Fuel Burned

While the majority of factors that impact total flight times and total fuel burn are outside AAMS control, an assessment may assist in AAMS benefit estimations and validate expected reductions in "dwell" times and fuel consumption. This section presents the baseline estimates for flight times for all arriving flights using Delta Air Lines and ATH data and total fuel consumed for Delta flights. Figures 40 and 41 present the total travel times and Figure 42 presents the total fuel consumed.

Ninety-percent (90%) of Delta flights to MSP had travel times between 50 and 222 minutes with an average time of 148 minutes. Average fuel consumption of these flights during the passive period was 10,140 pounds. Furthermore, 90% of flight arriving at MSP traveled between 36 and 186 minutes with an average of 103 minutes.

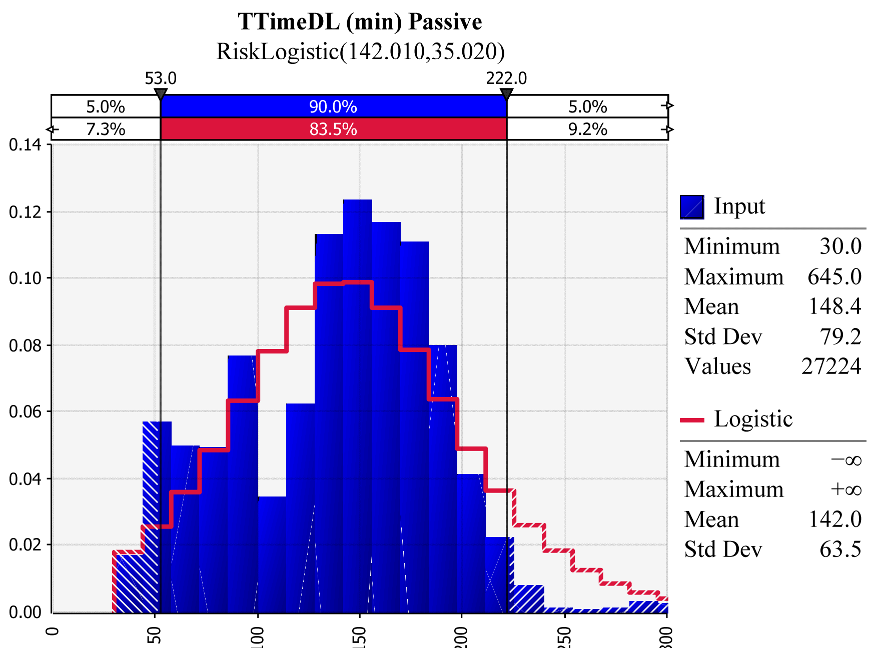

Figure 40. Distribution of the flight travel times for Delta Air Lines flights (minutes)

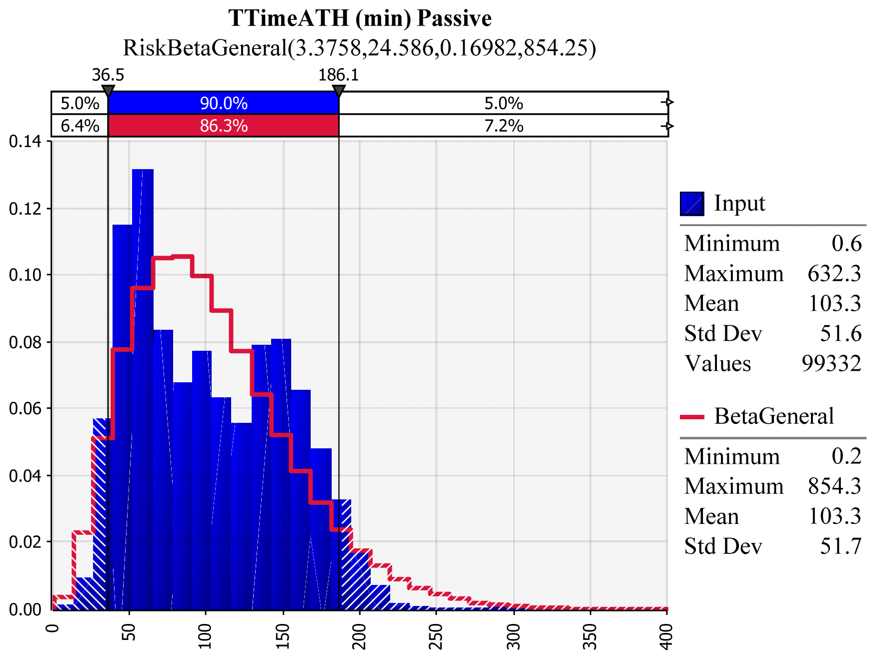

Figure 41. Distribution of the flights travel times for all MSP traffic (minutes)

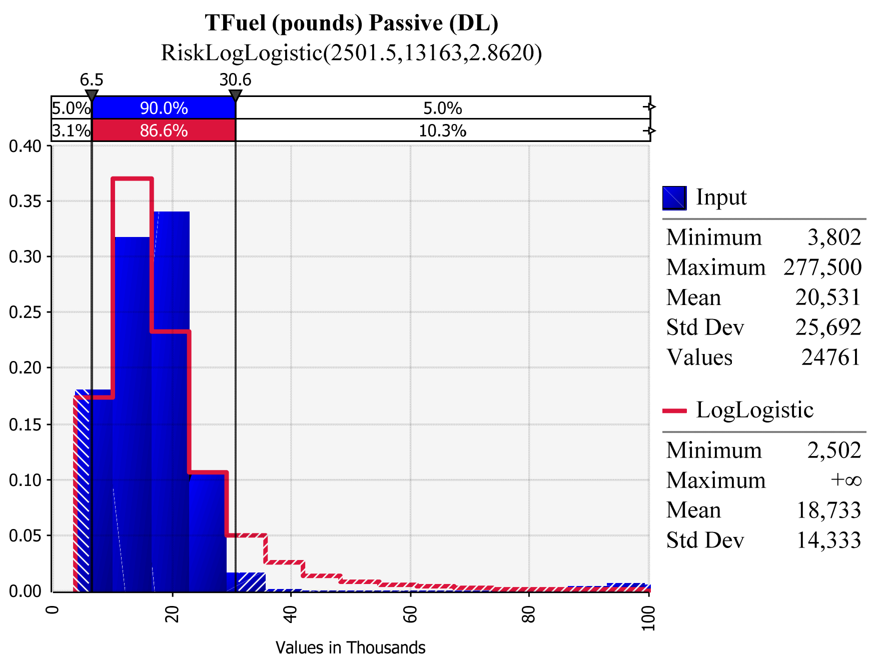

Figure 42. Distribution of the total fuel consumed by Delta flights during the passive period (pounds)

5.1.3.5 "Dwell" Times

This section establishes a baseline for dwell times at each corner post and arrival direction. The flight's dwell time is defined as the time between reaching a corner post and landing. The expectation is that activation of AAMS will result in a reduction in dwell times, thereby saving fuel and time for arriving traffic.

For each corner post and arrival direction a distribution of dwell times is presented. Additionally, distributions for TMA metering operations (on or off) and distributions of dwell times when all runways were operational or otherwise have been computed.

Figure 43 indicates that the distribution of all Dwell times at MSP for the passive period has an average of 15.4 minutes with 90% of flights having a dwell time between 10.6 and 22.8 minutes.

Figures 44, 45, 46, 47, 48, and 49 give the distributions for each corner post and then break the distributions into east and west arrival directions at the post. A summary of the dwell times at each corner post is presented in Table 8.

Figure 50 contrasts the dwell times for flights where TMA metering was on and off. The average dwell time with TMA on was 15.4 minutes while it was 14.7 with TMA off.

Figure 51 shows the dwell time distributions for flights arriving while all runways were open or one or more runways were closed according to NOTAMs. The average dwell time with all runways operational was 15.42 minutes while it was 15.36 minutes otherwise.

Table 8. Summary of Passive Period Corner Post Dwell Times by Direction (minutes)

Corner Post	Mean Dwell Time		Standard Deviation	
Direction	**East**	**West**	**East**	**West**
SHONN	15.7		8.7	
	14.8	16.2	11.7	6.1
OLLEE	16.6		10.3	
	15.9	17.1	12.1	9.1
DELZY	14.8		8.0	
	17.4	13.2	9.2	6.7
TRGET	14.8		6.3	
	17.4	13.3	6.5	5.6
TWINZ	15.7		8.6	
	18.5	13.8	9.4	7.3
BITLR	12.5		2.5	
	15.7	12.0	4.0	1.8

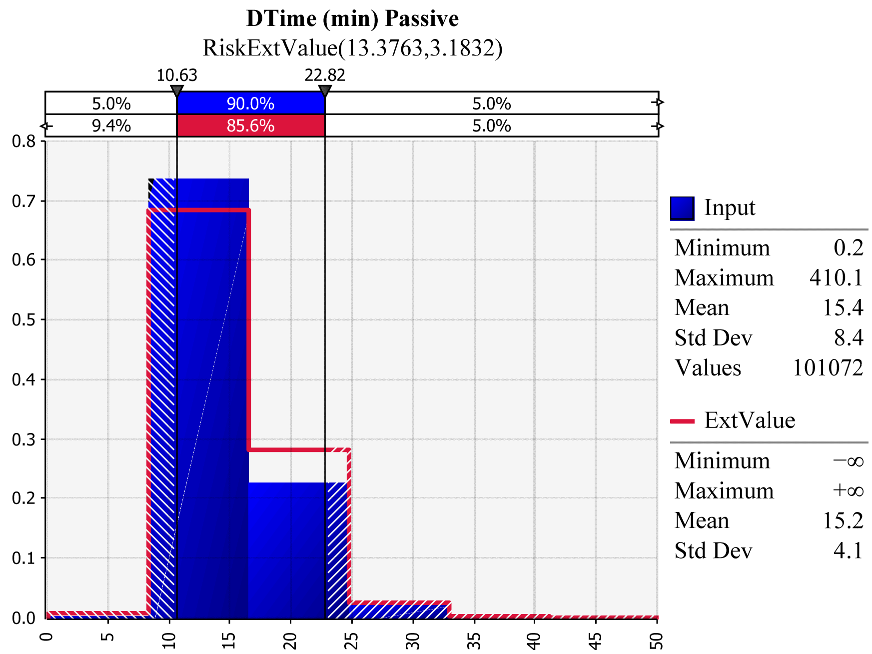

Figure 43. Distribution of all Dwell times for all flights (minutes)

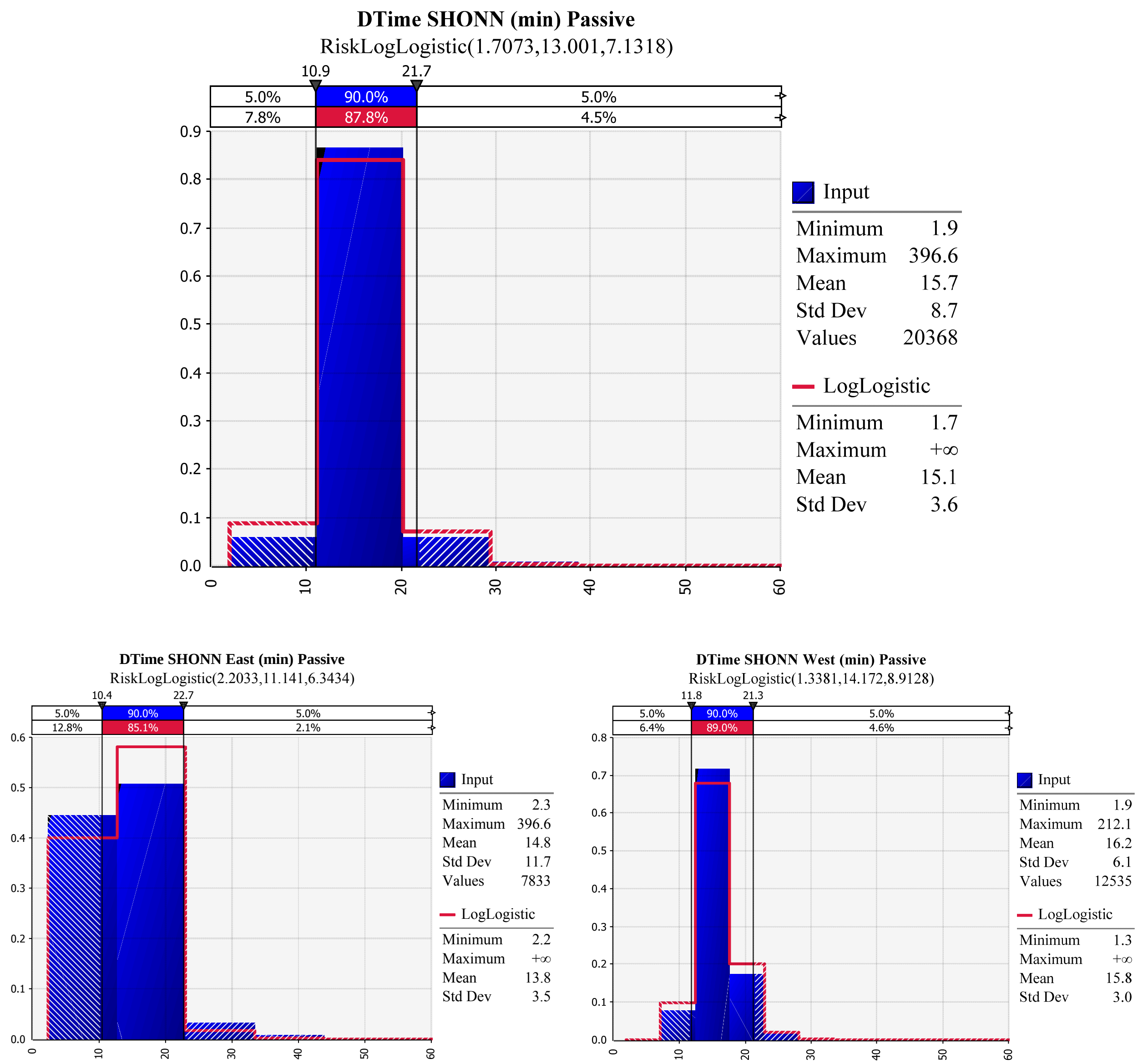

Figure 44. Distribution of dwell times for SHONN corner post arrivals (minutes)

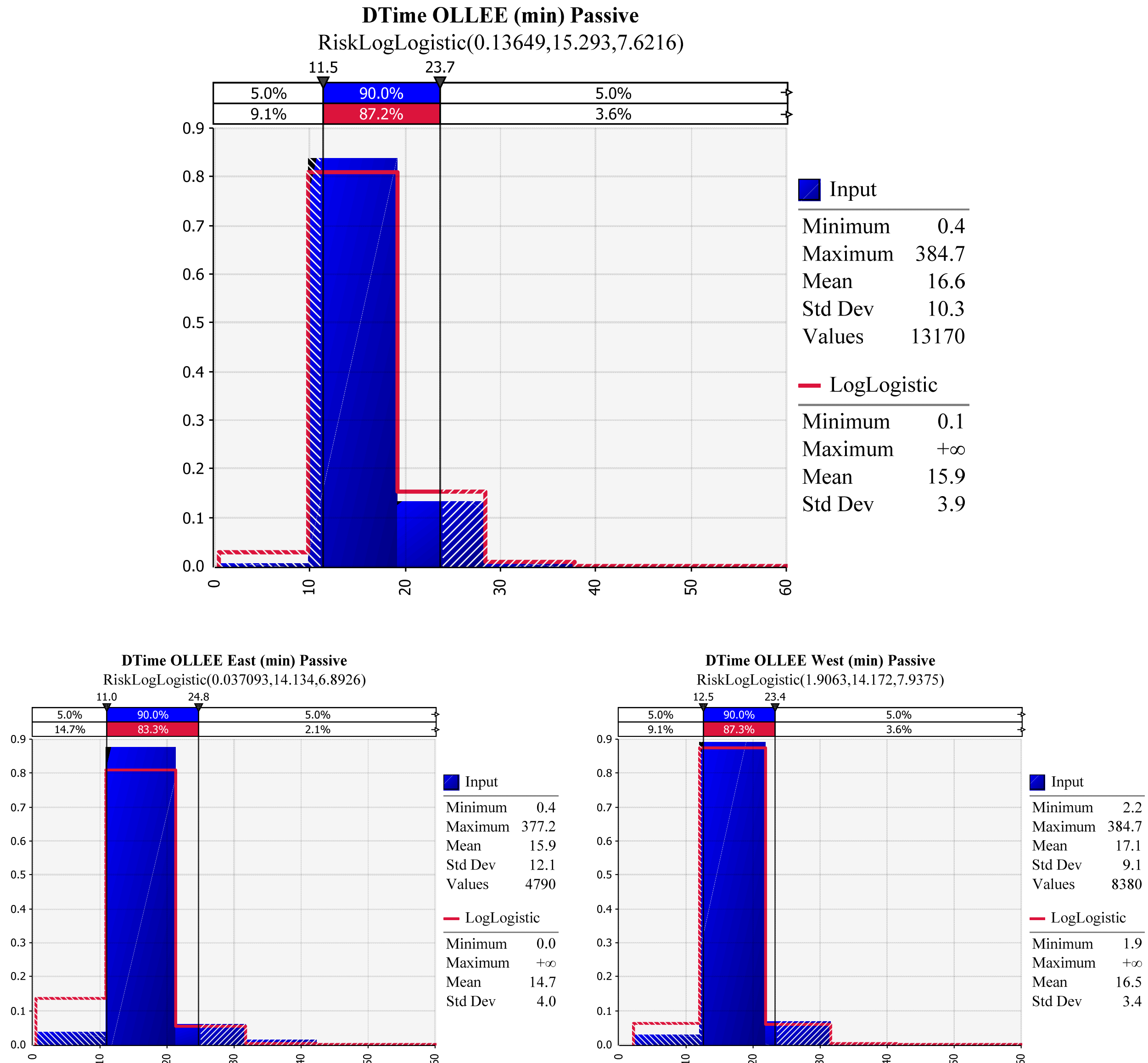

Figure 45. Distribution of dwell times for OLLEE corner post arrivals (minutes)

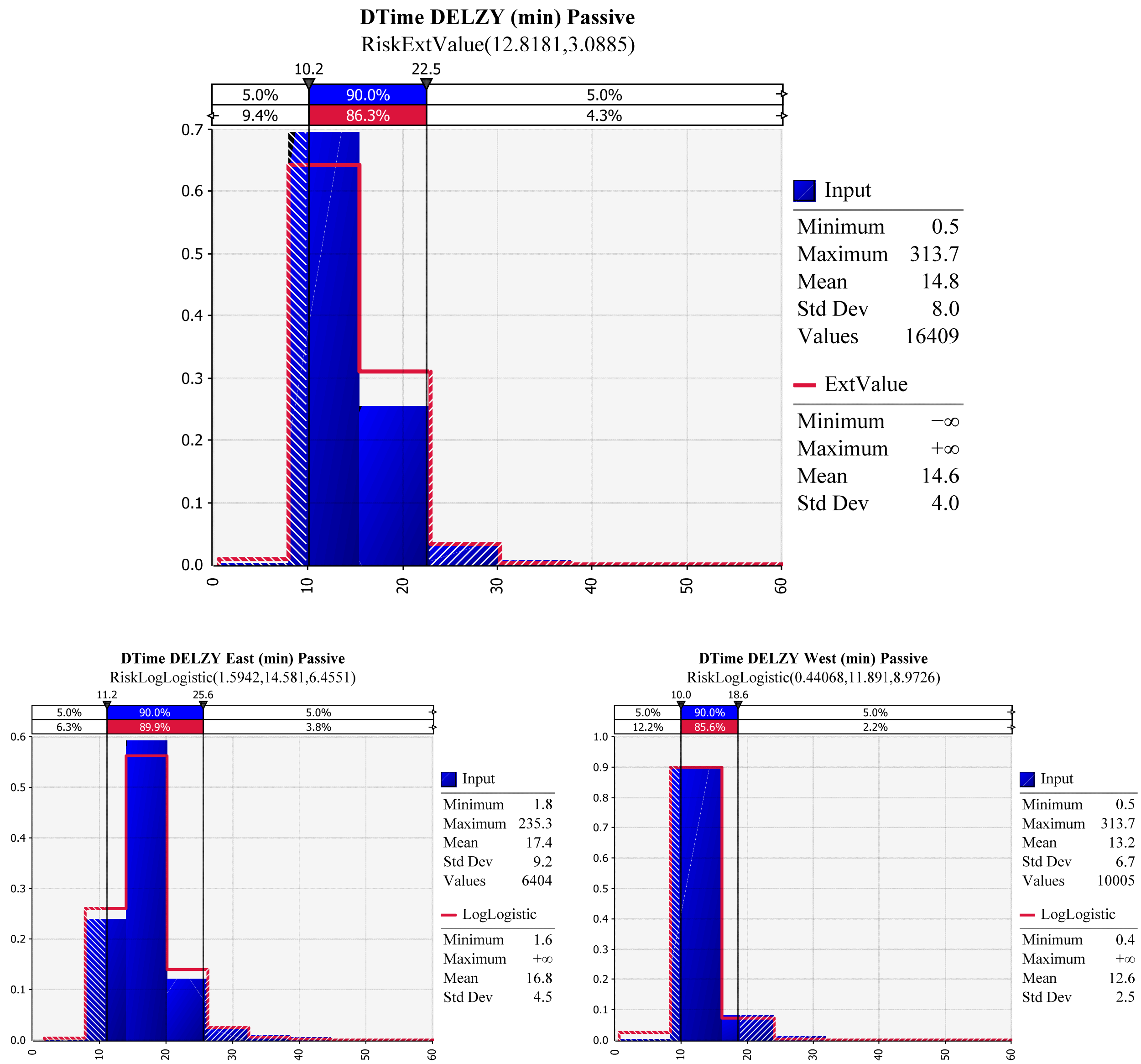

Figure 46. Distribution of dwell times for DELZY corner post arrivals (minutes)

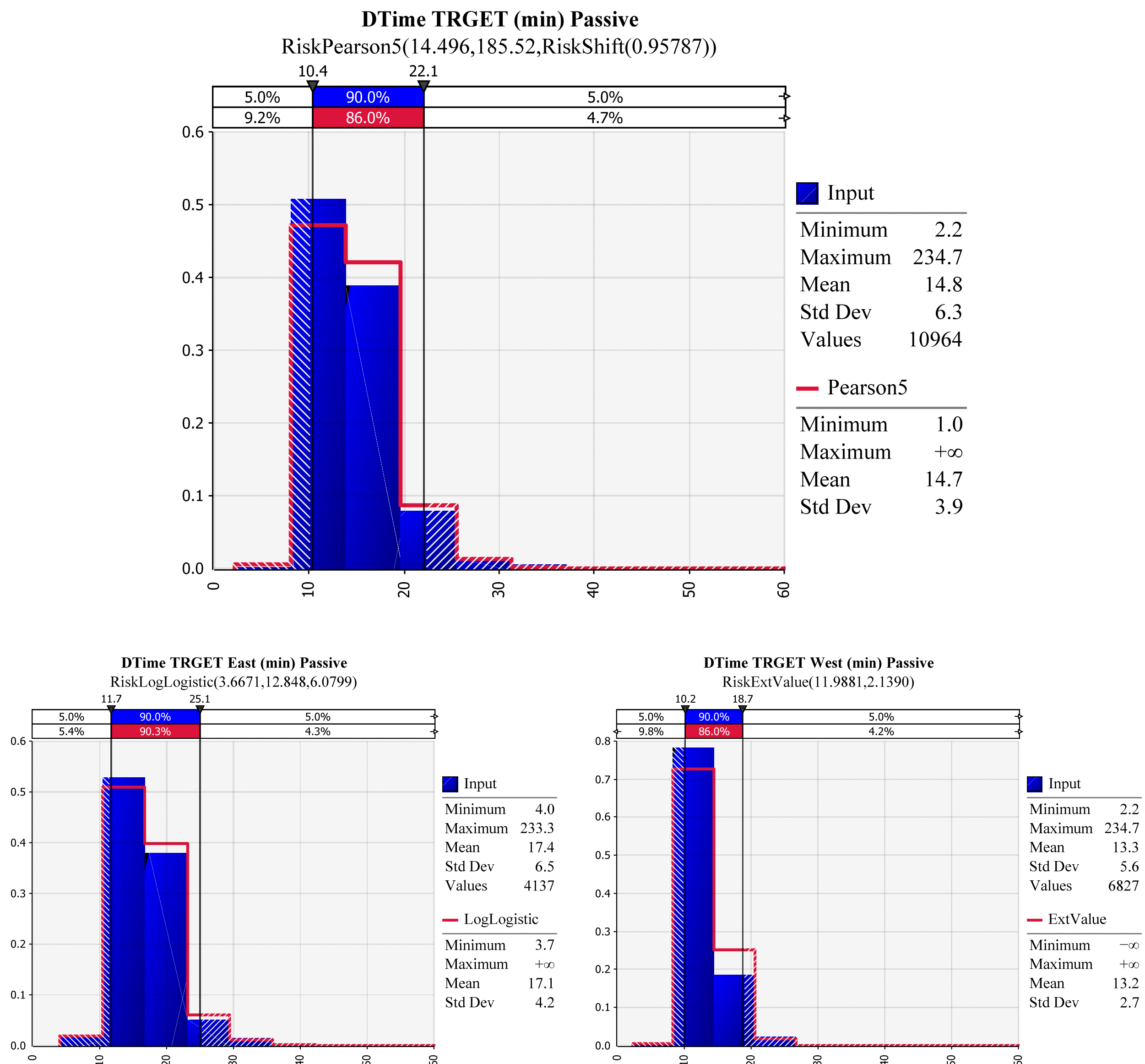

Figure 47. Distribution of dwell times for TRGET corner post arrivals (minutes)

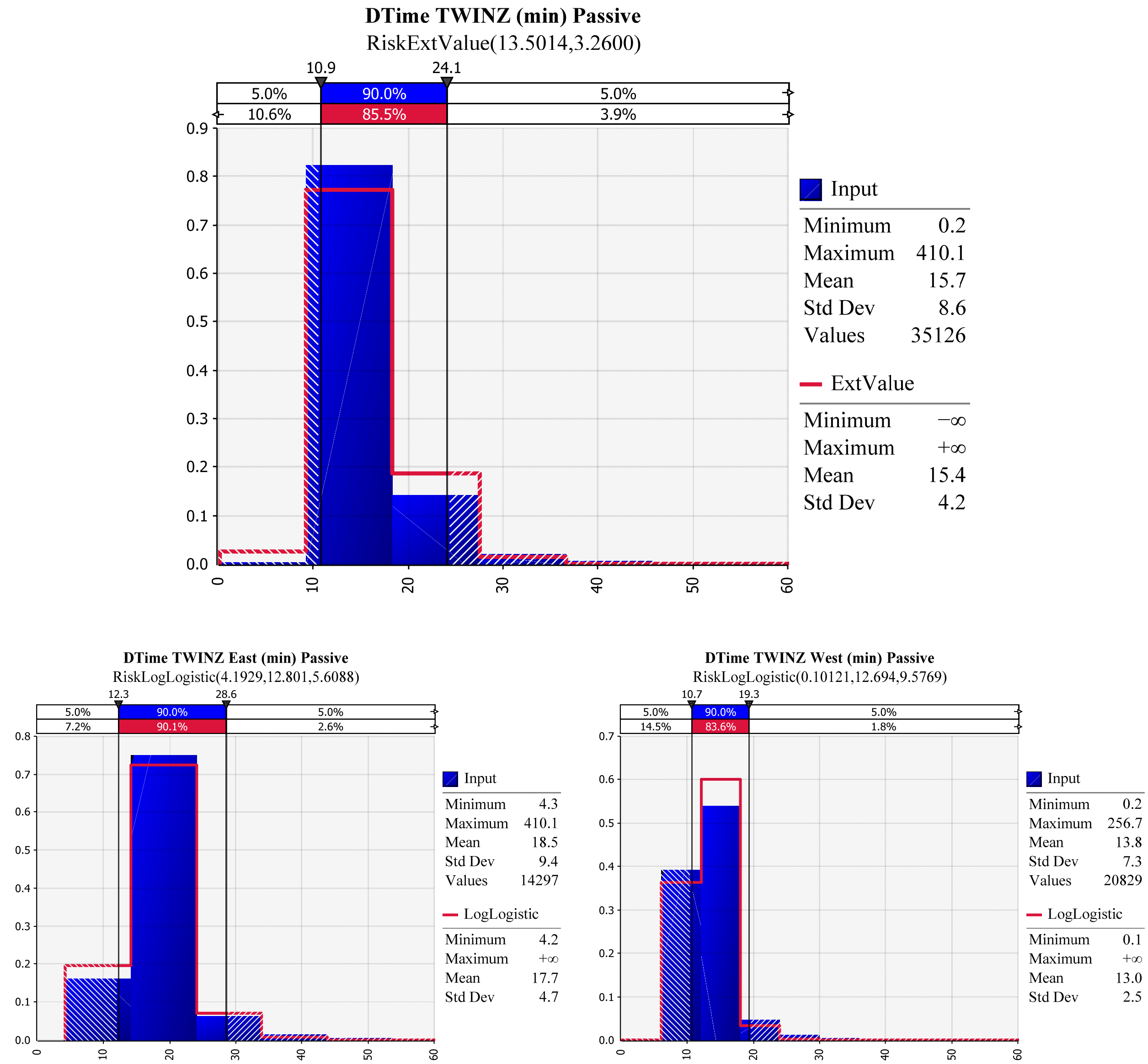

Figure 48. Distribution of dwell times for TWINZ corner post arrivals (minutes)

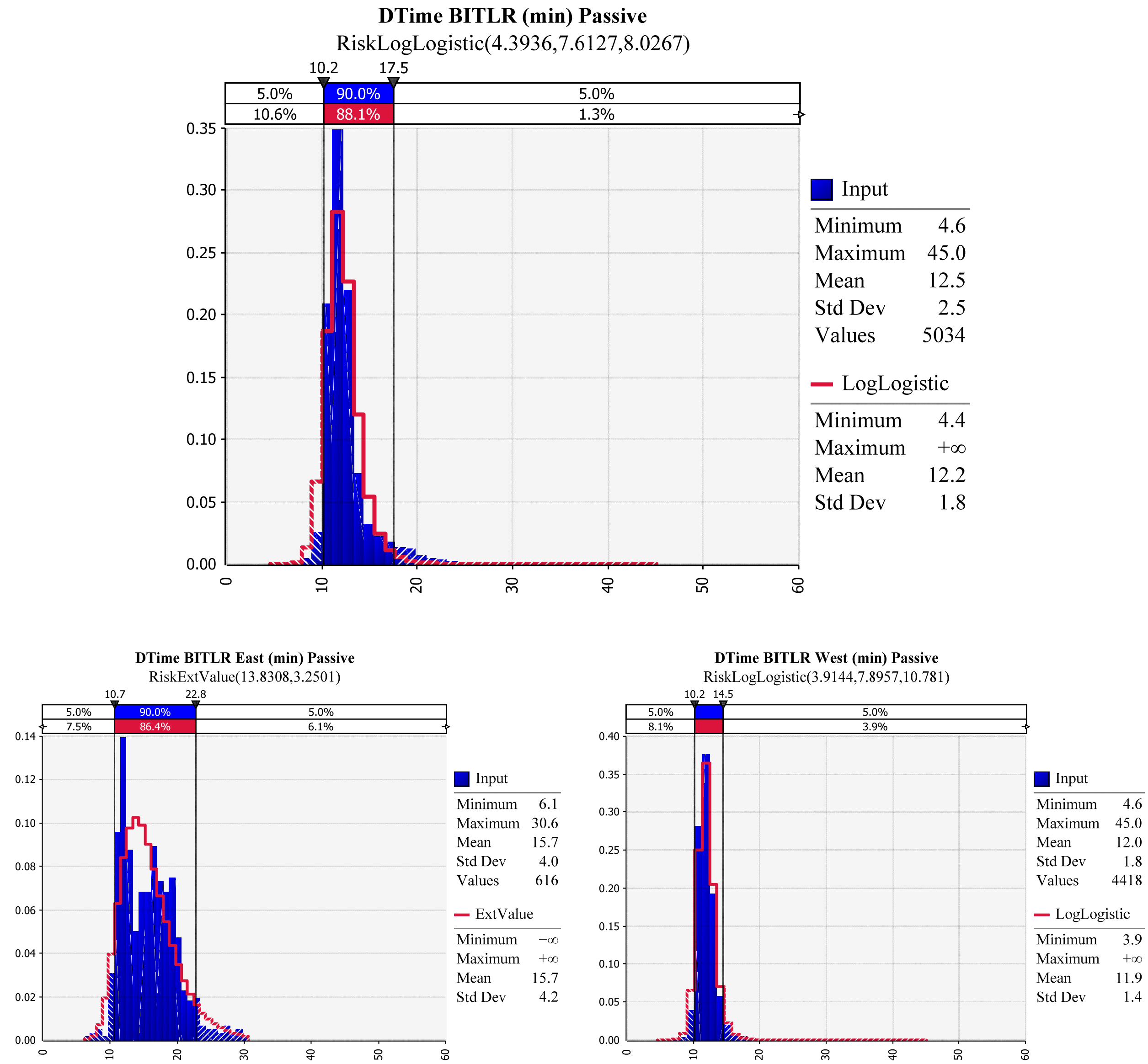

Figure 49. Distribution of dwell times for BITLR corner post arrivals (minutes)

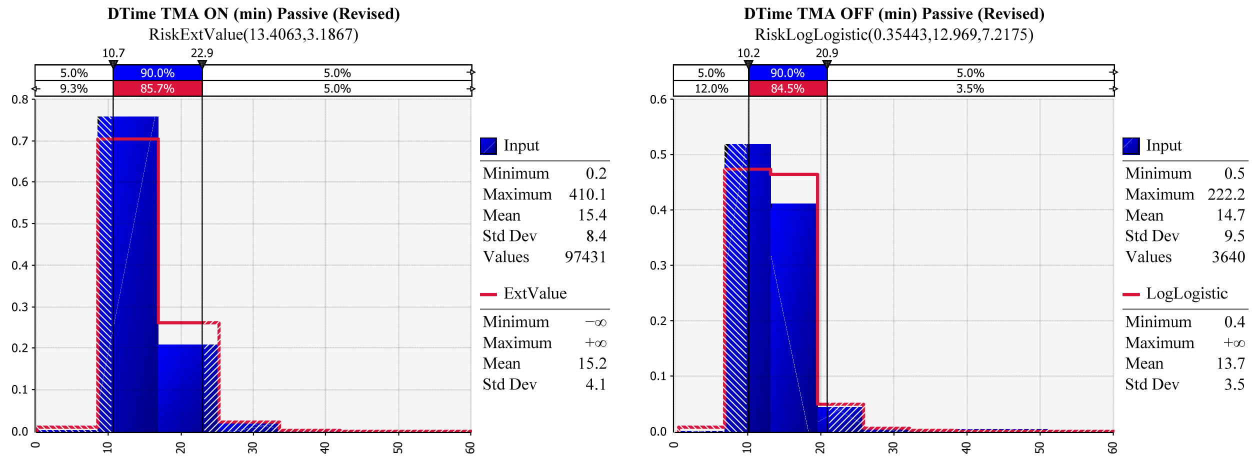

Figure 50. Distribution of dwell times categorized by TMA operation (minutes)

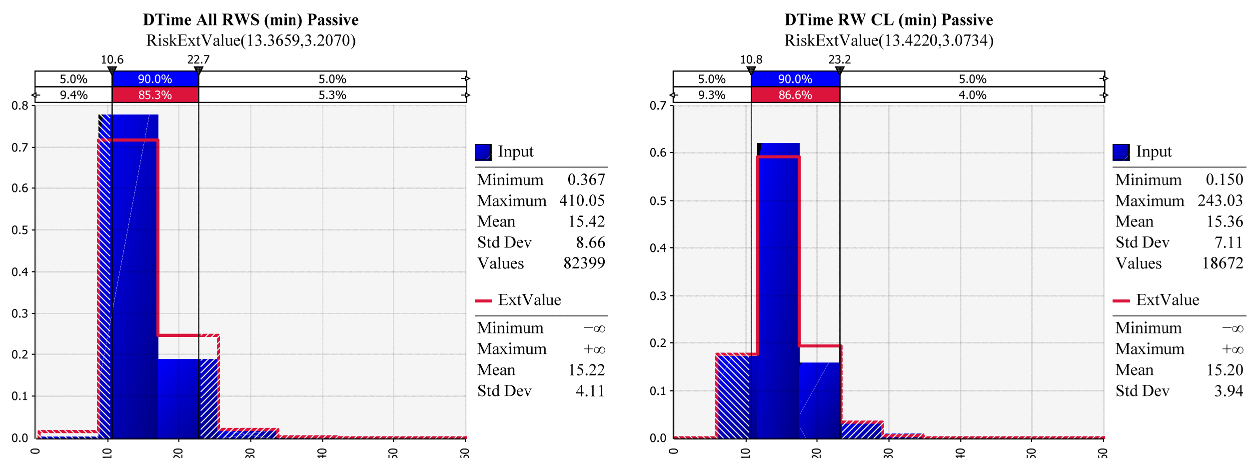

Figure 51. Distribution of dwell times categorized by runway operation (minutes)

5.1.3.6 "Dwell" Fuel

This section establishes a baseline for dwell fuel consumption during the passive period. The estimations for fuel consumption between the corner post and runway for each flight were formulated using EUROCONTROL's Base of Aircraft Data (BADA) references for low altitude cruise fuel burn, in pounds per minute, for the aircraft type multiplied by the corresponding dwell time.

Figure 52 illustrates the distribution of fuel consumed with an average of 892 pounds and a 90% range bounded by 363 pounds and 1778 pounds with a standard deviation of 596 pounds.

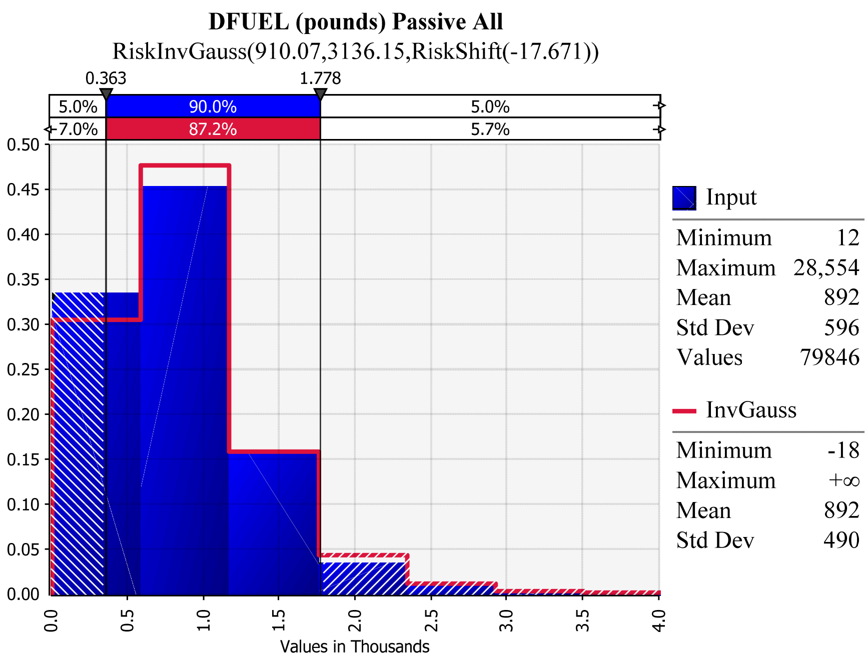

Figure 52. Distribution of dwell fuel consumption (pounds)

5.2 AAMS ACTIVE PERIOD PERFORMANCE

5.2.1 Data Collection Time Frame

The six months of the Active Phase data, collected November 1, 2011 to April 30, 2012, saw the AAMS RTAs uplinked by ACARS to Delta aircraft.

5.2.2 Descriptive Statistics

The descriptive evaluation of the data for the 100,680 recorded Active Phase flights is outlined in Figure 53. Of these flights records, 27% belonged to Delta Air Lines flights and 73% represented non-participating carriers and general aviation activity. The flights flew across MSP's six corner posts—SHONN, OLLEE, DELZY, TRGET, TWINZ, and BITLR with 19%, 14%, 16%, 11%, 34%, and 6% of flight records, respectively. East arrivals comprised 38% of the data and west arrivals made up 69% of the flights. TMA is also indicated as being active in 96% of flight records and 76% of flights arrived while all runways were open. Furthermore, with the unseasonably good weather this winter, only 1% of recorded flights operated on the two non-representative days in this period.

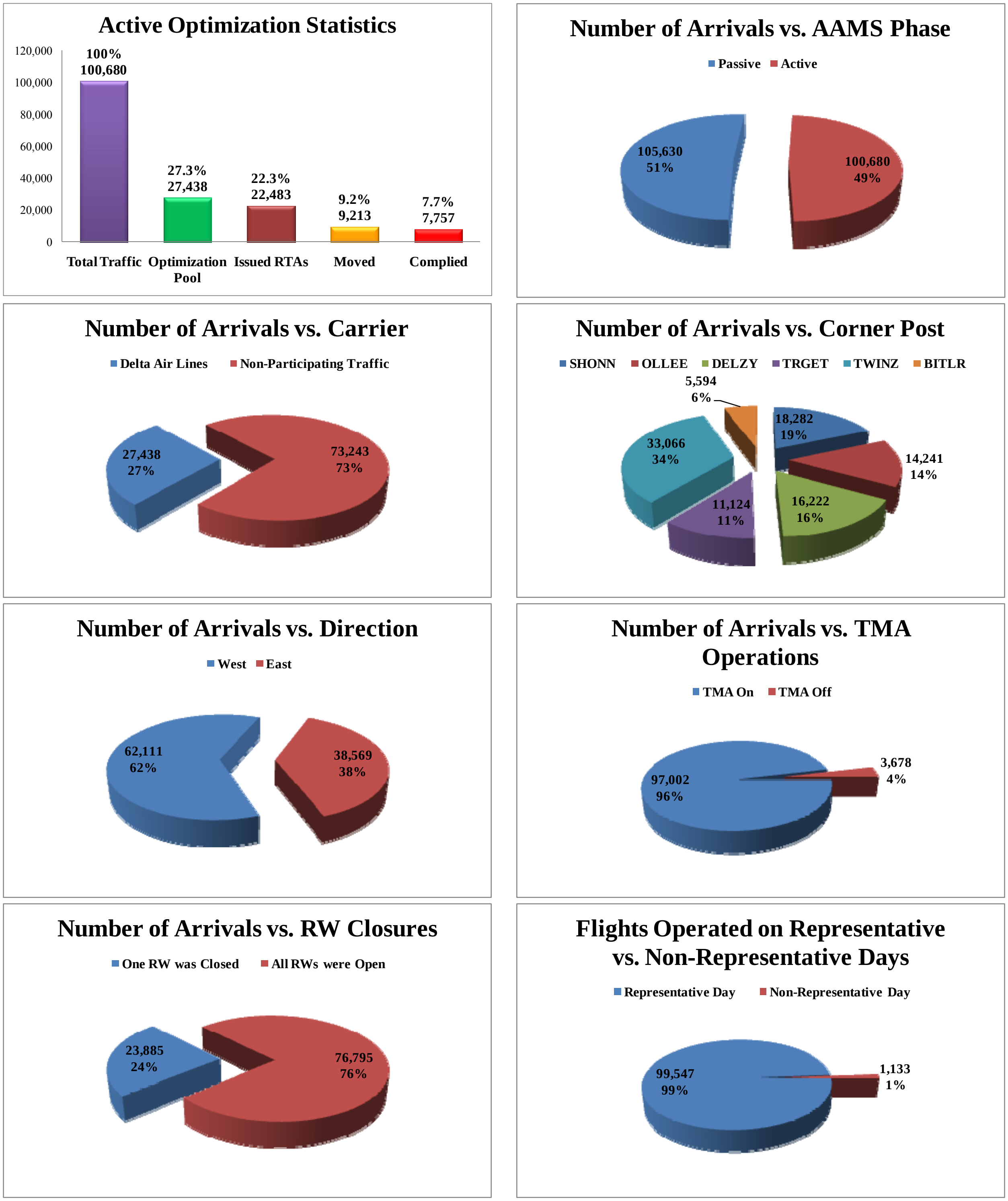

Figure 53. Active Phase Data Description and Distribution

5.2.3 Data Summary

5.2.3.1 On-Time Arrival Performance

Distribution of the difference between actual and scheduled arrival times of Delta Air Lines flights is presented against A0 and A14 windows in Figure 54 and Figure 55. Delta flights were observed operating 77.3% A0 and 91.1% A14 during the Active Phase according to Delta's recordings.

ATH's data for the three months of the Active Phase compare closely with Delta's arrival performance at MSP. As seen in Figure 56 and Figure 57, the ATH A0 and A14 performances are 74.8% and 89.9%, respectively. This is consistent with Delta's data given the difference in collection methods. All arrival figures also include distributions for the subsets of Optimized and Complied flights ("OPTC"), Representative Day flights ("Rep Day"), and their intersection.

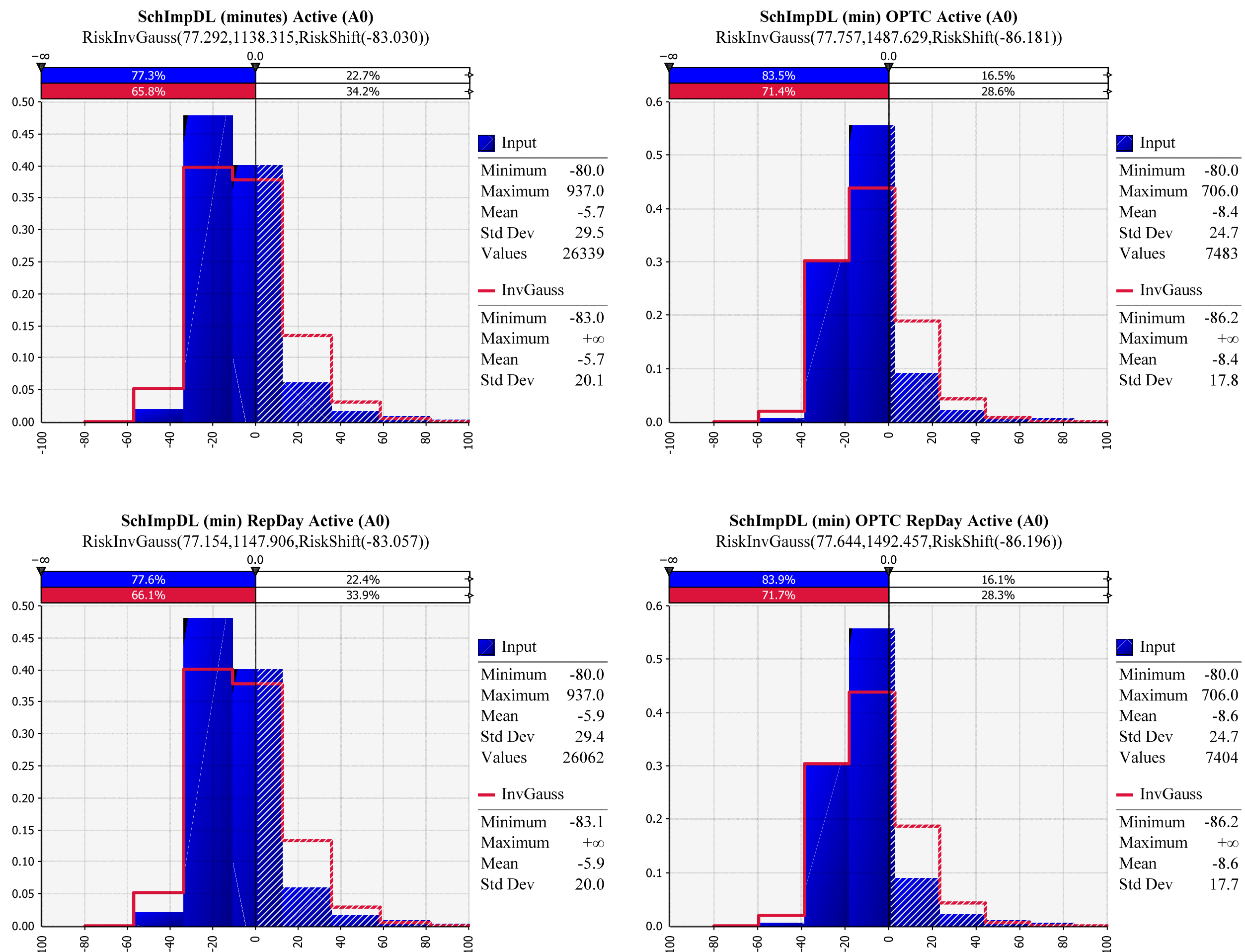

Figure 54. Distribution of the difference between actual and scheduled arrival times for Delta flights (0 minutes tolerance)

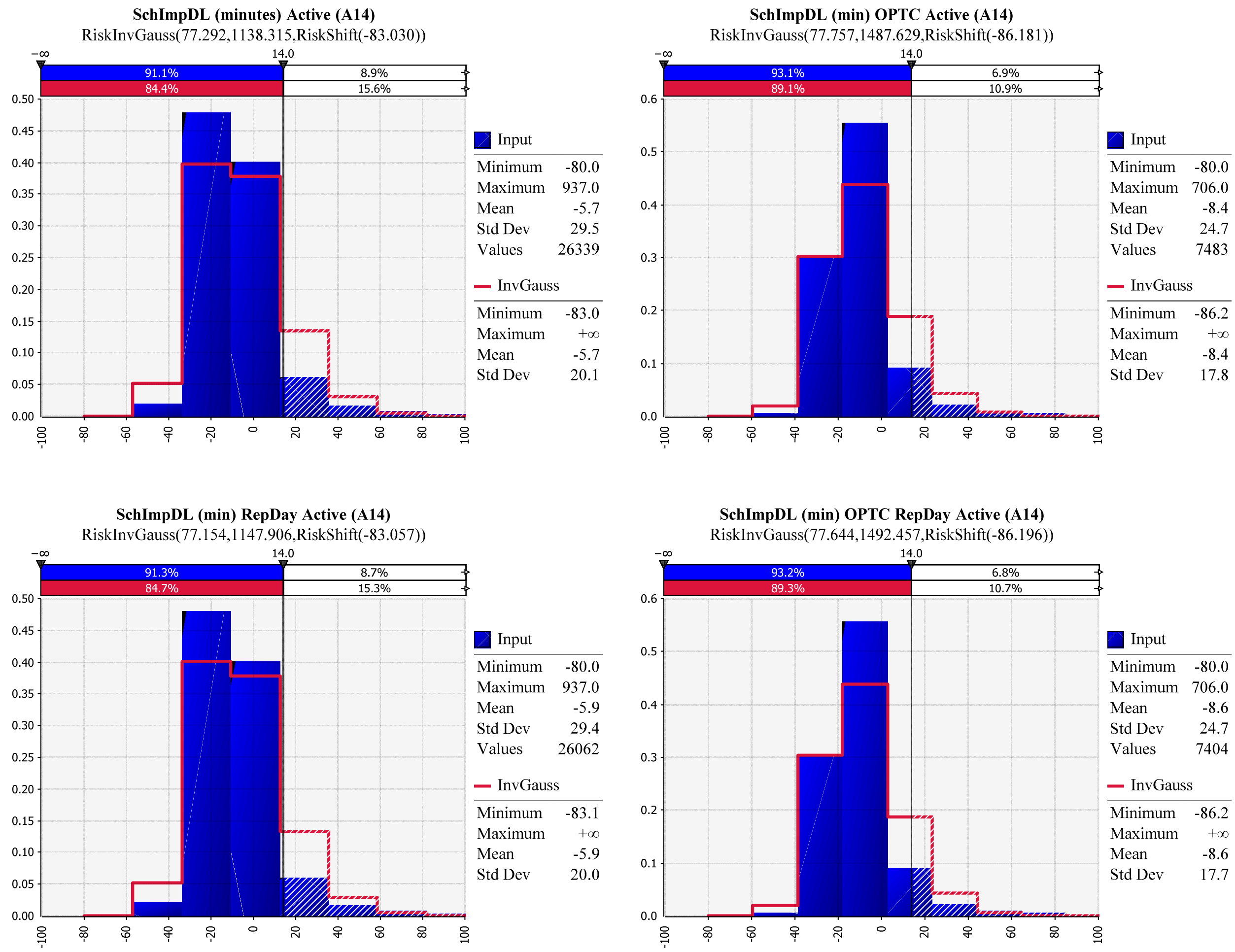

Figure 55. Distribution of the difference between actual and scheduled arrival times for Delta flights (14 minutes tolerance)

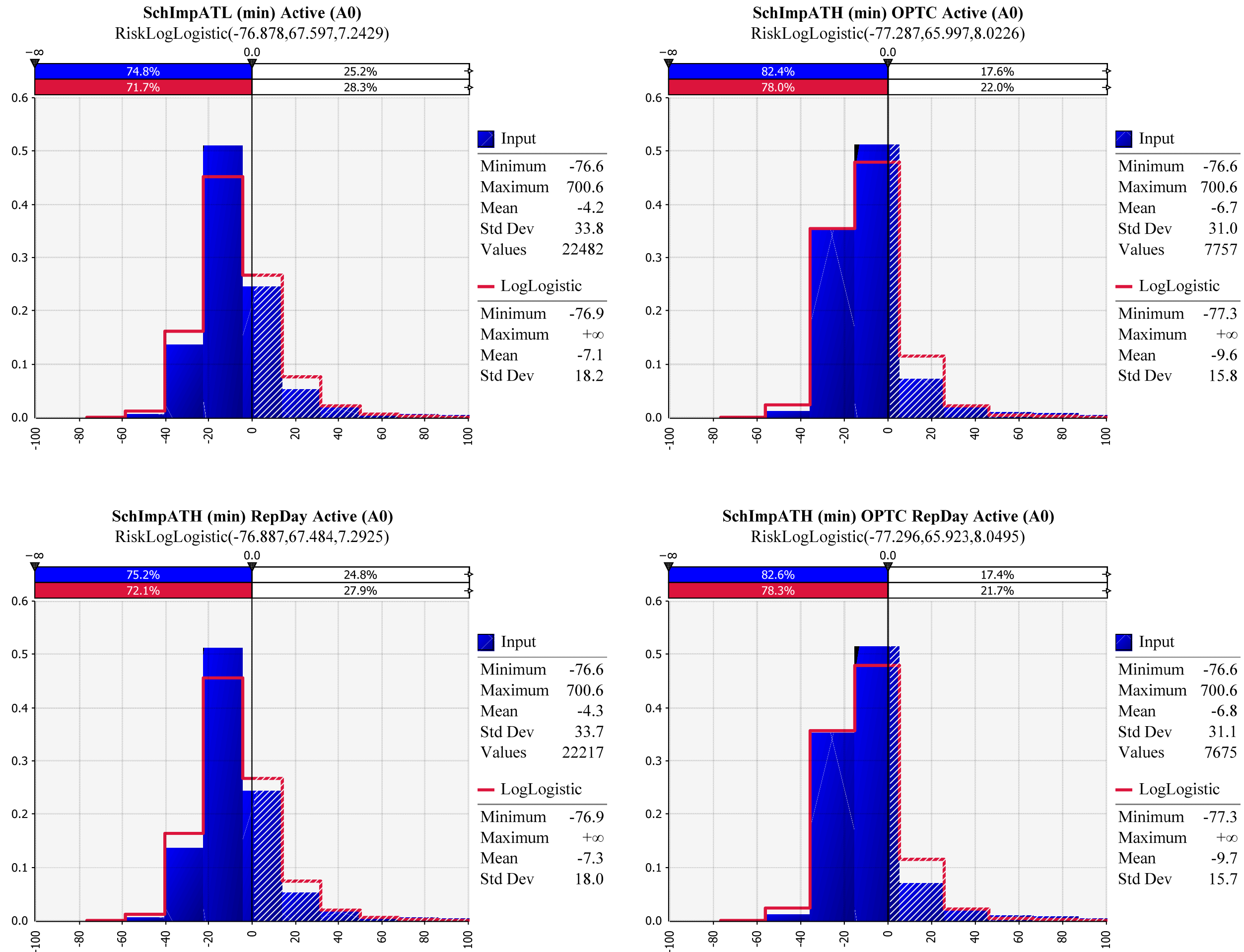

Figure 56. Distribution of the difference between actual and scheduled arrival times for ATH data (0 minutes tolerance)

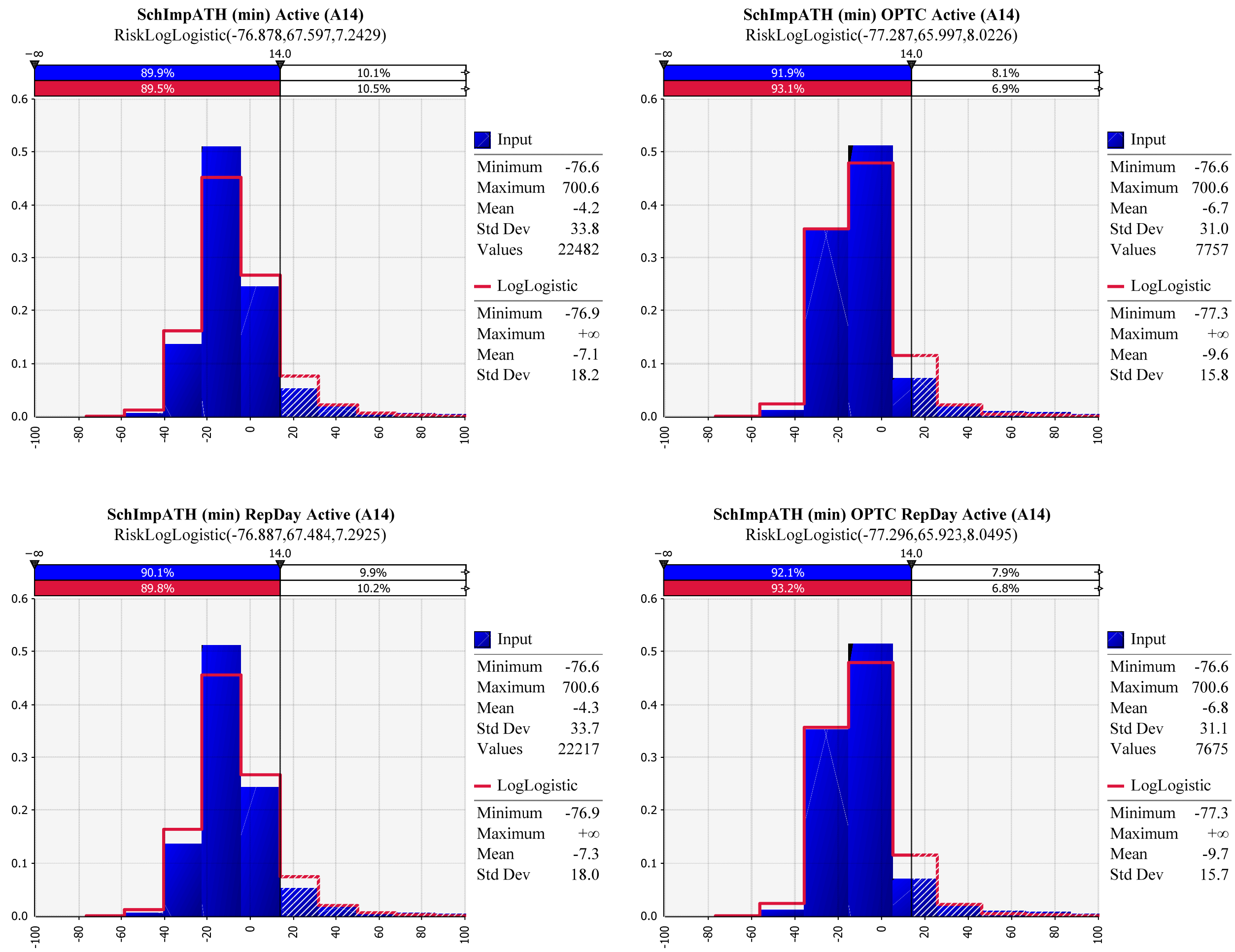

Figure 57. Distribution of the difference between actual and scheduled arrival times for ATH data (14 minutes tolerance)

5.2.3.2 Taxi-In and Taxi-Out Performance

As part of an effort to examine potential AAMS impact on ground operations, recorded taxi-in and -out times are compared to their scheduled times in Figure 58 and Figure 59. Sixty-six point five percent (66.5%) and 32.0% of flights met their taxi-in and -out times, respectively. Figure 58 and Figure 59 also have the distributions for the subsets of OPTC and Representative Days as applicable.

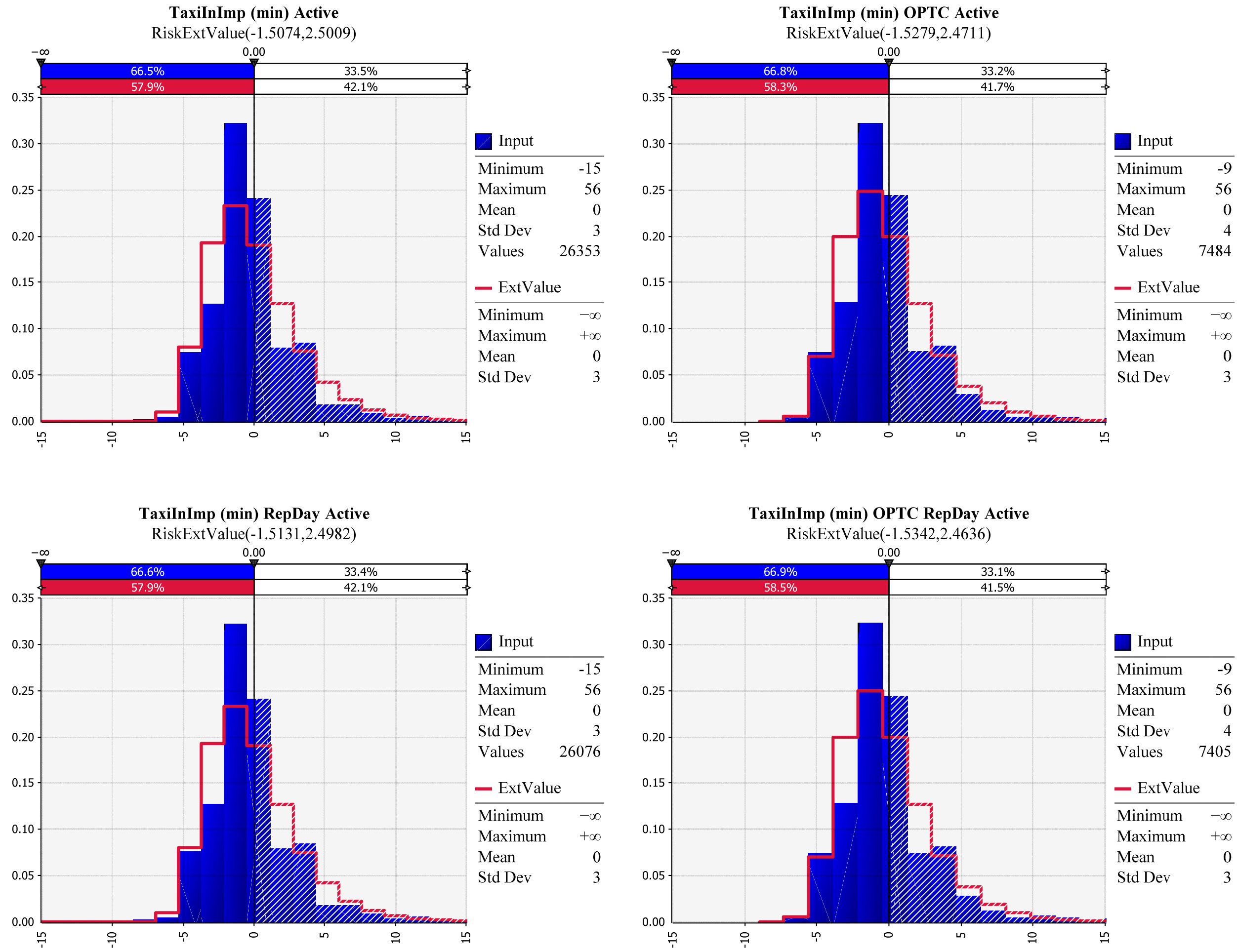

Figure 58. Distribution of the difference between actual and scheduled taxi-in time (minutes)

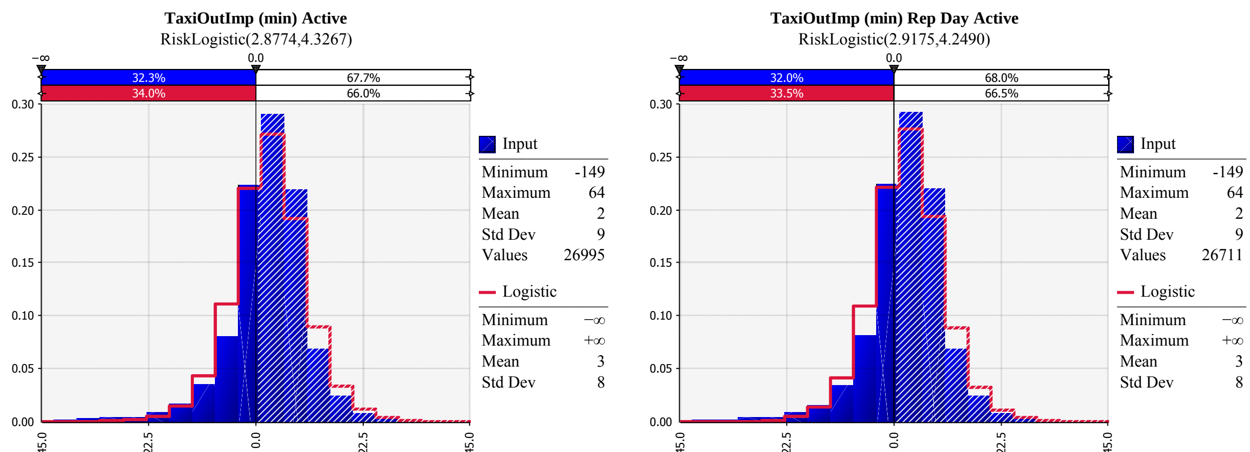

Figure 59. Distribution of the difference between actual and scheduled taxi-out time (minutes)

5.2.3.3 Total Flight Times and Trip Fuel

Delta flights flew 153 minutes on average with a standard deviation of 82 minutes with upper and lower 90% bounds of 220 and 55 minutes, as indicated in Figure 60. The average flying time of all MSP traffic, depicted in Figure 61, is 107 with upper and lower 90% bounds of 36 and 190 minutes with a standard deviation of 63 minutes.

The trip fuel consumption for inbound Delta flights averaged 19,869 pounds with a standard deviation of 20,532 pounds.

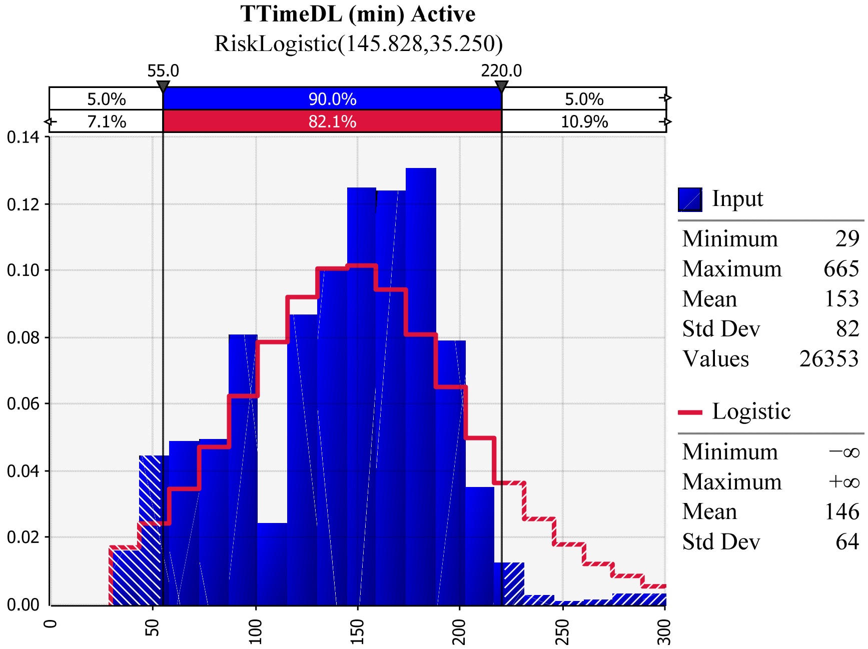

Figure 60. Distribution of the flight travel times for Delta Air Lines flights (minutes)

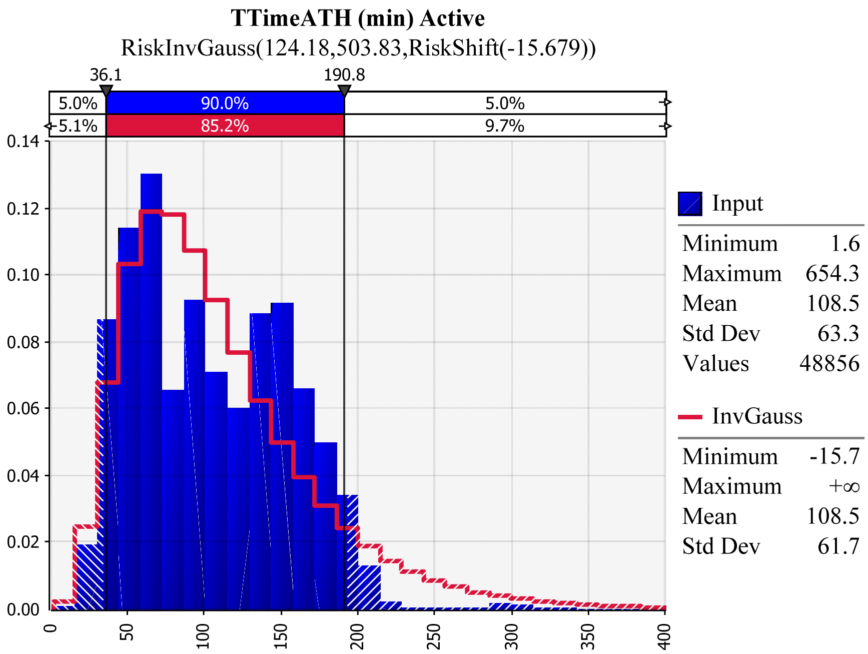

Figure 61. Distribution of the flights travel times for all MSP traffic (minutes)

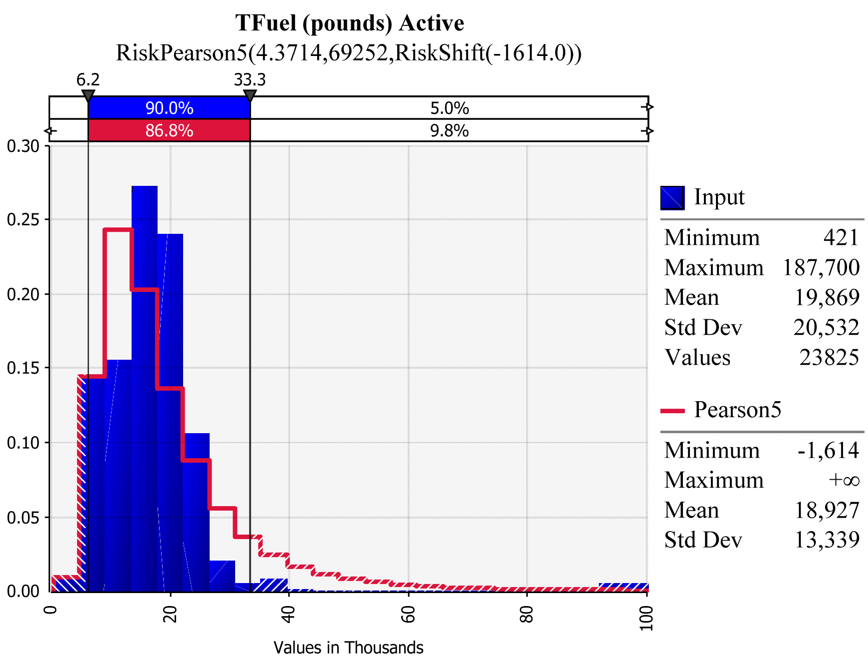

Figure 62. Distribution of trip fuel for inbound Delta Air Lines flights (pounds)

5.2.3.4 "Dwell" Times

The distribution of dwell times for all flights, depicted in Figure 63, averaged 14.6 minutes with a standard deviation of 7.1 minutes.

The six corner posts, SHONN, OLLEE, DELZY, TRGET, TWINZ, and BITLR, have their dwell time distributions presented with configuration direction in Figures 64, 65, 66, 67, 68, and 69. These are briefly summarized in Table 9.

Dwell time distributions are also plotted against TMA operation in Figure 70. These indicate that the average dwell time while TMA was active 14.6 minutes while times with TMA off averaged 15.3 minutes with standard deviations of 6.6 and 16.3 minutes, respectively.

Similarly, dwell times were plotted for when all runways were operational or one or more were closed in Figure 71. With all runways operational, the average dwell time was 14.5 minutes and 15.1 minutes with a closure.

Table 9. Summary of Active Period Corner Post Dwell Times by Direction (minutes)

Corner Post	**Mean Dwell Time**		**Standard Deviation**	
Direction	**East**	**West**	**East**	**West**
SHONN	14.9		9.0	
	13.3	15.9	9.4	8.6
OLLEE	15.3		6.3	
	13.6	16.4	5.9	6.3
DELZY	14.0		5.9	
	16.3	12.5	6.0	5.2
TRGET	14.1		6.2	
	16.4	12.8	6.4	5.6
TWINZ	14.9		7.2	
	17.4	13.2	8.3	5.7
BITLR	12.7		6.2	
	16.8	12.1	3.1	6.3

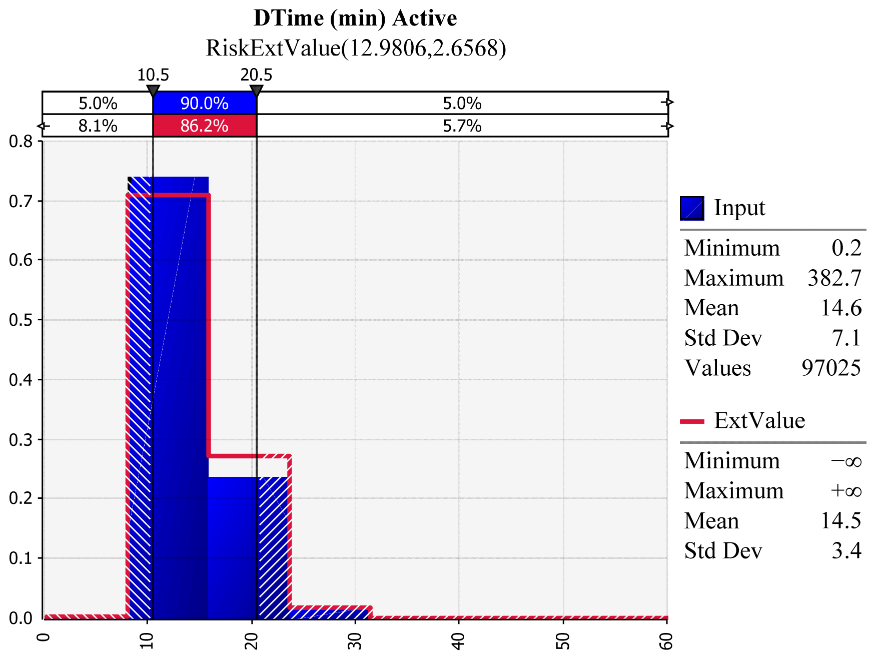

Figure 63. Distribution of all dwell times for all flights (minutes)

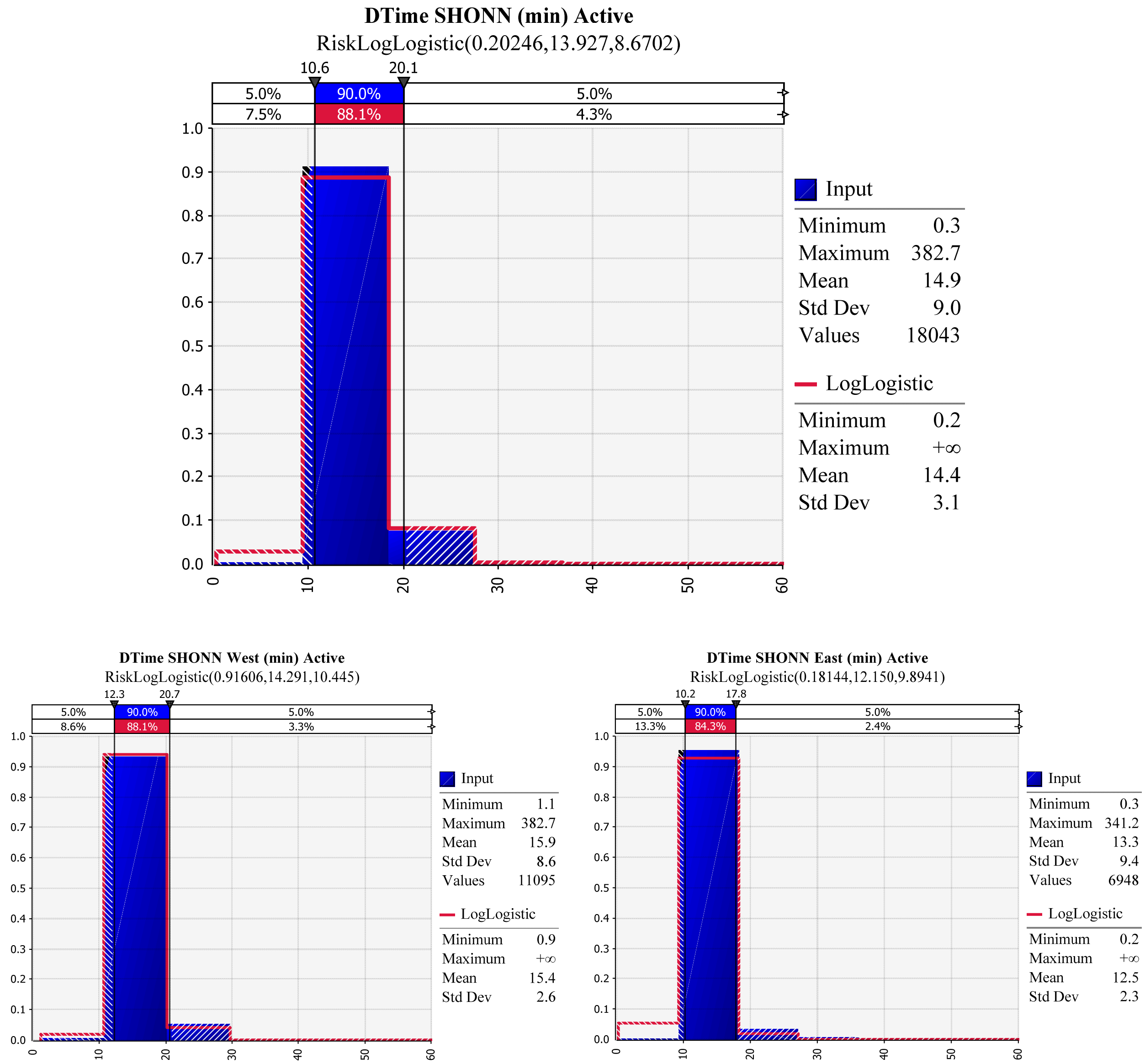

Figure 64. Distribution of dwell times for SHONN corner post arrivals (minutes)

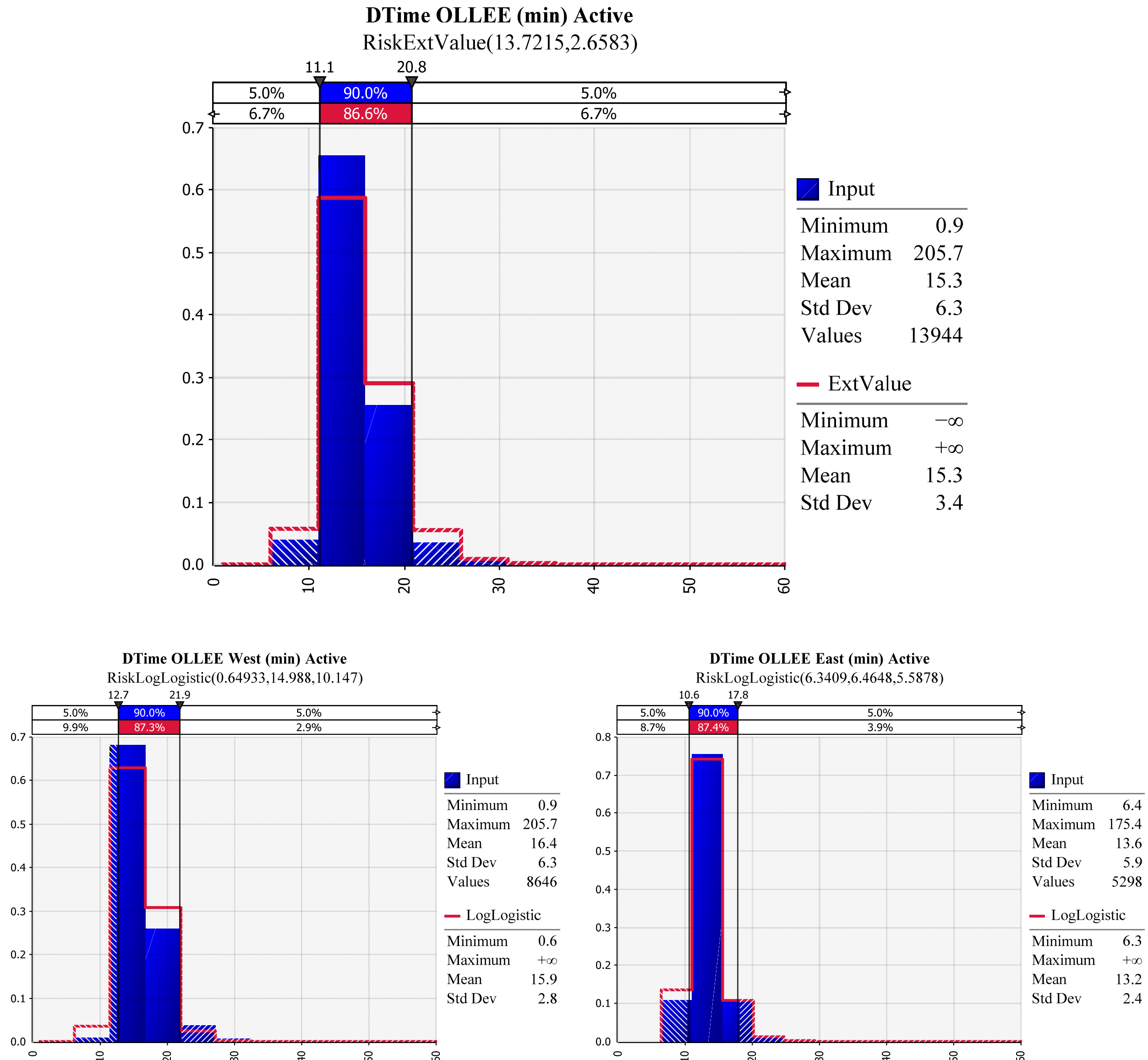

Figure 65. Distribution of dwell times for OLLEE corner post arrivals (minutes)

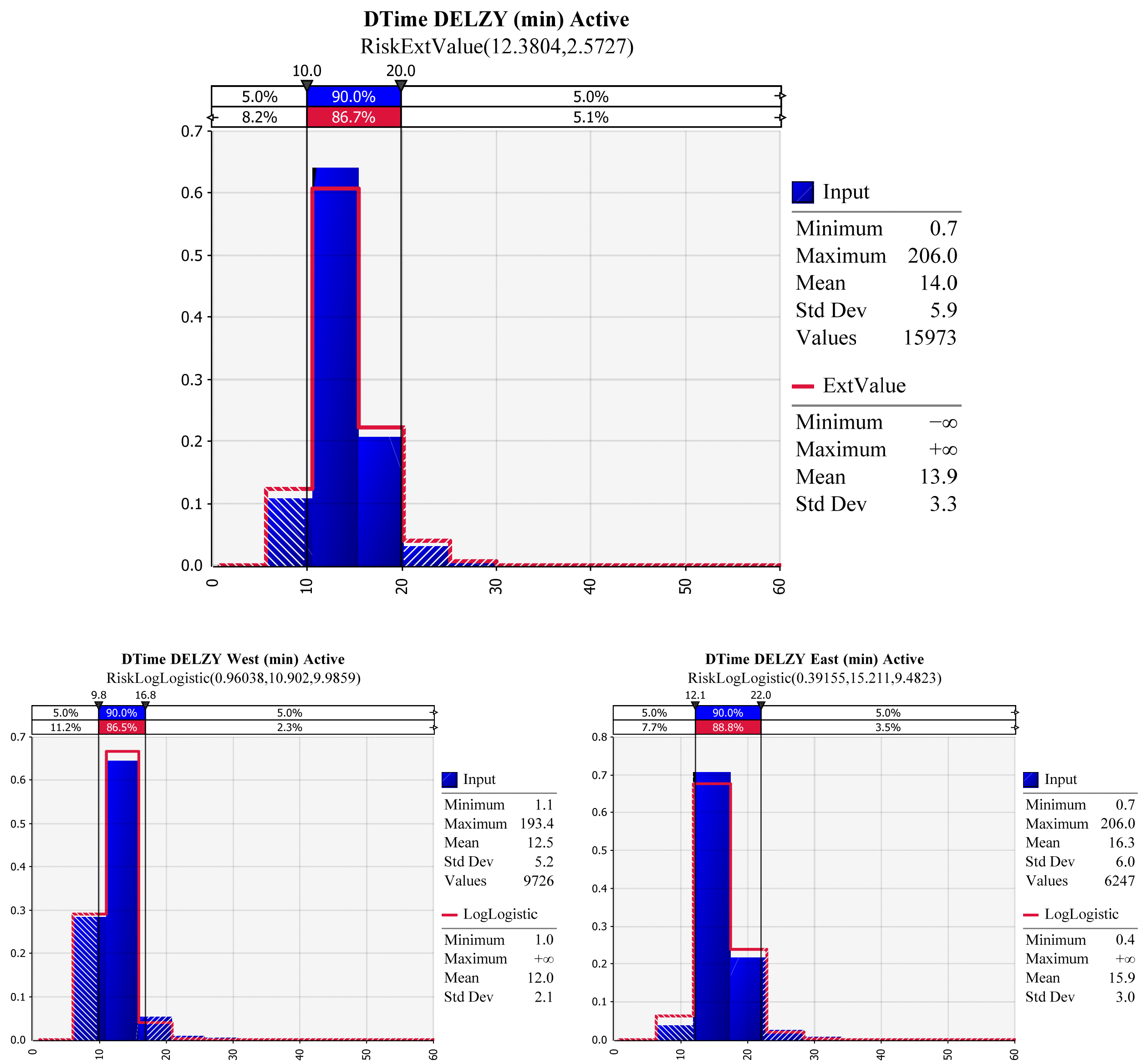

Figure 66. Distribution of dwell times for DELZY corner post arrivals (minutes)

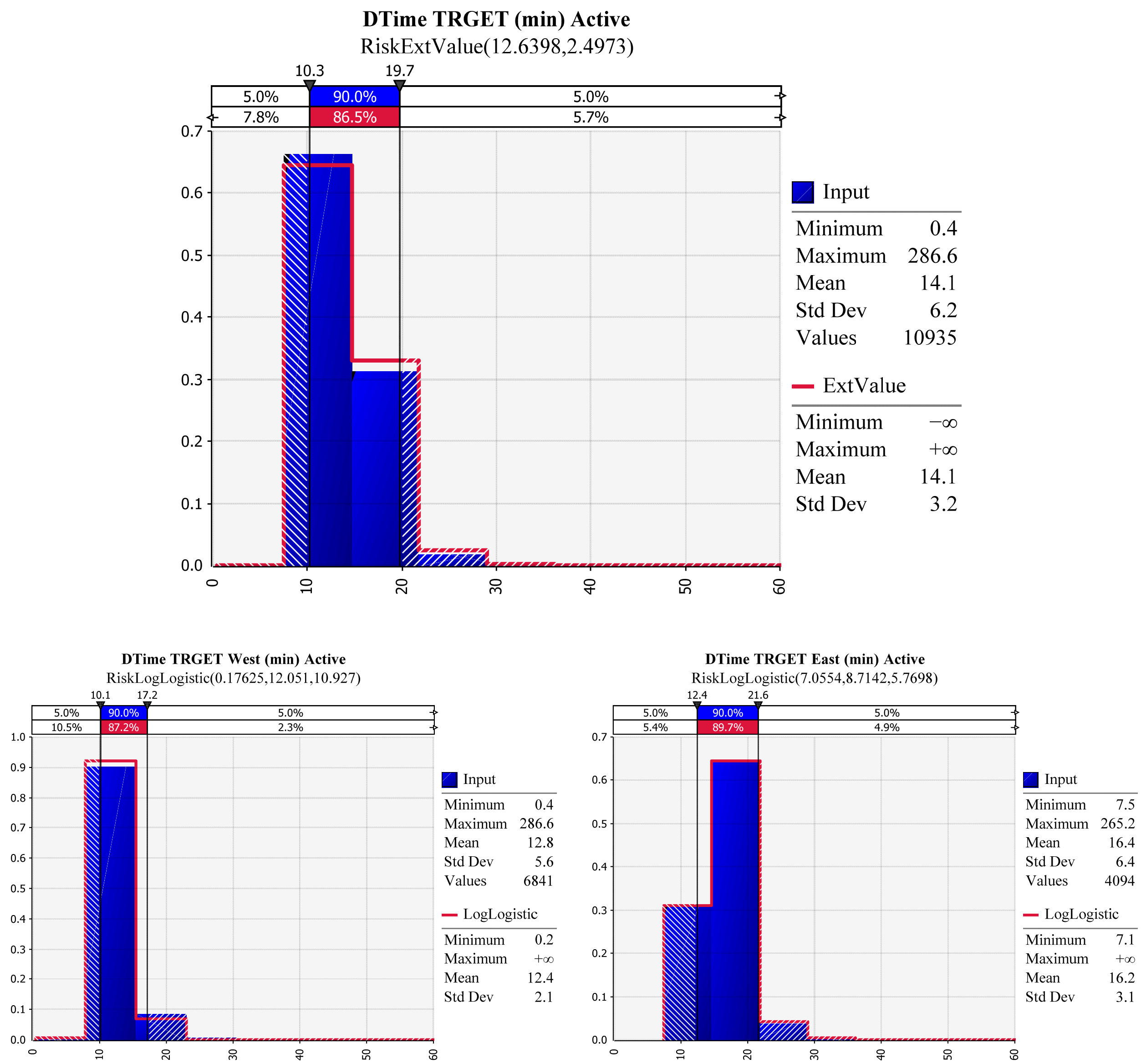

Figure 67. Distribution of dwell times for TRGET corner post arrivals (minutes)

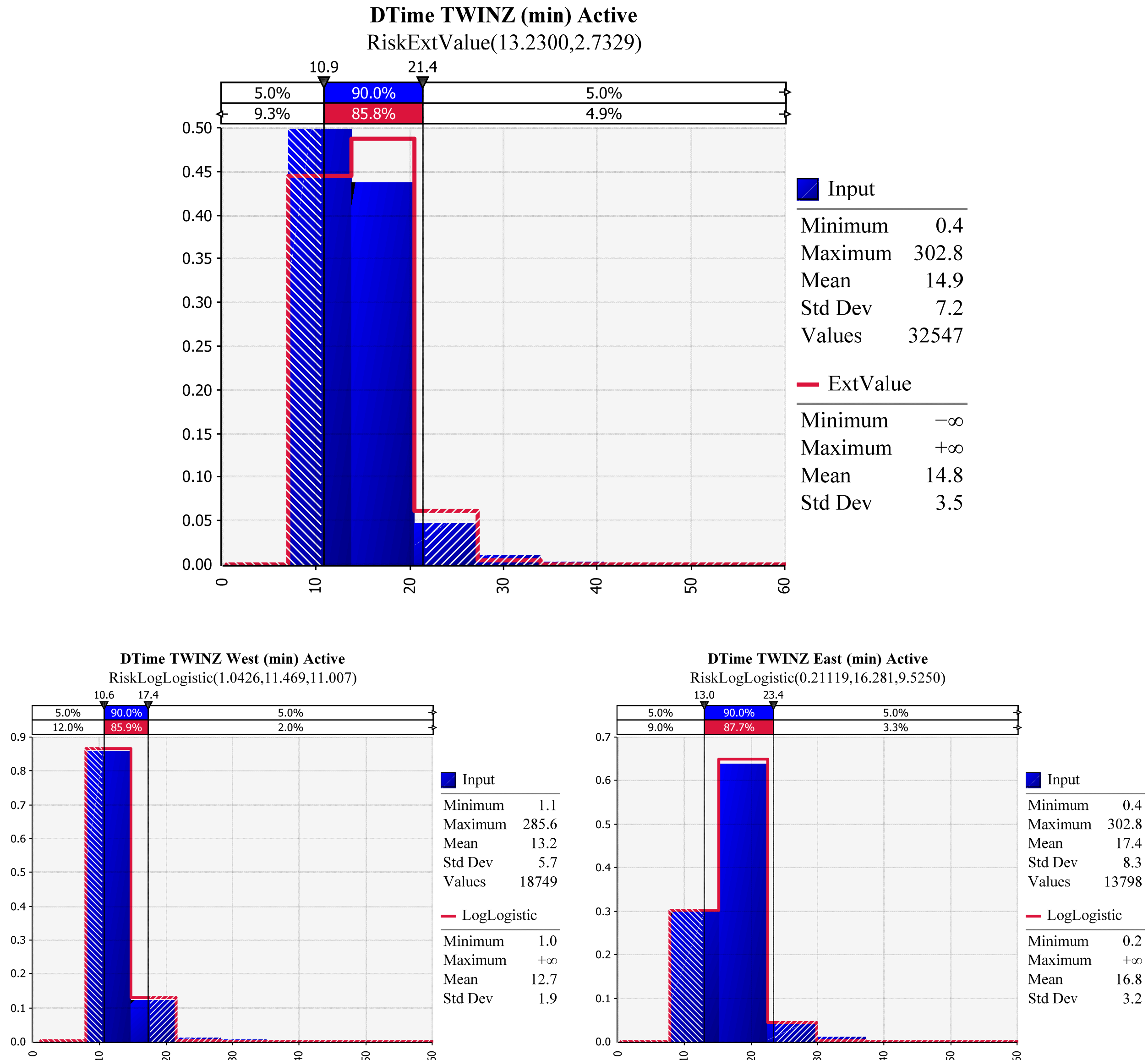

Figure 68. Distribution of dwell times for TWINZ corner post arrivals (minutes)

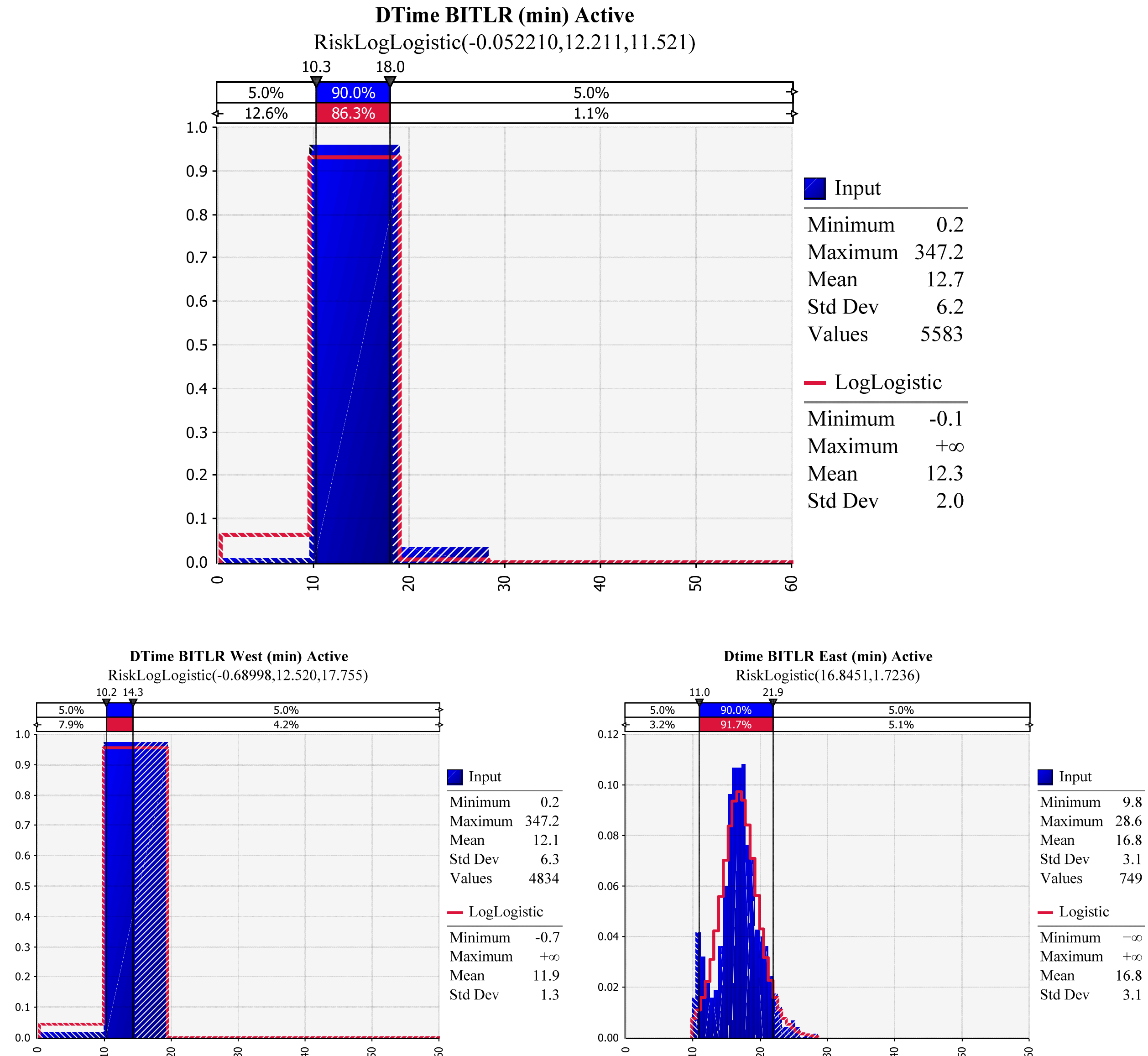

Figure 69. Distribution of dwell times for BITLR corner post arrivals (minutes)

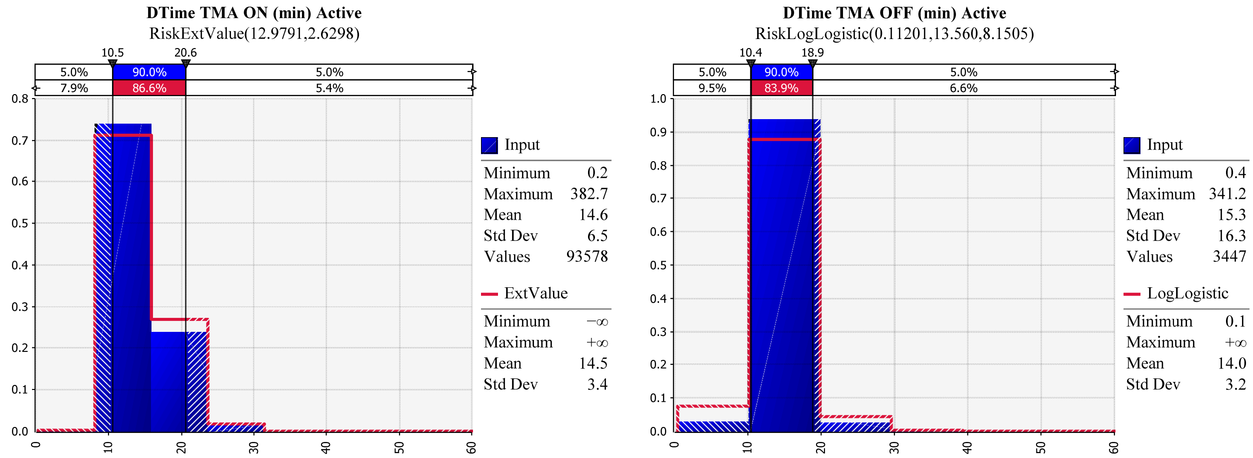

Figure 70. Distribution of dwell times categorized by TMA operation (minutes)

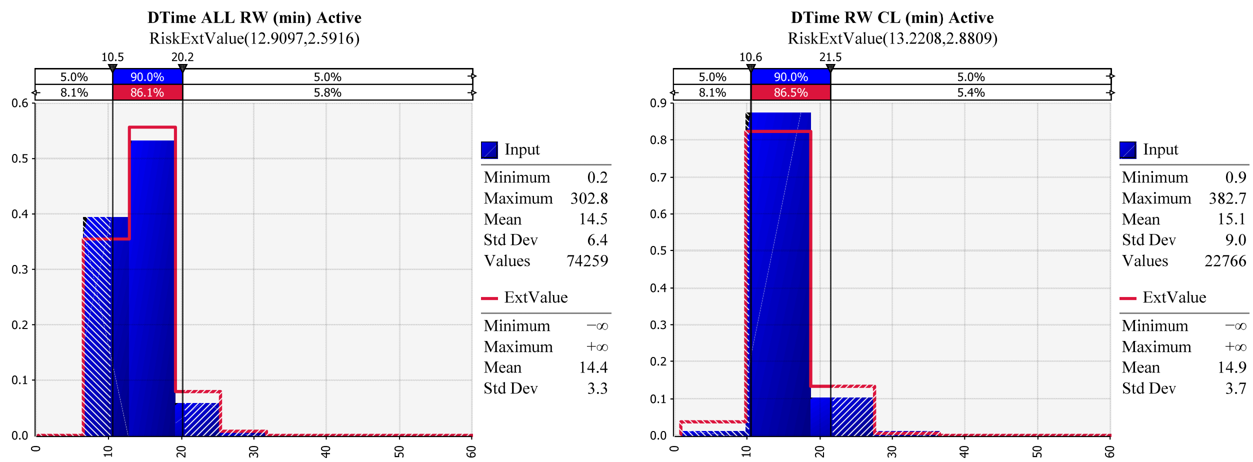

Figure 71. Distribution of dwell times categorized by runway operation (minutes)

5.2.3.5 "Dwell" Fuel

The EUROCONTROL's Base of Aircraft Data (BADA) -based low altitude dwell fuel burn estimations for the MSP active period sample are distributed in Figure 72. The average dwell fuel consumption for the period was 826 pounds with a standard deviation of 562 pounds. The upper and lower limits of the 90 % window were 1,574 and 360 pounds, respectively. On representative days during the period the average was 825 pounds and the standard deviation was 562 pounds.

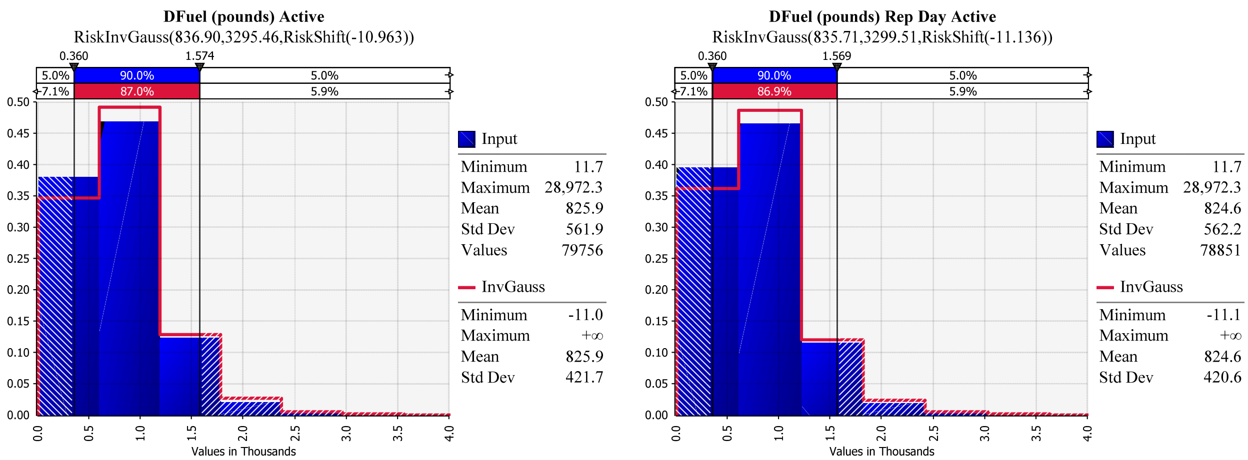

Figure 72. Distribution of dwell fuel consumption (pounds)

5.2.3.6 Optimization and Compliance Rate

The biweekly RTA issue rates show a few points considerably below the average rate. There are two explanations most readily available for this. The first is inactivity of the system due to irregular operations, weather, or disconnect. The largest deficit from Figure 73 in issued RTAs is about the time of an AAMS software update that attempted to reduce the number of ACARS messages issued by only sending RTA to aircraft that needed to adjust speed to meet the RTA.

Unlike the RTA issue rates, the compliance rates, depicted in Figure 74, did not have any notable dips; however, a gentle decline in compliance is perceivable on inspection. The results of the benefits and operational analysis do not indicate that these compliance rates had not been sufficient for evaluative purposes.

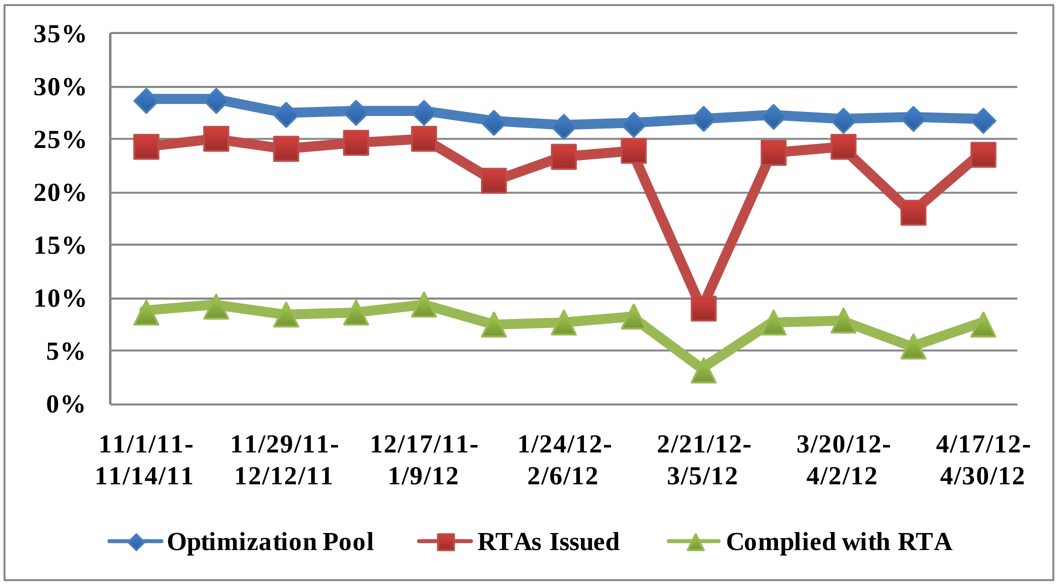

Figure 73. Bi-Weekly Period Optimization Rates as Percentage of Traffic

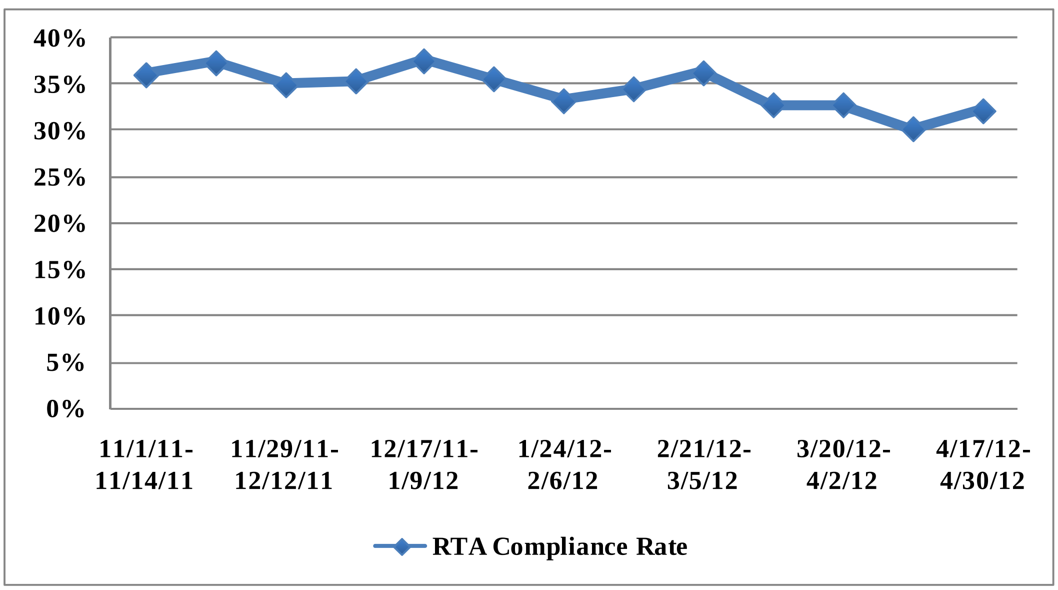

Figure 74. Bi-Weekly Period Percent of RTAs Complied

6 COST - BENEFITS ANALYSIS

6.1 Overview

The Cost Benefit Analysis (CBA) quantifies the costs, primarily incurred by Delta Air Lines, for implementation of the AAMS demonstrator and compares those costs to the benefits to the participating and non-participating airlines and the NAS identified through pre- and post-AAMS implementation operation analysis. The report addresses both direct (primary) benefits such as reduction in delays and improved arrival predictability, and indirect (secondary) benefits such as environmental impacts. Calculating costs and benefits requires the allocation of certain system costs and monetizing benefits. While evident, some benefits could not be monetized within the framework of this project and are reported separately.

6.2 Costs Identified

The costs for MSP AAMS demonstration are most significantly driven by installation and licensing fees for the ATH Airline Attila™. In addition to these expenses, the operating airline, Delta, incurred expenses in its installation and maintenance. In total:

- $415,000—ATH installation and hardware costs (only incurred the first year)
- $169,530—Delta's initial IT installation costs for the system (see below for detail)
- $960,000—ATH's monthly licensing fee ($80,000 per month)
- $9,000—Delta's IT support costs (10 hours per month at $75 per hour).

While the AAMS demonstration required additional inputs, such as ASDI feed, Delta has indicated that the company incurs these costs through other programs. As a result, for the first year, the AAMS cost Delta $1,553,530 to operate. Without the installation costs, the subsequent years would cost approximately $969,000. Furthermore, the installation cost incurred by Delta's IT installation efforts are actually for all their AAMS program installations (ATL, MSP, and DTW), though it is believed that the figure would not have been materially different if it were exclusively for this demonstration.

6.3 Direct (Primary) Benefits

6.3.1 Mechanisms of Direct Benefit

The primary mechanisms of the direct benefits of the AAMS implementation, as initially identified in the MSP demonstration are outlined in Figure 75.

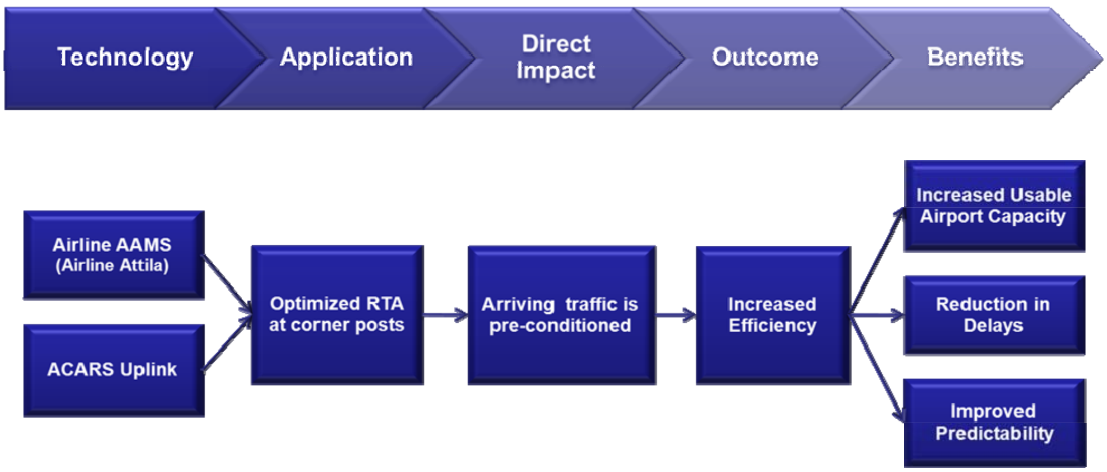

Figure 75. Direct Benefits: Benefit Mechanisms

1. Increased usable airport capacity.

    - Qualified participating aircraft receive RTAs that require speed increases to arrive earlier at the corner posts and potentially filling the empty slots forward in time. As a result, some of the otherwise lost airport arrival slots (spoilage) are recovered, thus, increasing airport arrival throughput.

2. Reduction in delays.

    - Arriving traffic is preconditioned leading to shorter arrival queues, which result in shorter total en route and in terminal area (dwell) times for both AAMS and non-AAMS flights.

    - The benefit of the demonstration of AAMS is a reduction in time and distance flown at low altitudes, thus producing saving in fuel and other airline's direct operating costs (ADOC) for both AAMS and non-AAMS flights.

3. Improved arrival predictability.

    - AAMS traffic preconditioning leads to a better on-time arrival performance, thus improving airline operational efficiency and quality of service. With improved arrival predictability the airlines will be able to plan and manage their resources more efficiently (gates, ground crews, maintenance, flight and cabin crews, etc.). Passengers will receive a better service with more predictable arrival times and fewer missed connections.

6.3.2 Reduction in Delays

6.3.2.1 Dwell Times

The dwell time aggregate benefit is presented in Table 10 below. The data represents the complete Passive Phase set and the full Active Phase set and demonstrates consistent and significant reduction in dwell times.

Table 10. Aggregate Dwell Times for Passive and Active (minutes, seconds)

	Passive Phase Data (minutes)		*Active Phase Data (minutes)*		*Difference in Means (seconds)*
	Mean	*St. Dev.*	*Mean*	*St. Dev.*	*Active - Passive*
SHONN East	14.7	17.0	13.2	13.5	-91*
SHONN West	16.1	11.4	15.6	19.7	-27*
OLLEE East	15.8	12.1	13.2	18.9	-157*
OLLEE West	17.1	9.1	16.3	6.4	-45*
DELZY East	17.4	9.2	12.3	25.0	-106*
DELZY West	13.2	6.7	12.5	12.0	-52*
TRGET East	17.4	6.5	16.4	11.2	-50*
TRGET West	13.3	6.6	12.8	5.7	-30*
TWINZ East	18.5	9.5	16.6	14.4	-68*
TWINZ West	13.8	13.2	13.2	7.8	-36*
BITLR East	15.7	4.0	16.2	18.4	29
BITLR West	12.0	18.4	12.1	6.4	3
TMA On	15.4	10.9	14.5	11.6	-53*
TMA Off	14.7	9.5	13.5	41.5	-73
Runways Open	15.4	10.3	14.4	13.8	-64*
Runway Closed	15.2	13.3	14.9	10.3	-20*

*** Indicates Statistical Significance**

The representative days dwell time statistics are outline in Table 11 and also show strong dwell time reductions over the passive period.

Table 11. Representative Day Dwell Times for Passive and Active (minutes, seconds)

	Passive Phase Data (minutes)		*Active Phase Data (minutes)*		*Difference in Means (seconds)*
	Mean	*St. Dev.*	*Mean*	*St. Dev.*	*Active - Passive*
SHONN East	13.9	11.1	13.2	13.5	-42*
SHONN West	15.9	11.8	15.6	19.7	-18
OLLEE East	14.8	11.6	13.2	18.9	-95*
OLLEE West	16.8	8.7	16.3	6.4	-31*
DELZY East	16.3	6.8	15.6	25.1	-40*
DELZY West	12.9	5.9	12.3	12.0	-36*
TRGET East	16.4	3.9	16.6	11.3	12
TRGET West	13.1	5.6	12.7	5.7	-21*
TWINZ East	17.2	8.2	17.3	14.4	4
TWINZ West	13.6	10.3	13.1	7.8	-27*
BITLR East	15.4	3.8	16.2	18.4	46
BITLR West	12.0	1.8	12.1	6.4	3
TMA On	14.8	9.2	14.5	11.7	-21*
TMA Off	13.4	7.6	13.5	41.5	7
Runways Open	14.8	8.7	14.4	13.8	-25*
Runway Closed	14.9	10.8	14.8	14.2	-5

*** Indicates Statistical Significance**

6.3.2.2 Multiple Regression Estimation of Dwell Times

Multiple regression analyses were performed on the data collected from the active and passive periods to quantify the temporal benefits of the AAMS. In addition to an aggregate data regression run on all observations, three additional regressions were run on the data to insure the robustness of the results. The second regression was run on all Delta flights in the demonstration. The third and fourth parameter estimates, as provided in Table 12, were calculated in regressions for flights on representative days and participating (Delta) flights on these days. The additional regressions are intended to assist in determining if the participating traffic had any difference in benefit and to assist in determining if any difference in benefits could be attributed to operation on representative days.

As previously stated, the first six regression terms, parameter values for which are presented in Table 12, are of most interest. The variables not included in the first six, and the TMA variable, control for variation outside the control of the AAMS program. In particular, the arrival configuration has a significant impact on the dwell times.

The regression result suggests that the system saw benefits in the form of reduced dwell times with statistical significance in the ACT parameter. Interestingly, the results do not indicate that optimized and complied flights (OPTC) experienced significant improvements over other traffic, however flights that moved forward to meet an RTA (OPTF) did see benefit. TMA operation (TMA and TMA*MOV) appears to have been detrimental to AAMS dwell time improvements in all four regressions. Between the four regressions it should be noted that the ACT parameter offers the greatest reduction for the participating traffic with a reduction of 55 seconds while all observations show a reduction of 50 seconds, representative days a reduction of 23 seconds, and 20-second reductions for Delta flights on representative days.

Table 12. Parameter Estimates for Dwell Time Regression Analyses

	All Observations		*Participating Traffic*		*Representative Days*		*Delta on Rep. Days*	
Regression Terms	Coefficient (seconds)	t-Statistics	Coefficient (seconds)	t-Statistics	Coefficient (seconds)	t-Statistics	Coefficient (seconds)	t-Statistics
(Constant)	933*	94.15	875*	44.11	888*	86.44	810*	37.04
ACT	-54*	-15.80	-55*	-6.62	-23*	-6.77	-20*	-2.33
OPTC	-10	-1.00	-10	-0.88	-10	-1.02	-10	-0.86
OPTF	-29*	-2.44	-27	-1.98	-29*	-2.50	-26	-1.87
OPTS	-27	-1.57	-22	-1.18	-24	-1.45	-18	-0.94
TMA	42*	4.71	113*	6.05	65*	7.01	155*	7.51
TMA*MOV	28*	2.74	23	1.91	27*	2.70	20	1.64
RW CL	20*	4.92	18*	2.14	22*	5.61	21*	2.42
SHONNE	-111*	-14.43	-124*	-10.08	-132*	-16.85	-148*	-11.16
OLLEEW	52*	7.03	9	0.53	49*	6.69	10	0.55
OLLEEE	-80*	-9.18	-104*	-4.66	-111*	-12.52	-136*	-5.59
DELZYW	-185*	-26.06	-202*	-15.66	-190*	-26.92	-211*	-15.59
DELZYE	42*	5.27	21	1.41	13	1.58	-12	-0.75
TRGETW	-169*	-21.31	-182*	-8.70	-170*	-21.50	-182*	-8.22
TRGETE	68*	7.22	77*	2.92	44*	4.65	45	1.57
TWINZW	-142*	-23.43	-148*	-13.25	-144*	-23.78	-150*	-12.72
TWINZE	123*	18.92	125*	10.00	93*	14.18	91*	6.76
BITLRW	-225*	-24.89	-239*	-12.30	-219*	-24.60	-232*	-11.50
BITLRE	9	0.46	24	0.50	6	0.33	23	0.45

*** Indicates Statistical Significance**

6.3.3 Arrival Performance and Predictability

Arrival predictability is addressed by estimating the percentage of flights that arrived as scheduled (A0) and within 15 minutes of schedule (A14) in both data collection periods. Table 13 presents on-time arrival and taxi performance for the overall sample of passive and active days. Using representative days to try to filter away irregular operations, Table 14 presents the performance figures for representative day operations.

Table 13. Aggregate On-Time Arrival and Taxi-In Performance

	All Passive Phase	*All Active Phase*	*Active Phase OPTC*
	Percent of Flights	*Percent of Flights*	*Percent of Flights*
Delta Flights Arrived as Scheduled (A0)	60.5	77.3	83.5
Delta Flights within 15 minutes (A14)	80.1	91.1	93.1
All flights arrived as scheduled (A0)	59.5	74.8	82.4
All Flights within 15 minutes (A14)	79.5	89.9	91.9
Flights Taxi In as Scheduled	68.5	66.5	66.8

Table 14. Representative Day On-Time Arrival and Taxi-In Performance

	All Passive Phase	*All Active Phase*	*Active Phase OPTC*
	Percent of Flights	*Percent of Flights*	*Percent of Flights*
Delta Flights Arrived as Scheduled (A0)	64.7	77.6	83.9
Delta Flights within 15 minutes (A14)	84.3	91.3	93.2
All flights arrived as scheduled (A0)	63.7	75.2	82.6
All Flights within 15 minutes (A14)	83.8	90.1	92.1
Flights Taxi In as Scheduled	70.1	66.6	66.9

As indicated by the percent of flights that arrived as scheduled and within 15 minutes of scheduled times, the flights in both Active Phase sets demonstrated better on-time arrival performance. In addition, optimized and complied flights displayed better on-time performance than the other flights in the same periods while taxi-in performance was slightly lower during the Active Phase.

6.3.4 Average Fuel Consumption

While many factors play a role in fuel consumption at the various stages of flight, the AAMS operational benefits on fuel consumptions can most reliably be seen in the dwell fuel consumption. Aggregate dwell fuel reductions, as presented in Table 15, amounted to approximately 66 pounds of fuel per arrival for all flights and approximately 32 pounds for arrivals on representative days.

Table 15. Dwell Fuel for Passive and Active Phases (pounds)

	Passive Phase		*Active Phase*		*Difference in Means*
	Mean	*St. Dev.*	*Mean*	*St. Dev.*	*Active-Passive*
All Flights	892	596	826	562	-66
Representative Days	857	534	825	562	-32

The total fuel consumed by arriving flights at MSP operated by Delta, outlined in Table 16, indicates that, while subject to a myriad of other factors, average fuel consumption was reduced by 662 pounds of fuel with a reduction of 514 pounds for the subset of flights on representative days.

Table 16. Trip Fuel for Delta Flights in Passive and Active Periods (pounds)

	Passive Phase		*Active Phase*		*Difference in Means*
	Mean	*St. Dev.*	*Mean*	*St. Dev.*	*Active-Passive*
All Flights	20,531	25,692	19,869	20,532	-662
Representative Days	20,379	25,513	19,865	20,547	-514

6.3.5 Dwell Fuel and Monetized Dwell Time Benefits

The reductions in dwell times outlined in the regressions for the active and passive periods can be used to develop dollar values for the impact of the AAMS on the airspace's traffic. From the statistically significant variables in the regressions AAMS is responsible for the three of the parameters. The ACT and OPTF parameters offer improvements in dwell times and, as a result, reductions in fuel consumption. Similarly, the TMA*MOV produced an increase in dwell time and resultant fuel consumption.

For the subsequent calculations it should be noted that there were 27,438 Delta arrivals, 96,330 total air carrier arrivals, 2,293 air taxi arrivals, and 3,021 general aviation arrivals during the six month of active AAMS.

6.3.5.1 Dwell Fuel Benefit

To estimate the fuel savings for the aircraft involved, the calculated dwell time savings for the corresponding parameters are matched with the BADA low altitude consumption figures for each aircraft type. As noted in the initial discussion of the regression results, the impact of regressing on all days or only representative days offers a range of benefit, presumably due to the effect of snowfalls. The results of the fuel savings estimations for using the all days and representative days regressions are outlined in Table 17.

Table 17. Dwell Fuel Benefit (pounds)

	All Observations	*Representative Days*
Impact Over 6 Months	*Fuel Saved (pounds)*	*Fuel Saved (pounds)*
ACT	4,169,179	1,775,761
OPTF	199,767	199,767
TMA*MOV	(259,545)	(250,276)
Total	**4,109,401**	**1,725,252**
Annualized Total	**8,241,381**	**3,459,985**

The fuel savings calculated in Table 17 are not used in subsequent monetization calculations as the fuel savings are rolled into the Aircraft Direct Operating Costs (ADOC) category.

6.3.5.2 Monetized Dwell Time Benefits

The main benefits of the AAMS installation that can be monetized are the reductions in the ADOC. The impact of the dwell time reduction on ADOC is calculated in a manner similar to the fuel benefit. In this case, the appropriate reductions are used with ADOC figures for the traffic type found in the “FAA Economic Analysis Guide for 2011”. The ADOC values for air carriers, air taxis, and general aviation are \$69.80, \$20.00, and \$11.40 per airborne minute, respectively. These values were then multiplied by the total time saved for each aircraft category which in turn was calculated by determining how many flights meet the description of the category and each of the relevant regression parameters. For example, there were 96,330 air carrier flights in the active period that saved 86,697 minutes as being an active flight. Of these air carrier flights, 6,679 were OPTF Delta flights that saved an additional 3,228 minutes while the 8,855 moved Delta flights under TMA operation gained a total of 4,232 minutes of dwell time. The impact has been calculated and presented in Table 18 and are calculated with only representative days and all observations.

Table 18. Dwell Time Aircraft Direct Operating Cost (ADOC) Benefits

	All Observations	*Representative Days*
Benefit Over 6 Months	*ADOC Savings*	*ADOC Savings*
Delta Air Lines	$1,660,545	$681,341
System Wide	$6,113,412	$2,599,626
Annualized Delta	**$3,330,214**	**$1,373,975**
Annualized System	**$12,328,152**	**$5,242,340**

In addition to the ADOC benefits, a value can be assigned to the Passenger Value of Time (PVT). The PVT is estimated by matching the dwell time reductions for air carriers discussed previously with the FAA 2011 average capacity, 108.4 passengers, with the average load factor, 82.1%, with the PVT rate of $44.20 per passenger per hour. Once more, the values for the two regressions are provided in Table 19.

Table 19. Dwell Time Passenger Value of Time Benefit

	All Observations	*Representative Days*
	PVT Benefit	*PVT Benefit*
Over 6 Months	$1,660,545	$681,341
Annualized	$6,113,412	$2,599,626

6.4 Indirect (Secondary) Benefits

While the indirect benefits associated with the AAMS generally cannot be quantified within the framework of this project an acknowledgement of these benefits provides insights into the value of AAMS.

6.4.1 Environmental

Environmental concerns place significant constraints on sustainable growth for aviation and, according to the FAA, should be addressed when assessing any operational improvements. In the AAMS demonstration project there are two potential environmental benefits—reduced noise, and reduced emissions.

6.4.1.1 Reduced Noise

As previously demonstrated, the AAMS operations resulted in shorter dwell times for arriving traffic comparing to the passive operation period. Consequently, arriving aircraft generate less noise at low altitudes in the vicinity of the airport. The exact estimation of noise reduction due to shorter dwell time is beyond the AAMS demonstration project scope. However, it is the research team's consensus that reduced noise is one of the environmental benefits of the AAMS.

6.4.1.2 Reduced Emissions

Aircraft jet engines, like many other vehicle engines, produce carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), unburned or partially combusted hydrocarbons (also known as volatile organic compounds (VOCs)), particulates, and other trace compounds. A small subset of the VOCs and particulates are considered hazardous air pollutants (HAPs). Aircraft engine emissions are roughly composed of about 70 percent CO_2, a little less than 30 percent H2O, and less than 1 percent each of NO_x, CO, SO_x, VOC, particulates, and other trace components including HAPs. Combustion of one pound of fuel yields 3.15 pounds of carbon dioxide gas. Carbon dioxide emissions are therefore 3.15 times the mass of fuel burned. The estimated annual CO_2 reductions for the AAMS operations using the representative days analysis is 10,898,953 pounds of CO_2 per year. Similarly, the figure using the all days data the gain is 25,960,350 pounds of CO_2 per year.

6.4.2 Safety and Productivity

The research team has consulted with multiple subject matter experts in the fields of safety, air traffic control, and airline operations management, including Delta Air Lines operations personnel, dispatchers and ATC specialists, and concluded that the AAMS operations has not affected the areas of safety and productivity of airline and ATC personnel. Consequently, there are no indirect benefits or disbenefits to report in the areas of safety and productivity.

6.5 Cost-Benefit Analysis Summary

The CBA of the AAMS has identified a suite of benefits that could be realized as early as the first year of operation. All cost and benefit figures are in 2011 dollars and annualized to facilitate comparison of costs and benefits on the same scale. PVT is not included and the Cost Benefit Analysis and reported separately. Also, the AAMS benefits that were identified in Section 4 which could not be monetized are not included in the Cost Benefit Analysis, making it intentionally conservative. This conservatism is extended to not include any benefits Delta may realize through Delta Connection operations in any values calculated concerning benefits to Delta.

One of the main considerations of a CBA is the selection of the evaluation period, which is the number of years over which the benefits and costs of an investment should be considered. Typically, the economic life and/or requirement life are of concern in determining the evaluation period. The economic life is the period over which the asset can be expected to meet the requirements for which it was acquired in a cost-effective manner. The requirement life is the period over which the benefits of the asset will be greater than the costs of producing it through the most cost-effective means. The FAA generally uses an economic life span of 20 years for Cost-Benefit Analyses of major infrastructure projects. However, the AAMS by and large is software with an uncertain economic life span. While functional obsolescence is not evident for properly licensed, maintained, and regularly updated software, technological and economic obsolescence should be considered. For example, the AAMS may become technologically obsolete due to increasing productivity and technological advances over time. Economic obsolescence is a reduction in the value of an asset due to events that are typically outside of the control of the owner of the asset, such as legal or regulatory restrictions, changes of social or economic conditions, etc. Since we cannot predict future technological advances or regulatory restrictions, properly maintained software does not become obsolete in any predictable way. While the value of tangible assets is typically depreciated using some depreciation schedules, software value tends to vary over time by a relatively small amount until the usually unpredictable point in time when a decision is made to replace it. Consequently, companies are establishing their own rules on how to evaluate investments in Information Technology (IT) infrastructure and software. In order to remain consistent with the CLT analysis, the Cost-Benefit Analysis is primarily focused on first year performance. While this one year requirement is aggressive, it is consistent with the FAA mandate to identify costs and benefits within the mid-term time frame of 2013-2018.

As presented in Equation 1, the B/C ratio is defined as the present value of benefits divided by the present values of costs.

$$B/C = \frac{\sum_{t=0}^{k} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{k} \frac{C_t}{(1+r)^t}} \qquad (1)$$

Where:

> *Bt* is annual benefits at time *t* in constant dollars;
> *Ct* is annual costs at time *t* in constant dollars;
> *r* is annual real discount rate;
> *t* is an index running from 0 to k representing the year under consideration.

Since the requirement period is one year, the benefits and costs do not need to be discounted and the B/C ratios are calculated simply by dividing benefits by corresponding costs. As discussed above, the CBA presented in this section is conservative by design. Some benefits cannot be monetized in the framework of this demonstration project (e.g., improved arrival predictability, reduced emissions and noise), while others intentionally are not included in the analysis (such as PVT).

Table 20 outlines these benefits and costs in the first year for the single-user AAMS based on Delta's involved costs. Also identified and presented are benefits not directly recoverable to an airline operator. The cost-benefit ratios indicate that under the representative days regression the project would nearly break even to Delta, while the all observations result would show strong gains to Delta. The system stands to gain significantly in either result.

Table 20. Costs and Benefits of AAMS in the First Year of Operations

	All Observations	*Representative Days*
Total System Costs	$1,553,530	$1,553,530
Total System Monetized Benefits	$12,328,152	$5,242,340
System Benefit/Cost Ratio	7.94	3.37
Total Costs (Delta Mainline)	$1,553,530	$1,553,530
Total Monetized Benefits (DL Mainline)	$3,330,214	$1,373,975
Benefit Cost Ratio (Delta Mainline)	2.16	0.88
Benefits not included in the CBA		
Improved Arrival Predictability	Flights arrived in the active period demonstrate better A0 and A14 performance. Optimized and complied flights show A0 and A14 improvement over other active flights	
Passenger Value of Time	$6,113,412	$2,599,626
Reduced CO_2 Emission (pounds)	25,960,350	10,898,953
Reduced Noise	With shorter dwell times, flights produce less noise at low altitude in vicinity of airport	

7 ISSUES AND OBSERVATIONS

7.1 Impact of Weather

As previously discussed, the weather during the Passive and Active Periods were remarkably different. In particular, the weather during the Active Phase was considerably more restrained and featured few days with major snow events to impact operations. Ostensibly, the result of this dichotomy in the weather is that the impact of representative days on the regression analyses is considerable.

7.2 Pilot Participation and Compliance Rates

As presented and discussed in Section 5.2.3.6, the optimization pool (Delta Air Lines flights) in the Active Phase represented 27.3% of total arrivals at MSP. RTAs were issued to 22.3% of overall flights, 9.2% of flights moved in response to the RTAs, and 7.7% of flights were optimized (complied with the RTAs). Obviously, the AAMS benefits would be higher with better pilot participation and compliance rates, which were between 30% and 37% during the Active Phase. In addition, the compliance rate exhibited a small decrease over the active period. The decrease can be explained by Delta Air Lines decision to stop transmitting the RTAs to those flights that did not require moving to meet their RTAs beginning February 2012.

8 CONCLUSIONS – RECOMMENDATIONS

The CBA of the Delta/MSP AAMS Demonstration Project identifies costs and benefits (both direct and indirect) of a single-user AAMS concept using a commercially available ATH Airline Attila™ system. The analysis of operational data collected in pre- and post AAMS implementation periods suggests that there are observable system-wide and airline-specific benefits. The Cost-Benefits ratios estimated using only ADOC-based monetized benefits imply that the AAMS-related costs could be quickly recovered. Using the worst case regression the project would nearly break even on the first year and produce positive results in subsequent years while the more optimistic result shows strong benefits from the start of the program. In addition, the analysis provides evidence of benefits that cannot be monetized within the framework of this project: Improved arrival predictability and environmental benefits. Also, while the PVT was monetized, it was not included in the CBA.

The AAMS-MSP demonstration project confirms the viability of the AAMS concept and suggests that if implemented, the AAMS will generate considerable benefits to participating airlines as well as the overall AAMS airport operations.

APPENDIX A: AIRLINE COMMENTS

Delta Air Lines, Inc. first implemented the Attila system in ATL during the spring of 2006. Due to the Attila efficiencies realized in ATL, Delta expanded the system to include MSP and DTW arrivals in September 2011. Benefits have been seen through significant fuel savings as well as improved utilization of airport capacity.

Delta Air Lines views the Attila aircraft arrival management system as complimentary to FAA TMA in the terminal area by looking well beyond the current TMA Freeze Horizon and adjusting aircraft speeds to sequence aircraft according to Delta's business priorities. Although FAA terminal traffic management follows a first come, first served method, airlines have long wanted more input into the sequencing and prioritization of aircraft arrivals. Attila AAMS provides the mechanism for Delta to accomplish some of this desire for more input into sequencing the arrival stream. Unfortunately, while the Attila AAMS and FAA TMA are relatively complimentary to each other, we do occasionally see conflicts and contradictory instructions from the two systems due to a lack of coordination. Delta feels that integrating an Attila AAMS system with TMA in NEXTGEN, and accepting airline input and sequencing arrivals based on airline business priorities, would be a huge step forward and would improve airspace and fuel efficiency.

As this aircraft arrival management system concept develops, it must include slot swapping functionality when the TMA CAP data becomes available to the industry. This will be critical to operators being able to prioritize based on customer and business requirements.

APPENDIX B : ACRONYMS

Acronym	*Meaning*
AAMS	Aircraft Arrival Management System
ACARS	Aircraft Communications Addressing and Reporting System
ADOC	Aircraft Direct Operating Cost
AOC	Airline Operations Center
ASDI	Aircraft Situational Display to the Industry
ATC	Air Traffic Control
ATH	ATH Group, Inc
ATL	Hartsfield-Jackson Atlanta International Airport
BADA	EUROCONTROL's Base of Aircraft Data
CF	Critical Flights
CLT	Charlotte Douglass International Airport
DAL or DL	Delta Air Lines, Inc. (based on ICAO and IATA identifiers)
DME	Distance Measuring Equipment
DTW	Detroit Metropolitan Wayne County Airport
FAA	Federal Aviation Administration
FMS	Flight Management System
IROP	Irregular Operations
MSP	Minneapolis-St. Paul International Airport
NAS	National Airspace System
NextGen	Next Generation of Air Transportation System
NM	Nautical Miles
OOOI	(Electronically Captured) Out, Off, On and In aircraft data
OPTC	Optimized and Complied
PVT	Passenger Value of Time
RTA	Required Time of Arrival
TCI	Tactical Cost Index
TMA	Traffic Management Advisory
TBO	Trajectory Based Operations