Airport Departure Flow Management System (ADFMS)

Final Report

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EXECUTIVE SUMMARY

The goal of Team AirportDFM was the definition, preliminary design, and analysis of the implementation of an Airport Departure Flow Management System (ADFMS) at Philadelphia International Airport (PHL).

ADFMS implementation at PHL will improve the efficiency of the PHL airport departure queue, reducing excess taxi time spent on airport surface taxiways, resulting in lower fuel consumption for airlines and lower aircraft emissions into the atmosphere. Lower fuel consumption reduces airline operational costs. ADFMS will increase efficiency within the departure queue by eliminating the first-come, first-served (FCFS) queuing model and replacing it with a new paradigm in which aircraft are sequenced into the departure queue via ADFMS support to PHL Ramp Control operators.

ADFMS enables reduced operating costs through the implementation of two important system functions: Departure Slot Scheduling and Departure Queue Management. Departure slot scheduling levels demand across the PHL airport capacity. Once the airlines have scheduled departure slots in advance, ADFMS enables airlines to trade departure slots amongst themselves to satisfy their needs and objectives. On departure day, ADFMS enables Ramp Control to sequence flights into the departure queue by dividing the queue into physical and virtual components, assigning expected pushback times within expected pushback windows that allow aircraft to remain at their gates as long as possible while still meeting their assigned departure slot times. The time at the gate is the virtual queue. The controlled metering of departure aircraft into the physical queue at the effective airport departure rate reduces excess taxi times by decreasing conflicts between taxiing aircraft on PHL ramps, aprons, taxiways, and the threshold of the departure runway. The Trade Brokering function of ADFMS allows airlines to trade slots within the virtual queue to meet airline needs while maintaining departure queue efficiency.

Implementation of ADFMS will require an initial investment of $5 million at PHL; with $2 million annual operating costs over a ten-year system lifecycle, the ADFMS project will realize a net present value of $22 million to the stakeholder airlines operating at PHL. Estimates show that the project will pay off in the second year of operation.

Team AirportDFM developed and analyzed the ADFMS concept and design for PHL through domain research and stakeholder analysis; concept and requirements development; operational and system architecture development; PHL departure queue modeling, simulation, and analysis; and cost benefit analysis. Using a systems engineering approach with an operations research analysis component, the multifunctional team of GMU Systems Engineering and Operations Research (SEOR) Department graduate students completed this design and analysis over the course of the 2010 Spring Semester. Team AirportDFM proposed the project definition and initial technical approach at the onset of the semester with a supporting work breakdown structure (WBS) and project plan. Team AirportDFM executed the project plan with slight refinements due to the progressive elaboration of the project.

This report provides the results of this semester-long effort. The main body describes the high level background, approach, concept, requirements, architecture, model, simulation, analysis, results, and recommendation. Most of the major paragraphs of the main body are supported with an appendix with detailed information and figures that elaborate on project results. The project management approach and team biographies are located in Appendix G of this report.

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1. INTRODUCTION

1.1 Background

Air Traffic Management (ATM) or Air Traffic Flow Management (ATFM) systems and procedures have been effectively implemented for air operations between major U.S. airports to include enroute, arrival, and departure separation. The U.S. airspace is controlled by the Department of Transportation's Federal Aviation Administration (FAA) air traffic control systems, which includes a tiered system of Air Traffic Control operators that oversee arrival and departure (Tower Control), approach control (Terminal Radar Approach Control – TRACON), enroute control (Air Route Traffic Control Centers – ARTCCs), and overall coordination and control (Air Traffic Control System Command Center – ATCSCC) of the National Airspace System (NAS). The Air Traffic Control system is supported by an automated system of systems that effectively controls the separation and throughput of air traffic.

The ATCSCC's implementation of Ground Delay Programs (GDPs) improve airline efficiency by delaying aircraft departures at origination airports as an improvement to delaying airport arrivals at destination airports that use the method of the more costly holding pattern. The use of GDPs provide a more cost effective option to holding patterns through the reduction in fuel consumption, reduced aircraft operating hours (reduced aircraft maintenance), reduced emissions, and reduced piloting hours. GDPs also improve airline safety as separation on the ground is significantly less complicated than airborne separation and much less catastrophic.

All major airports have a Ramp Control or Ground Control procedures for the management of separation of all surface movement on airport taxiways, inactive runaways, holding areas, transitional aprons, and intersections. However, the procedures do not provide for efficiency of airline operations on the ground. Airlines and airplanes establish a queue for departure at the runway threshold. The queue is not controlled, but instead a free-for-all where airlines depart their gates when ready (and approved by Ground Control) and taxi based upon instructions from Ground Control personnel. Departing aircraft establish a departure queue that is not based upon departure time or announced arrival time, but instead based upon a first-come, first-served basis, where Ground Control's primary purpose is to ensure separation and safety. Once established within a queue on a taxiway, the queue cannot be reordered if the width and configuration of the airport aprons, taxiways, and runways cannot support the simultaneous movement of aircraft within what is normally restricted space.

Stakeholders in the air transportation industry have long recognized the need for an automated system to better manage and improve the operation of the departure queue. The ability to establish a virtual queue for departure that would improve the efficiency for participants is highly desired. This virtual queue would hold aircraft at its gate until the right time so that the aircraft could taxi directly to the departure runway with minimal taxiway delays as well as best support airlines in meeting departure and arrival times that are so important to airline rating systems.

1.2 Stakeholder Identification/Analysis

Based on experiences and past knowledge, Team AirportDFM analyzed and categorized ADFMS stakeholders appropriately. Extensive research was conducted to acquire all stakeholders' best interests. The identification of stakeholders was carried out by analyzing complexity, uniqueness, participation, and methods. The complexity depended upon the management of resources dealing with understanding and managing the complex relationships between humans and resources upon which they depend. In each situation, the analysis required an understanding of local conditions and realities. Following such an approach in which everybody can participate, the decisions of the management are accepted conveniently by those involved and who have been taking part in the decision-making process. Consequently, time, resources, and attention can be allocated to the needs and expectations of all actors.

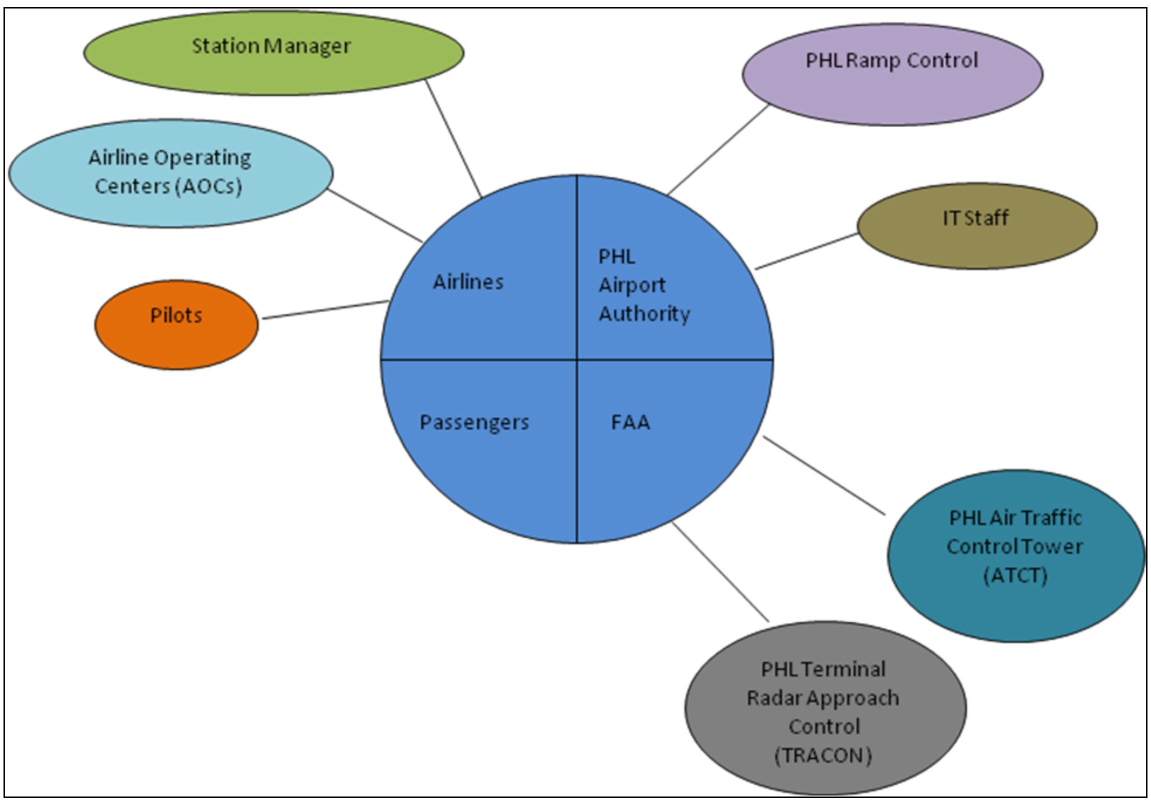

Figure 1 Stakeholders

An airport departure management system's stakeholders are all those who could and should have a stake in the development, planning, organization, management, and maintenance process. The stakeholders identified were:

- Airlines: Station Manager, Airline Operating Centers, Pilots
- Airport Authority: Ramp Control, Information Technology Staff

- Federal Aviation Administration: Air Traffic Control Tower (ATCT), Terminal Radar Approach Control (TRACON)
- Passengers

The departure management system will assist all stakeholders in the following ways:

- Station Manager – Help manage schedule and exchange departure slots
- Airline Operating Centers – Enable allocation of departure slots
- Pilots – Provide freedom from inconveniences of departure delays
- Ramp Control – Manage departures
- Air Traffic Control Tower (ATCT) – Optimizes the airport and flight operations
- Terminal Radar Approach Control (TRACON) – Optimizes the airport and flight operations
- Passengers – Provides benefits in terms of time and economics

1.3 Problem Statement

All major U.S. airports are scheduled with departures at peak travel periods in excess of the runway departure capacity. As a consequence of over-scheduling, and the procedures for push-back, a free-for-all occurs amongst the airlines to secure a slot in the long taxiway departure queues that occur every day. These queues result in excess fuel burn and emissions, and create unnecessary taxiway congestion. Airlines are also unable to rearrange queue positions / slots in the event of delay or disruption. A proposed solution is an automated system with operational procedures for a virtual queue model implementation using departure slots that lead to a reduction in excess taxi time for departing flights by alleviating taxiway congestion, thereby reducing fuel burn and emissions.

Team Airport DFM defined, developed, and analyzed a preliminary concept for an Airport Departure Flow Management System (ADFMS) for the Philadelphia International Airport (PHL) in which airlines reserve departure slots and are able to trade slots in the event of delay or disruption.

2. OBJECTIVE/SCOPE

2.1 The Project

The GMU Center for Air Transportation Systems Research (CATSR) requires the development of definition and design for an Airport Departure Flow Management System that would improve the collective efficiency and effectiveness of airline operations and traffic management from the gate to departure at a major U.S. airport.

Team AirportDFM has defined the requirements and developed a preliminary design of the Airport Departure Flow Management System at the Philadelphia International Airport

(PHL). Team AirportDFM has also conducted and carried out a cost-benefits analysis of the stakeholders for the proposed system.

Team AirportDFM has fulfilled its objective of defining the system requirements, creating a concept of operations, developing an initial design, and performing scenario analysis which is covered in more detail throughout the report.

2.2 Scope Definition

The scope of the Airport Departure Flow Management System (ADFMS) involves the coordination and management of airport departures at the Philadelphia International Airport (PHL) from gate push-back to departure. The terminals, gates, taxiways, and runways as well as the different number of carriers, capacity for individual aircraft as well as maximum sustainable departure rates constitute a unique physical scale and configuration for each airport. The scope of the Airport Departure Flow Management Systems (ADFMS) is the Philadelphia International Airport (PHL). The scope involves the analysis of current ground operations and departure queuing at PHL. The 'ground operations' constitute the ground traffic, movements, and sequencing of aircraft from the gate until departure. The project scope involves only the departures and does not take into account the arrivals. The effect of weather and ground delay programs (GDPs) on departure operations is also not considered. The project involves only the airlines that share common terminals, taxiways, and departure runways; general aviation aircraft are not considered as part of the scope.

Figure 2 shows the diagram of Philadelphia International Airport as it appeared during the time frame of the project.

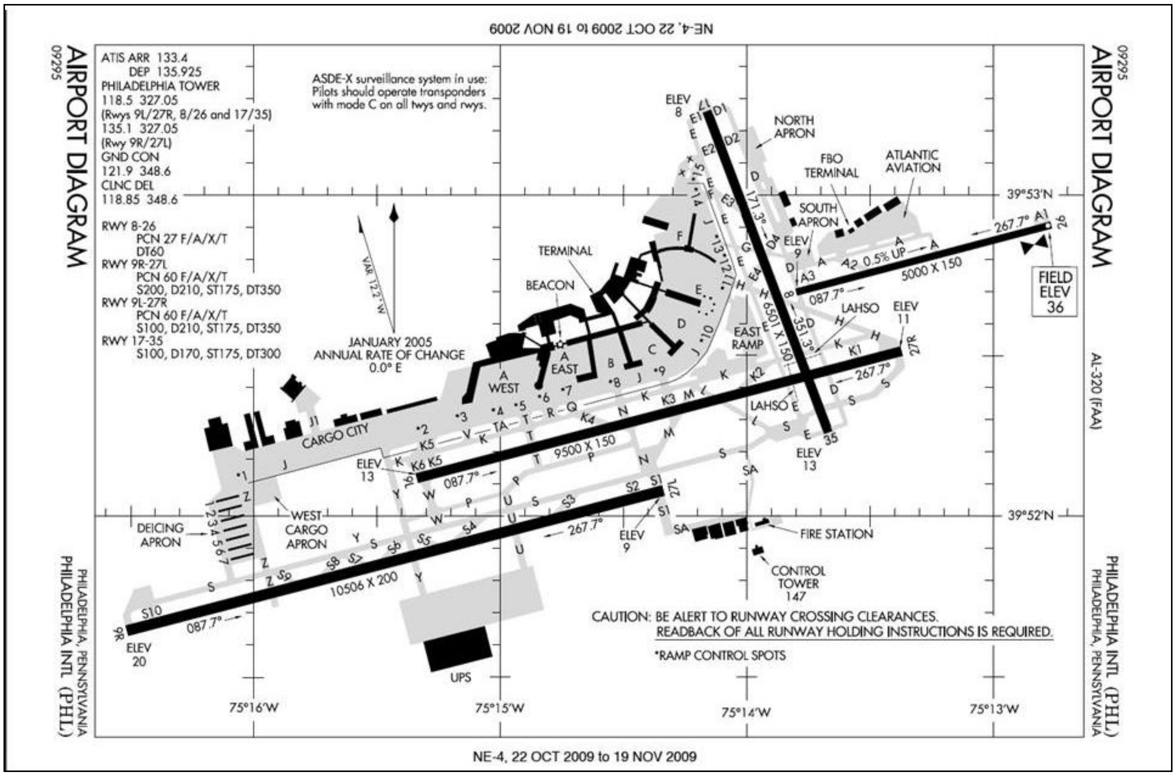

Figure 2 Airport Diagram for PHL (http://www.airnav.com/airport/KPHL)

2.3 Assumptions and Limitations

The following are the project assumptions:

- The primary cause of departure delays is over-scheduling, congestion, and simultaneous pushback of planes

The following are the project limitations:

- Data obtained does not show the cause of delay
- Data obtained does not show the departure gate
- Only one runway for departure (no runway reconfiguration)
- No reassignment of aircraft gates
- Model does not de-conflict taxiing aircraft within departure queue
  e.g. – no assignment of expected push-back times
- De-conflicted departures are manually created, become inputs to the simulation
- Simulation outputs form the basis of project results

3. TECHNICAL APPROACH

Team AirportDFM applied the V-Model Process as shown in Figure 1 DoD Systems Engineering Process, throughout the life cycle of the ADFMS. Team AirportDFM was able to complete the left side of the V-Model, the Design Processes. The right side of the V-Model was outside of the team's scope due to the schedule constraint of only 12 weeks. The detailed activities of each in-scope phase are specified below.

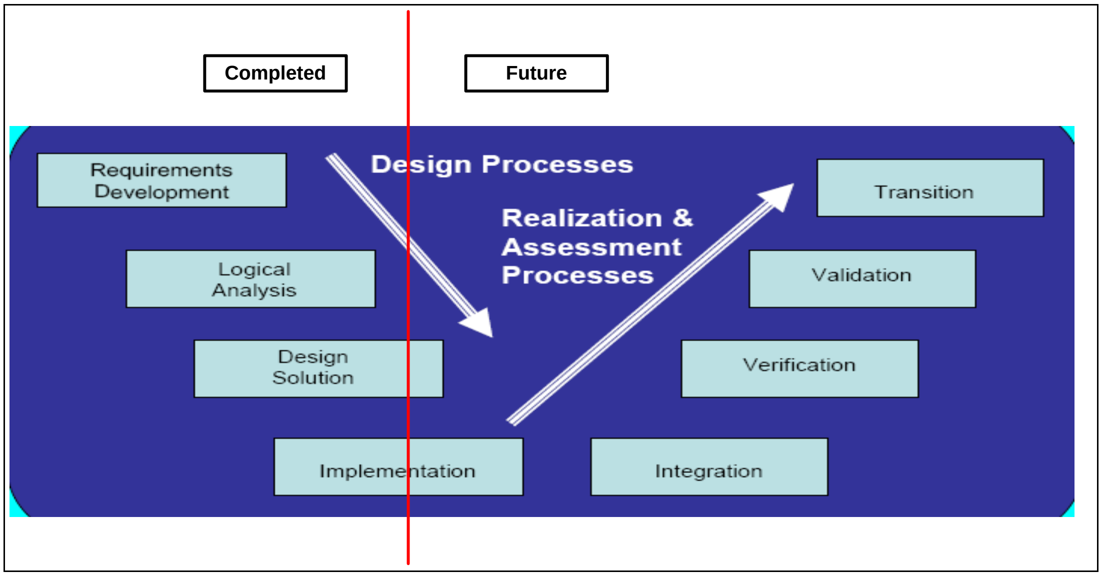

Figure 3 DoD Systems Engineering Process

3.1 Requirements Development

In this phase Team AirportDFM conducted research for the project, and met with the sponsor to understand more about the project and sponsor's requirements. Team AirportDFM was able to draft the system requirements document (SRD) and concept of operations document (CONOPs).

3.2 Logical Analysis

In this phase Team AirportDFM decomposed the requirements to obtain the system architectures that describe the relationship of the system's functional, behavioral and data flow characteristics. Team AirportDFM was able obtain the system's functional characteristics through structured analysis and the system's behavioral and data flow characteristics through object-oriented analysis. See Section 5 for detailed information on structured and object-oriented analysis. Team AirportDFM started to work on the modeling and simulation of the queuing aspect of the project as well.

3.3 Design Solution

In this phase Team AirportDFM finalized the SRD and architecture products and was able to implement the point systems for the ADFMS. Team Airport DFM was able to finalize the modeling and simulation of the queuing and performed the business case analysis for the system.

3.4 Implementation

This phase was out of the scope for Team AirportDFM, however all the preliminary work was accomplished in order to prepare for this phase in the future.

4. CONCEPT OF OPERATIONS

Team Airport DFM developed the ADFMS Concept of Operations (Appendix B) upon completion of literature review, stakeholder analysis, and sponsor meetings. A high-level Operational Concept was the starting point for both CONOPs development as well as architecture development. Once a high-level concept was derived, the Team developed the CONOPs concurrent with the functional decomposition of the system and requirements development. The Team developed a system concept that included three main capabilities/modules to the system: departure slot scheduling (slot assignment / control), departure queue management, and trade brokering, with supporting modules for alerts / notifications and reports. These are captured in the functional decomposition shown below.

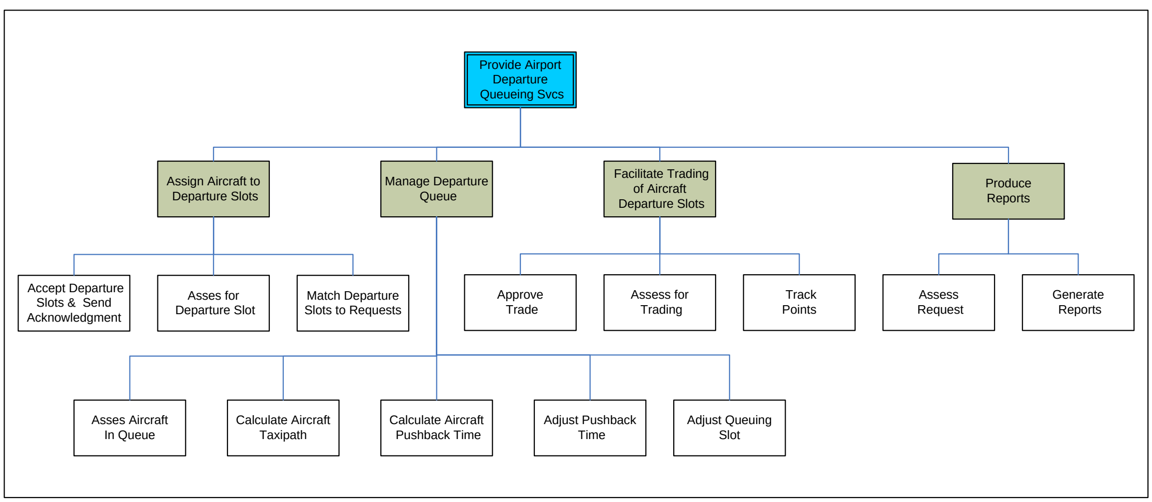

Figure 4 Functional Decomposition

The Scheduling Module provides for departure slot management: it levels demand across the airport capacity and establishes a departure queue 90 days prior to scheduled departure. The Scheduling Module assigns departure slots at the airport departure rate (ADR) of ten departures in a 15 minute period, by dividing a 15-minute Take-Off Time

Window (TOTW) into 1.5 minute intervals lettered A through J, and assigns these slots to specific flights. This is represented in Figure 5.

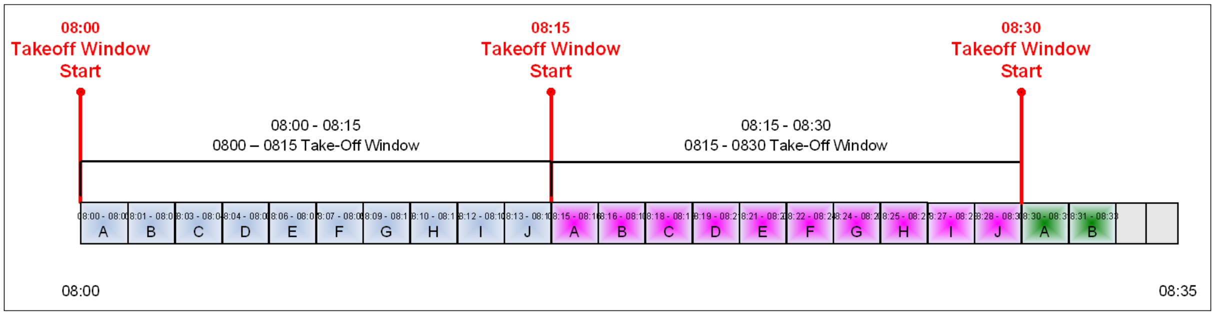

Figure 5 Departure Slot Schedule

The Queuing Module manages all departure slots and assigns flights by dividing the departure queue into physical and virtual components for each aircraft. The physical component of the departure queue begins when the aircraft pushes back from the gate and occupies space on the airport surface. The physical component ends for each flight when it takes-off from the departure runway. The virtual queue component of the departure queue begins with the departure slot assignment 90 days out, and ends when the aircraft pushes back from the gate. The portion of the virtual queue of interest for ADFMS is the portion on departure day.

The virtual queue component is further subdivided into the near-term virtual queue and extended virtual queue. ADFMS determines the physical queue component and near-term virtual queue by first determining each flight's taxi-path based upon the current runway configuration and the flight's assigned departure gate. ADFMS then calculates the required minimum taxi-time to determine the required pushback time, which is the time that the aircraft must pushback from the gate to taxi – unimpeded – to the departure runway and meet it departure slot time. The time between this required pushback time and the scheduled pushback time (the aircraft's schedule departure time per the Official Airline Guide (OAG)) becomes the expected pushback window. The Queuing Module assigns an expected pushback time within the expected pushback window in order to sequence aircraft into the physical queue with minimal conflict between maneuvering aircraft. The expected pushback window is the near-term virtual queue, which becomes the critical period for the Queuing Module. The time prior to the scheduled pushback time is the end of the extended virtual queue. Figure 6 shows the relationship between the various pushback times and the various queues.

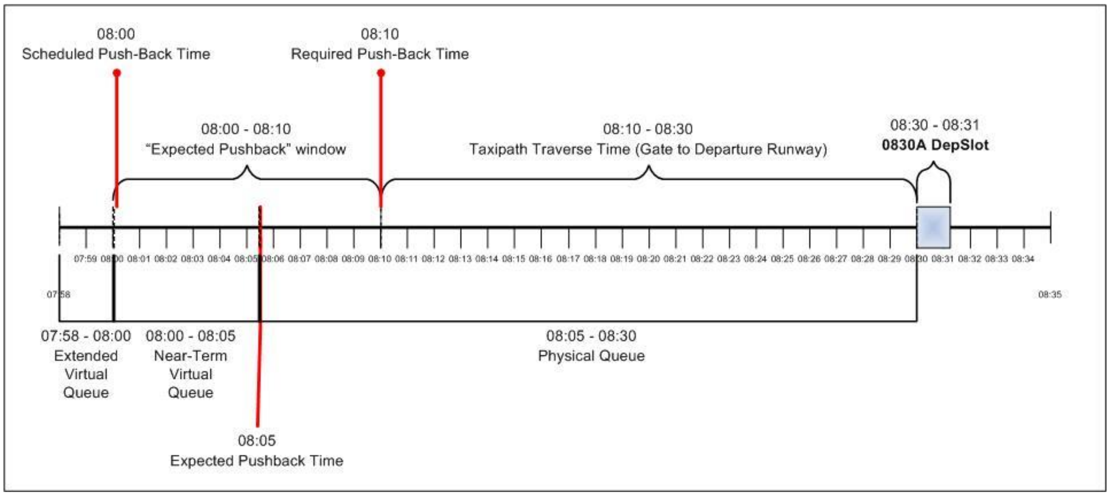

Figure 6 Queue Management

All flights must be ready for pushback at the beginning of the expected pushback window. While each flight is assigned an expected pushback time within this window, ADFMS continuously monitors all aircraft within the physical queue and the near-term virtual queue to determine the best sequencing of flights in order to minimize each aircraft's taxi-time on the PHL surface by eliminating conflicts along the taxi-paths that converge at the departure runway. ADFMS also compresses the queue by bumping flights up incrementally in the near-term virtual queue when a previously scheduled departing flight cannot meet its expected pushback time for any reason. The criticality of each flight's readiness to pushback at the scheduled pushback time – the beginning of its expected pushback window – cannot be overstated as it is necessary in order to achieve optimization of the departure queue.

The Trade Brokering Module allows for departure slots swaps within the virtual queue and also facilitates bumping up of flights in the queue when flights are required to fall-back due to unforeseen problems. Trade Brokering is supported by a nominal point system which encourages but regulates trading of departure slots amongst individual flights (and airlines) due to the individual needs of the particular flight. Results of departure slots trades within the Trade Brokering Module are fed back into the Queuing Module in order to resequence the virtual and physical queue and recalculate required and expected pushback times.

Figure 7 represents a trading situation where a flight wants to leave earlier than scheduled. The point system is based on the departure slots. Each departure slot is worth one point. With a departure slot every 1 minute and 30 seconds, if a flight wants to leave 15 minutes early, then it will require 10 points in order to make the trade. The picture below shows the allocation of 10 departure slots for every 15 minutes. In the example below, the flight is trading to leave 12 minutes earlier or 8 departure slots. The trade can occur any time within the trade window. A processing time is required for the queue manager to update the queue. The two flights conducting the trade have scheduled and expected pushback times which will need to be recalculated for the trade to occur. There must be enough time for the system to conduct this processing.

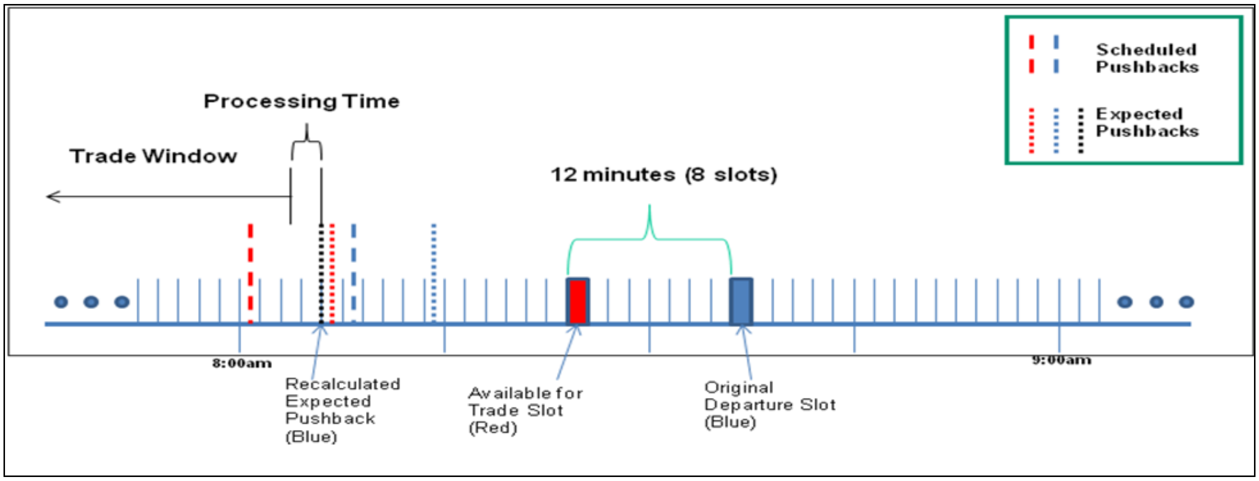

Figure 7 Trading for an Earlier Departure Slot

5. REQUIREMENTS

The ADFMS System Requirements Document (SRD) in Appendix C is the source requirements specification that establishes the basis for the design, development, performance, and test requirements for the ADFMS. The SRD was developed based on the key system capabilities. These key capabilities are as follow:

- Users Input/Departure Slots Request
- Departure Slot Lottery and Assignment
- Virtual and Physical Queue Management
- Trade Brokering
- System Notification and Acknowledgement
- Reporting

The SRD identifies functional requirements, non-functional requirements and requirements test verification methods for the system. The following are the non-functional requirements the SRD addresses:

- Performance Requirements
- Interface and Interoperability Requirements
- Operational Requirements
- Security Requirements
- Reliability and Maintainability Requirements
- Safety Requirements

The requirements were also traced to the system functions in CORE to ensure that every requirement was being addressed during system development. The requirements hierarchy tree is provided on the Team AirportDFM website.

6. ARCHITECTURE

Due to the complexity of the problem, it quickly became apparent that an architecture would need to be developed in order to examine and work through a solution. There are many stakeholders to consider and many different ways for the stakeholders to interact. Though initially only an object-oriented analysis was planned, the team later decided to also include a functional decomposition and associated IDEF0 structured analysis approach.

The current queuing method, first come, first-served (FCFS), allows for the possibility of oversubscribing the departure capacity. Airlines can schedule as many flights as they deem necessary. This leads to situations where delays are incurred due to the number of flights attempting to take off during peak periods. The proposed solution of departure slots changes this to a system where over subscription is not possible, as each flight is assigned a specific time for departure. By limiting the number of departures during these peak periods, the departure slots have an increased value as there will not be enough to handle all of the requests. Upon completing a random assignment it will be necessary for those slots to be traded. In order to allow for slot trading, a point system was created. Airlines use points to trade departure slots. The day of flight activities is the focus of the architecture which includes departure slot trading, handling delayed flights and completing a successful departure.

The architecture products that were developed are included in Appendix D.

6.1 Object Oriented Analysis

The architecture development began with defining the purpose, viewpoint and scope of the architecture. The purpose for this architecture is to assist in developing a design to implement a departure slot reservation and queuing system for airplane departures from Philadelphia International Airport (PHL). The viewpoint is that of the airport operations manager who understands the management of airplanes around the airport and the detailed operations of the airport. The scope included both operational and systems architectures.

The next step was developing the operational concept diagram (shown in the Figure 8 below) which needed to include the key stakeholders and the new concept of a departure slot. An organizational diagram was developed at this stage.

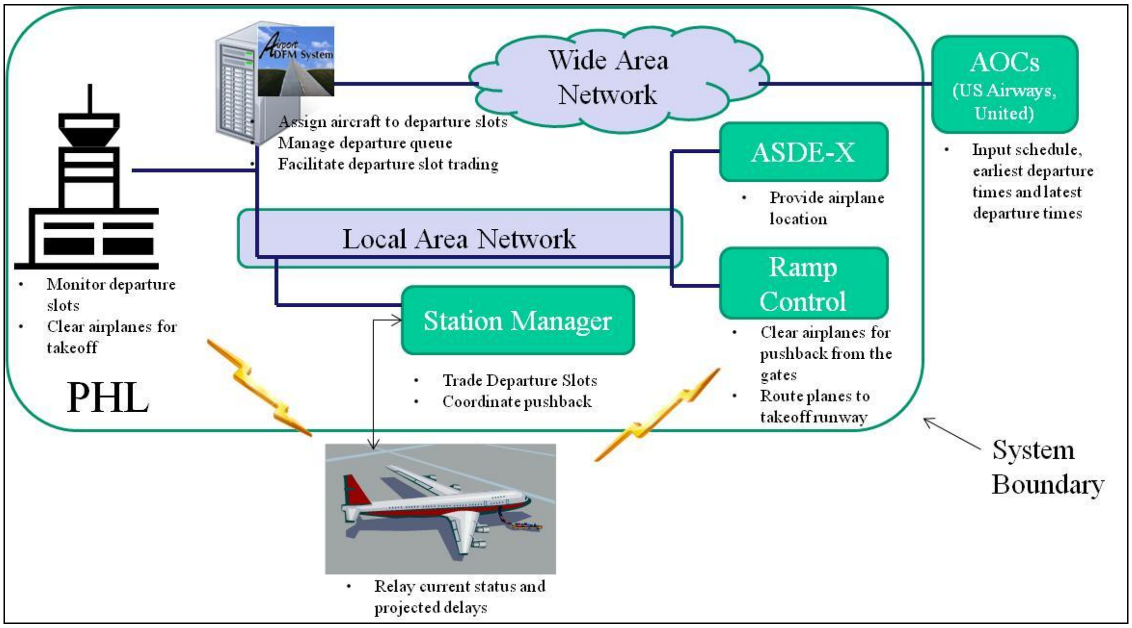

Figure 8 Operational Concept

Development of the operational concept was followed by working through use cases. A few of the key use cases were identified for further consideration. The key uses cases are the following:

- Managing overall aircraft departure (Above sea level use case)
- Attempt to secure an earlier departure slot (Sea level use case)
- Attempt to secure a later departure slot (Sea level use case)
- Aircraft taxi (Sea level use case)

In order to explore the use cases, activity diagrams were created. These were expanded upon by working through a series of sequence diagrams based on the activity diagrams. While developing the sequence of activities, it became apparent that rules needed to be developed that governed the activities. Throughout the development of the architecture, the class diagrams were updated as appropriate. This same approach was used in order to develop a systems architecture which shows the details of the system interactions.

6.2 Structured Analysis

Team AirportDFM used Integration Definition for Function Modeling (IDEF0) to decompose the requirements to show the interaction between the system's functions. Team AirportDFM developed the External Systems Diagram (A-1) first to show the relationship and the interaction of the external entities to the ADFMS. From the External Diagram (A-1), the Context Diagram (A-0) was created to show the system inputs, outputs, controls and mechanisms. From the A-0 diagram, Team AirportDFM decomposed the requirements down to Level 0, 1st tier functions (A0) diagrams and then

Level 1, 2nd tier functions (A1, A2, A3, A4) diagrams. Shown below is the A0 diagram. The other supporting diagrams can be found in Appendix D.

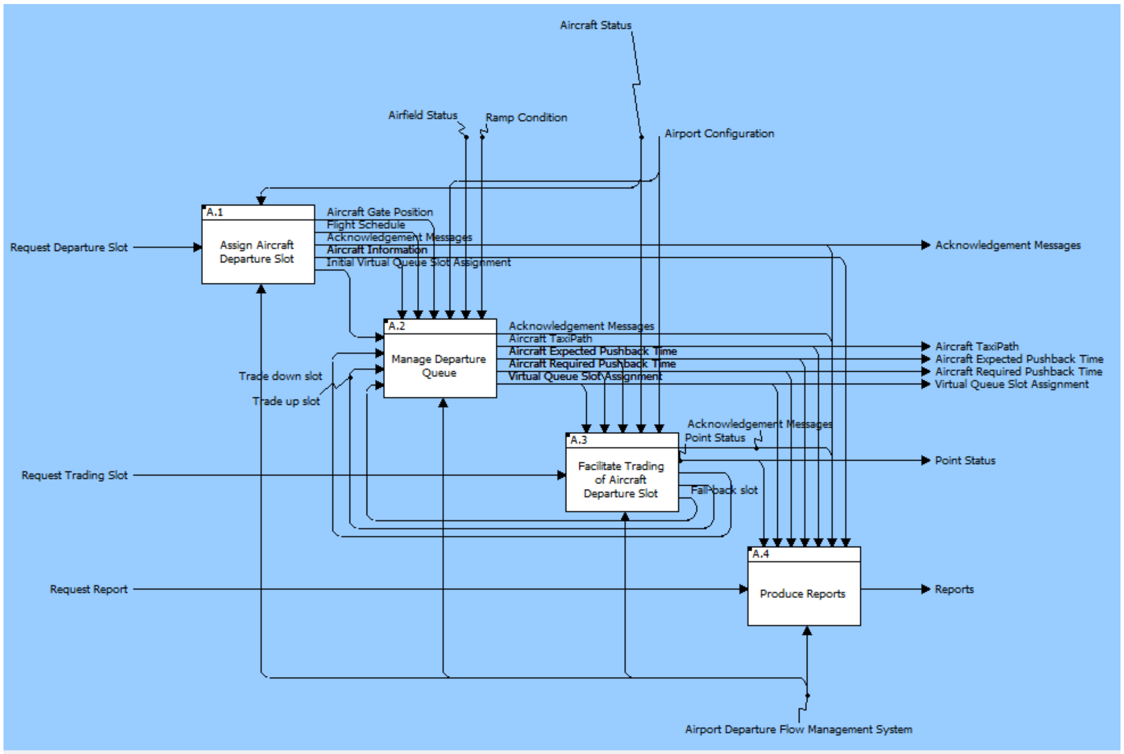

Figure 9 Structure Architecture IDEF0 A0 Diagram

7. MATHEMATICAL MODEL

When measuring the effectiveness of a queuing system, there are several metrics of interest one may consider, such as average or overall queue duration, probability of waiting, server utilization rate, or throughput. These metrics may be observed through event-oriented bookkeeping, which has to do with modeling the system and updating the status whenever an event occurs. This differs from time-oriented bookkeeping, in which the system is updated at fixed time intervals (Gross 2008).

Large queues form on the airport surface, particularly in departure rush times, when the departure demand exceeds the departure capacity of the runway system. During its taxi-out, an aircraft spends some time taxiing between the gate and the runway, some time holding to absorb any imposed delays (by downstream restrictions for example), and some time queuing behind other aircraft waiting to use the departure runway. Therefore, the long queues are a major factor in causing long taxi-out times (Idris 2001).

The ADFMS team examined flight data obtained through the Bureau of Transportation Statistics from July 08-28, 2007 and Aug 12-18, 2007 (BTS 2010). As these were peak travel periods at PHL, analyzing them allowed the team to observe conditions at the airport when demand exceeded capacity. The data available included air carrier, date, flight number, scheduled departure time, actual departure time, and wheel off time. The team developed two types of analytical models. The first model used a 14 day running average of reported flights to estimate taxi-out times. This was the method employed by the FAA's Enhanced Traffic Management System. The second model developed was a queuing model using event-oriented bookkeeping.

Running Average Model Development

For the running average model, flight data was sorted by air carrier, date, and flight number. To create running averages for taxi times of flights in the week of July 22-28, the ADFMS team used the formula:

```
If ((Date of flight x > July21) and
        (Flight Number of x = Flight Number of (x-14))),
                then sum (Taxi Time of flight (x-14) to Taxi Time of flight (x-1)).
```

Comparing the estimated with the actual taxi times of flight x allowed a computation of prediction error (Appendix E Figure 1).

Queuing Model Development

For the Queuing model, N(t) was defined as the number in the system at an arbitrary time t, or {the number of arrival in (0, t)}-{the number of services completed in (0, t)}. To obtain N(t) from the data, flights were sorted by actual pushback time and by day. The number of arrivals was the number of planes that had pushed back at time t. The number of services completed was the count of planes that had taken off at time t. The taxi-out time (*T)* was measured as the duration between the pushback time (t_{out}) and the takeoff time (t_{off}).

Regression analysis revealed that the correlation between taxi out time and number of aircraft that were present on the taxiways at pushback time (N) was low (Appendix E Figure 2). The number of departing aircraft present on the airport surface at the pushback time of an aircraft does not accurately reflect the size of the takeoff queue that the aircraft faces. This is due primarily to the passing between aircraft that takes place in the ramp areas and along taxiways. A more accurate representation of the queue size faced by a taxiing flight x is the number of planes present on the airport surface at pushback time minus the number of planes that pushed back before x but took off after flight x (denoted as N^p) plus the number of planes that pushed back after flight x but took off before flight x (denoted as N_p).

For each day, to calculate N^p, Team AirportDFM team used the formula:

If (N(t)=0), $N^p = 0$, else N^p = (rank of take-off time of flight x among all take-off times from (0,t)-1).

To calculate N_p, the team used the formula:

N_p = (rank of take-off time of flight x among all take-off times from (t_x, t of final take-off that day)-1).

Queue size for each departing flight was then calculated as $N(t)-N^p+ N_{p.}$ An example of queue size calculation is shown in the figure below. Aircraft 37 enters the system at 7:59. 30 planes had already taken off (column N), leaving 6 planes along the taxiways (column O). However, although aircraft 36 had pushed back 2 minutes before 37, it did not take off until 3 minutes after aircraft 37 did. Also, aircraft 38 and 40 pushed back after 37, but took off before it. Thus the true queue size faced by aircraft 37 is 37-30-1-1+2=7.

R9 Queue Size

A	H	L	M	N	O	P	Q	R
Pushback Number	Actual Pushback Time	Wheels-off Time	Taxi-out Time	took off count	Number Aircraft at t-out	pushed back before, took off after	pushed back after, took off before	Queue Size
34	7:53	8:12	19	28	5	0	0	5
35	7:53	8:14	21	28	6	0	0	6
36	7:57	8:25	28	29	6	0	3	9
37	7:59	8:22	23	30	6	1	2	7
38	8:00	8:20	20	30	7	2	0	5
39	8:00	8:35	35	30	8	0	4	12
40	8:03	8:21	18	31	8	3	0	5
41	8:03	8:27	24	31	9	1	0	8

Figure 12 Example Calculation of Actual Queue Size

Next, discrete probability mappings of queue size for each N (number of aircraft at t_{out}) (Appendix E Figure 3) were created. The ADFMS team also plotted taxi times encountered for each queue size and created point estimates for taxi time given queue size T(Q) by linear regression. By taking the sum of the product of the point estimates of T for each Q and the probability of Q given N, the team arrived at an expected value for taxi time given N, expressed by the equation: $T(N)=\Sigma_q(T(Q)*P(Q|N))$. In the figure below, row 129 displays the result of this calculation for N=0 to 8 as an example.

65			N								
66	T(Q)	Q Size| N	0	1	2	3	4	5	6	7	8
67	9.370	0	0.896	0.148	0.029	0.011	0.000	0.007	0.000	0.000	0.000
68	11.184	1	0.083	0.580	0.208	0.115	0.043	0.007	0.007	0.014	0.000
69	13.088	2	0.000	0.193	0.520	0.218	0.116	0.062	0.029	0.036	0.000
70	15.080	3	0.021	0.023	0.133	0.374	0.165	0.131	0.114	0.000	0.000
71	17.161	4	0.000	0.023	0.040	0.121	0.402	0.200	0.121	0.058	0.057
72	19.330	5	0.000	0.011	0.035	0.052	0.134	0.345	0.143	0.180	0.083
73	21.589	6	0.000	0.000	0.012	0.029	0.043	0.110	0.286	0.194	0.121
74	23.936	7	0.000	0.000	0.006	0.017	0.012	0.034	0.121	0.273	0.197
75	26.372	8	0.000	0.011	0.000	0.017	0.037	0.041	0.064	0.079	0.261
76	28.897	9	0.000	0.000	0.006	0.006	0.000	0.021	0.071	0.079	0.102
77	31.511	10	0.000	0.000	0.000	0.011	0.000	0.014	0.007	0.029	0.070
128											
129	T(N)	SumProduct:	9.640	12.398	13.777	16.469	18.843	20.024	21.552	23.973	26.346

Figure 13 Estimate of Taxi Time by N: T(N)=Σq(T(Q)*P(Q|N))

A quadratic linear equation through the T(N) values provided an approximate model of the expected taxi out times (Figure 14). From these, predicted taxi times and prediction error were computed for each flight.

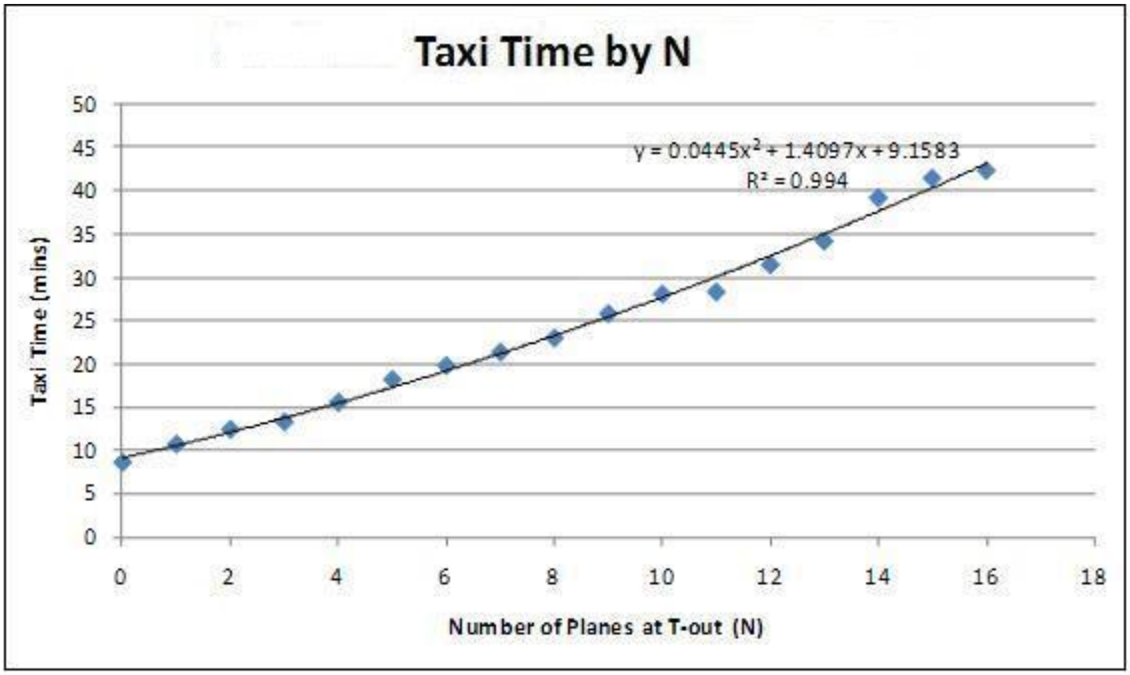

Figure 14 Model to Estimate Taxi Time by N

8. SIMULATION MODEL

When modeling PHL departures, Team AirportDFM examined the taxiway paths from each control spot and partitioned them into equal length segments of approximately 250 feet (Appendix E Figures 4 & 5). Then the team identified points of congestion where taxi paths intersect and converge towards the departure runway. For flights along each taxi path, the team calculated the length of time to traverse segments (intersection point to intersection point) based on taxiing speed of 5-20 nautical miles per hour (Appendix E Figure 6). Next, team ADFMS identified segments where conflicts occur for a given departure sequence and uniform taxi speed. An example for control spot 2 is shown below in Figure 15. If three flights follow the departure sequence displayed, there would be two possible conflicts. If a flight passes through control spot 3 at T=0 and a flight passes through control spot 2 at T=1 (min), there would be a conflict at step 4, T=1.5 on taxiway segment K5. Moreover, if a flight from control spot 2 and control spot 11 both pushed back at T=1, they would both reach taxiway segment S1 at the same time step. Consequently, the team established rules to sequence the departures in a way that avoids conflicts.

Time (mins)	T=0	T=0.5	T=1	T=1.5	T=2	T=2.5		T=12	T=12.5	T=13
Steps	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	....	Step 25	Step 26	Step 27
CS2 Taxiway			CS 2	K5	K6	Cross Runway	....	S1	S1-27L turn	27L
CS3 Taxiway	CS 3	Apron	Apron-K5 turn	K5	K6	Cross Runway	....	S1	S1-27L turn	27L
CS11 Taxiway			CS 11	H	H-E turn	Eg	....	S1	S1-27L turn	27L

Figure 15 Control Spot 2 Conflict Scenario Example

The Team used a flight schedule of the airport operating at max capacity (40 flights per hour) across all ramp areas to a single departure runway. The baseline model allowed 10 aircraft every 15 minutes to pushback and flow through the taxiways on a FCFS basis. The team also created models that allowed for 20 flights to pushback every 30 minutes as well as 5 flights every 7.5 minutes. Next, the team created two models with greater than 40 flights per hour to demonstrate the effects of sustained operation above capacity. Finally, the team created a Departure Flow Management System model with controlled departure sequences to avoid conflicts, unlike the other models.

The simulation was modeled with Arena (Appendix E Figure 7). Twenty-four hour flight schedules were used as input files containing data related with air carrier, arrival time to gate, pushback time, grams of CO_2/ HC/ NO_x/ SO_x emissions per kg of jet fuel burned, and kg of jet fuel burned per second for each flight. Each control spot and possible conflict point was modeled in the simulation as process modules with a seize-delay-release process for a set amount of time. Setting quantity and capacity to 1 ensures that no two planes could occupy the same spot at the same time and that queues would develop if more than one plane approached a taxi-path segment at the same time. Variability was introduced through use of a triangular distribution of service times for conflict points. The runway was a seize-delay-release process module with a constant service time of 90 seconds and quantity and capacity set to 1 to allow for 40 take-offs per hour with 90 seconds of separation. The output of the simulations included the max, min, and average queue size and length encountered at each possible conflict point. There were also figures related to server utilization. The team's main objectives were to observe whether conflicts occurred and to obtain average taxi time, standard deviation of taxi times, average greenhouse gas emissions, and average fuel burned per taxiing aircraft.

Simulation Accuracy

According to the Central Limit Theorem, as the sample size increases, the sample mean will be normally distributed for most underlying distributions. There is some argument over sufficient sample sizes. However, there is not any definite cut-off due to the infinite degrees of non-normality the underlying population could have. The worse the distortion is from normality, the higher the sample size needs to be to form a normal sampling distribution.

For the initial runs, the team chose twenty-five replications. For each model, the team computed the mean taxi time and standard deviation along with confidence intervals. The goal was to have 99% confidence interval half-lengths within two and a half minutes of the mean so the team calculated the number of simulations necessary to achieve this objective. An example is shown below in Figure 16 for Model Z: FCFS with 11 planes per 15 minutes. The 99% Confidence Interval half length was 5.75 minutes. To obtain half lengths with the desired half length of 2.5 minutes, the team calculated 5.75/2.5= (2.57*sqrt(var/25)) / (2.57*sqrt(var/number of replications)). Cancelling like terms simplified the formula to 2.3= sqrt(1/25)/sqrt(1/n). Solving for n provided the number of replications necessary for the desired half-length.

	Model Z: FCFS with 11 per 15 mins				
	Avg Taxi Time	77.71			
	Stdev	11.16			
			Lower	**Upper**	
	Normal 80% CI for Mean:		74.85	80.57	
	Normal 90% CI for Mean:		74.04	81.38	
	Normal 95% CI for Mean:		73.34	82.09	
	Normal 99% CI for Mean:		71.97	83.46	
			Lower	**Upper**	
	P(mean Taxi <78):		0.68	0.47	
	80%CI of P:		0.56	0.80	
	90%CI of P:		0.53	0.83	
	95%CI of P:		0.50	0.86	
	99%CI of P:		0.44	0.92	
	Half-length(99%CI) w 25 replications:			5.75	
	Desired Half-Length:			2.5	
	Total Reps Required:			132.2	

Figure 16 Simulation Accuracy

9. RESULTS AND SENSITIVITY ANALYSIS

Team AirportDFM tested the prediction accuracy of the models by estimating the taxi out times from flight data for July 2007. Absolute error was computed by taking the predicted taxi time minus the actual taxi time and then taking the absolute value of the difference. Compared to the running average model, the team observed a 30.1% reduction in mean absolute error of predicted times in the queuing model. In addition, the five minute-error margin accuracy rate improved with a 15.4% increase. An examination of prediction error by time of day revealed that average taxi time and prediction errors tended to be highest along periods of time when departure scheduling was most aggressive- between 9:00-11:00, 16:00-20:00, and 21:00-22:00 (Appendix E Figure 8). In order to improve the results, the team created 20 separate sub models – one for each airline – for both peak and off-peak hours – as shown in Figure 17.

Models to Estimate Taxi Time by Number of Planes at T-Out by Carrier		
Air Carrier	PEAK	NON PEAK
9E	y = 0.0871x2 + 0.7932x + 15.19	y = 0.0382x2 + 1.3956x + 14.212
AA	y = 0.1655x2 - 0.6296x + 18.275	y = 0.178x2 - 0.2314x + 15.877
CO	y = 0.0474x2 + 1.6088x + 9.8808	y = 0.4558x2 - 2.7988x + 14.949
DL	y = 0.0367x2 + 1.7949x + 10.357	y = 0.0703x2 + 0.662x + 16.517
OH	y = 0.0101x2 + 2.6974x + 4.7858	y = 0.0108x2 + 1.7343x + 13.306
FL	y = 0.1061x2 + 0.2596x + 14.191	y = 0.0858x2 + 1.2603x + 8.0073
NW	y = 0.0952x2 + 0.4106x + 19.351	y = 0.1373x2 + 0.4397x + 15.121
UA	y = 0.0161x2 + 2.0121x + 9.0063	y = 0.113x2 + 0.7049x + 13.966
US	y = 0.0674x2 + 0.8609x + 16.997	y = 0.0878x2 + 1.0407x + 12.515
WN	y = 0.0095x2 + 2.5355x + 6.3191	y = 0.0634x2 + 1.3851x + 9.3158

Figure 17 Peak and Non-Peak Models to Estimate Taxi Time

Team AirportDFM also accounted for runway configuration indirectly by matching models and test data sets created from days in which wind direction was the same. As a result, the team observed an additional 7% decrease in mean absolute error and a 2.5% increase in the number of predicted taxi times that were within 5 minutes of the actual (Figure 18). Results using the August dataset were consistent with the results obtained with the July dataset.

The queuing model allowed the team to observe the relationship between queue size and taxi delays. The results for each sub model were fairly consistent. As the queue size increased, the pass-through rate of departures increased without issue until reaching a point of saturation, after which the equilibrium of demand and capacity broke and taxi times became much less predictable. By keeping the queue size below the saturation point, departing flights could avoid unnecessary congestion and excess taxi delays (Appendix E Figure 9). This concept was fundamental in the development of a system to limit taxi times and variance by limiting the queue sizes encountered by taxiing aircraft.

Model	% Mean Abs Error Reduction Vs Running Average Model
Original Queuing Model	**30.1%**
By Air Carrier (10 subsets)	**32.3%**
By Air Carrier, Peak or Non-Peak Times, and Wind Direction (20 subsets)	**37.1%**

Figure 18 Mean Absolute Error Reduction by Model

The simulations verified the results of the queuing model. As the team pushed the demand of departures above capacity, queues grew quickly and the rate of growth for mean taxi times and standard deviation accelerated (Appendix E Figure 10). Figure 19 below displays the conflict points along the taxi paths and indicates whether or not a queue built up at each point for a given model. As more planes pushed back simultaneously, conflicts increased and congestion got heavier. Fewer regulations on departure flow correlated with increases in taxi time, given the same arrival rate into the system. With controlled, sequenced departures, there was a reduction in the average taxi time and in their standard deviation.

Conflicts Experienced (Y=Yes, N=No)						
Segment	FCFS with Rate of 11 per 15 Minutes	FCFS with Rate of 21 per 30 Minutes	FCFS with Rate of 20 per 30 Minutes	FCFS with Rate of 10 per 15 Minutes	FCFS with Rate of 5 per 7.5 Minutes	With Departure Flow Managem ent
Control Spot 3	Y	Y	N	N	N	N
Control Spot 6	Y	Y	Y	N	N	N
Control Spot 7	Y	Y	Y	Y	N	N
Control Spot 8	Y	Y	Y	Y	N	N
Control Spot 9	Y	Y	Y	Y	N	N
Control Spot 10	Y	Y	Y	Y	Y	N
Control Spot 11	Y	Y	Y	Y	N	N
Intersection Q	Y	N	N	N	N	N
Intersection TA	Y	N	N	N	N	N
Intersection ED	Y	Y	Y	N	N	N
Intersection EG	Y	Y	Y	Y	N	N
Intersection K3A	Y	Y	Y	Y	Y	N
Intersection NB	Y	Y	Y	Y	N	N
Intersection ND	Y	Y	Y	Y	Y	N
Intersection NE	Y	Y	Y	Y	Y	Y
Intersection S1	Y	Y	Y	Y	Y	Y
27L Runway	Y	Y	Y	Y	Y	Y

Figure 19 Conflicts Encountered by Model

As fuel burn amount (Figure 20) is a function of taxi time, and emissions amount (Figure 21) is a function of fuel burned, these metrics may be helpful to build a case for the adoption of a departure flow management system. The baseline model that most closely matches the actual mean taxi time at PHL is highlighted in red. The controlled, sequenced departure model, ADFMS, is highlighted in green. A comparison of the actual per flight average fuel burn and emissions with the FCFS Baseline model (10 push-backs per 15 minutes) results is provided in Appendix E, Figure 11.

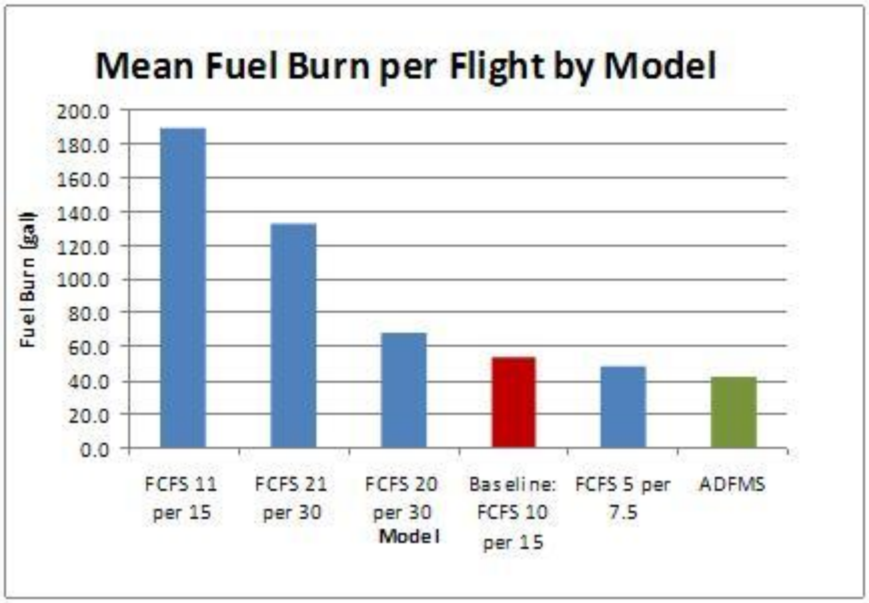

Figure 20 Fuel Burned per Flight by Model

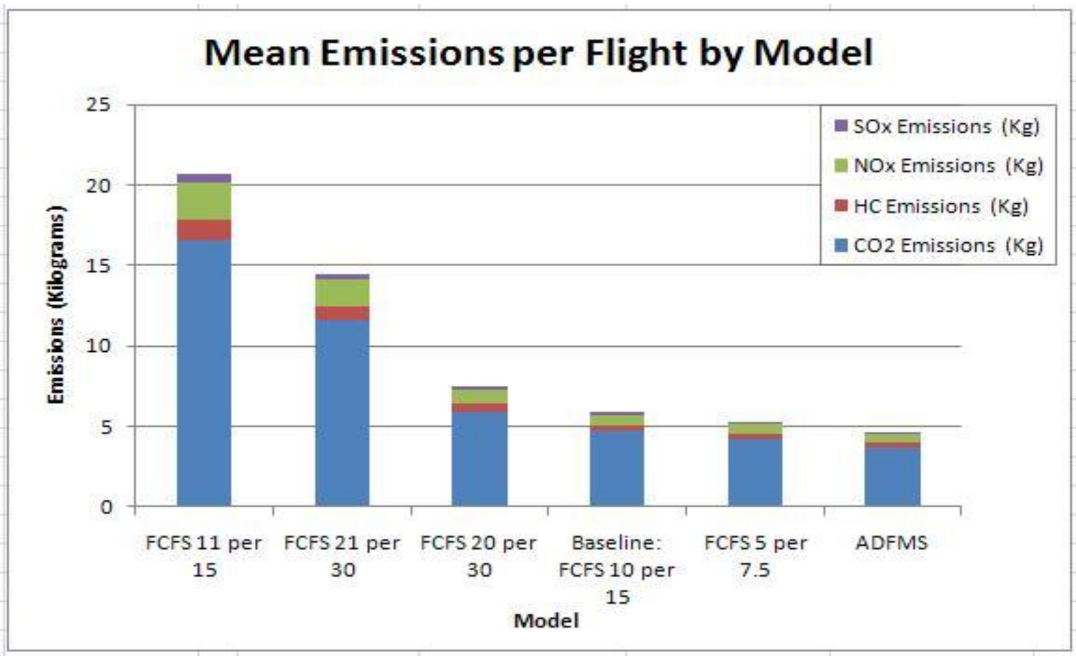

Figure 21 Greenhouse Gas Emissions per Flight by Model

Increasing or decreasing all of the service times together for each segment of the taxiways models the effect of faster or slower taxi speeds. For taxi speeds within reason (between 5 knots and 20 knots) the fractions of taxi time and fuel burn increase or reduction across the models were fairly consistent. Allowing variance of taxi speed in segments within the same model allowed the team to check if our assumptions and results were valid for stochastic settings. The team obtained results with confidence intervals which overlapped with the results for the initial deterministic simulations.

10. EVALUATION

The results of the simulation model depict a situation in which the implementation of the Airport Departure Flow Management System (ADFMS) will reduce the mean aircraft taxi time as well as the standard deviation of aircraft taxi times at PHL. These reductions in taxi time and variation are directly convertible into annual dollar cost savings as a function of reduced fuel burn per year. Offset by the required capital investment in ADFMS, with a conservative (high) estimation of $5 million, and conservative $2 million in annual operating costs, the implementation of ADFMS at PHL realizes $22 million in net benefits solely attributable to fuel savings offset by investment and implementation costs over a ten-year lifecycle. These dollar amounts include an estimate of $2.05 per gallon of jet fuel in year one, increased annually based upon the U.S. Energy Information Administration's Annual Energy Outlook 2010. These dollar amounts do not include estimates for growth in departures for PHL: additional aircraft departures will result in even greater savings for the airlines beyond the current status quo of unconstrained demand and first-come, first-served queue implementation. These figures do not account for reduced aircraft emissions (i.e. the value of better air quality) or intangibles such as passenger satisfaction ratings, increased aircrew morale, and positive impacts on downstream National Airspace System operations (such as Airport Traffic Flow Management) administered by the FAA.

				Return Rate	8.00%	
Year	**Fuel Burn Reduction ADFMS**	**Annual O&M Costs**	**Capital Expenditures**	**Net Savings**	**Net Savings (NPV) at Return Rate**	**Cumulative Net Savings**
0			**$5000**	-$5000	-$5000	-$5000
1	$5160	$2000		$3160	$2709	-$2291
2	$5631	$2000		$3631	$2882	$591
3	$6021	$2000		$4021	$2956	$3547
4	$6285	$2000		$4285	$2916	$6463
5	$6480	$2000		$4480	$2823	$9286
6	$6728	$2000		$4728	$2759	$12045
7	$6947	$2000		$4947	$2673	$14718
8	$7137	$2000		$5137	$2570	$17288
9	$7267	$2000		$5267	$2440	$19728
10	$7384	$2000		$5384	$2309	$22037
All figures in thousands (000's)						
					Total:	$22037

Figure 22 Incremental Savings / Net Present Value of ADFMS

The detailed Scenario Analysis for ADFMS implementation at PHL is found in Appendix F.

11. RECOMMENDATION

The Philadelphia Airport Authority should continue to investigate and analyze the benefits and costs, as well as the implementation courses of action, for the Airport Departure Flow Management System at PHL. PHL should work in close concert with the project stakeholders to include the airlines and the FAA. PHL should lead the capital investment and undertake the implementation of ADFMS after expanding the concept, requirements, design, and evaluation to include out-of-scope conditions of this initial ADFMS project.

The preliminary definition, design, and analysis of an ADFMS system at PHL results in a project with positive net present value as well as many other intangibles that should be undertaken to improve airport operations and customer satisfaction at PHL.

12. FUTURE WORK

There were additional aspects of the problem that were out of scope for a semester long project that can be addressed. These include aircraft arrivals, multiple runway configurations and weather.

There is also additional work that can be completed with respect to more detailed aspects of the departure management system. A simulation of departure slot trading mechanisms would be useful to work through extended trading scenarios. The scenarios examined by the team were limited in length. Also an approach to implementing a lottery of initial departure slots is necessary.

13. ACKNOWLEDGEMENTS

The ADFMS Team would like to acknowledge the project sponsor, Dr. Lance Sherry, and the class professor, Dr. Kathryn Laskey. They both provided valuable guidance on how to proceed with the project, which led to a successful completion.

A. APPENDIX A Project Proposal

Airport Departure Flow Management System (ADFMS)

Project Proposal

Version 1.1
Date February 11, 2010

Prepared by: Team AirportDFM

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SYST 798/OR 680 Spring 2010
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1. PROBLEM DEFINITION

1.1 Problem Description

Air Traffic Management (ATM) or Air Traffic Flow Management (ATFM) systems and procedures have been effectively implemented for air operations between major U.S. airports to include enroute, arrival, and departure separation. The U.S. airspace is controlled by the Department of Transportation's Federal Aviation Administration (FAA) air traffic control systems, which includes a tiered system of Air Traffic Control operators that oversee arrival and departure (Tower Control), approach control (Terminal Radar Approach Control – TRACON), enroute control (Air Route Traffic Control Centers – ARTCCs), and overall coordination and control (Air Traffic Control System Command Center – ATCSCC) of the National Air Space (NAS). The Air Traffic Control system is supported by an automated system of systems that effectively controls the separation and throughput of air traffic.

The ATCSCC's implementations of Ground Delay Programs (GDPs) improve airline efficiency by delaying aircraft departures at origination airports rather than using the more costly holding pattern method. The use of GDPs provide a more cost effective option to holding patterns through the reduction in fuel consumption, reduced aircraft operating hours (reduced aircraft maintenance), reduced emissions, and reduced piloting hours. GDPs also improve airline safety as separation on the ground is significantly less complicated than airborne separation and much less catastrophic.

All major airports have Ramp Control or Ground Control procedures for the management of separation of all surface movement on airport taxiways, inactive runaways, holding areas, transitional aprons, and intersections. However, the procedures do not provide for efficiency of airline operations on the ground. Airlines and airplanes establish a queue for departure at the runway threshold. The queue is not controlled, but instead a free-for-all where airlines depart their gates when ready (and approved by Ground Control) and taxi based upon instructions from Ground Control personnel. Departing aircraft establish a departure queue that is not based upon departure time or announced arrival time, but instead based upon a first-come, first-served basis, where Ground Control's primary purpose is to ensure separation and safety. Once established within a queue on a taxiway, the queue cannot be reordered if the width and configuration of the airport aprons, taxiways, and runways cannot support the simultaneous movement of aircraft within what is normally restricted space.

Stakeholders in the air transportation industry have long recognized the need for an automated system to better manage and improve the operation of the departure queue. The ability to establish a virtual queue for departure that would improve the efficiency for participants is highly desired. This virtual queue would hold an aircraft at its gate until the right time so that the aircraft could taxi directly to the departure runway with minimal taxiway delays as well as best support airlines in meeting departure and arrival times that are so important to airline rating systems.

1.2 Project Definition

The GMU Center for Air Transportation Systems Research (CATSR) has a requirement for the definition and design for an Airport Departure Flow Management System that would improve the collective efficiency of airline operations from the gate to departure at a major U.S. airport.

Team AirportDFM will define the requirements and prepare and prove a preliminary design for an Airport Departure Flow Management System (ADFMS) for the Philadelphia International Airport (PHL). Team AirportDFM will also conduct a Cost-Benefits Analysis for each of the stakeholders for the proposed system.

Team AirportDFM's objective is to define system requirements, create a concept of operations, develop an initial design, and perform scenario analysis through modeling and simulation for an automated system with supporting operational procedures for a virtual queue implementation and optimization to provide collective benefits to all stakeholders at PHL.

1.3 Project Scope

While major U.S. airports have many common operations and functions, the physical scale and configuration of each airport's terminals, gates, taxiways, and runways, as well as differences in the numbers of carrier, capacity for individual aircraft as well as maximum sustainable departure rates, result in a unique problem for each airport.

The scope of the Airport Departure Flow Management (DFM) System definition and design for this proposal is PHL. Team AirportDFM will analyze current ground operations and queuing at PHL. For the purposes of this project, 'ground operations' is limited to the movements and sequencing of aircraft from the gate until departure.

Although airport departures and arrivals are highly coupled, in order to best focus the project, the project team will not make any consideration of airport arrivals. The project team will also not make considerations for the impact to departure operations due to the weather or ground delay programs (GDPs). The project team will limit the study to airlines that share common terminals, taxiways, and departure runways: there will be no consideration for general aviation aircraft that normally utilize a separate hanger space, apron, and runway.

2. PRELIMINARY REQUIREMENTS

2.1 Project Requirements

2.1.1 Team AirportDFM shall develop a system requirements document.
2.1.2 Team AirportDFM shall develop a concept of operations.
2.1.3 Team AirportDFM shall develop a preliminary design for the ADFMS.

2.1.4 Team AirportDFM shall develop an executable queuing model which will be used to evaluate departure delay, aircraft emissions and fuel burn.
2.1.5 Team AirportDFM shall document Scenario Analysis results.
2.1.6 Team AirportDFM shall develop a Cost-Benefit Analysis for stakeholders of the proposed ADFMS.
2.1.7 Team AirportDFM shall provide regular progress reports at time defined by the class schedule.
2.1.8 Team AirportDFM shall provide a final presentation and final report that includes all deliverables.
2.1.9 Team AirportDFM shall develop an ADFMS web site to publish all project documentations and ADFMS results.

2.2 Composite Requirements

2.2.1 The ADFMS shall implement a virtual queue of planes waiting for takeoff to replace the physical queue currently established on the taxiway.
2.2.2 The ADFMS shall be able to support an airport configuration consisting of one runway dedicated to arrivals and one runway dedicated to departures.
2.2.3 The ADFMS shall be available over the internet.
2.2.4 The ADFMS shall account for interaction with air traffic control, ground control and airlines.

2.3 Functional Requirements

2.3.1 The ADFMS shall have a planning component based on flight schedules or airline departure slot reservations.
2.3.2 The ADFMS shall be able to accept flight schedules as input.
2.3.3 The ADFMS shall have a real-time component to handle flight delays and flight changes.
2.3.4 The ADFMS shall minimize the duration of time that aircraft use the taxiway and holding areas prior to take off.
2.3.5 The ADFMS shall output pushback times that account for current airport traffic.
2.3.6 The ADFMS shall maintain a departure slot for flights scheduled to depart from the airport.

2.4 Performance Requirements

2.4.1 The ADFMS shall be capable of handling 12 flights every 15 minutes
2.4.2 The ADFMS shall be capable of storing 3 months worth of departure slots

3. TECHNICAL APPROACH

An evolutionary acquisition incremental approach will be applied to the ADFMS to allow for the incorporation of emerging technologies, changing user needs, and knowledge gained during operation. Team AirportDFM will apply the concept of the DoD Systems Engineering Process as shown in Figure A-1, throughout the life cycle of the ADFMS.

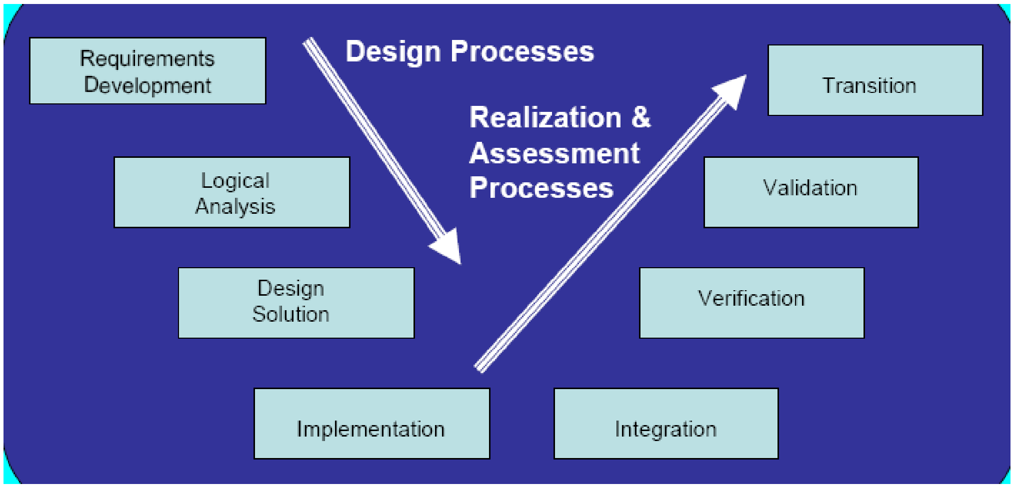

Figure A-1 DoD Systems Engineering Process

3.1 Requirements Development

During the requirement development phase Team AirportDFM will conduct the following activities:

- Understand the requirements from the stakeholders: This activity includes meeting with various stakeholders to understand their needs, understand the current problem through review of literature and historical data, and research for solutions in similar problems.
- Develop the system life cycle requirements: This activity identifies all the life cycle system requirements in order to develop, design, test, operate and sustain the system.
- Develop the system requirements consistent with the stakeholders' requirements: This activity includes the documenting of the requirements gathered from the stakeholders and various research efforts into the system functional requirements and system performance requirements.
- Validating the requirements: This activity is to ensure that specified requirements are correct and consistent with the stakeholders' requirements.

3.2 Logical Analysis

During this phase Team AirportDFM will decompose the requirements to obtain architectures that explain and show relationship of the system's functional and behavioral characteristics.

Team AirportDFM will use UML modeling to develop both the functional architecture and behavioral architecture.

3.3 Design Solution

During this phase Team AirportDFM will use the output from the Logical Analysis and functional architectures to establish the product architecture and finalize the system design requirements.

3.4 Implementation

The Implementation phase involves the modeling of ADFMS from the established product architecture and system design requirements. The Arena Software will be used to model the ADFMS.

3.5 Integration

The Integration phase involves an analysis of all different models created during the implementation to come up with the final proposed solution for the ADFMS.

3.6 Verification and Validation

The verification phase involves comparing the final model of ADFMS to the established requirements to see whether the model meets the requirements. The validation phase involves demonstrating the model to the stakeholders to determine whether the model meets the stakeholders' requirements.

3.7 Transition

This phase involves the gathering of all documentation and the packaging of the model's coding into an executable model to be delivered to the stakeholders.

4. EXPECTED RESULTS

Through iterative system definition and system design processes, Team AirportDFM expects to provide refined system definition and design documentation. Initial system definition activities will results in an initial system design. Through modeling and simulation of the design, Team Airport DFM expects to refine the initial system definition and design until a feasible executable model can be established that meets the stakeholder objectives for the virtualization of the departure queue at PHL. Simulation will be performed to validate various scenarios within the problem set.

The refined system definition, design, and scenario will provide a foundation for alternative follow-on activities:

- Additional systems definition and design to account for conditions out of scope of this initial effort

- Statement of Work (SOW) and Request for Proposal (RFP) formulation for initial system development

4.1 Deliverables:

The major deliverables for ADFMS are as follows:

4.1.1 Concept of Operations (CONOPs) Document

The CONOPs document shall describe the characteristics of a proposed system from the viewpoint of an individual who will use the proposed system and how the system will be used. It will be used to communicate the quantitative and qualitative system characteristics of all stakeholders.

4.1.2 System Requirements Document

This document shall consist of a structured collection of information that would constitute the requirements of the system. These requirements shall be based on the business and system needs of the clients and the stakeholders, and help identify the potential problems and propose solutions.

4.1.3 Scenario Analysis Document

This document would involve the process of analyzing possible future events by considering the alternative possible outcomes (scenarios). This analysis would allow improved decision-making by allowing consideration of outcomes and their implications.

4.2 System Design Results

The desired and expected outcomes of the operational functionality of the ADFMS project to be achieved at completion are as follows:

- The most fundamental and primary functionality of the ADFMS shall comprise a queuing model based on departure slots in which the airlines would be able to reserve slots and trade or exchange them in the event of a delay or disruption.

- The ADFMS shall provide the cost-benefit analysis and tradeoff, based on mathematical and numerical calculations.

- The ADFMS shall also minimize the losses incurred from departure delays, aircraft emissions, and fuel burns by alleviating the problem of unnecessary taxiway congestions.

- The ADFMS would propose such a strategy in which the airplane would wait at the gate before the clearance to go ahead. Once the airplane departs the gate and leaves for the runway, there is minimal or no waiting period involved.

- At the completion of the project, the expected business value would be derived.

- The ADFMS would operate in real-time dynamically, accepting the schedule data and building the queuing slot model based on that.

- The feasibility studies of the proposed systems solution would be carried in the technical domain.

- The ADFMS would also propose a centralized management and control authority for the proper operation and functionality of the system.

- The ADFMS would replace the first-come, first-served (FCFS) queuing method with an efficient queuing algorithm taking into account ground control factors and constraints.

5. INITIAL PROJECT PLAN

Team AirportDFM's initial project plan for the ADFMS definition, design, assessment and transition follows. Team AirportDFM will refine the project plan during the system definition phase:

5.1 Work Breakdown Structure

The project WBS is structured according to the deliverables that Team AirportDFM will prepare during the course of the project duration.

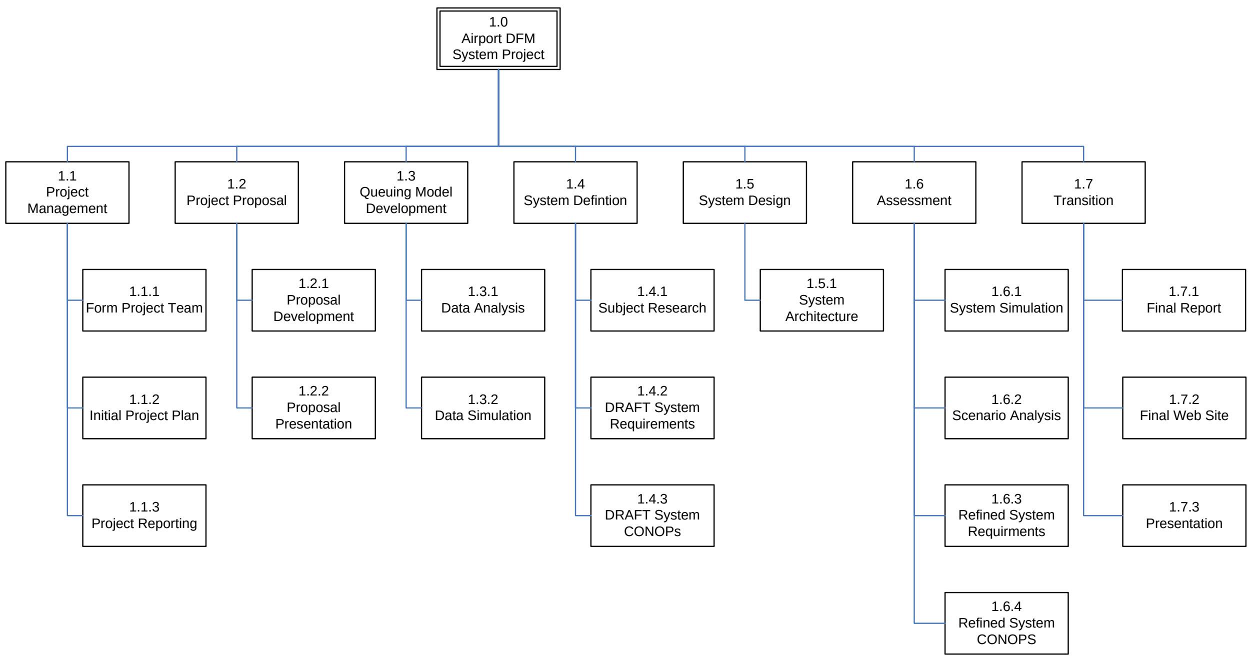

Figure A-2 Team AirportDFM System Project Work Breakdown Structure

Project Schedule

The following high-level project schedule is designed to best meet Team AirportDFM milestones and deliverable due dates. Due to time limitations, queuing model development is concurrent with the system definition and design phases at the recommendation of the project sponsor.

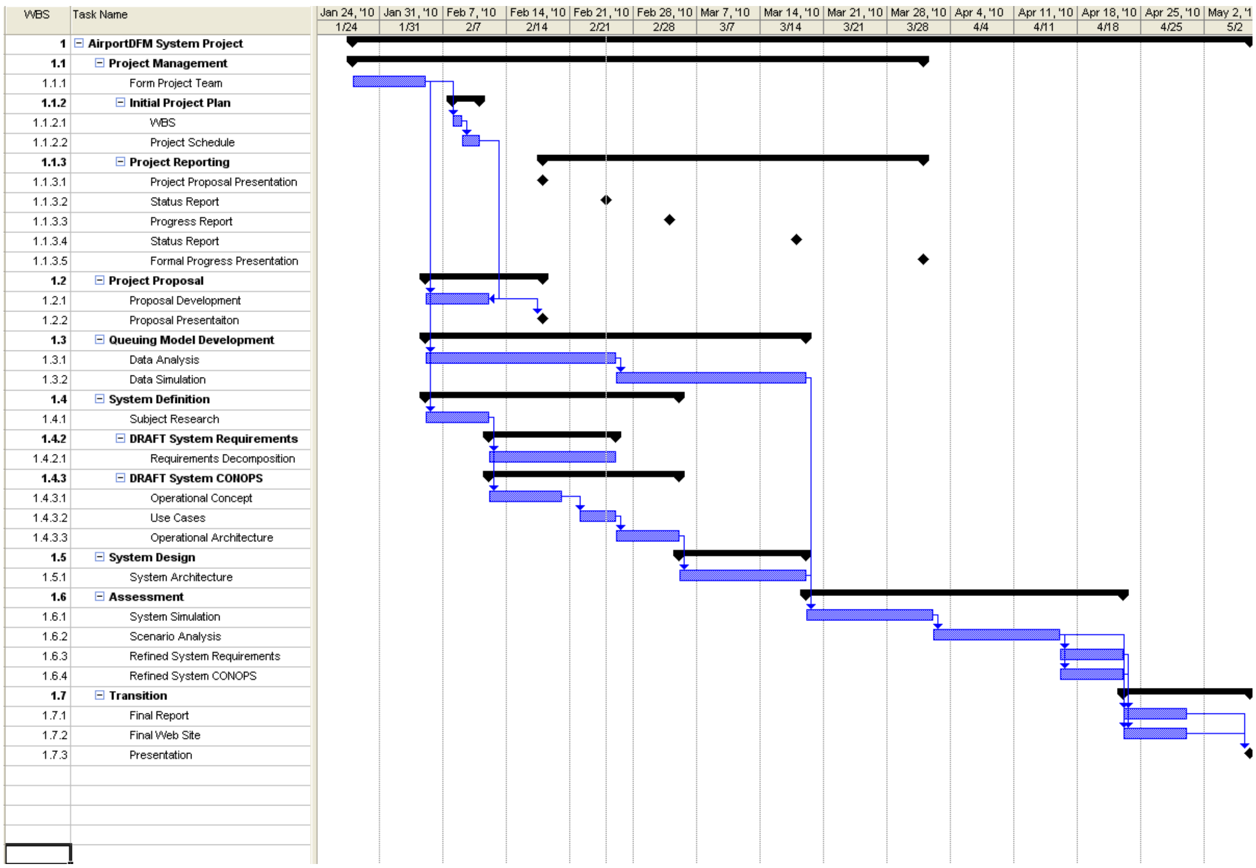

Figure A-3: Team AirportDFM System Project Schedule

5.2 Project Deliverables

Team AirportDFM proposes to provide project deliverables in accordance with the following schedule:

Project Deliverables	Delivery Date
Project Proposal	11-Feb-10
Status Report	18-Feb-10
Progress Report	4-Mar-10
Status Report	18-Mar-10
Formal Progress Presentation	1-Apr-10
Final Report *****(includes AirportDFM System deliverables)	29-Apr-10
Project Web Site	29-Apr-10
Final Presentation	7-May-10

Figure A-4: Team AirportDFM System Deliverables Schedule

The Final Report will include, along with the class requirements, the AirportDFM System deliverables:

- System Concept of Operations (CONOPs)
- System Requirements Document
- Scenario Analysis document

B. APPENDIX B Concept of Operations Document

Airport Departure Flow Management System (ADFMS)

Concept of Operations

Version 1.0
Date April 22, 2010

Prepared by: Team AirportDFM

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SYST 798 / OR 680 Spring 2010
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Table of Contents

1.0 INTRODUCTION

This Concept of Operations (CONOPs) communicates overall system characteristics of Airport Departure Flow Management System (ADFMS) at Philadelphia International Airport (PHL).

PHL Airport Authority currently manages aircraft departures using the First-Come, First-Served (FCFS) queuing paradigm. In this paradigm, airlines schedule departures three or more months out. The implementation of ADFMS at PHL will enable a pre-ordered, efficient queue that retains the ability for airlines to schedule departures three months out, but also allows for efficiency and flexibility within the departure queue to accommodate airline and individual aircraft needs. The Philadelphia Airport Authority will procure, operate and maintain ADFMS at PHL in order to efficiently conduct airport operations to the benefit of all stakeholders.

1.1 Purpose

The purpose of this document is to identify and describe the overall concept of operations for the Airport Departure Flow Management System at PHL. This CONOPs will serve as the basis for the ADFMS System Requirements document.

1.2 Scope

The Airport Departure Flow Management System (ADFMS) will coordinate and manage airport departures at the Philadelphia International Airport (PHL) from push-back to take-off.

ADFMS provides a user-friendly, Web-based aircraft departure flow management system for users to search, view, enter, and manage airline and airport departure information to best utilize PHL airport resources and meet efficiency needs while conserving airline resources.

ADFMS will be easily accessible and usable at PHL as well as the Airline Operating Centers (AOCs) and the Federal Aviation Administration's (FAA's) National Airspace System (NAS) air traffic control centers. ADFMS will allow for single sign-on within the PHL airport domain.

The ADFMS interoperates with the following systems: FAA's Air Flow Traffic Management (AFTM) System, PHL's Airport Surface Detection Equipment, Model X (ASDE-X), the Airline Operating Center Network (AOCnet), and the Official Airline Guide (OAG).

1.3 Stakeholders

1.3.1 Users

The Airport Departure Flow Management System will be used by the following participants within the PHL airport operations domain:

1.3.1.1 Airlines

- Station Managers

There is one Station Manager for each airline at the airport. Each Station Managers is responsible for management and oversight of its airline operations at PHL. The Station Manager also coordinates with PHL Ramp Control with respect to all local airline matters and departure schedules. They will be responsible for handling all the flights of the airline and maintaining the schedules on behalf of the airline. They will be responsible for dealing and handling the trade and exchange of departure slots just within the two-hour time-frame window before the actual departure of the flight. They will have an interface and access to the ADFMS system via which they would be able to view the schedule, manage airline specific information and data, and trade / exchange departure slots. They will be able to communicate directly with the PHL Airport Authority and Ramp Control via ADFMS system for all necessary accommodations and procedures. They will deal with all immediate operations right before the departure.

- Airline Operating Centers (AOCs)

The airline operating center (AOC) is the main headquarters of a particular airline and will be responsible for the operation of requesting departure slots and their allocation via ADFMS system. The AOC is responsible for handling all the flights of the airline, making the departure schedule and dealing with trade and exchange slots outside the two-hour time frame window of the departure. They will be able to address, accommodate and resolve all concerns and issues relating to delays by employing ADFMS system. The will be able to communicate with and respond to the PHL Airport Authority in a timely manner.

- Pilots

The pilots are the secondary stakeholder and are not directly involved in the operation of ADFMS system. They do not receive any direct advantages and benefits of the system. They mainly adhere to the functionality of ADFMS system and act accordingly. They receive the benefits of avoiding hassles and inconveniences from departure delays and waiting periods.

1.3.1.2 PHL Airport Authority

- PHL Ramp Control

The ADFMS system is hosted in the PHL Airport Operations Center within the Ramp Control tower. PHL Ramp Control owns, manages, and operates ADFMS, thereby providing the overall supervision for the system. The final and ultimate authority of ADFMS rests with PHL Ramp Control. The PHL Ramp Control staff deals with ramp areas and corresponding clearances, aprons, and taxiways, assisting the aircraft to steer and reach the runway. They are responsible for maintaining the system and ensuring that it is operating normally. They are also responsible for providing adequate user training to the new staff. They will be able to track and monitor the history of all operations and penalize the airlines who fail to abide by the system.

- Information Technology (IT) Staff

The Information Technology (IT) staff will be responsible to manage, operate and maintain the airport system's network infrastructure on which the ADFMS functions.

The IT personnel will be responsible to ensure the security of data and systems involved. They would make sure that the data is available and the system is up and operational all the times. They would also make sure the concepts such as authorization, authentication, and data integrity and security are implemented so that the system and data are never comprised. If a problem arises, they would ensure prompt repair, so the system is in operational mode instantaneously. The IT staff would also provide redundancy by maintaining the backup of the data for the worst case circumstances. They would also replace the equipment and devices when appropriate and required. Moreover, they would keep up to date on latest state-of-the-art technology and upgrade the systems and the Intranet. The IT staff is responsible to hire technicians who will perform the manual as well as technical work such as building, modifying, managing the physical internetworking infrastructure. The IT personnel would also be responsible to train and educate the airport system's users such as airlines, PHL Airport Authority, and FAA on using the system efficiently. They would also provide help desk support when an airport system's administrative staff member runs into a problem.

1.3.1.3 Federal Aviation Administration

- PHL Air Traffic Control Tower (ATCT)

The air traffic control tower (ATCT) is not a key player and does not have any direct involvement in the operation of the ADFMS system. The ATCT controls the immediate airport environment and maintains situational awareness via the visual observation from the control tower and using automated monitoring systems. The tower controller is responsible for the separation and efficient movement of the aircraft which constitute the ground control and movement planner duties. The ATCT takes over the control when the aircraft reaches the departure runway and gives clearance to take off. The ATCT maintains the control until the aircraft reaches a certain height after the take off and is within certain distance from the airport, usually within 2 to 5 nautical miles. The ATCT is also responsible for carrying out runway crossings. The ATCT also desires improved reactivity of unforeseen circumstances and reducing its negative impact. The ATCT requires that ADFMS distribute the information and new plan based on the current situation to the different operators and stakeholders at the airport.

- PHL Terminal Radar Approach Control (TRACON)

The Terminal Radar Approach Control (TRACON) is also not a key player and contributor and does not have any sort of involvement in the operation and management of ADFMS. The TRACON takes over the control of the departure aircraft from the control tower at an altitude of about 1,000 feet to 2,000 feet. The TRACON places the departing aircraft on a track and in a geographical location that is pre-determined by the en-route center controller. Although the TRACON is not directly connected to the ADFMS since the system specifically deals with ground operations and movement, TRACON does receive the benefits in terms of ease and convenience of operations as a result of the consistency, safety and orderly flow of operations achieved by the ADFMS.

1.3.1.4 Passengers

Passengers are end beneficiaries of ADFMS. Their main concerns are punctuality and customer satisfaction. ADFMS achieves these objectives by ensuring on-time departures. The passengers also get the advantage in economical and financial terms, since the airlines and PHL airport authority save resources and money by employing ADFMS.

2.0 AIRPORT DEPARTURE FLOW MANAGEMENT SYSTEM CONCEPT

ADFMS provides continuous situational awareness of the status of the airport departure queue via a database of scheduled and historical departures and their business data, to include airline and flight number, aircraft type, destination, scheduled departure time (scheduled "push-back" time per airline schedule (OAG)), departure slot, gate, expected and actual push-back times, take-off time, taxiway-path, departure runway, physical queue size, and actual take-off time (wheels off).

ADFMS provides three main capabilities: schedule of airline departure requests into assigned departure slots; segmentation of the physical departure queue into a departure queue with physical and virtual components; and brokering of the virtual queue to allow aircraft to trade departure slots and to fall-back to later departure slots to support airline needs and desires.

ADFMS enables PHL Ramp Control to efficiently sequence aircraft departures, via assigned aircraft departure slots and expected and actual push-back times, into a correctly-ordered physical departure queue at the departure runway threshold, accounting for multiple taxi-paths from 120 different departure gates across seven different terminals to one or more departure runway queues dependent upon the runway configuration and the aircraft's assigned departure slot.

ADFMS also enables airlines to trade-up departure slots as necessary to meet airline needs for an earlier departure slot, or to trade-down to a later departure slot to accommodate aircraft delays due to gate operations, extended turnarounds, late arrivals and connections, or unscheduled maintenance. When an airline cannot find a willing trading partner to execute a trade to a later departure slot, ADFMS will enable airlines to fall-back to a later slot with the corresponding bump-up of aircraft in subsequent departure slots, to accommodate the airline's needs. ADFMS will enable trading of departure slots via a point system currency that allows airlines to spend points to "buy" an earlier desired departure slot and earn points to "sell" an earlier departure slot. Within the "fall-back" scenario, airlines will not be charged points unless the number of "fall-backs" over a specific time period exceeds an allowable limit to discourage airlines from holding on to departure slots too long prior to requesting a trade.

The ADFMS system is hosted within the Philadelphia Airport Operations Center within the Ramp Control Tower. ADFMS operates locally on the PHL local area network (LAN), but is exposed to the World Wide Web to accommodate remote users to include Airline Operating Centers (AOCs) across AOCnet. ADFMS also interoperates with other systems through IP-based routing on the Internet.

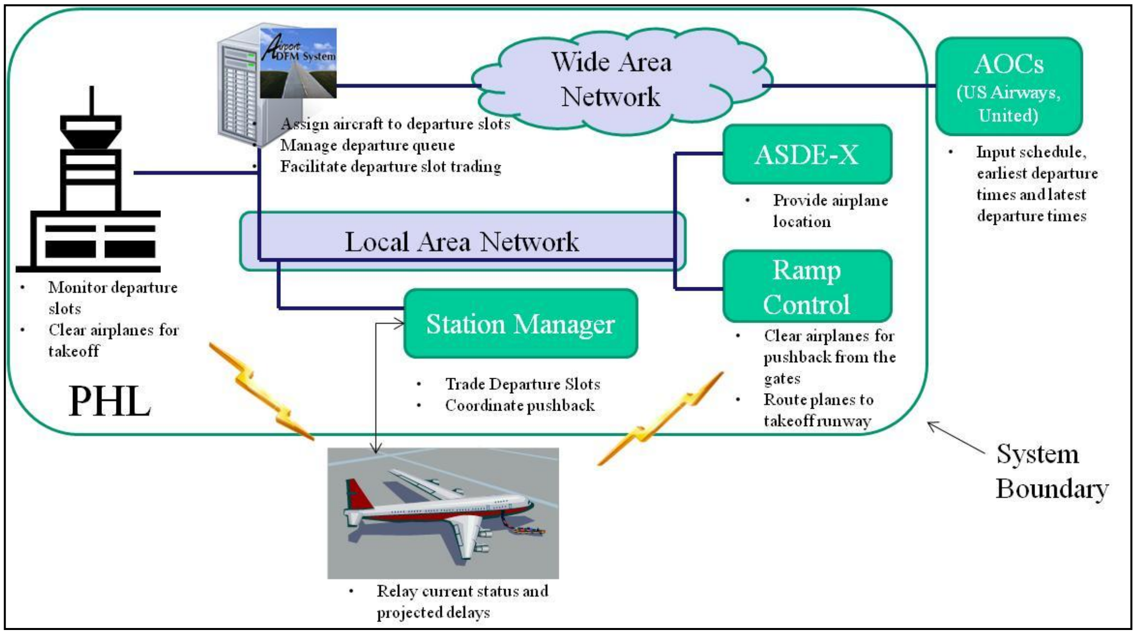

Figure B-1: ADFMS Operational Concept

3.0 PHILADELPHIA INTERNATIONAL AIRPORT

Philadelphia International Airport (PHL) is the 11th largest airport in the United States. It is situated along the Delaware River in south Philadelphia and accommodates 34 airlines. In 2008, it handled a total of 31.8 million passengers and had 499,653 total flight movements. It contains two main parallel runways (9L/27R and 9R/27L) as well as an intersecting runway (17/35) and a runway (8/26) for general aviation flights. The PHL airport is the primary international hub of US Airways. It serves destinations in the U.S., Canada, Caribbean, Latin America, Europe, and the Middle East. (PHL - Philadelphia International Airport, www.phl.org)

This CONOPs describes system capabilities for the Airport Departure Flow Management System (ADFMS) for Philadelphia International Airport (PHL).

Figure B-2: PHL International Airport

("Philadelphia International Airport - Google Maps." *Google Maps*. Google, n.d. Web. 13 Feb. 2010)

3.1 ADFMS / PHL Surface Areas

ADFMS assigns each gate to a default taxi path for each departure runway, which is based upon the PHL runway configuration and an aircraft's assigned departure runway. PHL's two parallel runways (27R/9L and 27L/9R) and its intersecting runway (35/17) are the primary runways in support of major airline operations. These runways can be configured into different runway configurations dependent upon prevailing winds, visibility, and other weather and operational conditions.

There are 120 departure gates at PHL, spread across seven terminals. With gates located on each side (generally, east side and west side of each terminal, with the exception of terminals E and F, which are oriented differently), there are nine separate ramp areas where aircraft taxi within close proximity to each other. Team AirportDFM defines the PHL ramp areas as follows:

Ramp Areas	Location	Ramp Control Spots
Red	West of A-West Terminal	2 and 3
Orange	Between A-West and A-East Terminals	4 and 5
Yellow	Between A-East and B Terminals	6 and 7
Green	Between B and C Terminals	8
Blue	Between C and D Terminals	9
Indigo	Between D and E Terminals	10
Violet	Between E Terminal and F1 Concourse	11
Purple	Between F2 and F3 Concourses	13
Black	Between F3 and F1 Concourses	14

Figure B-3: PHL Ramp Areas and Ramp Control Spots

ADFMS assigns each departure gate to a Ramp Area and Ramp Control Spot. From each Ramp Control Spot, ADFMS assigns the default taxi path to the specific departure runway. ADFMS stores the maximum taxi path traverse time based upon a rolling average of taxi times for the same taxi path over the previous four-week period. These taxi path times accommodate times for taxi-way clearance and Hold Short Of (HSO) runway clearance. Based upon the stored values for departure gate, departure runway, and taxi path traverse time, along with the aircraft's assigned departure slot, ADFMS calculates the required pushback time for the aircraft. Then within the expected pushback window – the time between the aircraft's scheduled pushback (per the Official Airline Guide) and the required pushback time – ADFMS calculates the aircraft's expected pushback time. The expected pushback time is the time that the airline must meet in order to arrive at the departure runway threshold in the correct physical sequence with respect to other departing aircraft.

Figure B-4: Ramp Areas and Ramp Control Spots

(Airport Graphic by "Philadelphia PHL Services --> Main Terminal / Concourses." iFly.com The Web's Best Guide to Airports. < http://www.ifly.com/resources/img/airports/terminal-maps/Philadelphia-PHL-terminal-map.jpg)

ADFMS calculates the expected push-back time to accommodate 12 to 20 aircraft taxiing simultaneously on PHL from various departure gates to a single departure runway that enables a sustained maximum departure rate of ten aircraft take-offs every 15 minutes. ADFMS sequences the airport simultaneously over multiple taxi paths that comprise multiple feeder queue paths into a single physical queue at the runway threshold no larger than three stationary aircraft, sequenced correctly with respect to departure slot. In order to perform this sequencing successfully, ADFMS assigns expected push-back times where an aircraft with a later departure slot may pushback prior to an aircraft with an earlier departure slots due to the respective departure gates and taxi paths of each aircraft.

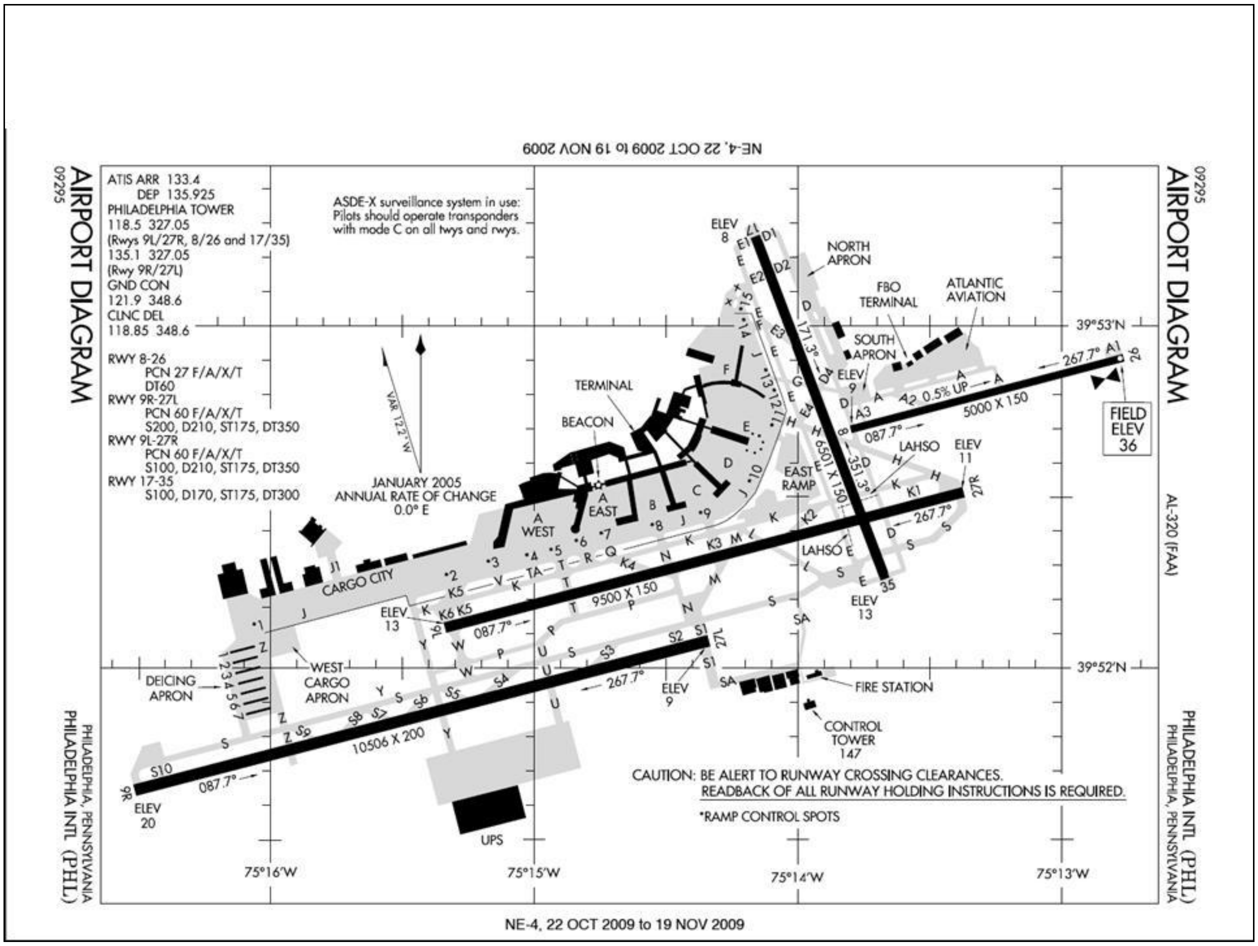

Figure B-5: Airport Diagram for PHL (http://www.airnav.com/airport/KPHL)

Ramp Area	Control Spot	Taxi-path to 27L	LAHSO
Red	2 and 3	K5 - K6 - W - S- S1	27R
Orange	4 and 5	T - P - N - S1	27R
Yellow	6 and 7	Q - K - N - S1	27R
Green	8	N - S1	27R
Blue	9	K3 - M - N - S1	27R
Indigo	10	J - K3 - M - N - S1	27R
Violet	11	H - E - S - S1	27R
Purple	13	G - E - S - S1	27R
Black	14	E3 - E - S - S1	27R

Figure B-6: ADFMS Assigned Taxi paths for Departure Runway 27L

3.2 ADFMS PHL Display

ADFMS works with PHL's ASDE-X system to provide situational awareness and display of aircraft location. ADFMS will overlay ADFMS data over the ASDE-X display to append assigned departure slot, departure gate, taxiway path, and expected push-back time. ADFMS will utilize the ASDE-X data to monitor the status of the physical queue.

4.0 ADFMS CAPABILITY PACKAGES

The Airport Departure Flow Management System provides the following capability packages in order to support the PHL Airport Operations / Departure process:

- Departure Slot Lottery and Assignment
- Virtual and Physical Queue Management
- Departure Slot Brokering
- Virtual Queue Reconfiguration
- ADFMS Notification and Alerts
- ADFMS Reporting

4.1 Departure Slot Lottery and Assignment

ADFMS provides the ability for Airline Operating Centers (AOCs) to request and reserve departure slots at PHL three months in advance. The ADFMS scheduling module imposes a deadline for requests for aircraft departures for a specific Take-Off Time Window (TOTW) 100 days out before the proposed departure date. The lottery assigns each requestor to a specific departure slot within a 15-minute window. With the sustained departure rate of ten aircraft per 15 minutes, flights are input to and output from the departure process every one minute and 30 seconds. Airlines are assigned to departure slots designated by the following schema:

- Each Take-Off Time Window (TOTW) commences on the quarter of each hour. E.g. 0800, 0815, 0830, 0845, 0900, . . .
- There are 10 slots per 15 minutes, these slots are lettered A through J.

When an airline requests a Take-Off Time Window of 0815, ADFMS will assign one of 10 available departure slots in the window , such as 0815A (eight-fifteen Alpha), 0815E (eight-fifteen Echo), or 0815J (eight-fifteen Juliet).

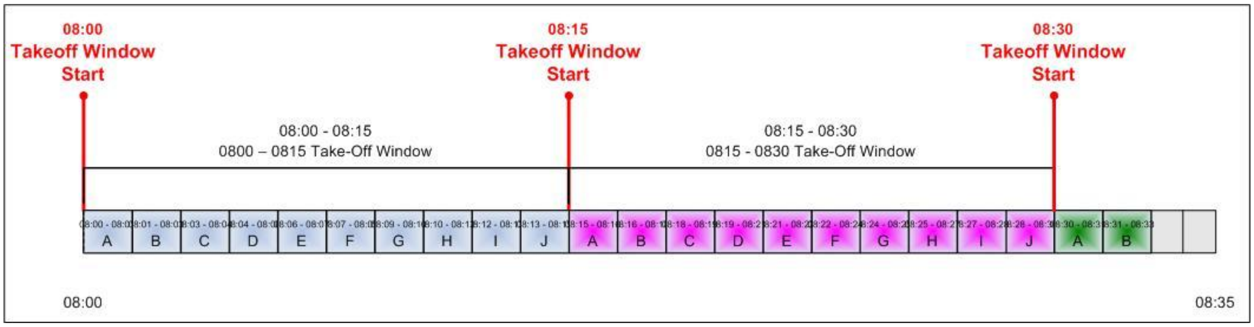

Figure B-7: ADFMS Departure Slots

ADFMS assigns these slots to the airlines based upon a lottery, and levels demand across the airport capacity. ADFMS confirms departure slots to the airlines no later than 95 days prior to departure. The assignment of departure slots to the airlines allows the airlines to finalize its flight schedule and lock-in its departure time per their reservation system (the reservation departure time is the scheduled push-back time). ADFMS imposes a minimum time of 30 minutes prior to departure slot for the announced scheduled pushback time. This 30-minute window will allow for minimum physical queue (taxi path) and near-term virtual queue flexibility (managed by ADFMS and Ramp Control) to optimize the physical queue. Airlines may request trades via ADFMS within the extended virtual queue in order to acquire more optimal departure slots (see paragraph 4.3 Departure Slot Brokering and Virtual Queue Reconfiguration).

4.2 Virtual and Physical Queue Management

The ADFMS Queuing Module enables the management of the departure queue with virtual and physical components that accommodates each aircraft's departure gate, ramp area, taxi path, departure runway, and departure slot relative to all other aircraft that are concurrently taxiing on PHL ramps and taxi paths while ensuring proper separation and sequencing.

The purpose of a virtual queue is to mitigate ramp and taxiway congestion while efficiently conserving airline resources. The virtual queue component therefore exists to optimize the sequencing of the physical queue component. To allow for this optimization, aircraft must be ready for pushback at the time of their scheduled pushback (i.e., for the entire expected pushback window) in order to allow for ADFMS-enabled flexibility within the near-term virtual queue.

The near-term virtual queue is the time between an aircraft's scheduled pushback time and the expected pushback time. The near-term virtual queue also serves as the last opportunity for the resequencing of aircraft prior to commitment to a Ramp Control Spot, taxi path and departure runway queue in order to accommodate airline desires to trade departure slots or fall-back to a later departure slot. The near-term virtual queue is the critical time period; ADFMS can accommodate trades and fall-backs of aircraft within the extended virtual queue (prior to scheduled pushback) with less impact on departure queue due to less critical required response times.

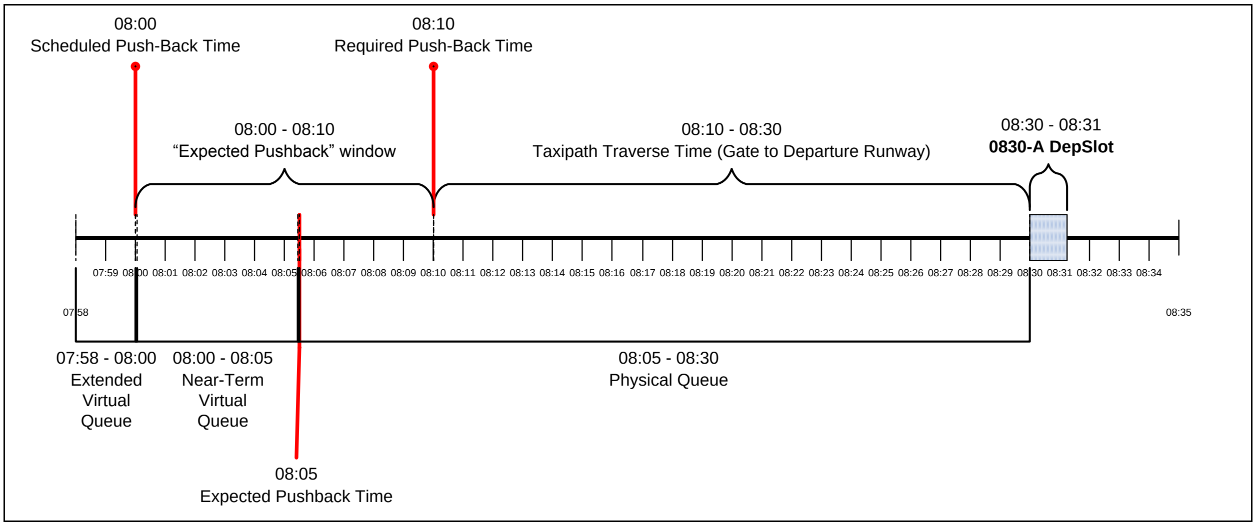

Figure B-8: ADFMS Virtual and Physical Queue

4.3 Departure Slot Brokering and Virtual Queue Reconfiguration

The ADFMS scheduling module assigns departure slots to airlines via lottery no later than 95 days prior to departure. These departure slots comprise the extended virtual queue that exists until an aircraft departure enters the near-term virtual queue at its scheduled pushback time. Once within the virtual queue, airlines are free to trade departure slots within the virtual queue utilizing the ADFMS brokering module.

The ADFMS brokering module enables an airline with a departure slot to request to trade-up (i.e. “buy”) an earlier departure slot to meet airline needs. The trading of slots is facilitated through the use of a point system for which each preceding departure slot is worth one point and requires the bidder to offer an amount of points equal to the number of preceding departure slots bypassed to acquire the desired earlier departure slot. Using ADFMS, an airline’s AOC can accept a trade offer by swapping (“selling”) its earlier departure slot and accepting the buyer’s departure slot. During this transaction, the selling airline acquires the points offered by the buyer. The net points in the transaction are zero: the selling airline acquires the points of the buying airline. If transactions are made between aircraft within the same airline (e.g. the US Airways hub at PHL would potentially be the source of many transactions), the net points to the airline would be zero. The offer to sell a departure slot to an airline bidding to trade is voluntary: no movement of aircraft in the queue will be accommodating without a willing seller. Therefore, there is no inherent unfairness to the aircraft surpassed within the queue as there is a one-for-one trade of departure slots.

The ADFMS brokering module will also enable an airline to request a trade-down to a later departure slot to meet airline needs. However, the trade request is a request to “sell” the earlier departure slots, as an earlier slot is always an asset within ADFMS relative to a slot with a later departure slot. The airline that “buys” the earlier slot in response to a trade request for a later departure slot would be debited a number of points equal to the number of departure slots later within the departure queue that it desires to drop back; the requesting (“seller”) airline acquires the points of the buyer in the transaction.

A third scenario is the ability for an airline to “fall-back” to a later departure slot to meet airline needs. As unscheduled maintenance is a common cause of aircraft delays, these situations are not likely to occur within the extended virtual queue (where ADFMS can best facilitate a swap), but instead within the near-term virtual queue. When an offer for trade-down to a later departure slot goes unfulfilled, an aircraft will have to fall-back to a later slot based upon an estimated recovery period, and all other aircraft prior to this later departure slot will bump-up one departure slot in order to optimize the physical queue. Aircraft that successfully bump-up to an earlier slot will earn one point for each preceding slot it achieves. However, the fall-back aircraft will not lose any points due to the general inability to foresee unscheduled maintenance. Point penalties will be counted but not assessed. When an airline surpasses a monthly point ceiling, point deductions will begin to be assessed to discourage airlines from allowing situations that lead to unplanned fall-back situations. Each airline’s monthly point ceiling threshold will differ; it will be based upon a percentage (perhaps 5%) of all scheduled monthly departures for the airline, but will also have allow a minimum number of fall-back occurrences so that low-volume airlines at PHL are not unfairly punished due to percentage calculations.

Airlines acquire points to facilitate the trading of departure slots. These points have no monetary value, and instead exist to encourage good behavior amongst the airline participants at PHL. Each airline starts out the month with a base set of points to first enable buying departure slots from willing sellers. Sellers acquire points to facilitate buying desired departure slots during the month as well. Points expire after four weeks to discourage the hoarding of points that may discourage future cooperative activity amongst all airlines at PHL.

Trade requests are made by the airlines’ AOC within the virtual queue up to two hours prior to scheduled pushback time. Within the last two hours of the extended virtual queue, and within the near-term virtual queue, all trade offers are made within ADFMS by the airline Station Managers. Once an airline enters its expected pushback window, it must be ready to pushback immediately in order to accommodate the fall-back and bump-up scenario that occurs due to unscheduled maintenance activity and other unforeseen circumstances.

4.3.1 The Points System

The point system is defined by a set of rules.

1. An airline cannot execute a buying transaction when points are less than zero.
2. When a departure slot is purchased, the number of points spent is equal to the number of slot positions moved.
3. Points are transferred from the buyer to the seller.
4. Unused or unfilled slots can be acquired without spending points.
5. Airlines only purchase slots scheduled to departure earlier.
6. Airlines do not purchase slots in order to depart later; however, they could attempt to sell a slot to go later. If the sale does not happen, the slot is simply lost.

The points system comprises rolling points system based on weeks which are reset periodically. Any unused points expire periodically. The reset period removes the possibility of unlimited point totals. The points roll over to the subsequent weeks in first-in first-out (FIFO) fashion.

Consider an example based on an average of 40 points over a four week period as shown in the example below.

Each week 10 points are acquired. After conducting the buying and selling transactions throughout the week, the points for the most recent last three weeks get rolled over to the next week and 10 points are gained for the new week. The points for the fourth previous week expire. The initial point total is defined as the number of points added each period times the number of periods. As shown in the diagram below, the number of points per period is 10 and the number of periods is 4. This yields 40 initial points.

Week Ending	20-Feb	27-Feb	6-Mar	13-Mar	20-Mar	27-Mar	3-Apr	10-Apr	17-Apr	24-Apr	1-May
Weekly Starting Total	40	40	40	35	50	50	55	45	55	45	50
3 weeks	10	10	10	5	10	10	20	10	15	5	20
2 weeks	10	10	10	10	10	20	10	15	10	20	10
1 week	10	10	10	10	20	10	15	10	20	10	10
current week	10	10	10	10	10	10	10	10	10	10	10
Buys		10	15			10			20		10
Sells				10		5		10			
End of Week Total	40	30	25	45	50	45	55	55	35	45	40
3 weeks	~~10~~	~~0~~	0	5	10	0	20	10	0	5	10
2 weeks	10	10	5	10	10	20	10	15	5	20	10
1 week	10	10	10	10	20	10	15	10	20	10	10
current week	10	10	10	20	10	15	10	20	10	10	10

Expiring Points   10 points acquired each week

Figure B-9: Point System

The rolling points system is based on three rules applied at the end of each week (or other defined period):

1. The oldest points expire.
2. Non-expiring points shift one week in age.
3. 10 points are added for the current week.

If needed the period length (currently one week), maximum point age (currently three weeks) and points added each period (currently 10 points) can vary in order to better suit the users of the system.

4.3.2 Virtual Queue Reconfiguration

The ADFMS virtual queuing module works with the brokering module to reconfigure the virtual queue to accommodate the departure slot swapping and fall-back scenarios. Each pair of exchanged departure slots requires ADFMS to recalculate each aircraft's taxi path, required pushback time, expected pushback window and expected pushback time to best reconfigure the virtual and physical queue sequencing.

4.4 Notifications and Alerts

The Airport Departure Flow Management System uses notifications and alerts to assist Ramp Control and Station Managers in the execution of their duties. ADFMS notifications and alerts are system messaging, not email. Notifications and alerts are instantly recognizable on the ADFMS display.

ADFMS will notify AOCs of departure slots assignments after the scheduling module completes the departure slot lottery and levels demand across airport capacity. On the day of departure, ADFMS will notify AOCs and Station Managers of each airline's expected pushback time per flight after determinations are made for PHL runway configuration and aircraft gate assignments. ADFMS will update the each flights' expected pushback time to account for changes in runway configuration or gate assignment and send out alerts when changes are made.

ADFMS will notify Station Managers of departure slot trade requests per flight while the aircraft is in the extended virtual queue. Station managers may accept or reject trade requests through their ADFMS interface/display. ADFMS will send notification of a trade confirmation or rejection to the participating Station Managers.

Once a flight enters the near-term virtual queue component of the departure queue, ADFMS will send alerts to Station Managers when there are updates to the flight's expected pushback time, normally the result of the need for an aircraft with an earlier departure slot to fall-back for unscheduled maintenance or other unforeseen need.

ADFMS will also send notifications for point transactions as a result of trades and assessed penalties.

4.5 ADFMS Reports

ADFMS provides a reporting capability that allows ADFMS users to generate, view, print, and save reports relating to current and historical operational status of PHL airport departure operations. The ADFMS reporting module provides pre-defined reports as well as an ad hoc reporting capability. Pre-defined reports includes a record of performance for individual and collective airline flights with respect to expected and actual pushback times, actual taxi time per flight and airline with data to include departure gate, taxi path, departure runway and take-off time. ADFMS also reports on the results of the trade brokering module to include a record of airline trade requests (made and received), acceptances, and rejections; fallback and bump up occurrences, suspended and assessed penalties, and current and historical airline point totals. ADFMS reports will include a record of trades and point exchanges both intra-airline and inter-airlines, as well as a report that documents undesired behavior to include unused departure slots (both significantly delayed as well as cancelled departures) flights. The ad hoc reporting capability will enable ADFMS users to create reports based upon desired database fields as necessary to meet the users' needs.

C. APPENDIX C ADFMS System Requirements Documents (SRD)

Airport Departure Flow Management System (ADFMS)

System Requirements Document

Version 1.0
Date April 1, 2010

Prepared by: Team AirportDFM

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Table of Contents

1.0 Requirements

1.1 Functional Requirements

1.1.1 System Input and Request Capability

1.1.1.1 The ADFMS shall have a pre-populated data containing aircraft type, airline information for users to select from instead of manually entering the information.

1.1.1.2 The ADFMS shall provide users a capability to request for a departure slot.

1.1.1.3 The ADFMS shall provide the airlines a capability to input the flight schedules into the system.

1.1.1.4 The ADFMS shall detect and notify the user of an invalid request for departure slot.

1.1.1.5 The ADFMS shall be capable of accepting departure slot request 100 days prior to the actual departure date.

1.1.1.6 The ADFMS shall be capable of allowing users to adjust the business rules of the system.

1.1.2 System Acknowledgement and Notification Capability

1.1.2.1 The ADFMS shall provide an acknowledgment message to the user within 5 seconds upon receiving a valid request.

1.1.2.2 The ADFMS shall notify and alert the user of a change in the updated request status within 60 seconds upon the system receiving the change.

1.1.2.3 The ADFMS shall notify and alert the user of a change in the wait time of the virtual queue within 60 seconds upon the system receiving its updated status.

1.1.2.4 The ADFMS shall notify and alert users when the virtual queue has an open slot that is available for reservation.

1.1.2.5 The ADFMS shall notify and alert the AOCs of assigned departure slots.

1.1.2.6 The ADFMS shall notify and alert the Station Managers of the expected pushback time and updated expected pushback times.

1.1.2.7 The ADFMS shall notify and alert the Station Managers of the assigned taxi-path.

1.1.2.8 The ADFMS shall notify and alert the Station Managers of all trading transactions.

1.1.3 System Departure Queuing Capability

1.1.3.1 The ADFMS shall implement the departure queuing slots using virtual queue system.
1.1.3.2 The ADFMS shall assign an aircraft a departure slot based on the aircraft's flight schedule, aircraft's flight status, runway configuration, aircraft's gate position, and aircraft's taxi path.
1.1.3.3 The ADFMS shall assign an aircraft slot such that the time between pushback time and the actual departure time is minimized.
1.1.3.4 The ADFMS shall update the virtual queuing slot and notify the users that have been placed in the virtual queuing every 60 seconds until the user is no longer in the virtual queuing.
1.1.3.5 The ADFMS shall minimize the time difference between the departure request time and the actual departure time.
1.1.3.6 The ADFMS shall be capable of adjusting the slot in the virtual queue to allow an emergency request to either enter or leave the queuing slot.
1.1.3.7 The ADFMS shall be capable of allowing users to trade up or trade down the slot position in the virtual queue with other users.
1.1.3.8 The ADFMS shall predict and provide the Station Manager with the expected pushback time once an aircraft has been assigned a departure slot.
1.1.3.9 The ADFMS shall prevent more than two aircraft simultaneously approaching at the entrance of the runway for take off.
1.1.3.10 The ADFMS shall support at least three taxi-paths for aircraft approach to the entrance of the runway for take off.

1.1.4 Aircraft Tracking and Monitoring Capability

1.1.4.1 The ADFMS shall provide a near real-time situational awareness map tracking all aircraft at the ramp, apron, taxiway and runway. Near real-time is defined as a 5 second delay from the actual time.
1.1.4.2 The ADFMS shall track and monitor the status of each aircraft that has been entered in the virtual departure queue.
1.1.4.3 The ADFMS shall track and monitor the status of each aircraft that has been entered in the departure physical queue.
1.1.4.4 The ADFMS shall update aircraft position every 10 seconds.
1.1.4.5 The ADFMS shall provide aircraft positions to users upon request.
1.1.4.6 The ADFMS shall predict an aircraft taxi out time within +/- 60 seconds of the actual taxi out time.
1.1.4.7 The ADFMS shall predict an aircraft expected pushback time within +/- 60 seconds of the actual pushback time.
1.1.4.8 The ADFMS shall be capable of providing the ramp traffic status upon user request.
1.1.4.9 The ADFMS shall compute the taxi-path for the aircraft.

1.1.5 System Search Capability

1.1.5.1 The ADFMS shall allow users to query the database using key words, time, date, airline, pilot name, aircraft flight number, aircraft type, pushback time, and departure slot.

1.1.5.2 The ADFMS shall allow users to sort the database.

1.1.6 Trading and Exchanging Slots

1.1.6.1 The ADFMS shall keep a record of each airline's trading slot transactions. A record shall contain at the minimum of the following data: date, time, original queue slot, new queue slot, trading party, number of points exchanged, reason for trading.

1.1.6.2 The ADFMS shall keep track of points for each airline and update the points within 30 seconds of the transaction.

1.1.6.3 The ADFMS shall check for expired points and automatically update the point records for each airline.

1.2 Performance Requirements

1.2.1 System Response Requirements

1.2.1.1 The ADFMS shall respond to a delay notification within 30 seconds.

1.2.1.2 The ADFMS shall be capable of assigning a slot with the departure rate of 10 flights every 15 minutes.

1.2.1.3 The ADFMS shall respond to a user request for service within two seconds.

1.2.1.4 The ADFMS shall be capable of processing 50 transactions per second.

1.2.2 System Capacity

1.2.2.1 The ADFMS shall be capable of storing three months of departure slots data.

1.2.3 System Update and Refresh

1.2.3.1 The ADFMS shall update the departure queue at every 30 seconds and notify all impacted users of the status.

1.2.3.2 The ADFMS shall automatically refresh the system every 30 seconds.

1.3 Interface and Interoperability Requirements

1.3.1 Existing Communication Links

1.3.1.1 The ADFMS shall not interfere with the existing radio systems at PHL.

1.3.1.2 The ADFMS shall interface with the existing communication systems used by aircraft, airlines, Station Managers, Ramp Controllers, and ATCT.

1.3.2 Existing Hardware Systems

1.3.2.1 The ADFMS shall be capable of interfacing with the ASDE-X system to integrate the data into ADFMS.

1.3.2.2 The ADFMS shall be capable of interfacing with existing ATC systems.

1.3.2.3 The ADFMS shall be capable of interfacing with the AOCnet system**.**

1.4 Operational Requirements

1.4.1 Graphical User Interface

1.4.1.1 The ADFMS shall provide graphical user interface to users.
1.4.1.2 The ADFMS shall provide a web-based system to users.

1.4.2 Printing Capability

1.4.2.1 The ADFMS shall support the printing capability to allow users to print data.

1.5 Security Requirements

1.5.1 System Accessibility

1.5.1.1 The ADFMS shall implement a security mechanism to prevent unauthorized users from accessing the system.
1.5.1.2 The ADFMS shall implement a security mechanism to prevent unauthorized users from making modifications to the system.
1.5.1.3 The ADFMS shall implement a security mechanism to prevent unauthorized users from transferring data off the system.

1.5.2 Security Alert

1.5.2.1 The ADFMS shall alert and notify the system administrator when malicious activity is detected.
1.5.2.2 The ADFMS shall alert and notify the system administrator when a predefined number of unsuccessful logon attempts are exceeded.

1.5.3 Data Encryption

1.5.3.1 The ADFMS shall encrypt all data residing on the system.
1.5.3.2 The ADFMS shall encrypt all data being transferred off the system.

1.5.4 Data Backup

1.5.4.1 The ADFMS shall automatically backup data daily based on user specified time.
1.5.4.2 The ADFMS shall store the backup data in a separate hard-drive that is not used for the primary data.

1.6 Reliability Requirements

1.6.1 The ADFMS shall be accessible to the users 24 hours a day.
1.6.2 The ADFMS shall be capable of performing self-system diagnostics check test.
1.6.3 The ADFMS shall be operable without crashing or locking up the system at least 99% of the time.

1.7 Maintainability Requirements

1.7.1 The ADFMS shall support remote access for system maintenance and upgrade.
1.7.2 The ADFMS shall provide self-system troubleshooting procedures to the system maintainer.

1.8 Safety Requirements

1.8.1 The ADFMS shall incorporate the safe separation distance of aircraft into the prediction of aircraft expected pushback time.

1.8.2 The ADFMS shall notify and alert the Ramp Controllers when an aircraft has exceeded the safe separation distance in the airfield.

1.8.3 The ADFMS shall comply with FAA safety regulations.

2.0 Requirements Verification Methods

Team AirportDFM defined four verification methods to be used in requirements verification testing. These methods are inspection, demonstration, test and analysis.

- Inspection (I): Inspection is the examination of an item to determine whether it conforms to the specified requirements. This verification method includes the inspection of compliant certificate and documentation.

- Demonstration (D): Demonstration is the actual operation of an item to provide evidence that the required functions were accomplished under specific scenarios.

- Test (T): Test involves scientific principles and procedures that applied to determine the properties or functional capabilities of items.

- Analysis (A): Analysis uses established technical or mathematical models or simulations, algorithms, charts, graphs, circuit diagrams, or other scientific principles and procedures to provide evidence that the item meets its specified requirement.

Section	Requirements Name	Verification Method
1.1.1	System Input and Request Capability	
1.1.1.1	The ADFMS shall have a pre-populated data containing aircraft type, airline information for users to select from instead of manually entering the information.	D
1.1.1.2	The ADFMS shall provide users a capability to request for a departure slot.	D
1.1.1.3	The ADFMS shall provide the airlines a capability to input the flight schedules into the system.	D
1.1.1.4	The ADFMS shall detect and notify the user of an invalid request for departure slot.	D
1.1.1.5	The ADFMS shall be capable of accepting departure slot request 100 days prior to the actual departure date.	D
1.1.1.6	The ADFMS shall be capable of allowing users to adjust the business rules of the system.	D
1.1.2	System Acknowledgement and Notification Capability	

1.1.2.1	The ADFMS shall provide an acknowledgment message to the user within 5 seconds upon receiving a valid request	D
1.1.2.2	The ADFMS shall notify and alert the user of a change in the updated request status within 60 seconds upon the system receiving the change.	D
1.1.2.3	The ADFMS shall notify and alert the user of a change in the wait time of the virtual queue within 60 seconds upon the system receiving its updated status.	D
1.1.2.4	The ADFMS shall notify and alert users when the virtual queue has an open slot that is available for reservation.	D
1.1.2.5	The ADFMS shall notify and alert the AOCs of assigned departure slots.	D
1.1.2.6	The ADFMS shall notify and alert the Station Managers of the expected pushback time and updated expected pushback times.	D
1.1.2.7	The ADFMS shall notify and alert the Station Managers of the assigned taxi-path.	D
1.1.2.8	The ADFMS shall notify and alert the Station Managers of all trading transactions.	D
1.1.3	System Departure Queuing Capability	
1.1.3.1	The ADFMS shall implement the departure queuing slots using virtual queue s	D
1.1.3.22	The ADFMS shall assign an aircraft a departure slot based on the aircraft’s flight schedule, aircraft’s flight status, runway configuration, aircraft’s gate position, and aircraft’s taxi path.	D
1.1.3.33	The ADFMS shall assign an aircraft slot such that the time between pushback time and the actual departure time is minimized.	T
1.1.3.44	The ADFMS shall update the virtual queuing slot and notify the users that have been placed in the virtual queuing every 60 seconds until the user is no longer in the virtual queuing.	D, T
1.1.3.5	The ADFMS shall minimize the time difference between the departure request time and the actual departure time.	T, A
1.1.3.6	The ADFMS shall be capable of adjusting the slot in the virtual queue to allow an emergency request to either enter or leave the queuing slot	D
1.1.3.7	The ADFMS shall be capable of allowing users to trade up or trade down the slot position in the virtual queue with other users.	D
1.1.3.8	The ADFMS shall predict and provide the Station Manager with the expected pushback time once an aircraft has been assigned a departure slot.	D, T
1.1.3.9	The ADFMS shall prevent more than two aircraft simultaneously approaching at the entrance of the runway	D, T

	for take off.	
1.1.3.10	The ADFMS shall support at least three taxi-paths for aircraft approach to the entrance of the runway for take off.	D
1.1.4	Aircraft Tracking and Monitoring Capability	
1.1.4.1	The ADFMS shall provide a near real-time situational awareness map tracking all aircraft at the ramp, apron, taxiway and runway. Near real-time is defined as a 5 second delay from the actual time.	D
1.1.4.2	The ADFMS shall track and monitor the status of each aircraft that has been entered in the virtual departure queue.	D
1.1.4.4	The ADFMS shall update aircraft position every 10 seconds.	D
1.1.4.5	The ADFMS shall provide aircraft positions to users upon request.	D
1.1.4.6	The ADFMS shall predict an aircraft taxi out time within +/- 60 seconds of the actual taxi out time.	D
1.1.4.7	The ADFMS shall predict an aircraft expected pushback time within +/- 60 seconds of the actual pushback time.	D
1.1.4.8	The ADFMS shall be capable of providing the ramp traffic status upon user request.	D
1.1.4.9	The ADFMS shall compute the taxi-path for the aircraft.	D
1.1.5	System Search Capability	
1.1.5.1	The ADFMS shall allow users to query the database using key words, time, date, airline, pilot name, aircraft flight number, aircraft type, pushback time, and departure slot	D
1.1.5.2	The ADFMS shall allow users to sort the database.	D
1.1.6	Trading and Exchanging Slots	
1.1.6.1	The ADFMS shall keep a record of each airline's trading slot transactions. A record shall contain at the minimum of the following data: date, time, original queue slot, new queue slot, trading party, number of points exchanged, reason for trading.	D
1.1.6.2	The ADFMS shall keep track of points for each airline and update the points within 30 seconds of the transaction.	D
1.1.6.3	The ADFMS shall check for expired points and automatically update the point records for each airline.	D
1.2	Performance Requirements	
1.2.1	System Response Requirements	
1.2.1.1	The ADFMS shall respond to a delay notification within 30 seconds.	D
1.2.1.2	The ADFMS shall be capable of assigning a slot with the departure rate of 10 flights every 15 minutes.	D
1.2.1.3	The ADFMS shall respond to a user request for service within two seconds.	D, T
1.2.1.4	The ADFMS shall be capable of processing 50 transactions per second.	D, T

1.2.2	System Capacity	
1.2.2.1	The ADFMS shall be capable of storing three months of departure slots data.	D
1.2.3	System Update and Refresh	
1.2.3.1	The ADFMS shall update the departure queue at every 30 seconds and notify all impacted users of the status.	D
1.2.3.2	The ADFMS shall automatically refresh the system every 30 seconds.	D
1.3	Interface and Interoperability Requirements	
1.3.1	Existing Communication Links	
1.3.1.1	The ADFMS shall not interfere with the existing radio systems at PHL.	D, T
1.3.1.2	The ADFMS shall interface with the existing communication systems used by aircraft, airlines, Station Managers, Ramp Controllers, and ATCT.	D, T
1.3.2	Existing Hardware Systems	
1.3.2.1	The ADFMS shall be capable of interfacing with the ASDE-X system	D
1.3.2.2	The ADFMS shall be capable of interfacing with existing ATC systems.	D
1.3.2.3	The ADFMS shall be capable of interfacing with the AOCnet system.	D
1.4	Operational Requirements	
1.4.1	Graphical User Interface	
1.4.1.1	The ADFMS shall provide graphical user interface to users.	D
1.4.2	Printing Capability	
1.4.2.1	The ADFMS shall support the printing capability to allow users to print data.	D
1.4.1.2	The ADFMS shall provide a web-based system to users.	D
1.4.2	Printing Capability	
1.4.2.1	The ADFMS shall support the printing capability to allow users to print data.	D
1.5	Security Requirements	
1.5.1	System Accessibility	
1.5.1.1	The ADFMS shall implement a security mechanism to prevent unauthorized users from accessing the system.	D, T
1.5.1.2	The ADFMS shall implement a security mechanism to prevent unauthorized users from making modifications to the system.	D, T
1.5.1.3	The ADFMS shall implement a security mechanism to prevent unauthorized users from transferring data off the system.	D, T
1.5.2	Security Alert	
1.5.2.1	The ADFMS shall alert and notify the system administrator when malicious activity is detected.	D, T

1.5.2.2	The ADFMS shall alert and notify the system administrator when a predefined number of unsuccessful logon attempts are exceeded.	D
1.5.3	Data Encryption	
1.5.3.1	The ADFMS shall encrypt all data residing on the system.	D, I
1.5.3.2	The ADFMS shall encrypt all data being transferred off the system.	D, I
1.5.4	Data Backup	
1.5.4.1	The ADFMS shall automatically backup data daily based on user specified time.	D, T
1.5.4.2	The ADFMS shall store the backup data in a separate hard-drive that is not used for the primary data.	D, I
1.6	Reliability Requirements	
1.6.1	The ADFMS shall be accessible to the users 24 hours a day.	I, A
1.6.2	The ADFMS shall be capable of performing self-system diagnostics check test.	D, A
1.6.3	The ADFMS shall be operable without crashing or locking up the system at least 99% of the time.	T, A
1.7	Maintainability Requirements	
1.7.1	The ADFMS shall support remote access for system maintenance and upgrade.	D
1.7.2	The ADFMS shall provide self-system troubleshooting procedures to the system maintainer.	D
1.8	Safety Requirements	
1.8.1	The ADFMS shall incorporate the safe separation distance of aircraft into the prediction of aircraft expected pushback time.	I
1.8.2	The ADFMS shall notify and alert the Ramp Controllers when an aircraft has exceeded the safe separation distance in the airfield.	D, I
1.8.3	The ADFMS shall comply with FAA safety regulations.	I

Figure C-1: System Requirements

D. APPENDIX D Architecture

Airport Departure Flow Management System (ADFMS)

Architecture

SYST 798 / OR 680
April 22, 2010

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Table of Contents

1. Operational Architecture

1.1 Purpose

The purpose for this architecture is to assist in developing a design to implement a departure slot reservation and queuing system for airplane departures from Philadelphia International Airport (PHL).

1.2 Viewpoint

The viewpoint is that of the airport operations manager who understands the management of airplanes around the airport and the detailed operations of the airport.

1.3 Scope

Operational and Systems Architecture

1.4 Organizational Relationship

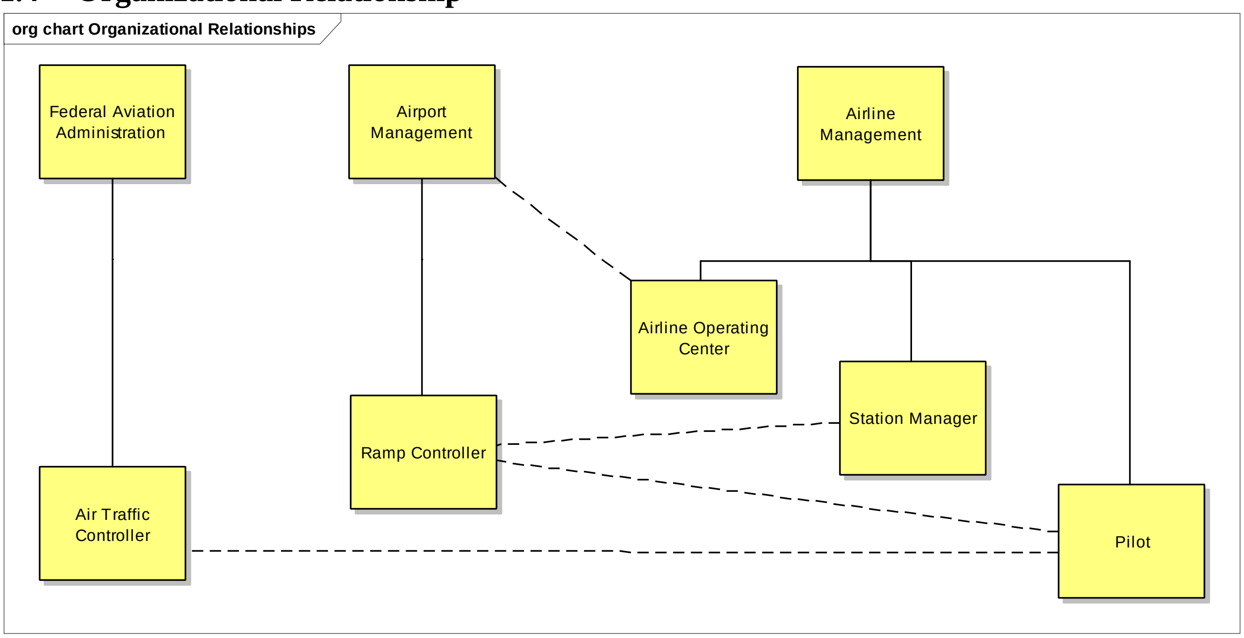


Figure D-1 Organizational Relationship

1.5 Class Diagram

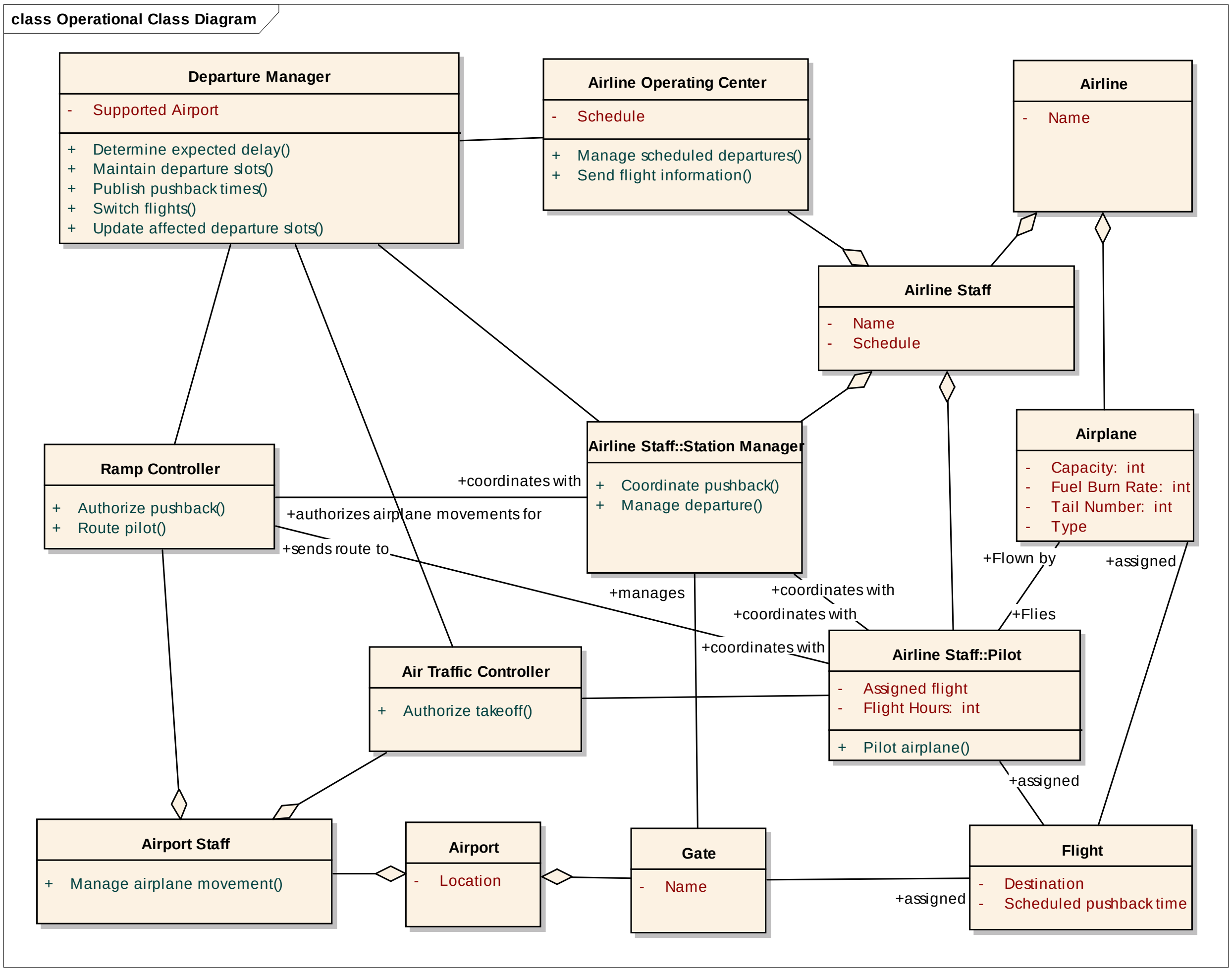


Figure D-2 Operational Class Diagram

1.6 Operational Concept

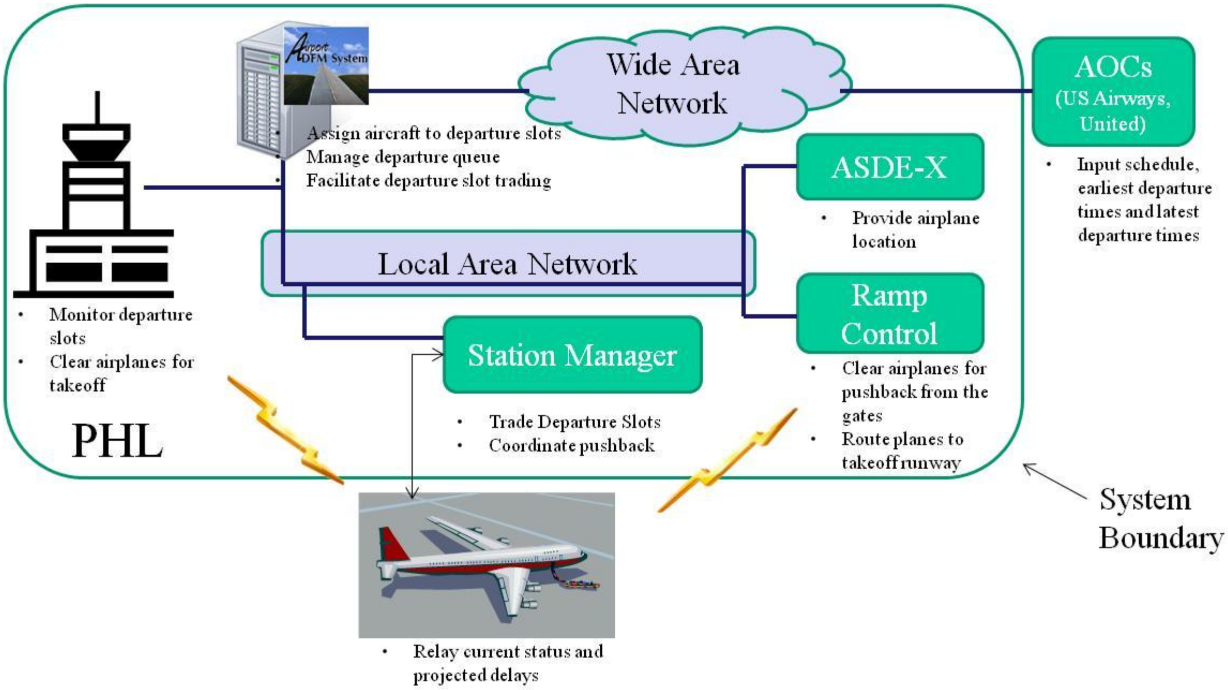


Figure D-3 Operational Concept

- Airlines reserve departure slots at the airport based on their flight schedules. ADFMS uses information about ramp use and gate to runway taxi times to compute when the plane should push back for departure to meet its departure slot time.
- Departure slot information and expected pushback times are used by Station Managers and Ramp Control to manage aircraft departures.
- If a flight is running late for mechanical or other problems then the airline can trade the departure slot for a later departure slot.
- ADFMS tracks the airplanes that it is projected to release from each ramp in order to account for ramp congestion.
- ADFMS accounts for taxiway congestion when calculating the proper pushback time.

1.7 Use Cases

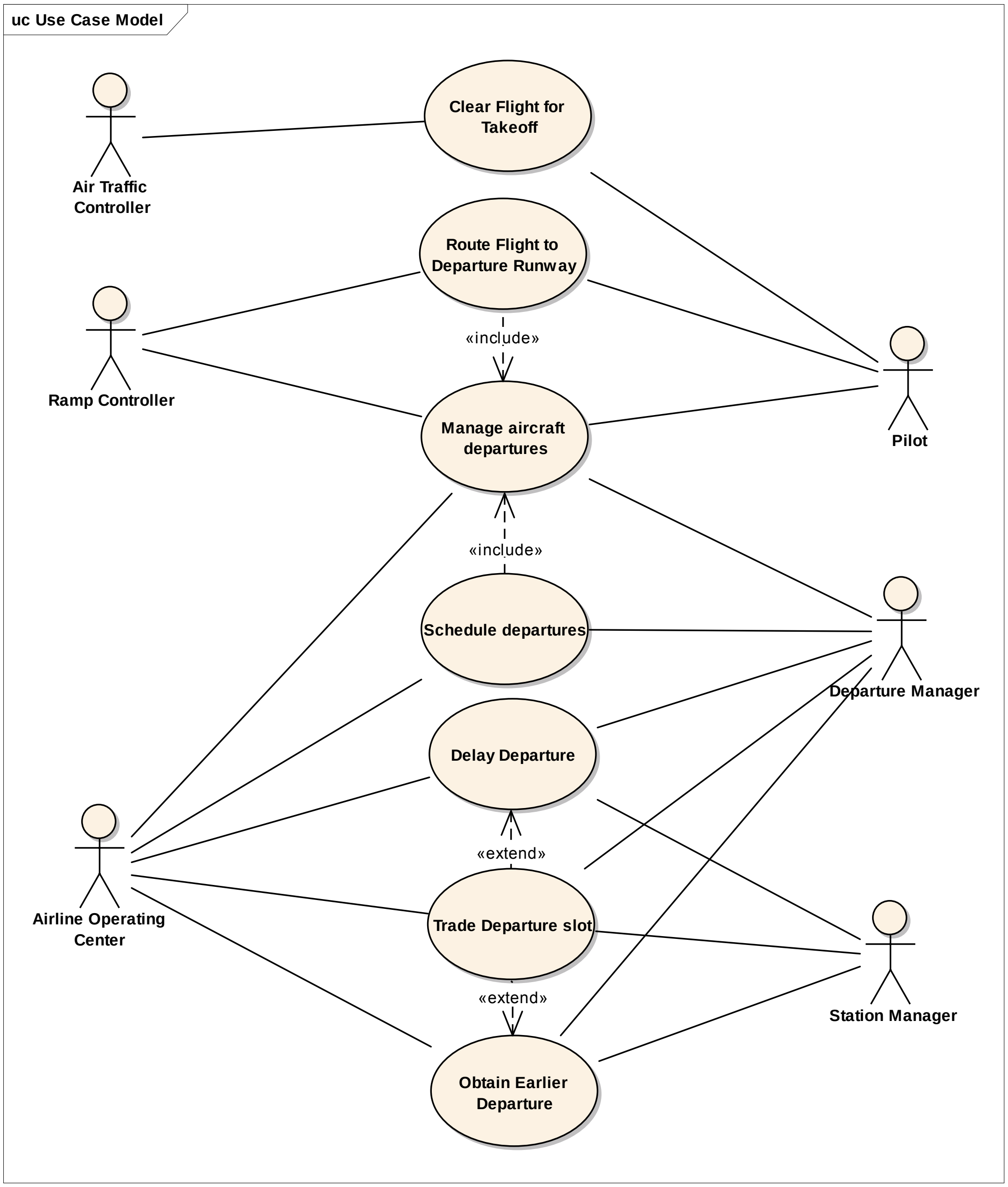


Figure D-4 Use Case Diagram

Use Case: Manage airplane departures.

Precondition: Airline schedule available for input

Actors: Airline Operating Center, Ramp Controller, Pilot, Station Manager

Goal Level: Above Sea Level

1. Airline Operating Center calculates preliminary schedule and requests departure slots.
2. Departure manager assigns departure slots.
3. The Station Manager assigns gates to the flights.
4. Departure manager calculates expected pushback times.

5. Ramp Controller contacts pilot for pushback based on expected pushback times.
6. Pilot proceeds to departure runway based on Ramp Controller instructions.
7. Pilot contacts air traffic control for departure.

Post-condition: Airplane ready for departure.

Use Case: Attempt to secure a later departure slot

Pre-condition: Flight needs to be delayed

Actors: Station Manager #1, Station Manager #2 (or Airline Operating Center depending on timeframe)

Goal Level: Sea Level

Main Success Scenario

1. Station Manager #1 selects the affected flight and inputs a scheduled pushback time and earliest and latest wheels up time.
2. Departure manager reviews empty departure slots and selects the closest available, minimizing the difference between the expected push back time and the scheduled push back time.
3. Departure manager places a reservation in the departure slot and keeps the other slot information to see if another airline wishes to trade.
4. Departure manager places a sell order for the original departure slot.
5. Departure manager sends the departure slot and expected push back time.
6. Station Manager #1 accepts the new departure slot.
7. Upon reaching the scheduled pushback time associated with the original reservation, Departure manager removes the reservation if it still exists.

Main Success Scenario Extensions:

2a. An empty departure slot is established by shifting the schedule. (All departure slots move forward one slot creating an open slot for the aircraft)

1. Departure manager sends new schedule to Station Managers.

2b. Later departure slot is not available within the requested time window.

1. Departure manager assigns the next closest slot.
2. Departure manager notifies Station Manager #1 of the new slot. (Station Manager can now try to buy an earlier slot).

4a. Station Manager #2 in interested in the available departure slot

1. Station Manager #2 logs selects departure slot sale.
2. Station Manager #2 the flight to move to an earlier departure slot.
3. Departure manager switches the flights and calculates updated pushback times.

Post-condition: departure slot is updated based on delay.

Use Case: Attempt to secure an earlier departure slot

Pre-condition: Flight is able to leave earlier than scheduled

Actors: Station Manager #1, Station Manager #2 (or Airline Operating Center depending on timeframe)

Goal Level: Sea Level

Main Success Scenario

1. Station Manager #1 selects the affected flight and inputs a scheduled pushback time and earliest and latest wheels up time.
2. Departure manager reviews empty departure slots and selects the closest available, minimizing the difference between the expected push back time and the scheduled push back time.
3. Departure manager sends the departure slot and expected push back time.
4. Station Manager #1 accepts the information.

Main Success Scenario Extensions:

2a. Primary departure slots filled but next best is acceptable

   1. Departure manager determines that all departure slots are filled for the desired time.
   2. Departure manager sends the two best available options based on latest departure time and scheduled departure time. Departure manager also sends the option to enter a buy option along with the airline point total and price for the move.
   3. Station Manager #1 selects a best available option

2b. Airline Operating Center selects the buy option

   1. Departure manager determines that all departure slots are filled for the desired time.
   2. Departure manager sends the two best available options based on latest departure time and scheduled departure time. ADFMS also displays the option to enter a buy option along with the airline point total and price for the move.
   3. Station Manager #1 selects the buy option
   4. Departure manager notifies all PHL users of the buy option
   5. Station Manager #2 accepts the buy option
   6. Departure manager switches the flights assigned to the departure slots and conducts the point transaction.

Use Case: Taxi Airplane

Pre-condition: Airplane is ready for pushback.

Actors: Station Manager, Ramp Controller, Pilot

Goal Level: Sea Level

Main Success Scenario

1. Station Manager tells Ramp Control that flight is prepared for pushback.
2. ADFMS notifies Ramp Controller than a flight needs to pushback.
3. Ramp Controller examines ramp and clears airplane for push back from gate.
4. Plane is pushed from gate by ground crew.
5. Ramp Controller clears airplane to the end of the ramp.
6. Ground controller sends the pilot directions to reach the takeoff runway.
7. Pilot takes plane to the takeoff runway following ground controller instructions.
8. Ground control notifies pilot to contact air control.

Post-condition: Airplane is ready for takeoff.

Below are diagrams showing some additional uses cases that were identified, but were not expanded upon as part of this analysis.

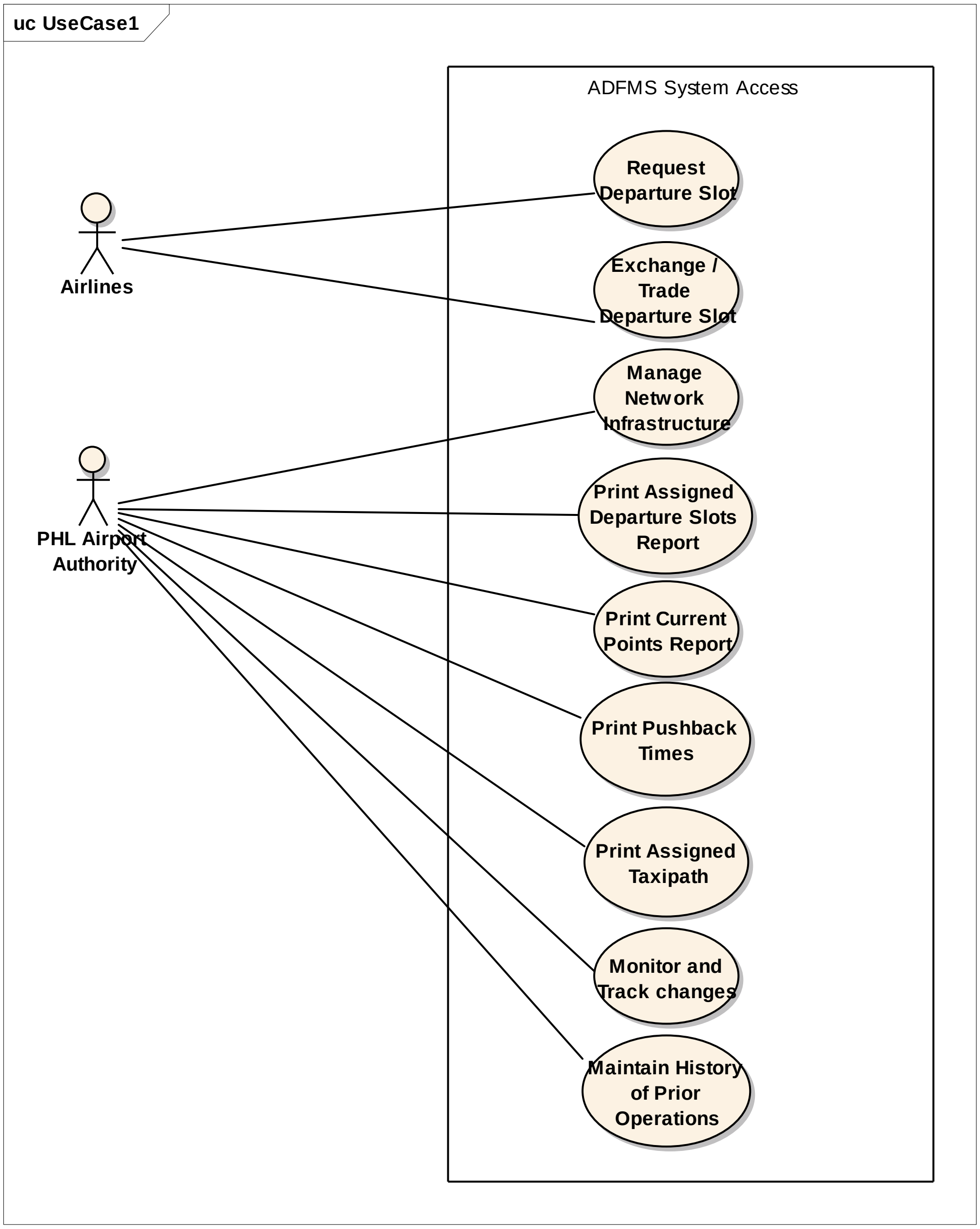


Figure D-5 Additional Use Cases 1

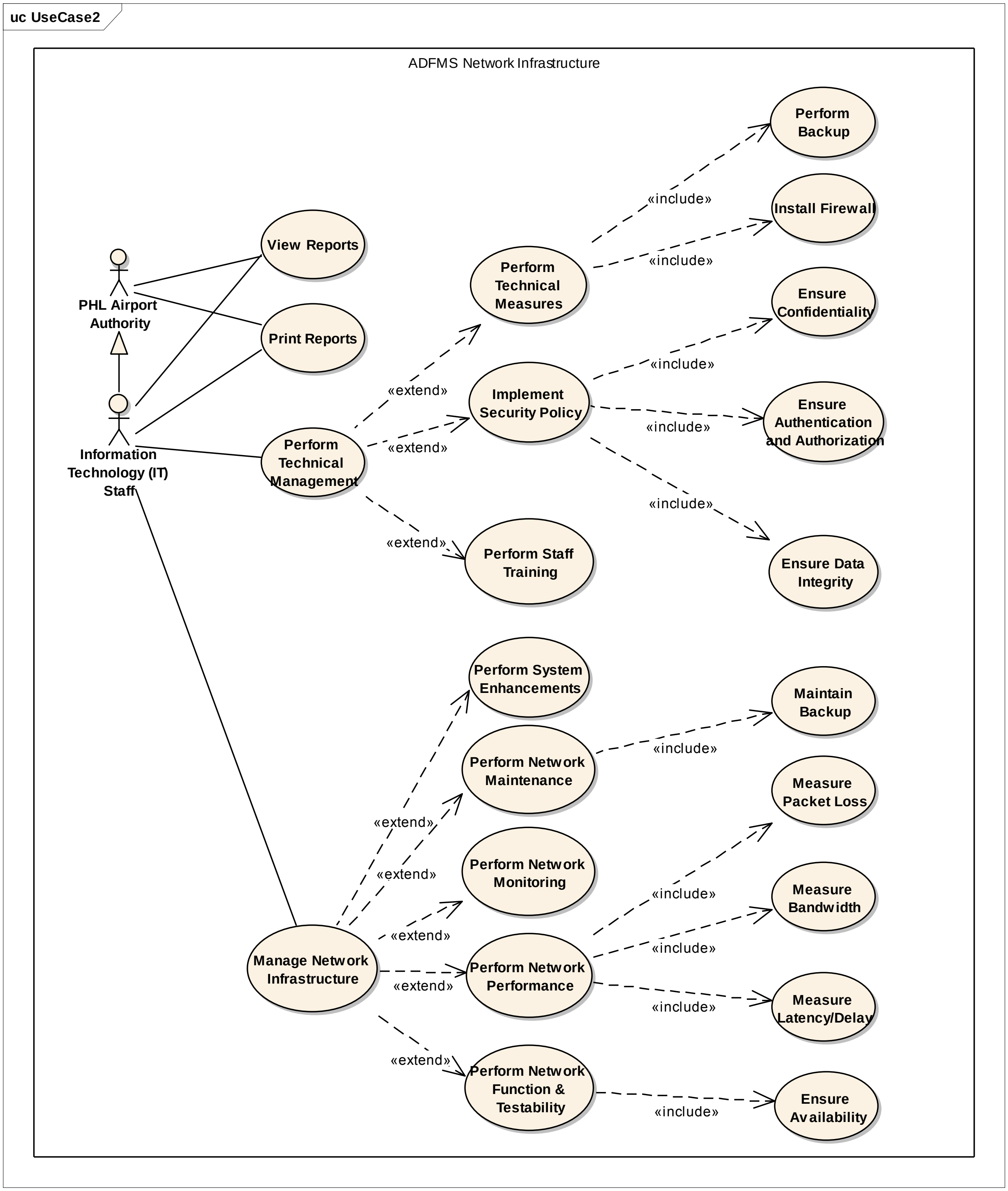


Figure D-6 Additional Use Cases 2

1.8 Operational Activity Diagrams

Use Case: Attempt to secure a later departure slot

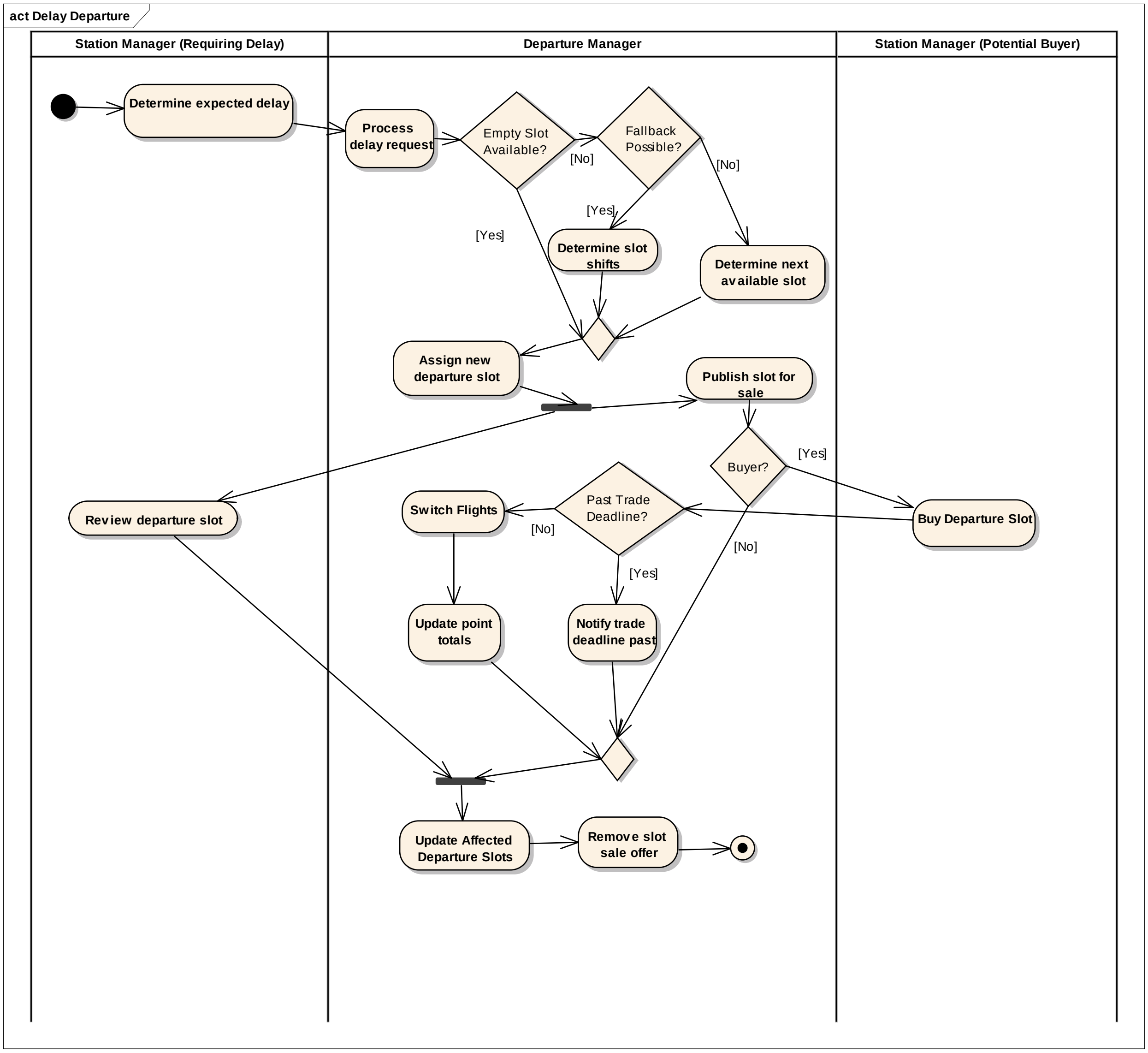


Figure D-7 Attempt to secure a later departure slot Activity Diagram

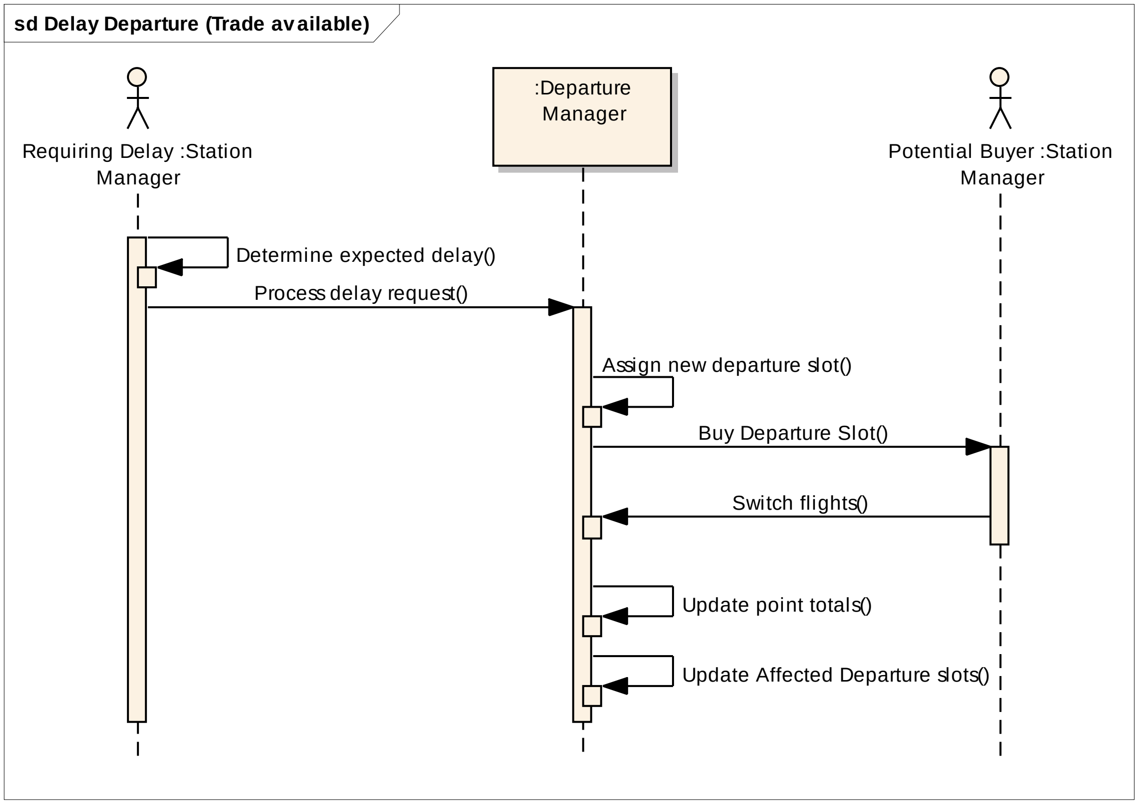


Figure D-8 Delay Departure (Trade available) Sequence Diagram

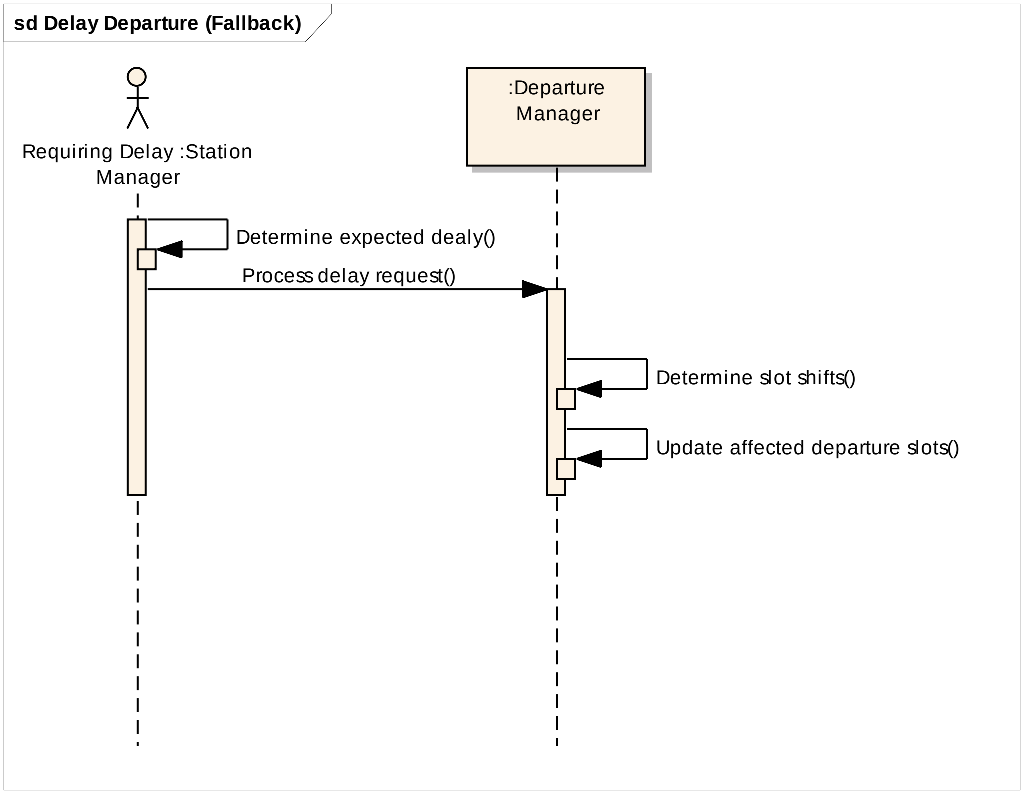


Figure D-9 Delay Departure (Fallback) Sequence Diagram

Use Case: Attempt to secure an earlier departure slot

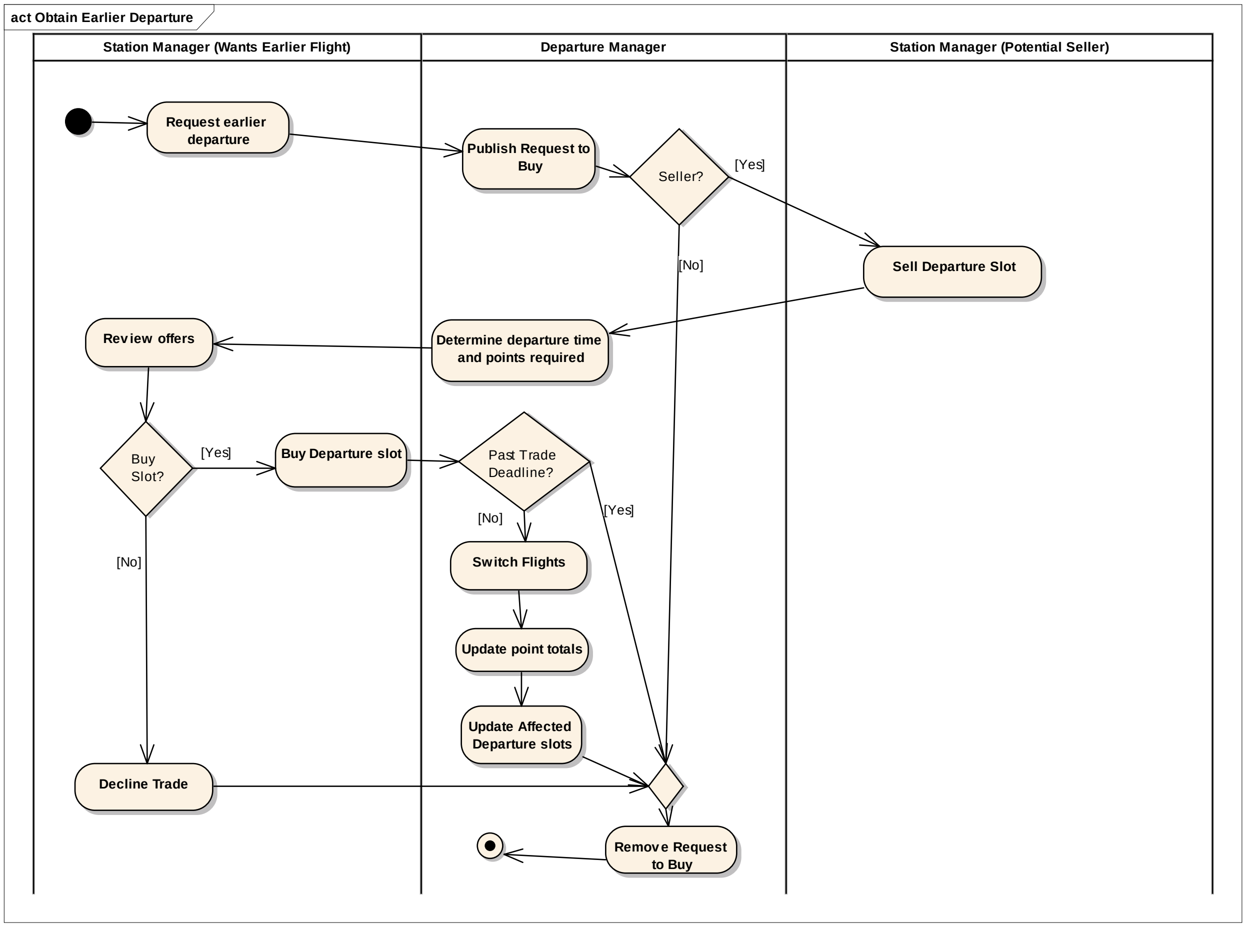


Figure D-10 Attempt to secure an earlier departure slot Activity Diagram

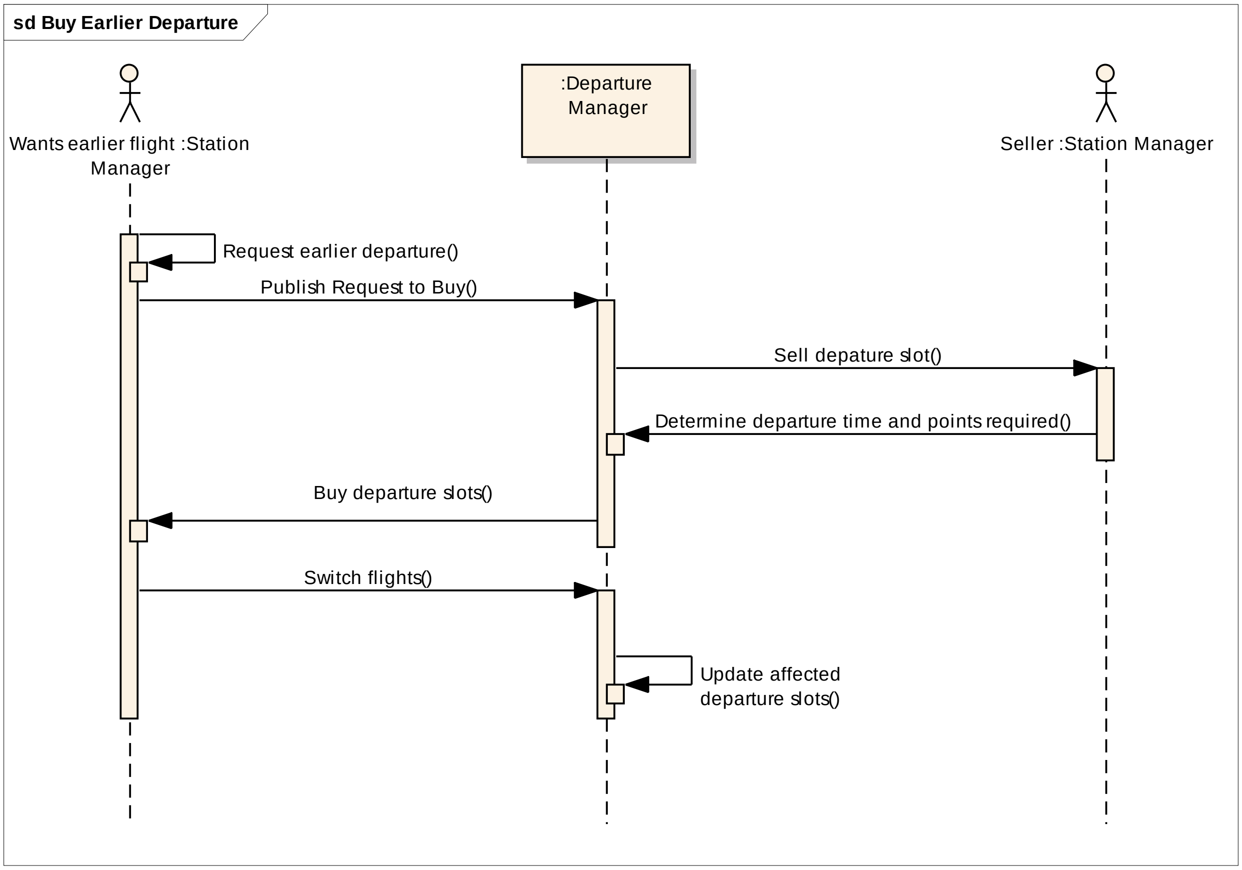


Figure D-11 Buy Earlier Departure Sequence Diagram

Use case: Manage Aircraft Departures

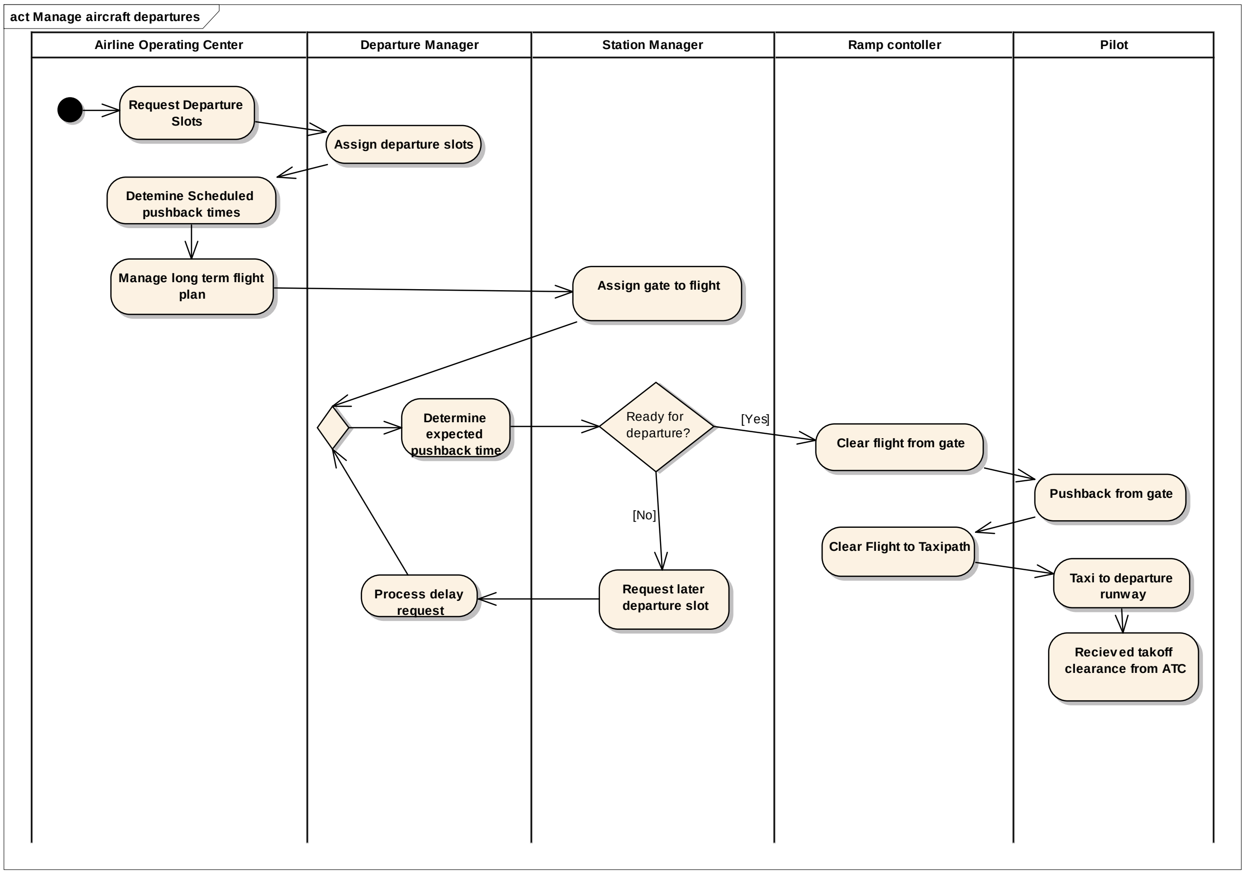


Figure D-12 Manage Aircraft Departures Activity Diagram

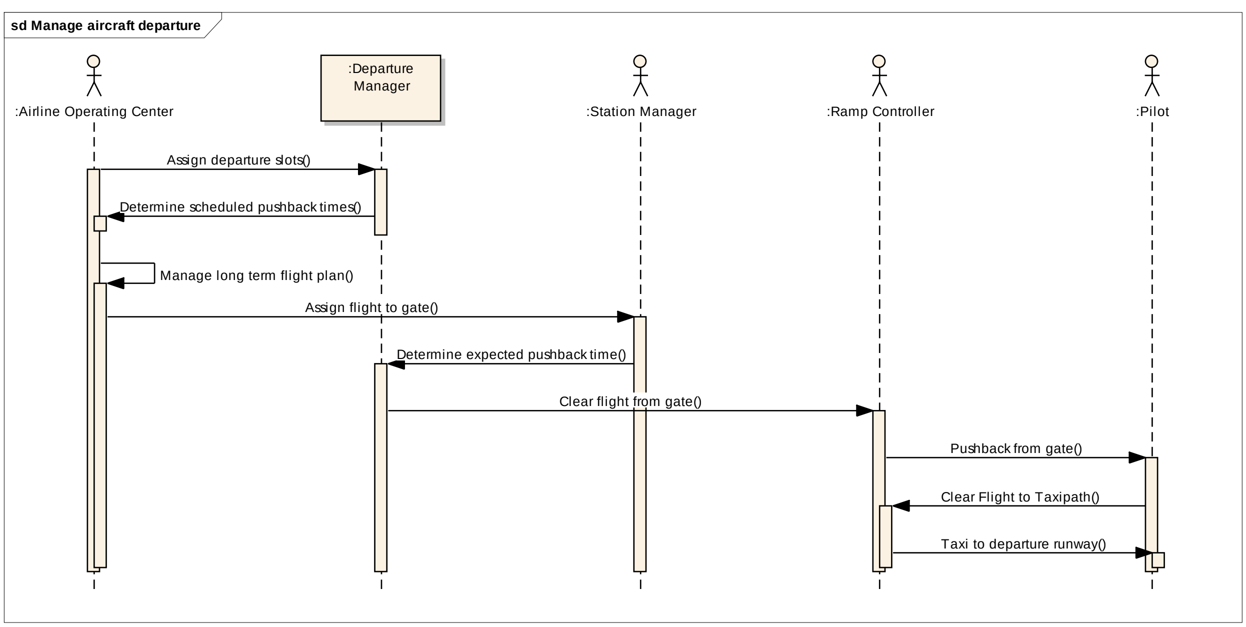


Figure D-13 Manage Aircraft Departure Sequence Diagram

1.9 Operational Rules Model

If the request for delay is past the scheduled pushback time, then calculate new penalty total:

> Penalty = number of delays requested that are past scheduled pushback time with the last month divided by the total number of flights in the last month.

If penalty total is passed the threshold value of 5%, decrease the weekly rollover value by 50%. If an airline does not have enough points to complete a trade, do not allow the trade.

1.10 Operational State Charts

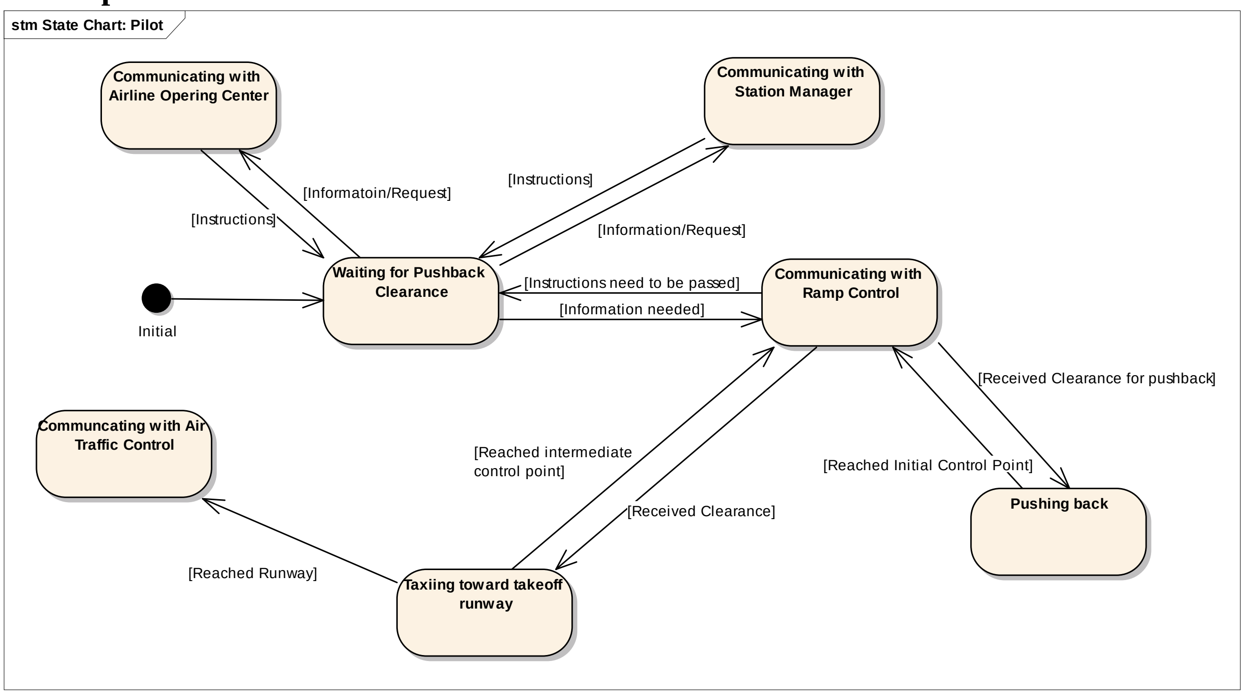
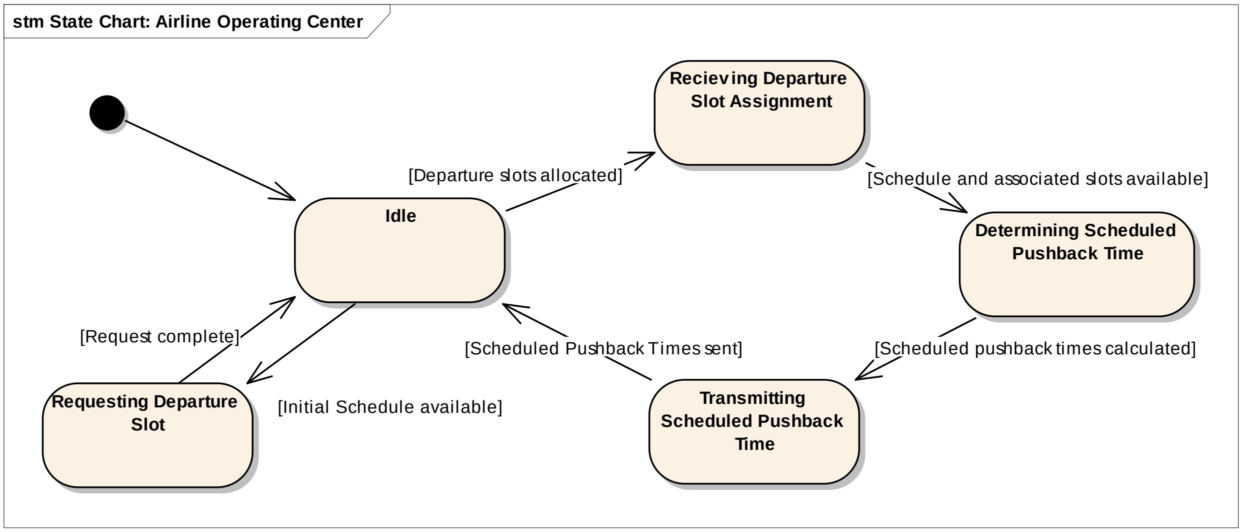


Figure D-14 Pilot State Chart



FigureD-15 AOC State Chart

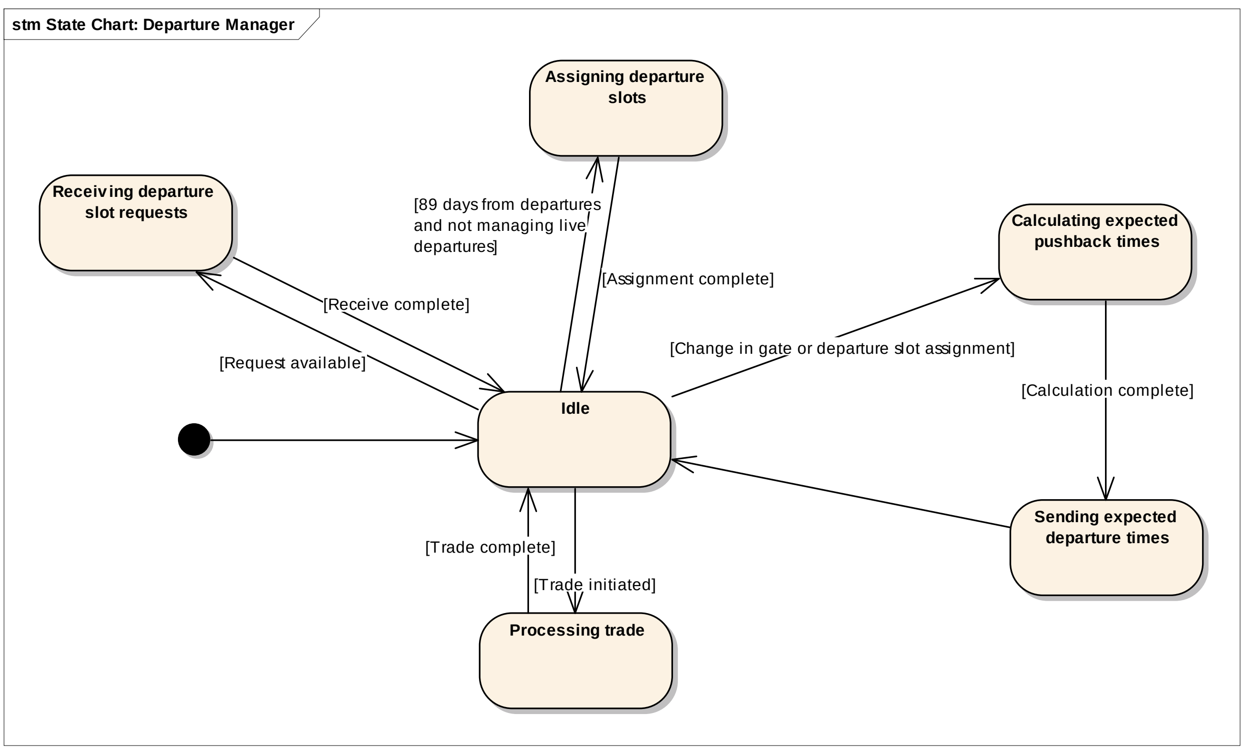


Figure D-16 Departure Manager State Chart

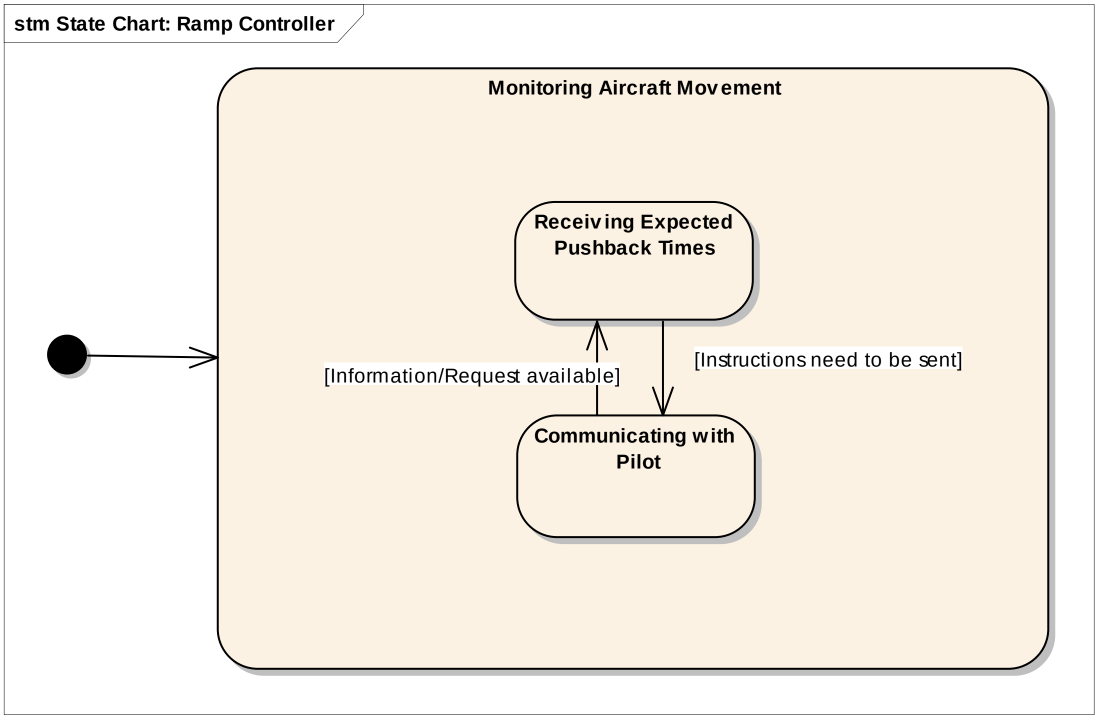


Figure D-17 Ramp Controller State Chart

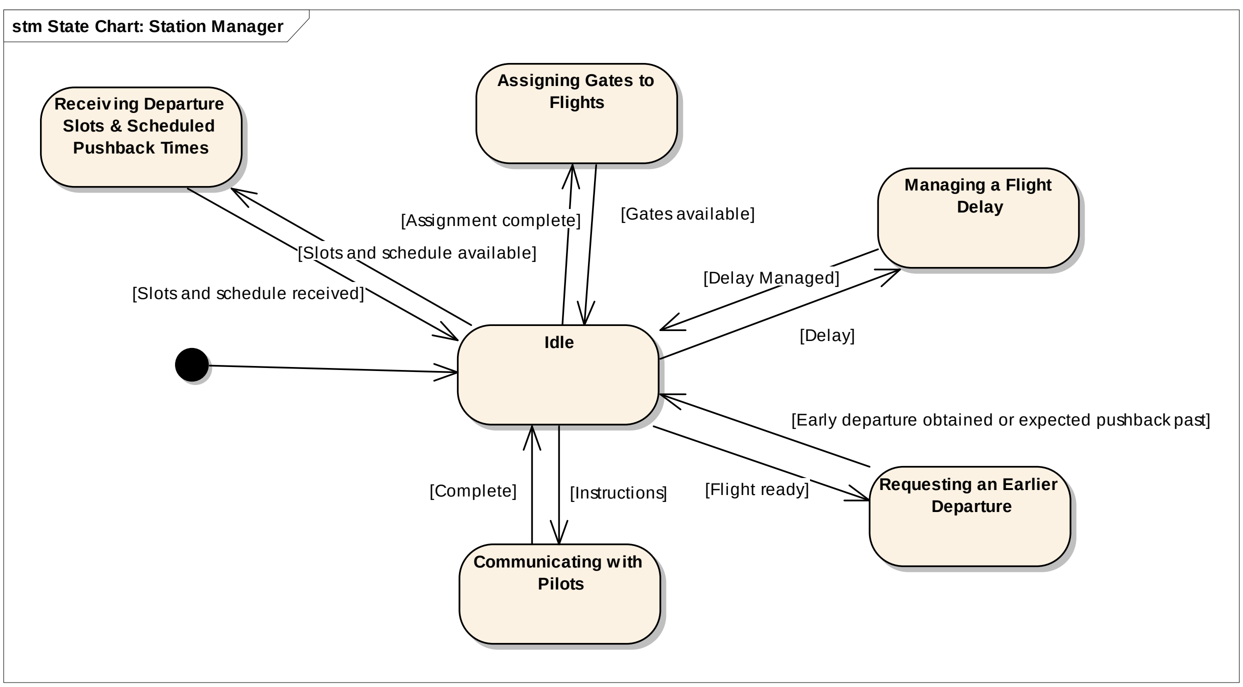


Figure D-18 Station Manager State Chart

2. Systems Architecture

2.1 Long Term Scheduling and Initial Slot Assignment

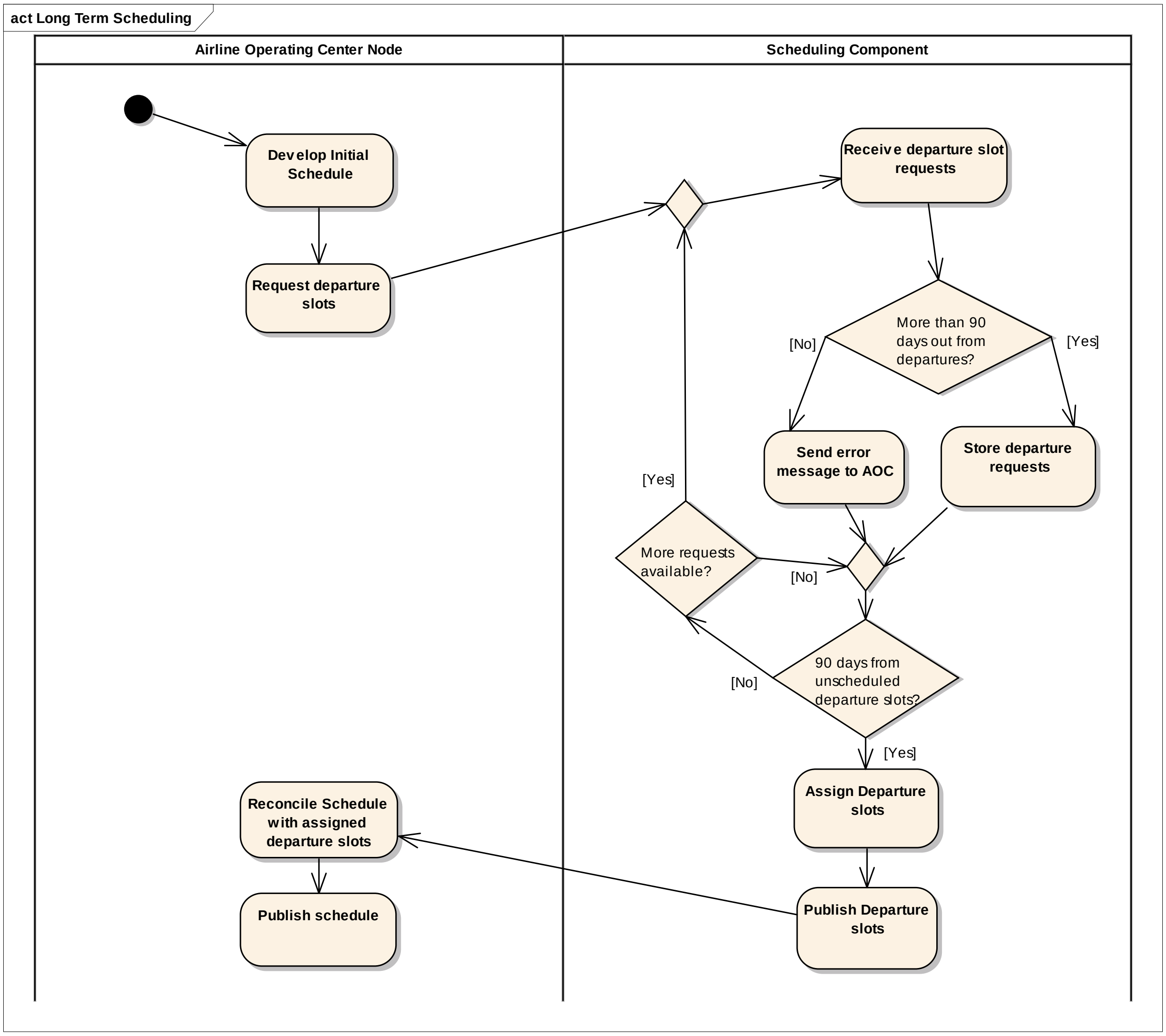


Figure D-19 Long Term Scheduling and Initial Slot Assignment Activity Diagram

2.2 Near Term Scheduling and Flight Management

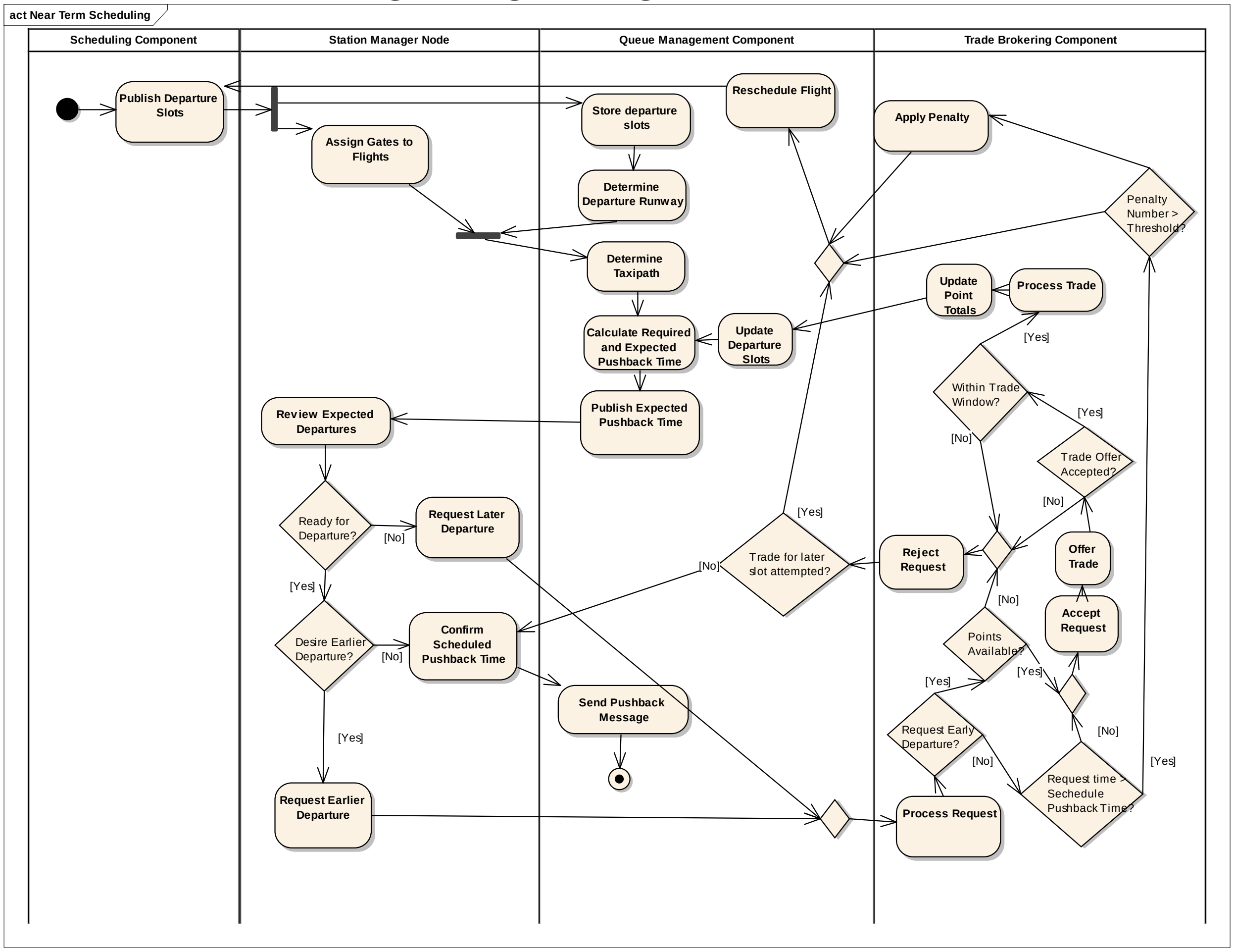


Figure D-20 Near Term Scheduling and Flight Management Activity Diagram

2.3 Flight Rescheduling

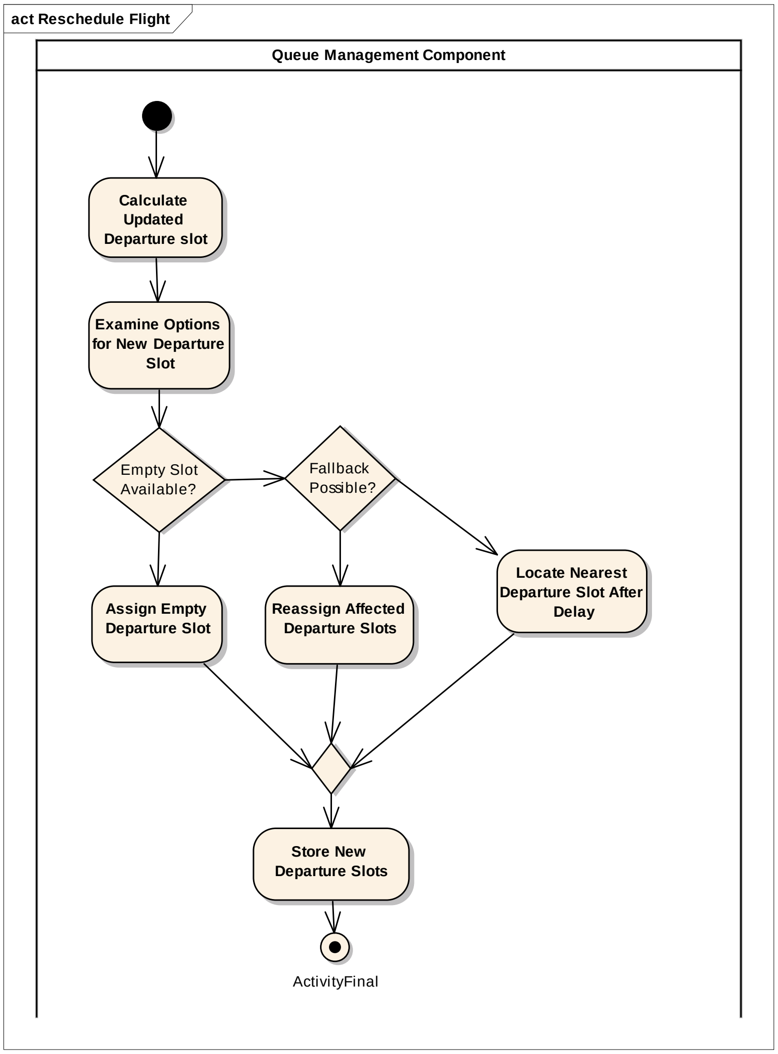


Figure D-21 Flight Rescheduling Activity Diagram

2.4 Sequence Diagrams

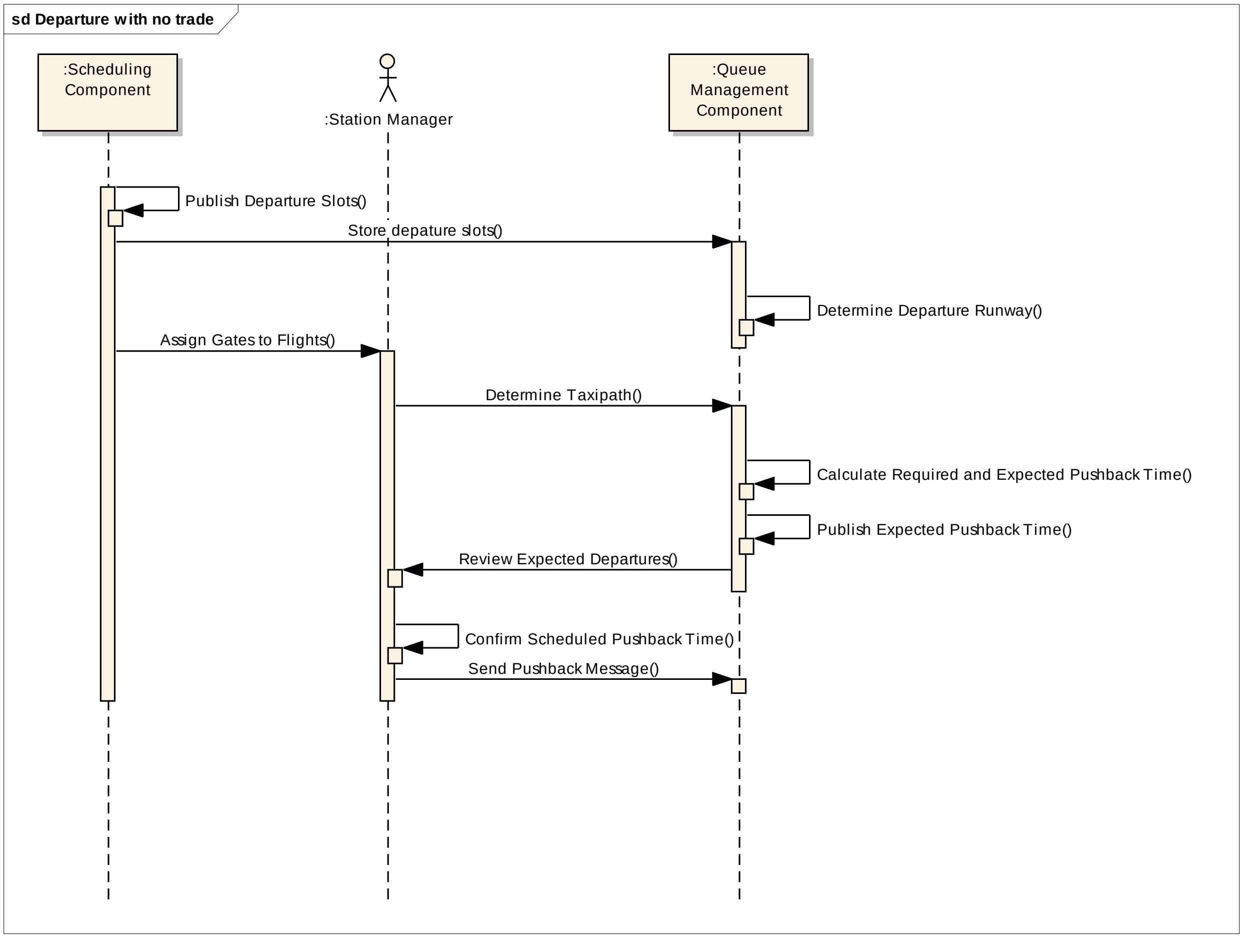


Figure D-22 Departure with no Trade Sequence Diagram

2.5 Fallback Due to a Lack of Trade for a Later Slot

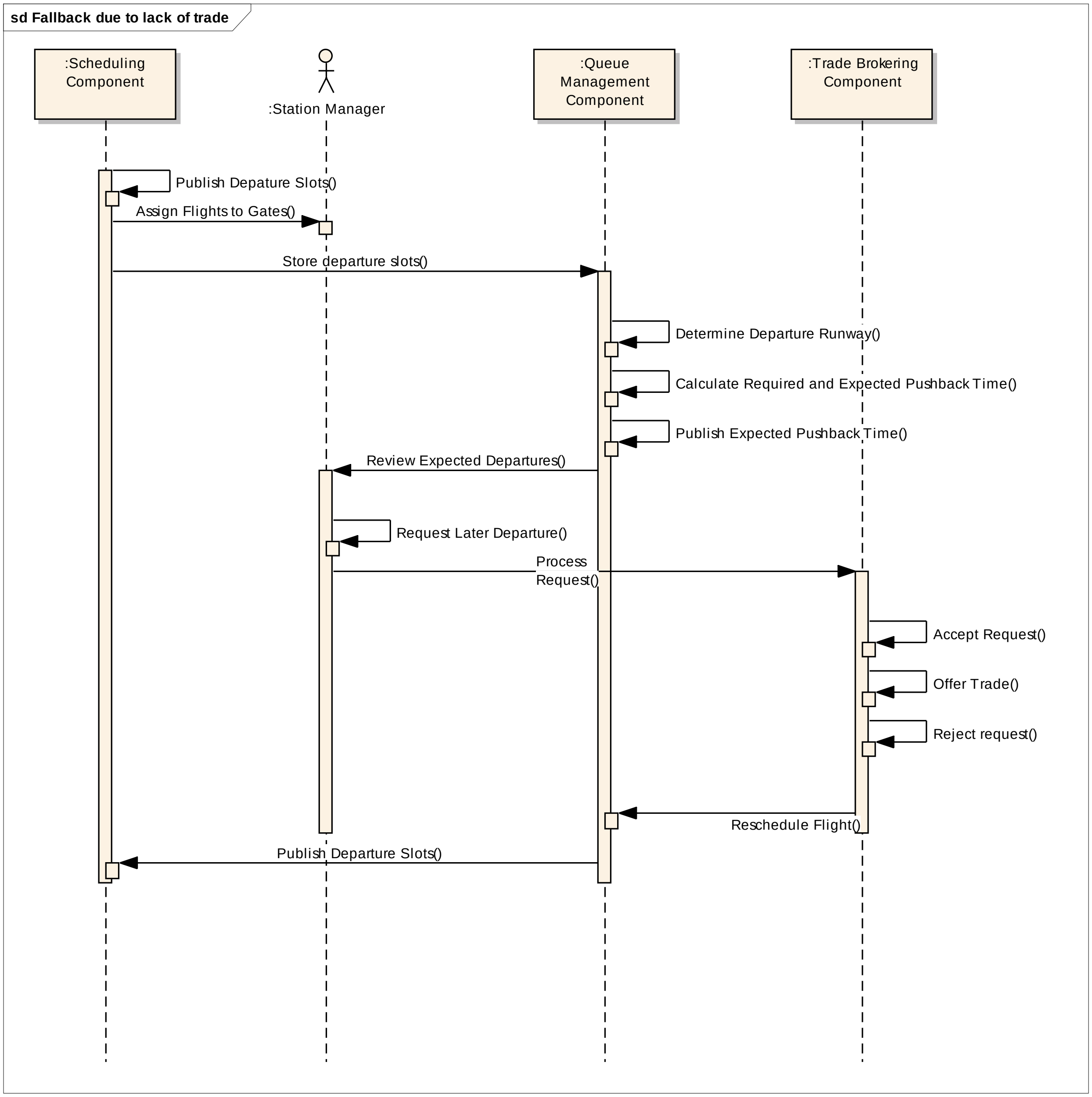


Figure D-23 Fallback Due to a Lack of Trade for a Later Slot Sequence Diagram

2.6 Create Long Term Schedule

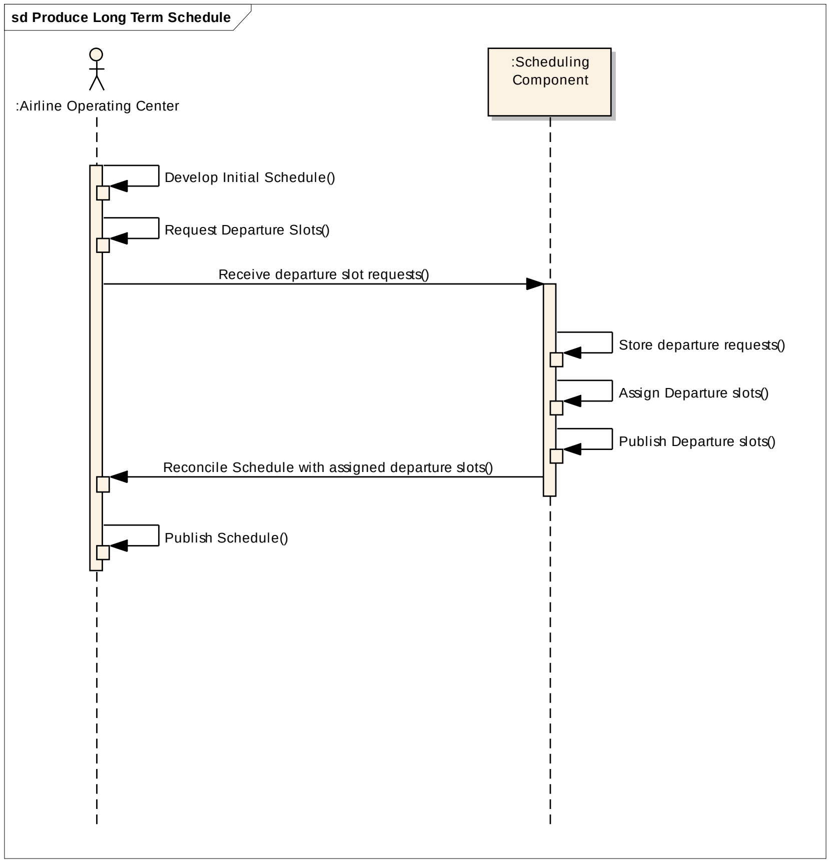


Figure D-24 Create Long Term Schedule Sequence Diagram

2.7 Trade for Earlier Departure Slot

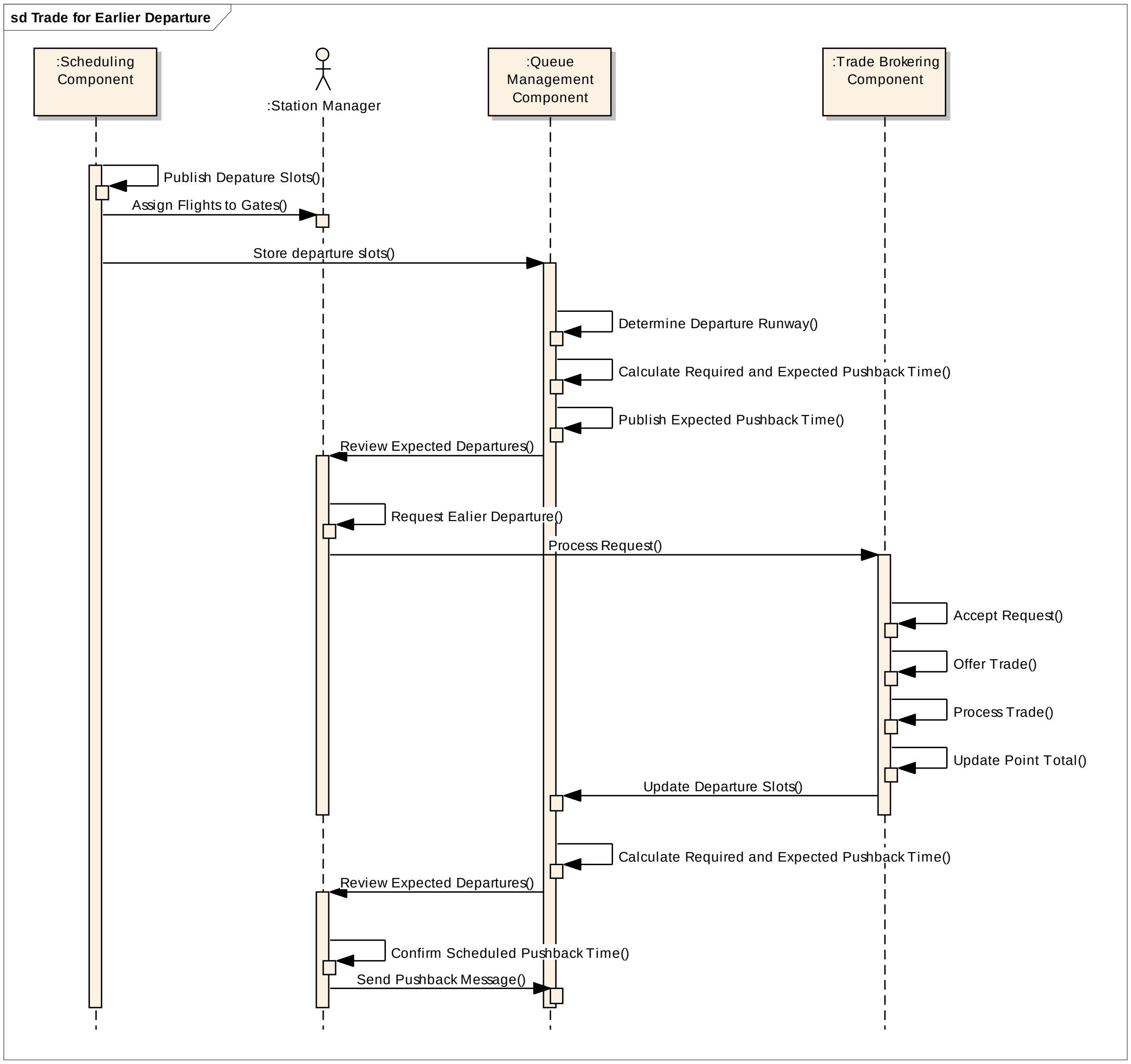


Figure D-25 Trade for Earlier Departure Slot Sequence Diagram

2.8 Trade for Later Departure

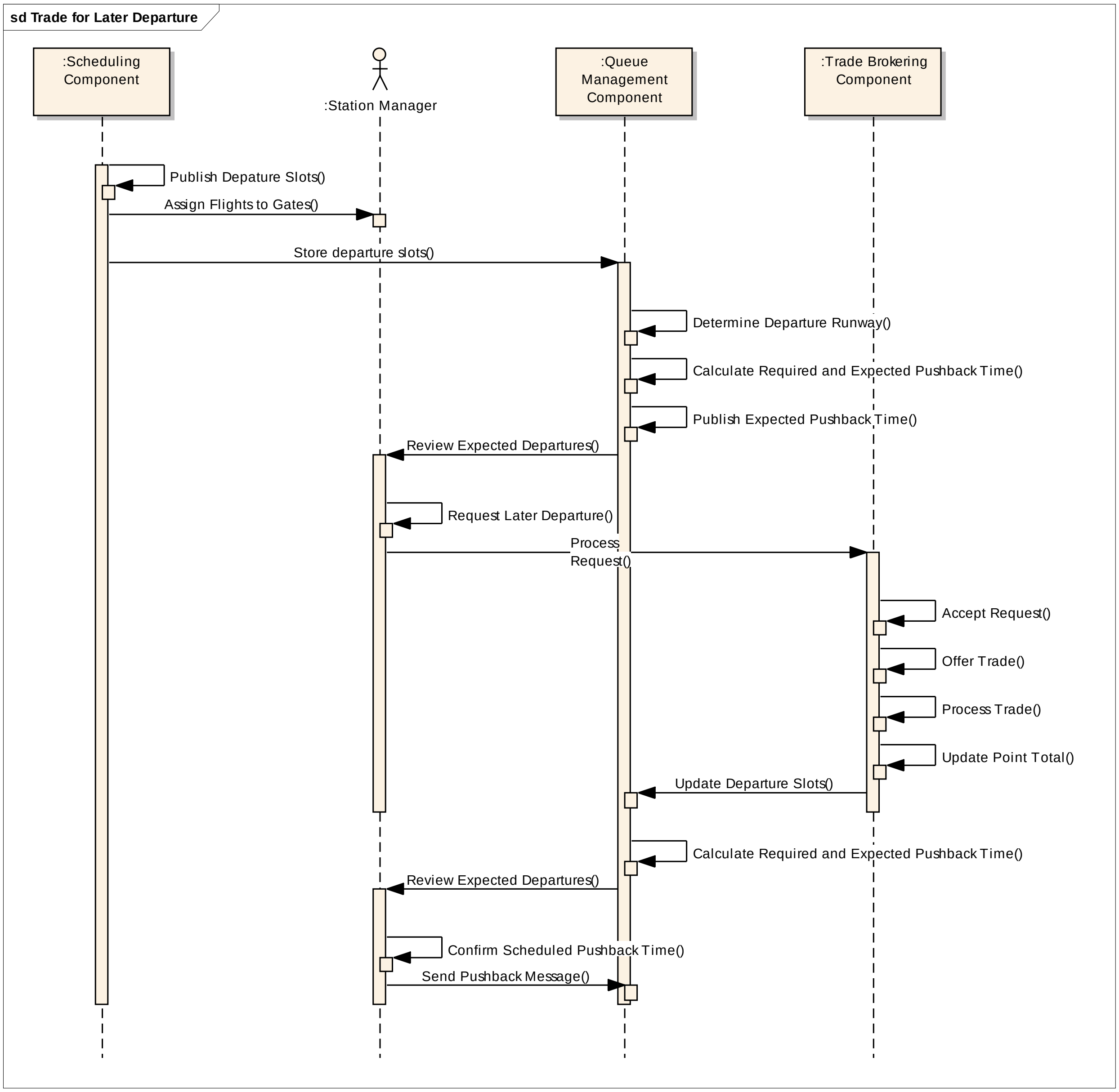


Figure D-26 Trade for Later Departure Sequence Diagram

2.9 State Charts

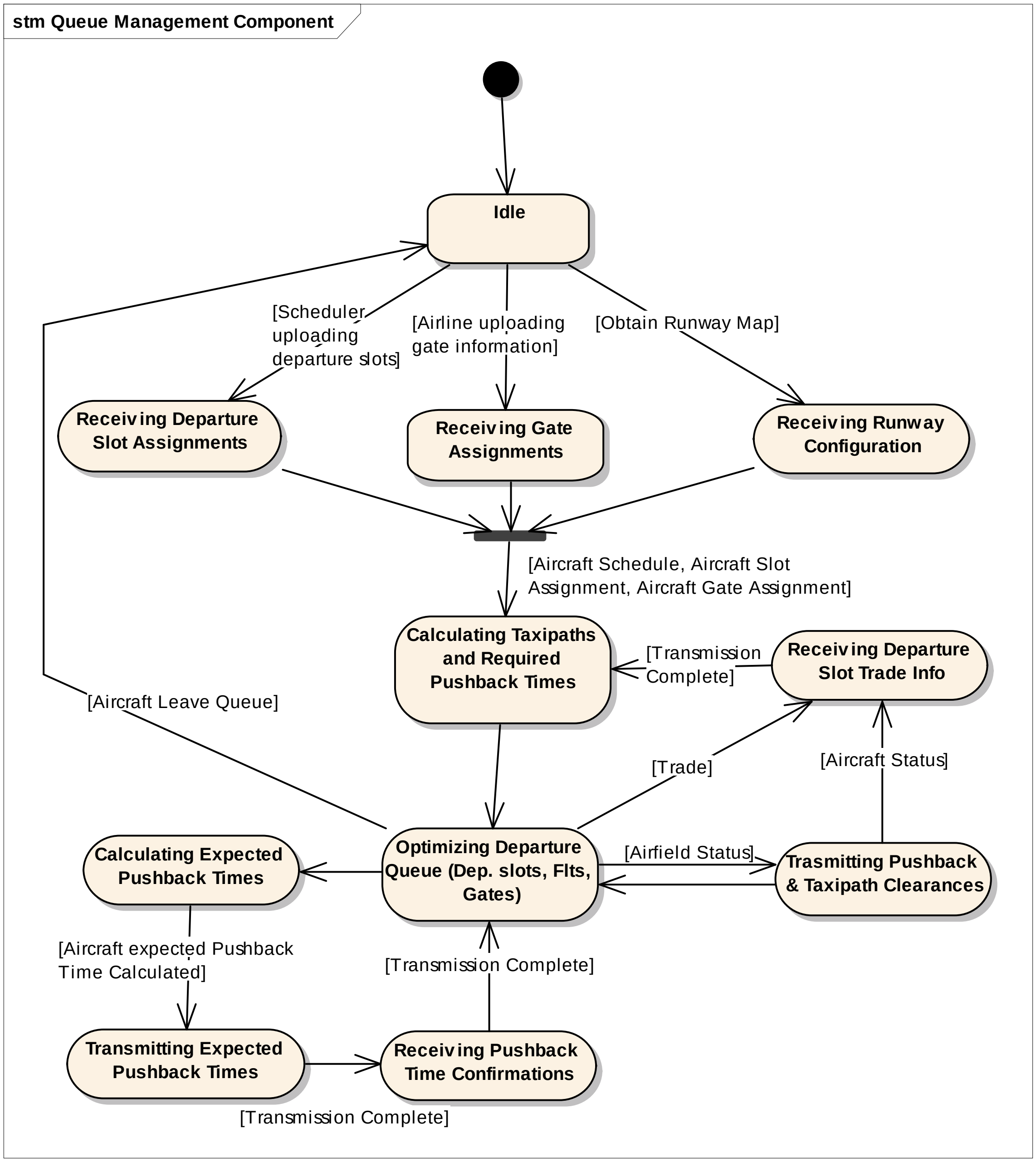


Figure D-27 Queue Management Component State Chart

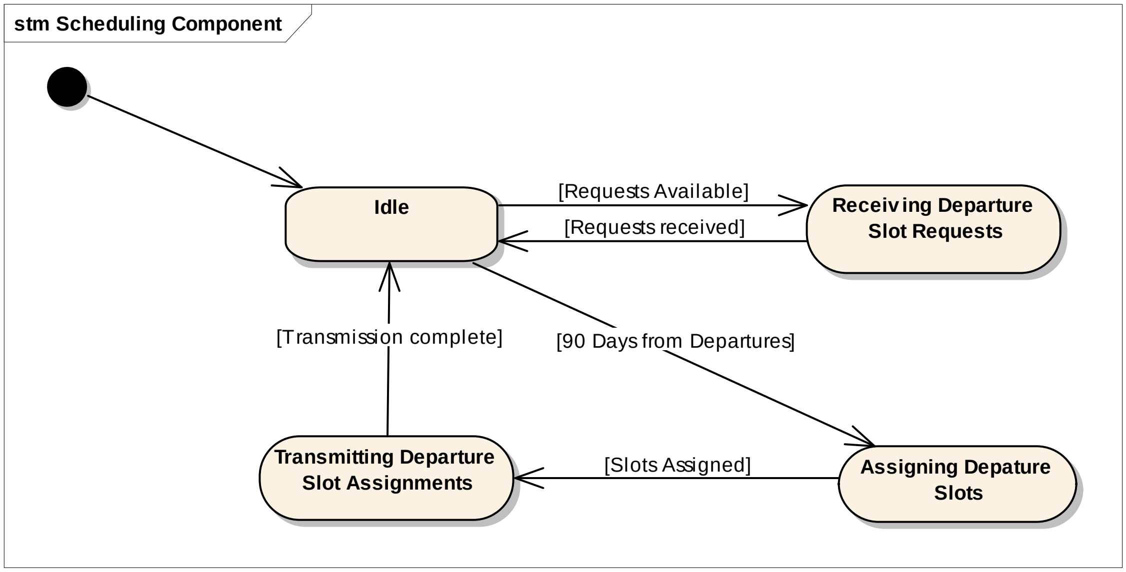


Figure D-28 Scheduling Component State Chart

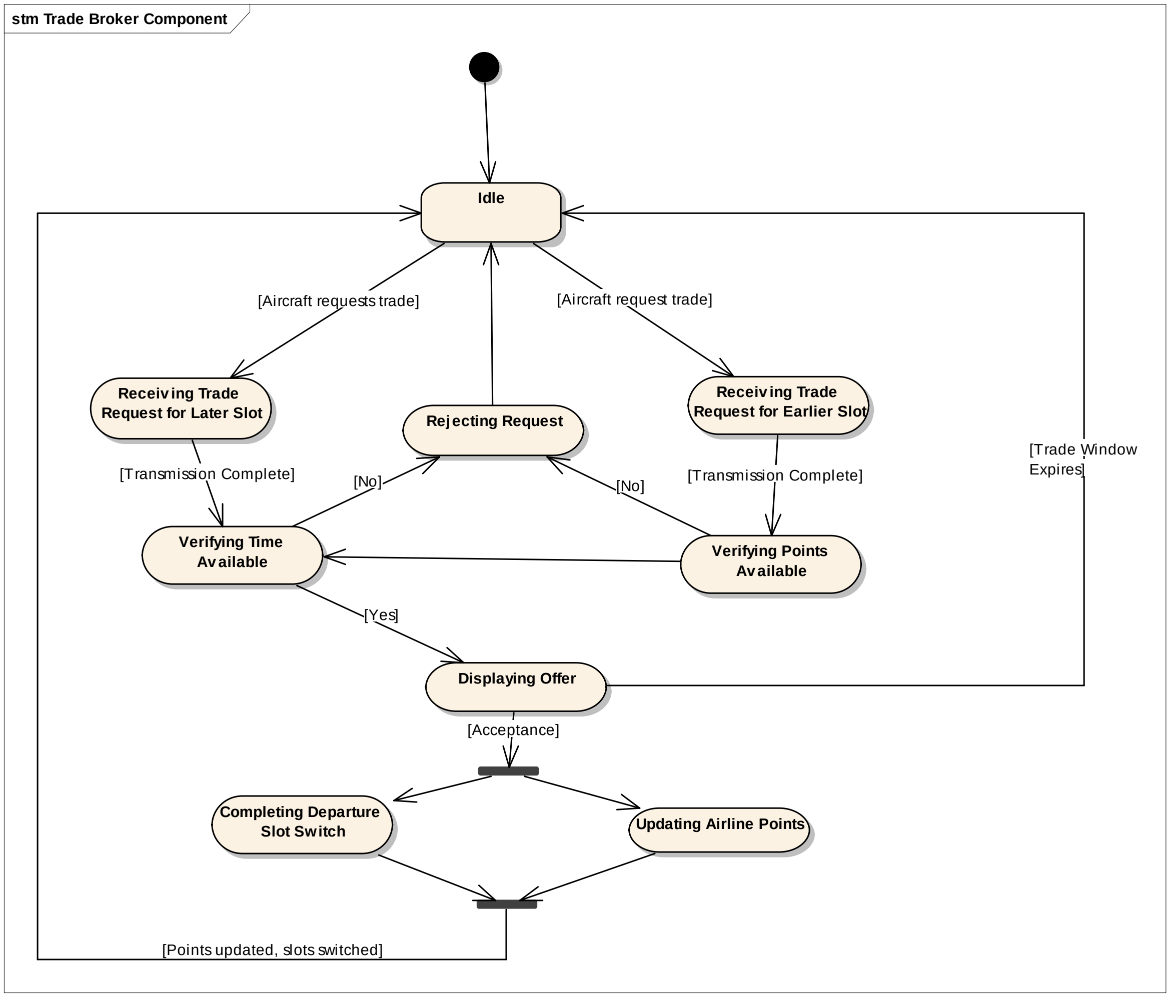


Figure D-29 Trade Broker Component State Chart

2.10 Class Diagram

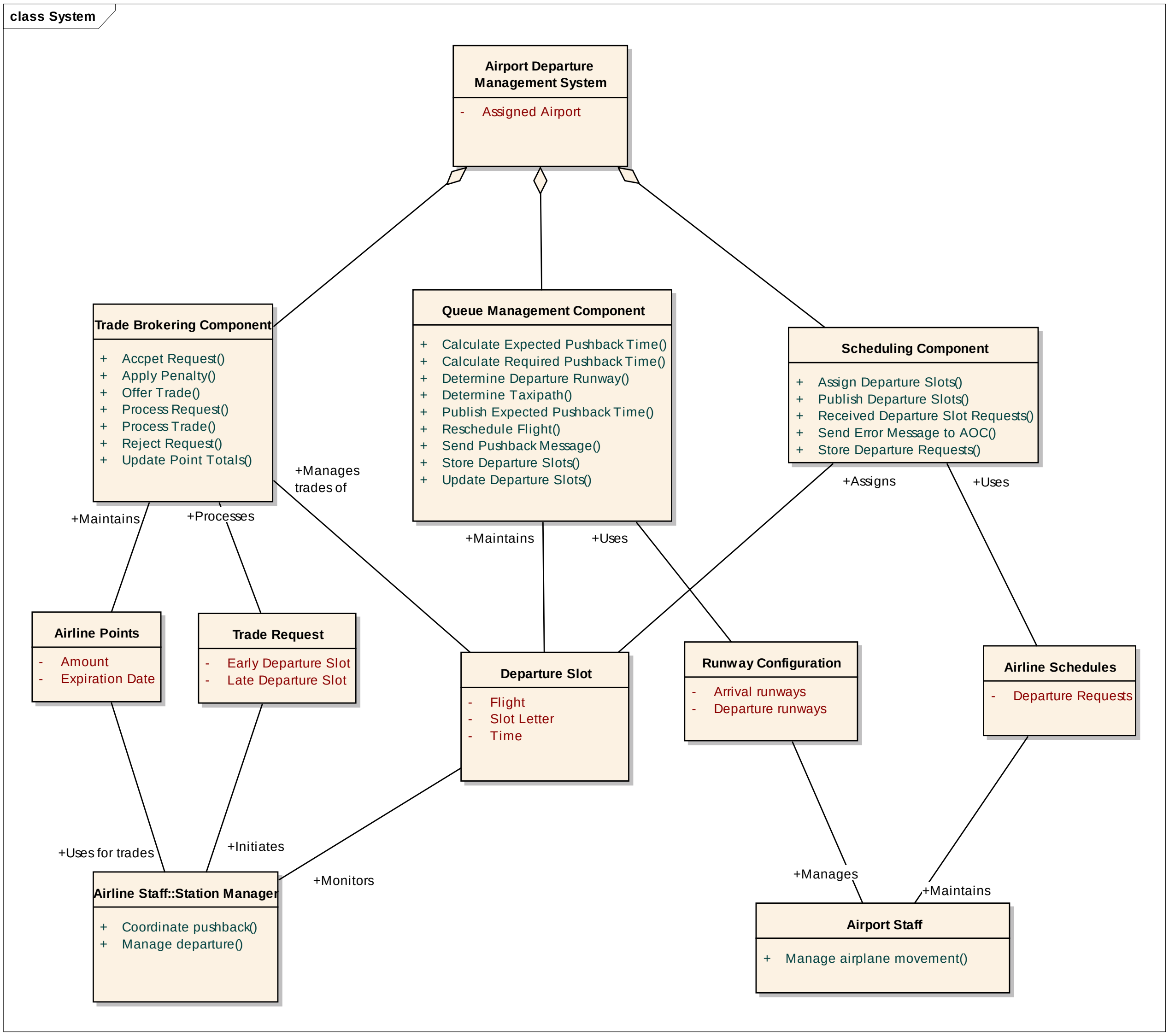


Figure D-30 System Class Diagram

3. Structured Analysis

3.1 External Diagram

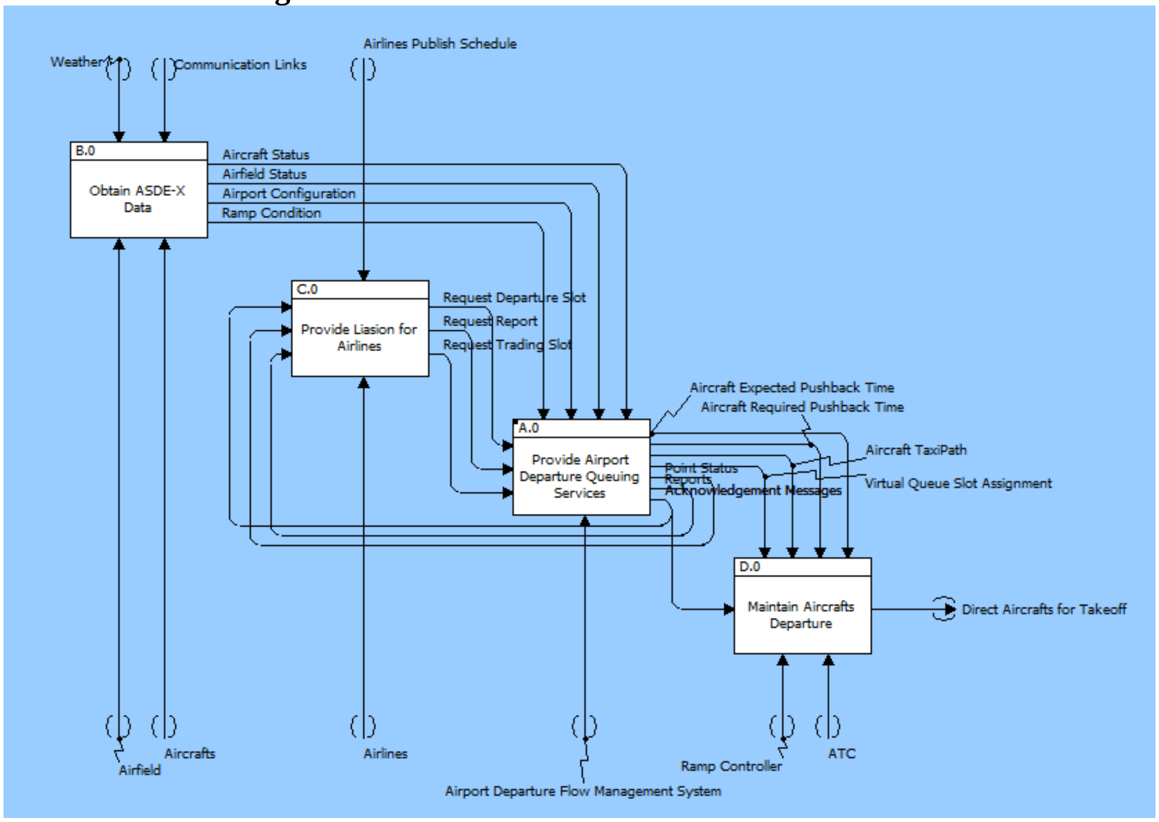


Figure D-31 External Diagram

3.2 A-0 Diagram

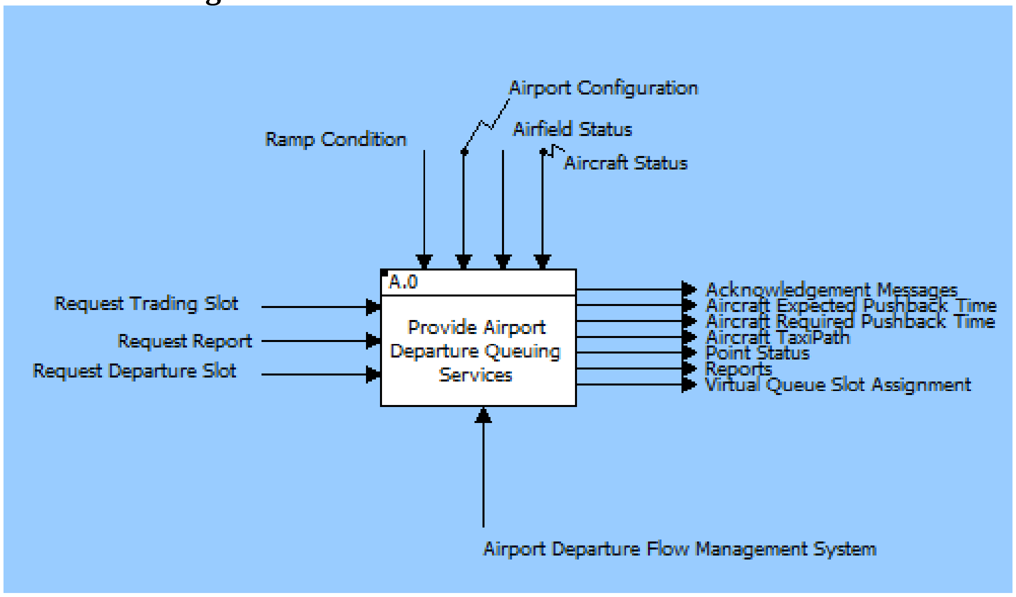


Figure D-32 A-0 Diagram

3.3 A0 Diagram

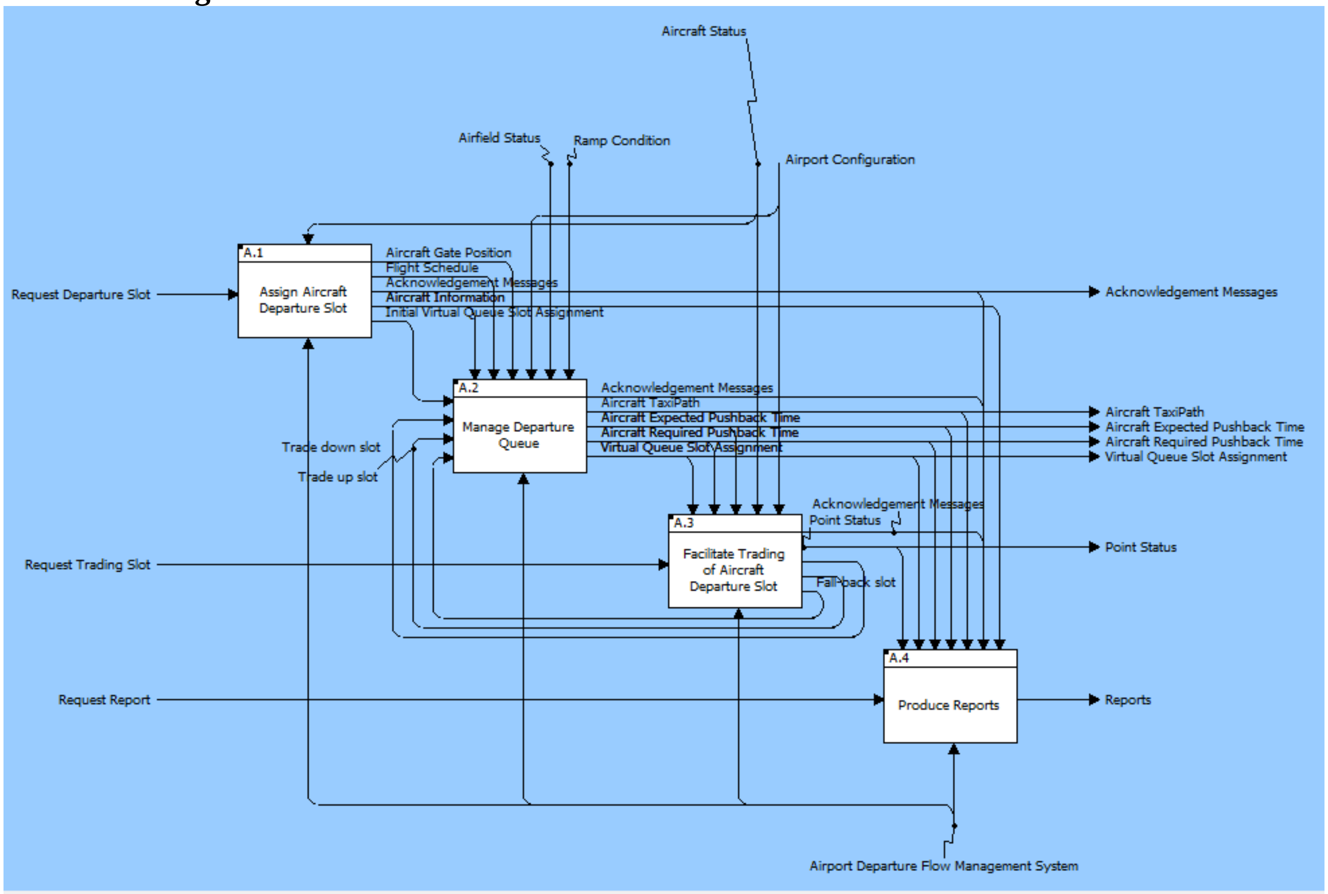
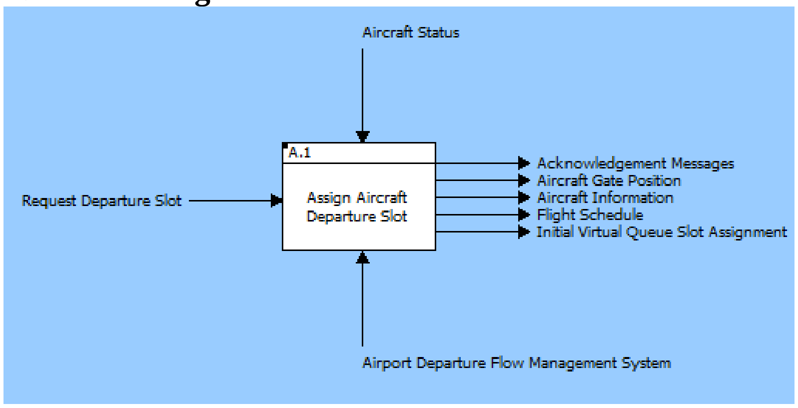


Figure D-33 A0 Diagram

3.4 A1 Diagram



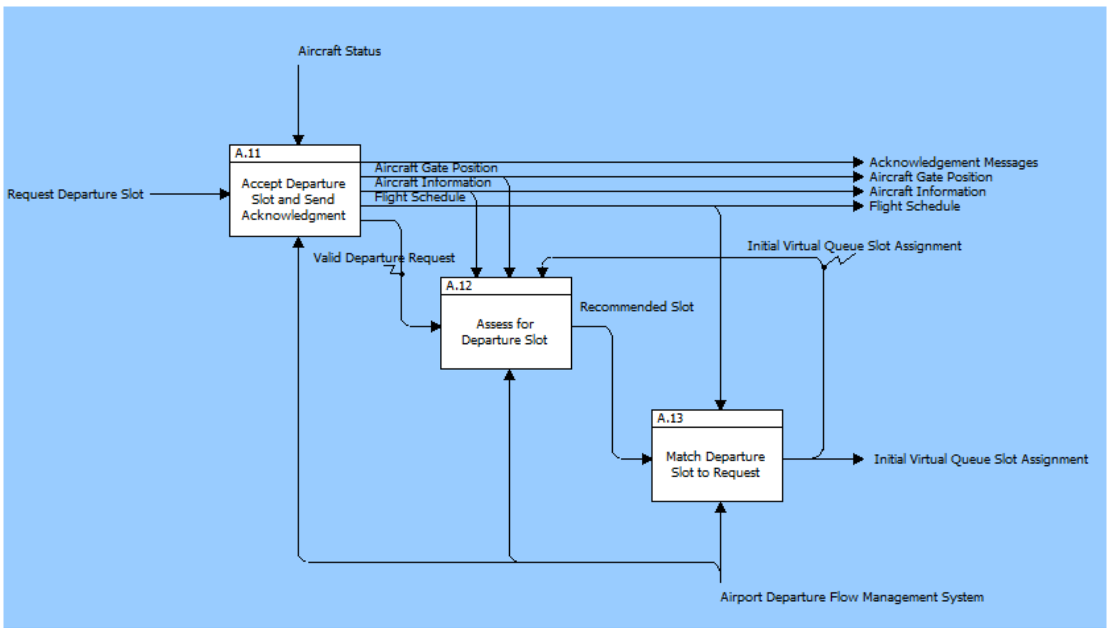
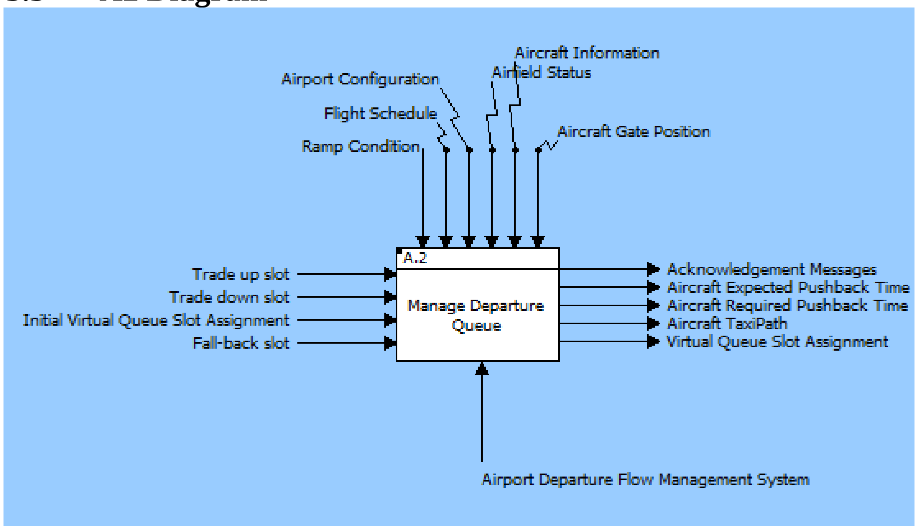
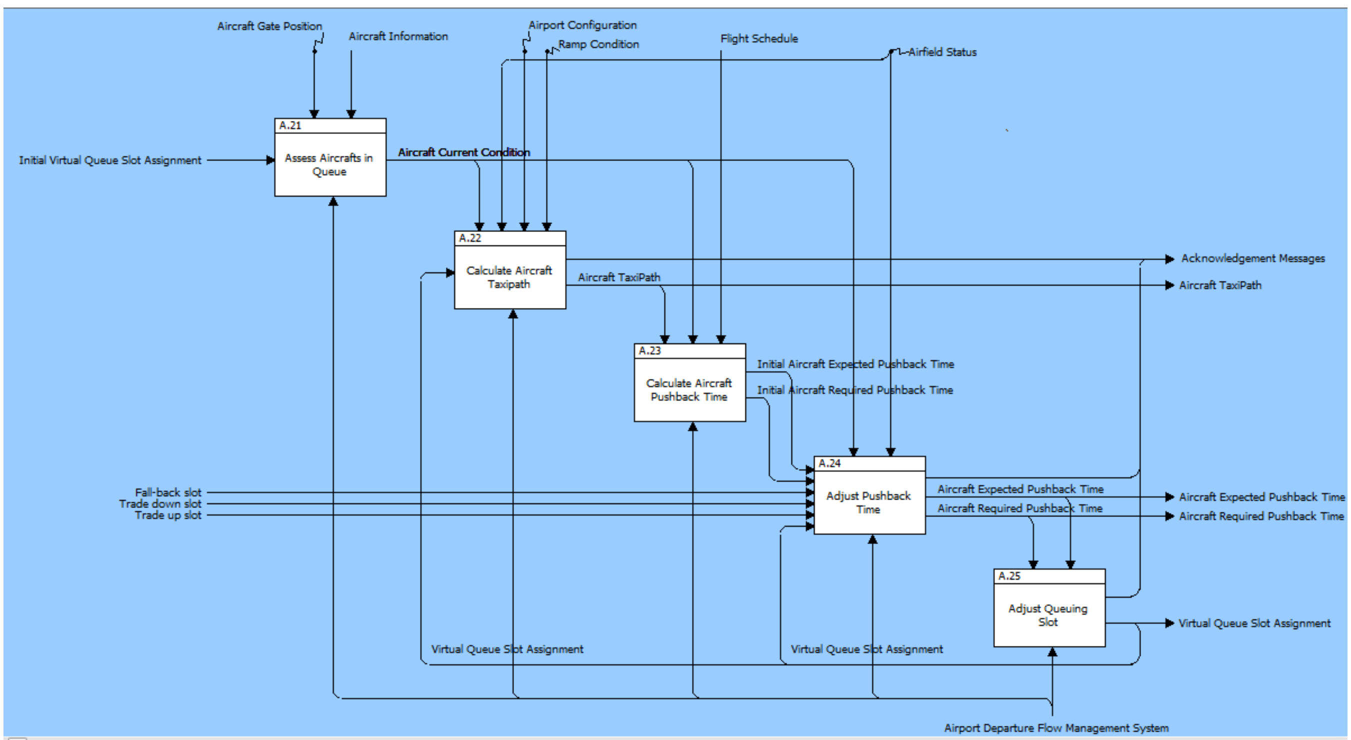


Figure D-34 A1 Diagram

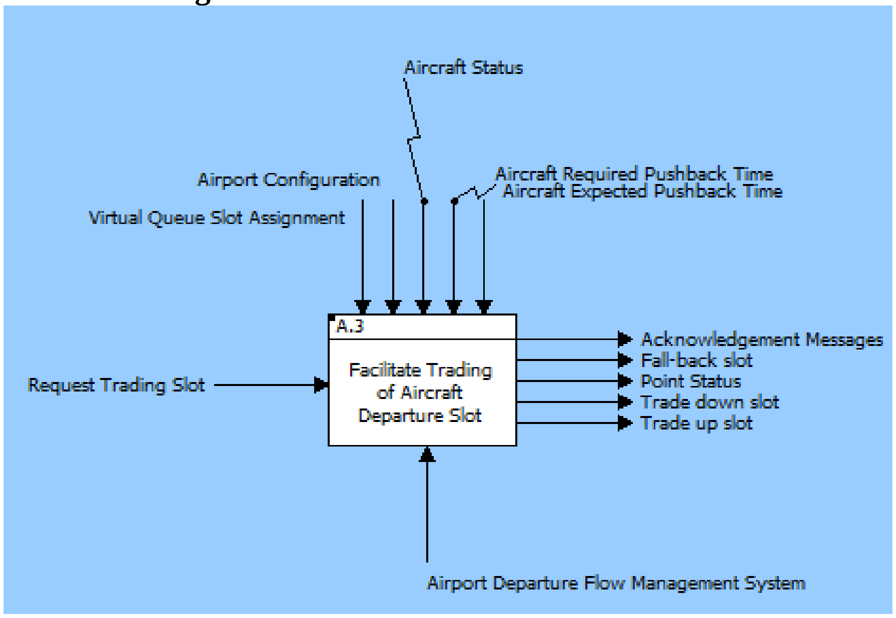
3.5 A2 Diagram





FigureD-35 A2 Diagram

3.6 A3 Diagram



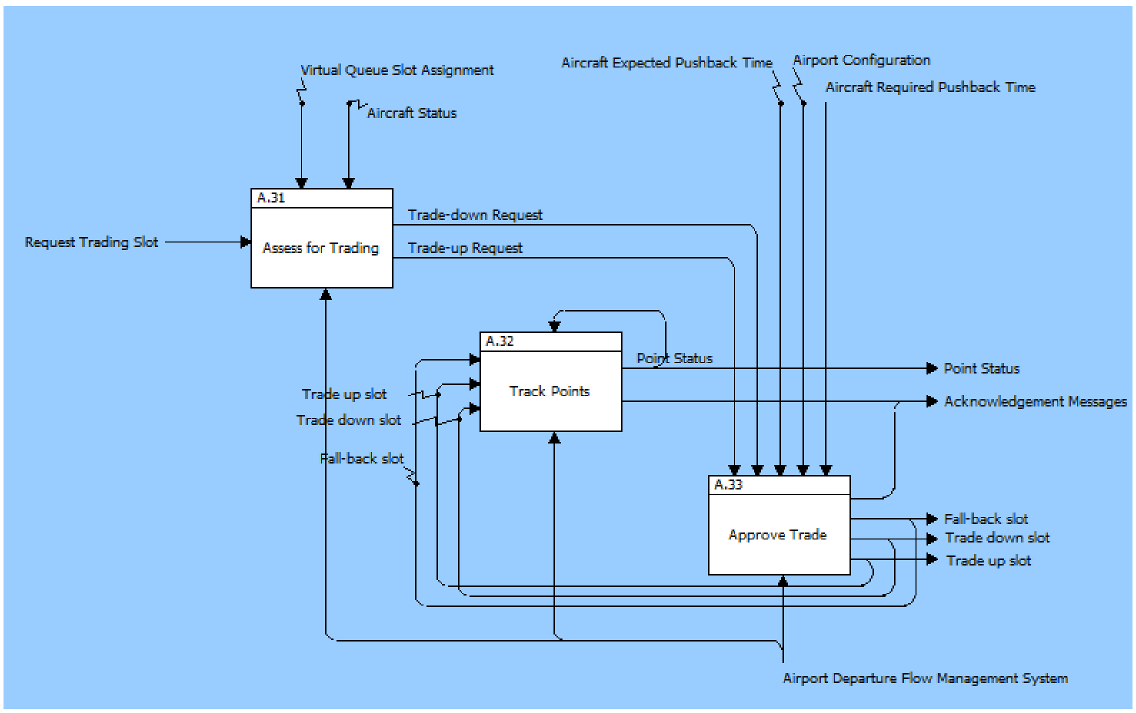
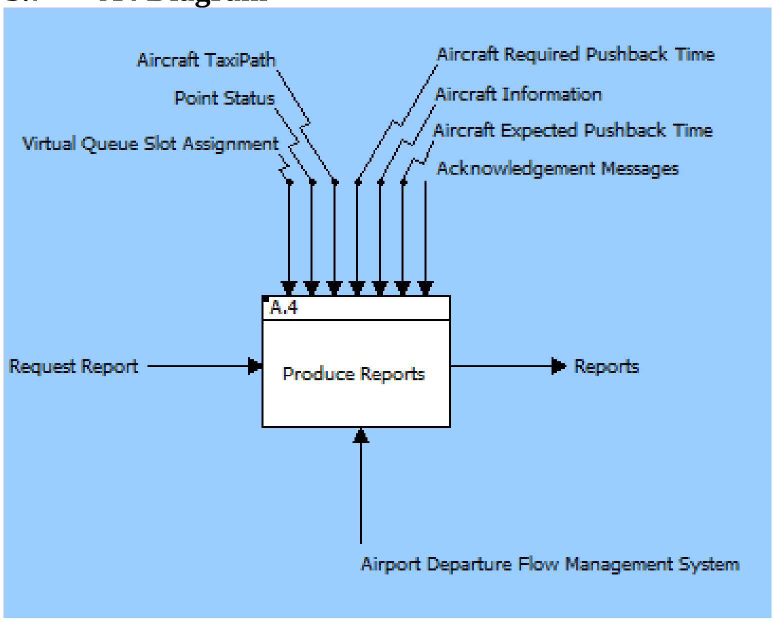


Figure D-36 A3 Diagram

3.7 A4 Diagram



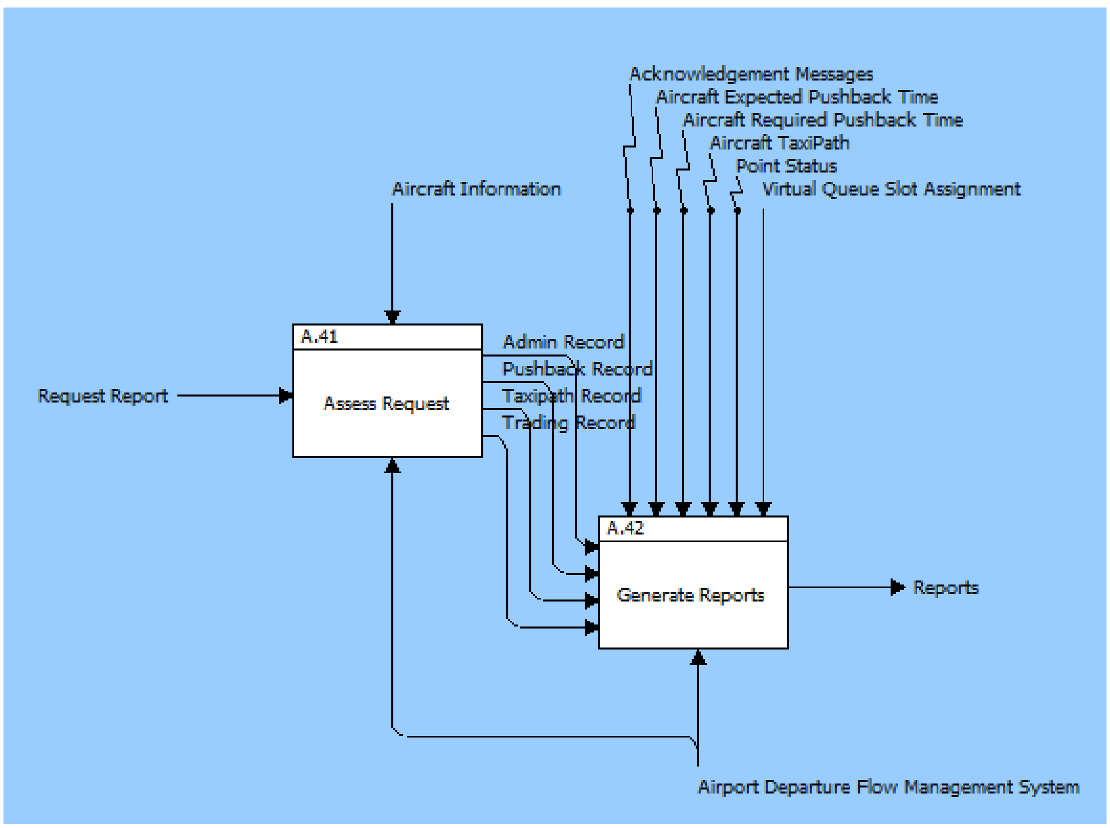


Figure D-37 A4 Diagram

E. APPENDIX E Model and Simulation

Figure E-1 illustrates the methodology used to create the running average model for taxi out prediction (Section 7.1). For a given flight number, the taxi out time is estimated as the average of the previous 14 taxi times of that flight. Prediction error is the predicted taxi time minus the actual taxi time for a given flight.

STDEV =IF(AND(B20>B$30,B6>=B$2,C6=C20),AVERAGE(L6:L19),"")

	A	B	C	L	M	N	O
1	Carrier Code	Date (MM/DD/YYYY)	Flight Number	Taxi-out Time	Running average	error	abs(error)
2	NW	7/8/2007	183	29			
3	NW	7/9/2007	183	21			
4	NW	7/10/2007	183	17			
5	NW	7/11/2007	183	55			
6	NW	7/12/2007	183	16			
7	NW	7/13/2007	183	15			
8	NW	7/14/2007	183	16			
9	NW	7/15/2007	183	21			
10	NW	7/16/2007	183	47			
11	NW	7/17/2007	183	48			
12	NW	7/18/2007	183	67			
13	NW	7/19/2007	183	35			
14	NW	7/20/2007	183	37			
15	NW	7/21/2007	183	27			
16	NW	7/22/2007	183	41	32.2142857	-8.78571	8.785714
17	NW	7/23/2007	183	43	33.0714286	-9.92857	9.928571
18	NW	7/24/2007	183	46	34.6428571	-11.3571	11.35714
19	NW	7/25/2007	183	38	36.7142857	-1.28571	1.285714
20	NW	7/26/2007	183	74	=IF(AND(B20	-38.5	38.5
21	NW	7/27/2007	183	100	39.6428571	-60.3571	60.35714
22	NW	7/8/2007	343	16			
23	NW	7/9/2007	343	18			

Figure E-1 Running Average Model to Predict Taxi Time

Figure E-2 displays the correlation between number of aircraft present at time of pushback and taxi out time experienced (Section 7.2). A regression fit through the data points reveals a relatively low R^2 value of 0.3436.

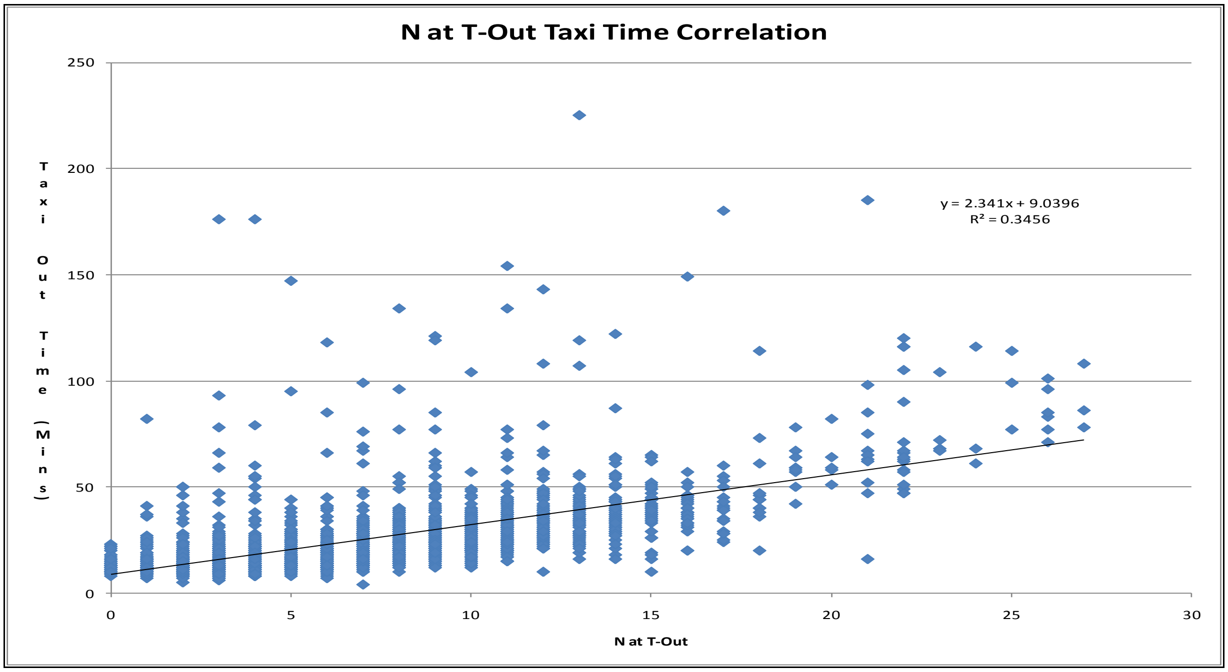


Figure E-2 Taxi Time by Number of Aircraft Present at Pushback

Figure E-3 displays probability distributions for queue size given number of aircraft present at time of pushback. The graph shows N from 0 to 6 for July 08-21, 2007 departures as an example.

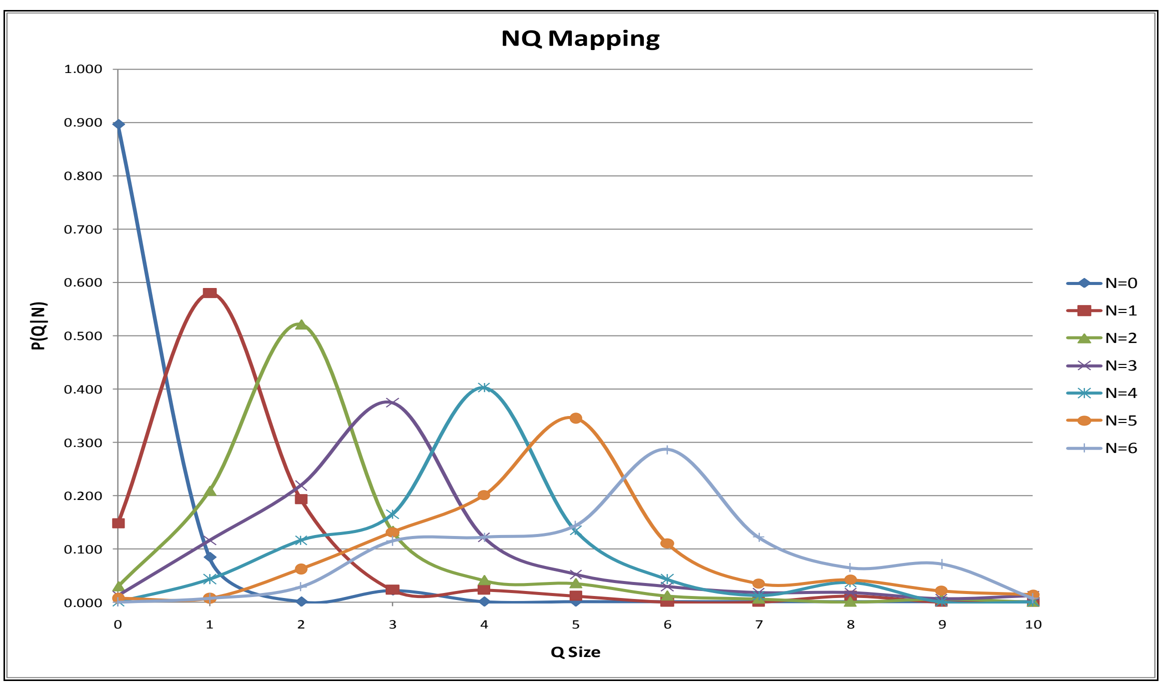


Figure E-3 (Q|N) Probability Distributions

Figure E-4 displays taxi paths from each control spot at PHL (Section 8). Points of intersection where paths converge are bottlenecks for the taxi out process.

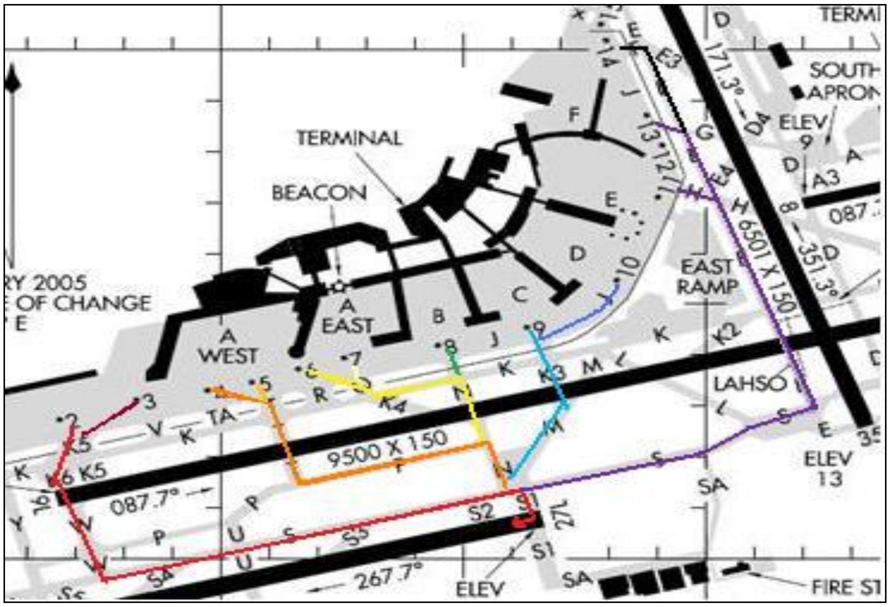


Figure E-4 Mapping of Taxiway Paths at to 27L at PHL

Ramp Area	CS	Taxi Distance (ft.)	Number of Steps
Red	2	6250	25
Red	3	6750	27
Orange	4	5000	20
Orange	5	4500	18
Yellow	6	4250	17
Yellow	7	3750	15
Green	8	2500	10
Blue	9	2750	11
Indigo	10	3750	15
Violet	11	6250	25
Violet	12	6500	26
Purple	13	6750	27
Black	14	7500	30

Figure E-5 Partition of Taxiway Paths into Equal Length Segments

Red	2	K5	K6	W	S	S1	27L	Total	Total Minutes
Distance (mm)		4.0	5.0	15.0	50.0	2.0	2.0	78.0	
Distance (Ft)		328.3	410.4	1231.2	4103.9	164.2	164.2	6402.1	
5nmhTime(seconds)		38.9	48.6	145.8	486.0	19.4	19.4	758.1	12.6
10nmhTime(seconds)		19.5	24.3	72.9	243.2	9.7	9.7	379.3	6.3
15nmhTime(seconds)		13.0	16.2	48.6	162.1	6.5	6.5	252.9	4.2
20nmhTime(seconds)		9.7	12.2	36.5	121.6	4.9	4.9	189.7	3.2
Red	3	K5	K6	W	S	S1	27L		
Distance (mm)		10.0	5.0	15.0	50.0	2.0	2.0	84.0	
Distance (Ft)		820.8	410.4	1231.2	4103.9	164.2	164.2	6894.6	
5nmhTime(seconds)		97.2	48.6	145.8	486.0	19.4	19.4	816.4	13.6
10nmhTime(seconds)		48.6	24.3	72.9	243.2	9.7	9.7	408.5	6.8
15nmhTime(seconds)		32.4	16.2	48.6	162.1	6.5	6.5	272.3	4.5
20nmhTime(seconds)		24.3	12.2	36.5	121.6	4.9	4.9	204.2	3.4
Orange	4	T	P	N	S1		27L		
Distance (mm)		8.0	12.0	23.0	10.0		2.0	55.0	
Distance (Ft)		656.6	984.9	1887.8	820.8	0.0	164.2	4514.3	
5nmhTime(seconds)		77.8	116.6	223.5	97.2	0.0	19.4	534.6	8.9
10nmhTime(seconds)		38.9	58.4	111.8	48.6	0.0	9.7	267.5	4.5
15nmhTime(seconds)		25.9	38.9	74.6	32.4	0.0	6.5	178.3	3.0
20nmhTime(seconds)		19.5	29.2	55.9	24.3	0.0	4.9	133.7	2.2
Orange	5	T	P	N	S1		27L		
Distance (mm)		4.0	12.0	23.0	10.0		2.0	51.0	
Distance (Ft)		328.3	984.9	1887.8	820.8	0.0	164.2	4186.0	
5nmhTime(seconds)		38.9	116.6	223.5	97.2	0.0	19.4	495.7	8.3
10nmhTime(seconds)		19.5	58.4	111.8	48.6	0.0	9.7	248.0	4.1
15nmhTime(seconds)		13.0	38.9	74.6	32.4	0.0	6.5	165.3	2.8
20nmhTime(seconds)		9.7	29.2	55.9	24.3	0.0	4.9	124.0	2.1
Yellow	6	Q	K	N	S1		27L		
Distance (mm)		7.0	2.0	11.0	20.0		2.0	42.0	
Distance (Ft)		574.5	164.2	902.9	1641.6	0.0	164.2	3447.3	
5nmhTime(seconds)		68.0	19.4	106.9	194.4	0.0	19.4	408.2	6.8
10nmhTime(seconds)		34.0	9.7	53.5	97.3	0.0	9.7	204.2	3.4
15nmhTime(seconds)		22.7	6.5	35.7	64.8	0.0	6.5	136.2	2.3
20nmhTime(seconds)		17.0	4.9	26.7	48.6	0.0	4.9	102.1	1.7
Yellow	7	Q	K	N	S1		27L		
Distance (mm)		4.0	2.0	11.0	20.0		2.0	39.0	
Distance (Ft)		328.3	164.2	902.9	1641.6	0.0	164.2	3201.0	
5nmhTime(seconds)		38.9	19.4	106.9	194.4	0.0	19.4	379.0	6.3
10nmhTime(seconds)		19.5	9.7	53.5	97.3	0.0	9.7	189.7	3.2
15nmhTime(seconds)		13.0	6.5	35.7	64.8	0.0	6.5	126.4	2.1
20nmhTime(seconds)		9.7	4.9	26.7	48.6	0.0	4.9	94.8	1.6
Green	8	N	S1				27L		
Distance (mm)		7.0	18.0				2.0	27.0	
Distance (Ft)		574.5	1477.4	0.0	0.0	0.0	164.2	2216.1	
5nmhTime(seconds)		68.0	174.9	0.0	0.0	0.0	19.4	262.4	4.4
10nmhTime(seconds)		34.0	87.5	0.0	0.0	0.0	9.7	131.3	2.2
15nmhTime(seconds)		22.7	58.4	0.0	0.0	0.0	6.5	87.5	1.5
20nmhTime(seconds)		17.0	43.8	0.0	0.0	0.0	4.9	65.7	1.1
Blue	9	K3	M	N	S1		27L		
Distance (mm)		7.0	8.0	8.0	5.0		2.0	30.0	
Distance (Ft)		574.5	656.6	656.6	410.4	0.0	164.2	2462.3	
5nmhTime(seconds)		68.0	77.8	77.8	48.6	0.0	19.4	291.6	4.9
10nmhTime(seconds)		34.0	38.9	38.9	24.3	0.0	9.7	145.9	2.4
15nmhTime(seconds)		22.7	25.9	25.9	16.2	0.0	6.5	97.3	1.6
20nmhTime(seconds)		17.0	19.5	19.5	12.2	0.0	4.9	72.9	1.2
Indigo	10	J	K3	M	N	S1	27L		
Distance (mm)		3.0	14.0	8.0	8.0	5.0	2.0	40.0	
Distance (Ft)		246.2	1149.1	656.6	656.6	410.4	164.2	3283.1	
5nmhTime(seconds)		29.2	136.1	77.8	77.8	48.6	19.4	388.8	6.5
10nmhTime(seconds)		14.6	68.1	38.9	38.9	24.3	9.7	194.5	3.2
15nmhTime(seconds)		9.7	45.4	25.9	25.9	16.2	6.5	129.7	2.2
20nmhTime(seconds)		7.3	34.0	19.5	19.5	12.2	4.9	97.3	1.6
Violet	11	H	E	S	S1		27L		
Distance (mm)		3.0	3.0	33.0	37.0		2.0	78.0	
Distance (Ft)		246.2	246.2	2708.6	3036.9	0.0	164.2	6402.1	
5nmhTime(seconds)		29.2	29.2	320.7	359.6	0.0	19.4	758.1	12.6
10nmhTime(seconds)		14.6	14.6	160.5	179.9	0.0	9.7	379.3	6.3
15nmhTime(seconds)		9.7	9.7	107.0	120.0	0.0	6.5	252.9	4.2
20nmhTime(seconds)		7.3	7.3	80.2	90.0	0.0	4.9	189.7	3.2
Purple	13	G	E	S	S1		27L		
Distance (mm)		2.0	3.0	44.0	37.0		2.0	88.0	
Distance (Ft)		164.2	246.2	3611.4	3036.9	0.0	164.2	7222.9	
5nmhTime(seconds)		19.4	29.2	427.6	359.6	0.0	19.4	855.3	14.3
10nmhTime(seconds)		9.7	14.6	214.0	179.9	0.0	9.7	427.9	7.1
15nmhTime(seconds)		6.5	9.7	142.6	120.0	0.0	6.5	285.3	4.8
20nmhTime(seconds)		4.9	7.3	107.0	90.0	0.0	4.9	214.0	3.6
Black	14	E3	E	S	S1		27L		
Distance (mm)		2.0	4.0	58.0	37.0		2.0	103.0	
Distance (Ft)		164.2	328.3	4760.5	3036.9	0.0	164.2	8454.0	
5nmhTime(seconds)		19.4	38.9	563.7	359.6	0.0	19.4	1001.1	16.7
10nmhTime(seconds)		9.7	19.5	282.1	179.9	0.0	9.7	500.9	8.3
15nmhTime(seconds)		6.5	13.0	188.0	120.0	0.0	6.5	333.9	5.6
20nmhTime(seconds)		4.9	9.7	141.0	90.0	0.0	4.9	250.4	4.2

Figure E-6 Traversal Time Approximations from Each Control Spot

Figure E-7 displays a flow diagram for the Arena simulation of the departure process at Philadelphia International Airport. Input files contained the flight schedule along with several attribute values for each flight such as air carrier, fuel burn rate, carbon emissions index, etc. Flights were held at the gate until a condition, based upon scenario, was met. For instance, if the scenario involved fifteen minute departure windows and allowed for ten simultaneous pushbacks, then the ten flights at the front of the queue (based on time in) would be released at the start of each departure window. Several performance metrics were calculated after take-off.

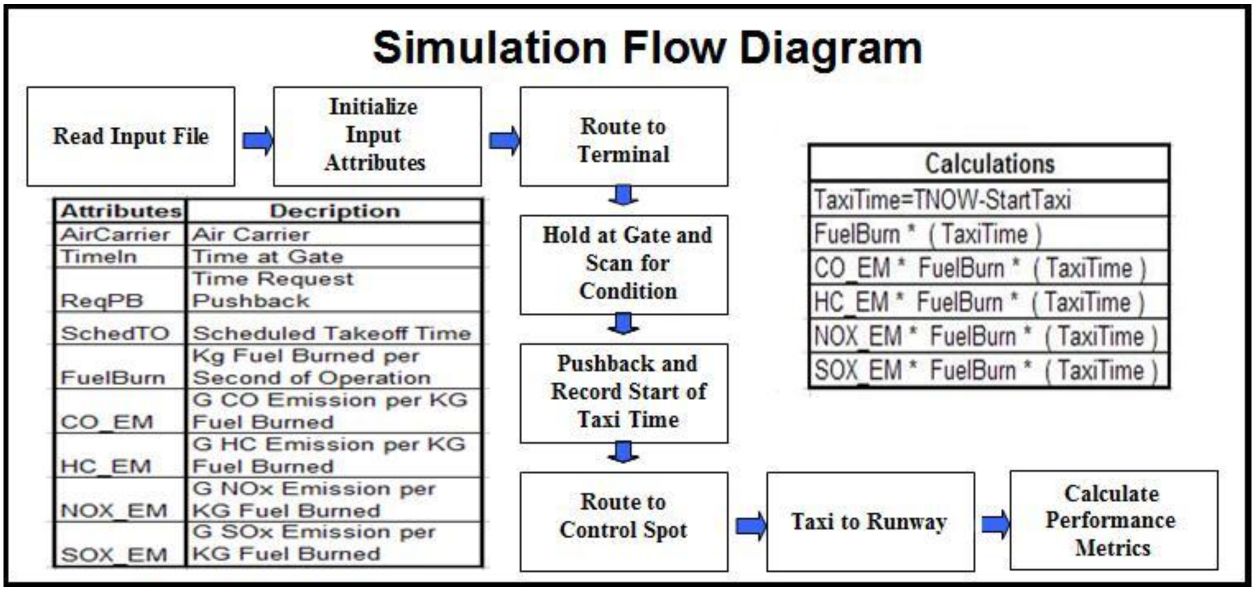


Figure E-7 Flow Diagram for Arena Simulation of PHL Departure Process

Figure E-8 displays the prediction error of the original queuing model (corresponding to the Y axis on the right) and the average taxi time (corresponding to the Y axis on the left) by time of day. Prediction error and average taxi time tended to be highest around peak schedule times- between 7:00-9:00, 16:00-20:00, and 21:00-22:00 (As described in Section 9).

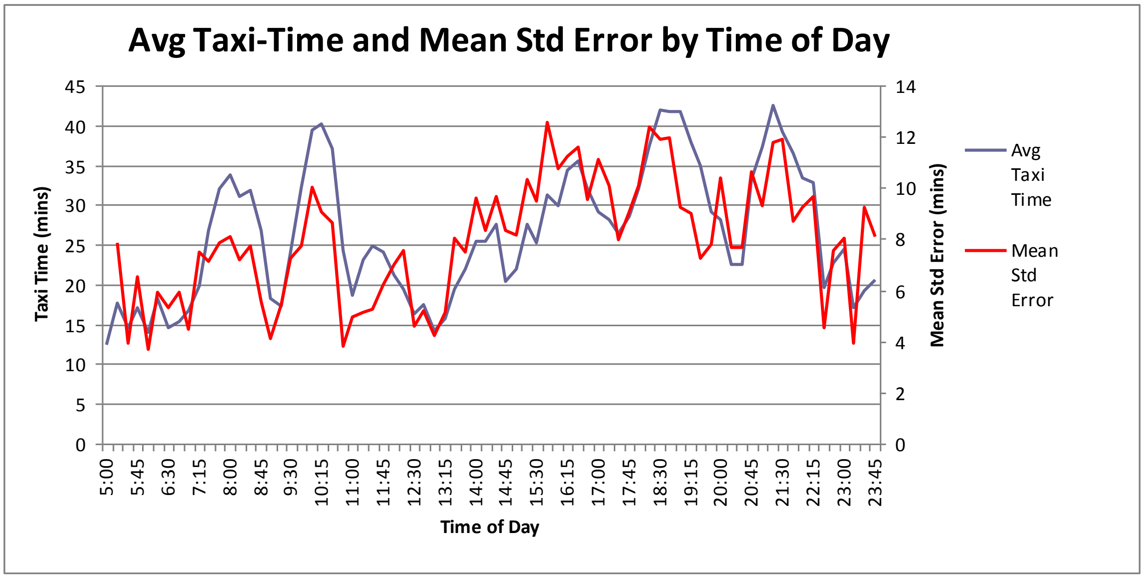


Figure E-8 Average Taxi Time and Mean Standard Error by Time of Day

Figure E-9 illustrates that as queue size grew in each departure window, the rate of takeoffs and average taxi time grew until reaching a saturation point beyond which the rate of takeoffs stagnated while taxi time kept increasing. By keeping queue size below the saturation point, flights could avoid excess taxi times and congestion while maintaining desired throughput. The values observed from the July and August 2007 datasets were used to calibrate the simulations and validate results.

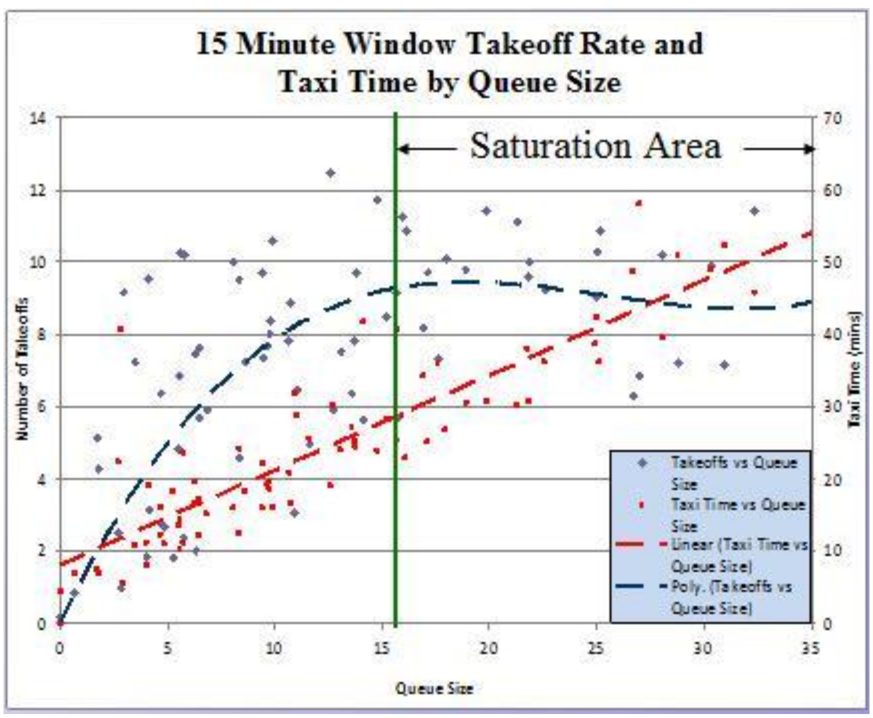


Figure E-9 Average Taxi Time and Number of Takeoffs by Queue Size

Figure E-10 displays the average taxi time (Y-axis on the left) and standard deviation (Y-axis on the right) per flight from the six simulation models.

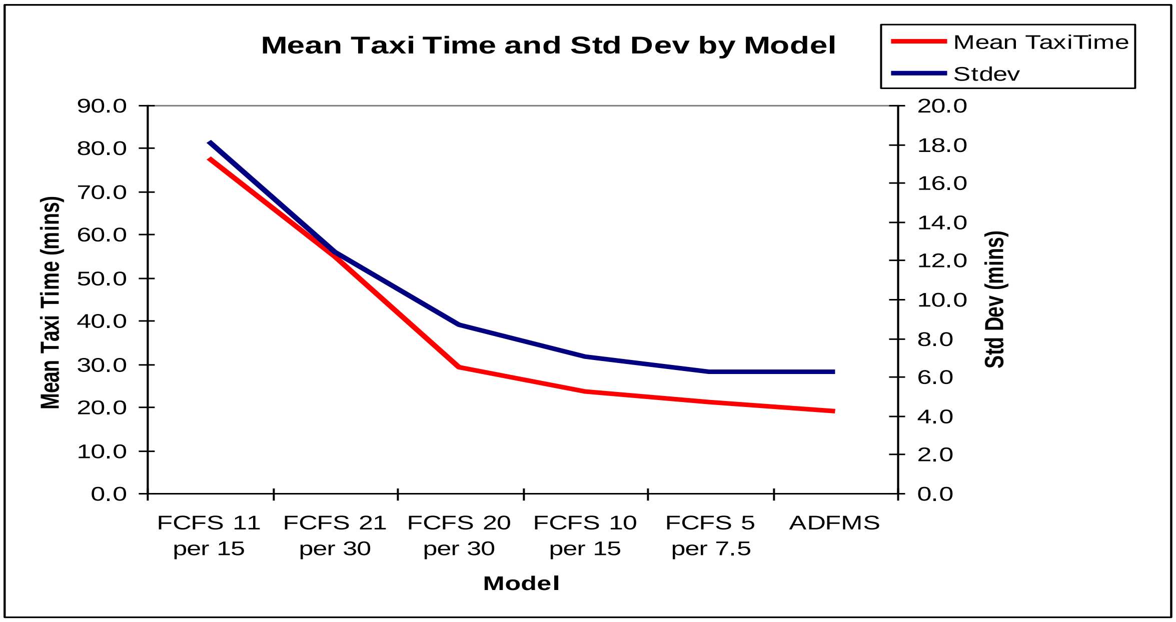


Figure E-10 Mean Taxi Time by Model

Figure E-11 offers a comparison of the actual average fuel burn and emissions per flight at PHL from 2005-2009 with the simulated results from the FCFS Baseline model with ten pushbacks per fifteen minutes.

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Fuel Burned (gal)	55.3	54.2	42.4
Fuel Burn Reduction (gal) Using DFM	13.0	11.9	0.0
%Fuel Burn Reduction Using DFM	23.4%	21.9%	0.0%

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Emissions (Kg)	6.1	6.0	4.7
Emissions Reduction (Kg) Using DFM	1.5	1.3	0.0
% Emissions Reduction Using DFM	23.9%	22.2%	0.0%

Figure E-11 Comparison of Baseline Model with PHL 2005-2009 Actuals

F. APPENDIX F Scenario Analysis

Airport Departure Flow Management System (ADFMS)

Scenario Analysis

Version 1.0
Date April 22, 2010

Prepared by: Team AirportDFM

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SYST 798 / OR 680 Spring 2010
Course Professor: Dr. Kathryn Laskey
Project Sponsor: Dr. Lance Sherry

Table of Contents

1. Introduction

The results of the simulation model depict a situation in which the implementation of the Airport Departure Flow Management System (ADFMS) will reduce mean aircraft taxi time as well as the standard deviation of aircraft taxi times in Philadelphia. The reduction in mean aircraft taxi time is achieved as the actual taxi time approaches the unimpeded taxi time per aircraft, otherwise the time it would take the aircraft to taxi from its gate (actual pushback) to the departure runway and takeoff (wheels-up) without any conflicts or queuing on the airport surface areas.

With 46 percent of the airport traffic, or aircraft movements, US Airways and its code share carriers (Piedmont, Air Wisconsin, Chautauqua, et al) stand to gain the greatest benefits from the reduction in departure queues. However, all airlines that operate at PHL will stand to benefit from Departure Flow Management.

The implementation of ADFMS at PHL introduces two concepts that are foundational to the reduction in departure delays at PHL: the departure slot scheduling/assignment of airline flights [three or more months in advance], and centrally-controlled (queue-managed) aircraft movements on ramps, aprons, taxiways, and runways.

2. Background

Philadelphia International Airport (PHL) is rated the 11th business airport in the world and 8th busiest airport in the United States (RITA | BTS). Along with the positive rating in terms of airport volume is the correlated downside: PHL is rated 5th in terms of airport departure delays.

A non-scientific survey of Web-based forums for air travel passengers / consumers, with postings over the last few years, results in much consternation and disaffection for Philadelphia International Airport and its major tenant – US Airways. Airline passengers are more likely to complain than to praise when participating in on-line forums – and these postings are often the result of the lack of any other method of redress from airlines due to delays and other negative experiences during the course of air travel.

Airlines operating in and out of PHL need to take notice. While these complaints range from poor (and surly) customer service from flight attendants, gate attendants, and ticketing agents at PHL; poor food and beverage service; and lost, delayed, or damaged baggage; the common theme across the great majority of complaints is flight delays. Most commonly mentioned are delays departing PHL, including one commentary that spoke to the scenic route from the gate to the departure runway due to circuitous taxi routing.

3. Benefits of ADFMS

Departure slot scheduling / assignment (slot control) levels departure demand across airport capacity of ten aircraft departures per 15-minute window, effectively metered to a sustained departure rate of one take-off every 1.5 minutes. With a demand that does not exceed the capacity – or airport departure rate (ADR) – aircraft movements can be collectively sequenced into a departure queue with virtual and physical components that efficiently uses and conserves airport and airline resources.

Queue management sequences all aircraft movements on PHL surfaces to reduce conflicts at surface control points and minimize the physical queue. By holding aircraft at the gate as long as possible while still meeting departure slot times, excess taxi time is reduced, resulting in reductions in aircraft fuel consumption and aircraft emissions. Reduced fuel burn is one benefit and the source of immense cost savings to each airline. Reduced emissions are another benefit to the environment and the local community. Reducing mean excess taxi time via queue management will also reduce the uncertainty airlines face as to how long any one flight will be required to taxi. The corresponding reduction in standard deviation will allow airlines to reduce the "schedule padding" that all airlines do meet Official Airline Guide (OAG) departure and arrival times.

Trade brokering enables airlines to trade departure slots within the virtual queue in order to better meet airline needs. ADFMS uses a point system to facilitate departure slot trading on an equitable basis. If a specific flight needs an earlier departure slot for any reason, the airline's Station Manager can request a trade to an earlier departure slot; ADFMS displays the trade request and enables other Station Managers to accept the trade, subject to available time, and swap departure slots. A requesting Station Manager may also swap departure slots amongst its airlines' flights.

If a specific flight needs a later departure slot, due to delays for unscheduled maintenance, delayed arrivals, or ramp or gate operations issues, the airline's Station Manager it can offer its earlier departure slot for trade; ADFMS displays the trade request and enables other Station Managers to accept the trade, also subject to available time. Again, a requesting Station Manager can swap departure slots amongst its airline's flights. If a willing trading partner for a later departure slot does not materialize via ADFMS, an aircraft will be able to fall-back to a later departure as necessary; the ADFMS Queue Management function will re-sequence pushback times amongst the aircraft in the virtual queue in order to maintain the airport departure rate and limit the emergence of taxi delays within physical queue. The point system will track, but suspend, penalty points for these occurrences of unaccepted trades that result in bump-backs. Upon reaching a penalty point threshold, penalties will be assessed to discourage excessive delayed notification of anticipated missed pushback times to ADFMS. Point penalties may also address other root causes of departure delays, including intentional "overbooking" of departure slots, and flight cancellations.

Reducing both the mean taxi time and the standard deviation of taxi times are key points to all airlines: lower costs. Departure slot scheduling is the key enabler for achieving reductions in taxi times, for it establishes the virtual queue, which can then be managed by ADFMS for the benefit of all airlines at PHL. Trade brokering does not reduce airline costs per se, but it does better enable efficient use of airport capacity / airport departure rate. While it would be a challenge to place a monetary value on trade brokering, all airlines would stand to gain operational efficiencies and other intangible benefits with the flexibility established via structured departure slot trading within ADFMS.

4. Analysis

There are three baseline cases for the ADFMS comparison – all with non-optimized pushback and taxi from the gate to the departure runway. Each case is established at the airport capacity (ADR) of 40 aircraft departures across a one-hour long departure window, but with different movement initiations.

- Scenario A is the situation in which ten aircraft request clearance from Ramp Control to pushback simultaneously in a 15-minute window, followed by three additional 15-minute windows of ten aircraft pushback requests and taxi initiations. This scenario utilizes the First Come First-Served (FCFS) queuing method, and most closely resembles the actual taxi times at PHL
- Scenario B simulates the FCFS queueing method with five aircraft entering the queue every 7.5 minutes, a 100 % improvement in metering.
- Scenario C simulates the Airport Departure Flow Management System (ADFMS) managed queue.
- Scenario X is the situation in which 20 aircraft request clearance from Ramp Control to pushback simultaneously in a 30-minute window, with another 20 aircraft pushing back in the second 30-minute window. Ramp Control authorizes these pushback requests with the same consideration for separation and safety as Scenario A and B.

There are also two baseline cases for ADFMS comparison that represent an overscheduling condition where demand exceeds the airport capacity of 40 aircraft departures within one hour. In both cases, these scenarios were selected for comparison due to the limitation of the academic version of the Arena software which reaches its maximum amount of concurrent events of 150.

- Scenario Y simulates the FCFS queuing method in which 21 aircraft simultaneously pushback within a single 30-minute window (42 attempted departures per hour).
- Scenario Z simulates the FCFS queuing method in which 11 aircraft simultaneously pushback in a single 15-minute window (44 attempted departures per hour).

The ADFMS comparison is the situation in which there are 40 aircraft assigned to 40 different departure slots across a one hour-long departure window, each with a known gate and therefore, known required pushback time and calculated expected pushback time that together minimize conflicts on the PHL surface areas between taxiing aircraft.

Each baseline case demonstrates the following: the more aircraft that pushback simultaneously, the more conflicts and the heavier the congestion on the taxiways that result in departure delays. Corralling aircraft push-backs into a 30-minute window, then a 15-minute window, and finally through a departure slot controlling mechanism that injects one moving aircraft into the physical queue every 1.5 minutes results in minimal, foreseeable, and therefore avoidable conflicts that reduce aircraft taxi time on the airport surfaces.

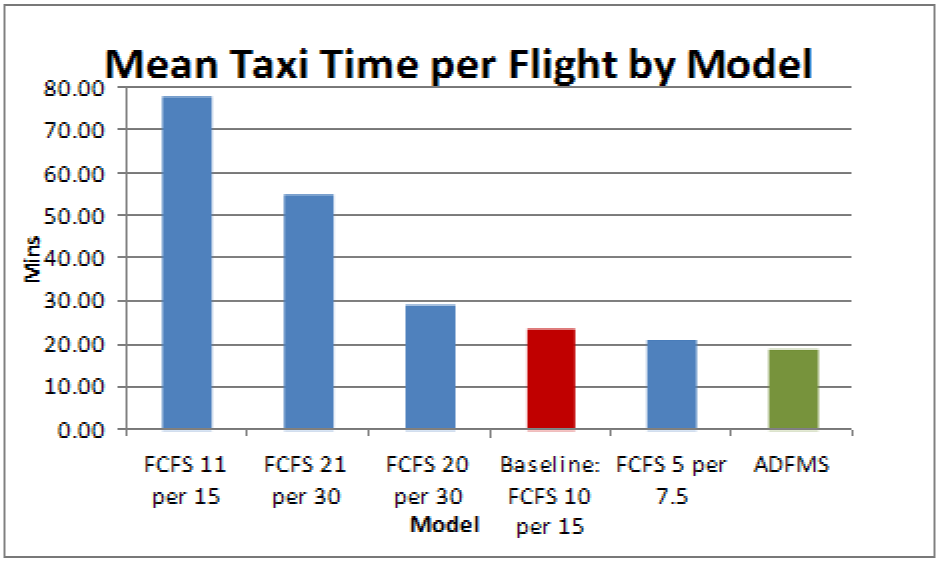

Figure F-1 Mean Taxi Time per Departing Flight

The reduction of mean taxi time per aircraft flight, along with the reduction in variation (uncertainty) is the core component for the business value of ADFMS. Reduction and/or elimination of excess taxi time per flight can be converted into reduced operating costs for airlines, primarily in reduced fuel consumption, but also in reduced anticipated maintenance costs, as scheduled maintenance intervals are based upon aircraft operating hours. The ADFMS results for mean taxi time are the lowest of all the comparison cases, significantly lower than the FCFS queue at peak times (over-scheduling scenarios Y and Z), but also less than FCFS queue at demand equal to capacity where conflicts occur on airport surface areas.

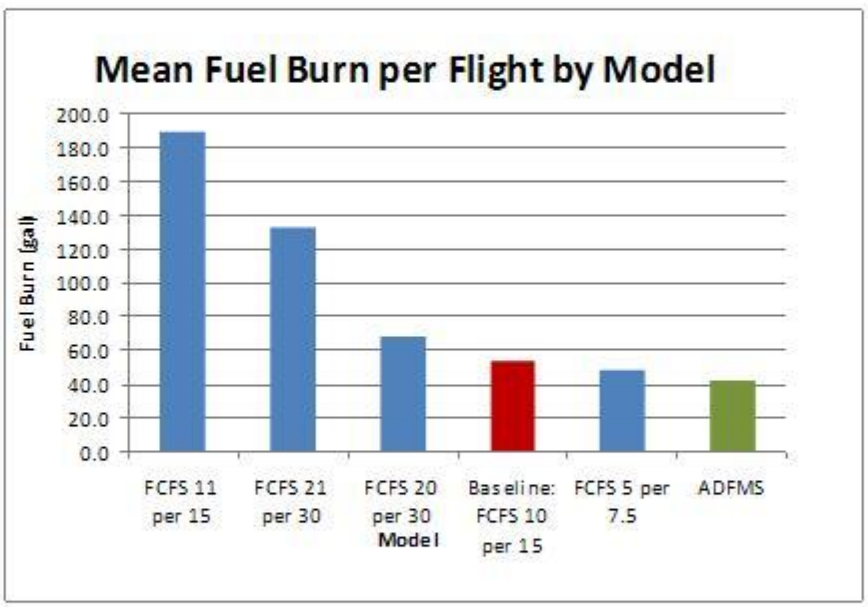

Figure F-2 Mean Fuel Burn per Flight by Model

Taxi out times and aircraft tail numbers for flights were provided by On-Time Summary data through the Bureau of Transportation Statistics. The tail numbers were then used to find the aircraft manufacturer and type for each aircraft. With this information, the ADFMS team was able to map each aircraft to its corresponding Emission Index in the EDMS (Emission and Dispersion Modeling System) database, which provides rates of jet fuel burned in kg's per second of operation and grams of CO_2/ HC/ NO_x/ SO_x emissions per kg of jet fuel burned (EDMS 2010). The simulation input files contained the rates for each flight and calculated the average fuel burn by multiplying each rate by each flight's taxi time, summing over the entire schedule, and then dividing by the total number of flights for a per flight average. Average emissions were calculated in a similar manner.

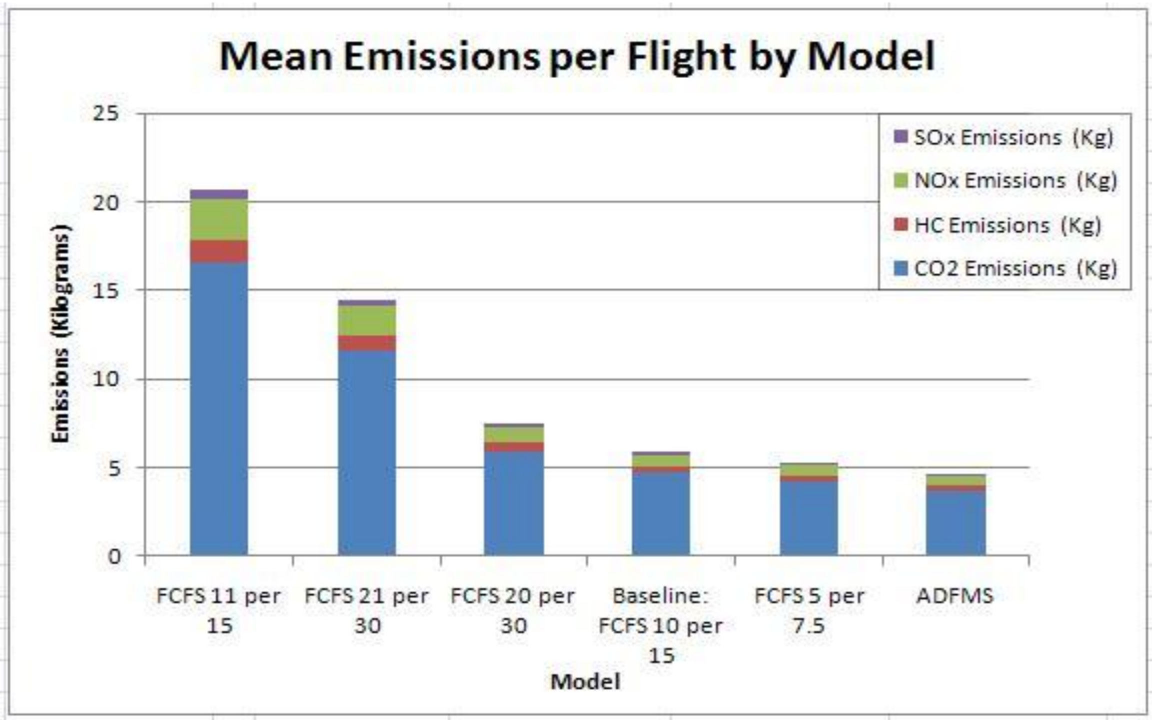

Figure F-3 Mean Emission per Flight by Model

Consistent with the reduction in fuel burn is a proportional reduction in emissions of greenhouse gases into the atmosphere due to the reduction and/or elimination of excess taxi time with the implementation of ADFMS. Greenhouse gas emissions produced during engine combustion processes are air pollutants. Reduction in emissions is a measurable and tangible result of ADFMS implementation for the local PHL community.

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Fuel Burned (gal)	55.3	54.2	42.4
Fuel Burn Reduction (gal) Using DFM	13.0	11.9	0.0
%Fuel Burn Reduction Using DFM	23.4%	21.9%	0.0%

Per Flight	2005-2009 AVG	Baseline A: FCFS 10 per 15	ADFMS
Emissions (Kg)	6.1	6.0	4.7
Emissions Reduction (Kg) Using DFM	1.5	1.3	0.0
% Emissions Reduction Using DFM	23.9%	22.2%	0.0%

Figure F-4 Mean Fuel Burn and Emission Reduction per Flight Using ADFMS

5. Capital Investment and Operations Cost

The decision to undertake an effort such as ADFMS is one of initial capital investment as well as follow-on operational and sustainment costs. The return of the investment is measured through the estimated annual value realized by the airlines through a reduction in fuel consumption costs, in turn due to the reduced taxi time (elimination of excess taxi time). Using the Fuel Burn Reduction values from the simulation (at an initial cost of $2.05 per gallon of jet fuel (EIA 2010)), an estimated capital investment (non-recurring) cost of $5 million and annual operating expenses of $2 million, the investment realizes a net present value of $22 million on a 10-year service life at a 8 per cent rate of return. The payback period is within the second year of operations per Figure F-5 below.

				Return Rate	8.00%	
Year	**Fuel Burn Reduction ADFMS**	**Annual O&M Costs**	**Capital Expenditures**	**Net Savings**	**Net Savings (NPV) at Return Rate**	**Cumulative Net Savings**
0			**$5000**	-$5000	-$5000	-$5000
1	$5160	$2000		$3160	$2709	-$2291
2	$5631	$2000		$3631	$2882	$591
3	$6021	$2000		$4021	$2956	$3547
4	$6285	$2000		$4285	$2916	$6463
5	$6480	$2000		$4480	$2823	$9286
6	$6728	$2000		$4728	$2759	$12045
7	$6947	$2000		$4947	$2673	$14718
8	$7137	$2000		$5137	$2570	$17288
9	$7267	$2000		$5267	$2440	$19728
10	$7384	$2000		$5384	$2309	$22037
All figures in thousands (000's)					**Total:**	$22037

Figure F-5 Incremental Savings / Net Present Value of ADFMS

The Fuel Burn Reduction values are the result of the comparison between mean taxi time for scenario A (FCFS queue with ten aircraft pushback every 15 minutes) compared to mean taxi time for scenario C (ADFMS queue with one aircraft pushback every 1.5 minutes). The team calculated an annual taxi cost savings per flight and multiplied that cost savings by the total number of departures at PHL annually for each of the past five calendar years (as reported by the RITA BTS Airline Data for PHL) to arrive an average fuel burn reduction cost for the next ten years. The average price of a gallon of jet fuel increases annually, based upon the U.S. Energy Information Administration's Annual Energy Outlook 2010. The overall fuel burn reduction assumes no increase in aircraft departures over the investment period, currently at 220,000 departures per annum.

Team ADFMS used an initial capital expenditure of $5 million for system development and implementation. This $5 million amount is a conservative estimate for this valuation in that expected capital investment should be much lower. Available comparisons for localized airport system implementations are the deployment and operations of Airport Collaborative Decision Making (CDM) in Europe (European Organisation for the Safety of Air Navigation "Airport CDM Cost Benefit Analysis v1.4")

Annual operating costs of $2 million per year are based upon estimates for additional Ramp Control staff required to operate ADFMS as well as operations and maintenance costs for the ADFMS information technology solution itself. This is a conservative estimate as costs should be much lower: Eurocontrol estimates operational costs of 7 million Euros (approximately $9.4 million) over a ten-year period per airport. Team AirportDFM uses a conservative $2 million operations and maintenance costs annually to further justify the return on investment for ADFMS.

Team AirportDFM used a return rate of eight percent for the valuation. Eight percent is a conservative estimate. A lower rate of return, which is much more likely, will result in a higher net present value (NPV), while a higher rate of return will result in lower NPV. Unless the rate of return is significantly high (higher than 40 %), the investment in ADFMS will pay off in the second year of operations.

6. Investment Alternatives

Once the Philadelphia International Airport partners / community of interest recognizes that the cost of not doing anything to reduce departure delays exceeds the cost of implementing the Airport Departure Flow Management System (ADFMS), the question of financing and administering the system procurement and implementation arises. Alternative investment scenarios include investment and administration by the Federal Aviation Administration, airlines, and the Philadelphia Airport Authority.

6.1 FAA Investment and Administration

Capital investment and administration of ADFMS by the Federal Aviation Administration (FAA) would be a government acquisition. While the ADFMS concept of operations characterizes the FAA as a stakeholder in ADFMS, neither the Air Traffic Control Tower nor the PHL Terminal Radar Approach Control (TRACON) facility is a primary user of ADFMS. The primary users are airline AOCs, Station Managers, and PHL Ramp Control.

Perhaps the greatest pro to an FAA-driven investment scenario is that the airlines would realize the benefits of an unbiased arbiter for limited airport resources.

The FAA would realize benefits of ADFMS implementation, to include: improved departure queue operations that are part of the supply chain for National Airspace System flight operations; government-sponsored reduction in emissions / air pollutants; and better fuel efficiency in an energy-conscious national context. However, the FAA would not realize the direct benefits of the fuel burn reductions that reduce airline operating costs.

Also, it's unlikely that the FAA would invest and administer a system that would not fall under their operational control. FAA investment and administration of ADFMS would require redevelopment of the ADFMS concept of operations, either eliminating or significantly reducing the role of PHL Ramp Control in the PHL airport surface operations. Increasing the scope of FAA responsibility at PHL would require additional staff and/or additional training for Air Traffic Control Tower personnel, and would also make the FAA subject to liability claims by airlines and passengers for airport surface area mishaps and other issues. These conditions and risks are unlikely to be undertaken by the FAA for an inherently local issue which would set a precedent for NAS boundary expansion from the departure and arrival runways at each airport and instead encroach upon airport surface areas.

6.2 Airline Investment and Administration

Capital investment and administration of ADFMS by the airlines would require organization and governance to acquire and oversee the system. While the primary benefit of ADFMS is reduced operating costs due to reduced fuel burn, collective and fair governance and operations amongst hypercompetitive airlines in a consolidating industry that is highly susceptible to economic and other external conditions would be a tremendous challenge. While efficient use of airport resources and surface areas is a worthy endeavor, airlines would not be likely to pay for this benefit through a direct capital investment structure compared with other competing strategic investment needs. The airlines would still require an unbiased arbitrator to the allocation of PHL resources (departure slots and airport surface areas), a role best filled by the local airport authority.

6.3 PHL Airport Authority Investment and Administration

Capital investment and administration of ADFMS by the Philadelphia Airport Authority would be a local government acquisition, similar to other airport-specific enhancements such as terminal construction and improvements, runway and taxiway expansion, or other facility improvements, such as the AeroTrain people mover system recently opened at Washington-Dulles International Airport. While PHL would not realize the direct benefit of dollar cost savings due to reduced fuel burn, it benefit is many other ways. Unlike the FAA or airlines, PHL has direct operational control over the current departure queue through its Ramp Control responsibility, and would retain that responsibility with ADFMS. PHL would oversee ADFMS development and direct its implementation, and retain its status as an unbiased arbiter of PHL resources. PHL would also stand to recoup some or all initial investment or annual operational costs through a pass-through charge to the airlines and/or through alternatives to include increased gate fees or possibly passenger facility charges (PFCs) at PHL.

Although one of the two Ramp Control Towers at PHL is operated by US Airways Airlines, PHL would take on the responsibility to implement ADFMS is an appropriately administered methodology that eliminates the perception of bias. PHL would also hire the required additional staff to operate and maintain ADFMS for PHL.

The city of Philadelphia would stand to benefit from the intangibles associated with this kind of investment, to include increased satisfaction amongst passengers for the reduction in departure delays.

G. APPENDIX G Project Management

1. Work Breakdown Structure

WBS	Task Name
1	**AirportDFM System Project**
1.1	**Project Management**
1.1.1	Form Project Team
1.1.2	**Initial Project Plan**
1.1.2.1	WBS
1.1.2.2	Project Schedule
1.1.3	**Project Reporting**
1.1.3.1	Project Proposal Presentation
1.1.3.2	Status Report
1.1.3.3	Progress Report
1.1.3.4	Status Report
1.1.3.5	Formal Progress Presentation
1.2	**Project Proposal**
1.2.1	Proposal Development
1.2.2	Proposal Presentaiton
1.3	**Queuing Model Development**
1.3.1	Data Analysis
1.3.2	Data Simulation
1.4	**System Definition**
1.4.1	Subject Research
1.4.2	**DRAFT System Requirements**
1.4.2.1	Requirements Decomposition
1.4.3	**DRAFT System CONOPS**
1.4.3.1	Operational Concept
1.4.3.2	Use Cases
1.4.3.3	Operational Architecture
1.5	**System Design**
1.5.1	System Architecture
1.6	**Assessment**
1.6.1	System Simulation
1.6.2	Scenario Analysis
1.6.3	Refined System Requirements
1.6.4	Refined System CONOPS
1.7	**Transition**
1.7.1	Final Report
1.7.2	Final Web Site
1.7.3	Presentation

Figure G-1 Work Breakdown Structure List

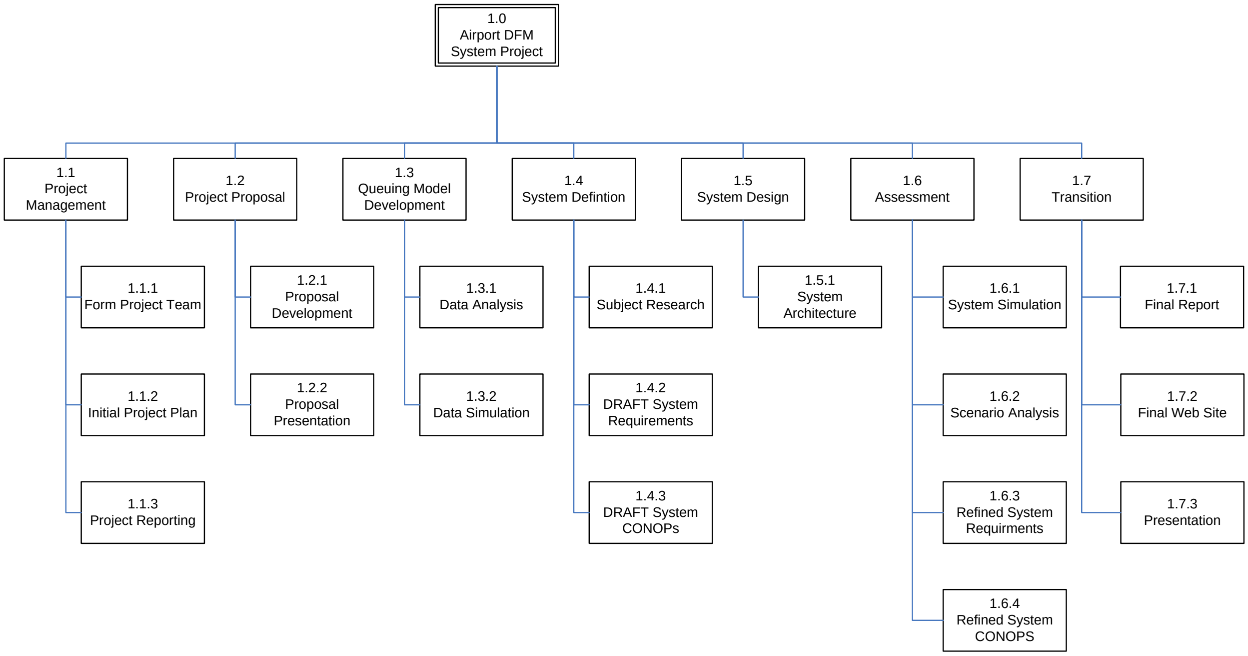

Figure G-2 Work Breakdown Structure Tree

2. Schedule (GANTT Chart)

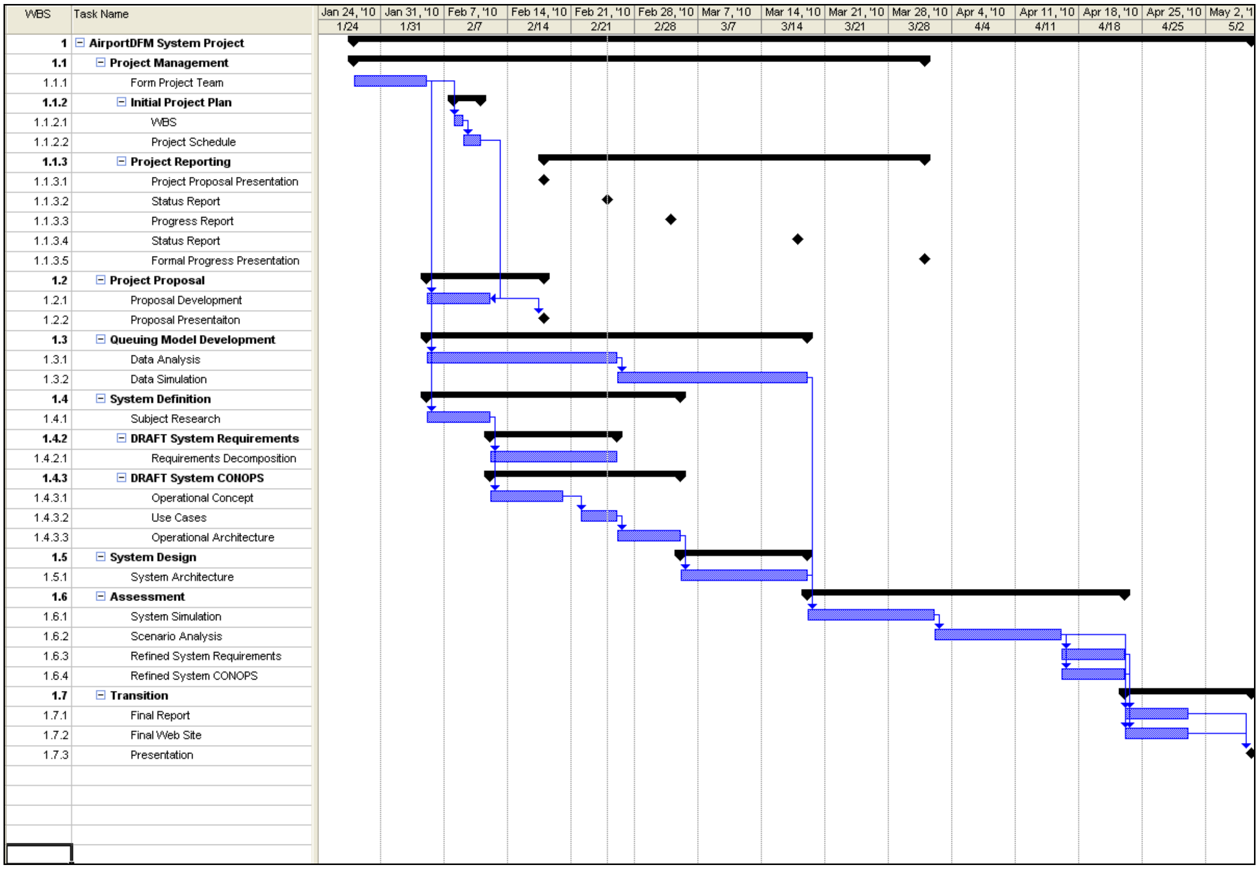

Figure G-3 Project Schedule

3. Earned Value Management

The earned value management is based on each student making $10 per hour for their work on this project. This means that at $10 per hour for five students for 14 weeks that is a total of $7000. The schedule was somewhat heavier during the first half, which meant the team had slightly more work planned for the first half than the second. The work performed by the team each week was relatively even excluding week 5 where the team put in extra hours to bring the project more in line with the schedule. The increase work later in the schedule was due to unexpected updates to some of the products as the team worked through detailed system architecture and scenario analysis. This reduced amount of work scheduled toward the end allowed for these updated to be made without sliding the schedule.

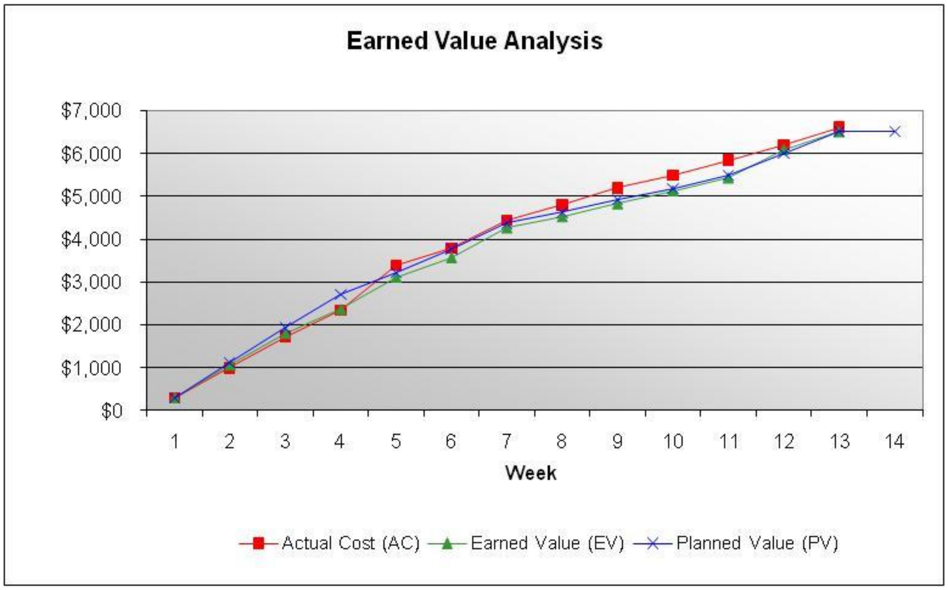

Figure G-4 Earned Value Analysis

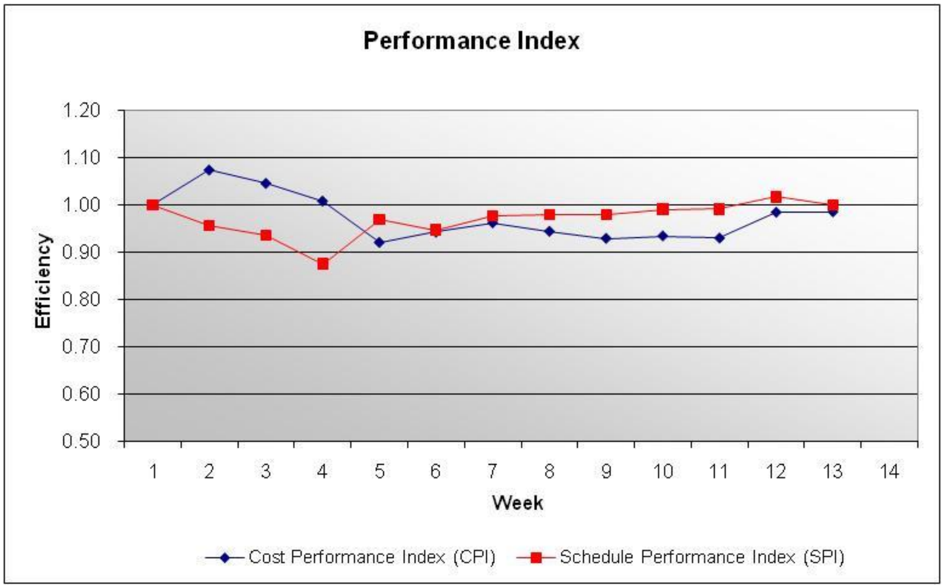

Figure G-5 Project Performance Index

4. Roles & Responsibilities

Each team member contributed to some extent to most of the products; however, the focus of each member is as follows:

- Doug Disinger (Project Manager): Project Management, CONOPS, Object Oriented Architecture, Scenario Analysis
- Lily Tran (Chief Engineer): Requirements, Web site, Structured Analysis
- Hassan Hameed (Assistant Engineer): Requirements, CONOPS

- Kenneth Tsang (Chief Analyst): Mathematical Model, Simulation, Results, Scenario Analysis
- Chip West (Chief Architect): Operational Concept, Object Oriented Architecture

5. Team Biographies

Douglas Disinger is a graduate student in George Mason University’s Systems Engineering Master Program specializing in Architecture-Based Systems Integration. Doug obtained a B.S. in Mechanical Engineering and a Master of Business Administration prior to being a graduate student at GMU. He also served 12 years as an active duty Army Aviation officer. Currently Doug is working at Science Applications International Corporation (SAIC) as a project manager and systems engineer.

Hassan Hameed is a full time graduate student in George Mason University’s Systems Engineering Master Program specializing in Computer-Based Systems. This is his last semester at GMU. He obtained a BS in Computer Engineering with a minor in Mathematics at University of Alabama in Huntsville in 2007. Hassan's recent coursework was working with classmates in development of statement of work and system requirements specification. His other coursework was design/development of a mechanism to produce sine wave from DAC12, controlling frequency from potentiometer using Texas Instruments MSP430F1611 microcontroller and a hotel reservation system, Ophelia’s Oasis in the Amlet Desert, using C++ and UML.

Lily is a graduate student in George Mason University’s Systems Engineering Master Program. She earned her undergraduate degree in Electrical Engineering at the University of Washington in 2005. She is currently working for the Marine Corps Systems Command as a Systems Engineer where she is responsible for life cycle support of the electronic maintenance system that was delivered to the Marines in 2008. Her current focus is the development of requirements for future increments of this system.

Kenneth Tsang is a graduate student in George Mason University’s Operations Research. Ken is currently working at Northrop Grumman as an operations research analyst performing cost analysis, some simulation and modeling, data mining, and case studies. He is familiar with the following tools: Excel, SimTools (Monte Carlo), Arena, ACE-IT Suite (Cost Estimating software), REVIC (Cocomo) and some basic programming languages (MPL, C++, VB).

Stirling “Chip” West is a graduate student in the systems engineering program, architecture focus, at George Mason University. After earning his Bachelors degree in mechanical engineering, he spent six years in the Army Signal Corps. Following his time in the Army, he conducted system of systems analysis for five years at Science Applications International Corporation. Currently, he does systems engineering for a defense contractor.

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I. APPENDIX I Acronyms

Acronyms

ADFMS	Airport Departure Flow Management System
ADR	Airport Departure Rate
ARTCC	Air Route Traffic Control Centers
ATCT	Air Traffic Control Tower
ATCSCC	Air Traffic Control System Command Center
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
CATSR	Center for Air Transportation Systems Research
CONOPs	Concept of Operations
DFM	Departure Flow Management
FAA	Federal Aviation Administration
FCFS	First Come First Served
GDP	Ground Delay Program
IDEF0	Integration Definition for Function Modeling
NAS	National Air Space
OAG	Official Airline Guide
PHL	Philadelphia International Airport
SRD	System Requirements Document
TOTW	Take-Off Time Window
TRACON	Terminal Radar Approach Control