Project ‘CTAAS’
Controlled Time of Arrival for Airports System

Final Report

SYSTS 798/OR 680

Spring 2009

Akshay Belle (OR)

Arlen Lippert (OR)

Najia Hussaini (SE)

Michael Brinker (SE)

LaTrent Burdette (OR)

Sponsor: Dr. Lance Sherry

Faculty Advisor: Dr. Thomas Speller

Department of Systems Engineering and Operations Research

George Mason University

Fairfax, VA 22043

EXECUTIVE SUMMARY

The goal of the Controlled Time of Arrival for Airport Systems (CTAAS) team was to develop a business case for a software-based system that uses inputs from new technology to reduce the arrival flow variance at busy airports by directing flight arrival information to incoming aircraft.

The CTASS project team developed PERT and GANTT charts to identify all of the elements of the project and to establish a schedule.

There has been an increase in the average block time for airlines. One of the factors contributing to this increased block time is arrival flow variance. Arrival flow variance is the random arrival of aircraft with undesired inter-arrival times and gaps. By reducing the arrival flow variance the aircraft should be able to proceed directly to land which will result in reduced block time.

The CTAAS system is dynamic/real-time software that will utilize new aviation technology to provide flight guidance to arriving aircraft. The CTAAS system will depend upon highly accurate GPS feeds from the aircraft via a secure data communications link. This information will be analyzed to provide real-time flight guidance, which will be transmitted to the inbound aircraft to minimize the arrival flow variance.

In 2006, 116.5 million system delay minutes (up 5 percent from 2005) drove an estimated $7.7 billion in direct operating costs (up 11 percent from 2005) for U.S. airlines. The cost of aircraft block (taxi plus airborne) time was $65.80 per minute, 6 percent higher than in 2005. On average, extra fuel consumption and crew time are estimated at $42.55 per minute, followed by maintenance and aircraft ownership ($20.14 per minute) and all other costs ($3.10 per minute).

CTAAS simulation has shown a 39.5 million minutes saving resulting in $2.6 billion annual savings for the airlines.

CTAAS system will require an initial investment of $42.7 million and will have a return on investment in 10 years of 877 percent.

Further information regarding the CTAAS project can be found the group website which is described in Appendix A. Additional information regarding the CTAAS development group can be found in Appendix B. CTAAS development schedule details can be found in Appendix C.

Table of Contents

List of Figures

1. INTRODUCTION

The consistent growth of air traffic demand is causing the operational volumes at hub airports to approach their maximum capacities. The core issue strangling the hubs is the operational production variance. Production variance is the uncertainty in block times i.e., time needed to complete a flight leg. High production variance adds to airlines costs as they are forced to work with longer schedule block time to overcome the variance in the actual block time. The average actual Block times have been increasing every year, in the last eight years the block times on an average have gone up by 3 to 5 percent (Figure 1).

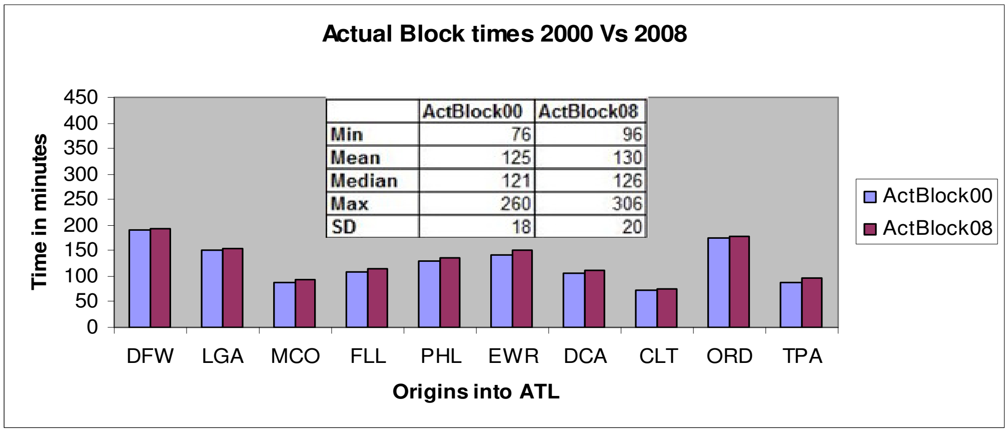

Figure 1 – Average Actual Block Time Distribution

In addition to the increase in average block time there has been an increase arrival flow variance which has lead the airlines to increase their scheduled block in an effort to maintain their "on-time" statistics which also reduced their aircraft utilization.

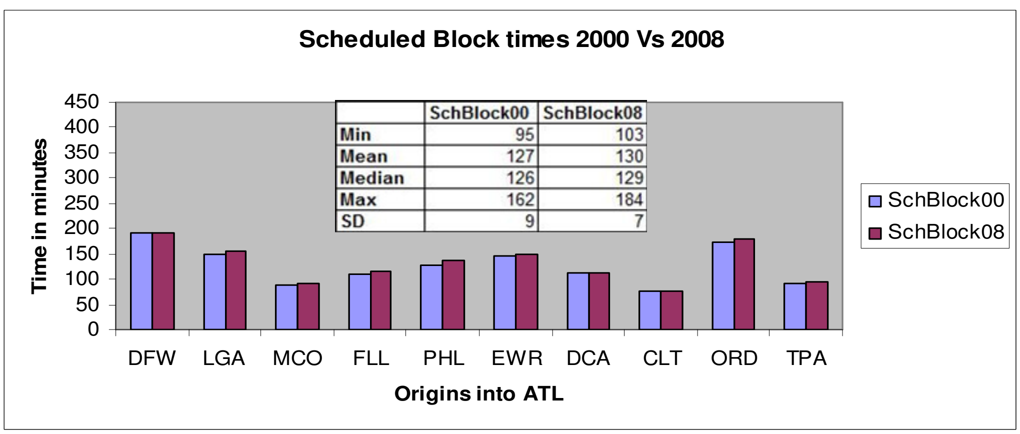

Figure 2 – Ever Increasing Block Times

The most important factor that adds to the variance of the block time is the unbalanced arrival flow of aircrafts at the initial approach fix/corner post of the destination airport.

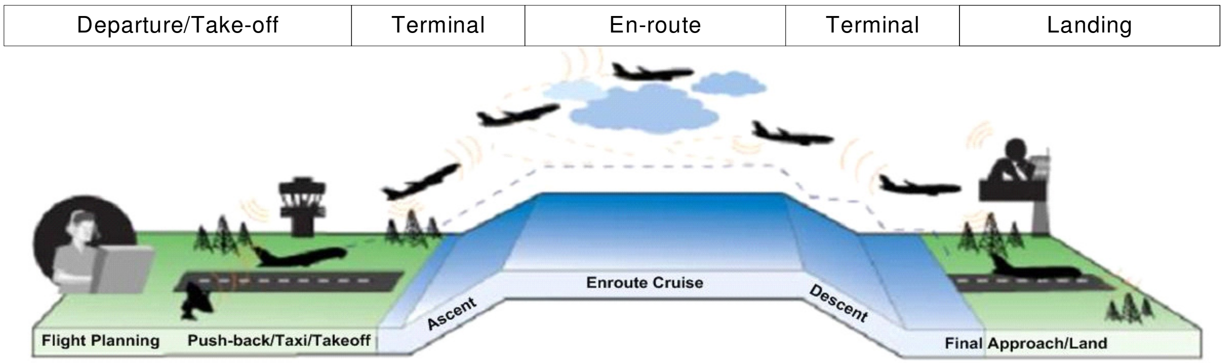

Figure 3 – Flight leg phases

When aircraft arrive at the Initial Approach Fix/"Corner Post" (the point where the initial approach segment of an instrument approach begins, it is the start of the terminal area for inbound flights) with the proper inter-arrival times/gaps they should be able to proceed directly to the runways for landing with minimum delays. However no mechanism is in place to facilitate synchronized sequenced arrivals.

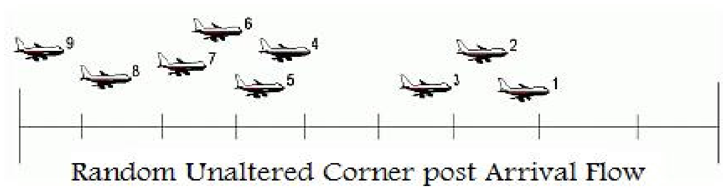

Figure 4 – Random Arrivals

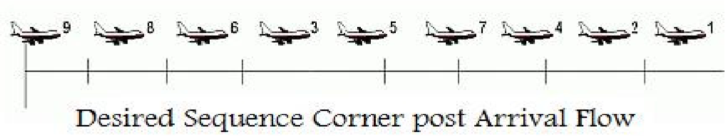

Figure 5 – Balanced Arrivals

Currently the Federal Aviation Administration (FAA)/Air Traffic Control (ATC) primary focus of arrival flows is to ensure minimum safety separation between leading and trailing aircrafts, gaps cannot be appreciable closed by ATC to reduce the arrival flow variance. This project aims to develop and market a system which utilizes new and emerging technologies combined with real time/dynamic software to provide flight guidance to arriving aircraft which will reduce costs associated with arrival flow variance. The envisioned system namely, Control Time of Arrival for Airports System (CTAAS) would communicate with the inbound flight in their en-route cruise phase using next generation Communication, Navigation and Surveillance (CNS) systems and provide velocity updates which would enable flights to speed up or slow down such that they would eventually approach the corner post in a synchronized manner with minimal arrival flow variance. This new system would help minimize the trombone effect, which is a procedure that ATC uses to extend the flight path of aircraft to increase the separation between arriving aircraft, as depicted in Figure 5.

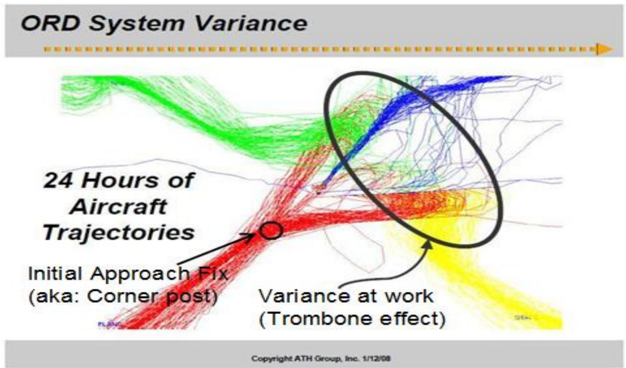

Figure 6 – Variance At Work [ATH Group]

2. STAKEHOLDER IDENTIFICATION

Based on the CTAAS's experiences and past knowledge, the team analyzed the stakeholders and categorized them appropriately. Extensive research and stakeholder's feedback was obtained to acquire all stakeholders' best interest. The CTAAS team had a rationale for identifying stakeholders by analyzing complexity, uniqueness, participation, and methods. The complexity was based upon the natural resource management that deals with understanding and managing the complex relationships between humans and resources upon which they depend. Each situation is unique, and requires an understanding of local conditions and realities. In a participatory approach, management decisions are more easily embraced by those who have been part of the decision-making process, and greater attention is paid to the needs and expectations of all actors. Participation is often perceived by planners and managers as a simple process that does not require specific skills and methods. However, experience has shown that poorly designed participatory processes can be ineffective, and can even have negative social and environmental impacts. Rigorous methods, suited to local conditions are therefore required. See appendix D. [1]

2.1. STAKEHOLDER DEFINITION

After determining what rationale is analyzed to identify the stakeholders, the team defined the stakeholders. CTAAS's stakeholders are all those who could and should have a stake in a planning and management process. After the stakeholders were identified they were categorized as in Figure 7 and as follows:

- Industry: Pilot, Aircraft, Airport, Airlines (Airline Station Manager), CTAAS
- Government: Federal Aviation Administration (FAA)/ Air Traffic Control (ATC) (Towers at each airport)
- Civilians: Passengers, SEOR (Systems Engineering and Operational Research) Faculty

[1] http://www.canari.org/Guidelines5.pdf

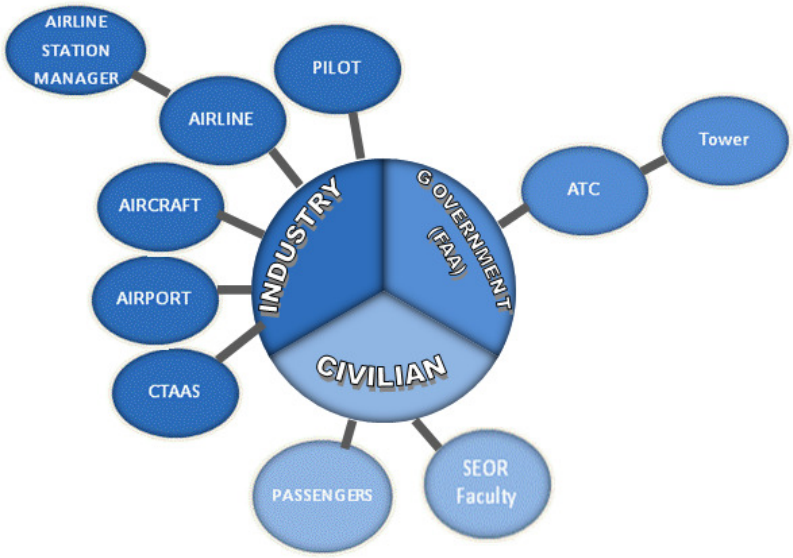

Figure 7 – CTAAS Stakeholder Community

Industry Stakeholder Definition

CTAAS will assist all stakeholders in the Industry category by the following:

- Pilot - Ease workload and improve perceived safety
- Airlines (Airline Station Manager) - Provide gates and services to all incoming aircrafts
- Aircraft Producers - Potential for increased business – new and retrofit integration
- Airport - Effective utilization of Airport Resources
- CTAAS - Improve Knowledge Base and Learning Curve and hopefully a patent

Government Stakeholder Definition

CTAAS will assist ATC in providing less congestion when airplanes arrive at the corner posts of final destinations. In order for pilots to accomplish this, CTAAS will be guiding them throughout their trip from the point when they depart cruise altitude level until they get to the corner post and finally land. The ATC main concerns are to organize and speed up traffic flow so there is less congestion to improve safety. They also provide support to pilots in guiding them if needed. When CTAAS sequences them before the airplanes get to the corner post then ATC will have fewer issues to worry about.

Civilians Stakeholder Definition

CTAAS will assist passengers and SEOR faculty in providing improved safety aspects. The passengers' most important need is safety and on-time or early arrival will help obtain that. Also, they are concerned with either making their connection flight or getting to their final destination by arriving without long delays. The SEOR faculty is mainly interested in continued contribution to automated air traffic control.

Sponsorship

The team's sponsor Dr. Lance Sherry has been very supportive of our research, model, and the project as a whole. He is the Executive Director of Center for Air Transportation Systems Research (CATSR) and Associate Professor and Researcher in the SEOR Dept. Dr. Sherry has written numerous reports regarding airport delays. His recent articles were "*U.S. Airline Passenger Trip Delay Report", "Methodology for Estimation of Benefits of Human-Computer Interaction Engineering in NextGen/SESAR Development", "Application of Reinforcement Learning Algorithms for Predicting Taxi-out Times", "Effects of Fuel Prices and Slot Controls on Air Transportation Performance at New York Airports"*, and many more which can be found on the following website: http://catsr.ite.gmu.edu/pubs.html .

2.3. STAKEHOLDER VALUE MAPPING

After identifying who our stakeholders are, we then analyzed their needs and wants. We mapped them out to produce an effective way for understanding our stakeholder interests. This is the team's initial starting position to begin to focus attention on the project and provide a prospective of how to go about finding the best implementation. "This allows supply chain specialists to determine what kinds of outputs are necessary to make the decisions. Stakeholders Value Mapping is a decision-making approach. Most of the steps of the proposed framework correspond directly to those of the Stakeholder Value Mapping process (Stakeholders' assessment, Stakeholders' re-evaluation. The Stakeholder Value Mapping serves as the stakeholder-process element of the proposed framework. The goal of the Stakeholder Value Mapping process is not to have agreements on every single issue, but to agree as a group on a package of strategies/alternatives that are acceptable as a whole and successfully identify the value added by them."[2] Please see Appendix E.

3. TECHNICAL CONCEPT OF OPERATIONS

3.1. OPERATIONAL CONCEPT

The CTAAS system will provide aircraft arrival sequencing services and in-flight guidance to aircraft that are en route to the destination airport that is equipped with the CTAAS system. The arrival sequencing service will provide each in-bound aircraft with a unique arrival time (and runway designator in the case of an airport with multiple arrival runways). The flight guidance from the CTAAS system will be able to be transmitted from the CTAAS Airport Operations Center to the aircraft via two distinct paths:

1) By direct communication with the aircraft; or
2) By communicating with the Airlines AOC.

The direct communication with the aircraft will be via secured data-link and will be received and displayed in the aircraft cockpit on yet-to-be-determined transceiver-communications equipment. When passing data to the aircraft through the airline's AOC, the data will be passed primarily via a CTAAS user interface via a secured network connection.

The CTAAS system will provide flight guidance information primarily via a text messages based system, but will also have the capability to provide flight guidance via common avionic and ground-support voice and

[2] http://etd.fcla.edu/CF/CFE0002108/Alvarado_Moore_Karla_P_200805_PhD.pdf

data communication channels when communicating with either the aircraft or AOC, respectively. The Systems Requirements Document upon which these use cases are based can be found in Appendix F.

3.2. USE CASE ANALYSIS

The following diagram shows the interaction between the Airline AOC and the CTAAS system when scheduling a flight.

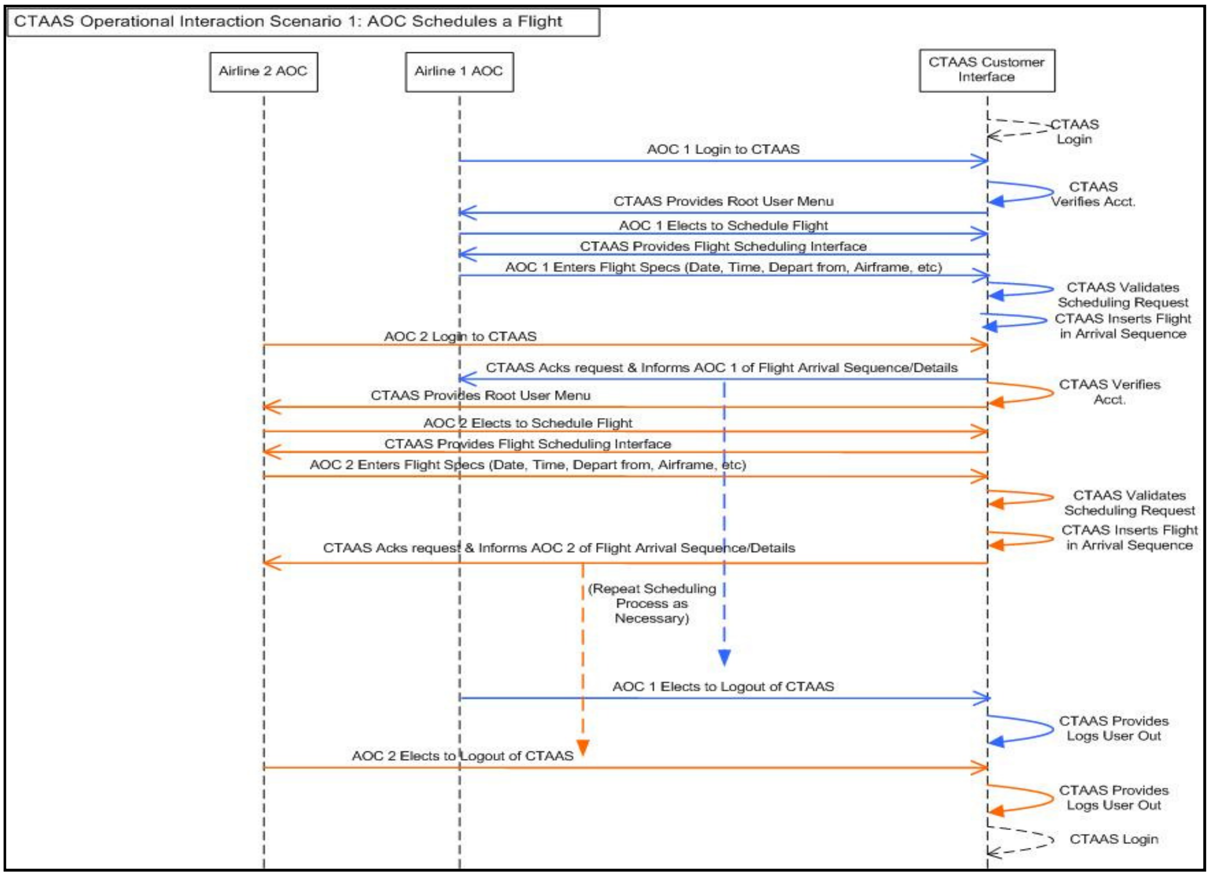

Figure 8 – Use Case

Please see Appendix G for additional Use Case scenarios.

4. SIMULATION MODEL

The simulation model validates the benefits of balancing the flow of aircraft as they approach the initial approach fix/corner post. The CTAAS simulation model takes into consideration the effect of implementing the system in phases. This is accomplished by letting only a certain percentage of flights make velocity changes to close any existing gaps. In every subsequent case an additional ten percent of flights are allowed to change velocities, until in the tenth case all flight are allowed to speed up to close any remaining gaps. The ten cases are compared with the baseline case. The baseline case is where only minimum safety separation is maintained and flights do not speed up to close excess gaps. Figure 9 gives a list of cases and their description.

Serial#	Cases	Description
1	Baseline	Only minimum flight separation is maintained
2	10% Compliance	Baseline + 10% flights speed up, if needed
3	20% Compliance	Baseline + 20% flights speed up, if needed
4	30% Compliance	Baseline + 30% flights speed up, if needed
5	40% Compliance	Baseline + 40% flights speed up, if needed
6	50% Compliance	Baseline + 50% flights speed up, if needed
7	60% Compliance	Baseline + 60% flights speed up, if needed
8	70% Compliance	Baseline + 70% flights speed up, if needed
9	80% Compliance	Baseline + 80% flights speed up, if needed
10	90% Compliance	Baseline + 90% flights speed up, if needed
11	100% Compliance	Baseline + 100% flights speed up, if needed

Figure 9 – Simulation Case Description

The assumptions made for the simulation model are as follows:

- Velocities assigned to the aircraft are average cruise velocity.
  - For a given case (Compliance level) it remains constant.
  - Is a function of the separation at the initial approach fix?
- Four Initial approach fix are considered
- The Airport is assumed to have two independent runways.
- Influence of Departures is not considered.
- The maximum possible velocity that flights can speed up to is 340 knots.

Figure 10 below is a graphic representation of the corner post and the runways that pertain to the simulation model.

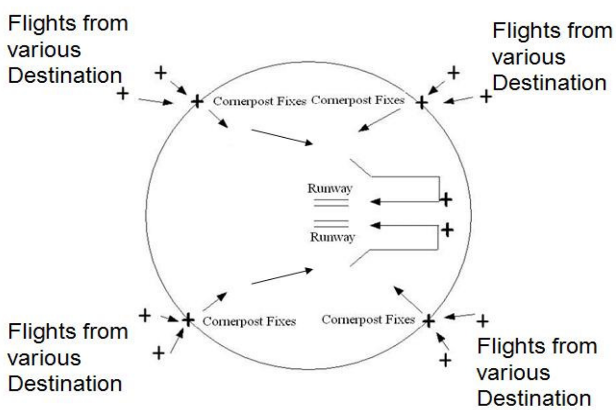

Figure 10 – Airport Approach Diagram

4.1. Model Description

Figure 11 shows the working of the simulation model. Each flight is assigned a flight type, a corner post that it must fly to, distance (D) to corner post and an average cruise velocity (V). The flights arrive at the assigned corner post after a flying time T = D/V. The average cruise velocities are calculated such that the inter-aircraft separation is at the minimal 5 nautical miles as the flights approach the corner post. The terminal area flying time is modeled as a Gaussian distribution $N(600,10^2)$ in seconds, where 600 is assumed from an average distance of 30 nm and an average terminal area speed of 180 knots. The runway occupancy time is assumed to be $N(48,8^2)$ (Haynie 2002) in seconds. The average cruise velocity of an aircraft is a function of its separation with respect the aircraft in front of it, as this aircraft reached the initial approach fix.

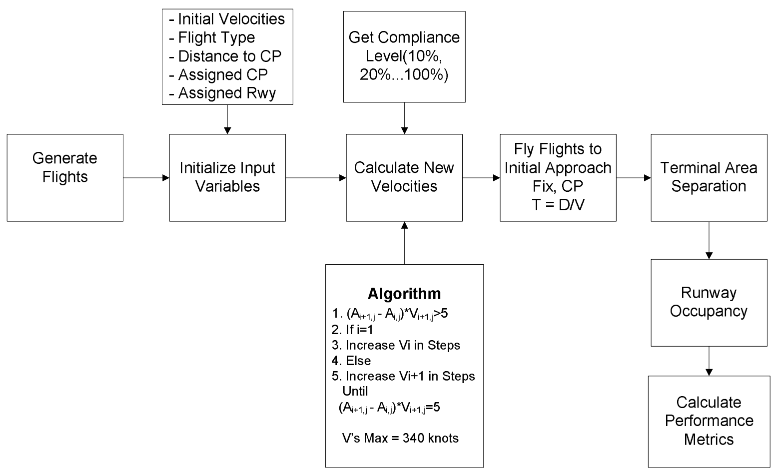

Figure 11 – Model Description

The average cruise velocities are calculated based on the following algorithm.

Step 1: Check if $(A_{i+1,j} - A_{i,j})*V_{i+1,j}>5$

Step 2: If i=1

Step 3: Increase V_i in Steps

Step 4: Else

Step 5: Increase V_{i+1} in Steps Until $(A_{i+1,j} - A_{i,j})*V_{i+1,j}=5$

Where,

V_i's<=340 knots

A_{ij} is the arrival time of flight i at corner post j.

4.2. Results

The simulation was run for all the cases and performance metrics were calculated. The improvement in system performance was evaluated based on the following metrics.

- Average time separation between aircraft pair
- Block time gained per flight
- Average airport throughput
- Average increase in cruise velocity

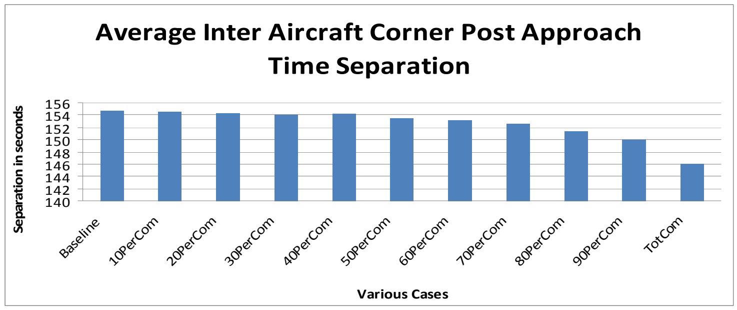

Figure 12 – Average time separation between aircraft pair

The average time separation between aircraft pair at they approached the corner post went down by as much as 8 second per aircraft pair. The closing of excess gap yielded to time gained when compared to the baseline case. When hundred percent of the flights were made to change their velocities to close excess gaps, as much six minutes per flights was gained in landing time. Figure 12 shows the average inter-aircraft time separation for each of the eleven cases and Figure 13 shows the time gained per flight with respect to the baseline case.

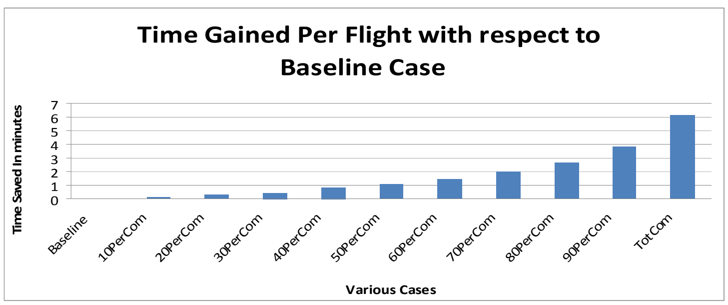

Figure 13 – Time gained per flights

Throughput of the airport is an important metric for the validation of the model. For current day operation the maximum throughput per runway is 40 per hour, assuming only arrivals. Since our model has two runways the throughput should be around 80 per hour. Figure 14 shows the airport throughput per hour for the simulation model. The baseline case has just the right throughput of about 77 per hour. The throughput for 100% compliance case was as high as 81 per hour.

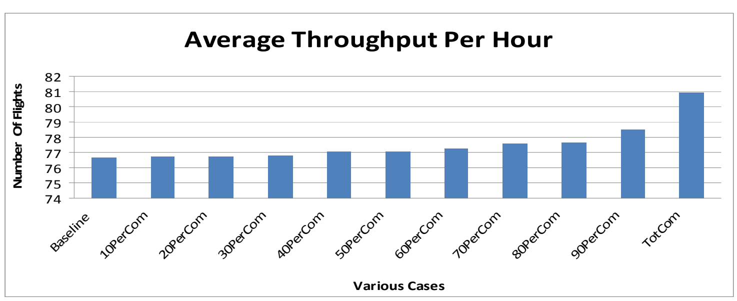

Figure 14 – Average Airport Throughput

The level of block time savings and the increase in throughput was achieved by speeding up flight to close excess gaps. The difference in average cruise velocity between the baseline case and the 100% compliance case was 30knots.

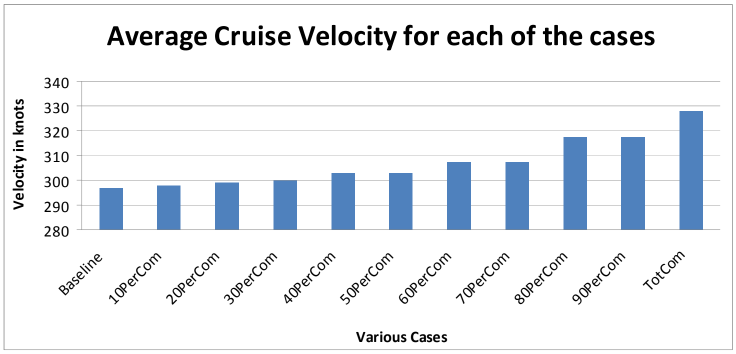

Figure 15 – Average Cruise Velocities

The saving in block time can be equated to saving in cost. On an average there are about 500 peak hour arrivals a day at busy airports. Even if only the OEP- 35 airports are considered that amounts to 6.4 million flights per year. Considering a savings of six minutes per flight, the total savings in cost is about 2.5 billion dollars a year, for 100% compliance case.

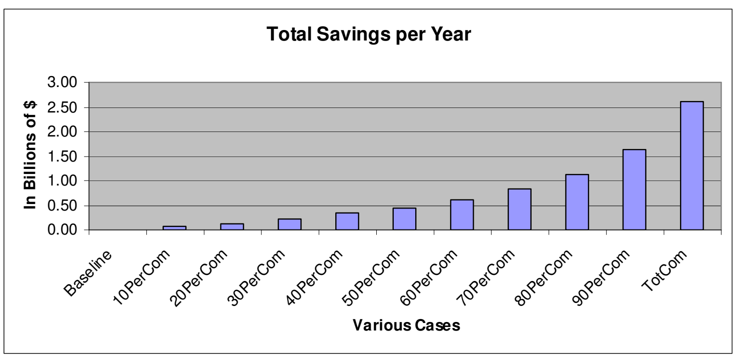

Figure 16 – Total savings per year

5. SYSTEM ARCHITECTURE

Several operational architectures were considered for the CTAAS system: Distributed, Centralized, and Decentralized. The Distributed architecture, while most robust of the three candidates, would be nearly impossible to implement with existing technologies. This Distributed architecture is similar in concept to network centric operations, where each entity (in this case aircraft, airports, and airlines) are in communication with each other and are knowledgeable of the others' location. The Centralized architecture, in which there is one CTAAS system for the entire United States, turned out to be an unrealistic candidate due to the sheer amount of flight information that would need to be processed to handle all of the sequencing and flight guidance tasks for all of the airports and related in-bound aircraft in the United States airspace system. The last architecture and the one that has been deemed most appropriate for implementation with the CTAAS system is the Decentralized architecture. In this configuration, there will be one CTAAS system per major airport. This CTASS system will handle all sequencing and provision of flight guidance to in-bound aircraft at the destination airport. Please see Appendix H for graphical representations of the CTAAS candidate architecture, Appendix I for architecture development process with the functional architecture views contained in Appendix J.

6. BUSINESS CASE

6.1. MARKET SITUATION

The aviation industry is a key contributor to the national economy and quality of life in the U.S.

The aviation and aerospace industries are a keystone of the U.S. economy. By providing air travel for approximately 750 million passengers annually, air transportation services promote economic growth and improvements to America's quality of life. The industry contributes $640 billion to the U.S. economy or 5.4 percent of U.S. gross domestic product (GDP) accounts for more than 9 million jobs8 and about $314 billion in wages. The industry has also been one of the strongest contributors to the U.S. trade balance net aerospace exports totaled more than $36 billion in 2005. Aerospace is the third largest U.S. export category and one of the few in which the U.S. has a trade surplus.[3]

As air travel continues to be the safest form of transportation,[4] and that ticket prices have steadily declined since industry deregulation, consumer demand for air travel has increased substantially in the United States. Since the late 1970s, the number of commercial carriers has doubled, and low-cost carriers are currently injecting the market with a new breed of competition. Today, 85 percent of airline passengers have a choice of two or more carriers, compared with only 67 percent in 1978.[5] Further, the hub-and-spoke system led to growth in smaller markets that may not have been otherwise serviced in a linear route system. The broader population can now afford air travel, and commercial and regional carrier revenue passenger miles have grown more than 93 percent since 1990 (see Figure 17).

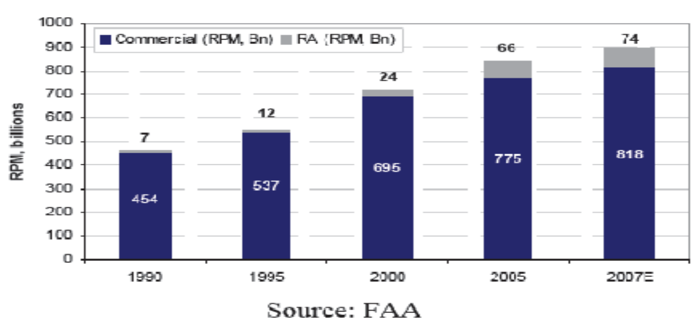

Figure 17 – Commercial and Regional Carriers Historical Revenue Passenger Miles

[3] FAA Business Outlook, 2008

[4] The FAA reports that between 2002 and 2006, U.S. scheduled air carriers transported over 3 billion passengers with a miniscule fatal accident rate of 0.023 per 100,000 flight departures.

[5] Air Transport Association, Airline Handbook

There are clear signs that the current system is already under serious strain because of the growth in air traffic. The percentage of on-time arrivals has steadily declined each year since 2002, when 82 percent of flights arrived on time at the nation's 35 busiest airports. In 2006, the on-time arrival rate at those airports fell to 75 percent, and on-time arrivals are expected to continue to decline in 2007 (Figure 18). At the three most delayed airports in the nation Newark, JFK, and LaGuardia only 65 percent of arrivals were on-time and delays averaged 1 hour. Moreover, the current system is extremely sensitive to any unscheduled delays. As every traveler knows, even isolated weather delays create ripple effects throughout the country.[6]

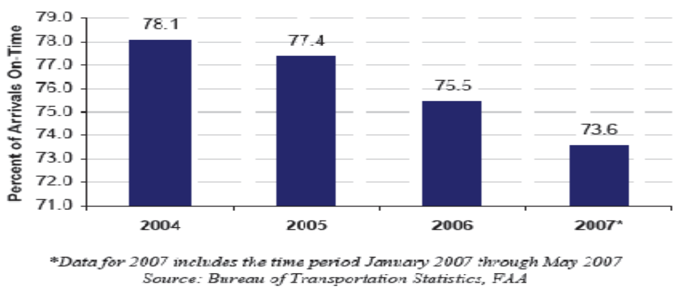

Figure 18 – 2004-2007 Percent On-Time Arrival Performance for All U.S. Airports

Between January and May 2007, the country's top-five airports experienced 171,222 flight delays, cancellations, or diversions which account for more than 4.9 years of passenger delay time. Currently, 60% to 70% of system delays are attributed to weather. Moreover, as traffic grows, weather-related delays will worsen. The FAA estimates that unless progress can be made on better weather forecasts, by 2014 there could be 29 days of delay worse than the worst delay day of 2006.

Air travel demand has rebounded since 9/11, and the upward trend is expected to continue for all segments of the market. Total commercial revenue passenger miles (RPM) are forecasted to increase 63 percent by 2020, and regional carrier RPMs are forecasted to more than double during the same period. Similarly, the total general aviation (GA) fleet is projected to increase more than 21 percent, and the GA turbine engine fleet is expected to grow nearly 65 percent by 2020. While fleet compositions continue to evolve, the FAA estimates that the number of aircraft operations at airports with FAA and contract traffic control service will grow significantly by 2020 (Figure 19).

Nationwide estimates may misrepresent the real impact to the air traffic control system. In heavily traveled areas, air travel is projected to increase between 100 percent and 300 percent by 2025.[7] For example, most of the East Coast, the Chicago area, the Midwest, and the Southwest are all projected to experience demand that is more than 200 percent current capacity.

[6] Mr. John Hayhurst, President, Air Traffic Management, The Boeing Company, Testimony to the United States House of Representatives, Subcommittee on Space and Aeronautics Committee on Science, July 2001.

[7] Borener, et al. "Can NGATS Meet the Demands of the Future?" Joint Planning and Development Office. January-March, 2006 quarterly issue of the ATCA Journal of Air Traffic Control.

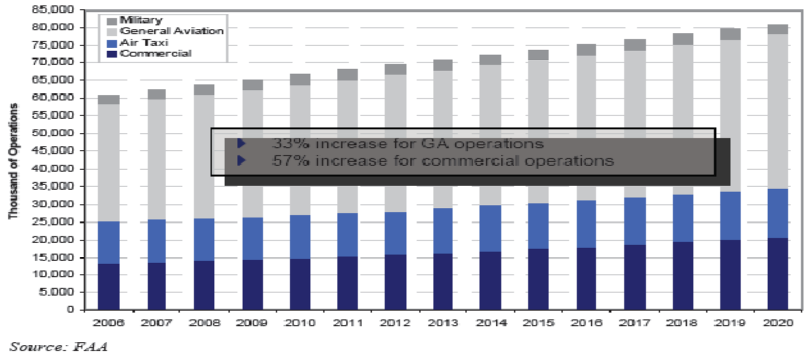

Figure 19 – Total Combined Aircraft Operations at Airports with FAA and Contract Traffic Control Service

The future congestion issues are not only constrained to areas around major airports but also to the high-altitude air traffic routes throughout the country. This additional demand on the airspace will put additional strain on the current National Airspace System (NAS). Figure 20 illustrates this growth by 2025 under the assumption of a threefold increase in traffic.

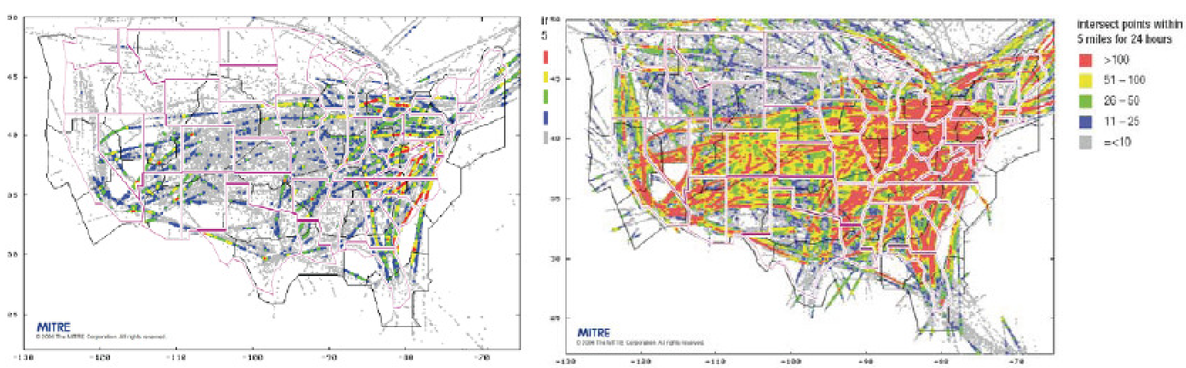

Figure 20 – Projected Air Traffic Patterns at Current Growth Rate

The U.S. air transportation system, as we know, it is under significant stress. With demand in aircraft operations expected to grow up to three times through the 2025, the current air transportation system will not be able to accommodate this growth. Antiquated systems are unable to process and provide flight information in real time, and current processes and procedures do not provide the flexibility needed to meet the growing demand. New security requirements are affecting the ability to efficiently move people and cargo. In addition, the growth in air transportation has triggered community concerns over aircraft noise, air quality, and congestion. To meet the need for increased capacity and efficiency while maintaining safety, new technologies and processes must be implemented.

The current air traffic system was built on technology that has reached the limits of its ability to handle more traffic. Although the U.S. has the safest aviation system in the world, the current system is based on a foundation of technologies developed as far back as the 1940s and 1950s, and many of these systems have far exceeded their original life expectancy. Traditional air traffic control is essentially the same as it was 50 years ago a labor-intensive system in which aircraft are monitored and controlled by individual air traffic controllers using the basic tools of radar surveillance and analog radios. This system does not scale well; doubling or tripling its capacity means doubling or tripling the number of controllers and subdividing controlled airspace into ever-denser units. Even if that were possible, the required demand could not be met because just the workload associated with the constant frequency changes from small sector to ever-smaller sector would make the operation untenable. Also, in such a system, the opportunity for human error becomes a significant safety risk.

As air traffic grows, so do concerns over its impact on the environment. Current operational trends show that environmental impacts such as noise, air emissions, water pollution, land use, climate change, and fuel consumption will be primary constraints on the capacity and flexibility of the air transportation system unless these impacts are managed and mitigated. Environmental issues have resulted in the delay and/or downscaling of certain airport capacity projects over the past decade. Aircraft noise continues to be a primary area of concern. Similarly, air quality, water quality, and other environmental demands are a growing challenge to enabling significant capacity expansion without a detrimental impact to the environment.

The FAA, industry analysts, and technical experts all agree that the existing system cannot accommodate the projected growth, and therefore must be overhauled.[8] In the past, adding more controllers solved many capacity issues, but such strategies can no longer cope with growing demand.[9] An FAA study shows that by the year 2025 as many as 14 to 27 airports and roughly 8 to 15 metropolitan areas will be capacity constrained.[10] Growth trends will continue to affect many of the same metropolitan areas such as Chicago Midway, LaGuardia, and Newark that historically have had a need for additional capacity. Figure 21 shows the potential areas that will need increased capacity if planned improvements (and aggressive technological improvement assumptions) are not realized. However, capacity constraints will not be isolated to particular cities. With severe congestion at major hubs, the number and duration of flight delays will change the face of air transportation in the United States.

[8] www.smartskies.org

[9] Air Transport Association

[10] Capacity Needs in the National Airspace System – An Analysis of Airport and Metropolitan Area Demand and Operational Capacity in the Future. The MITRE Corporation Center for Advanced Aviation System Development, May 2007.

Source: Capacity Needs in the National Airspace System – An Analysis of Airport and Metropolitan Area Demand and Operational Capacity in the Future. The MITRE Corporation Center for Advanced Aviation System Development, May 2007.

Figure 21 – Airport and Metropolitan Areas that Need Additional Capacity in 2025

Severe air traffic congestion could handicap the U.S. economy. Individuals and businesses rely heavily on air transportation to ship and receive goods daily, and 25 percent of all companies' sales depend on air transport.[11] Therefore, if system wide delays become too cumbersome, the entire business world, not only the airline industry, will be negatively affected.

System delays generate a huge cost to industry, passengers, shippers, and government. Cost statistics vary widely, but however stated, the sums are enormous.[12] In 2000, one of the worst years for flight delays, the average delay of 12 minutes per flight segment led to more than $9 billion in delay costs to commercial airlines. More recently, an average of 900 daily flight delays of 15 minutes or more costs the airlines and their customers more than $5 billion annually.[13]

In 2006, 116.5 million system delay minutes (up 5 percent from 2005) drove an estimated $7.7 billion in direct operating costs (up 11 percent from 2005) for U.S. airlines (see Table 1).[14] The cost of aircraft block (taxi plus airborne) time was $65.80 per minute, 6 percent higher than in 2005. On average, extra fuel consumption and crew time are estimated at $42.55 per minute, followed by maintenance and aircraft ownership ($20.14 per minute) and all other costs ($3.10 per minute).

[11] Air Transport Action Group, The economic and social benefits of air transport, 2005.
[12] Mr. John Hayhurst, President, Air Traffic Management, The Boeing Company, Testimony to the United States House of Representatives, Subcommittee on Space and Aeronautics Committee on Science, July 2001.
[13] Air Transport Association
[14] Air Transport Association

Direct (Aircraft) Operating Costs Calendar Year 2006	$ Per Block Minute	Annual Delay Costs ($ millions)
Fuel	$28.31	$3,296
Crew - Pilots/Flight Attendants	14.25	1,659
Maintenance	10.97	1,277
Aircraft Ownership	9.18	1,069
Other	3.10	361
Total DOCs	**$65.80**	**$7,663**

Figure 22 – Cost of Flight Delays

Notes: 1. Costs based on data reported by U.S. passenger and cargo airlines with annual revenues of at least $100 million. 2. Arrival delay minutes taken from the FAA Aviation System Performance Metrics (ASPM 75) database.

6.2. INVESTMENT OPPORTUNITIES

The flying public continues to demand more choices, increased convenience, and better value. By 2016, the FAA projects a 27 percent increase in domestic flights, and passenger traffic between the U.S. and international destinations will grow by 70 percent;[15] worldwide traffic growth projections are roughly 80 percent.[16] These traffic growth projections raise serious questions about the ability of the NAS to supply the capacity to accommodate the increased demand of more flights. If traffic grows as expected, by 2014, delays in the U.S. will increase by 62 percent of 2004 levels, and could be even greater if weather conditions are more severe. Passengers will bear the brunt of these delays, which could conceivably double by 2014 because of missed connections and cancelled flights[17].

To serve the growing demand for air travel, the aviation industry requires more flexibility and fewer restrictions from our NAS. However, the current NAS infrastructure cannot accommodate increasing traffic demands that hamper the industry's ability to innovate and respond to market demands. The increases in traffic growth and current limitations of our NAS are already affecting industry behavior and market dynamics. The aviation industry is mired with challenges to adapt to the increasing constraints of our NAS (e.g., airspace capacity, airport capacity, weather, equipment outages) as manifested in fleet management decisions, cautious investments in internal research and development (IR&D), mergers and acquisitions, and unsustainable business and pricing models geared toward survival. For airlines, the FAA estimates $2 billion in lost profits that could have otherwise been used for future fleet modernization and expansion. For the economy, congestion already exacts a toll of $9.4 billion per year because of passenger delays,[18] and that number could grow to $20 billion by 2025.[19] Investing simply to maintain the "status quo" results in a constrained economy that is driven by the *limitations* of our nation's airspace system, the *tolerance* of the flying public, and industry consolidation and competition to *survive.* The impact of this supply /demand imbalance to consumers will be increased prices, decreased choices, and growing inconvenience.

[15] FAA API estimates
[16] FAA ATO-P Strategy & performance Analysis Office
[17] FAA ATO-P
[18] "National Strategy to Reduce Congestion on America's Transportation Network", DOT, May 2006
[19] Socio-economic demand forecast study, NASA and FAA, 2005

6.3. CTAAS OBJECTIVE

CTAAS will use new and emerging technologies such as satellite-based navigation, surveillance, and networking, to facilitate an arrival flow sequencing process for commercial aircraft at busy airports. Investments in new technology provide the means to move from a command and control system, where controller workload is driven by directing aircraft step-by-step, to a more decentralized, user-driven, planned-in-advanced, strategic management concept.

CTAAS will provide the Air Traffic Management (ATM) infrastructure with a service that leverages this new technology by receiving specific information from airborne aircraft, compiles this information, deconflicts and sequences arriving aircraft and then communicates this directive information back to the individual arriving aircraft to reduce potential delays induced by the Air Traffic Control facilities at each of the associated airport who must ensure required flight separation between arriving aircraft.

6.4. BUSINESS CASE CONCEPTS OF OPERTIONS

There are two concepts of operations. The first concept is simply a software development approach where the CTAAS software will be developed and sold to the customer which in this case would be the FAA. The second concept of operations is to market CTAAS as a service to the FAA and provide the controlled time of arrival services to those airport that develop delays as a result of variance in aircraft arrivals.

With the first concept of operations the majority of the effort is to develop the software and market it to the FAA. The potential exist to maintain a support service to the FAA and to provide routine updates depending on the nature of the terms of sales. The required financing is limited to developing and marketing the software. The return of investment would be realized relatively quickly depending on the specific term of sale. The maintenance support service would have some potential cash value however the reoccurring update market may have unlimited grow potential depending on the panoply of services envisioned in the FAAs vision of the next generation of enroute and terminal approach services provided to the airlines and general aviation.

The second concept of operations has the same development requirements however instead of providing the FAA a turn key type product CTAAS would provide a continuous service to the FAA which would necessitate the creation of an operations center with trained staff and equipment to provided the service.

6.5. CTAAS BENEFITS AND COSTS

Preliminary benefits analyses indicate that CTAAS capacity increases could yield economic growth of as much as $175 billion through 2025. These benefits are not achievable without investments by the government and industry. Initial estimates of the FAA investment required to achieve the benefits are projected at $15 billion to $22 billion through 2025. Preliminary estimates for the collateral investments required from the aviation industry are projected to be $14 billion to $20 billion during this same time frame.

Additional analyses still need to be completed to refine expected capacity increases, define direct user benefits derived from these capabilities, and clearly bound the pool of aggregate benefits. The following paragraphs explain the preliminary analysis and benefit estimates completed to date, along with more qualitative descriptions of how these individual assessments and estimates fit within the larger vision.

6.5.1. CTAAS CAPACITY BENEFITS

CTAAS should provide the necessary system capacity and scalability to accommodate growing demand for air transportation services that will accompany a growing economy. As previously stated, the efficient movement of people and cargo is vital to our national economy and international commerce. The inability of our air transportation system to serve market demands results in traffic delays and flight cancellations that have negative economic consequences. Air traffic delays also have other related consequences including adverse environmental impacts and implications for our nation's defense and security mission. Conversely, an air transportation system that provides the capacity and flexibility to accommodate emerging demand profiles is a catalyst for economic activity and growth; additional benefits include reduced carbon emissions and noise pollution and improved national security.

A fundamental way to measure the potential economic benefits of CTAAS is to consider the demand forecast for the next 20 years and quantify how much of this demand can be accommodated with and without these capabilities. Each flight represents quantifiable value to the economy. Passengers and cargo create demand for commercial aviation; the number of flights and their associated operational characteristics represent a demand on the air transportation system.

6.5.2. ENVIRONMENTAL BENEFITS

Potential operational improvements and fleet evolution will provide a number of environmental benefits such as fuel efficiency using CDAs and RNP arrivals and departures at the 34 FAA-designated Operational Evolution Partnership (OEP) airports within the continental United States. For example, in the terminal area, these capabilities and improvements in aircraft engine technologies (fleet evolution) will produce a 15-to-21 percent improvement in fuel efficiency for arrivals compared to the baseline case; the overall improvement in fuel efficiency is estimated at 6 percent compared to the baseline.

6.5.3. INVESTMENTS REQUIRED TO ACHIEVE THESE CAPABILITIES

To fully realize the capacity improvements and expected economic benefits resulting from this system, the FAA, other government agencies, and private industry must collaboratively invest in new technologies and infrastructure. The estimated FAA investment for this system implementation is estimated to be between $15 billion and $22 billion.

The capital costs for the system are evolving. Stage 1 estimates are well-defined and have been included in the FAA fiscal year 2008 reauthorization. The specificity and detail of cost estimates for the investments in stage 2 and 3 continue to evolve.

Implementation also requires a corresponding industry investment in new avionics that will interface with the infrastructure and allow aircraft operators to take full advantage of additional operational flexibility and capacity. The more aircraft that are equipped, the greater the systemwide benefits. Early indications are that some air carriers are proactively aligning with the system, but these early entrants need the right combination of infrastructure (systems and workforce), new procedures, FAA policy (mandates and incentives), as well as industry participation to encourage timely user equipage and pilot training to reap the full benefits of these significant investments.

Based on a preliminary analysis of the avionics investment costs developed by MITRE's Center for Advanced Aviation System Development (CAASD), an estimated probable range of $14 to $20 billion in total avionics costs will be required to meet the air traffic management requirements. This analysis acknowledges that a wide range of costs is possible, depending on the bundling of avionics and the alignment of equipage schedules. Given this uncertainty, MITRE notes in its analysis that avionics cost estimates will rise over time rather than shrink. MITRE also notes that this is a work in progress; hence, the numbers will change but the fact that costs are significant (more than $14 billion) will not.

6.5.4 Return on Investment

CTAAS financial analysis has shown that the Return on Investment for the Software as a Product business case will be 877 percent based on a $44.8 million investment, and the Return on Investment for the Software as a Service business case will be 294 percent based on a $59 million investment.

6.6. Financial Analysis

To evaluate our proposed business models, a projection of cash of flows was calculated for SaaP and SaaS over a ten year period. These projections were analyzed to determine the most significant drivers on Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. Next, a probabilistic model was applied to those drivers to access the risk profile of each model. Lastly, we selected a business model based upon the results of our analysis.

6.7. Financial Objectives

We conducted a financial analysis of our proposed business models to enable us to select the business model that would best achieve CTAAS's follow financial objectives:

- a high but reliable Net Present Value
- an internal rate of return that would outpace potential increases in cost of capital
- return of capital within 3 years of generating revenue

6.8. Assumptions

In constructing our cash flow projection models, we made baseline decisions for the values of the following parameters: cost of capital, price escalation rate, market adoption/implementation profile, consulting factor, system price, and fringe & fee rate. In setting these values, we considered that our customer would be the FAA, a government client who is sensitive to price changes and who would implement the CTAAS software system in phases.

For cost of capital, we evaluated the historic market returns and prevailing interest rates because CTAAS has yet to establish sufficient operating capital upon which to calculate a weighted cost of capital specific to our company. Therefore, we viewed historic and prevailing returns on investment and decided that the average return on the S&P index from 1992 to 2007 of 10.48%[i] would be the most appropriate to CTAAS given current market conditions, solvency of our client, industry served, and the highly profitable characteristics of our business models.

Additionally, we determine that the government was very sensitive to price escalation due to the advance planning exhibited in the governments planning, programming, budgeting, and execution system. Considering that inflation has increased the past three years and the 2007 inflation rate was 4.28%, we set the price escalation rate for our software system and labor rates to 7.5% annually.

Next, we constructed our market adoption/implementation profile as a phased and scheduled adoption or implementation of the CTAAS software and/or services. This assumption was made to be consistent with our overall business strategy where we would sell CTAAS to the FAA who would mandate the purchase/implementation of CTAAS via three phases: prototyping, full-implementation, and network expansion. The prototyping phase would implement CTAAS at no more than three airports to allow for adequate testing, training, and lessons learned documentation.

For the SaaP model, we used a consulting factor which represents the percent of software sales that we could anticipate in additional revenues in the form of consulting services. Determining this factor proved to be a difficult tasks because of inconsistencies in market data. For example, many software companies either packaged some services with their software (quasi SaaS models) or had too many revenue sources and product lines to present a clear relationship between service-based revenue and the sales of underlying software product. In surveying market data, it was not uncommon to see consulting service revenue double software sales; however, there was clearly more data supporting a more conservative percentage between 25% and 50%, especially for upstart single product companies with a product focus. Therefore, we set the consulting factor to 35% for the SaaP model.

We, also, determined a baseline price for CTAAS software system for the SaaP model. We based are pricing on the recoupment of development and marketing cost with an overriding goal of payback period of less than five years and thus set a price of $600,000 for the system in the base case.

Lastly, we determined a fringe & fee rate to be applied to the direct cost of our personnel and an additional fee applied to our overhead and operations costs. We surveyed local small and medium IT companies in the government sector to find appropriate rates. The survey revealed that a fringe rate of 35% and a fee of 10% were typical for these companies, so we set 45% (35% plus 10%) as our fringe & fee rate in the SaaS model.

To compare both models fairly, we made the following assumptions for both business models:

1. Evaluation period of ten years
2. Equal development, marketing, and overhead costs for each year; and
3. Equal cost of capital and price escalation rate for both models.

6.9. Cash Flow Projections

We constructed cash flow projections based upon projected revenue, expenses, and cost of capital using the assumption listed above. The cash flow projections for the SaaS and SaaP model are provided in Figure 23 below. Additionally, Figure 23 illustrates promising growth in cash flow for both models, although the growth for the SaaP model is significantly greater.

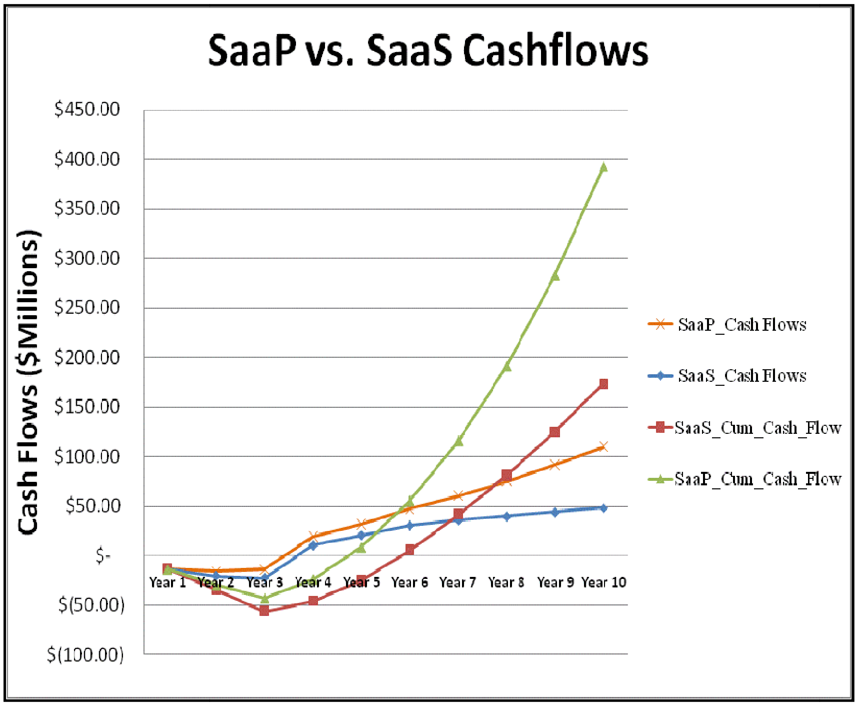

Figure 23 – SaaP vs. SaaS Cash Flow Projections

The cash flow projections yielded the resulting Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period listed in the table below.

	SaaP	SaaS
Model NPV	$171,921,242.51	$65,727,847.35
Model IRR	54.47%	31.00%
Payback Period	4.73	5.82
ROI	877.02%	294.2%
Required Investment	$ 44,875,687.50	$ 59,046,750.00

Figure 24 – Deterministic Results of Financial Analysis

The results above clearly show that SaaP is the preferred business model for the introduction of CTAAS to the market. However, these projections used only our baseline assumptions without taking into account the uncertainty of whether our assumptions will hold in reality. Therefore, it was necessary to conduct sensitivity analysis to assess how the parameters above would respond to different market conditions which could invalidate our baseline assumptions.

6.10. Sensitivity Analysis

To perform sensitivity analysis, we used Syncopation's Decision Programming Language (DPL) Software. Using DPL, we were able to determine the drivers of NPV, IRR, and Payback Period for both models via Influence diagrams. We, then, used this information to develop tornado diagrams to determine which driver affected NPV, IRR, and Payback Period the most. These steps are shown below.

6.11. Influence Diagram

Influence Diagrams allowed us to isolate the drivers of our selection criteria of NPV, IRR, and Payback Period.

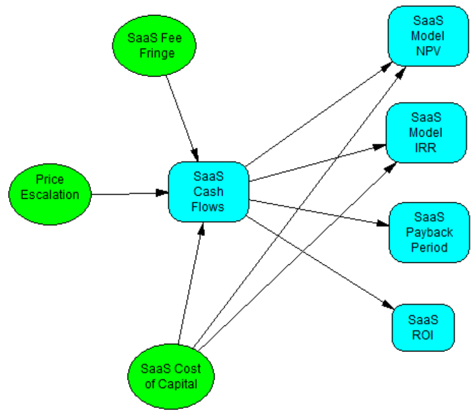

Figure 25 – SaaS Discrete Stochastic Influence Diagram

The influence diagram for the SaaS model shows that fringe & fee rate, price escalation, and cost of capital are the drivers of cash flows which directly affect our selection objectives. However, it should be noted that cost of capital directly affects our selection objectives as well which would imply that cost of capital has the greatest affect of all the drivers. This implication is validated in the tornado diagram below.

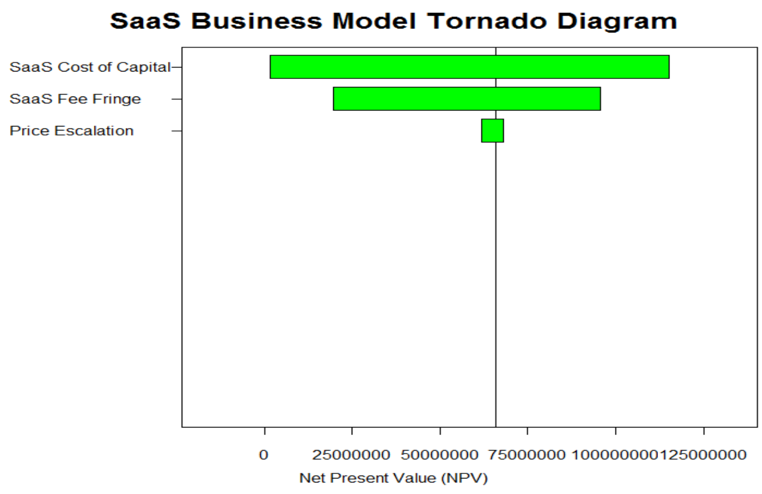

Figure 26 – SaaS Tornado Diagram

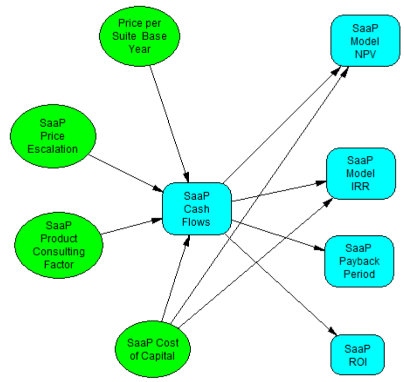

Figure 27 – SaaP Discrete Stochastic Influence Diagram

The influence diagram for the SaaP model shows that system price, price escalation, consulting factor and cost of capital are the drivers of cash flows which directly affect our selection objectives. Again, it should be noted that cost of capital directly affects our selection objectives, implying that the cost of capital has the greatest affect of all the drivers which is supported in the tornado diagram below.

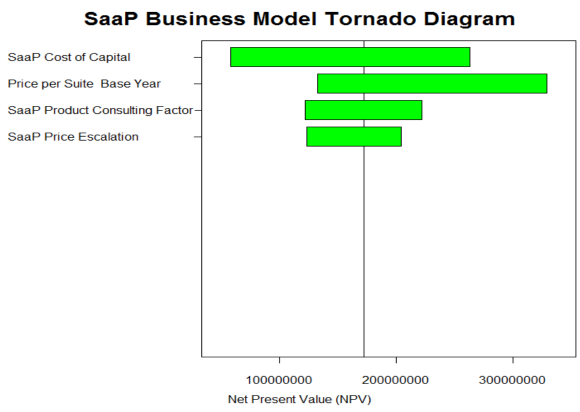

Figure 28 – SaaP Business Model Tornado Diagram

Both tornado diagrams above show that variation in the drivers above could significantly affect our decision objectives, potentially causing us to change our preliminary model selection. Therefore, it was necessary to construct a decision trees for each of our models based upon probabilistic scenarios for each driver. The table below presents the probabilities and values for each scenario and driver by model. The sensitivity parameters for both the SaaS and SaaP models are provided in Appendix K.

	Cost of Capital			Price Escalation			System Price			Consulting Factor		
	Scenario	Value	Probability	Scenario	Value	Probability	Scenario	Value	Probability	Scenario	Value	Probability
SaaP	Low	5.0%	25.0%	Low	1.03	30.0%	Monopoly	$ 1,000,000.00	10.0%	Low	0.25	30.0%
SaaP	Nominal	10.0%	65.0%	Nominal	1.075	40.0%	Aggressive	$ 750,000.00	25.0%	Nominal	0.35	40.0%
SaaP	High	30.0%	10.0%	High	1.1	30.0%	Fair	$ 600,000.00	55.0%	High	0.55	30.0%
SaaP							Competitive	$ 500,000.00	10.0%			

Figure 29 – Sensitivity Analysis Parameters for SaaP

6.12. Risk Evaluation

DPL utilized the values and probabilities above along with the decision trees provided in the appendices to create a cumulative distribution risk profile for each of our decision objectives for both models Appendix K. The cumulative distribution of NPV for the SaaS business model is provided in Figure 30, as an example.

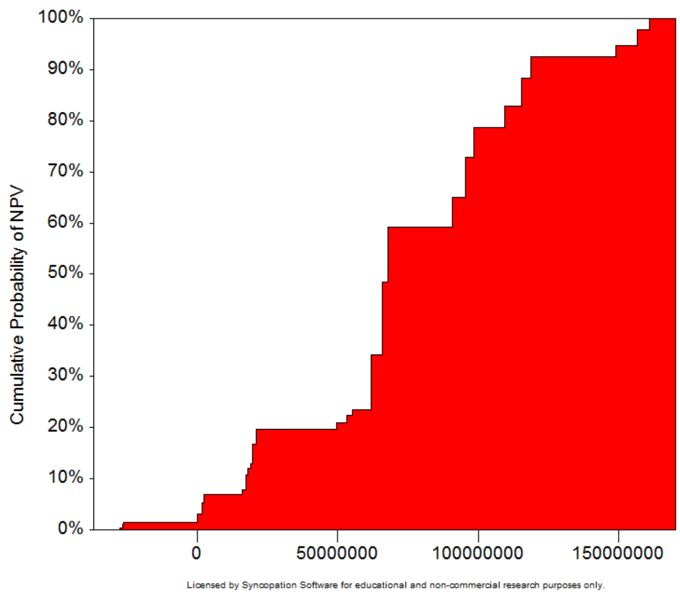

Figure 30 – Results of Cumulative Probability of NPV

Using these cumulative distributions, we adjusted our model selection criteria to the following:

1. Probability of NPV < 0
2. 85% of exceeding NPV value
3. 85% of exceeding IRR value
4. Probability of Payback Period < 5 years

6.13. Business Model Selection

We evaluated our proposed business models using the selection criteria above. Again, the SaaP business model clearly provides superior results to the SaaS model, so we have selected SaaP as our business model to bring CTAAS to market. Nevertheless, the SaaS model still provides attractive results which makes SaaS an acceptable alternative in case the FAA is not receptive to the SaaP model. The table below summarizes the results of our selection criteria for SaaS and SaaP.

	SaaS	SaaP
Probability of NPV < 0	1.70%	0.00%
85% of exceeding NPV value	$19.6M	$114.9M
85% of exceeding IRR value	21.10%	46.50%
Probability of Payback Period < 5 years	0.00%	75.00%

Figure 31 – Results of Business Model Selection Criteria

7. CONCLUSION AND RECCOMMENDATION

With such substantial benefits to the nation, it is clear that investing in CTAAS is both necessary and worthwhile. In addition to the system's impact on the aviation market and GDP, the flexibility and scalability that it offers will produce other enduring benefits, including environmental benefits, safety and security benefits, and benefits to our nation's homeland security and defense mission. The investment requirements and benefits presented in this business case assume that these capabilities will be developed, delivered, and financed under a business model similar to the current model used by FAA to manage the NAS.

The CTAAS team recommends pursuing the Software as a Product business model to fill a significant capability gap with current flight operations which will yield significant savings to the airline and should provide a considerable Return on Investment to the CTAAS venture capital investors.

APPENDICES

APPENDIX A: WEB SITE

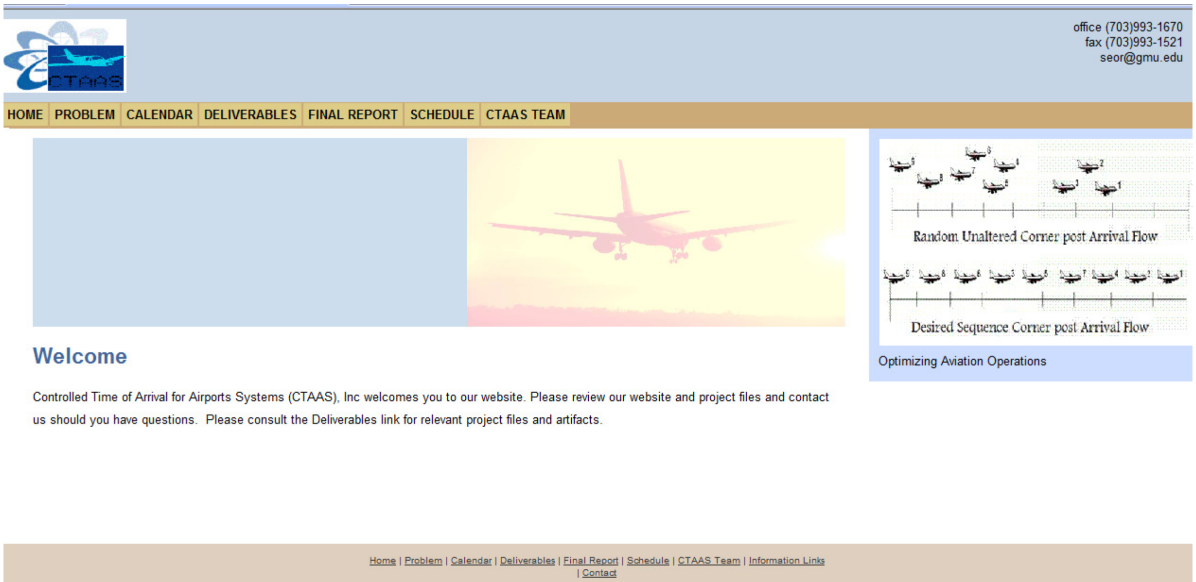

Figure A32 – CTAAS Website - "mason.gmu.edu/~lburdett"

APPENDIX B: TEAM ROLE AND RESPONSIBILITIES

Akshay Belle – Project Management: has accountability and responsibility for the project's success, and has the power to make all decisions, subject to oversight by the executive bodies

Michael Brinker – System Architecture Team: develops and manages the development of the system architecture, including functional specification.

Najia Hussaini & LaTrent Burdette – Analytical Team: controlling and tracking the detailed plan, will write and managing documentation, preparing reports and, control and distribute project files, and submit deliverables, including website development and management

Akshay Belle & Michael Brinker – Model Team: responsible for carrying out technical activities within the context of the application, and data, also develops strategic, logical, and physical designs and oversee analysis and implementation activities

Arlen Lippert & LaTrent Burdette – Business Case Team: responsible for the market research, financial model development, and the business case selection criteria.

Najia Hussani, Arlen Lippert, & Akshay Belle – Quality Assurance Team: responsible for processes and procedures that ensure required levels of quality are achieved.

APPENDIX C: PROJECT SCHEDULE AND PERT

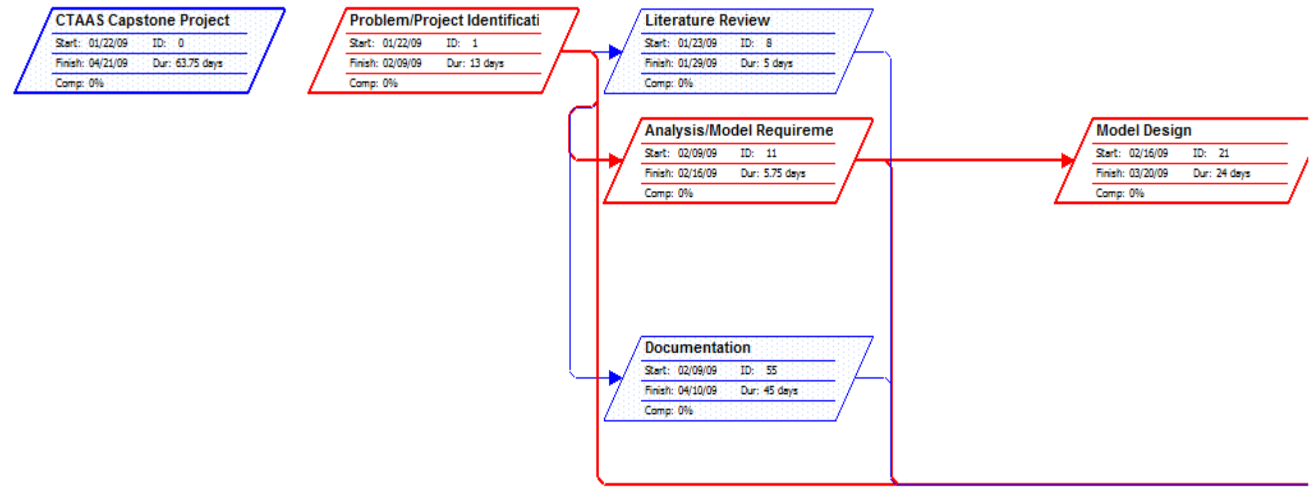

Figure C33 – CTAAS PERT

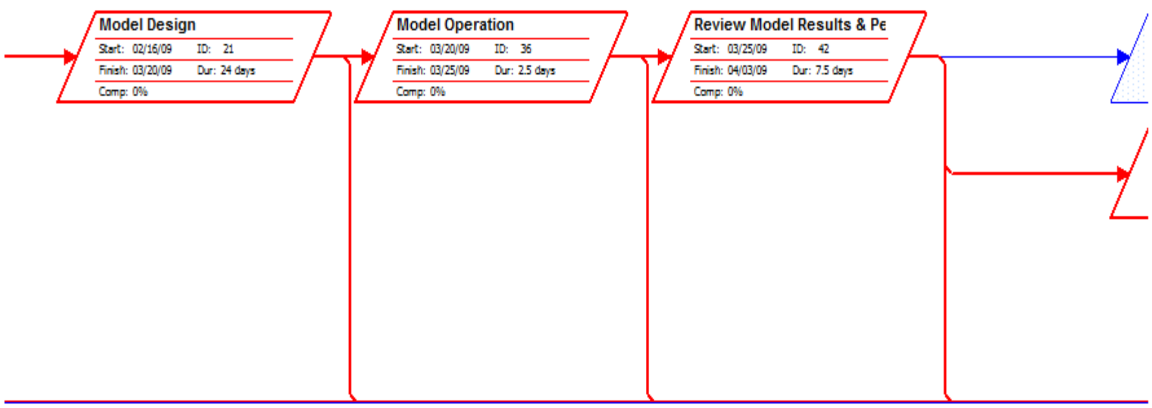

Figure C34 – CTAAS PERT …continued

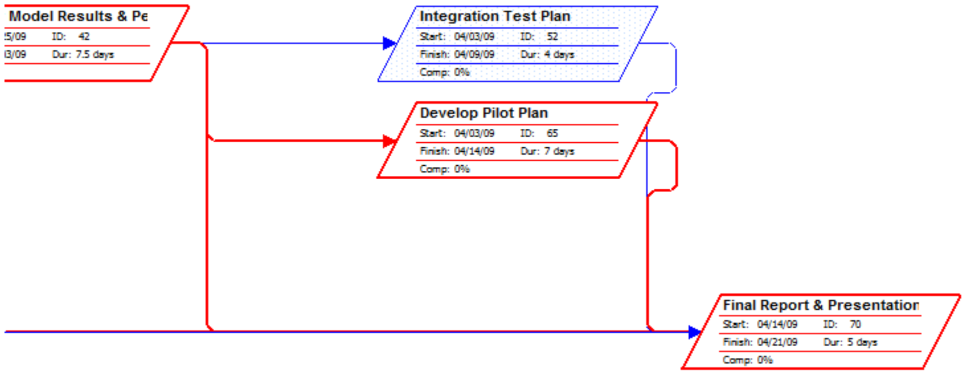

Figure C35 – CTAAS PERT …continued

ID		Task Name	Duration	Start	Finish
0		CTAAS Capstone Project_Mar05_2009	71 days?	Thu 01/22/09	Thu 04/30/09
1	✓	Project Management	71 days	Thu 01/22/09	Thu 04/30/09
12	✓	Problem/Project Identification	15 days	Thu 01/22/09	Wed 02/11/09
19	✓	Scope & Preliminary CONOPS	12 days	Tue 01/27/09	Wed 02/11/09
22	✓	Literature Review	5 days	Fri 01/23/09	Thu 01/29/09
25	✓	Analysis/Model Requirements	5.75 days	Wed 02/11/09	Wed 02/18/09
35	✓	Model Design	9.25 days?	Wed 02/18/09	Tue 03/03/09
49	✓	Model Development	7 days	Mon 03/02/09	Wed 03/11/09
54	✓	Test & Validate Design	8 days	Mon 03/09/09	Thu 03/19/09
59	✓	Verify Model Operations	2.88 days	Thu 03/19/09	Tue 03/24/09
65	✓	Verify CONOPS based upon Model Resu	2 days	Tue 03/24/09	Thu 03/26/09
70	✓	Perform Sensitivity Analysis	5.5 days	Thu 03/26/09	Fri 04/03/09
74	✓	Review Model Results & Analysis Complete	0 days	Fri 04/03/09	Fri 04/03/09
75		Documentation	45 days	Thu 01/22/09	Wed 03/25/09
85	✓	Finalize System CONOPs	14.5 days	Thu 03/26/09	Thu 04/16/09
93	✓	Final Report & Presentation	5 days	Thu 04/16/09	Thu 04/23/09

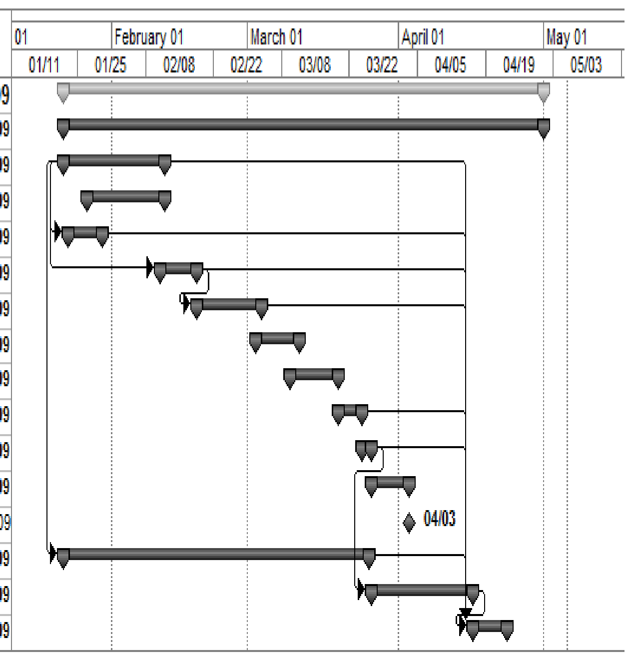

Figure C36 – CTAAS GANTT

APPENDIX D: STAKEHOLDER IDENTIFICATION

Based on the CTAAS's experiences and past knowledge, the team analyzed the best stakeholders and categorized them appropriately. Extensive research and stakeholder's feedback was obtained to acquire all stakeholders' best interest. The CTAAS team had a rationale for identifying stakeholders by analyzing complexity, uniqueness, participation, and methods. The complexity was determined upon the natural resource management that deals with primarily the understanding and managing the complex relationships between humans and resources which they depend. Each situation is unique, and requires an understanding of local conditions and realities. In a participatory approach, management decisions are more easily embraced by those who have been part of the decision-making process, and greater attention is paid to the needs and expectations of all actors. Participation is often perceived by planners and managers as a simple process that does not require specific skills and methods. However, experience has shown that poorly designed participatory processes can be ineffective, and can even have negative social and environmental impacts. Rigorous methods, suited to local conditions are therefore required. [20]

D.1. STAKEHOLDER DEFINITION STAKEHOLDER DEFINITION

After determining what rationale is analyzed to identify the stakeholders, the team defined the stakeholders. CTAAS's stakeholders are all those who could and should have a stake in a planning and management process. After the stakeholders were identified they were categorized as in Figure 37 and as follows:

- Industry: Pilot, Aircraft, Airport, Airlines (Airline Station Manager), CTAAS
- Government: Air Traffic Control (ATC) (Towers at each airport)
- Civilians: Passengers, SEOR (Systems Engineering and Operational Research) Faculty

[20] http://www.canari.org/Guidelines5.pdf

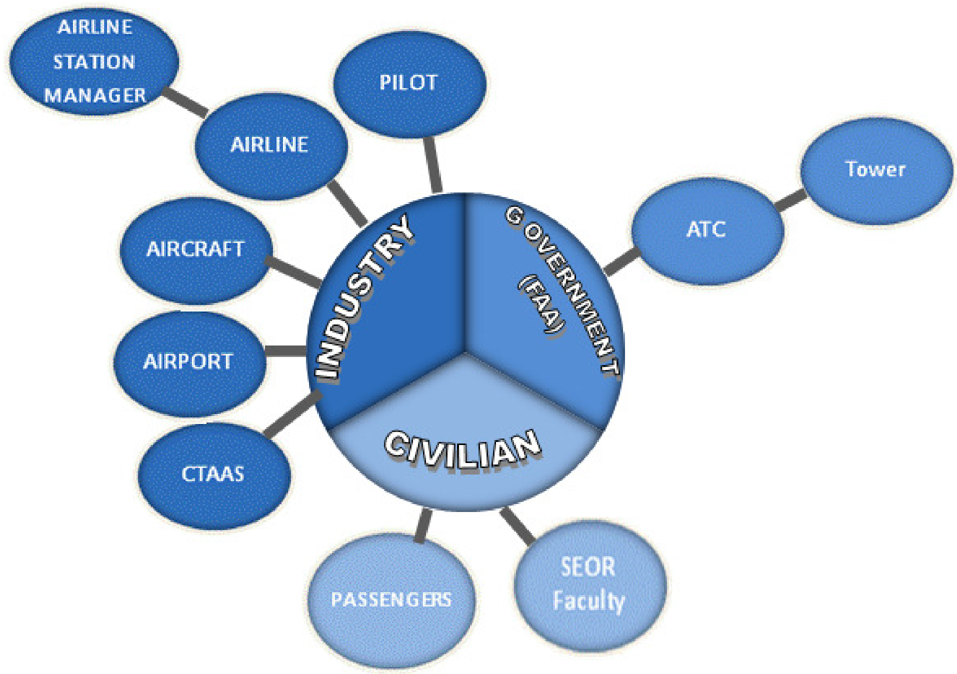

Figure D37 – CTAAS Stakeholder Community

D.1.1. INDUSTRY STAKEHOLDER DEFINITION

CTAAS will assist all stakeholders in the Industry category by the following:

- Pilot - Ease workload and improve perceived safety
- Airlines (Airline Station Manager) - Provide gates and services to all incoming aircrafts
- Aircraft Producers - Potential for increased business – new and retrofit integration
- Airport - Effective utilization of Airport Resources
- CTAAS - Improve Knowledge Base and Learning Curve and hopefully a patent

D.1.2. GOVERNMENT STAKEHOLDER DEFINITION

CTAAS will assist ATC in providing less congestion when airplanes arrive at the corner posts of final destinations. In order for pilots to accomplish this, CTAAS will be guiding them throughout their trip from the point when they depart to altitude level until they get to the corner post and finally land. The ATC main concerns are to organize and speed up traffic flow so there is less congestion to prevent collisions. They also provide support to pilots in guiding them if needed. When CTAAS controls them before the airplanes get to the corner post then ATC will have fewer loads to worry about.

D.1.3. CIVILIAN STAKEHOLDER DEFINITION

CTAAS will assist passengers and SEOR faculty in providing the best safety aspects. The passengers' most important need is safety and an on-time or early arrival will help obtain that. Also, they are concerned with either making their connection flight or getting to their final destination by arriving without long delays. The SEOR faculty is mainly interested in continued contribution to automated air traffic control.

D.1.4. SPONSORSHIP

CTAAS will assist passengers and SEOR faculty in providing the best safety aspects. The passengers' most important need is safety and an on-time or early arrival will help obtain that. Also, they are concerned with either making their connection flight or getting to their final destination by arriving without long delays. The SEOR faculty is mainly interested in continued contribution to automated air traffic control.

D.2. STAKEHOLDER VALUE MAPPING

After concluding who our stakeholders are, we then analyzed their needs and wants. We mapped it out to produce an effective way for understanding our stakeholder interests. This is the team's initial start to focus the attention on the project and how to go about finding the best implementation. "This allows supply chain specialists to design what kinds of outputs are necessary to make the decisions. Stakeholders Value Mapping is a decision-making approach. Most of the steps of the proposed framework correspond directly to those of the Stakeholder Value Mapping process (Stakeholders' assessment, Stakeholders' re-evaluation. The Stakeholder Value Mapping serves as the stakeholder-process element of the proposed framework. The goal of the Stakeholder Value Mapping process is not to have agreements on every single issue, but to agree as a group on a package of strategies/alternatives that are acceptable as a whole and successfully identify the value added by them."[21]

After Identifying what the needs are for each stakeholder, we mapped out their values on a scale of 1 (no value to stakeholder satisfaction) to 4 (critical to stakeholder satisfaction). The scale is as follows:

Assessment Scale	
4	Critical to stakeholder satisfaction
3	Highly recommended for stakeholder satisfaction
2	Some value but not to the full stakeholder's satisfaction
1	Minimum value but not necessary to stakeholder satisfaction
0	No value to stakeholder satisfaction

Figure D38 – Stakeholder Value Scale

Depending on each stakeholder needs, the team analyzed each stakeholders weight. The primary stakeholder was the Airline and ATC and our main focus and our last priority, but also very important, was the Aircraft Producers and SEOR Faculty.

[21] http://etd.fcla.edu/CF/CFE0002108/Alvarado_Moore_Karla_P_200805_PhD.pdf

Stakeholder Weights	
5	Airline – Airline Station Manager
5	Air Traffic Control - Tower
4	Airport
3	Pilots
2	Passengers
1	Aircraft Producers
1	SEOR Faculty

Figure D39 – Stakeholder Weights

Following the stakeholder scale, needs, and weights, a CTAAS Stakeholder Needs/Wants Analysis Matrix was developed. The matrix was calculated and finally the relative weights were calculated for each need. The most critical needs/wants for stakeholders was Needs#2 which is Safety because all stakeholders are most concerned about whether it is for themselves or their customers. The last, but also important, needs/wants for stakeholders was Need#6 which is Increased Sales/ Revenue because if you don't have safety and reliability then there will not be any customers to receive any revenue. All these needs and wants are taken into full consideration when it is being designed.

Stakeholder Matrix									
		Stakeholder							
Need #	Needs/Wants	Airline – ASM (5)	FAA-ATC-Tower (5)	Airport (4)	Pilots (3)	Passengers (2)	Aircraft Producers (1)	SEOR Faculty (1)	Relative Percentage Weight
1	Minimize cost	4	1	4	1	4	4	3	59
2	Increasing Safety	4	4	4	4	4	4	4	84
3	Optimal utilization of Resources	4	4	4	3	1	4	4	75
4	Eased Workload	3	4	3	4	1	3	2	66
5	Convenience	2	2	2	4	4	1	2	51
6	Increased Sales/Revenue	4	0	4	1	0	4	0	43
7	Improve Operations	4	4	4	3	0	3	4	72

Figure D40 – Stakeholder Value Mapping

D.3. QUALITY FUNCTION DEPLOYMENT (QFD)

Quality Function Deployment (QFD) is a tool used by the CTAAS project team to translate stakeholder needs into design quality and to ensure subsystems and component parts achieved design quality that is consistent with stakeholder needs. QFD is often used in Value Engineering (cite, Wikipedia: http://en.wikipedia.org/wiki/Quality_Function_Deployment). QFD required the mapping of stakeholder needs across the primary CTAAS system functions. Also, QFD allowed us to analyze and rate our potential competitors on their ability and/or desire to meet the relevant stakeholder needs. The use of QFD enabled us to validate the necessity of all our systems functions, while identifying the "Generation of Aircraft Arrival Sequence" as the CTAAS system most important function.

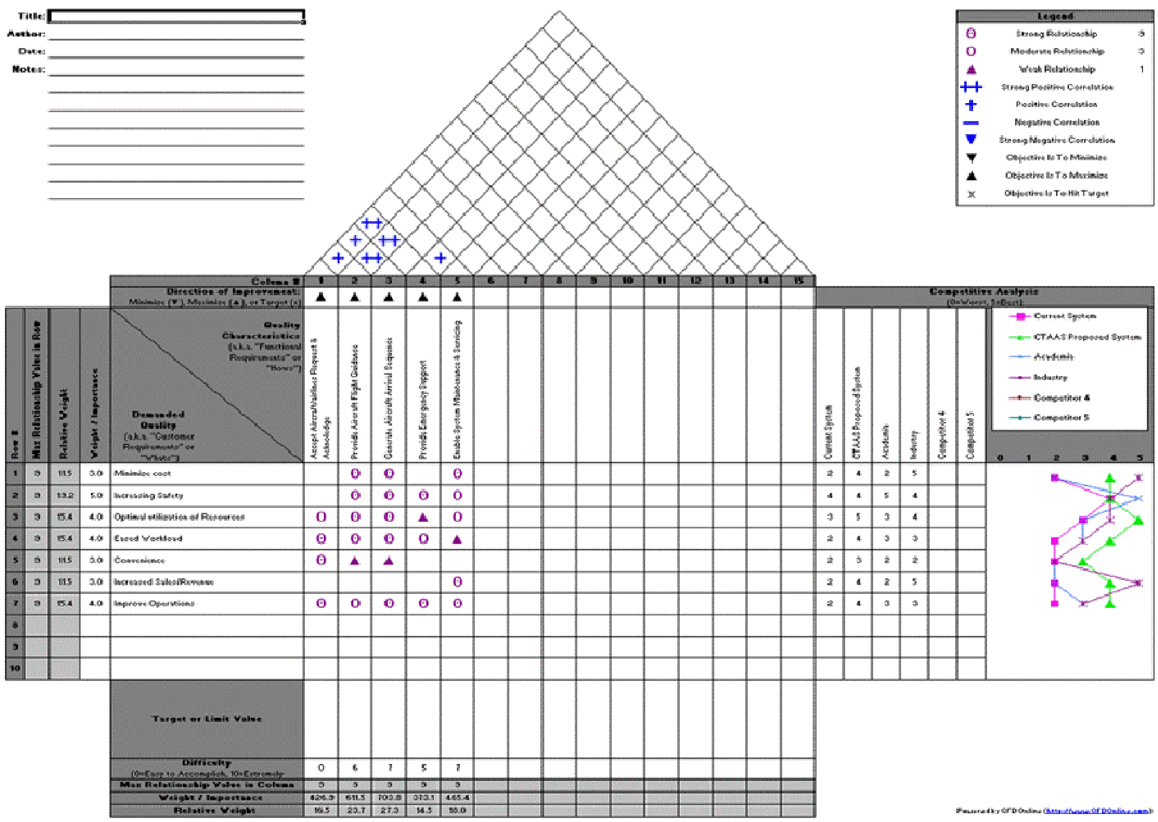

Figure D41 – CTAAS QFD

APPENDIX E: PRODUCT/DELIVERABLE VALUE MAP

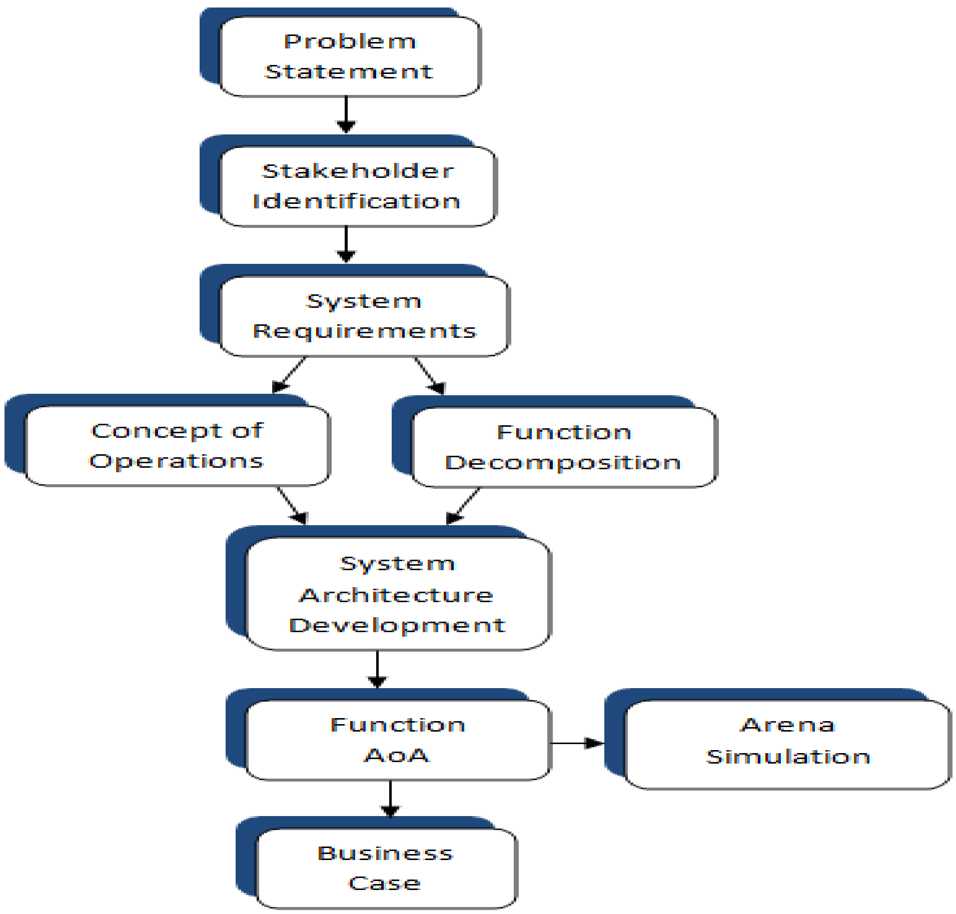

Figure E42 – Deliverable Value Map

In Figure 42 above is a top down approach which states the CTAAS deliverable value map. It maps out and shows how we came upon completing this project.

APPENDIX F: SYSTEM REQUIREMENTS DOCUMENT

F.1. Introduction

F.1.1. Purpose

This document addresses the high-level requirements that describe the operational capabilities necessary to achieve the aircraft arrival sequencing goals to be achieved by the Federal Aviation Administration's (FAA) future airspace control system. These requirements are grouped under the functional component of the Controlled Time of Arrival for Airports System (CTAAS) within which the requirements will be met.

F.2. Function Descriptions

F.2.1. Accept Aircraft/Airlines Request & Acknowledge

F.2.1.1. This high-level function will be responsible for handling all requests from the Airlines/Aircraft, will route the request to the appropriate functional component of the CTAAS, and will provide an acknowledgement message to the system user of receipt of the request.

i. Support Aircraft Requests – This component will receive and route any requests from the Aircraft to the appropriate component of the CTAAS.
ii. Support Airlines Requests - This component will receive and route any requests from the Airlines to the appropriate component of the CTAAS.
iii. Support Aircraft/Airline Entities Requests in Emergency – This component will receive and process all requests from the Airlines or Aircraft related to a current emergency situation. These requests will be given priority over other routine, non-emergency requests.

F.2.1.2. Provide Aircraft Flight Guidance – This high-level function will be responsible for providing all flight guidance for inbound flights. This direction will come from the *Generate Aircraft Arrival Sequencing* component of the CTAAS system and the flight guidance will be provided to the Aircraft and Airlines as appropriate.

i. Receive Sequence Requirements – This component will receive the inbound-aircraft sequencing data, and compare this information to the inbound-aircraft's current flight characteristics. From this comparison, any modifications to the inbound-aircraft's flight characteristics will be calculated, and provided to the *Provide Aircraft Flight Guidance* Component.
ii. Provide Aircraft Flight Guidance – This component will take the inbound-aircraft's flight characteristic modifications and provide them to the Aircraft and/or Airlines entities as appropriate.

F.2.1.3. Generate Aircraft Arrival Sequencing – This high-level function will be responsible for requesting inbound flight status from both the inbound-aircraft and from the airlines, receiving and processing these messages, generating a queued sequence of arrival for all inbound aircraft, and will provide emergency support for any sequence changes as a result of an emergency situation.

i. Request Inbound Flight Status – This component will poll aircraft and airlines to provide up-to-date flight status (location, speed, heading, etc) for all inbound-aircraft.

ii. Receive and Process Messages – This component will receive the inbound-flight status messages from the aircraft and airlines. The data from these messages will be passed to the *Enqueue Aircraft* component as a basis upon which the arrival sequence will be based. If an emergency situation is reported, it will routed to the *Emergency Support* component of this high level function.

iii. Send Acknowledgement Messages – This function will generate an acknowledgement message to the Aircraft and Airlines from which the navigation data was received. The message will be routed to the *Accept Airline/Aircraft Request and Acknowledge* component to be returned to the user.

iv. Enqueue Aircraft – This component will take all flight creation requests, inbound-flight modification requests, flight emergency requests, and all inbound-flight status datum, and generate or modify the inbound arrival sequence as appropriate. After the sequence has been updated or modified, any flight guidance would be routed to the *Provide Aircraft Flight Guidance* high-level function for eventual dissemination to the aircraft or airlines as appropriate.

v. Emergency Support – This component will receive all emergency requests from the *Accept Airline/Aircraft Request and Acknowledge* component, and will provide priority input to the *Enqueue Aircraft* component as appropriate in order to provide best support/solution to the emergency situation.

F.2.1.4. Provide Emergency Support – This high-level function will be responsible for receiving and processing the emergency-related messages. It will generate an internal acknowledgement message to eventually be routed to the aircraft or airlines that reported the emergency situation. Finally, it will generate a best course of action plan to deal with the emergency situation, and where appropriate, will contact and inform ground based emergency support organizations to inform them of the emergency situation.

i. Receive and Process Emergency Message – This component will receive the Emergency messages routed from the *Accept Airline/Aircraft Request and Acknowledge* component and will send the data to the *Send Emergency Action-Related Message & Direction* component.

ii. Send Acknowledgement of Emergency Message – This component will generate an acknowledgement message that will be routed to the *Airline/Aircraft Request and Acknowledge* component to be returned to the user.

iii. Send Emergency Action-related Message and Direction – This component will analyze the Emergency Situation and will provide a best course of action for the situation. This course of action may include placing all inbound-flight into a holding pattern upon arrival at the airport corner post to speed the landing process for the aircraft experiencing the emergency. This course of action may also include diverting the aircraft in emergency to another airport that is closer to the aircraft's current location. Additionally, if necessary this component will contact the appropriate ground-based emergency support entities and advise them of the emergency situation, and required emergency support.

F.2.1.5. Enable System Maintenance and Servicing – This high-level function is responsible for the service and maintenance of the system. This includes handling service/maintenance requests, analyzing the system for any system problems or failures, conducting maintenance as appropriate, and for reporting the system diagnostic and status messages to both internal and external users.

i. Receive Service/Maintenance Request – This component will receive any requests for service to the system. The requests can originate from both internal and external sources.
ii. System Analysis – This component will analyze the system for any operational issues, and could include the execution of internal built-in-tests or other test of the system's functionality.
iii. Conduct Maintenance – This component will execute fixes and other maintenance required on the system.
iv. Report System Diagnostic and Status Messages – This component will report system diagnostic message and system status messages back to the appropriate users. This includes direction to servicing personnel of operational issues detected during system functionality analysis.

F.3. Functional Requirements

F.3.1. Accept Aircraft/Airlines Request & Acknowledge

v. Support Aircraft Requests
    1. The CTAAS shall notify the originator of any problems with flight plan amendments.
    2. The CTAAS shall retrieve flight plan data upon receipt of users' request.
    3. The CTAAS shall accept requests from users to retrieve flight plans.
    4. The CTAAS shall accept requests to close flight plans.A11
    5. The CTAAS shall close flight plans.A11
    6. The CTAAS shall accept requests for assistance from pilots.

vi. Support Airlines Requests
    1. The CTAAS shall accept flight plans from users.
    2. The CTAAS shall accept proposed flight plan information.
    3. The CTAAS shall format proposed flight plan information.
    4. The CTAAS shall notify the originator when a flight plan has been accepted.
    5. The CTAAS shall accept flight plan amendments.
    6. The CTAAS shall accept amendments to proposed flight plans.
    7. The CTAAS shall accept amendments to active flight plans from users.
    8. The CTAAS shall notify users when an amendment has been accepted.

9. The CTAAS shall accept corrections to proposed flight plans.
10. The CTAAS shall accept requests to cancel flight plans.
11. The CTAAS shall cancel flight plans.
12. The CTAAS shall notify the originator of any problems with flight plan amendments.
13. The CTAAS shall retrieve flight plan data upon receipt of users' request.
14. The CTAAS shall accept requests from users to retrieve flight plans.

vii. Support Aircraft/Airline Entities Requests in Emergency

1. The CTAAS shall monitor the status of aircraft. A31
2. The CTAAS shall acquire flight information for each controlled aircraft inbound towards destination airport A31
3. The CTAAS shall acquire flight information for each controlled inbound aircraft to destination airport. A31
4. The CTAAS shall retrieve flight information for each controlled inbound aircraft to destination airport. A31
5. The CTAAS shall detect overdue aircraft. A31
6. The CTAAS shall retrieve essential information on overdue aircraft. A31
7. The CTAAS shall retrieve essential information on missing aircraft. A31
8. The CTAAS shall determine the location of an aircraft in an emergency situation. A31
9. The CTAAS shall disseminate Emergency Alerts. A31

F.3.2. Provide Aircraft Flight Guidance

viii. Receive Sequence Requirements

1. The CTAAS shall disseminate flight plan information to users.
2. The CTAAS shall determine the velocity of aircraft in en route airspace.A32
3. The CTAAS shall determine aircraft trajectories. A32
4. The CTAAS shall up The CTAAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations.A22 date flight path projections. A32
5. The CTAAS shall detect deviations from the active flight plan. A32
6. The CTAAS shall disseminate landing area outlines to users.A22
7. The CTAAS shall disseminate runway area outlines to users. A22
8. The CTAAS shall generate aircraft maneuvers to avoid separation standards violations.A22
9. The CTAAS shall generate resolution advisories for aircraft in violation of separation standards.A22
10. The CTAAS shall disseminate alerts for separation standards violations.A22
11. The CTAAS shall alert users to predicted aircraft separation standards violations.A22
12. The CTAAS shall disseminate aircraft maneuvers to avoid predicted separation standards violations.A22

13. The CTAAS shall disseminate control directivesA22

ix. Provide Aircraft Flight Control Direction

F.3.3. Generate Aircraft Arrival Sequencing

x. Request Inbound Flight Status

1. The CTAAS shall acquire position reports from properly equipped aircraft in en route airspace.
2. The CTAAS shall acquire position reports from properly equipped aircraft in selected volumes of en route airspace.

xi. Receive and Process Messages

1. The CTAAS shall detect errors in flight plans.
2.
3. The CTAAS shall validate user amendments to proposed flight plans.
4. The CTAAS shall process position reports from aircraft.
5. The CTAAS shall correlate actual flight information to flight plan information for each controlled aircraft.
6. The CTAAS shall update flight plans based on current position.
7. The CTAAS shall disseminate aircraft position.
8. The CTAAS shall identify aircraft in the en route environment.
9. The CTAAS shall disseminate weather information covering the US delegated airspace for flight planning. A32
10. The CTAAS shall disseminate weather information aloft for all U.S. delegated airspace for flight planning. A32
11. The CTAAS shall disseminate surface aviation weather information for flight planning. A32
12. The CTAAS shall disseminate en route weather information for flight planning. A32
13. The CTAAS shall disseminate hazardous weather information for flight planning A32
14. The CTAAS shall disseminate the predicted movement of thunderstorms for flight planning. A32
15. The CTAAS shall disseminate weather information to users for flight planning. A32
16. The CTAAS shall disseminate weather information to users. A32
17. The CTAAS shall disseminate route-oriented weather information for flight planning. A32
18. The CTAAS shall disseminate visibility information for flight planning. A32
19. The CTAAS shall disseminate special weather observations for flight planning. A32
20. The CTAAS shall disseminate wind information for hazardous weather avoidance. A32
21. The CTAAS shall disseminate hazardous weather information to users. A32
22. The CTAAS shall disseminate weather advisories information upon users request. A32

23. The CTAAS shall disseminate weather advisories to users. A32
24. The CTAAS shall support navigation for all phases of flight. A32
25.
26. The CTAAS shall monitor the status of operational systems. A32
27. The CTAAS shall disseminate weather information covering the US delegated airspace for flight planning. A32
28. The CTAAS shall disseminate weather information aloft for all U.S. delegated airspace for flight planning. A32
29. The CTAAS shall disseminate surface aviation weather information for flight planning. A32
30. The CTAAS shall disseminate en route weather information for flight planning. A32
31. The CTAAS shall disseminate hazardous weather information for flight planning A32
32. The CTAAS shall disseminate the predicted movement of thunderstorms for flight planning. A32
33. The CTAAS shall disseminate weather information to users for flight planning. A32
34. The CTAAS shall disseminate weather information to users. A32
35. The CTAAS shall disseminate route-oriented weather information for flight planning. A32
36. The CTAAS shall disseminate visibility information for flight planning. A32
37. The CTAAS shall disseminate special weather observations for flight planning. A32
38. The CTAAS shall disseminate wind information for hazardous weather avoidance. A32
39. The CTAAS shall disseminate hazardous weather information to users. A32
40. The CTAAS shall disseminate weather advisories information upon users request. A32
41. The CTAAS shall disseminate weather advisories to users. A32
42. The CTAAS shall support navigation for all phases of flight. A32
43.
44. The CTAAS shall monitor the status of operational systems. A32
45. The CTAAS shall disseminate the performance of all CTAAS sub-systems. A32
46. The CTAAS shall disseminate systems parameters. A32
47. The CTAAS shall disseminate safety advisories to aircraft.A32
48. The CTAAS shall disseminate traffic advisories upon user request. A32
49. The CTAAS shall disseminate delay advisories in effect along the users proposed flight path. A32
50. The CTAAS shall disseminate flight restrictions to users. A32
51. The CTAAS shall disseminate safety critical information. A32
52. The CTAAS shall disseminate recommendations for hazardous weather avoidance.A22
53. The CTAAS shall disseminate CTAAS status information to users. A32

54. The CTAAS shall detect aircraft violations of separation standards. A32
55. The CTAAS shall detect the position of aircraft in selected volumes of en route airspace, independent of aircraft equipage.
56. The CTAAS shall detect each inbound aircraft to local destination airport.
57. The CTAAS shall determine the current altitude for each participating aircraft (in controlled airspace).
58. The CTAAS shall alert the user when a controlled aircraft's track position is outside of its clearance-based trajectory.A22
59. The CTAAS shall notify users when their aircraft deviates from its flight plan clearance by a prescribed amount.A22
60. The CTAAS shall transmit recommended airport locations to expedite resolution of emergency situations.A3

xii. Enqueue Aircraft

1. The CTAAS shall analyze conditions that affect traffic synchronization.A34
2. The CTAAS shall analyze arrival sequences. A34
3. The CTAAS shall evaluate alternate trajectories for sequencing. A34
4. The CTAAS shall establish arrival sequences. A34
5. The CTAAS shall sequence VFR aircraft in the arrival phase of flight. A34
6. The CTAAS shall establish minimum separation standards based on the operational environment. A34
7. The CTAAS shall recommend courses of action to any user declaring an emergency. A34
8. The CTAAS shall acquire weather information aloft for all U.S. delegated airspace for flight planning.A34
9. The CTAAS shall acquire forecast winds aloft information. A34
10. The CTAAS shall acquire current surface weather information for flight planning. A34
11. The CTAAS shall acquire en route weather information for flight planning. A34
12. The CTAAS shall acquire area forecast weather information for flight planning. A34
13. The CTAAS shall acquire special forecast weather information for flight planning. A34

xiii. Emergency Support

1. Provide Emergency Support

xiv. Receive and Process Emergency Message

1. The CTAAS shall accept an emergency transmission from any user declaring an emergency. A35

xv. Send Acknowledgement of Emergency Message

1. The CTAAS shall respond to requests for assistance from in-flight users.A42

xvi. Send Emergency Action-related Message and Direction

1. The CTAAS shall alert appropriate emergency services of an emergency alert.A35
2. The CTAAS shall alert ATC facilities to the existence of an emergency. A35
3. The CTAAS shall disseminate information to agencies involved in search and rescue activities. A43
4. The CTAAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations.A22

F.3.4. Enable System Maintenance and Servicing

xvii. Receive Service/Maintenance Request

1. The CTAAS shall receive service and maintenance requests from users.

xviii. System Analysis

1. The CTAAS shall perform physical inspections of facilities. A52
2. The CTAAS shall acquire data on completed equipment maintenance. A52
3. The CTAAS shall certify restoration of services following the completion of maintenance actions. A52
4. The CTAAS shall certify equipment performance of designated systems from designated remote locations. A52
5. The CTAAS shall verify operation of repaired operational systems. A52
6. The CTAAS shall determine the cause of system failures.A52
7. The CTAAS shall determine preventive maintenance intervals for all CTAAS equipment.A52
8.

xix. Conduct Maintenance

1. The CTAAS shall perform corrective maintenance on operational systems. A53
2. The CTAAS shall perform on-site maintenance of facilities. A53
3. The CTAAS shall perform preventative maintenance on operational systems. A53

xx. Report System Diagnostic and Status Messages

1. The CTAAS shall disseminate an alert when a CTAAS system fails. A54

F.4. Support Requirements

F.4.1. Infrastructure Requirements

xxi. The CTAAS shall exchange data between FAA and DoD air traffic control facilities.4.1
xxii. The CTAAS shall provide air-ground communications within the CTAAS.4.1
xxiii. The CTAAS shall provide VHF channels for air-ground communications. 4.1
xxiv. The CTAAS shall provide UHF channels for air-ground communications. 4.1
xxv. The CTAAS shall provide HF channels for air-ground communications. 4.1
xxvi. The CTAAS shall provide ground-to-ground communications. 4.1
xxvii. The CTAAS shall control equipment remotely.4.1
xxviii.

F.4.2. Security Requirements

xxix. The CTAAS shall establish emergency communications.4.2
xxx. All CTAAS systems shall provide recovery measures from security incidents.4.2
xxxi. The CTAAS shall prevent disclosure of sensitive information to unauthorized persons.4.2
xxxii.
xxxiii. The CTAAS shall control physical access to equipment and facilities.4.2
xxxiv. The CTAAS shall provide security measures at facilities for protection of CTAAS systems.4.2
xxxv.
xxxvi. The CTAAS shall protect CTAAS assets.4.2
xxxvii. The CTAAS shall protect assets from unauthorized modification4.2
xxxviii. The CTAAS shall protect assets from unauthorized deletion4.2
xxxix. The CTAAS shall protect assets from unauthorized creation4.2
xl. The CTAAS shall protect assets against false or misleading data4.2
xli. The CTAAS shall protect assets from denial of service4.2
xlii. The CTAAS shall protect assets from unacceptable degradation of service. 4.2

xliii. The CTAAS shall alert specialists when malicious activity is detected. 4.2
xliv. The CTAAS shall detect malicious activity. 4.2
xlv. The CTAAS shall deter malicious activity. 4.2
xlvi. The CTAAS shall record the security audit log during all operational states. 4.2
xlvii. The CTAAS shall control access to information. 4.2
xlviii.

F.4.3. Performance Requirements

xlix. The CTAAS shall monitor status of equipment without degrading equipment availability.

F.4.4. Reliability, Maintainability, and Availability

I. The CTAAS shall train system operators.

Ii. The CTAAS shall train maintenance specialists.

Iii. The CTAAS shall provide contingency plans for ARTCC's in the event of catastrophic failure4.5

Iiii. The CTAAS shall comply with all Occupational Safety and Health Administration

Iiv. (OSHA), FAA, and local safety and sanitary regulations.4.5

APPENDIX G: OPERATIONAL SCENARIOS

a. The following diagram shows the interaction between the Airline AOC and the CTAAS system when canceling a flight.

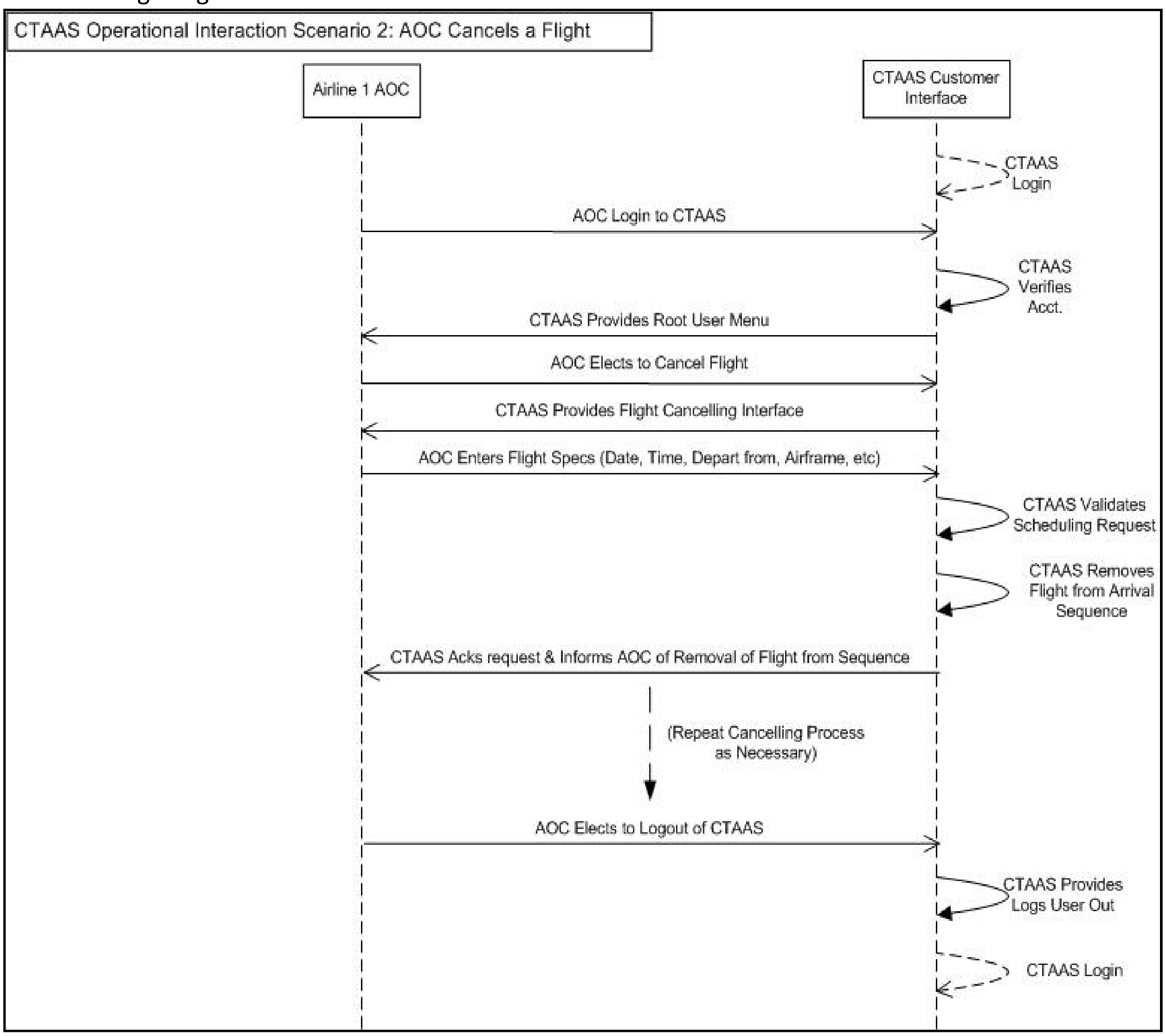

Figure G43 – AOC Cancels Flight

b. The following diagram shows the interaction between the Airline AOC and the CTAAS system when indicating an inbound flight is delayed.

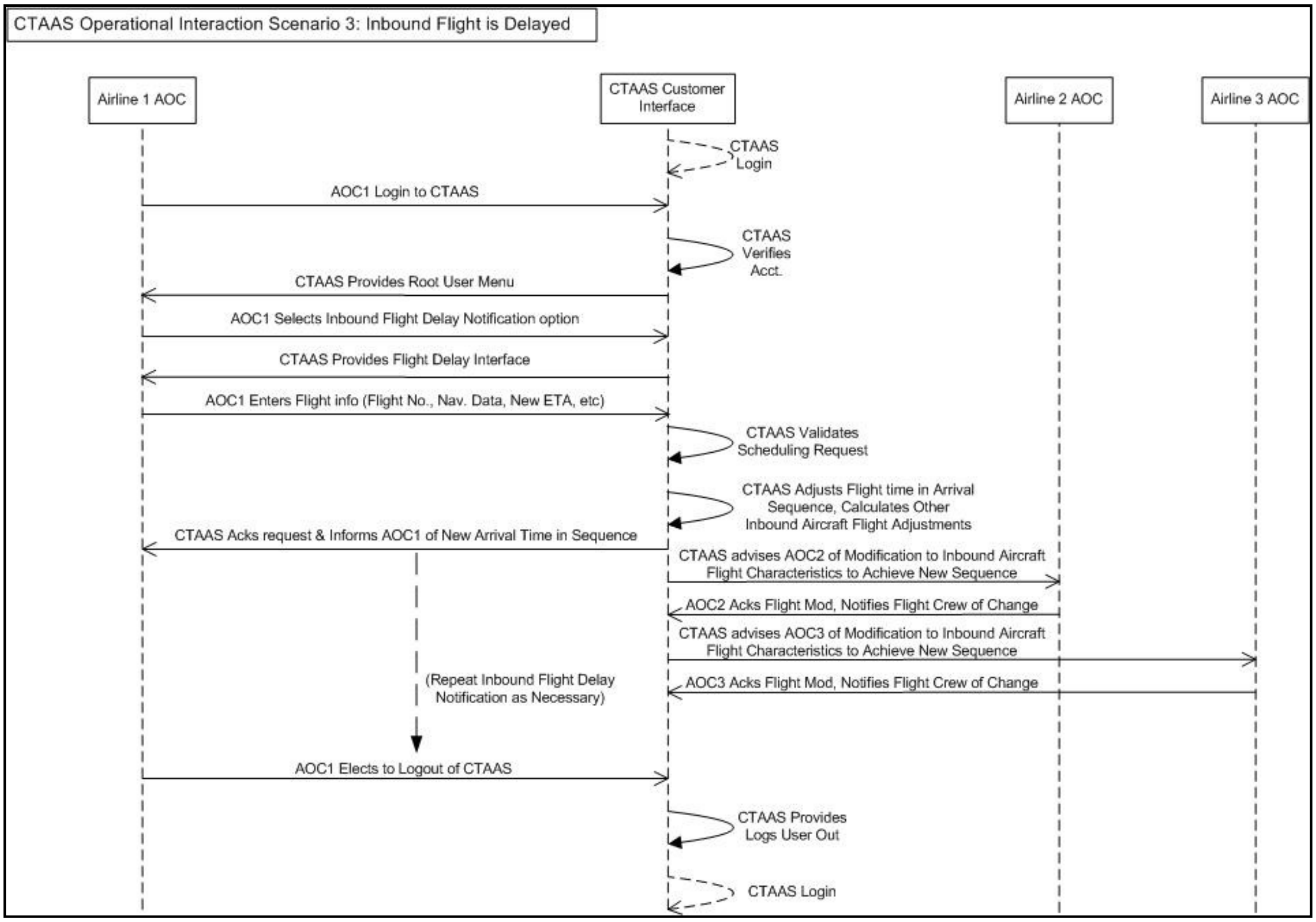

Figure G44 – Inbound Flight is Delayed

c. The following diagram shows the interaction between several Airline AOCs and the CTAAS system when one inbound flight experiences an in-flight emergency situation.

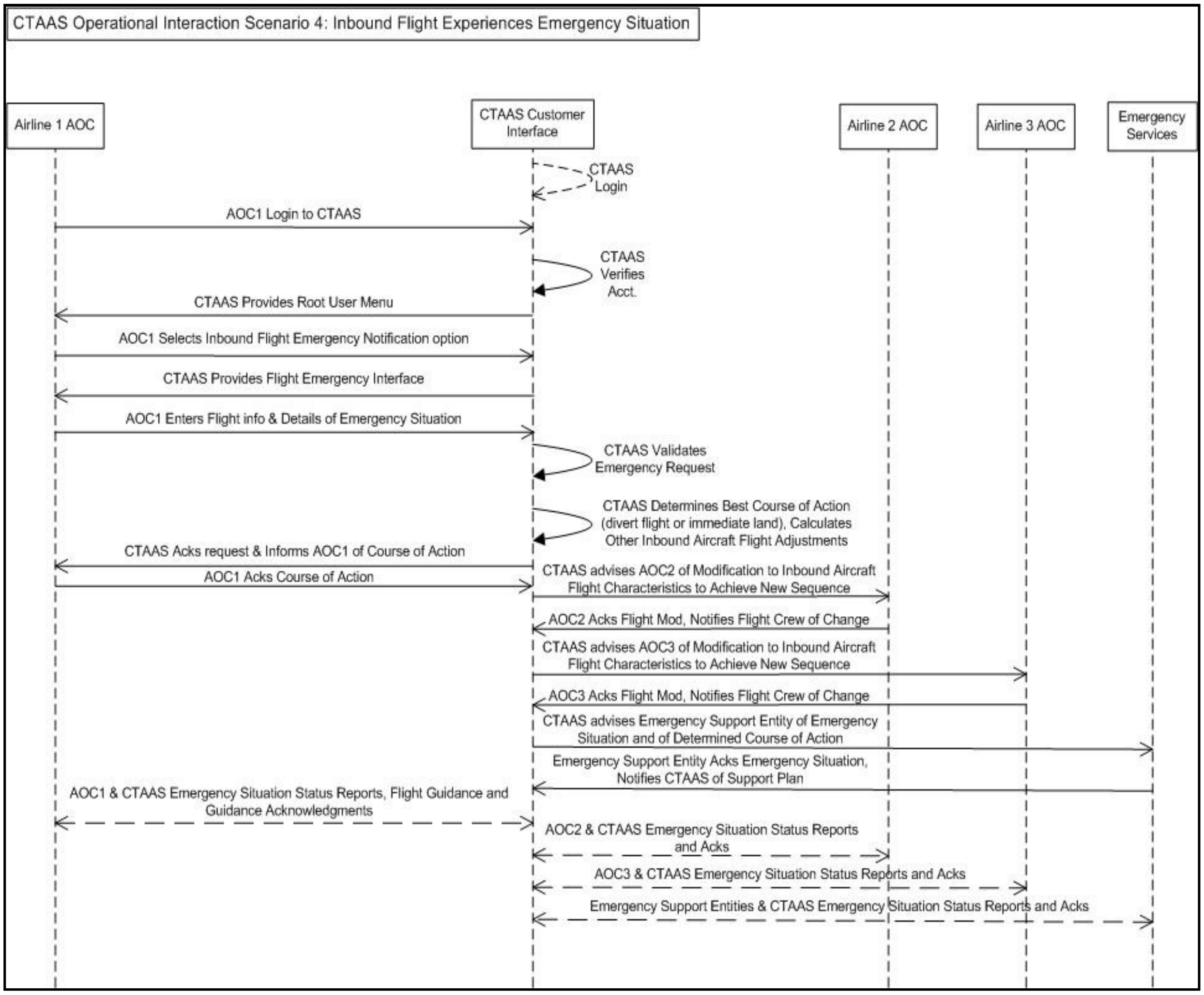

Figure G45 – Inbound Flight Experiences Emergency Situation

APPENDIX H: CTAAS PRODUCTS AND SERVICES

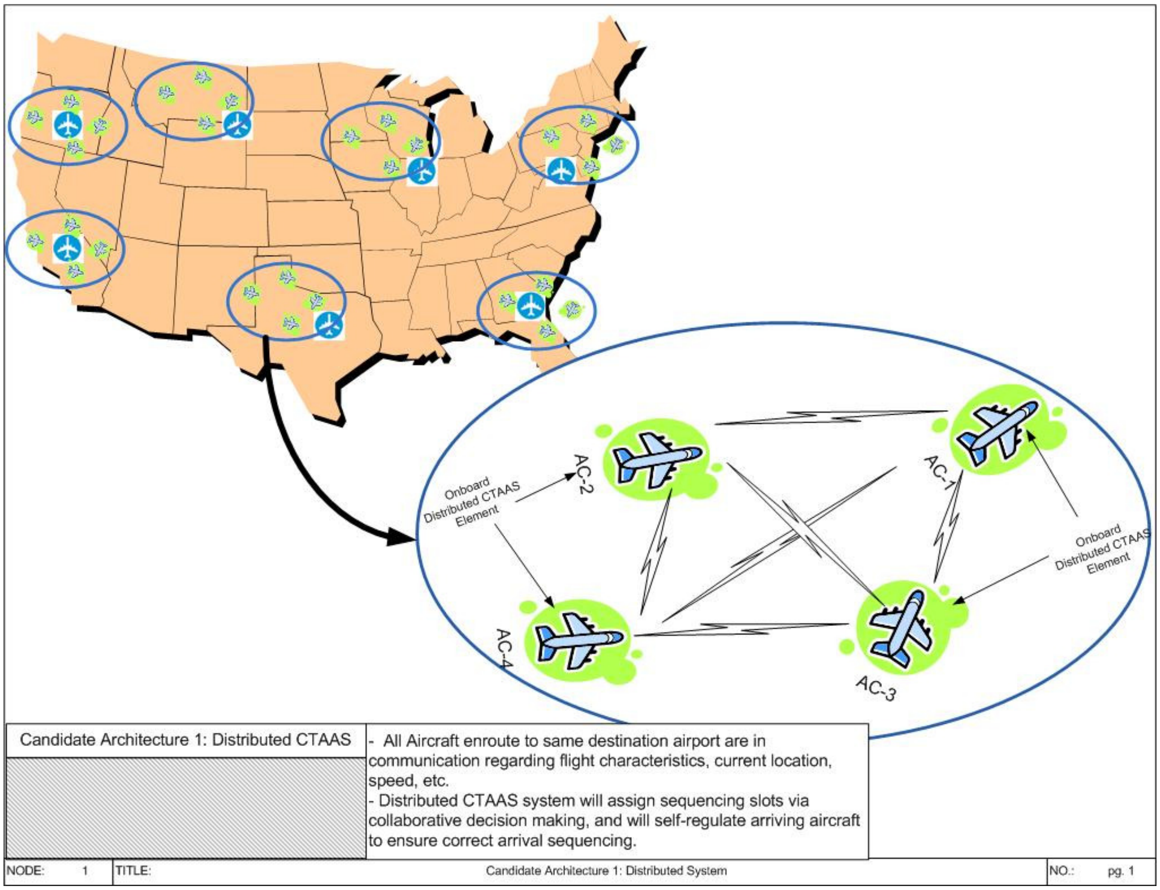

Figure H46 – Distributed CTAAS

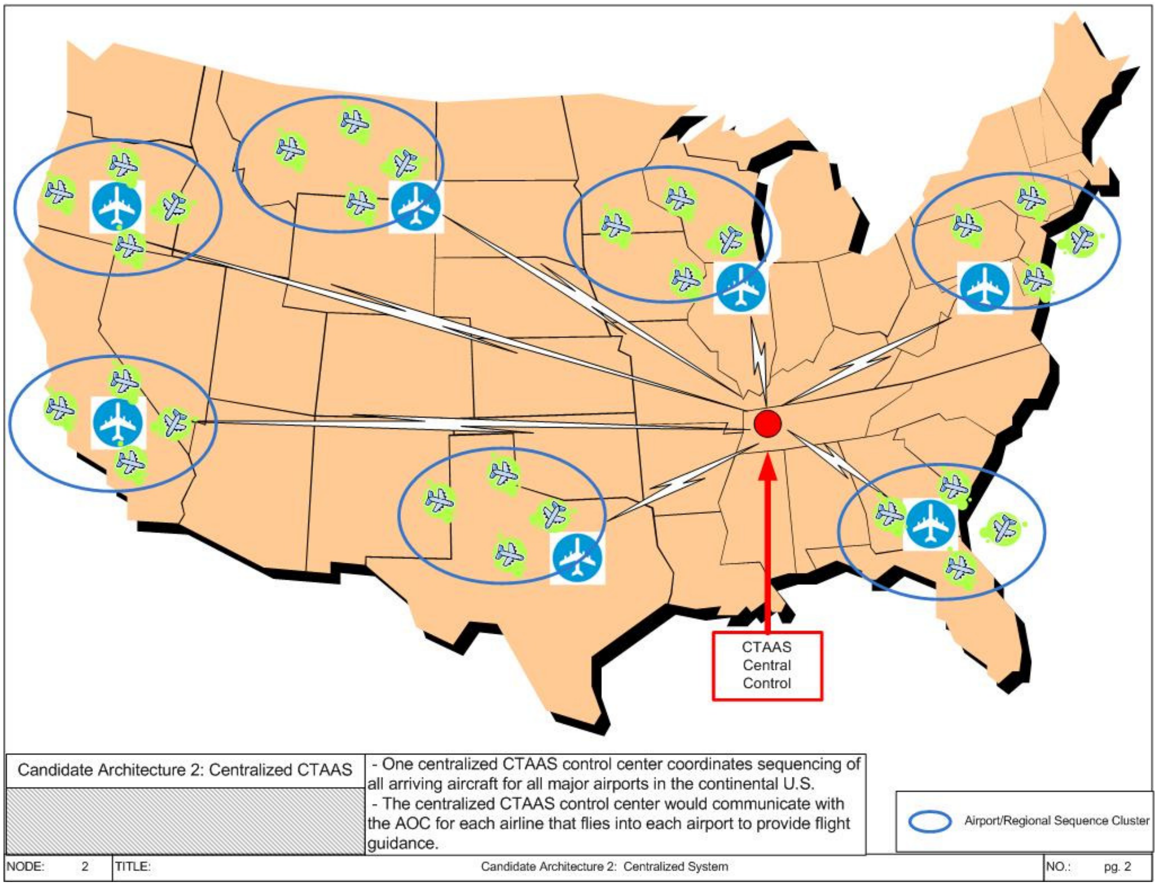

Figure H47 – Centralized CTAAS

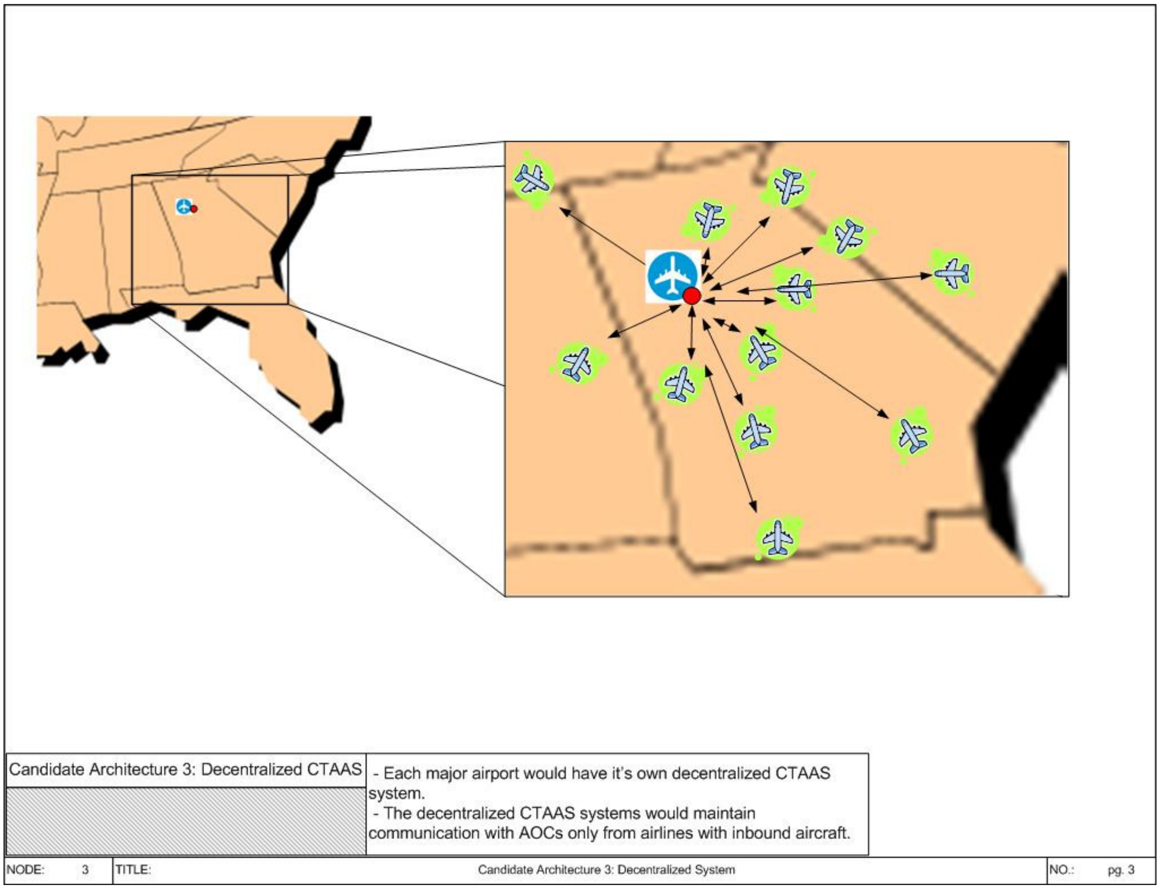

Figure H48 – Decentralized CTAAS

APPENDIX I: ARCHITECTURE AND PROCESS

I.1. INTRODUCTION

The CTAAS Project Process defines what methodology will be used to structure the scope and schedule of the Systems 798 Final Project and report. This document reviews the project scope that is tailored to the process, assignments and limitations of a semester project effort. This document also reviews systems engineering architecture frameworks the team has evaluated. The efforts clearly define the way ahead of the team's process and architecture for developing the CTAAS System.

I.2. CTAAS PROCESS

I.2.1. Process Definition

A model will be selected in order to represent the major components of the development work the CTAAS team plans to perform. The process will enable the team to define the Vee model, how it will be performed, divide it into manageable pieces, determine the project milestones, and communicate the strategy to stakeholders.

I.3. PROCESS EVALUATION

The following Vee model was evaluated by the CTAAS team. A description of the model and the process model selection is provided in the subsequent sections.

I.3.1. Vee Model

The Vee model is shaped like the letter V, using a top-down approach on the left side of the V and bottom-up approach on the right side of the V. The left side of the Vee represents the definition and decomposition of user requirements into parts and lines of code through the process. The right side of the Vee represents the verification and validation of the system components into successive levels of assembly. The upward iterations ensure that the technical baseline, as it evolves, continues to be satisfactory to the user.

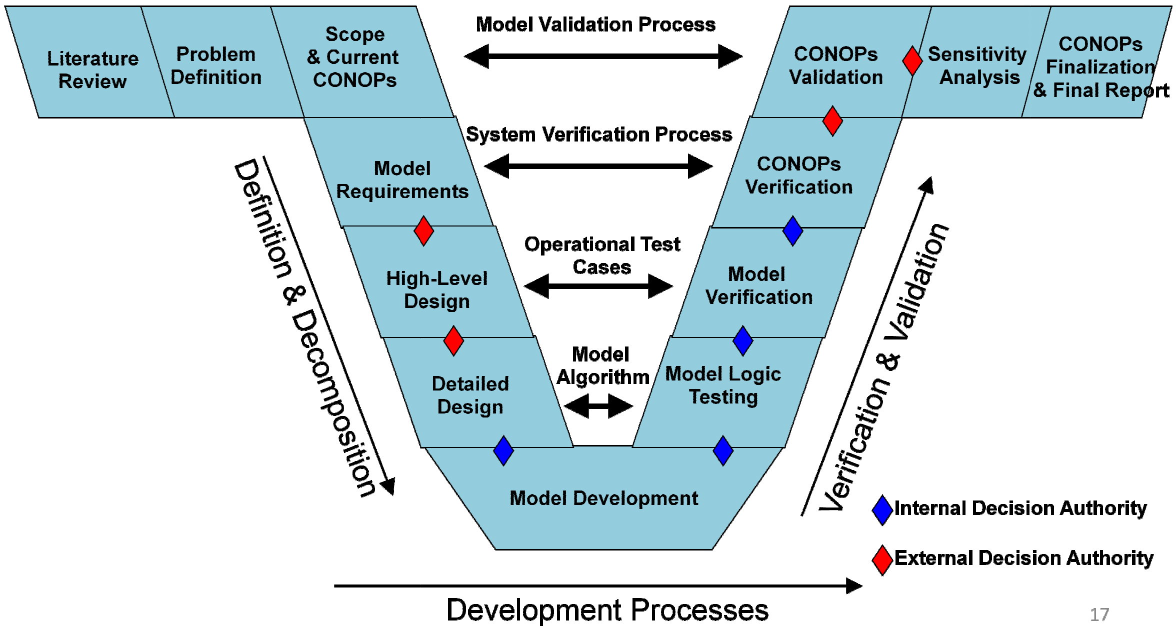

Figure I49 – Stakeholder Value Mapping

APPENDIX J: ARCHITECTURE VIEWS

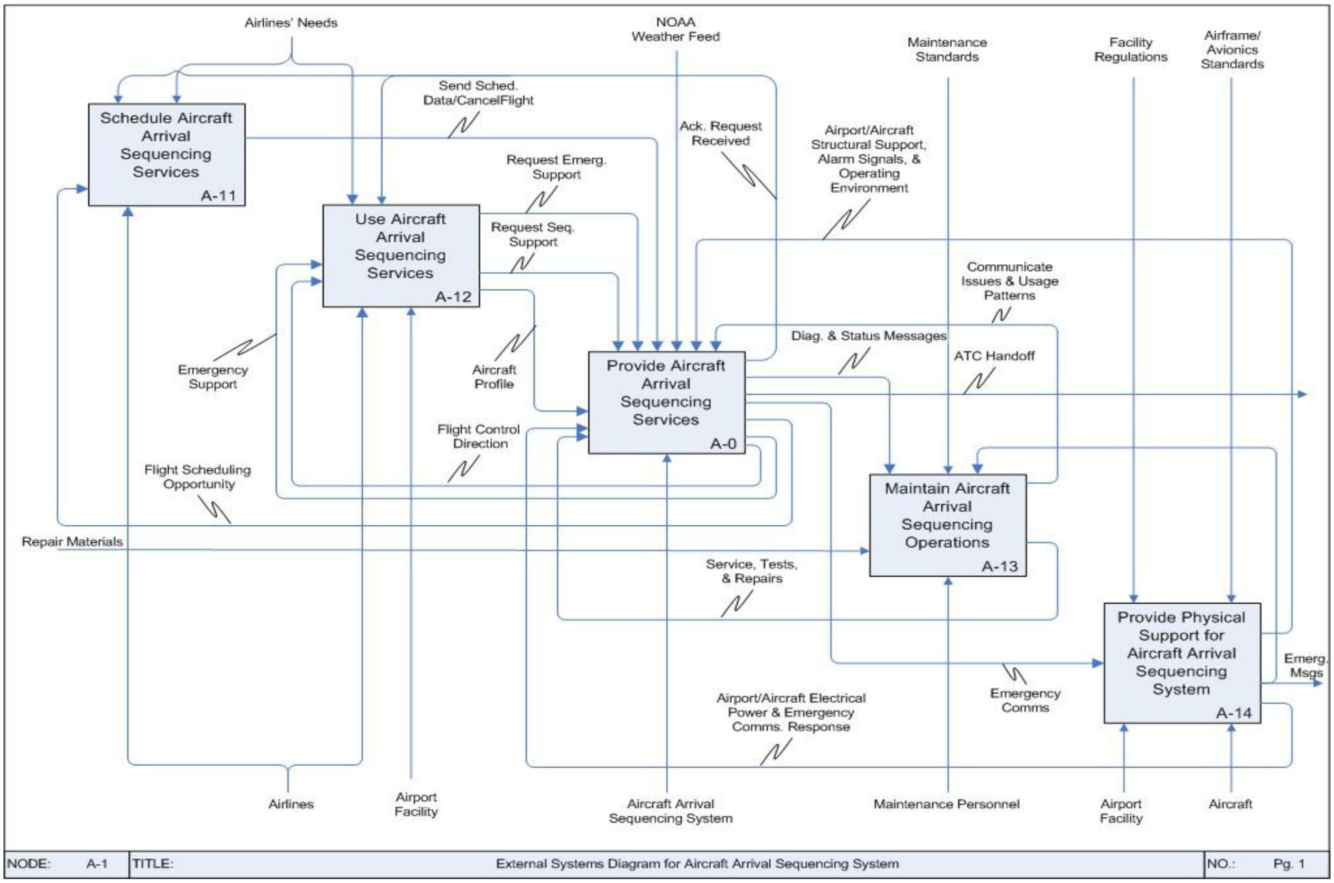

Figure J50 – A-1 Diagram

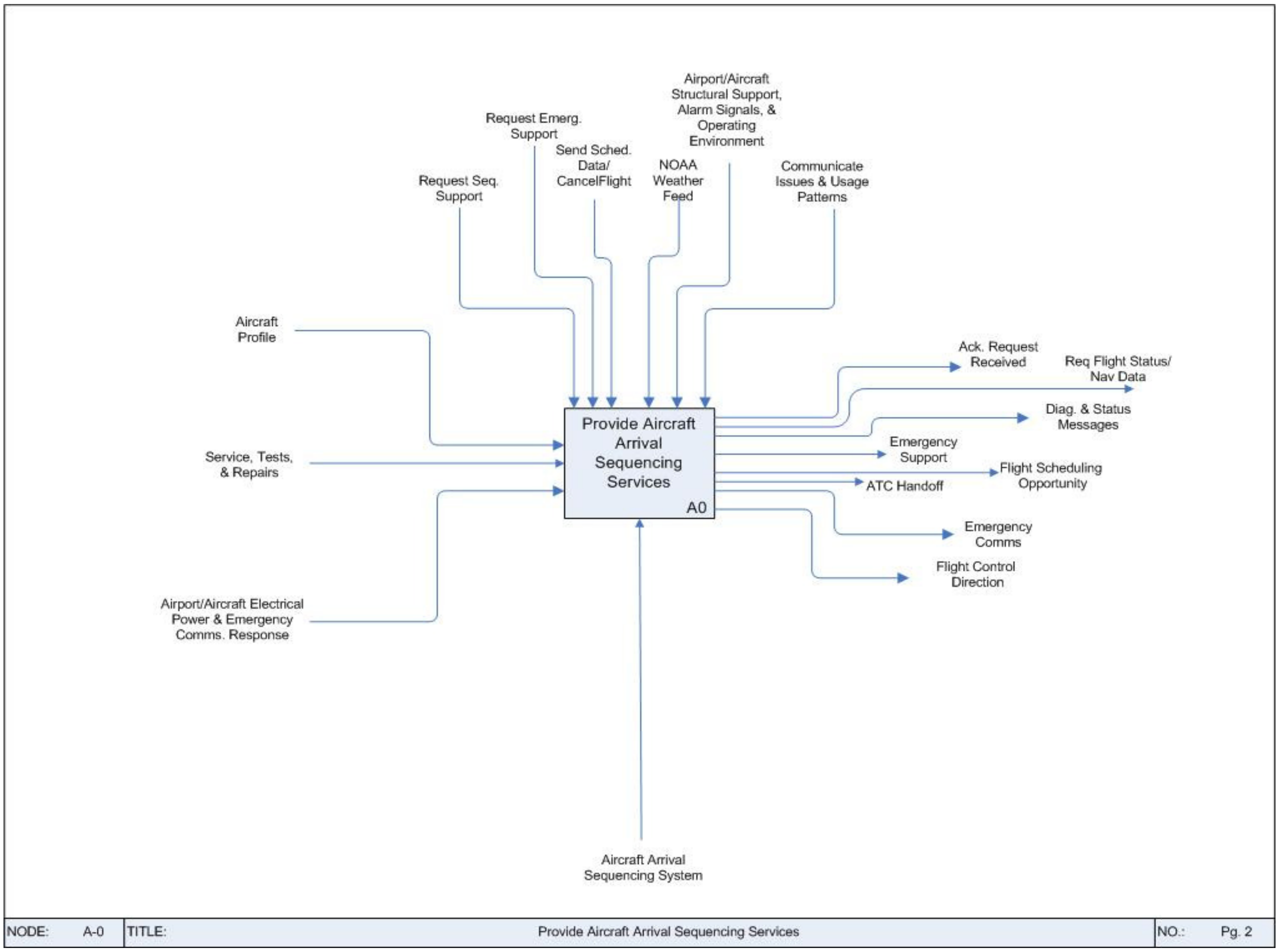

Figure J51 – A-0 Diagram

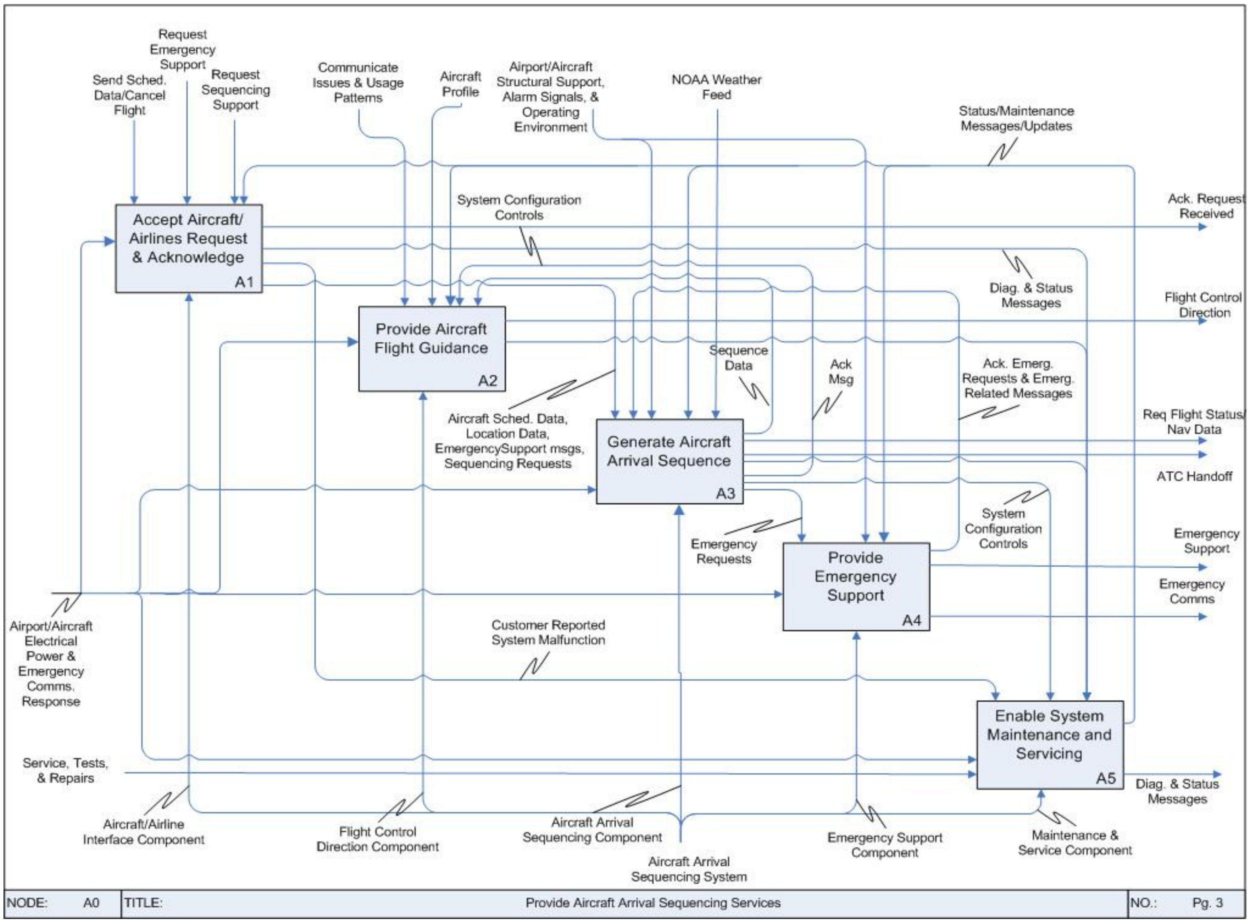

Figure J52 – A0 Diagram

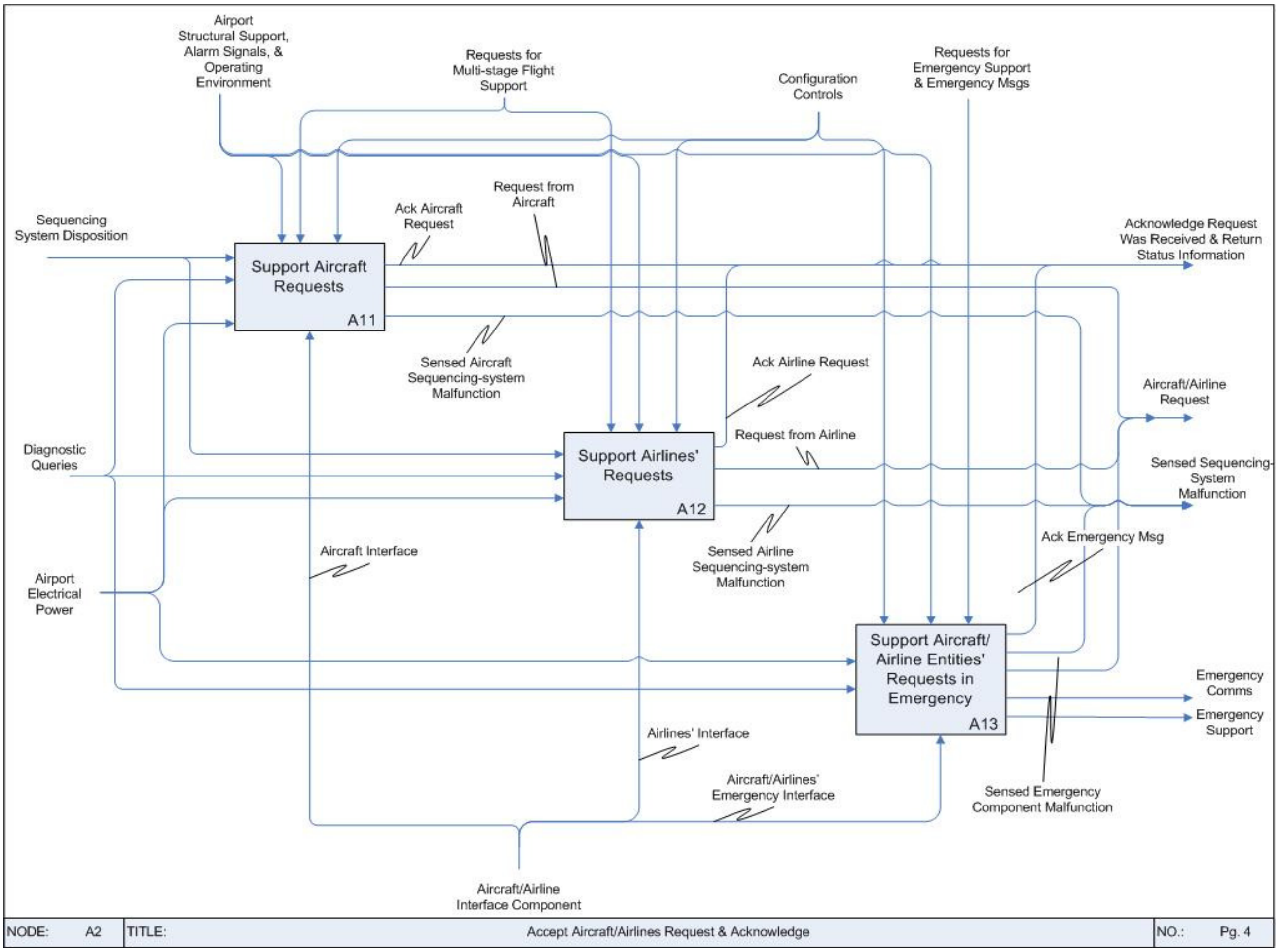

Figure J53 – A2 Diagram

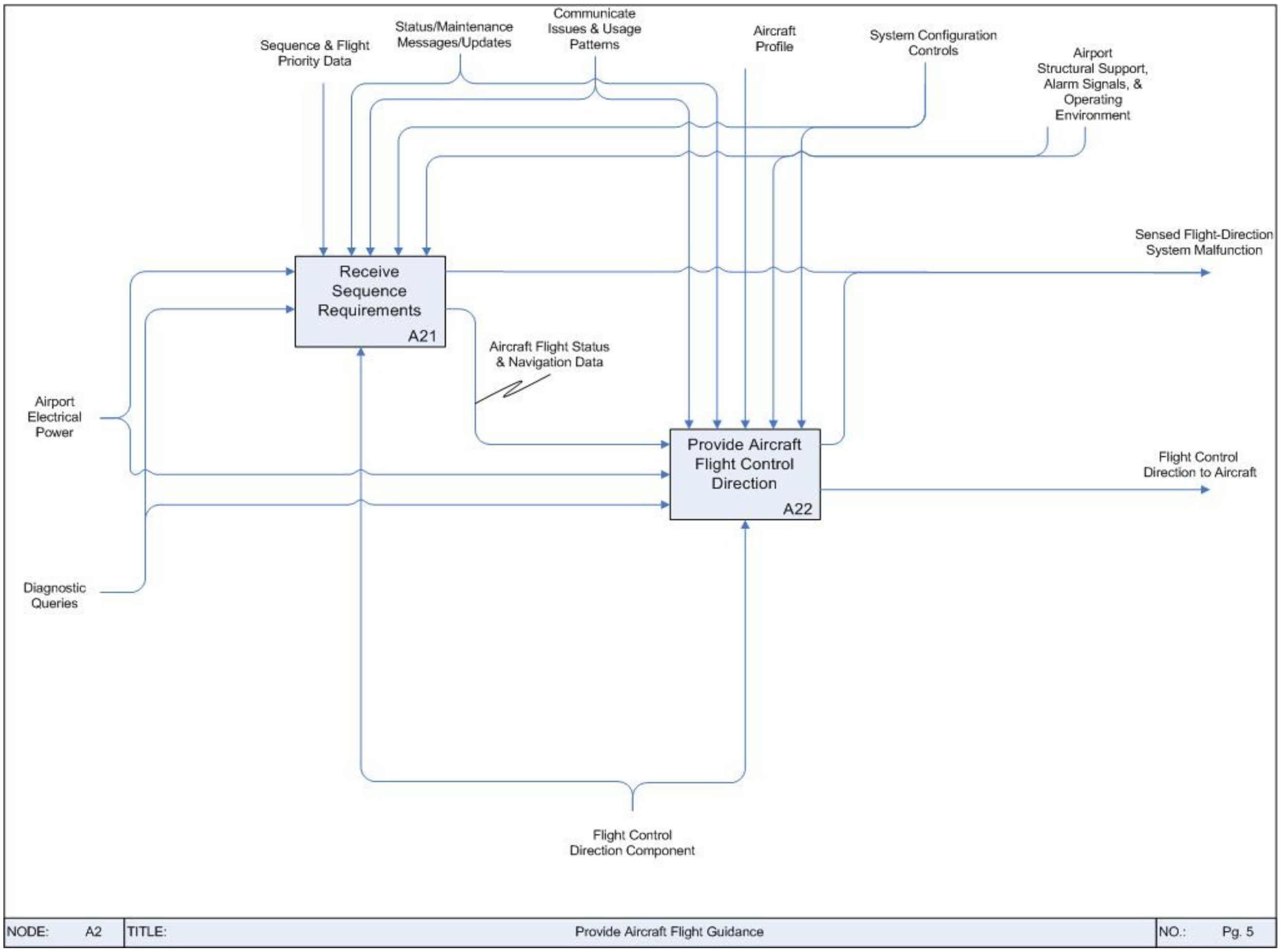

Figure J54 – A2 Diagram

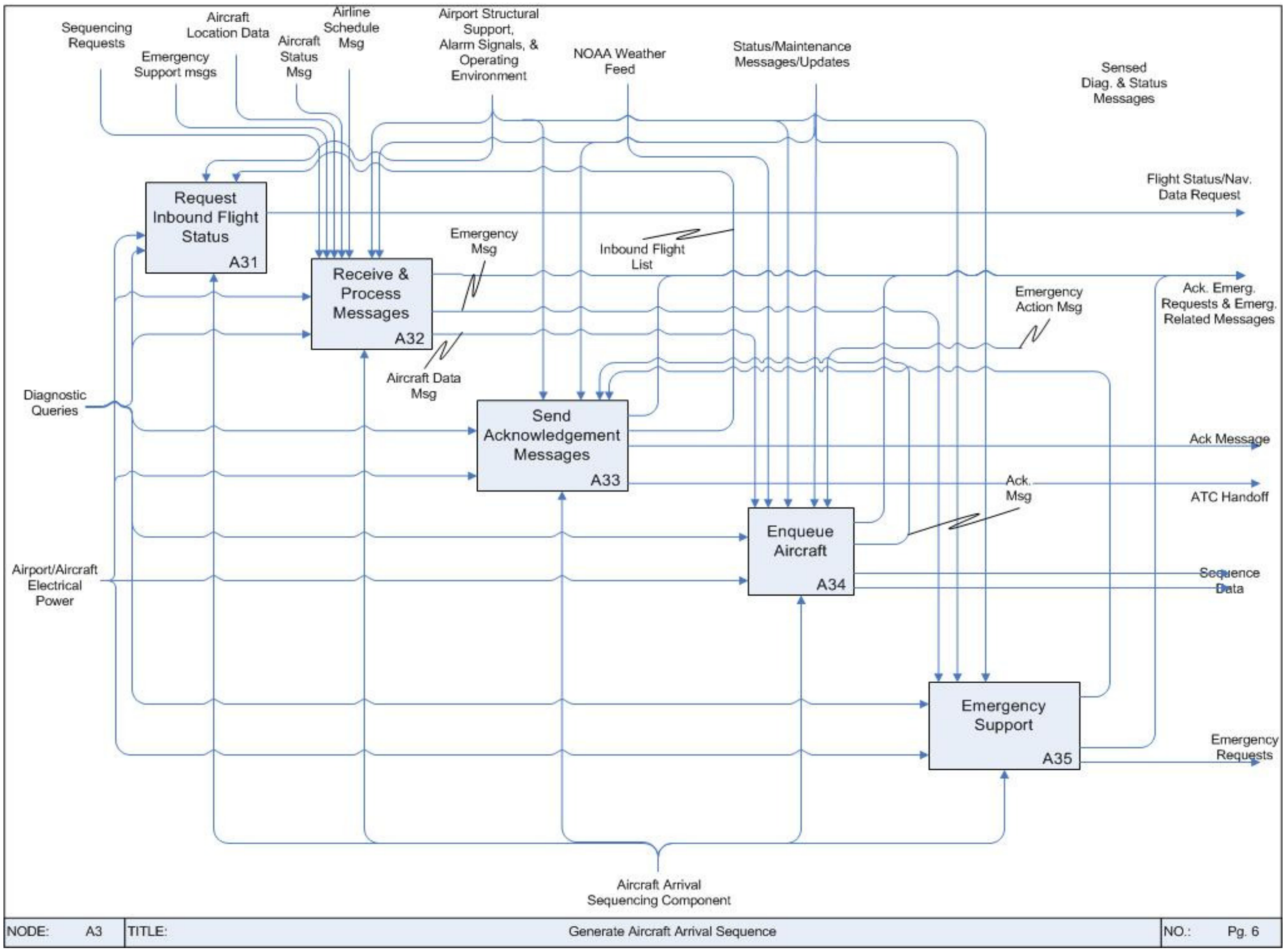

Figure J55 – A3 Diagram

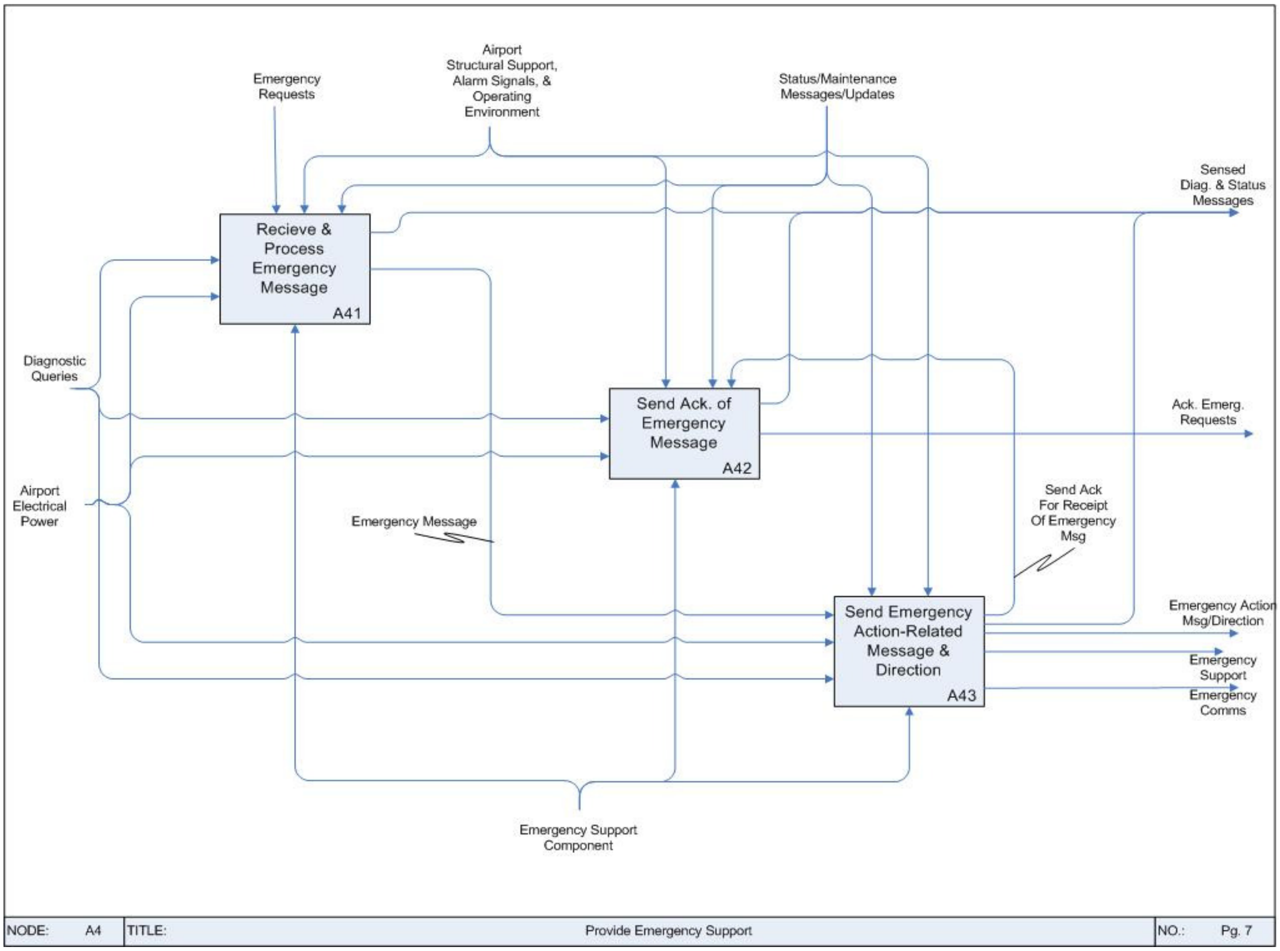

Figure J56 – A4 Diagram

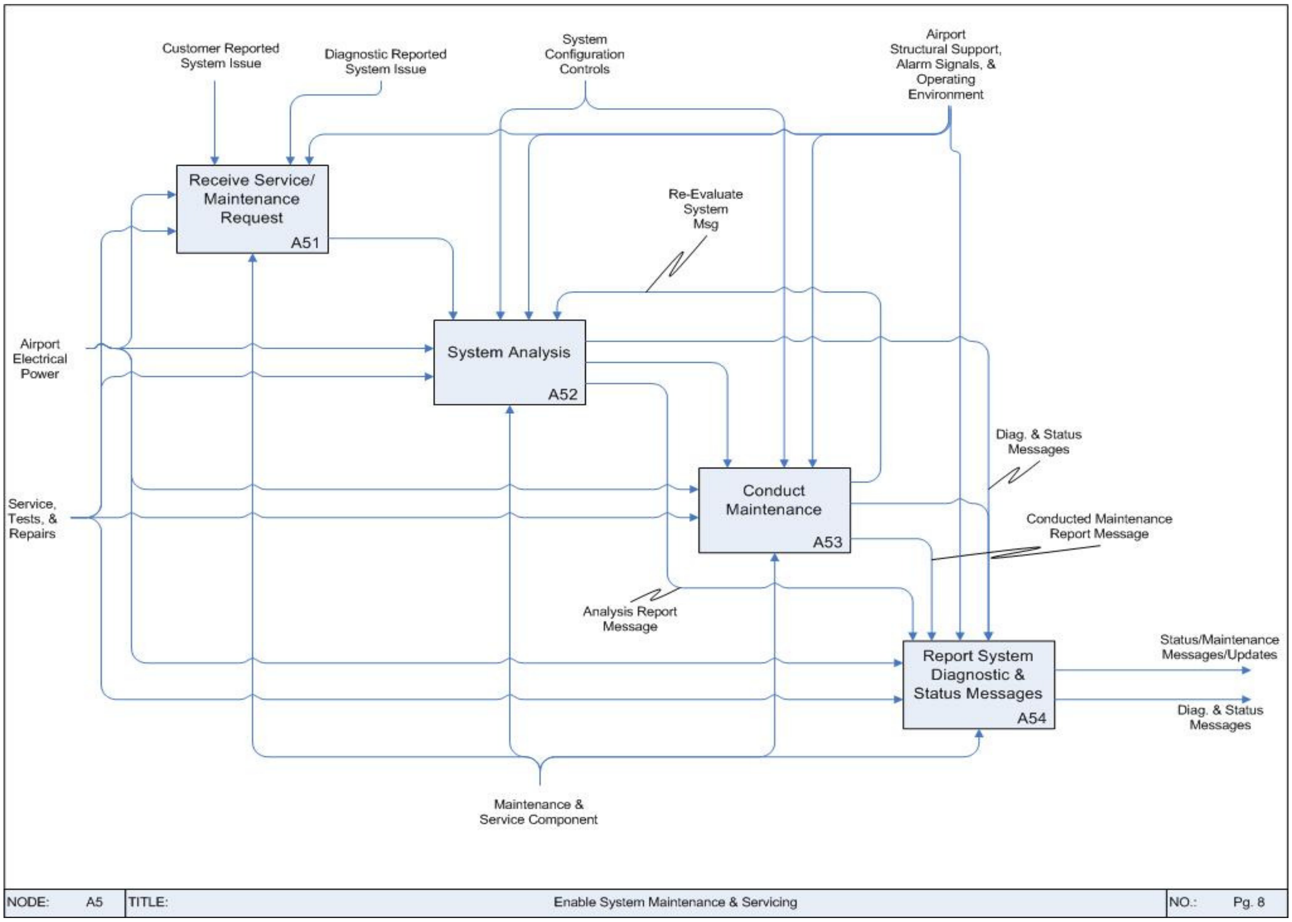

Figure J57 – A5 Diagram

APPENDIX K: FINANCIALS SENSITIVITY ANALYSIS

	Cost of Capital			Price Escalation			Fee & Fringe Rate			System Price			Consulting Factor		
	Scenario	Value	Probability	Scenario	Value	Probability	Scenario	Value	Probability	Scenario	Value	Probability	Scenario	Value	Probability
SaaS	Low	5.0%	25.0%	Low	1.03	30.0%	Low	30.0%	15.0%						
SaaS	Nominal	10.0%	65.0%	Nominal	1.075	40.0%	Nominal	45.0%	55.0%						
SaaS	High	30.0%	10.0%	High	1.1	30.0%	High	55.0%	30.0%						
SaaS															
SaaP	Low	5.0%	25.0%	Low	1.03	30.0%				Monopoly	$ 1,000,000.00	10.0%	Low	0.25	30.0%
SaaP	Nominal	10.0%	65.0%	Nominal	1.075	40.0%				Aggressive	$ 750,000.00	25.0%	Nominal	0.35	40.0%
SaaP	High	30.0%	10.0%	High	1.1	30.0%				Fair	$ 600,000.00	55.0%	High	0.55	30.0%
SaaP										Competitive	$ 500,000.00	10.0%			

Figure K58 – Sensitivity Analysis Parameters

K.1. INFLUENCE DIAGRAMS

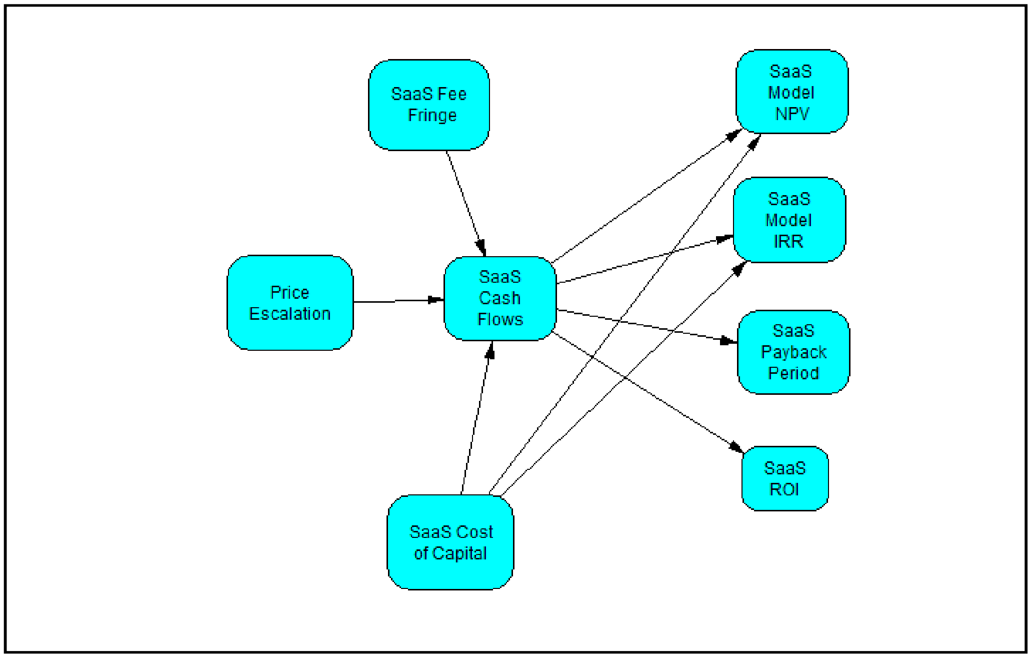

Figure K59 – SaaS Deterministic Influence Diagram

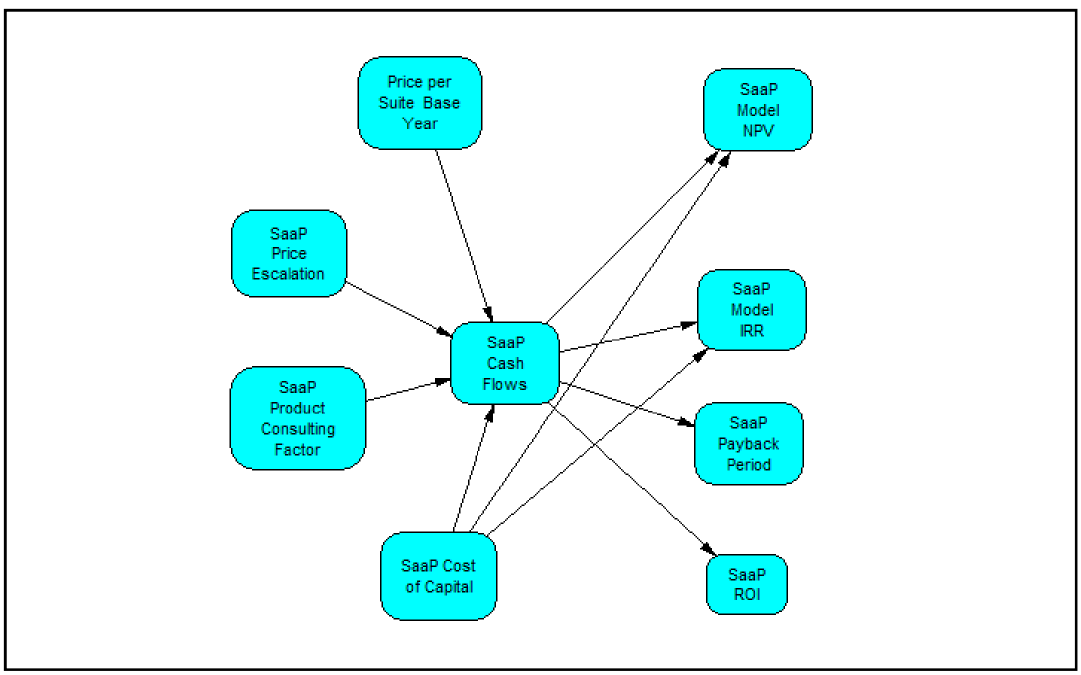

Figure K60 – SaaP Deterministic Influence Diagram

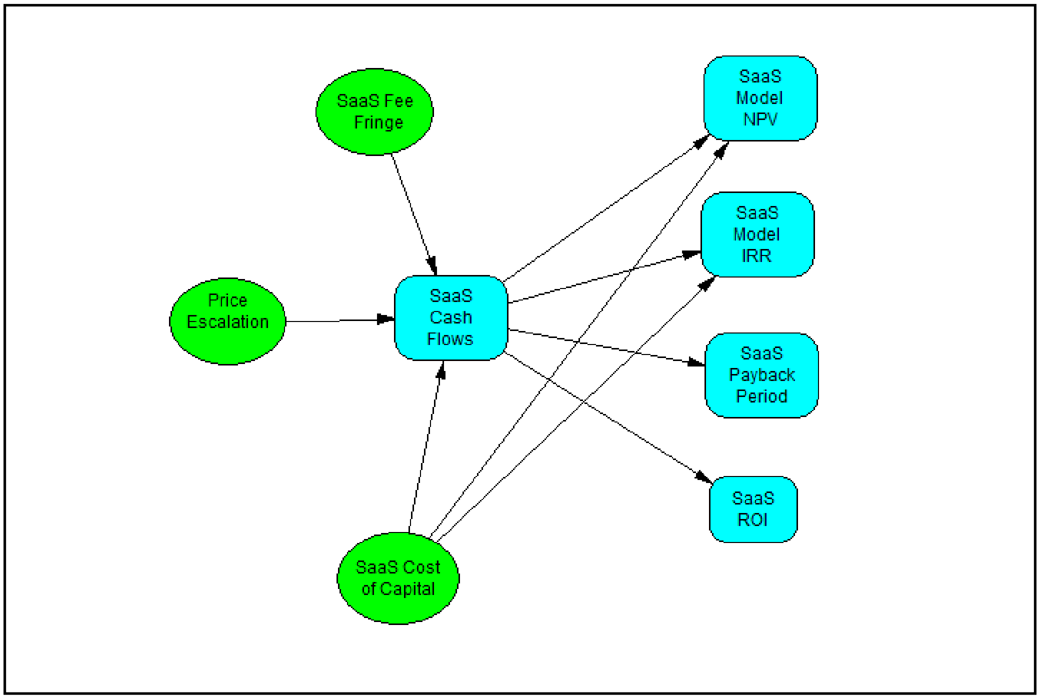

Figure K61 – SaaS Discrete Stochastic Influence Diagram

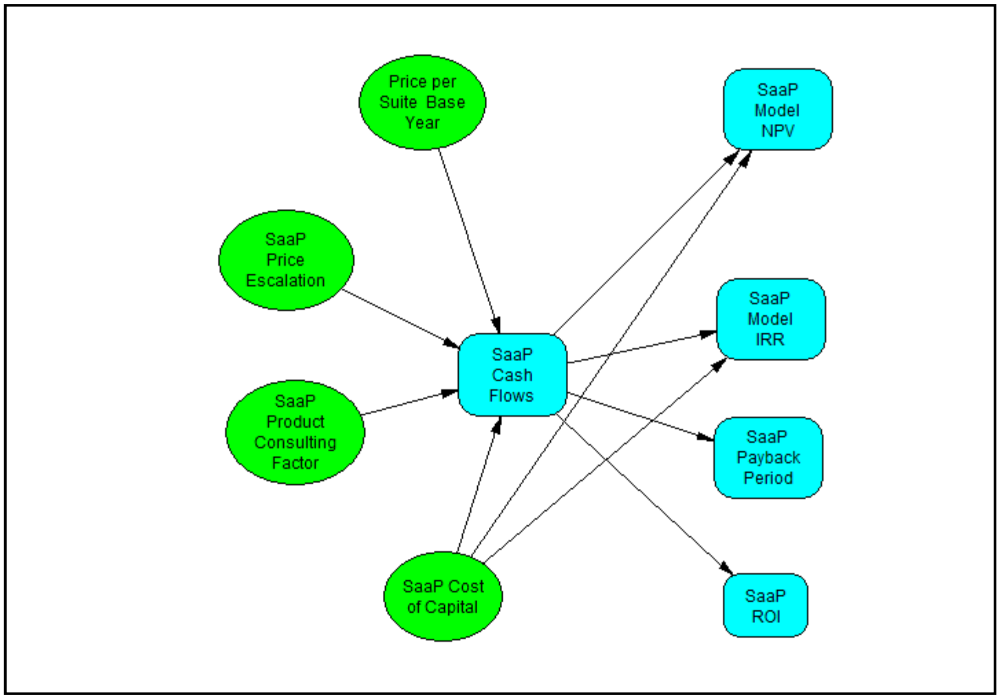

Figure K62 – SaaP Discrete Stochastic Influence Diagram

K.2. TORNADO DIAGRAMS

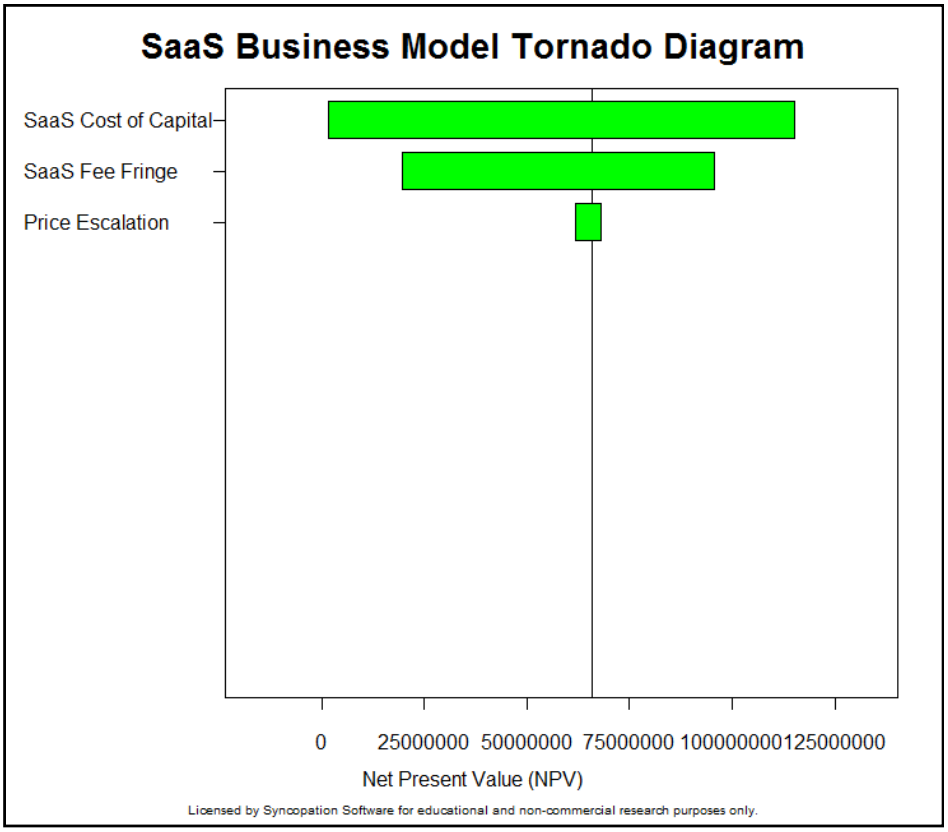

Figure K63 – SaaS Tornado Diagram

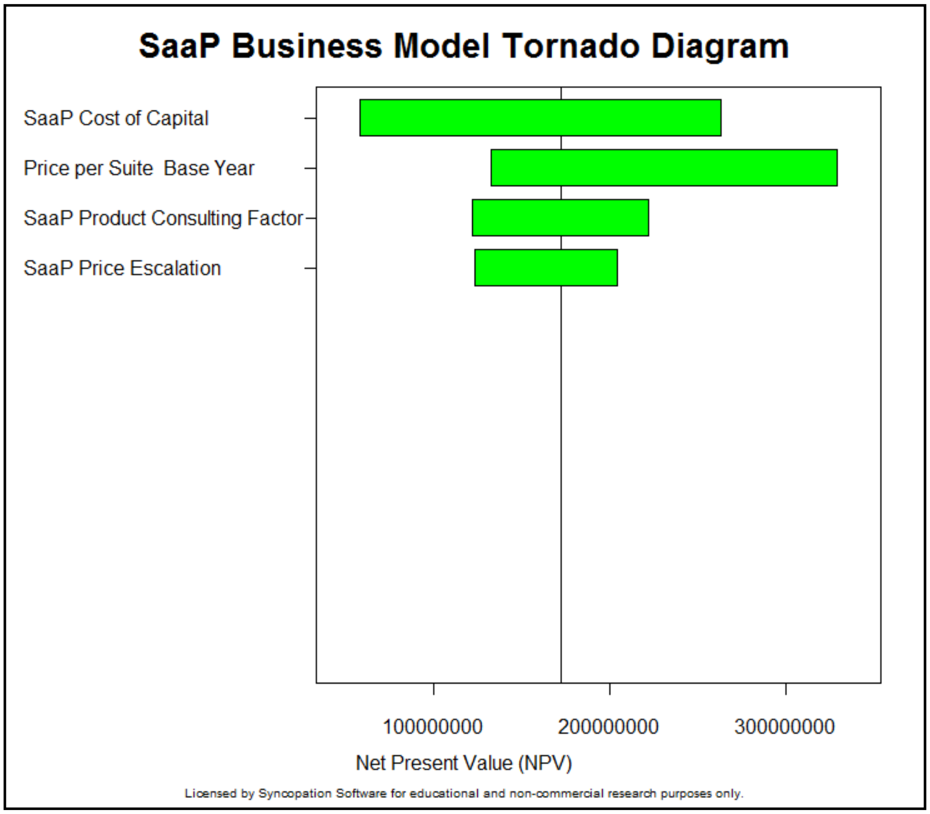

Figure K64 – SaaP Business Model Tornado Diagram

K.3. Cumulative Distributions

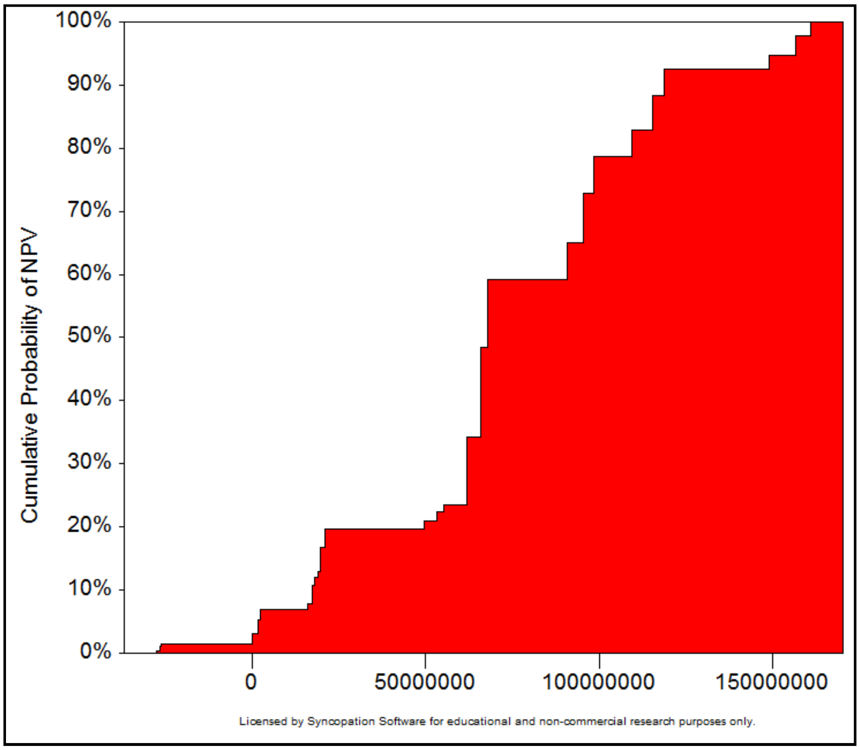

Figure K65 – SaaS Business Model NPV Cumulative Probability Curve

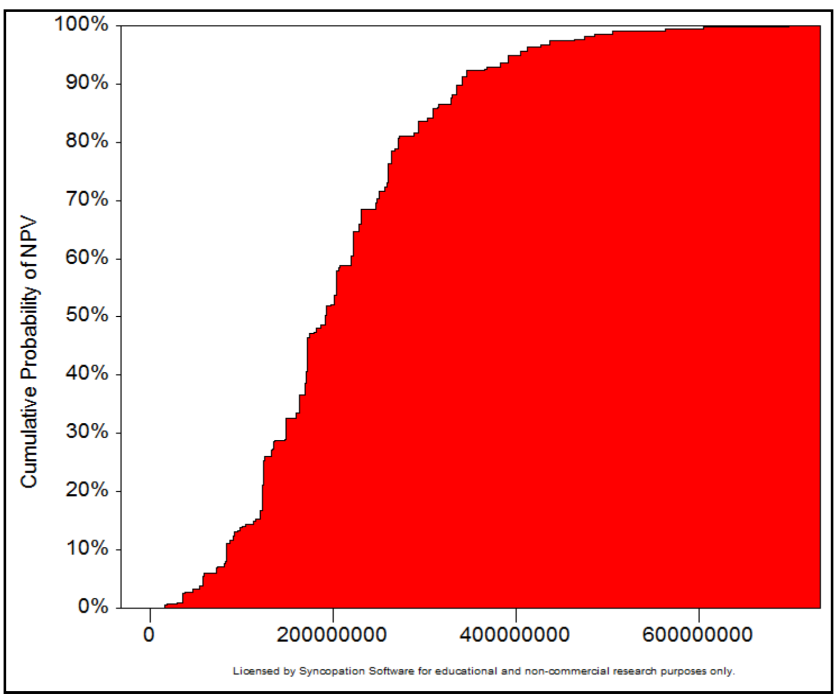

Figure K66 – SaaP Business Model NPV Cumulative Probability Curve

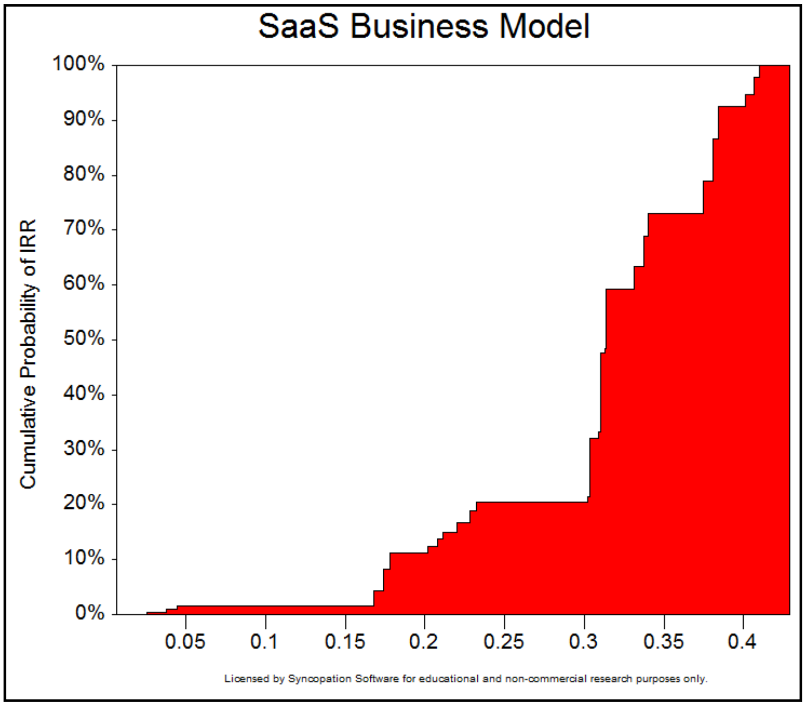

Figure K67 – SaaS Business Model IRR Cumulative Probability Curve

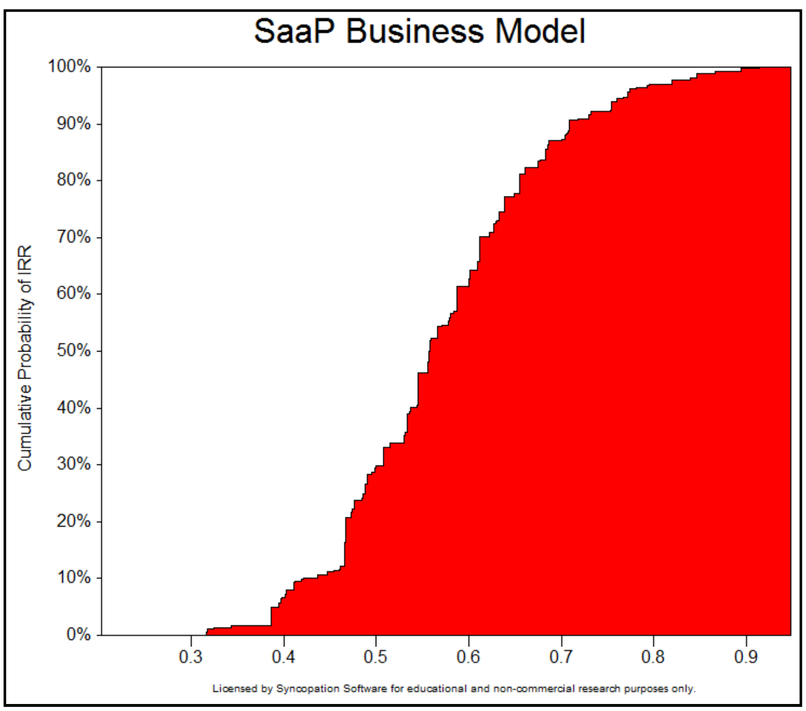

Figure K68 – SaaP Business Model IRR Cumulative Probability Curve

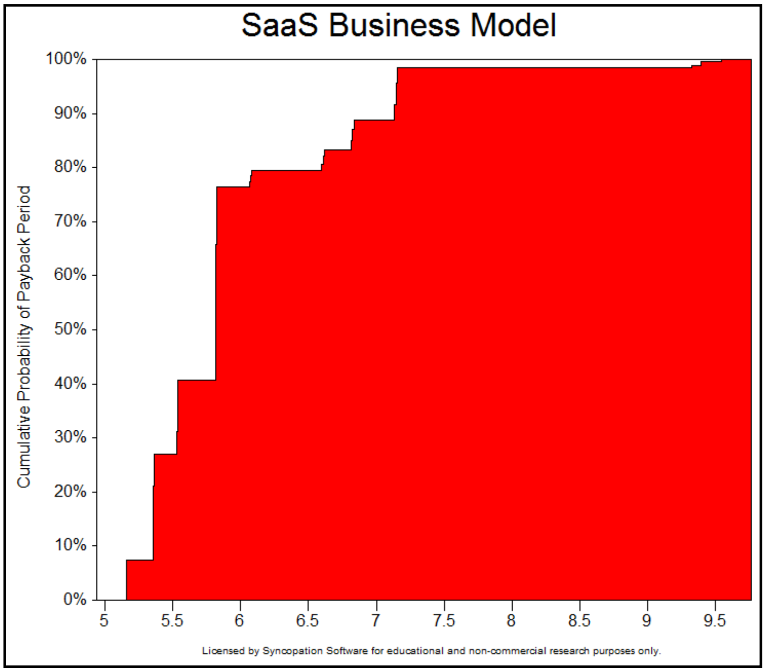

Figure K69 – SaaS Business Model Payback Period Cumulative Probability Curve

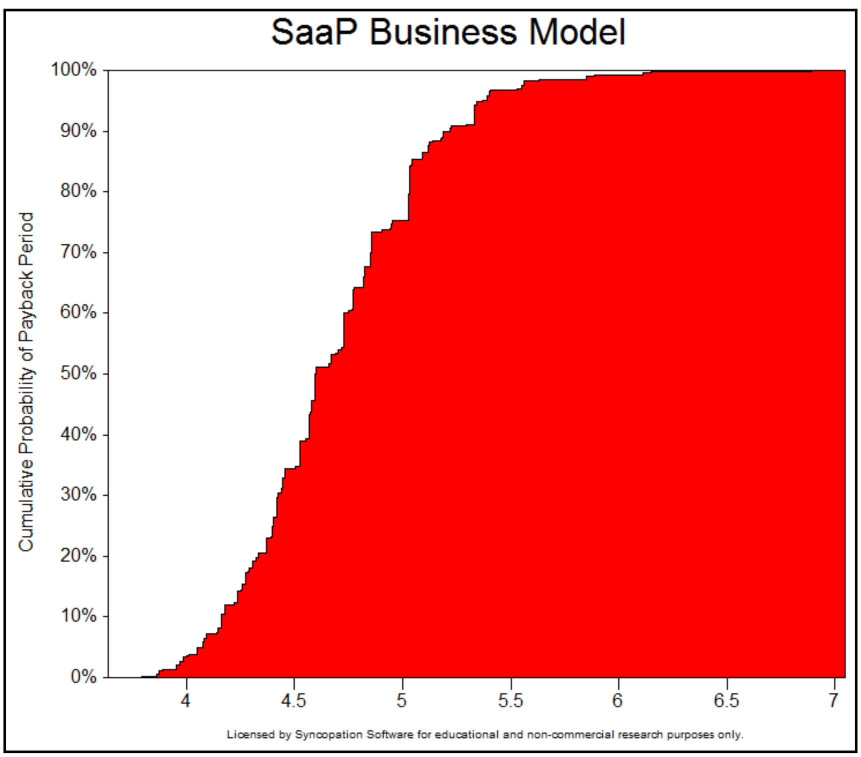

Figure K70 – SaaP Business Model Payback Period Cumulative Probability Curve

REFERENCES AND Works Cited

Wikipedia, http://en.wikipedia.org/wiki/S&P_500#Total_Annual_Returns_.28b.29.

Haynie, C. R. 2002. An Investigation of Capacity and Safety in Near-Term Airspace for Guiding Information Technology Adoption, doctoral dissertation, George Mason University, Fairfax, Virginia.

Yue Xie, John Shortle, George Donohue . 2004. Airport Terminal - Approach Safety and Capacity Analysis Using an Agent-Based Model.

ATH Group Inc. 2009. <http://www.athgrp.com/attila.html>

Randall Bone. 2008. Merging and Spacing and Implementation Plan

Stephen Szurgyi, Sanjiv Shresta, Dejan Neskovic, James DeArmon, and Scott Williams. 2009. Analysis of Observed Aircraft-to-Aircraft Separations, The MITRE Corporation, Center for Advanced Aviation System Development (CAASD), McLean, VA .

"The ADS-B / TCAS / ATCRBS/Mode S Transponders Home Page." Federal Aviation Administration. http://adsb.tc.faa.gov/

Vetter, Doug. "Avionics 2004:Traffic Information Services and the GTX330." Doug's Domain. 2004. http://www.dvatp.com/aviation/maintenance/avionics_2004/

Read, B.C. "Developing the next generation cockpit display system." Aerospace and Electronic Systems Magazine. 1996. IEEE. Oct. 1996. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=538798&isnumber=11614

"Controller Pilot Data Link Communications." Wikipedia. 2007. http://en.wikipedia.org/wiki/Controller_Pilot_Data_Link_Communications