RUNWAY OPERATIONAL QUALITY ASSURANCE

(ROQA)

FINAL PROJECT REPORT

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1. Context

Having the availability of air transportation plays a big role in maintaining a good economy. A well designed air transportation system is a back bone of a strong economy. According to the FAA report on the economic impact of aviation on the US economy states that economic activity attributed to civil aviation-related goods and services totaled $1.3 trillion in 2009, generating 10.2 million jobs with $394.4 billion in earnings. Aviation accounted for 5.2 percent of GDP, the value-added measure of economic activity [1]. In addition to that, the impact of aviation to the U.S G.D.P (Gross Domestic Product) has contributed 5 percent in average even during the 2001 and 2008 recessions. The table [2] below shows the overall trend of the impact of aviation to the U.S economy in terms revenue and number of jobs created for almost a decade.

Year	Output ($Billions)	Earnings ($Billions)	Jobs (Thousands)	Percent of GDP
2009	1,311.2	394.4	10,186	5.2
2008	1,437.1	432.6	11,138	5.5
2007	1,409.7	423.7	10,901	5.6
2006	1,307.8	393.5	10,149	5.4
2005	1,206.3	363.4	9,413	5.3
2004	1,106.2	333.4	8,641	5.2
2003	1,012.9	305.1	7,876	5.0
2002	1,003.1	301.1	7,740	4.7
2001	1,077.8	323.6	9,383	4.8
2000	1,131.0	339.5	9,891	5.2

Table 1: Summery, Impact of aviation on the U.S economy 2000-2009

Every year, millions of passengers go through airports across the nation. Due to the increasing number of passengers, airport operations (landing and takeoff) have increased. For instance, from 2011-2012, over 1.5 million airport operations were carried out just from the ATL airport and in New York, where over one third of all United States air traffic flies in an out of its airports, there were over 3.5 million airport operations [3]. If airports like the ones in New York or Atlanta become too congested, there needs to be an increasing level of capacity to meet demand for air transportation. Since the overall economic activity is associated with a demand for an increase in air transportation, the capacity should also meet the level of expectation. The figure below shows that how the increase in demand of air transportation through the years has an impact on the US economic activities. [4]

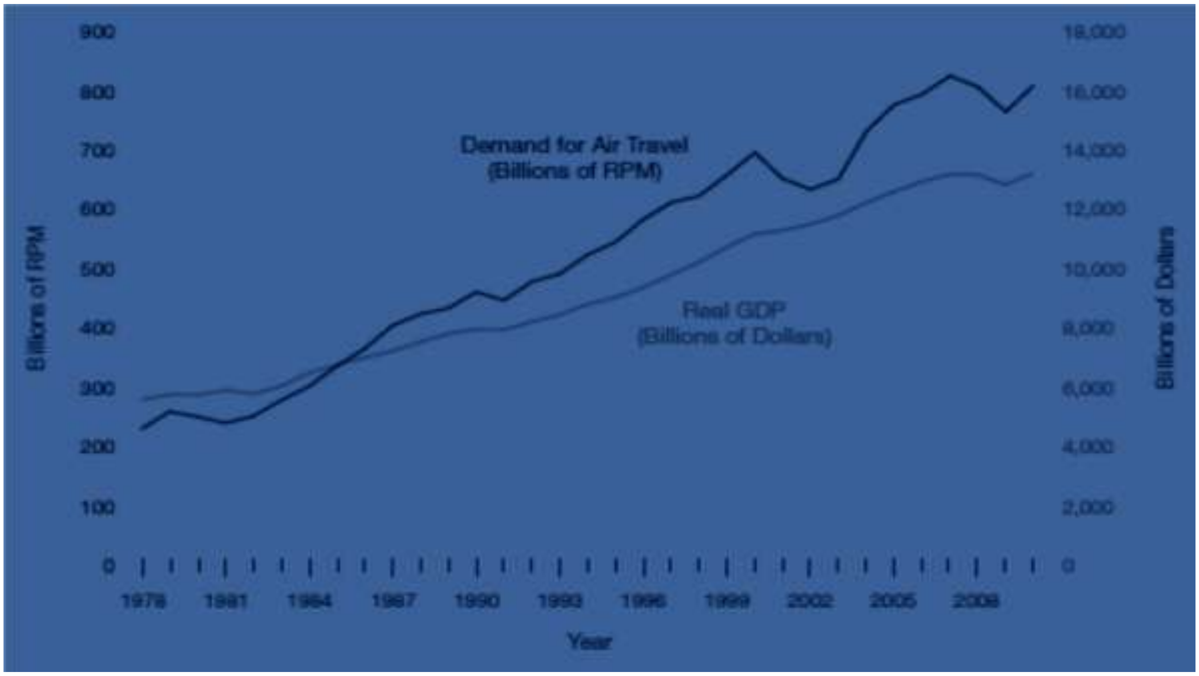


Fig 1: The Economy and Demand for Air travel

In order to endure the increase in the demand for air transportation, the capacity of the air transportation system should also be improved. According to FAA report, the demand for runway capacity has grown 2% in 2011 [5] and the delay costs due to the strain on airport capacity will continue to grow unless the current capacity issues, especially at the major international airports across the United States, are fixed. Delays at major airport and in the NAS (National Aviation System) have been increasing through the years due to the increasing number of passengers. According to the BTS (Bureau of transportation statistics) report, airport operation and heavy traffic volume contributes for more than one third (average) of flight delays in the NAS [6]. The figure below shows different factors for flight delays. [6]

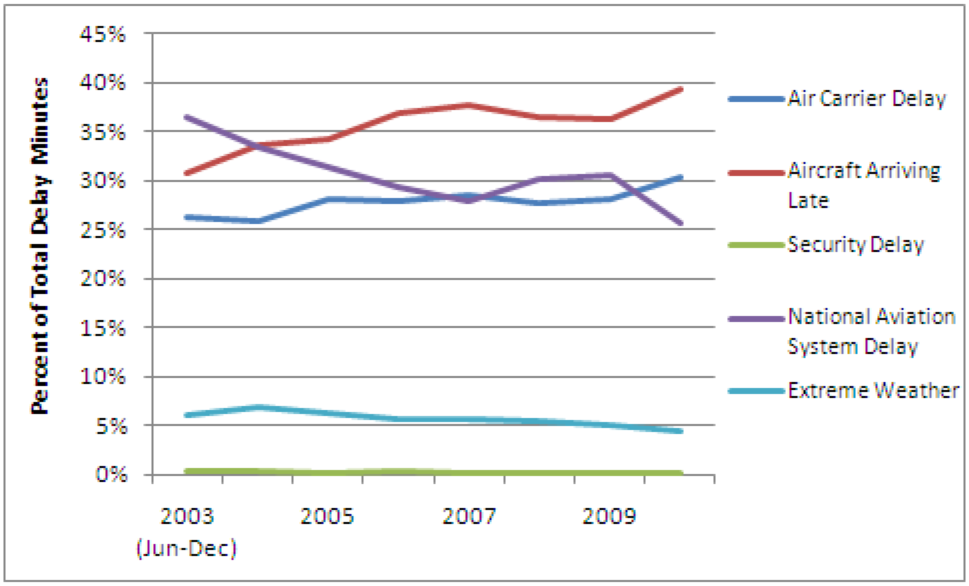


Fig 2: Causes of Flight Delays through the years

Airports have taken different alternatives in order to meet the increasing demand for air transportations. For instance, airports such as ATL international and Dulles international airports have invested millions of dollars in infrastructures such as runways. Although building new runways could be considered a direct approach to fix the increasing airport operations, it has limitations.

- **Expensive** – building new runways costs money. For instance, ATL airport had added Runway (R10-28) in 2006 by spending $1.28bln.[7]
- **Not enough space –** runways need space and airports in populated areas don't have the resources to build. Majority of the OEP-35(Operational Evolution Partnership) airports are located in metropolitan areas.
- **Environmental Impact -** building new runways has an impact on surrounding ecosystem(animals and plantations)

- **Negative influence –** building runways need an approval from authorities at city, county, state and federal level. Passing through different level of government would take time

In order to meet the demand for air transportation, the appropriate approach is to increase runway capacity by utilizing all the exciting resources systematically. The FAA air transportation forecast shows that even with the increase capacity with the new runways at different airports, the demand for more capacity will exceed the current level of capacity at major airports. FAA analysis on OPE-35 airports identified 14 airports and eight metropolitan areas that will need additional capacity beyond what is already planned. Six of these airports and four metropolitan areas are a continuation of the additional capacity needs beyond what is already planned for 2025. [8] If a method is not designed to meet the capacity, it is not possible to meet the demand by pumping money towards runway infrastructures only. In order to meet the demand for air transportation, the appropriate approach is to increase runway capacity by utilizing all the exciting resources systematically.

With the application of different technology to full potential, it is possible that airplanes could safely get closer together than they currently are. If they are closer together, then they can land and depart faster with a more consistent flow pattern and this would directly increase runway capacity. There is however a trade-off between maximizing runway throughput and safety. Airports as well as the pilots flying the airplanes always have the goal to improve efficiency while stakeholders, including ATC's and the FAA, have to maintain a certain safety level. Both ATC and FAA understand that there are risks that come with reducing separation. However, the big questions should be answered is finding the balance between safety and separation in order to maximize runway capacity.

For clarification purposes, below are listed some important terms which define the takeoff and landing operations on the runway.

- ***IAT (***Inter Arrival Time) time of consecutive aircraft to the Final Approach Fix
- ***ROT (***Runway Occupancy Time) is the length of time required for an arriving aircraft to proceed from the runway threshold to a point clear of the runway
- **SRO** (Simultaneous Runway Occupancy) is not allowed by the FAA under the current regulations

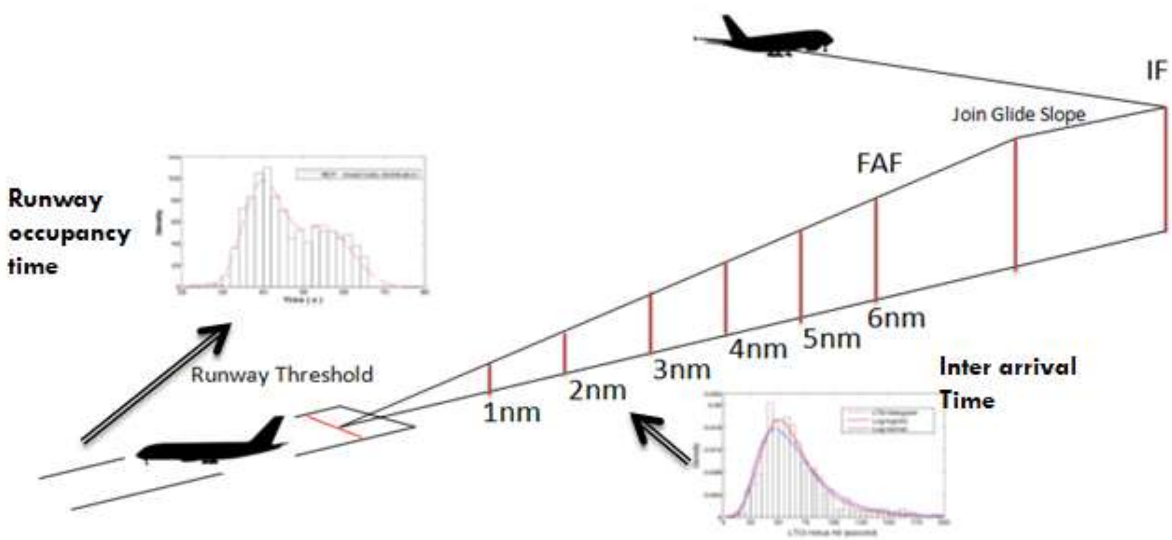


Fig 3- Arrival Process Diagram

Above is an arrival process diagram which represents the scope of our system. The aircraft enters into initial approach (IF) at altitude at about 2,500 ft. Then the aircraft follows a path from initial approach to final approach when the aircraft begins to descend to about 1,200 ft. Finally the aircraft touches down on the runway at a few hundred feet from the runway threshold.

The probability density functions shown above represent distributions characterizing the actions of aircrafts through each phase of landing. The inter arrival time (IAT) distribution shows the time between each aircraft through the final approach fix. The runway occupancy time

(ROT) represents how long each the aircrafts are on the runway as they land. An emphasis on runway safety is vital because of the stochastic nature of the landing process. In the FAF, aircrafts fly at high speed and close to each other.

The main points to focus on are the runway occupancy time (ROT) and the inter-arrival times into the final approach fix (IAT) to increase capacity. ROT is dependent on the fleet mix of arriving aircrafts and the time it takes each different aircraft to exit the runway after it crosses the threshold. IAT depends on the fleet mix, the minimum wake vortex separation distance and an added ATC buffer which is usually ten seconds with varying standard deviation.

Capacity of a single runway is determined by the throughput in a given amount of time. It defines the average movements (arrivals) that can be performed in an hour time. Capacity can be determined by the IAT and the ROT.

- The capacity of the runway to meet **SRO** (Simultaneous Runway Occupancy) runway determined ROT (runway occupancy time)

  Capacity(1 hr) = 3600sec/ $\Sigma[\mathrm{ROT}]_i$

- The Runway throughput for a runway with homogeneous fleet mix to account for the **ATC Separation Buffer** for maintaining **Wake Vortex Separation Distance** requirements is determined by the separation distance plus the **buffer distance**.

  Capacity (1 hr) =3600/(Σ_{tij} + b)

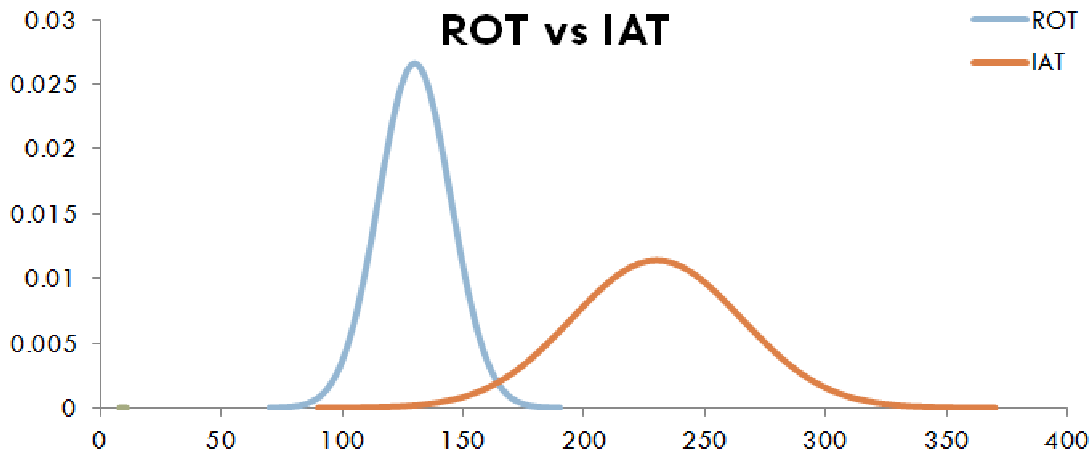


Fig 4 –Overlap of ROT and IAT pdf

Safety

Above is the joint distribution of runway occupancy time and lead time interval. Runway occupancy time shown in red describes the time an aircraft stays on a runway. Lead time interval shown in blue signifies the probability when a plane might land on the runway. The joint distribution or overlap between these two distributions gives the probability of Simultaneous Runway Occupancy (SRO). Current FAA regulations state that there should be no simultaneous runway occupancy or in other words that this probability should be 0. Clearly that is not the case as studies have shown that there is in fact always a probability of these occurrences as long as there is air traffic. Right now since this is measured as a discrete event it is only observed right when it happens. Measuring this occurrence and safety in general as probabilities gives more substantial information on the safety and performance of a runway.

1) Throughput vs. Safety

Wake turbulence encounter and SRO are the two main events to avoid when dealing with the safety of incoming aircrafts. Unfortunately reducing these risks (separating aircraft more) comes at the price of reducing runway throughput.

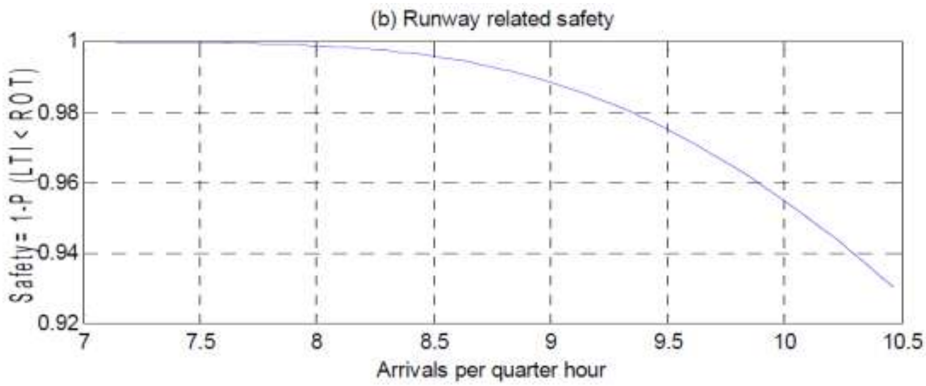


Fig 5 Arrivals vs. Safety – Runway safety decreases as throughput increases

The relationship between average throughput and runway related safety is shown in figure 5. Safety is defined by 1 minus the probability of SRO or 1-P(LTI<ROT). Throughput is shown as arrivals per quarter hour. Safety is sacrificed as average throughput increases.

Essentially the problem comes down to having to increase runway throughput and making sure that runway safety is properly maintained. This is problematic because the safety and runway throughput have shown to have an inverse relationship.

Capacity

To address the capacity shortfall, the FAA has planned to implement a new National Airspace System called the Next Generation Air Transportation System or NextGen. NextGen will be implemented in stages between 2012 and 2025. The system proposes to convert the aging ground based airport system to a satellite-based system using more GPS technology. Several new technologies part of the new system could improve runway capacity.

1) Automatic dependent surveillance-broadcast (ADS-B)

ADS-B is a surveillance technology part of NextGen which will allow for more precise positioning of aircrafts monitored by GPS. Pilots will be provided a display which will show all the aircrafts in the vicinity and show their altitude, speed and direction of flight. ATC will also be given this information and will be able to project the position of each aircraft as time progresses. The ability for air-traffic controllers and pilots to pinpoint an aircraft's location more precisely can make it possible to reduce in-trail separation.

This new technology proposes to reduce the variances of ROT and IAT (by reducing the ATC buffer standard deviation. Once the variance is reduced the means can be shifted resulting in increased capacity.

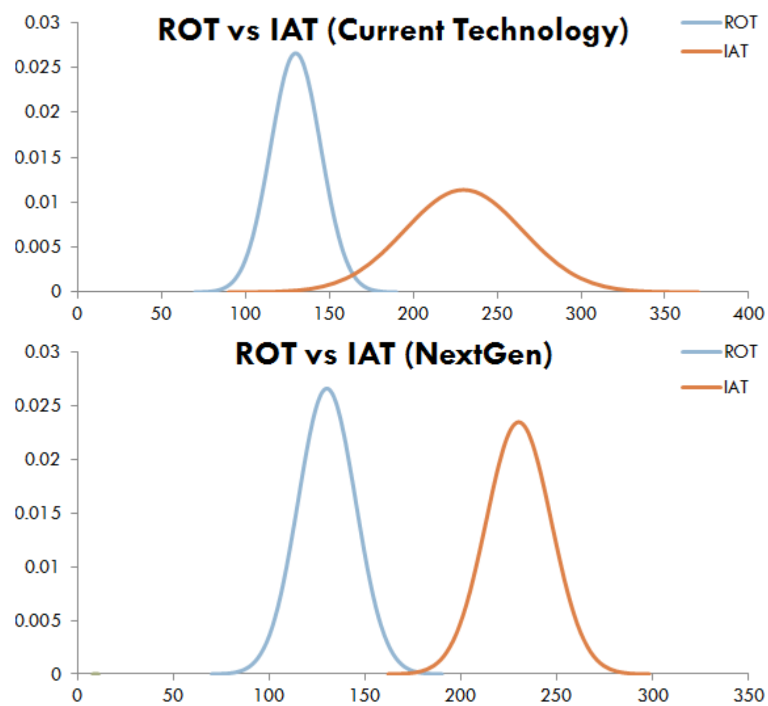


Fig. 6 Comparison between ROT vs. IAT for current technology and NextGen technology

Figure 6 is a conceptual look at how NextGen technology can be used to improve throughput and maintain safety. The figure portrays the union set between ROT and IAT and shows the difference between the union set for current standards and conceptual with NextGen technology implemented. ADS-B proposes to reduce the IAT variance. The bottom figure shows a decreased overlap between the distributions than the top figure which shows current technology. The expected decrease in variance from the IAT distribution is expected to also reduce the probability of simultaneous runway occupancy or P(SRO). In theory the improvements of NextGen could lead to reduced variance of these distributions, but its effects on throughput and safety are not known.

2. Stakeholder Analysis

The effective use of terminal airspace is dependent on the collaboration and operational capability of all stakeholders that are involved in aviation system. The major stakeholders of the ROQA system are the FAA, ATC, airports, airlines, and pilots. Safety and efficiency are the two important elements which determine the aircraft flow on the runway. The ROQA system would help the stakeholders to find the trade-off between these two elements. The cooperative contribution between the stakeholders would contribute in major way to make the terminal airspace safe and efficient.

<u>The Federal Aviation Administration (FAA)-</u>

The FAA has a major stake in airport operations. The FAA has different rules and regulations to keep the runways and the airspace environment safe. The FAA is working on different technologies such as Nextgen in order to keep the number of incursions minimal in runway operations. ROQA would be an addition to the existing regulations by applying a statistical based model. Under the FAA, the ATO (Air Traffic Operations) would be the primary use of the ROQA system. The main objective of the ATO is to move air traffic safely and efficiently. The ATO has different divisions such as the Terminal services, Safety and Technical Training and Technical Operation services which work together to maintain the safety of the runway by deploying different surveillance technology. In addition to ATO, departments such as the Federal Aviation Safety Officer (ASO) and Office of Airport safety and Standards work with ATC and airports by applying different programs in order to achieve the safety of the runway.

ATC controllers

ATC (Air traffic controllers) are the people who make the important decisions every day in airport operations and specifically on the runway. ATC controls all the movements of the arriving and departing aircrafts on the runways and taxiways. The primary focus of the Air traffic controllers is to make sure that aircrafts are moving safely separated in the arriving and departing aircraft flow. The ROQA system could be used as a supervisory and a live data safety system by ATC.

Pilots

Pilots are the main users of the runway. There every move on the runway is based on the communication that they have with ATC. Taking off and landing determined by the decision making ability of pilots. According to the GAO (General Accountability Office) report on the runway safety report for the fiscal year of 2007, 57% of runway incursions are caused by pilot error [1]. To deceases this rate of incursion caused by pilots, the ROQA system would be able to make pilots a better decisions makers by giving them a live and updated data in the terminal airspace.

Airlines-

Airlines are the primary users of the runway facilities. Arriving and departing to major airport would have been impossible without runways. Airlines spend millions of dollars in order to use runways. For this reason, airlines want to use the runways to maximum capacity. The ROQA system would be enable airlines to improve the level of performance on the runway.

Airports Runways are owned by airports. Airlines and others service providers pay significant amount to use different facilities at the airport. Airports are responsible for maintenance of

runways and other facilities in the airport vicinity. Airports generate their revenue from aeronautical and non-aeronautical activities; at the same time; airports spend significantly in repaving and widening runways. For instance, the ATL airport generated $45.4 million in profits from Aeronautical and Non-aeronautical activities [2, FAA form 127]. The table below presents the summery of the primary stakeholder for the ROQA system

Primary Stakeholders	**Contribution to the terminal airspace**	**ROQA system contribution**
FAA	Rules and regulation to measure safety	Enhancing level of safety
Pilots	Safe takeoff and landing within the airport airspace	Increase the level of safe movements

ATC	Monitoring safety(separation)	Optimum performance level
Airport	Owns the runways	Increase aircraft movements (Increase profit)
Airlines	Provide air transportation service	• Minimize delay • Maximize Profit*

Table 2- Summary of the Primary stakeholders

a. Stakeholder Interaction with the integration of the ROQA system

The Diagram below shows the interaction among the stakeholder and the ROQA system.

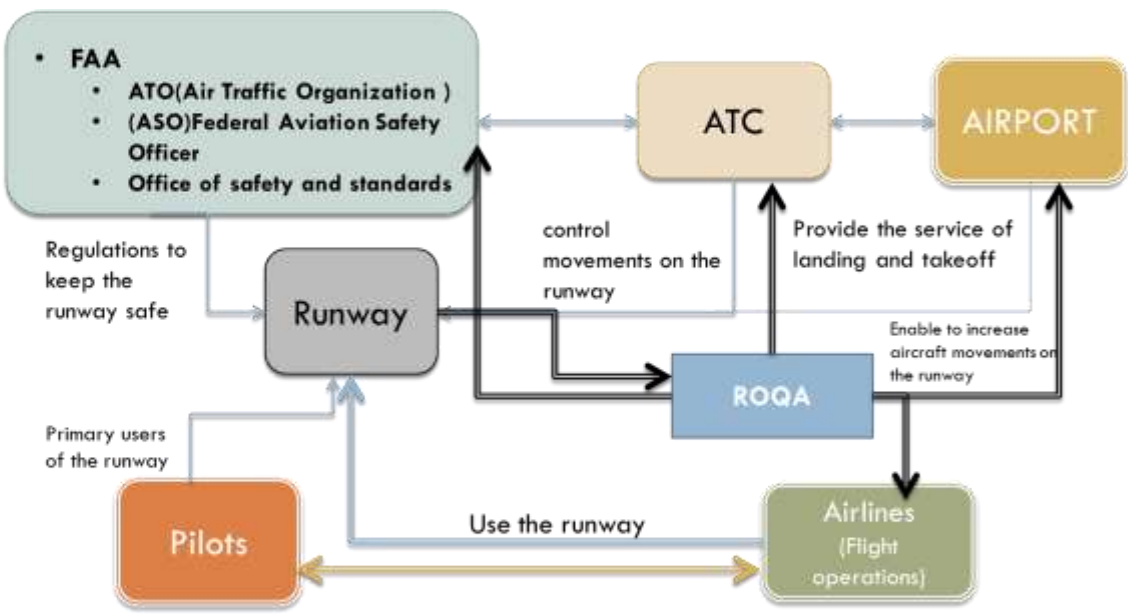


FIG 7- Stakeholder Interaction with the ROQA system and with each other

b. Stakeholder Money Flow

The primary source of funding for the FAA comes from the Airport and Airway Trust Fund (AATF). Created by the Airport and Airway Development and Revenue act, the AATF allocates the funding for the FAA after the details get the approval from congress. AATF generates revenues from the aviation related taxes on passenger, cargo and fuel. After getting the approved, the FAA distributes the fund to different departments such as the ATO. The Diagram below shows that how different department under the FAA get the funding.

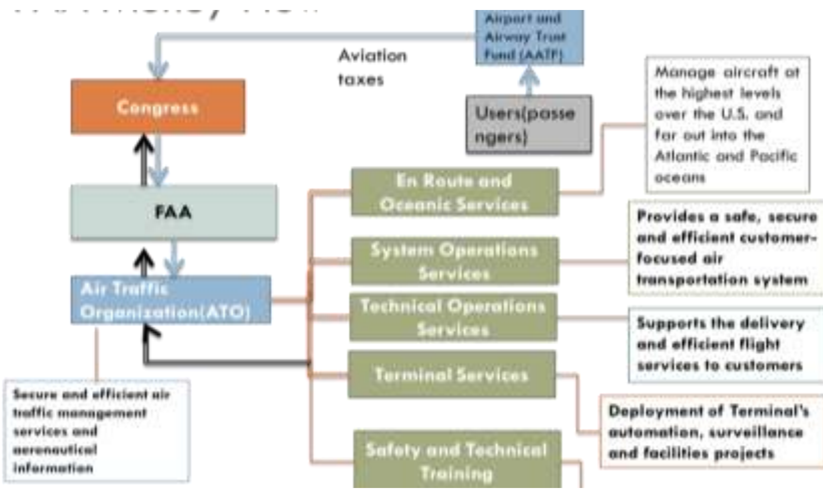


Fig 8- FAA Money Flow

c. FAA Operations

The Diagram below shows the operational structure under the ATO regarding safety.

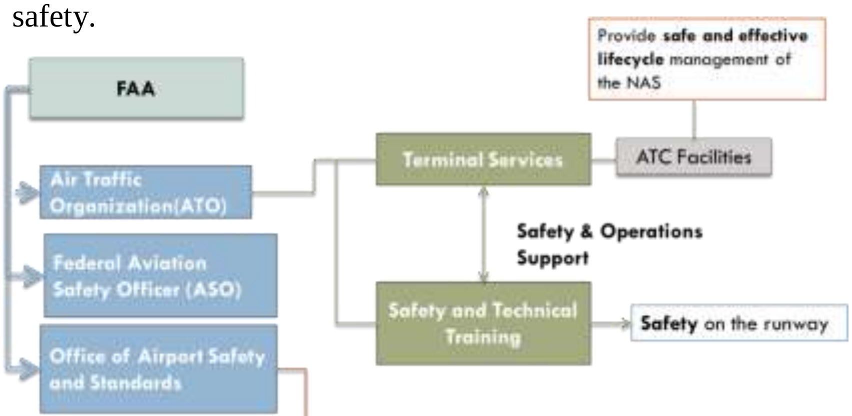


Fig 9- FAA Operational Flow

d. Stockholder tension

- FAA(ATO) vs. Airlines
    - ATO and Office of Airport safety and standards focus on safety conflicts with the airlines focus on wanting to increase capacity.
    - Inverse relationship.
- Airlines vs. Pilots
    - Airlines want to increase capacity(aircraft movements) therefore increasing profit while pilots have their own(aircraft) safety in mind

3. Problem Statement

The arrival of an aircraft to a runway is a stochastic process, but in order to measure any part of the system, it must be modeled as a discrete process. As of right now there are measures that the FAA has taken to reduce runway incursions but none that adequately measures the safety of runway operations in real-time. Current systems provide 15 minute reports on arrivals and departures but the flow of aircraft in a runway is not reported. A proper safety and performance metric can be used to improve system performance. Although maximizing capacity and efficiency is needed, runway occupancy and separation standards employed by the FAA must be followed.

Since no current real-time safety metric for flow of aircraft is being used right now, airports have no indication of whether or not they are maintaining proper safety. Regulations on runway occupancy and separation stand in the way of increasing runway capacity. Occupancy of a runway delays another approaching aircraft’s clearance to land. The separation (due to wake vortex turbulence) between each aircraft also limits the flow of incoming aircraft. These two factors combined with other aircraft uncertainties hinder runway efficiency.

4. Need Statement

Due to an increasing number of air passengers expected each year, bottlenecks have developed on runways as arriving aircraft await permission to land. This is a main factor contributing to delays and aviation accidents. With an increase in air traffic at airports capacity must also be increased while maintaining proper safety.

A system to monitor the safety and increase capacity of runway operations is needed in order to improve efficiency. A way to increase capacity is to make a reduction in safety separations. A methodology for measuring safety and flow of incoming aircraft will be beneficial in keeping track of and improving runway operations. A balance between safety and efficiency must be defined in order to improve runway.

5. Mission Requirements

1. The system shall have compatibility with airport surveillance devices such as ASDE-x(Airport Surface Detection Equipment) and AMASS(Airport Movement Area Safety System**)**
2. The system shall take inputs from surveillance data (IAT, ROT, Speed)
3. The system shall provide a report which would include the runway related risk (% SRO + wake vortex encounters) and throughput (arrivals per hour)
4. The system shall operate within 3-8 miles of runways signifying the final approach fix (FAF)

National Airspace System Requirements Specification (NAS-SR-1000)

1. The system shall have a mean-time between failures (MTBF) of more than 2190 hours
2. The system shall be 99.9 % available 24/7 under any weather conditions
3. The ROQA system shall not require more than 30 minutes mean time to repair (MTTR)

6. Design Plan

a. ROQA system Design

The ROQA system would have surveillance data input from ASDE-x (Airport Surface Detection Equipment model-x) . ASDE-x is a runway safety tool which enables air traffic controllers to monitor movements on the runway and taxiways. The ROQA system gets its data from ASDE-x because the of ASDE-x's ability to update itself frequently in order to give an accurate location of where aircrafts are at a given time. After getting the surveillance data from the ASDE-x, the ROQA system would compare and validate the data with the existing or modified aircraft separation on the runway authorized by the ATO and Office of Airport safety and standards.

In the ROQA system, all the computation and validation displayed or given as a report to the FAA (ATO), Airports Managers and ATC supervisors and Airline operational managers. After that the system gives out SRO, separation violations and throughput with some level of confidence interval. The figure below shows the inputs and outputs of the ROQA systems.

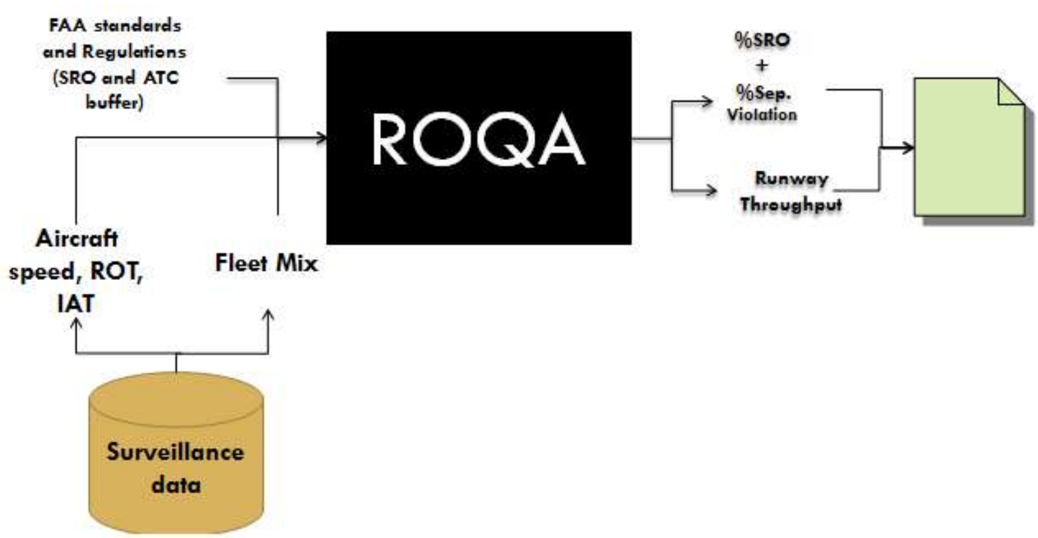


Fig10 – ROQA inputs & outputs

b. ROQA Design Alternative

The two factors that were found to affect safety and capacity are runway occupancy time (ROT) and the spacing of each aircraft. The design alternatives will be chosen based on changing these two main parameters. First, changing the ROT distribution by reducing its standard deviation, second changing the IAT distribution, would be achieved by changing the ATC buffer standard deviation, the third changing the ATC Buffer mean.

c. ROQA Model Flow Chart

The flow chart represents how the ROQA simulation model processes the activities on the runway. The model shows the arrival and departure events to and from the runway. The model considers SRO (simultaneous runway occupancy), ROT (runway occupancy time). In this model, although the arrival rates to the runway are scheduled, the activities on the terminal airspace have stochastic nature. These letters represent the different system characteristics.

t- Arrival time

a- the next arrival time

s_r – runway occupancy time

s_t – separation time between aircraft (required by the FAA)

LP (t) - the number of aircrafts in waiting to land

LS (t) – the number of aircrafts on the runway

A - Arrival event to runway

D – Departure from the runway

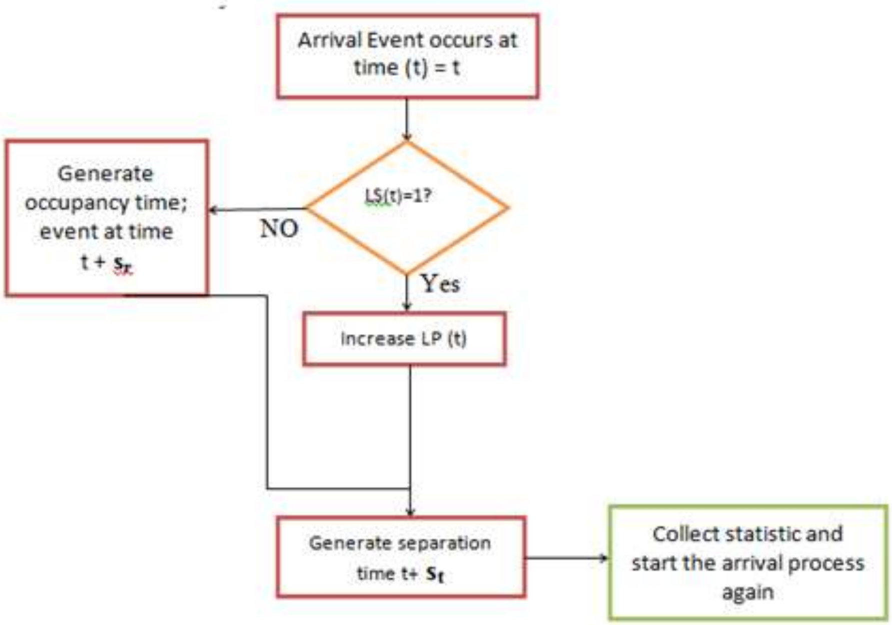


FIG11- Arrival Flow Diagram

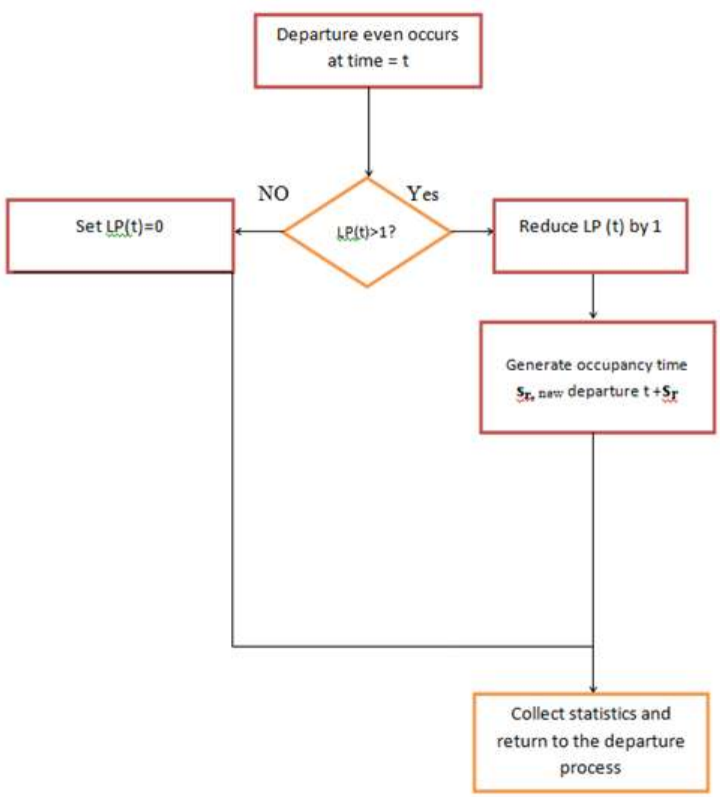


FIG12- Departure Flow Diagram

d. **ROQA simulation**

i. ROQA simulation and Java Prototype

A prototype ROQA system was developed using a Java simulation of the approach and landing process to a single runway. The simulation is used to show how changing several variables in the approach and landing process affects safety and throughput.

Equations

(1) Distance to Runway

Dist(t) = Dist(t-1) – (Ground Speed * Time)

(2) Approach Speed to Ground Speed

Ground speed = cos(Glide Angle) x Approach Speed

(3) NM/Hr to NM/Sec

NM/Sec = NM/Hr * .000278

(4) Compression Case

(3600*(RunwayLen+followSep/followSpeed – RunwayLen/leadSpeed))

(H-HLSM L-LMS M-MS S-S)

(5) Expansion Case

(3600*(followSep*1)/followSpeed)

(6) Compression Time

RunwayLen * (followSpeed-leadSpeed) * 3600

Simulation

A prototype ROQA system, modeling the approach and landing process to a single runway, was developed using Monte Carlo simulation written in Java code. The simulation is used to show how changing several variables in the approach and landing process affects safety and throughput.

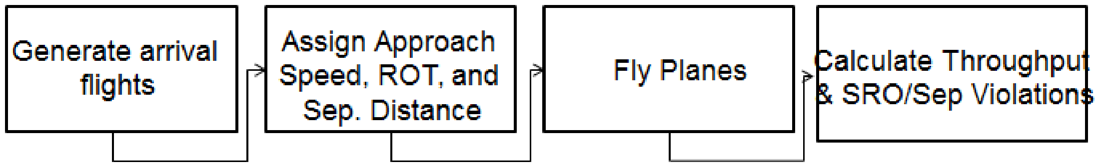


Fig 13- Step by step process for ROQA model

Using a fleet mix representative of DTW airport, where the probability of a small (S), medium (M), large (L), or heavy (H) plane is 13.4%, 6%, 76.6%, and 4% respectively, a random string of *n* nonhomogeneous arrival flights is generated and stored using a linked list data structure. As each aircraft is created, a speed and ROT is also generated and will become associated with that aircraft. Our model assumes that both speed and ROT follow normal distributions and is allowed to do so because the "long tail" scenarios are rare and our model is just concerned with the normal case. Based on whether the plane created is small, medium, large or heavy, a speed is drawn from a normal distribution with mean 90, 110, 130, or 150 with a default standard deviation of 5 and a ROT is drawn from a normal distribution with mean 50, 55, 60, or 70 with a default standard deviation of 5. Our model then assigns a separation distance to each aircraft based on the wake vortex separation distance table. Here the ATC buffer is also accounted for and the model handles the case when the lead plane is faster than the follow, known as the expansion case, and when the lead plane is slower than the follow, known as the compression case. In order to calculate the separation time for the expansion case, the model uses equation (5) in the cases where Lead=H:Follow=H,L,M,S, Lead=L:Follow=L,M,S, Lead=M:Follow=M,S, Lead=S:Follow=S. To calculate the separation time for the compression case, the model uses equation (4) and covers the other cases not included in the expansion cases. The ATC buffer is drawn from a normal distribution with a mean of 10 and default standard deviation of 0.

After creating all the aircrafts, the next step in the model calls "fly", a method of each aircraft, which uses the parameters associated with each aircraft to generate its trajectory starting when the aircraft enters the final approach fix, 6 nm from the runway and down a 3 degree glide slope, until it lands on the runway, updating every second. These trajectories are then used for lead/follow comparisons in order to determine if a separation violation or SRO violation has occurred. If the distance between where the lead plane and follow plane are on the glide slope becomes less than the wake vortex separation distance associated with the follow plane, then a separation violation has occurred. If after the lead plane lands the follow plane has less time in the glide slope than the ROT associated with the lead plane, an SRO violation has occurred. The output from this simulation is the throughput of the runway, and the number of separation violations and SROs which occurred, as a percentage, which will be used to support our design alternatives.

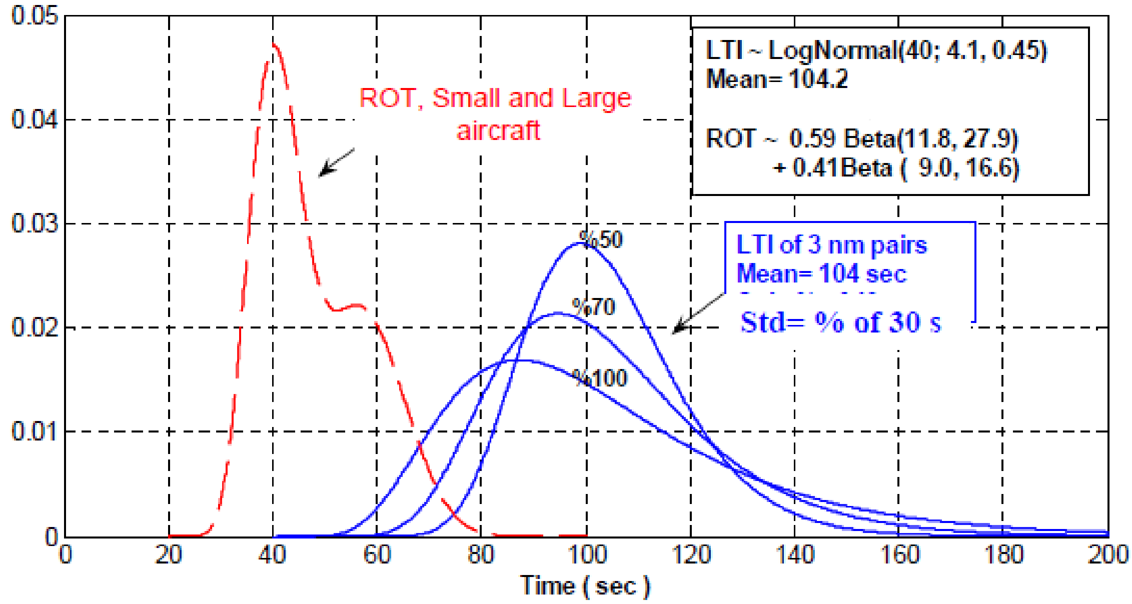


Fig 14- Distributions for ROT and IAT

Visually in the simulation, as we reduce the ROT standard deviation as well as the ATC buffer standard deviation and mean, we will change the shape of the ROT and IAT distributions. As the standard deviation decreases, the distributions become narrower and the overlap representing the probability of SRO decreases. As the mean of these distributions decreases, the overlap will increase as the graphs shift right on along the x-axis, allowing for an increase in capacity.

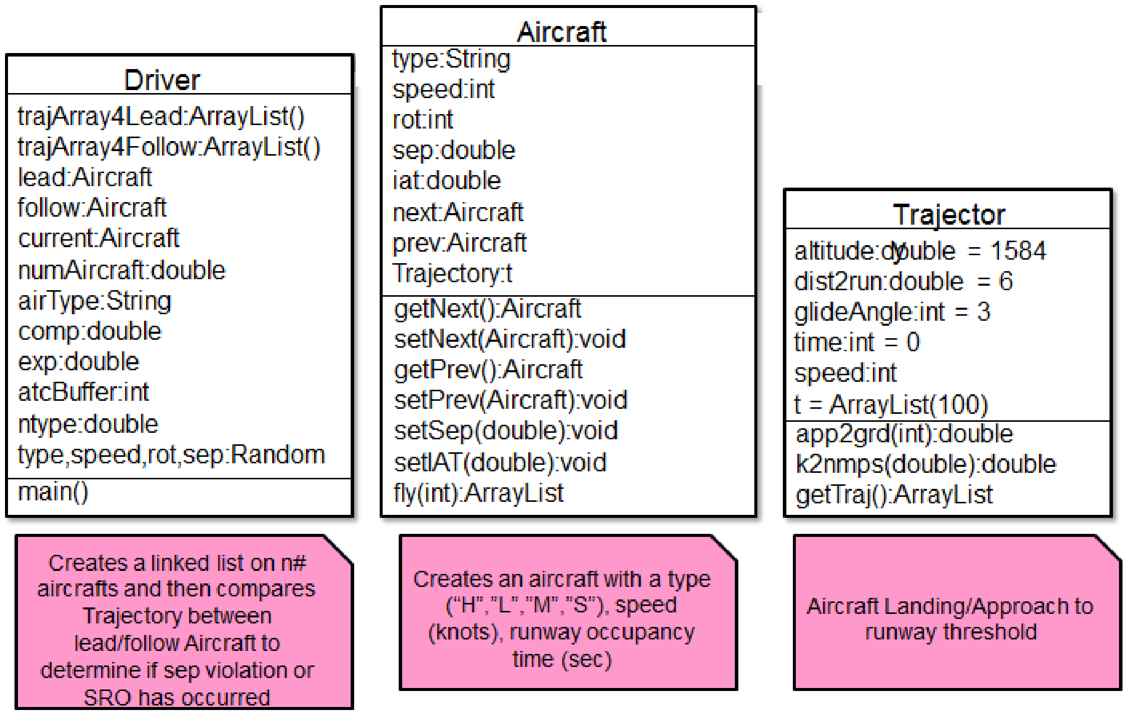
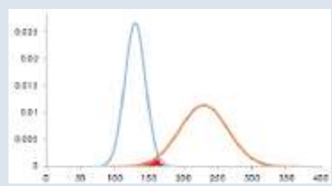
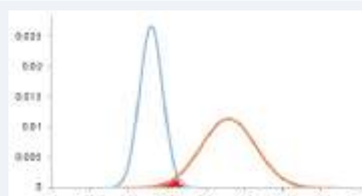


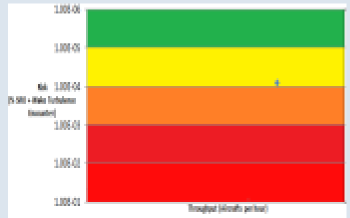
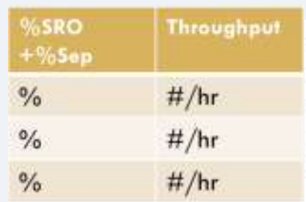
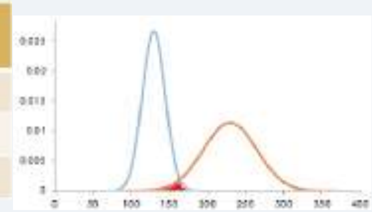
Fig 15 – ROQA class diagram

The simulation is approximately 350 lines long between the three classes. The Trajectory class holds all the information regarding the approach, including the glide angle and distance a plane is from the runway threshold. It is able to update every second, as if real ASDE-X surveillance data were being used, to calculate where a plane is in its trajectory to the runway. This class also handles simple conversions between the given approach speed to ground speed and nm/hour to nm/sec. The Aircraft class holds all the information regarding the aircraft being generated, which includes the associated type, speed, rot, iat, etc. It also has a method, fly, which generates a Trajectory for that aircraft when it is called that will be stored in the Aircraft Trajectory parameter for later comparison. The next and prev parameters are for generating the linked list of Aircraft in the Driver (main) class. It's also for computing, for example, the separation distance based on the Wake Vortex table, as the follow plane needs to know what type of aircraft is ahead of it. In the Driver class, a linked list structure is created to store n# of aircrafts. The driver class loops through the linked list structure to do the Trajectory comparison between lead/follow pairs of aircraft by storing the lead follow trajectories in ArrayLists. The lead plane will have started down the glide slope and after the lead plane has gone the required separation distance + ATC buffer + (possible compression time), the follow plane will enter the FAF. If the distance between the two lead/follow aircraft becomes less than the required FAA separation a separation violation will have occurred. Then if once the lead plane has "landed" on the runway, the follow plane has less time on the glide slope than the lead plane ROT, an SRO violation will have occurred. The simulation is able to switch between distance and time easily because it stores the distance in the ArrayList and uses the length of the ArrayList as the time it spends in the glide slope, since it's been coded to update every second.

Stakeholder Output

Users	Objective	Display
FAA (ATO)	The primary service of the Air Traffic Organization is to move air traffic safely and efficiently	
Airport Managers	The main objective of the airport manager is to ensure the safe and efficient operation of the runway on a daily basis	 %SRO +%Sep | Throughput % | #/hr % | #/hr % | #/hr

Users	Objective	Display

ATC supervisors	Responsible for the coordination and facilitation of the inbound movement of airplane	
Airline Operation Managers	Main objective is to look after both air traffic and ground operations control	 %SRO +%Sep / Throughput % / #/hr % / #/hr % / #/hr 

The output for each stakeholder is dependent on their goals in terms of monitoring the runway. The FAA will be given distributions as well as the safety information. Airline managers and airport managers will be given the distribution and the safety and throughput output from the simulation. The ATC supervisors will be given a simplified version of the output of throughput vs. safety.

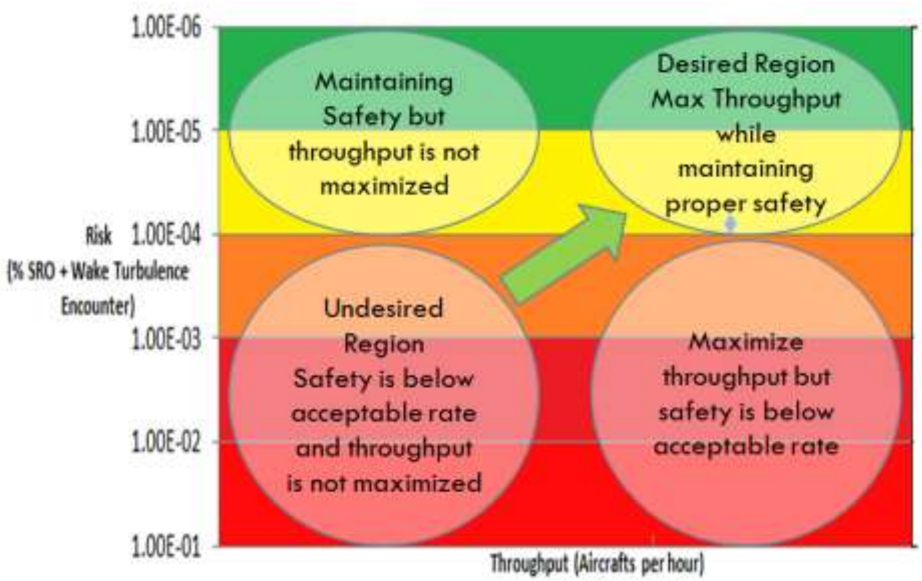
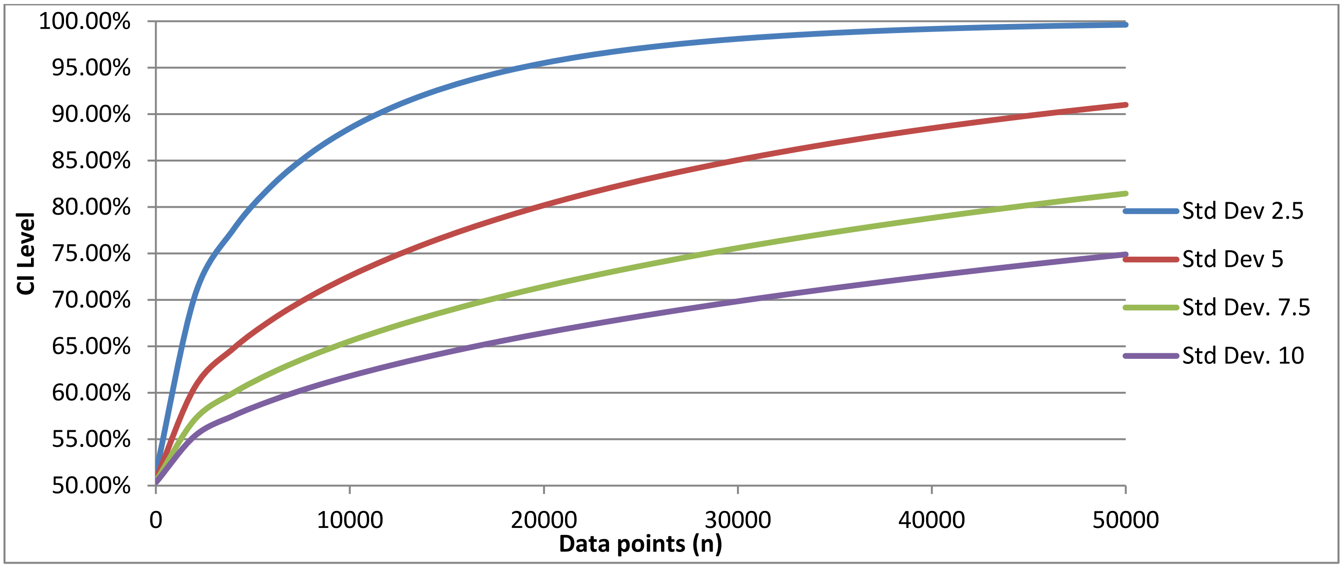


Figure 1 Display for ATC supervisor – safety and throughput information as well as the desired region for runway operation considering both safety and throughput

Stakeholder Output timeline



Assumptions:
Mean is constant
Change ATC Buffer Std Dev.
Error margin is .05

Stakeholder data points needed for report:

ATC supervisor: 10,000 data points, CI ranges from 60% to 85% depending on the ATC Buffer Std Dev

Airport and Airline Operation Managers: 30,000 data points, CI ranges from 60% to 85% depending on the ATC Buffer Std Dev

FAA (ATO): 50,000 data points, CI ranges from 75% to 100%

The interval when each of the stakeholders receives the ROQA monitoring report is dependent on the number of data points that can be gathered at a certain amount of time. As more data points are gathered, the CI level rises and the safety report becomes more accurate. The accuracy level changes with respect to the ATC Buffer standard deviation. Having a lower standard deviation allows the report to be more accurate with less data points. The ATC supervisors were determined to be given the report more frequently (less data points needed) because it would be more useful for them to be given this report in a regular basis. The FAA would be given the report after 50,000 data points because it would be more important to get an accurate report on the safety of runways.

7. Results

Change in Standard Deviation

The first phase of results consisted of changes to the standard deviation of the ATC Buffer and ROT. The purpose of these changes is to reveal whether or not there will be changes to safety and/or throughput. The output will consist of violations (% SRO + Wake vortex encounter) and throughput (arrivals per hour). This phase will determine which factor of the arrival process (ATC Buffer or ROT) affects safety and throughput the most.

Table 3-Results: ATC buffer standard deviation

Change in ATC Buffer Standard Deviation			
Mean(sec)	Standard deviation (sec)	% SRO + Wake vortex encounter	Throughput (Aircrafts per hour
10	0	0.00E+00	34.56
	2.5	1.50E-05	34.43
	5	1.20E-05	34.47
	7.5	1.80E-04	34.63

Table 3 shows the results for changing the standard deviation of the ATC Buffer. , the values were changed by increments of 2.5 with values of (0, 2.5, 5, 7.5) with 5 being the control. The main reason for changing the ATC buffer standard deviation would be to anticipate how new NextGen technology might affect runway performance in terms of throughput and violation percentage.

Increasing the ATC Buffer Standard Deviation showed to increase the rate of SROs and Wake vortex encounters. When the standard deviation was at its highest of 7.5 seconds, the violation rate showed to be at its highest at $1.8*10^{-4}$. It's important to note that changing the standard deviation affected safety but did not affect throughput. The throughput averaged out to about 34 with little variation.

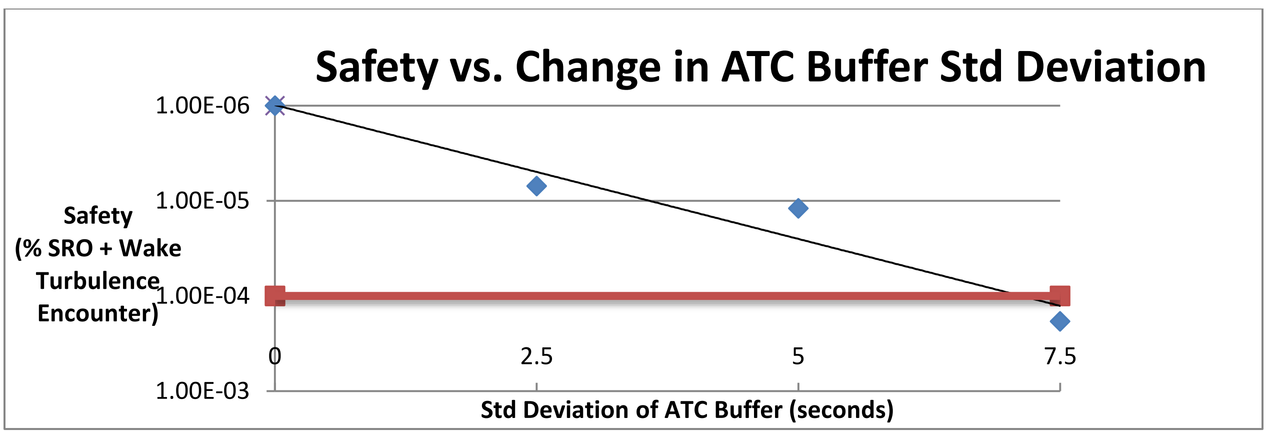


Fig 16: Results: ATC Buffer standard deviation

Figure 16 shows the plot of the results from table 3. The x-axis shows increasing standard deviation while the Y-axis shows the rate that violations occurred. The red line signifies the acceptable rate of safety which is 10^{-4}. Any point below the line would show that the rate of violations is at an unacceptable level. Figure 1 shows a better visual of how the changes affect safety. Safety and standard deviation of the ATC buffer showed to have an inverse relationship as increasing ATC buffer standard deviation decreased safety (increased the rate of violations).

Table 4- Results: ROT standard deviation

Change in ROT Standard Deviation		
Standard Deviation (sec)	% SRO + Wake vortex encounter	Throughput (Aircrafts per hour)
0	7.00E-06	34.49
3	1.10E-05	34.46
6	1.20E-05	34.77

The results from changes to the ROT standard deviation in Table 4 showed similar outcomes to the results when changing the standard deviation of the ATC buffer. The ROT standard deviation was increased from 0,3, to 6 and the violations and throughput was gathered. The throughput stayed fairly the same throughout each run of the simulation at about 34. In terms of safety, decreasing the standard deviation of ROT did affect safety but not as much as changing the standard deviation of the ATC buffer.

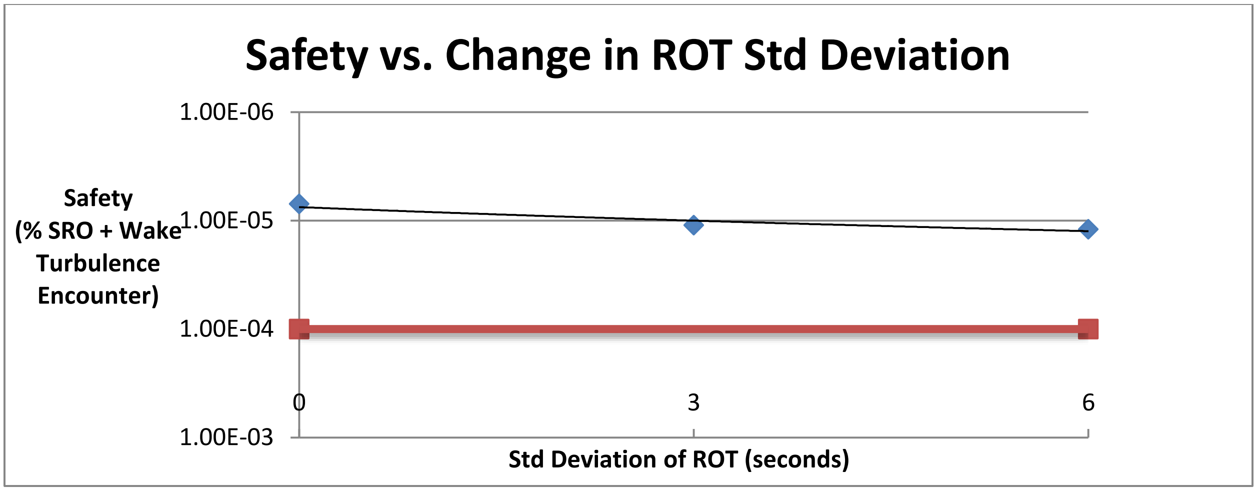


Fig 17: Results: ROT standard deviation

An increase of the standard deviation of ROT showed a higher rate of violations but not nearly as much as increasing the standard deviation of the ATC buffer.

The first phase of results which show changing the standard deviation of the ATC buffer and ROT reveal that varying the standard deviation of the buffer changes the safety. It is shown in the results that increasing the standard deviation of both ROT and ATC buffer both decrease safety or the percentage of violations which occur. The ATC buffer did show to change the safety the most. Although changing the standard deviation of both ROT and safety changed the percentage of violations which occurred, the throughput stayed fairly the same throughout each simulation run whether or not the standard deviations for ROT and ATC buffer were decreased or not.

Change in ATC Buffer Mean

The second phase of results involves changing the mean of the ATC buffer rather than changing the standard deviation. The decision to change the mean of the ATC buffer was made because it affects the mean of the inter-arrival distribution which is expected to affect throughput.

The standard deviations of ROT and the ATC buffer will be held constant at 5. The mean will be tested at its original value at 10 then will be decreased by increments of 2.5

Table 5- Results: ATC Buffer Mean

Change in ATC Buffer Mean			
Mean	Standard Deviation (sec)	% SRO + Wake vortex encounter	Throughput (Aircrafts per hour)
2.5	5	6.70E-02	39.43
5		5.00E-03	38.56
7.5		6.00E-04	37.02
10		1.70E-05	34.43
12.5		1.00E-06	33.29

Changing the mean of the ATC Buffer showed to alter both safety and throughput. Results in table 5 show that decreasing the mean increased the rate at which violations occurred. Although safety was at its lowest, the throughput was at its maximum value of 39.43 when the mean was at its lowest. On the other hand safety was at its best value (lowest rate of violations) when throughput was at its lowest value.

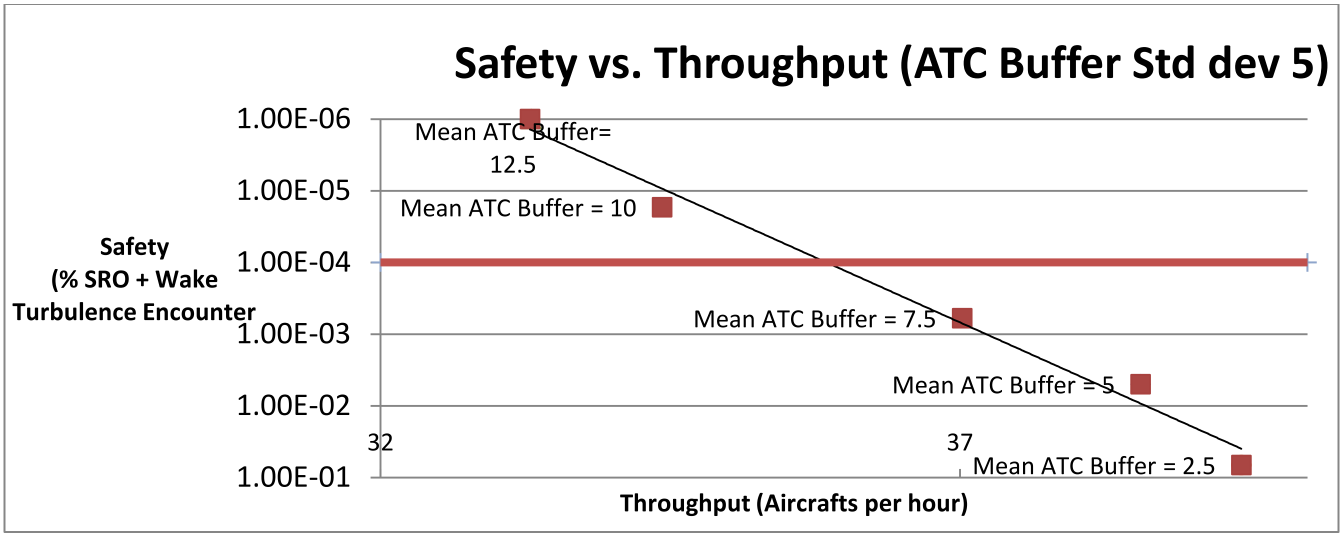


Fig 18: Results: ATC buffer mean and standard deviation – Runway safety decreases as throughput increases

Figure 18 shows the results from changing the mean of the ATC Buffer standard deviation. On the Y-axis is the rate of incursions and the X-axis shows throughput. Decreasing ATC buffer showed to increase throughput but in turn sacrificed safety as the rate of violations increased as throughput increased. The figure shows the inverse relationship and tradeoff between safety and throughput.

Verification

The results from changing the mean of the ATC Buffer were compared to result from an earlier study (Statistical Separation Standards For the Aircraft-Approach Process, Jeddi, Sherry, Shortle, 2006)

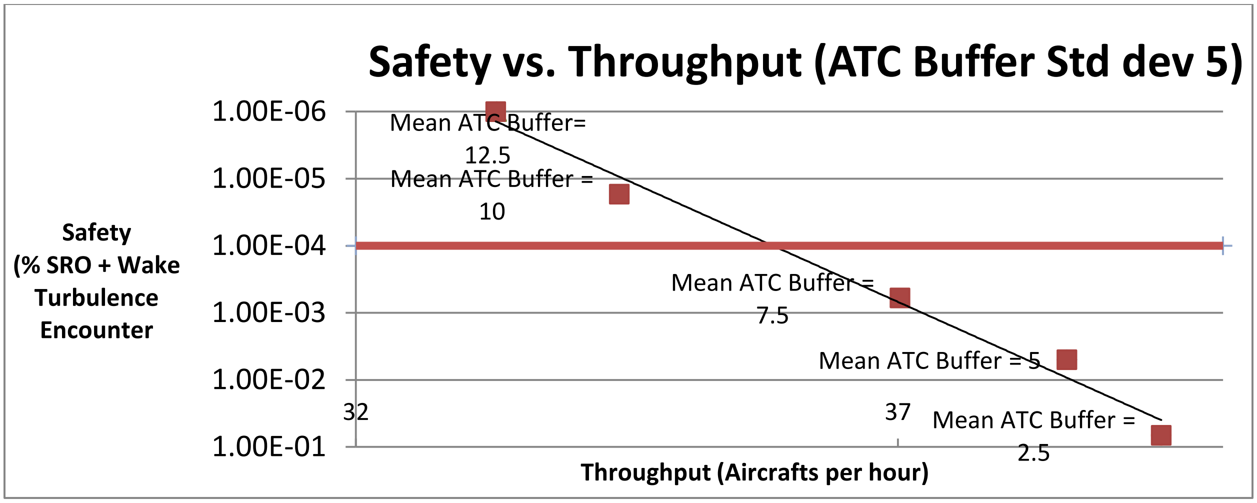


Fig 18: Results: ATC buffer mean and standard deviation – Runway safety decreases as throughput increases

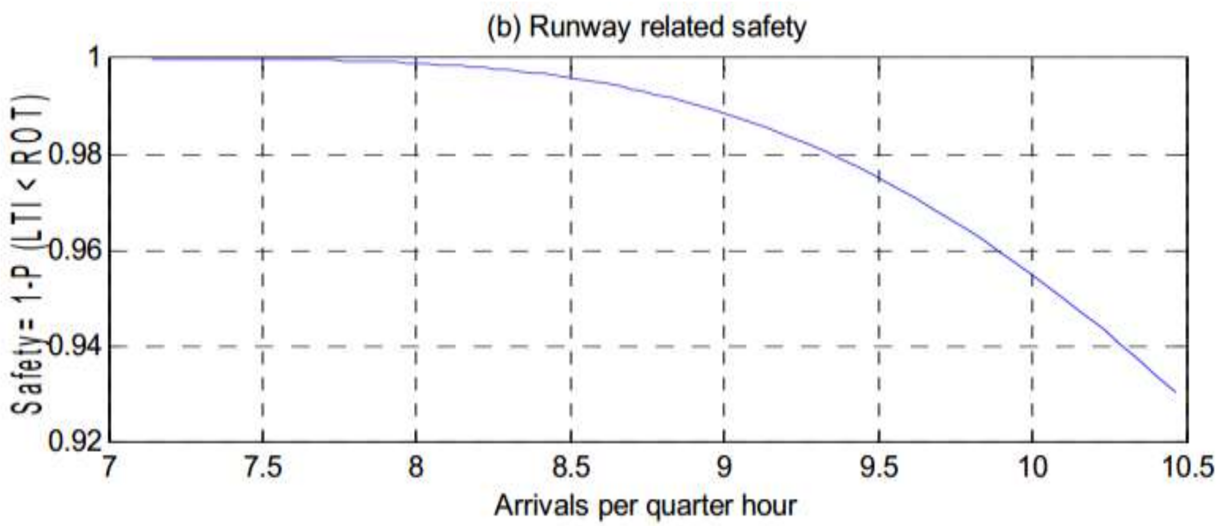


Fig 5 Arrivals vs. Safety – Runway safety decreases as throughput increases

Both results show the inverse relationship between safety and throughput. The results differ in the way they were obtained. The ROQA simulation measures SRO as well as wake vortex encounters.

Change in ATC Buffer mean and standard deviation

For the third phase of the results the mean of the ATC was changed but instead of keeping the standard deviation at a constant at 5 seconds it was reduced to 2.5 seconds. The change in the standard deviation to 2.5 represents expected changes to a reduction in variance with upcoming NextGen technology.

Change in ATC Buffer Mean (Std Dev 2.5)			
Mean(sec)	Standard Deviation	% SRO + Wake vortex encounter	Throughput (Aircrafts per hour)
2.5	2.5	3.40E-04	39.62
5		8.00E-05	37.89
7.5		4.00E-05	36.74
10		2.00E-05	34.75
12.5		1.00E-06	32.87

Table 6: Results: Comparison between ATC buffer standard deviation of 5 and 2.5 seconds.

Results were similar as the safety was reduced and throughput was increased with reducing the mean.

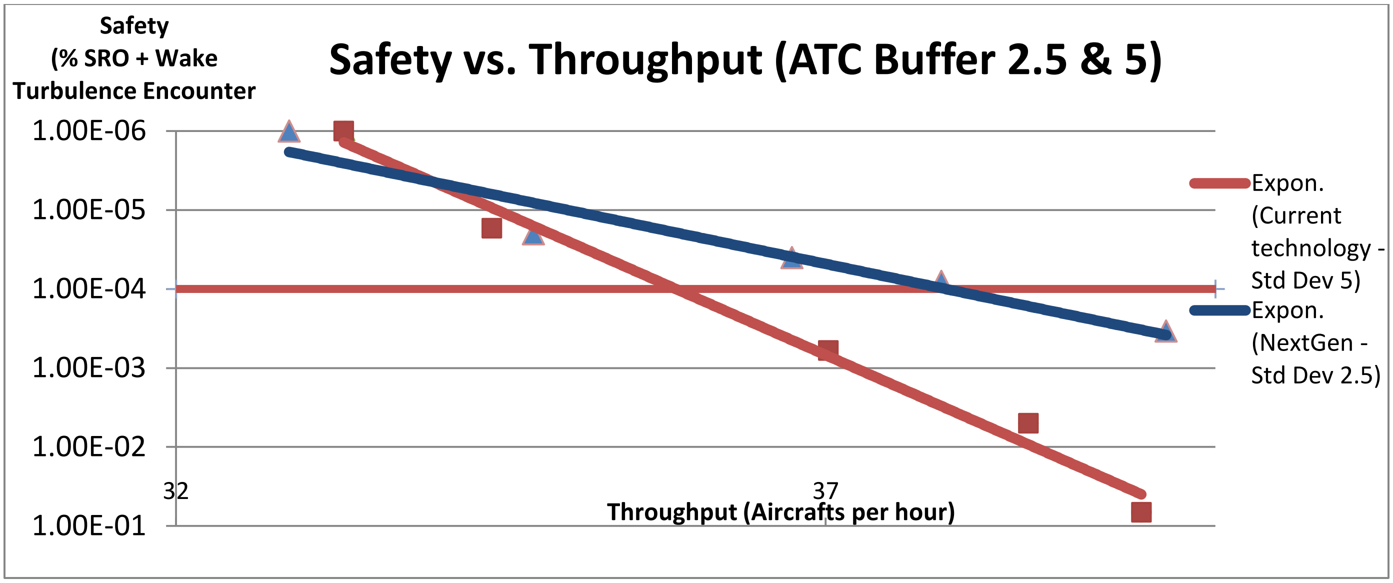


Figure 19 Comparison between ATC buffer standard deviation of 5 and 2.5 seconds.

In comparison to the ATC buffer standard deviation at 5, reducing the standard deviation to 2.5 showed a reduction in the rate of violations as the mean was increased. Figure 4 shows how a reduction the standard deviation allows for a higher throughput while still maintaining a proper safety level above the rate of 10^{-4}. The result of reducing the standard deviation show how there is a possibility of increasing safety while maintaining safety. Visually figure 4 reveals that the actual slope/ rate of violations decrease as standard deviation decrease.

Discussion

Based on the results from the simulation, it is recommended that a reduction to the standard deviation of the ATC buffer is implemented to improve safety. Reducing the standard deviation of the ATC buffer showed to improve safety as the rate of violations decreased with a reduction in standard deviation of ATC buffer. Throughput was only increased by reducing the mean of the ATC buffer.

Once the safety is improved the mean of the ATC buffer can be reduced to improve throughput. The only way to increase capacity while maintaining proper safety is to reduce the variance of IAT and ROT first, then reduce the mean of IAT. The technological improvements are expected to reduce the variance of IAT and ROT, but reducing the mean can only be achieved by changing procedure such as ATC buffer and/or separation minima.

8. Project Plan and Budget

a. WBS

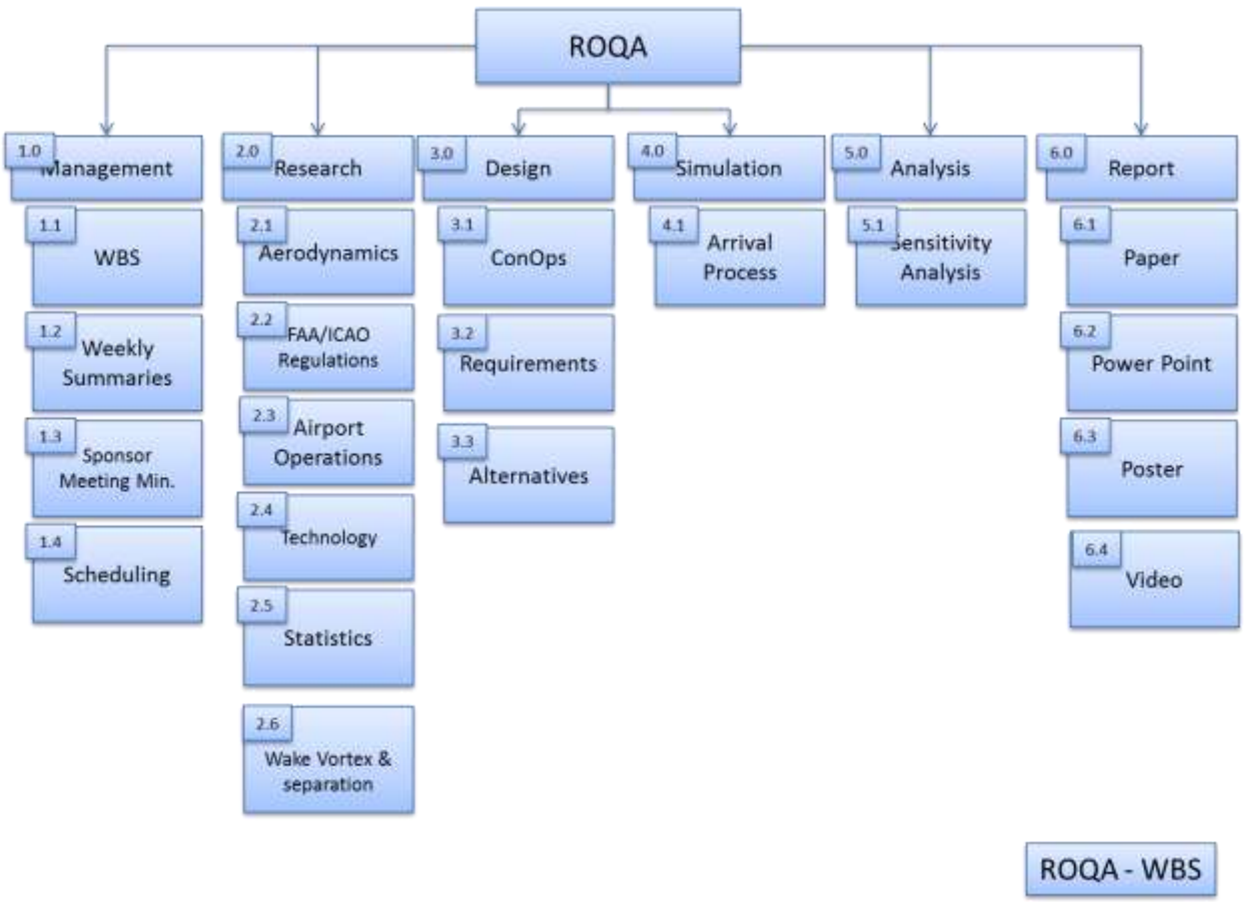
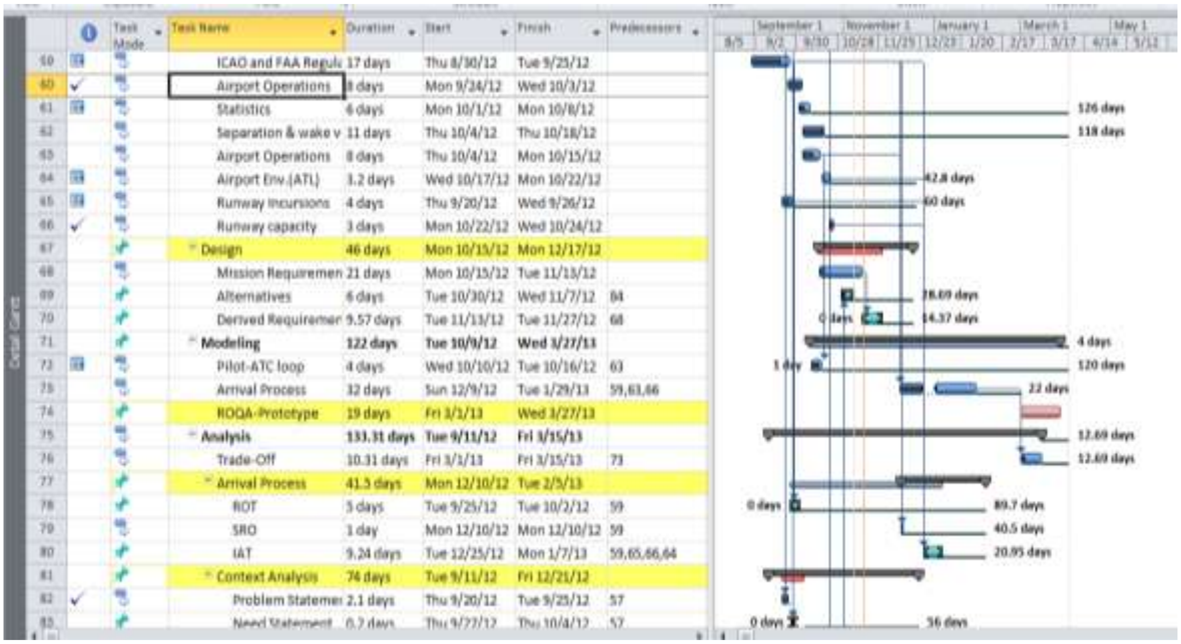


Fig20- ROQA Work Break Down Structure

b. Schedule

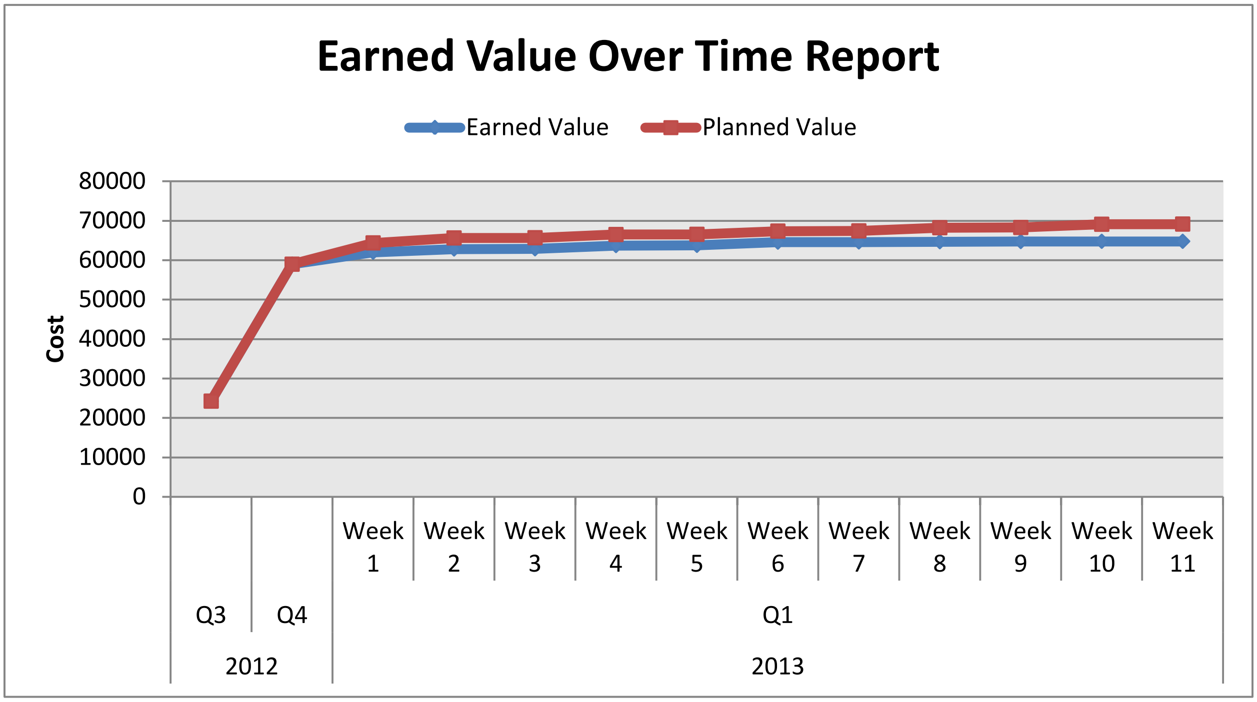
Using MS project, we generated the overall schedule of our project from beginning to completion. The project schedule show each tasks based on the Work break down structure. In addition, the tasks which are on the critical path are highlighted and represented on the gant chart. The figure below shows the schedule of the ROQA project.



c. Budget (total cost of the project)

Task Name	Planned Value - PV (BCWS)	Earned Value - EV (BCWP)
ROQA	**$70,008**	**$64,769**
Management	**$15,649**	**$13,206**
Research	**$27,949**	**$27,949**
Design	**$1,944**	**$1,944**
Analysis	**$19,842**	**$17,047**
Final Report	**$4,622**	**$4,622**

Table7- ROQA budget



d. Earned Value

FIG21- ROQA Earned Value Report

e. CPI (Cost Performance Index) and SPI (Schedule Performance Index)

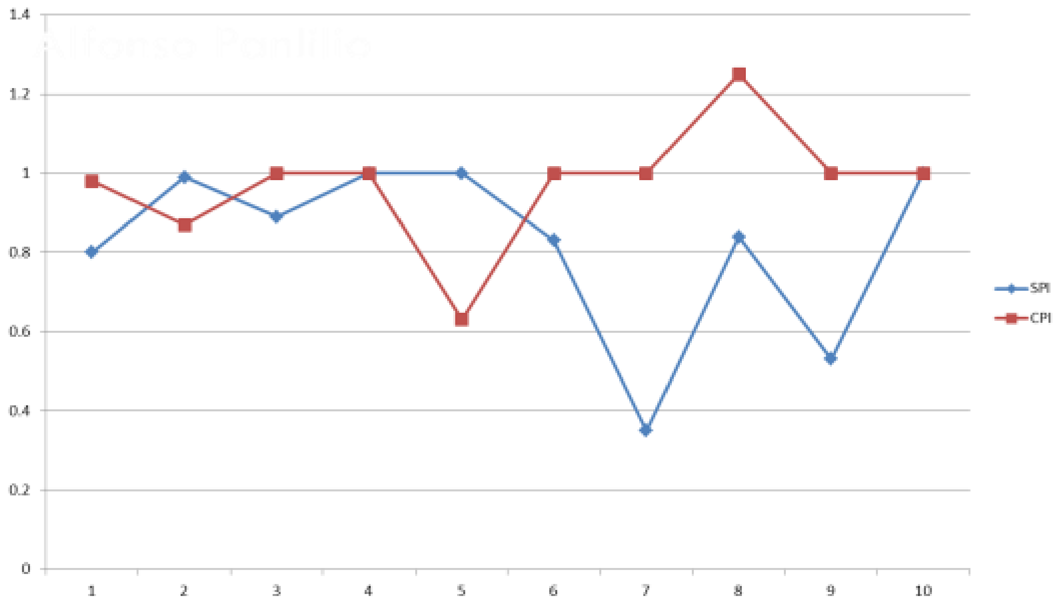


FIG22- CPI and SPI

CPI > 1, means under budget

SPI > 1, means ahead of schedule

f. Project Risk and Mitigation

- Risk: Not getting simulation completed by the due date
    - Encountering difficulties processing arrival data
    - Coding and debugging simulation
- Contingency plan: Allocate more time for completing simulation by due date

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