Federal Aviation Administrations

Next Generation Air Transportation System

Consolidated Risk Report

Taylor Harrington

Risk Management Fall 2018

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I. **Background**

Since the inception of the Federal Aviation Administration, several modernization efforts to air traffic control have been evaluated and implemented. Efforts began in the 1960's with the installment of semi-automated air traffic control systems and continued into the 1980's with the first air traffic control modernization program. The modernization program ultimately failed due to increased budget and timeline of implementation. This initial failure in air traffic control modernization, ultimately led to an estimated $51 million-dollar price tag for future modernization efforts. By 2016, the FAA's revised cost estimate for implementing NexGen through 2030 for 1) FAA and 2) Industry were $20.6 billion and $15.1 billion respectively. Implementation is currently ongoing, and for this report we use a hypothetical evaluation of $178.6 million over the next two years of implementation.

By the early 2000s, the FAA was experiencing significant congestion, and delays with approximately one in every four flights delayed. Additionally, trends showed an increase in ridership, with an anticipated forecast tripling air traffic by 2025. For example, in 1981 the U.S. air transportation system carried 281 passengers, by 2008 the system transported nearly 650 million passengers. This ultimately set into motion the implementation of Next Generation (NexGen) air traffic control. NexGen is defined as a system of systems designed to improve operations in all phases of flight, through the replacement of legacy radar-based air traffic control systems with a satellite-based system that includes digital communications amongst other improvements.

NexGen represents a fundamental transformation in modernization of air traffic control. Its dramatic technology improvements coupled with a phased approach seeks a long-term modernization without constant scope changes increasing the price and timeline for implementation. This modernization effort is not without inherent risk, first political disputes over the federal budget constantly threaten the continuation of NexGen. Avionics training, cybersecurity, and stakeholder involvement have been amongst other concerns throughout this process.

NexGen still remains a priority for the FAA to finish implementation. The phased implementation has provided some areas of the country with updated NexGen technology, while others are either in development or have not started. There has been no proper risk assessment conducted on the probability of events that could occur while the instillation of NexGen continues for the next two years. This report looks within the next two years and seeks to identify the probability of risk events, sources of risk, and their impact on the objectives of the FAA.

II. Introduction

The risk analysis below is being created to measure the risks of the implementation of the Federal Aviation Administration's Next Generation Technology (NexGen). Currently, implementation is ongoing, but for this report we utilize a hypothetical enterprise evaluation of $178.6M as the overall budget. Our team utilizes the Expert Choice: Riskion software to identify and record risk events, their sources, and objectives. Participants are selected based on expertise to provide judgments on the likelihood of events, sources, priority of objectives and the impact of consequences on objectives using a variety of measurement methods. Judgments below are based on the relationship between risk events their sources and the likelihood of events given the sources of the FAA's objectives and the impact of consequences against objectives. This report also highlights various controls as well as an optimization analysis of the costs or budget for the implementation of these controls to outline the most cost-effective strategy to mitigate the identified risks.

III. Project Framework

Risk Events:

Beginning our risk assessment, we first defined risk as an uncertainty that matters, and its occurrence causes a loss to the organization's objectives. We identified nine risk events based on expertise and research. Table 1 provides an in-depth look at risk events with associated descriptions, while Figure 1is a snapshot of input risk events into Riskion.

Table 1 Risk Events

Risk Events	Description
1. Degradation in Aircraft Avionics	When interference with satellite and or radio-based communications affect the information provided by pilot to air traffic control and vice versa.
2. Major Aircraft Accident	Characterized by midair or runway collision, includes loss of life or loss of aircraft
3. Minor Aircraft Accident	Characterized by runway congestion or near misses of aircraft
4. Aircraft Avionics Shutdown	Denial of aircraft surveillance technology in determining position via satellite navigation. Eliminates the connection with air traffic

Risk Events	Description
	controllers and provides little to no information to pilots, other than aircraft instruments.
5. Delayed NexGen Implementation	NexGen has a requirement for most aircraft to be outfitted with NexGen capabilities by January 2020; delays in implementation would cost organizations and tax payers additional monies
6. Performance Based Navigation Failure	NexGen uses Performance Based Navigation (PBN) to produce precise and direct routes for aircraft. Without PBN pilots would be forced to utilize alternate methods of navigation delaying aircraft arrival.
7. Loss of Funding	NexGen is a multibillion dollar investment through the federal government. Lost funding would haul all progress towards a safer airway travel.
8. Stakeholder Noncompliance	NexGen is one of FAA's major objectives and to accomplish this multiple stakeholder from across the federal government and private industry are brought together. The failure or noncompliance of one or many stakeholders has significant ripple effects for NexGen
9. Insufficient Resources to Install NexGen Technology	NexGen requires aviation companies to comply with federal guidelines for installment of NexGen equipment by Jan 2020. Resources are scarce for maintenance and instillation.

Figure 1: Riskion Events

Unique ID		Events
[13]		Degredation in Aircraft Avionics
[14]		Major Aircraft Accident
[15]		Minor aircraft accident
[17]		Aircraft Avionics Shutdown
[19]		Delayed NexGen Implementation
[20]		Performance Based Navigation Failure
[21]		Loss of Funding
[22]		Stakeholder Noncompliance
[23]		Insufficent resources to install NexGen technology

Sources:

Sources, defined as the origination of risk events are uncertainties that causes a risk event to occur. A risk event may have not need not be associated to a source, yet a source may be responsible for multiple risk events.

From our assessment we identified five categories for our sources (Environmental/ Political & Financial/ Human Factor/ Terrorism/ Technology). Categories were further defined by specific sources akin to each.

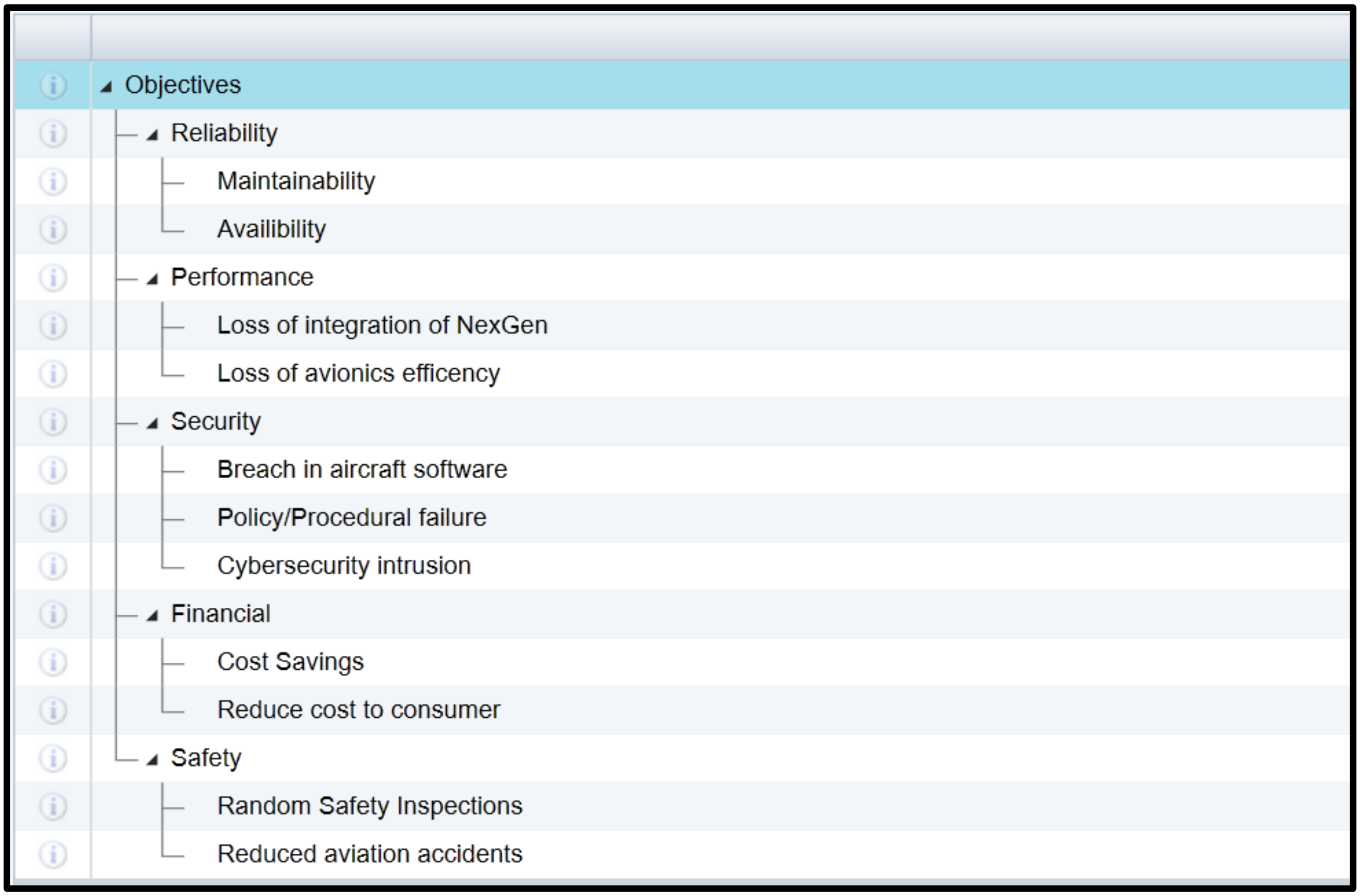
Figure 2: Sources

- Sources
  - Environment
    - Storm interrupts ground based avionics suite
    - Increased noise leves to communities
  - Political/Financial
    - High maintenance cost
    - FAA does not fund the continuation of NexGen
    - Turnover in FAA administration decides to go in a different direction
  - Human Factor
    - Lack of situational awareness
    - Insufficient training for pilots and controllers of NexGen integrated systems
    - Disregard to policy, procedures, and protocol
    - Requirements scope change post 2020 implementation date
    - Rapid availibity of UAV platforms interfering with commericial flights
  - Terrorism
    - Conventional Attack on Airports
    - Cyber-attack on aircraft avionics
    - Cyber-attack on air traffic control information system
  - Technology
    - Aircraft avionics failure
    - System software technology incompatible world-wide
    - System software technology corrupt
    - Information and Integration management unable to support NexGen requirements

Objectives:

We have identified consequences to objectives and categorized them into five categories (Reliability/ Performance/ Security/ Financial/ Safety)

Figure 3 Hierarchy of Objectives



Participants and Their Roles:

The team for the FAA consist of seven (7) members with subject matter expertise across multiple areas. Team members participate in various judgment consistent with subject matter expertise and experience. Through judgments team members help determine a ratio scale measure of risk and impacts.

- **Bryan Hayes –** ***Chief Engineer Officer*** – works in a wide range of fields, overseeing the engineering and technicians as they develop designs, approximate cost, and execute plans with highly technical skills.
- **Dan Miles –** ***Chief Operations Officer*** – tasked with implementing daily operations, aligned with the goal and the company strategy.
- **John Berstein –** ***FAA Administrator*** – works on a wide variety of tasks, includes managing daily calendars, appointments, answering incoming inquiries.
- **John Paul –** ***Cyber Security Officer*** – on the forefront of protecting company cyber assets from threats.

- **Kelly Steiz – *Chief Financial Officer*** – develops financial organizational strategies by contributing financial and accounting information, analysis, and recommendations to strategic and direction for the organization
- **Robert Ford – *Chief Systems Engineer*** – responsible for the technical supervision of the development, production or operation of engineering projects
- **Joel Frank – *Weather Forecaster*** – responsible for recording and analyzing data from worldwide weather stations for which might impede on FAA operations.

Figure 4 Participants and Roles for Judgment

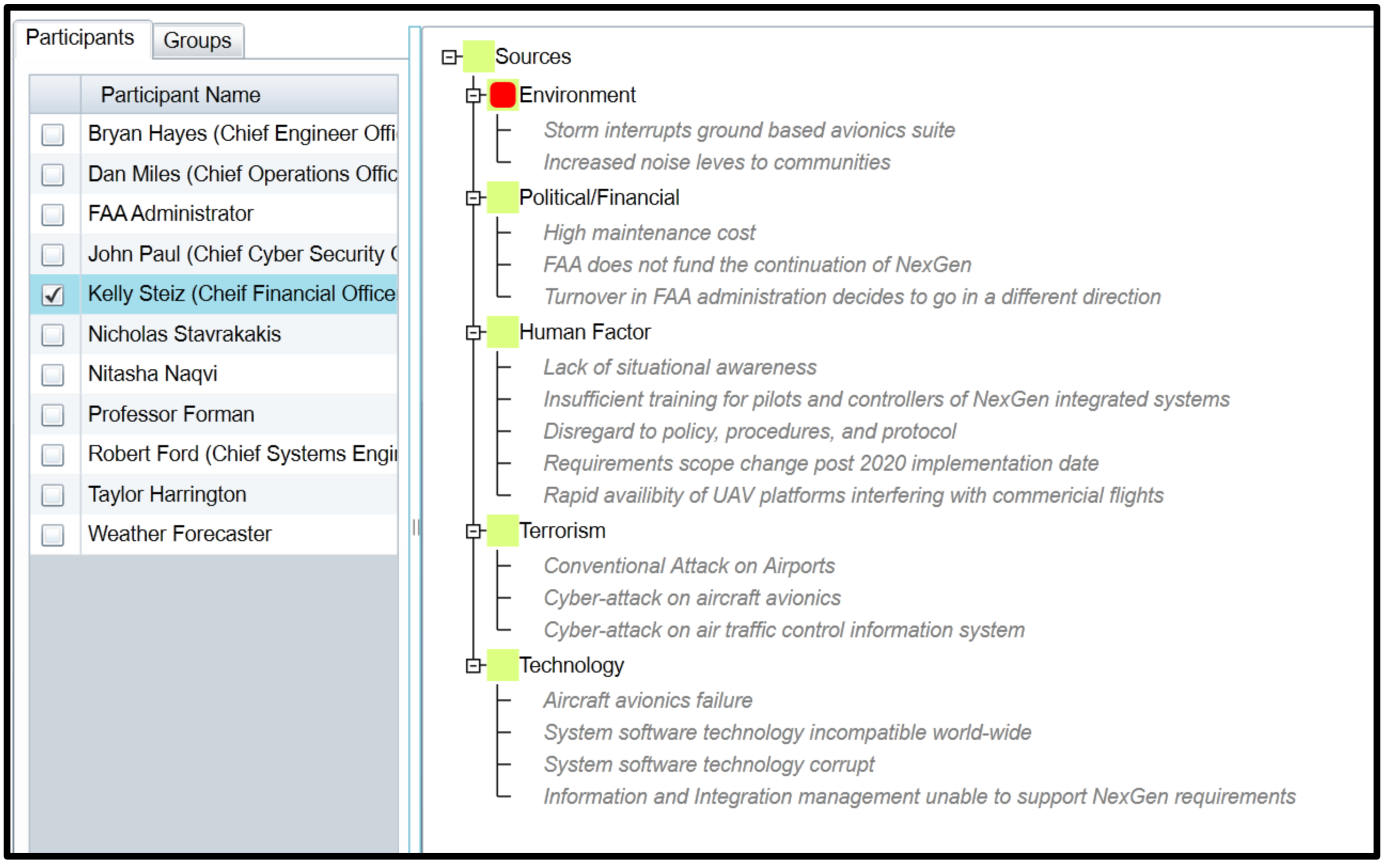


Figure 4, for example, illustrates that Mrs. Kelly Steiz, the chief financial officer, has roles to evaluate the importance of the top-level objectives as well as the sub-objectives under each top-level objective except the environmental sub-objectives.

IV. <u>Mapping (Events and Sources)</u>

Likelihood of Events to Sources:

The vulnerability grid is a visual depiction of the correlation between a source and risk event. By selecting a box, it establishes the relationship between source and risk event, note there can be multiple events linked to a singular source. For Example, the risk event Major Aircraft Accident, is linked to the sources of Environmental, Human Factors, Terrorism, and Technology.

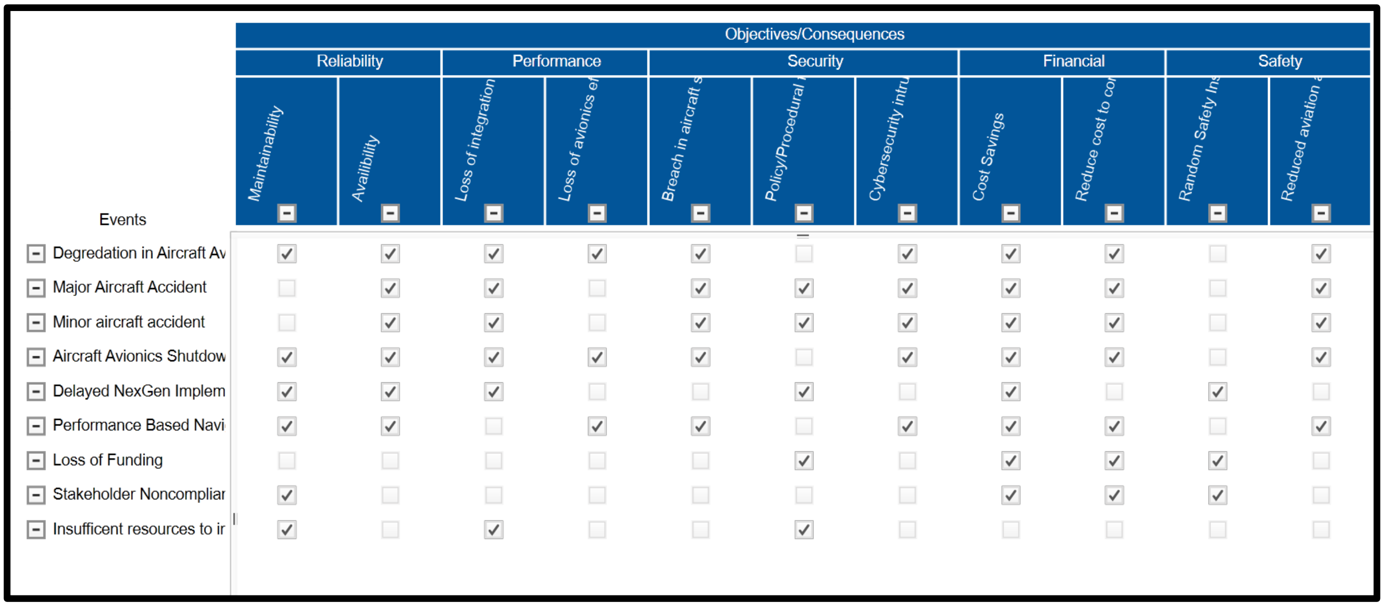
Figure 5: Likelihood of Sources to Events (Vulnerability Grid)

	Sources																
	Environment		Political/Financial			Human Factor					Terrorism			Technology			
Events	Storm interrupts g	Increased noise le	High maintenance	FAA does not fund	Turnover in FAA a	Lack of situationa	Insufficient trainin	Disregard to polic	Requirements sco	Rapid availibity of	Conventional Atta	Cyber-attack on a	Cyber-attack on a	Aircraft avionics fa	System software f	System software f	Information and In
Degredation in Aircraft Av	✓		✓			✓	✓	✓		✓	✓	✓	✓	✓		✓	
Major Aircraft Accident	✓					✓	✓	✓		✓	✓	✓	✓	✓		✓	
Minor aircraft accident	✓					✓	✓	✓		✓	✓	✓	✓	✓		✓	
Aircraft Avionics Shutdow		✓	✓			✓	✓			✓	✓	✓	✓	✓		✓	
Delayed NexGen Implem			✓	✓	✓				✓								✓
Performance Based Navi	✓	✓	✓			✓		✓		✓		✓	✓			✓	
Loss of Funding				✓	✓				✓						✓		✓
Stakeholder Noncompliar									✓						✓		✓
Insufficent resources to ir			✓	✓	✓				✓						✓		✓

Likelihood of Events to Losses on Objectives:

Much like the vulnerability grid, we determined the relationship between losses to objectives and risk events. By linking consequence of risk events on objectives with a risk event we establish that a risk event could cause a loss to the objective. Note, there can be multiple losses linked to one risk event. For example, the risk event Degradation in Aircraft Avionics, causes losses across multiple objectives (Reliability/ Performance/ Security/ Financial/Safety).

Figure 6 Impact of Objectives Grid (Consequence Grid)



Events	Reliability: Maintainability	Reliability: Availibility	Performance: Loss of integration	Performance: Loss of avionics ef	Security: Breach in aircraft s	Security: Policy/Procedural	Security: Cybersecurity intru	Financial: Cost Savings	Financial: Reduce cost to co	Safety: Random Safety Ins	Safety: Reduced aviation
Degredation in Aircraft Av	✓	✓	✓	✓	✓		✓	✓	✓		✓
Major Aircraft Accident		✓	✓		✓	✓	✓	✓	✓		✓
Minor aircraft accident		✓	✓		✓	✓	✓	✓	✓		✓
Aircraft Avionics Shutdow	✓	✓	✓	✓	✓		✓	✓	✓		✓
Delayed NexGen Implem	✓	✓	✓			✓		✓		✓	
Performance Based Navi	✓	✓		✓	✓		✓	✓	✓		✓
Loss of Funding						✓		✓	✓	✓	
Stakeholder Noncompliar	✓							✓	✓	✓	
Insufficent resources to ir	✓		✓			✓					

V. Judgments and Measurements

Setup:

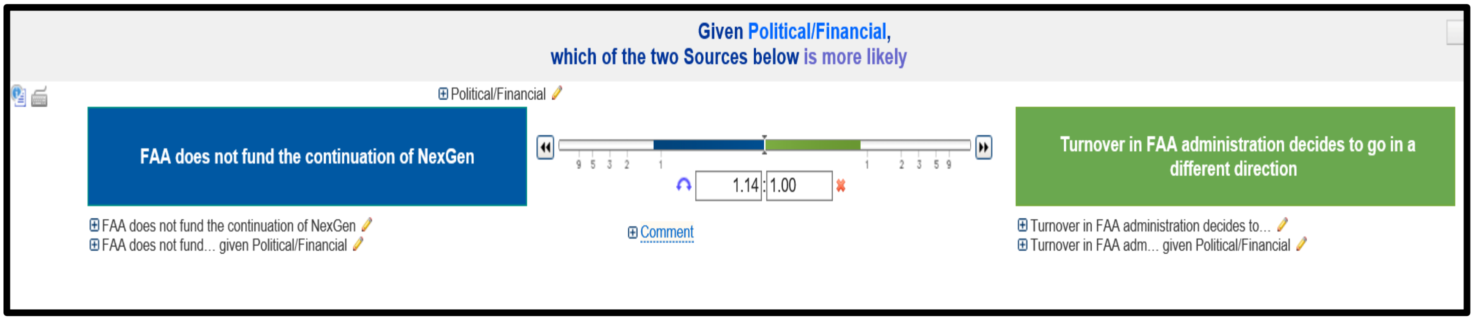
Establishing relationships between sources and risk events (vulnerability grid) and between consequences and risk events (impact grid) we begin to see the development many-to-many relationships. We use ratio scale measures to measure four things: likelihood of sources, likelihood of events given sources, priorities of objectives, and consequence of events on objectives. We compute risk events along with event likelihood and impact through mathematical formulas listed below and in more detail later on.

- Event risk is defined as the event likelihood times event impact (likelihood * impact).
- Event likelihood is defined as the sum of likelihood of sources times the likelihood of events given sources Σ(likelihood of sources * likelihood of events given sources).
- Event impact is defined as the sum of consequences of events on objective times importance of the objectives. Σ(consequence of event on objective * priority of objectives).

Measurement Methods: Pairwise Comparison:

Pairwise comparisons were used to express how much more likely or important one element of a pair is compared to the other. By reducing complex decisions to a series of pairwise comparisons, and synthesizing the results, we can capture both subjective and objective aspects of a decision. The Analytical Hierarchy Process (AHP) is considered as a tool able to translate evaluations made by the decision maker into rankings. Since it requires decision makers to express how options or criteria relate to each other (pairwise comparisons), pairwise comparison is an essential aspect to the AHP. Pairwise comparisons were used within our analysis to measure the likelihoods of sources, likelihoods of events given sources, priorities of objectives, and consequences of events on objectives.

Figure 7 Example Pairwise Comparison



Measurement Methods: Pairwise Comparison with Given Likelihood:

As with pairwise comparison, pairwise comparison with given likelihood is used to express how much more likely or important one element of a pair is compared to the other. The distinction is that pairwise comparison with given likelihood is used to anchor relative likelihood from pairwise comparison to a given likelihood. We applied given likelihoods to three sources (Environment – Storm interrupts ground based avionics system, Human Factor – lack of situational awareness, and Terrorism – conventional attack on airports) Given likelihoods were derived from research on the FAA which detailed the likelihood of potential causes for NexGen implementation. By using specified given likelihoods, we can calculate likelihoods and impacts to a known reference making our results more grounded based on qualitative data.

Figure 8 Measurement Method: Pairwise Comparison with Given Likelihood (Likelihood of Events Regarding Sources)

Measure Likelihood	Measurement Type	Measurement Scale or Given Likelihooc	Action
Sources	Pairwise Comparis		Copy
Environment	Pairwise with Give	Storm interrupts ground based …: 0.(	Copy
Storm interrupts ground based avionics s			
Increased noise leves to communities			
Political/Financial	Pairwise Comparis		Copy
High maintenance cost			
FAA does not fund the continuation of Ne			
Turnover in FAA administration decides t			
Human Factor	Pairwise with Give	Lack of situational awareness: 0.08	Copy
Lack of situational awareness			
Insufficient training for pilots and controlle			
Disregard to policy, procedures, and prot			
Requirements scope change post 2020 i			
Rapid availibity of UAV platforms interferi			
Terrorism	Pairwise with Give	Conventional Attack on Airport…: 0.3	Copy
Conventional Attack on Airports			
Cyber-attack on aircraft avionics			
Cyber-attack on air traffic control informa			

VI. Risk Analysis and Synthesized Results

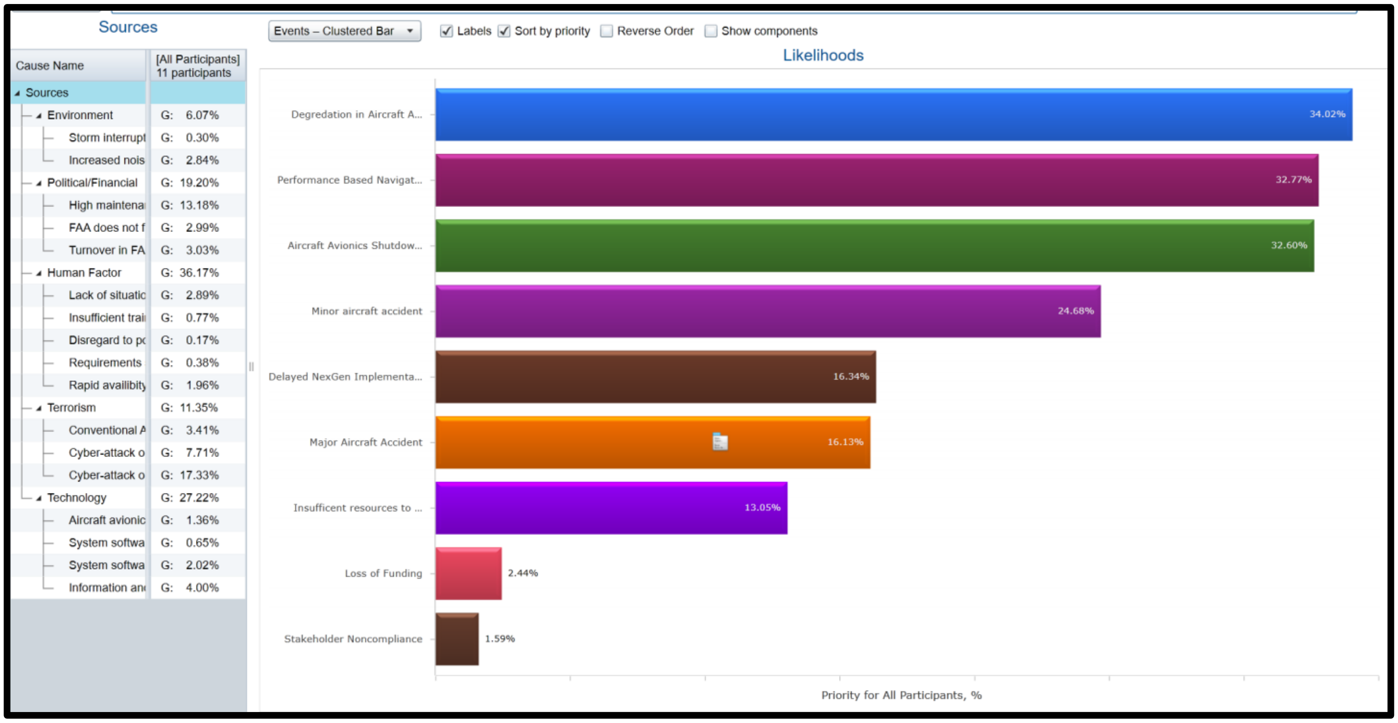
After completing evaluations, Riskion provides results that are mathematically meaningful because they are derived from ratio scale measurements. Results may be vied in a variety of configurations to show the depth of measurements. We analyze results using sensitivity analysis checking for outliers or extreme variations between participants.

Likelihood of Events and Sources:

Using pairwise comparison and pairwise comparison with given likelihood we estimate the likelihood of specific events occurring. Computed likelihoods of events given multiple sources can be higher than expected due to ‘double counting’ Monte Carlo simulation is preferred to combat this bias.

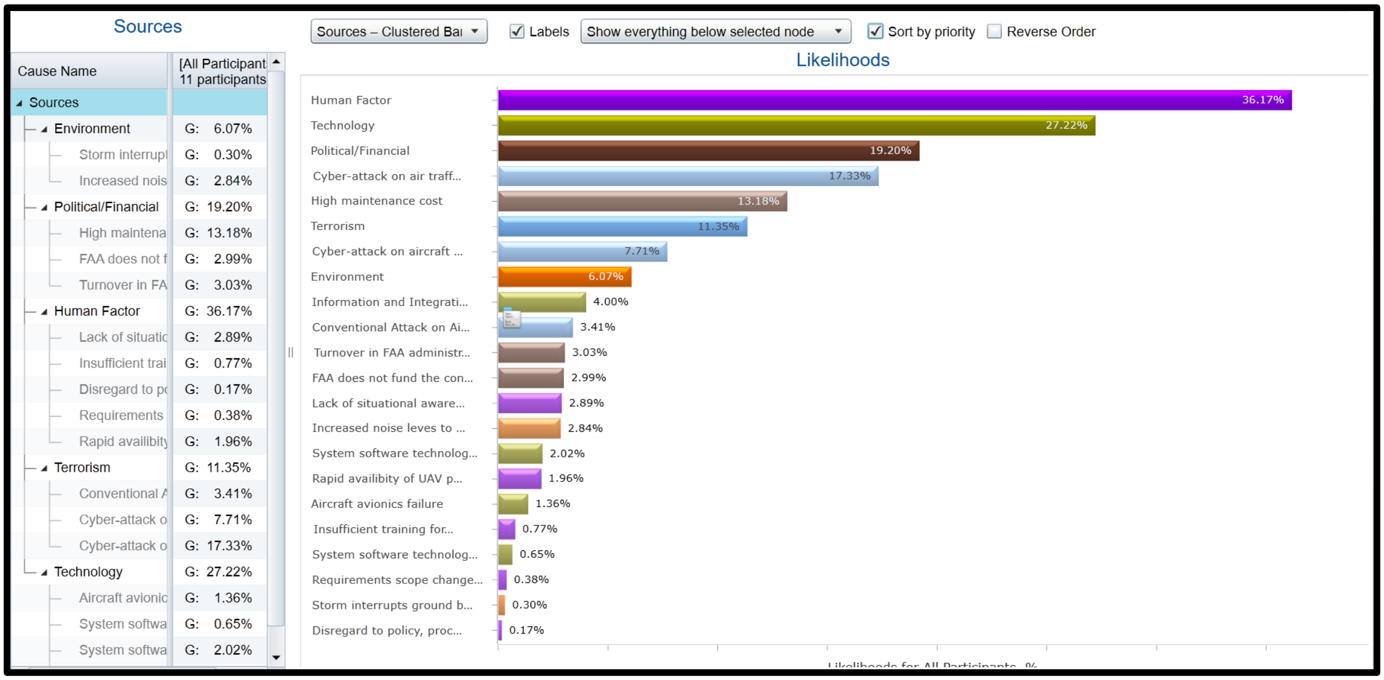
The results in the figure below display the likelihood of events sorted by priority or likelihood of occurrence. The results of events given sources depicts the highest risk event is “Degradation in Aircraft Avionics” with a likelihood of 34.02% followed by “performance-based navigation failure” with a likelihood of 32.77% and “aircraft avionics shutdown” with a likelihood of 32.60%.

Figure 9: Likelihood of Events



The figure below depicts the likelihood of sources sorted by priority or likelihood of occurrence. Human factor has the highest likelihood of occurrence at 36.17%, followed by technology, political/financial, terrorism and environment respectively. Measurement of likelihood are derived from participants judgments described in previous sections.

Figure 10: Likelihood of Sources



Impact of Events and Objectives:

The calculations of overall impact of risk events to objectives are depicted in the below figure. For example, an aviation accident risk has a 49.61% chance of resulting in a safety issue. Likewise, Figure 12 depicts the event impacts as described by participants on objectives. For example, participants have determined that the event aircraft avionics shutdown has a 74.69% likelihood of impacting objectives.

Figure 11: Impact of Objective Priorities on Objectives

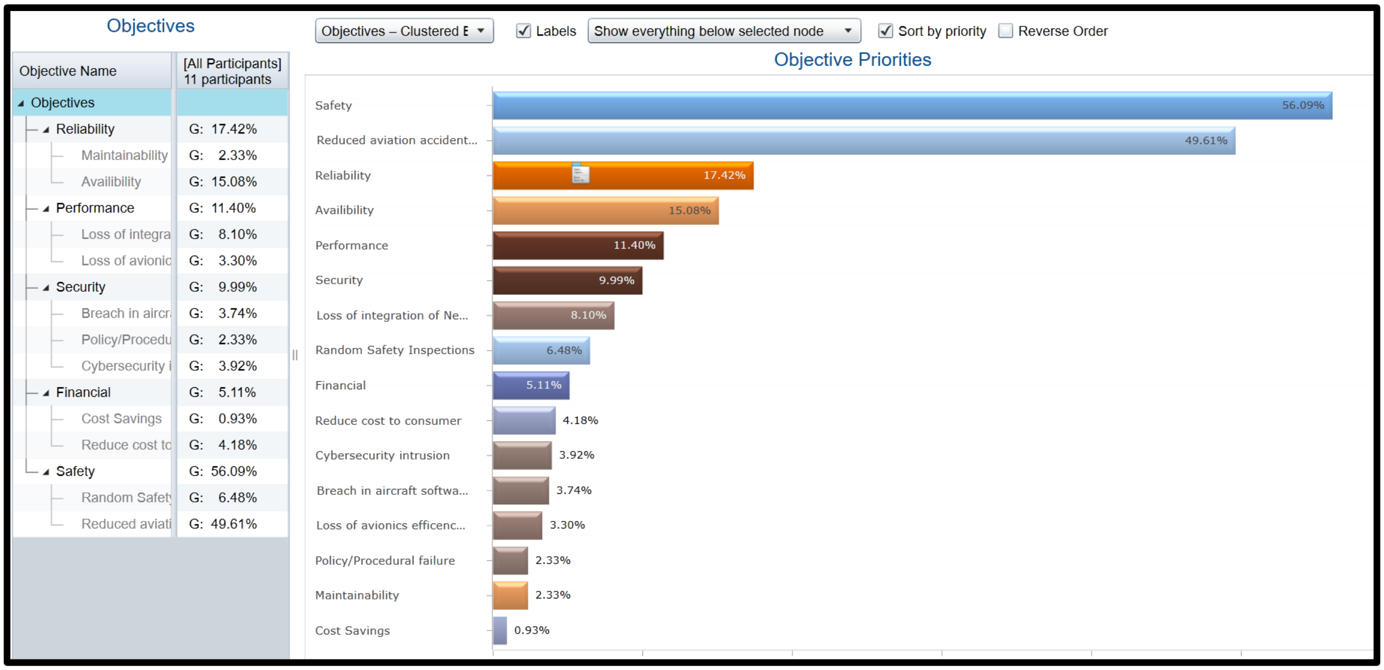
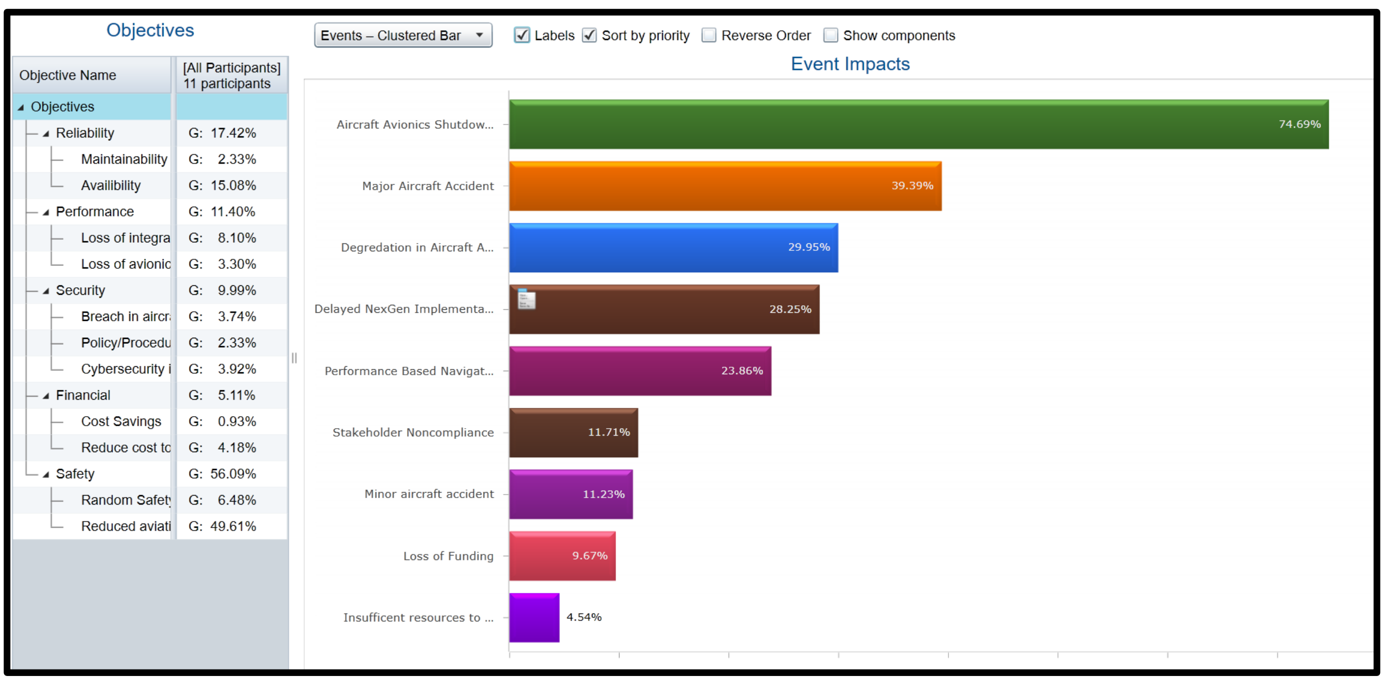


Figure 12: Event Impact on Objective



Sensitivity Analysis:

The figures below show the dynamic sensitivity of sources and likelihood of risk given sources. According to the below sensitivity of sources figure, the 'human factor' source is the most likely to trigger a risk event, and 'degradation in aircraft avionics' is the most likely event given sources to occur at approximately 34.02%. When the likelihood of sources changes the likelihood of events given sources change. For example, if the likelihood of 'human factor' changes to 5% (Figure 14) the 'performance-based navigation failure' becomes the most likely event given sources to occur.

Figure 13: Dynamic Sensitivity of Source and Event Likelihood

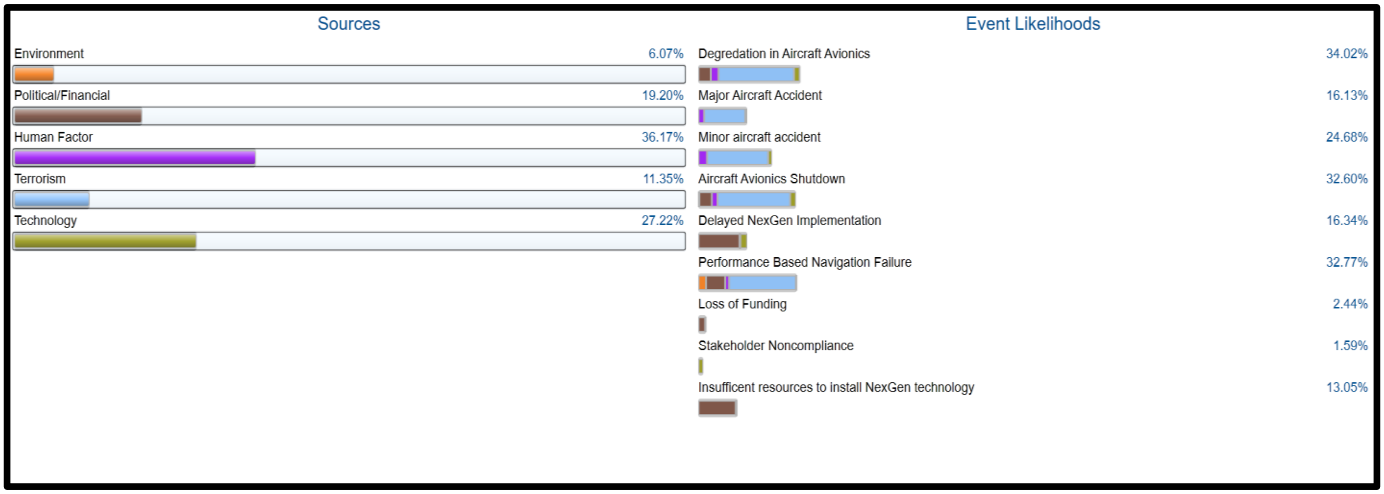


Figure 14: Dynamic Sensitivity of Sources and Event Likelihood (After Alteration)

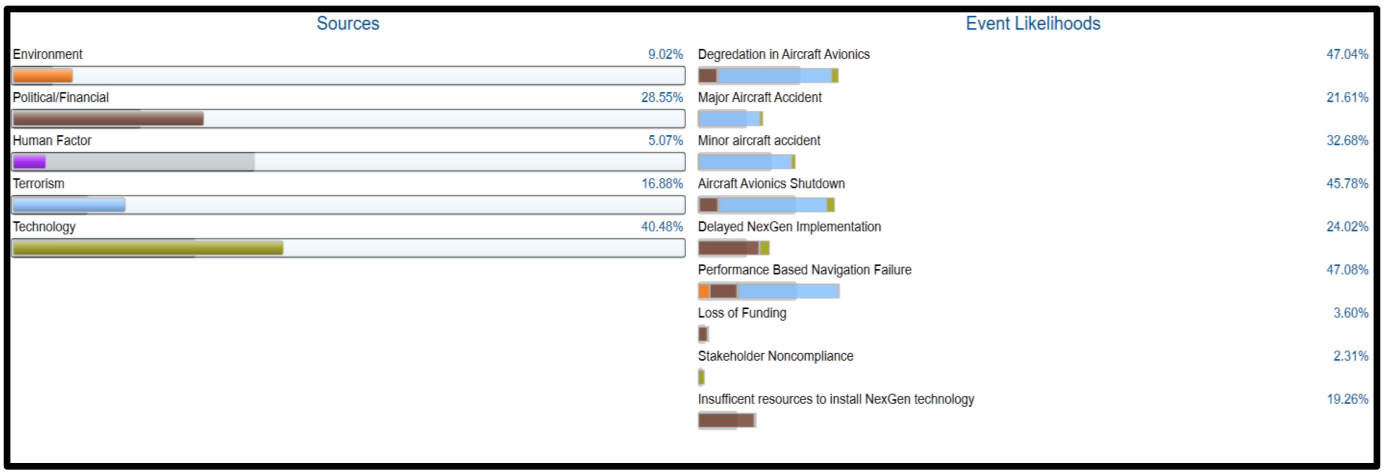
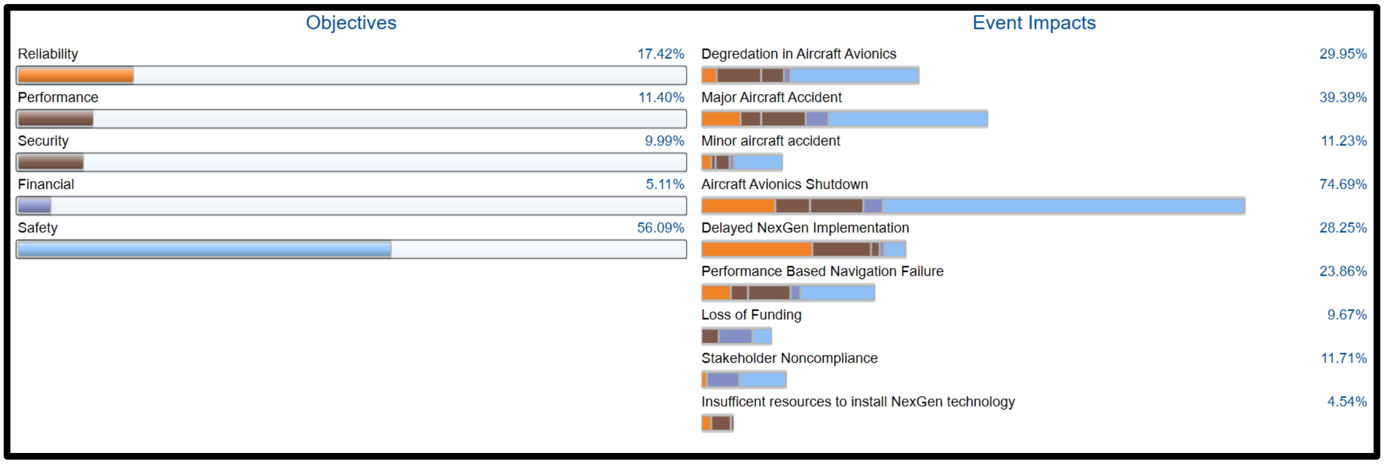
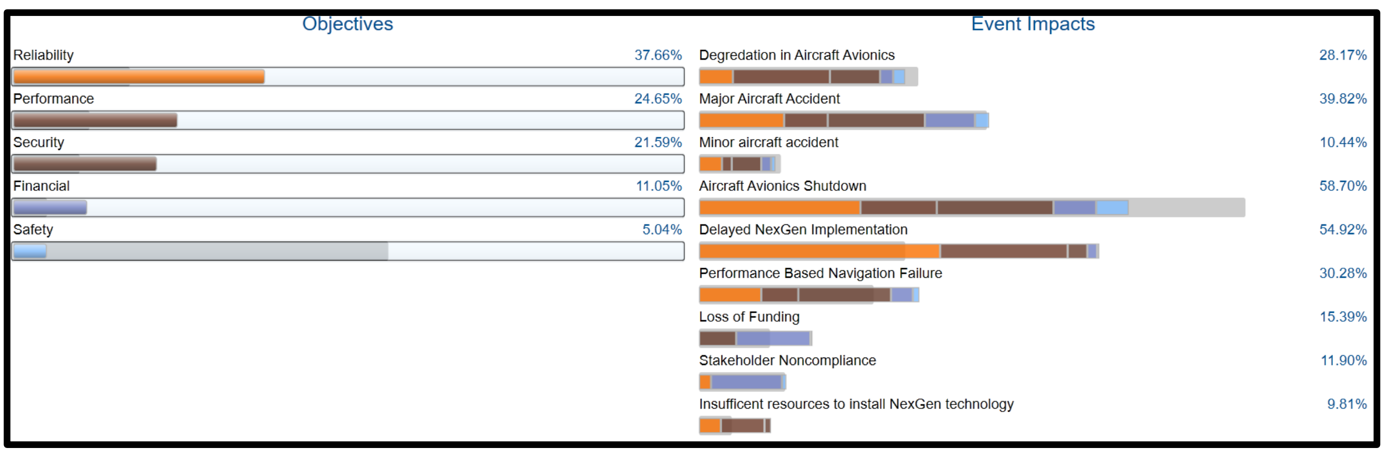


Figure 15: Dynamic Sensitivity Analysis of Consequences of Events on Objectives (Before Alteration)



According to the above sensitivity of objective figure, the 'Safety' objective is more important and 'aircraft avionics shutdown' has the most impact on this objective which is around 74.69%. When the priority of objectives change, the impact of risk events can change. For example, if the priority of the 'safety' objective changes to 5% (see in Figure 16), the 'aircraft avionics shutdown' risk event can have the highest impact on the objectives. Because of the objective priority change all event impacts can change.

Figure 16: Dynamic Sensitivity Analysis of Consequences of Events on Objectives (After Alteration)



VII. Risk Review

Overall Risk (Without Controls):

In section two, we defined risk as an uncertainty that matters, and its occurrence causes a loss to the organization's objectives. After identifying and measuring the likelihood of risk events as well as the impact of events, we can determine the greatest risk the FAA may face in the implementation of NexGen technologies. For this project we are using an enterprise evaluation of $179 million, derived from the input of a dollar figure for cyber security intrusion of $7 million. For this project, the valuations are hypothetical figures. Based on the computed likelihood, impact, and risk shown in Figure 17 we see a total risk of 57.11%.

Figure 17 Overall Computed Likelihoods, Impacts, Risk

No. ▲	Event	All Participants Likelihood Computed	Impact Computed	Risk Computed
[13]	Degredation in Aircraft Avionics	34.02%	29.95%	10.19%
[14]	Major Aircraft Accident	16.13%	39.39%	6.35%
[15]	Minor aircraft accident	24.68%	11.23%	2.77%
[17]	Aircraft Avionics Shutdown	32.60%	74.69%	24.35%
[19]	Delayed NexGen Implementation	16.34%	28.25%	4.62%
[20]	Performance Based Navigation Failure	32.77%	23.86%	7.82%
[21]	Loss of Funding	2.44%	9.67%	0.24%
[22]	Stakeholder Noncompliance	1.59%	11.71%	0.19%
[23]	Insufficent resources to install NexGen technology	13.05%	4.54%	0.59%
			Computed Total Risk	57.11%

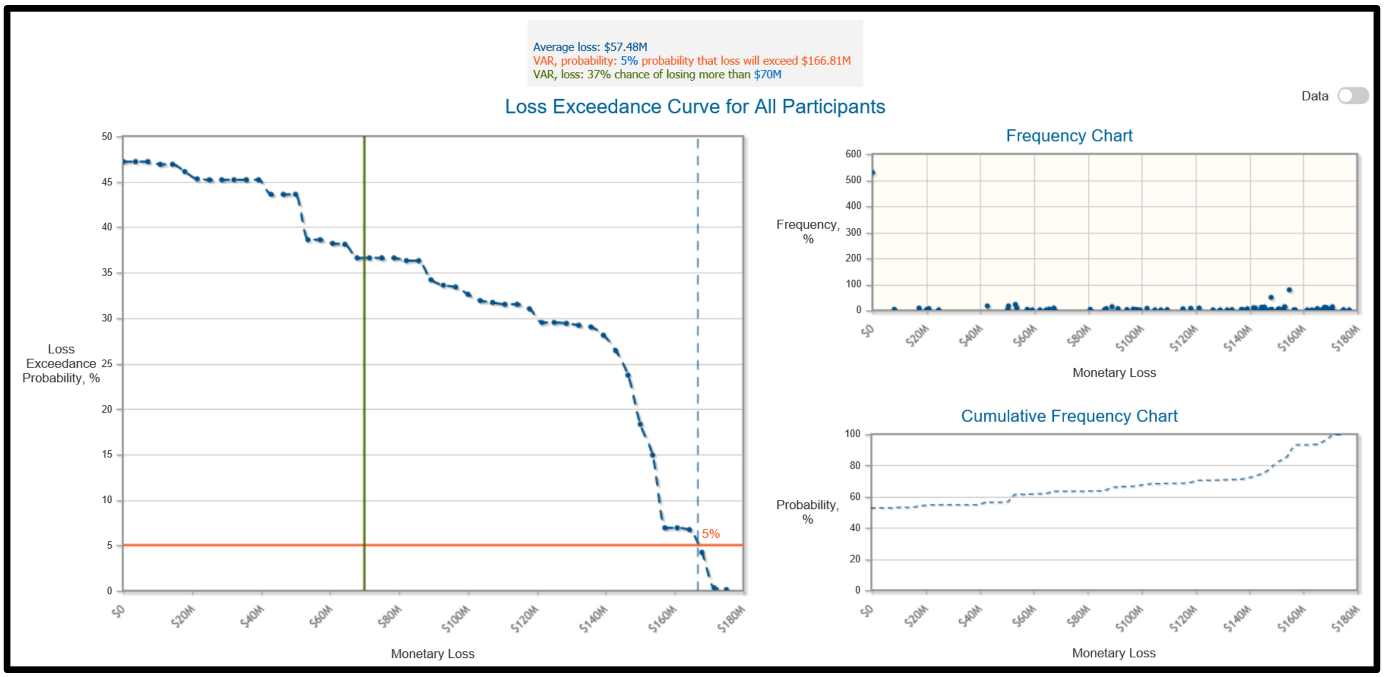
To reduce the double counting garnered by computed values, we use Monte Carlo simulations to overcome this bias. After the application of Monte Carlo Simulations, we observe the top three risk are Aircraft Avionics Shutdown (Risk = $23.5 million), Degradation in Aircraft Avionics (Risk = $9.8 million), and Performance Based Navigation Failure (Risk =$8.2 million)

Figure 18 Overall Simulated Likelihoods, Impacts, Risk (Simulated)

No. ▲	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[13]	Degredation in Aircraft Avionics	30.50%	32,420,460	9,888,240
[14]	Major Aircraft Accident	16.10%	39,056,231	6,288,053
[15]	Minor aircraft accident	23.10%	12,140,930	2,804,555
[17]	Aircraft Avionics Shutdown	29.30%	80,312,214	23,531,478
[19]	Delayed NexGen Implementation	18.40%	38,047,472	7,000,734
[20]	Performance Based Navigation Failure	30.90%	26,518,781	8,194,303
[21]	Loss of Funding	1.80%	13,411,602	241,408
[22]	Stakeholder Noncompliance	2.00%	15,337,270	306,745
[23]	Insufficent resources to install NexGen technology	15.00%	5,553,525	833,028
			Total Risk	Simulated $61,007,554

Monetary values can be credited to the impact and risk for each risk event once the values are identified for the projects overall budget. In Figure 19 we illustrate a loss exceedance curve. The line on the graph represents the probability that loss will exceed the corresponding value. For example, there is a 5% chance the that the loss will exceed $166.8 million! With a Value At Risk (VAR) set at 37% there is a change that the loss will exceed $ 70 million. The curve can be utilized to map out potential losses the company may consider before committing investments.

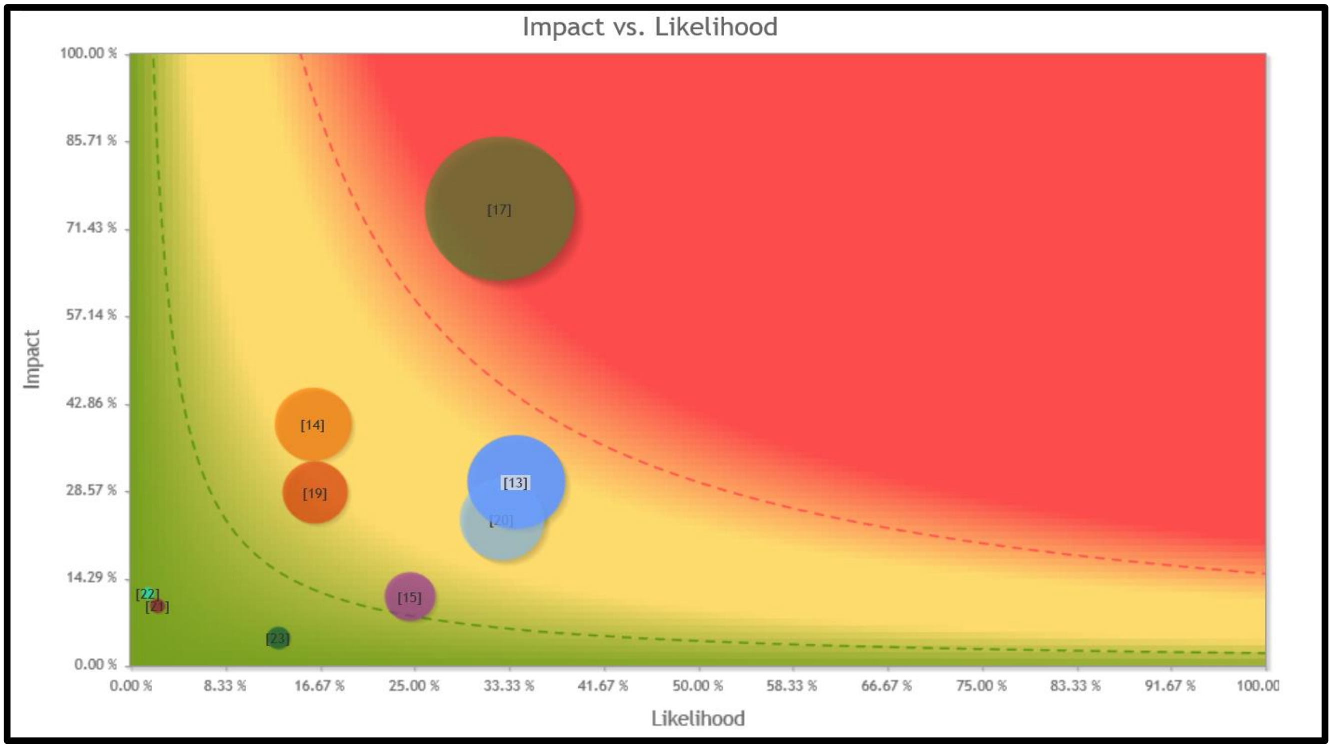
Figure 19 Loss Exceedance Curve



Risk Map (Heat Map) Without Controls:

The risk map in Figure 20 below represents the likelihood and impact of risk events and is an effective visual aid for the prioritization of events requiring controls. The size of the bubble fluctuates dependent upon the likelihood and impact on the project. A higher likelihood and impact creates a larger bubble. Based on the Risk Map risk event 17 “aircraft avionics shutdown” caused the greatest risk to the project with a simulated risk of $43.5 million. This makes sense that if aircraft avionics shutdown NexGen technologies are ineffective.

Figure 20 Overall Risk Map



Sample Bow-Tie Diagram:

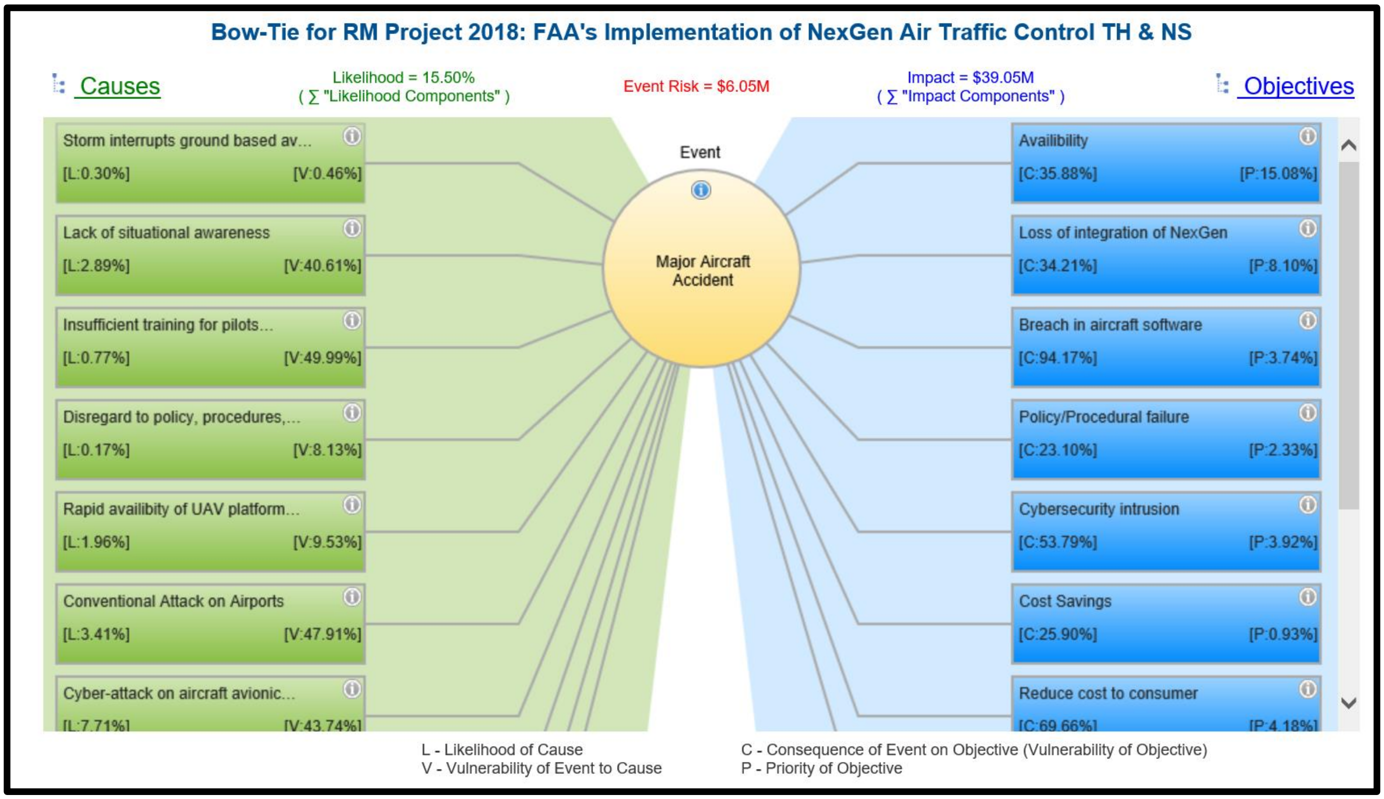
The Bow-Tie diagram further breaks down the overall risk analysis and provides a visual depiction of the likelihood components and impact in relation to the risk event. The identified risk is central to the diagram and has a computed event risk percentage. Risk percentage is dependent upon the relationship of causes and objectives. Causes are a list of identified sources and present the likelihood of the source (represented as a likelihood percentage) and vulnerabilities (which are represented as a vulnerability percentage).

The likelihood percentage of sources are calculated by multiplying the given likelihood of the source given the likelihood of the source it is categorized under. The vulnerability is calculated by multiplying the likelihood we calculated previously for the source and the likelihood of the risk event given the source. This calculation is produced for each event and a sum-total is collected to create the overall calculated likelihood.

The impact percentage is calculated by multiplying the measured priority of the objective and the consequence of the given event on the priority of the objective. This calculation is produced for each event and a sum-total is collected to create the overall calculated impact.

Multiplying both the total likelihood percentage and the total impact percentage will result in that event's risk percentage (see Figure 21).

Figure 21: Example Bow Tie Diagram

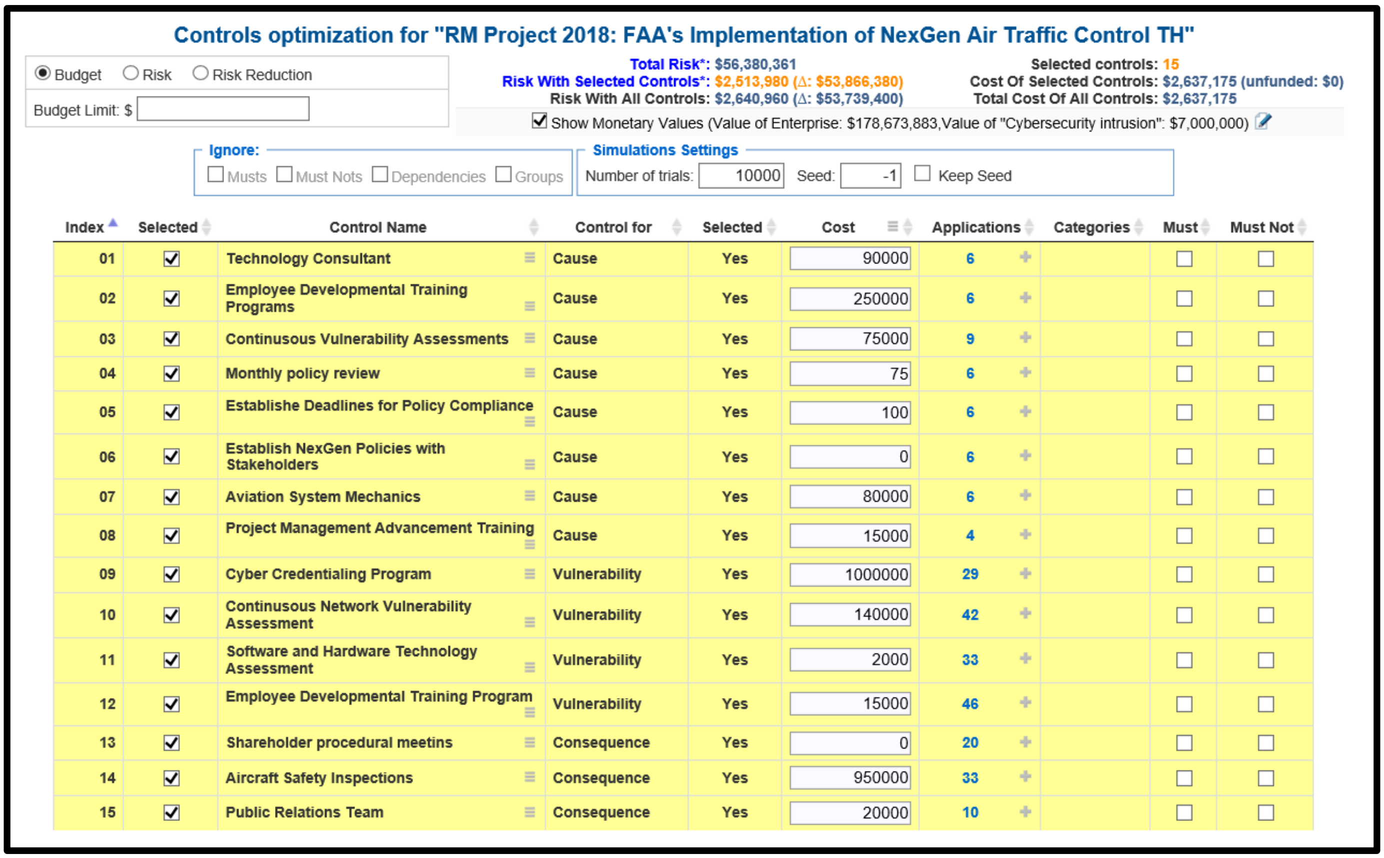


VIII. <u>Identify and Select Controls</u>

Identify Controls:

Many risk events are involved in project to mitigate risk events and the likelihood of occurrence we identify possible controls. Controls are applied to sources, events, or objectives. Fifteen controls were identified for this project; eight reduce the likelihood of sources, four reduce the likelihood events given sources, and three reduce the impact of events on objectives. The total cost to implement all controls is approximately $2.6 million.

Figure 22: Identifying Controls



Controls optimization for "RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH"

Budget | Risk | Risk Reduction

Budget Limit: $

Total Risk*: $56,380,361
Risk With Selected Controls*: $2,513,980 (Δ: $53,866,380)
Risk With All Controls: $2,640,960 (Δ: $53,739,400)

Selected controls: 15
Cost Of Selected Controls: $2,637,175 (unfunded: $0)
Total Cost Of All Controls: $2,637,175

Show Monetary Values (Value of Enterprise: $178,673,883,Value of "Cybersecurity intrusion": $7,000,000)

Ignore: Musts | Must Nots | Dependencies | Groups

Simulations Settings: Number of trials: 10000 | Seed: -1 | Keep Seed

Index	Selected	Control Name	Control for	Selected	Cost	Applications	Categories	Must	Must Not
01	☑	Technology Consultant	Cause	Yes	90000	6		☐	☐
02	☑	Employee Developmental Training Programs	Cause	Yes	250000	6		☐	☐
03	☑	Continusous Vulnerability Assessments	Cause	Yes	75000	9		☐	☐
04	☑	Monthly policy review	Cause	Yes	75	6		☐	☐
05	☑	Establishe Deadlines for Policy Compliance	Cause	Yes	100	6		☐	☐
06	☑	Establish NexGen Policies with Stakeholders	Cause	Yes	0	6		☐	☐
07	☑	Aviation System Mechanics	Cause	Yes	80000	6		☐	☐
08	☑	Project Management Advancement Training	Cause	Yes	15000	4		☐	☐
09	☑	Cyber Credentialing Program	Vulnerability	Yes	1000000	29		☐	☐
10	☑	Continusous Network Vulnerability Assessment	Vulnerability	Yes	140000	42		☐	☐
11	☑	Software and Hardware Technology Assessment	Vulnerability	Yes	2000	33		☐	☐
12	☑	Employee Developmental Training Program	Vulnerability	Yes	15000	46		☐	☐
13	☑	Shareholder procedural meetins	Consequence	Yes	0	20		☐	☐
14	☑	Aircraft Safety Inspections	Consequence	Yes	950000	33		☐	☐
15	☑	Public Relations Team	Consequence	Yes	20000	10		☐	☐

Participant Roles for Measuring Controls:

To synchronize and eliminate miscalculations based on bias, participant roles were identified for judgments made on controls. Mr. Dan Miles, Chief Operations Officer, has singular responsibility to input judgments for each control. Depicted below are participant roles.

Figure 23: Participant Roles

Participant Roles

Allow All | Drop All | Show: ○ All ◉ Controls for Causes ○ Controls for Vulnerabilities ○ Controls for Impacts

	Control Name	☐ FAA Administrator (bernstein34@faa	☐ Bryan Hayes (Chief Engineer Officer) (Bryan.Hayes@fa	☐ John Paul (Chief Cyber Security Officer) (cybersecurity@g	☑ Dan Miles (Chief Operations Officer) (dan.4.miles@faa.	☐ Professor Forman (forman@gwu.edu	☐ Weather Forecaster (Joel.Frank@wea	☐ Kelly Steiz (Cheif Financial Officer) (Kelly.3.Steiz@fa	☐ Nitasha Naqvi (nitashasyed@gw	☐ Nicholas Stavrakakis (nstavrakakis@gv
Controls for Causes										
☐	Technology Consultant	☐	☐	☐	☑	☐	☐	☐	☐	☐
☐	Employee Developmental Training Programs	☐	☐	☐	☑	☐	☐	☐	☐	☐
☐	Continuous Vulnerability Assessments	☐	☐	☐	☑	☐	☐	☐	☐	☐
☐	Monthly review	[illegible]	[illegible]	☐	☑	☐	☐	☐	☐	☐
☐	Establishe Deadlines for Policy Compliance	☐	☐	☐	☑	☐	☐	☐	☐	☐
☐	Establish NexGen Policies with Stakeholders	☐	☐	☐	☑	☐	☐	☐	☐	☐

Continusous Vulnerability Assessments

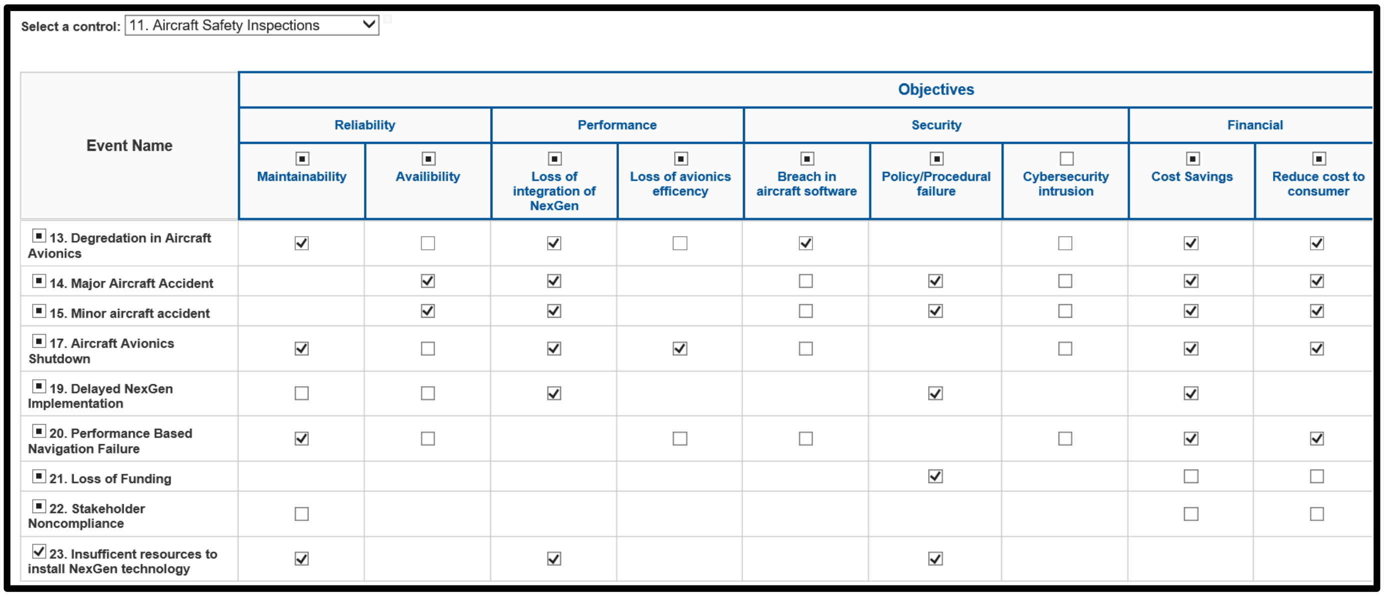
Linking Controls to Causes and Objectives:

Figure 24: Application of Controls to Sources (Causes)

Control Name	Sources								
	Environment		Political/Financial			Human Factor			
	Storm interrupts ground based avionics suite	Increased noise leves to communities	High maintenance cost	FAA does not fund the continuation of NexGen	Turnover in FAA administration decides to go in a different direction	Lack of situational awareness	Insufficient training for pilots and controllers of NexGen integrated systems	Disregard to policy, procedures, and protocol	Requirements scope change post 2020 implementation date
1. Technology Consultant	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. Employee Developmental Training Programs	☐	☐	☐	☐	☐	☑	☑	☑	☑
3. Continuous Vulnerability Assessments	☑	☐	☐	☐	☐	☑	☑	☑	☑
4. Monthly policy review	☐	☑	☑	☑	☑	☐	☐	☑	☑
5. Establishe Deadlines for Policy Compliance	☐	☐	☑	☐	☑	☐	☐	☑	☑
6. Establish NexGen Policies with Stakeholders	☐	☑	☑	☑	☑	☐	☐	☐	☐

After the identification of controls, we sought to link them to their sources, vulnerabilities, and consequences. Controls were applied if the control would have a positive impact on the specified cause. If the control was deemed not to have a positive impact on the cause, then it was not applied (depicted above). The same process to link controls to objectives is demonstrated below.

Figure 25 Application of Controls on Consequences of Events to Objectives



Select a control: 11. Aircraft Safety Inspections

Event Name	Objectives								
	Reliability		Performance		Security			Financial	
	Maintainability	Availibility	Loss of integration of NexGen	Loss of avionics efficency	Breach in aircraft software	Policy/Procedural failure	Cybersecurity intrusion	Cost Savings	Reduce cost to consumer
13. Degredation in Aircraft Avionics	☑	☐	☑	☐	☑		☐	☑	☑
14. Major Aircraft Accident		☑	☑		☐	☑	☐	☑	☑
15. Minor aircraft accident		☑	☑		☐	☑	☐	☑	☑
17. Aircraft Avionics Shutdown	☑	☐	☑	☑	☐		☐	☑	☑
19. Delayed NexGen Implementation	☐	☐	☑			☑		☑	
20. Performance Based Navigation Failure	☑	☐		☐	☐		☐	☑	☑
21. Loss of Funding						☑		☐	☐
22. Stakeholder Noncompliance	☐							☐	☐
23. Insufficent resources to install NexGen technology	☑		☑			☑			

Measure Effectiveness of Controls:

Mr. Dan Miles measured the effectiveness of controls to reduce the likelihood of the causes. Direct comparison methodology was used for all measurements, which allowed for the input of a number from 0 to 1, representing the effectiveness of each control as seen in the figure below.

Figure 26: Example of Control Using Direct Comparison Method

Overall Risk (with Controls):

After judgments were collected, we analyzed the impact the application of controls had on overall risk. Checking the application of all 15 controls first to see how much these controls reduce the likelihood of occurrence of risk events. By the application of all 15 controls with the approximate cost of $ 2.6 million, we can expect to reduce the risk by $53.3 million.

Figure 27: Overall Simulated Likelihood, Impacts, and Risk with Controls

Overall Likelihoods, Impacts, and Risks (With Controls) for RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH
(Controls are manually selected)

No. ▲	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[13]	Degredation in Aircraft Avionics	1.01%	13,579,334	137,151
[14]	Major Aircraft Accident	0.28%	23,050,869	64,542
[15]	Minor aircraft accident	0.39%	6,870,989	26,796
[17]	Aircraft Avionics Shutdown	1.21%	55,812,198	675,327
[19]	Delayed NexGen Implementation	1.99%	25,483,969	507,131
[20]	Performance Based Navigation Failure	3.03%	33,226,653	1,006,767
[21]	Loss of Funding	0.64%	9,075,521	58,083
[22]	Stakeholder Noncompliance	0.02%	4,616,768	923
[23]	Insufficent resources to install NexGen technology	5.36%	2,512,105	134,648

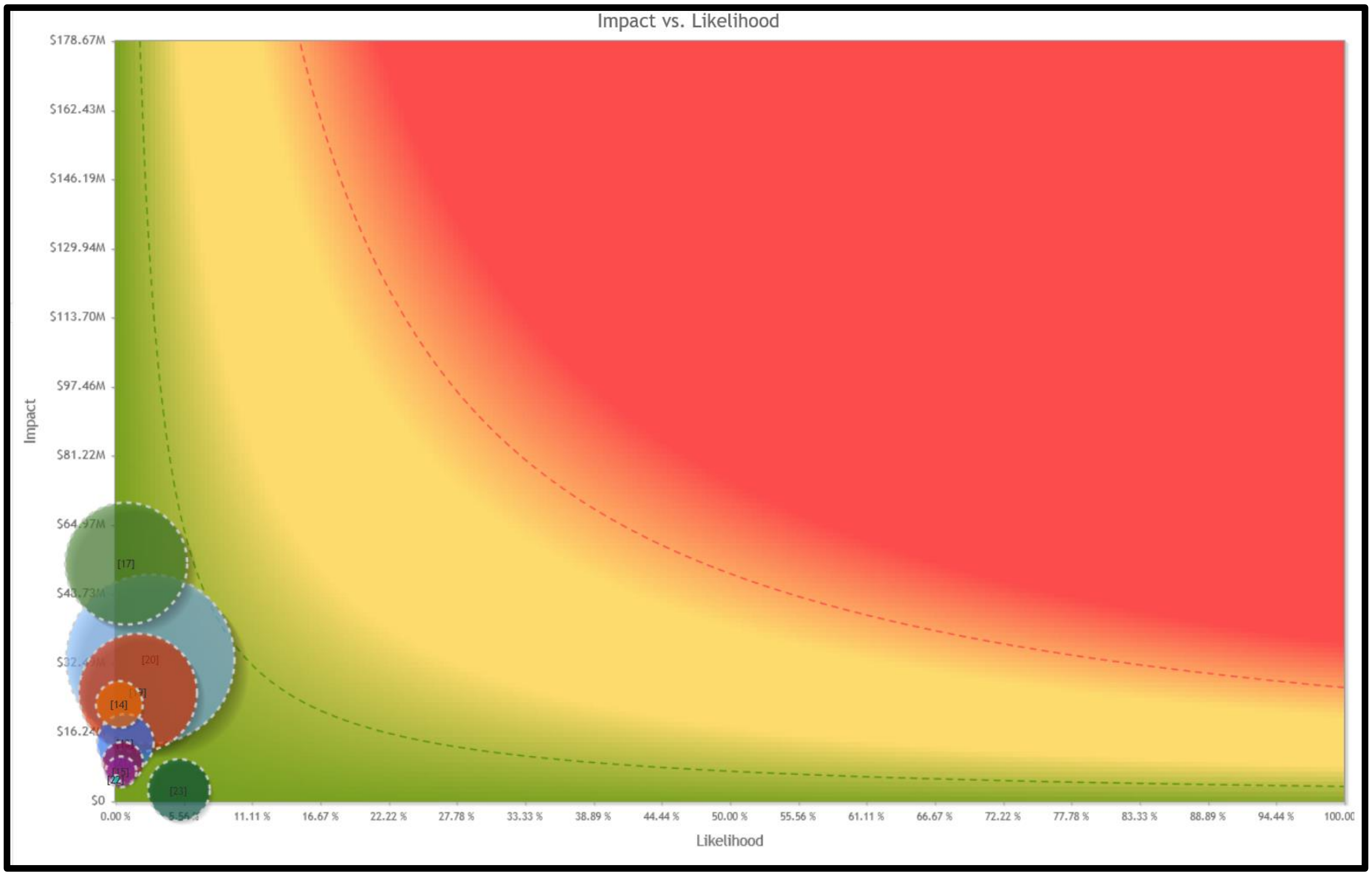
# Controls	Cost of Controls	How Selected
15	$2,637,175	Manually selected

	Simulated
Total Risk	$56,009,621
Risk Reduction	$53,398,249
Residual Risk	$2,611,372

Risk Map (Heat Mat) with Controls:

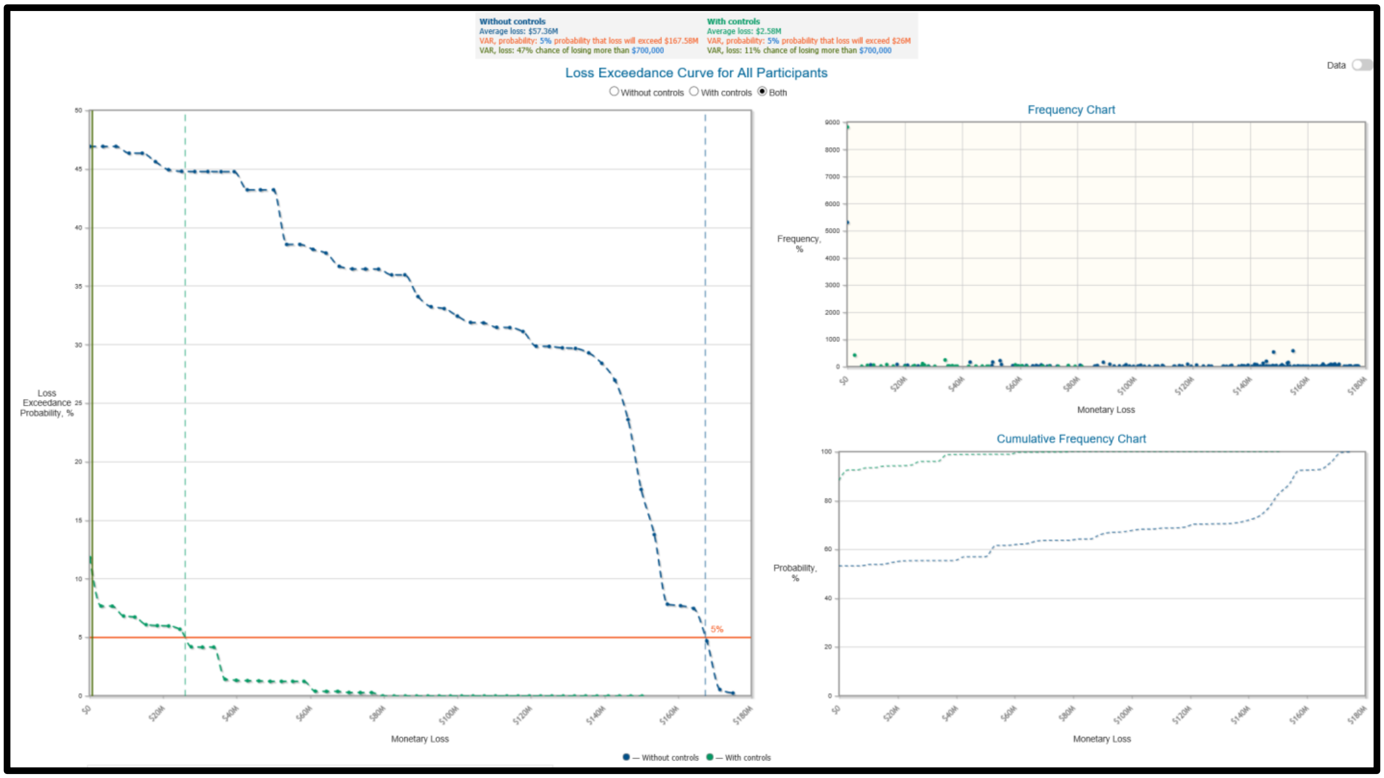
Figure 26 below depicts the overall risk map with controls. By using controls, it is clear the bubbles shifted to the left and the likelihood and impact of the risk reduced compared to Figure 18. Based on the overall risk map after the application of controls the three major events are Performance Based Navigation Failure (Risk = $1 Million), Aircraft Avionics Shutdown (Risk = $675,327), and Delayed NexGen Implementation (Risk = $507,131).

Figure 28 Overall Risk Map with Controls



Noted earlier, there was a 37% chance that the loss will exceed $ 70 million without controls. In addition, without controls there was a 5% change that loss would exceed $166.8 million. After adding controls, it appears the probability of losing $166.8 million has dropped to 0%. There is a 5% chance that loss will exceed $26 million.

Figure 29: Loss Exceedance Curve with Controls



Optimizing Controls:

Through statements we know that the project is expected to be complete in two years and the controls can affect the implementation of different aspects of the project increasing the timeframe beyond the two-year mark. For example, we can use stakeholder procedural meeting to track the project and ensure federal regulation compliance. Or implement employee development training to ensure employees understand the intricates of the new system before implementation. Since the project has a limited budget we are unable to select all controls, additionally we must weigh the fact that adding additional controls is not cost effective or beneficial. Controls were selected based on three budgetary constraints of $2 million, $1 million, and $700,000.

Scenario 1:

The optimization of controls with a budget of $150,000, we observe the selection of 4 controls with the expected risk reduction of $42.2 Million.

Figure 30 Controls Selected with a Budget of $150,000

Controls optimization for "RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH"

(•) Budget ( ) Risk ( ) Risk Reduction

Budget Limit: $ 150,000

Total Risk*: $57,987,754
Risk With Selected Controls*: $15,738,059 (Δ: $42,249,694)
Risk With All Controls: $2,509,545 (Δ: $55,478,209)

Selected controls: 4
Cost Of Selected Controls: $142,075 (unfunded: $2,495,100)
Total Cost Of All Controls: $2,637,175

☑ Show Monetary Values (Value of Enterprise: $178,673,883,Value of "Cybersecurity intrusion": $7,000,000)

Ignore: ☐ Musts ☐ Must Nots ☐ Dependencies ☐ Groups

Simulations Settings: Number of trials: 10000 Seed: -1 ☐ Keep Seed

Index	Selected	Control Name	Control for	Selected	Cost	Applications	Categories	Must	Must Not
01	☐	Technology Consultant	Cause		90000	6		☐	☐
02	☐	Employee Developmental Training Programs	Cause		250000	6		☐	☐
03	☐	Continusous Vulnerability Assessments	Cause		75000	9		☐	☐
04	☑	Monthly policy review	Cause	Yes	75	6		☑	☐
05	☐	Establishe Deadlines for Policy Compliance	Cause		100	6		☐	☐
06	☐	Establish NexGen Policies with Stakeholders	Cause		0	6		☐	☐
07	☐	Aviation System Mechanics	Cause		80000	6		☐	☐
08	☐	Project Management Advancement Training	Cause		15000	4		☐	☐
09	☐	Cyber Credentialing Program	Vulnerability		1000000	29		☐	☐
10	☑	Continusous Network Vulnerability Assessment	Vulnerability	Yes	140000	42		☐	☐
11	☑	Software and Hardware Technology Assessment	Vulnerability	Yes	2000	33		☑	☐
12	☐	Employee Developmental Training Program	Vulnerability		15000	46		☐	☐
13	☑	Shareholder procedural meetins	Consequence	Yes	0	20		☐	☐
14	☐	Aircraft Safety Inspections	Consequence		950000	33		☐	☐
15	☐	Public Relations Team	Consequence		20000	10		☐	☐

Figure 31 Overall Risk with a Budget of $150,000

Overall Likelihoods, Impacts, and Risks (With Controls) for RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH
(Controls are optimized based on simulated input and output)

No. ▲	Event	All Participants Likelihood Simulated	All Participants Impact, $ Simulated	All Participants Risk, $ Simulated
[13]	Degredation in Aircraft Avionics	5.84%	48,283,626	2,819,763
[14]	Major Aircraft Accident	2.92%	58,517,840	1,708,720
[15]	Minor aircraft accident	4.07%	17,519,483	713,042
[17]	Aircraft Avionics Shutdown	6.12%	108,307,827	6,628,439
[19]	Delayed NexGen Implementation	3.52%	45,188,102	1,590,621
[20]	Performance Based Navigation Failure	4.69%	37,955,457	1,780,110
[21]	Loss of Funding	2.18%	10,351,612	225,665
[22]	Stakeholder Noncompliance	0.18%	6,420,402	11,556
[23]	Insufficent resources to install NexGen technology	6.03%	2,444,349	147,394

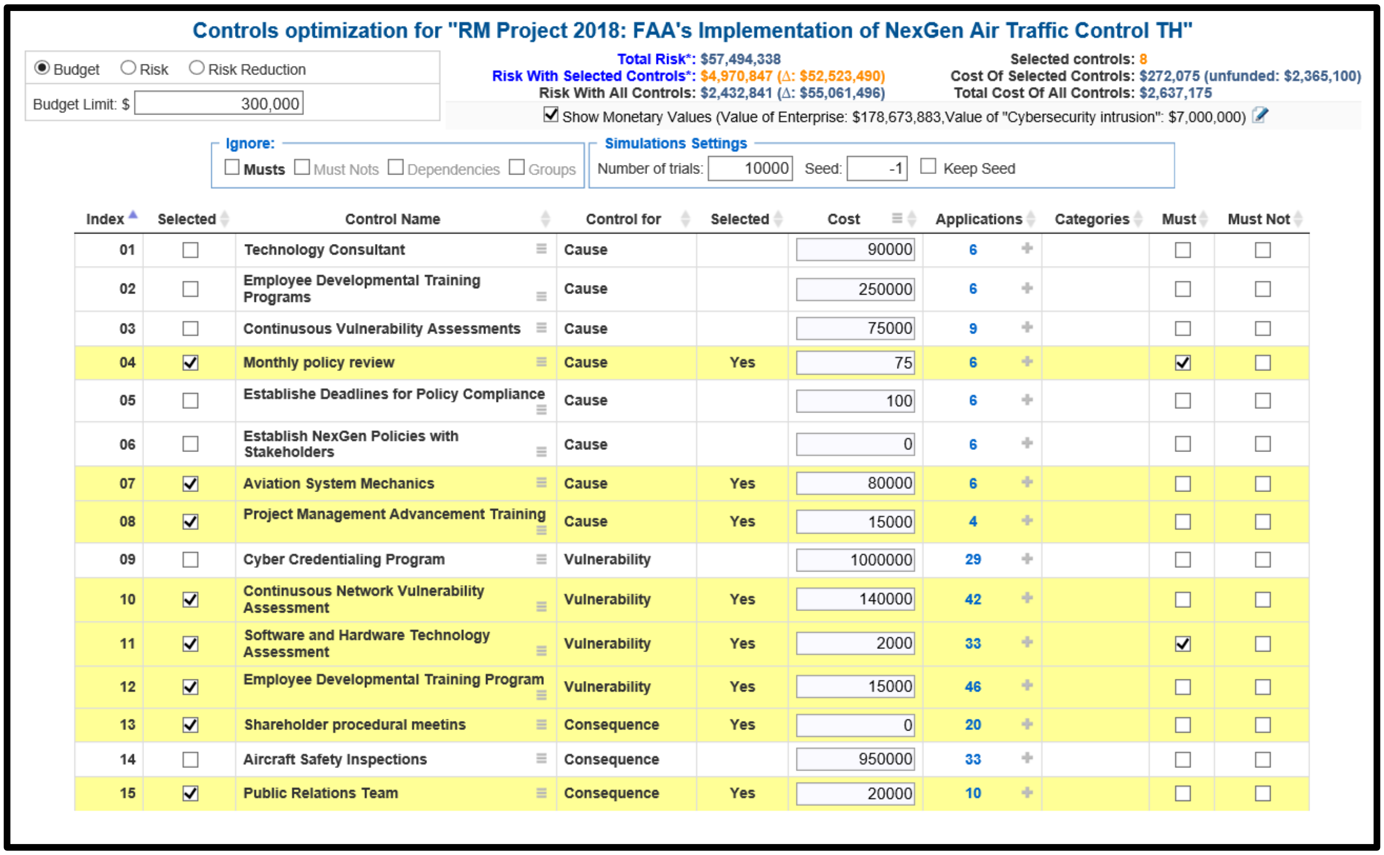
# Controls	Cost of Controls	How Selected
4	$142,075	Optimized based on simulated input and output with budget of $150,000

	Simulated
Total Risk	$56,220,831
Risk Reduction	$40,595,516
Residual Risk	$15,625,315

Scenario 2:

The optimization of controls with a budget of $300,000, we observe the selection of 8 controls with the expected risk reduction of $52.5 Million.

Figure 32 Controls Selected with a Budget of $300,000


Controls optimization for "RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH"

Budget / Risk / Risk Reduction

Budget Limit: $ 300,000

Total Risk*: $57,494,338
Risk With Selected Controls*: $4,970,847 (Δ: $52,523,490)
Risk With All Controls: $2,432,841 (Δ: $55,061,496)

Selected controls: 8
Cost Of Selected Controls: $272,075 (unfunded: $2,365,100)
Total Cost Of All Controls: $2,637,175

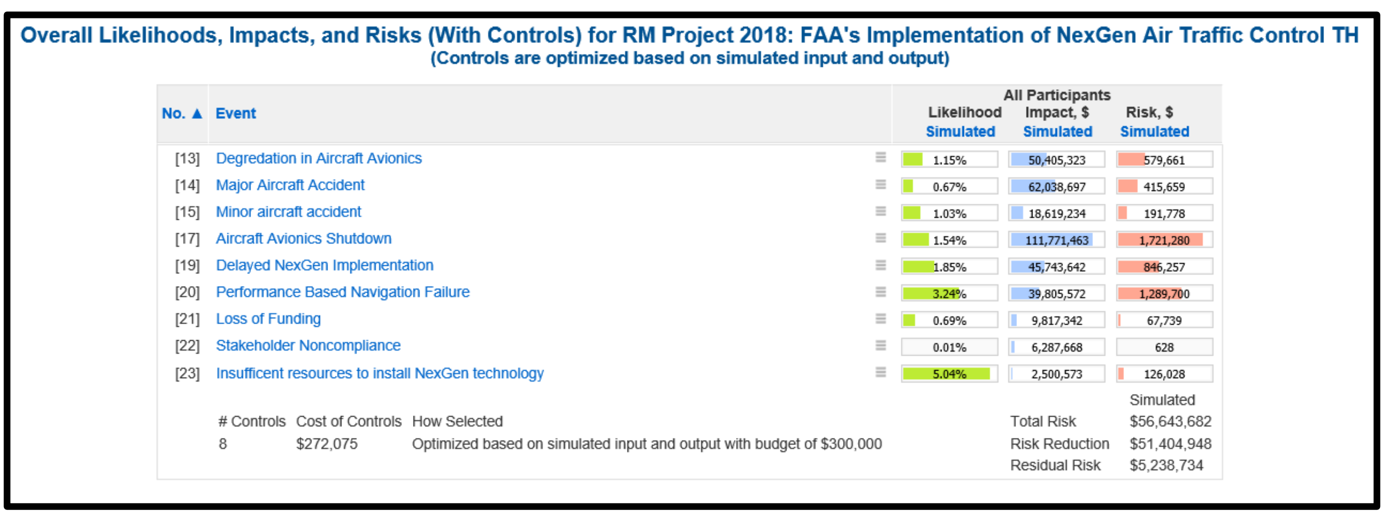
☑ Show Monetary Values (Value of Enterprise: $178,673,883,Value of "Cybersecurity intrusion": $7,000,000)

Ignore: ☐ Musts ☐ Must Nots ☐ Dependencies ☐ Groups

Simulations Settings: Number of trials: 10000 Seed: -1 ☐ Keep Seed

Index	Selected	Control Name	Control for	Selected	Cost	Applications	Categories	Must	Must Not
01	☐	Technology Consultant	Cause		90000	6		☐	☐
02	☐	Employee Developmental Training Programs	Cause		250000	6		☐	☐
03	☐	Continusous Vulnerability Assessments	Cause		75000	9		☐	☐
04	☑	Monthly policy review	Cause	Yes	75	6		☑	☐
05	☐	Establishe Deadlines for Policy Compliance	Cause		100	6		☐	☐
06	☐	Establish NexGen Policies with Stakeholders	Cause		0	6		☐	☐
07	☑	Aviation System Mechanics	Cause	Yes	80000	6		☐	☐
08	☑	Project Management Advancement Training	Cause	Yes	15000	4		☐	☐
09	☐	Cyber Credentialing Program	Vulnerability		1000000	29		☐	☐
10	☑	Continuous Network Vulnerability Assessment	Vulnerability	Yes	140000	42		☐	☐
11	☑	Software and Hardware Technology Assessment	Vulnerability	Yes	2000	33		☑	☐
12	☑	Employee Developmental Training Program	Vulnerability	Yes	15000	46		☐	☐
13	☑	Shareholder procedural meetins	Consequence	Yes	0	20		☐	☐
14	☐	Aircraft Safety Inspections	Consequence		950000	33		☐	☐
15	☑	Public Relations Team	Consequence	Yes	20000	10		☐	☐

Figure 33 Overall Risk with a Budget of $300,000


Overall Likelihoods, Impacts, and Risks (With Controls) for RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH
(Controls are optimized based on simulated input and output)

No.	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[13]	Degredation in Aircraft Avionics	1.15%	50,405,323	579,661
[14]	Major Aircraft Accident	0.67%	62,038,697	415,659
[15]	Minor aircraft accident	1.03%	18,619,234	191,778
[17]	Aircraft Avionics Shutdown	1.54%	111,771,463	1,721,280
[19]	Delayed NexGen Implementation	1.85%	45,743,642	846,257
[20]	Performance Based Navigation Failure	3.24%	39,805,572	1,289,700
[21]	Loss of Funding	0.69%	9,817,342	67,739
[22]	Stakeholder Noncompliance	0.01%	6,287,668	628
[23]	Insufficent resources to install NexGen technology	5.04%	2,500,573	126,028

# Controls	Cost of Controls	How Selected
8	$272,075	Optimized based on simulated input and output with budget of $300,000

	Simulated
Total Risk	$56,643,682
Risk Reduction	$51,404,948
Residual Risk	$5,238,734

Scenario 3:

The optimization of controls with a budget of $500,000, we observe the selection of 8 controls with the expected risk reduction of $50.9 Million.

Figure 34 Controls Selected with a Budget of $500,000

Controls optimization for "RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH"

◉ Budget ○ Risk ○ Risk Reduction

Budget Limit: $ 500,000

Total Risk*: $56,526,115
Risk With Selected Controls*: $5,562,371 (Δ: $50,963,744)
Risk With All Controls: $2,521,118 (Δ: $54,004,997)

Selected controls: 8
Cost Of Selected Controls: $272,075 (unfunded: $2,365,100)
Total Cost Of All Controls: $2,637,175

☑ Show Monetary Values (Value of Enterprise: $178,673,883,Value of "Cybersecurity intrusion": $7,000,000)

Ignore: ☐ Musts ☐ Must Nots ☐ Dependencies ☐ Groups

Simulations Settings: Number of trials: 10000 Seed: -1 ☐ Keep Seed

Index	Selected	Control Name	Control for	Selected	Cost	Applications	Categories	Must	Must Not
01	☐	Technology Consultant	Cause		90000	6		☐	☐
02	☐	Employee Developmental Training Programs	Cause		250000	6		☐	☐
03	☐	Continusous Vulnerability Assessments	Cause		75000	9		☐	☐
04	☑	Monthly policy review	Cause	Yes	75	6		☑	☐
05	☐	Establishe Deadlines for Policy Compliance	Cause		100	6		☐	☐
06	☐	Establish NexGen Policies with Stakeholders	Cause		0	6		☐	☐
07	☑	Aviation System Mechanics	Cause	Yes	80000	6		☐	☐
08	☑	Project Management Advancement Training	Cause	Yes	15000	4		☐	☐
09	☐	Cyber Credentialing Program	Vulnerability		1000000	29		☐	☐
10	☑	Continusous Network Vulnerability Assessment	Vulnerability	Yes	140000	42		☐	☐
11	☑	Software and Hardware Technology Assessment	Vulnerability	Yes	2000	33		☑	☐
12	☑	Employee Developmental Training Program	Vulnerability	Yes	15000	46		☐	☐
13	☑	Shareholder procedural meetins	Consequence	Yes	0	20		☐	☐
14	☐	Aircraft Safety Inspections	Consequence		950000	33		☐	☐
15	☑	Public Relations Team	Consequence	Yes	20000	10		☐	☐

Figure 35 Overall Risk with a Budget of $700,000

Overall Likelihoods, Impacts, and Risks (With Controls) for RM Project 2018: FAA's Implementation of NexGen Air Traffic Control TH
(Controls are optimized based on simulated input and output)

No. ▲	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[13]	Degredation in Aircraft Avionics	1.60%	50,782,532	812,520
[14]	Major Aircraft Accident	0.53%	61,958,916	328,382
[15]	Minor aircraft accident	1.13%	18,536,859	209,466
[17]	Aircraft Avionics Shutdown	1.41%	114,064,223	1,608,305
[19]	Delayed NexGen Implementation	1.89%	45,904,579	867,596
[20]	Performance Based Navigation Failure	3.04%	40,267,517	1,224,132
[21]	Loss of Funding	0.85%	9,749,764	82,872
[22]	Stakeholder Noncompliance	0.03%	6,704,830	2,011
[23]	Insufficent resources to install NexGen technology	5.00%	2,505,299	125,264

# Controls	Cost of Controls	How Selected
8	$272,075	Optimized based on simulated input and output with budget of $500,000

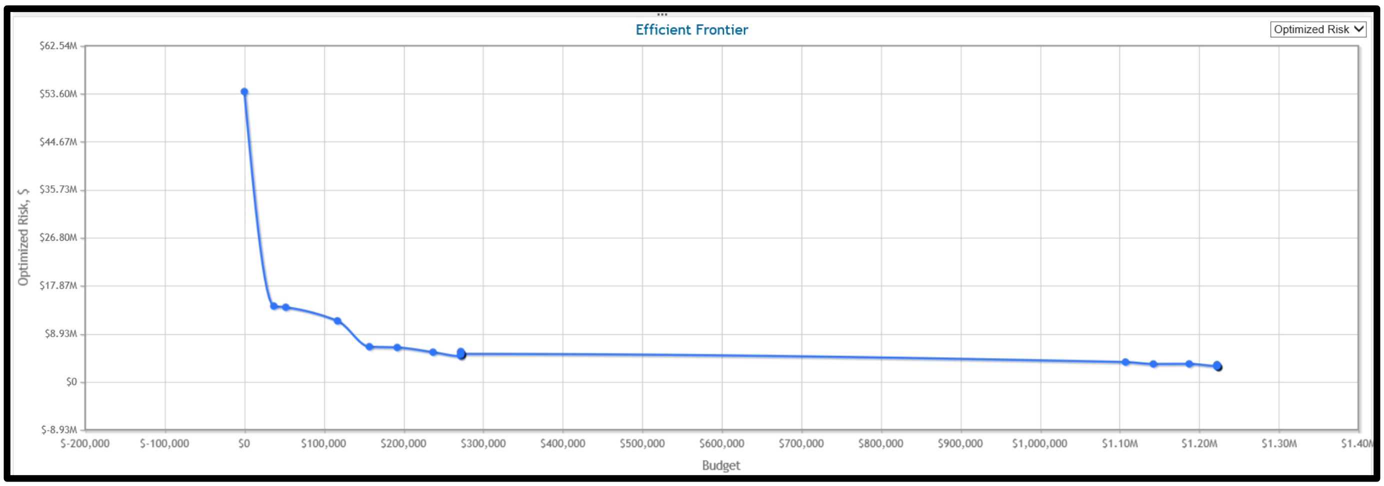
	Simulated
Total Risk	$55,247,233
Risk Reduction	$49,986,680
Residual Risk	$5,260,553

Budget Optimization Analysis

If we were to use all 15 controls, it would cost $2.6 Million. We optimized the controls with budgetary constraints of $150,000, $300,000, and $500,000 for a selection of 4 to 8 controls. Utilizing a budget of $300,000 means that we could save $300,000 at the beginning of the project. Based on results obtained, utilizing a budget of $300,000 can reduce the risk by $52.5 Million. The addition of $200,000 hinders the efficiency of controls and increases the residual risk. Therefore, it makes sense to consider spending the money at the beginning to mitigate the risk throughout the project.

According to Efficient Frontier by spending between $250,000 and $272,000 is the most efficient. Spending beyond $272,000 is no longer efficient in adding controls. The organization may consider double checking the optimization and consider increasing the budget to $700,000 (if needed) and determine if the risk reduction amount justifies the additional spending.

Figure 36 Efficient Frontier



IX. Recommendation and Conclusion

Air travel remains the safest form of transportation for individuals looking to travel long distances across the country. The implementation of NexGen technology is the result of years of research and development with oversight from government accountability offices. The technological improvements NexGen seek to adapt will continue to make the airways the safest form of travel. It is however obvious that a high degree of risk will be involved in this project, and it is best to identify and associate risk at the earliest possible opportunity.