Next Generation Commercial Airliners

The George Washington University

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Introduction

We, humans, love to travel by air and have been doing so for the past 100 years. The ever-growing demand for air passenger travel has led to a whole new dimension of building the next big commercial airliner in the world. Worldwide, commercial airlines carried over 3.8 billion passengers on scheduled flights in 2016 ("Airline Industry - Passenger Traffic Worldwide 2004-2017 | Statistic."). Industry-wide passenger traffic grew by 6.3 percent in 2016. According to the latest International Air Transport Association (IATA) figures, commercial airlines posted their strongest financial performance ever in 2016 — reporting $35.6 billion in net profit, just a bit above 2015 results and nearly double those of 2014. For the third consecutive year (and only the third year in airline industry history), carriers reported a positive return on invested capital ("www.strategyand.pwc.com/trend/2017-commercial-aviation-trends"). Per the International Air Transport Association (IATA), the number of air passengers will nearly double in the next few years. Therefore, this growth is encouraging commercial airline manufacturers like Airbus and Boeing to compete and innovate newer, bigger, and longer distance flying airplanes.

Building something newer, bigger, and more innovative comes with new set of challenges. Take the example of building the world's largest commercial airliner, the Airbus A380, which had many difficulties. Bottlenecks encountered in the definition, manufacturing, and installation of the A380's electrical systems and their more than 500 km. of internal wiring – combined with the customisation of airplane to customer specifications – led to the build-up of delivery delays. In June 2006, Airbus outlined a series of actions dealing with the situation including new processes for the outfitting of A380 fuselage sections and a revised pacing of their transfer to the final assembly line. The recovery process took some time to put the A380 output back on track. Reality has shown many issues with building the Airbus A380 and Boeing 787 Dreamliner with billions of dollars in penalties, increased production costs, and miscalculated delivery timetables. An evaluation of risk for any future commercial airliner is necessary to prevent and mitigate cost overruns, geopolitical issues, delivery timetables, component problems, and lack of sales.

Like every other mega project before starting to build the next big commercial airline, it is necessary to do a risk assessment of the project. Building a commercial airliner is a complex project containing precise time constraints, posing greater technical challenges, and rarely having enough skilled resources. We need to know that there are techniques that exist to better deal with risky and high demanding projects. By using these techniques effectively, the project can help recognize and manage potential problems. We have created a hypothetical project to study and evaluate the risks involved in building the next big commercial airliner.

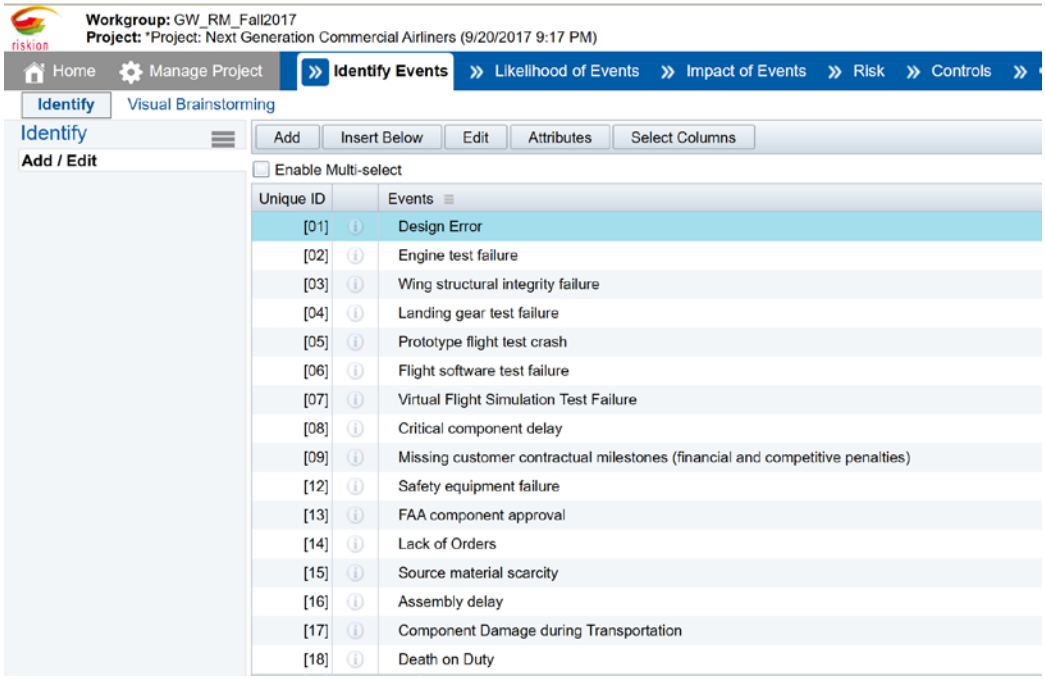
With the help of the Risk assessment tool "Riskion", we could identify, accurately measure and mitigate risks. By using pure ratio-based mathematics from Riskion, we could identify events, sources, and outcomes to help allocate the necessary resources to mitigate risks. The advantage of using Riskion is that it helps in identifying potential vulnerabilities in a business framework, improves accountability and control over potential risk scenarios, uncovers hidden triggers, events, and risks, and has reliable relative measures of risk that advance the ability to better allocate resources in managing and mitigating risks (Riskion by Expert Choice Software).

Risk Model Identification

Events

The first step in our project of Next generation commercial airliner was to identify events. An event must have a loss if it is to be called an Event (Risk event). We have identified events based on following criteria's.

- What are the events that could cause a loss to airplane manufacturing?
- What could go wrong during operations while airplane manufacturing?
- What are the sources to cause an event?



Sixteen risk events are identified which could bring potential loss to our project of Next Generation Commercial Airliners.

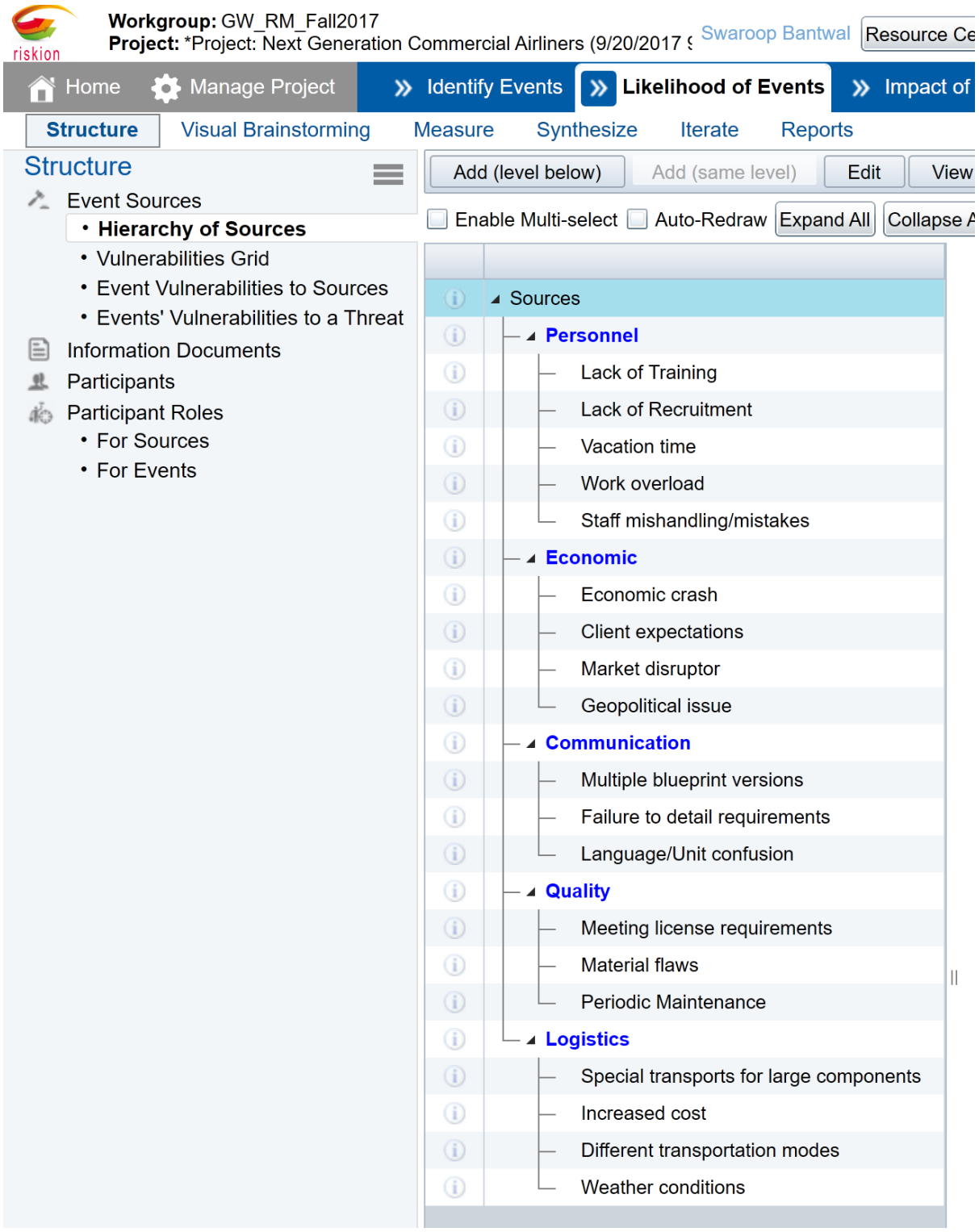
1. **Design Error**: Design errors are known to be mistakes waiting to happen. It is often seen that failure to consider a potential human error in designs leads to design errors. Lack of validation or quality control could lead to major loss to airline manufacturers potentially bringing a halt to a whole assembly line.
2. **Engine Test Failure**: Engines are the most critical component of an airplane. The engines are tested to suck in air, but they must be capable of handling everything else they may encounter in the sky, most notably birds and bad weather. To ensure that's the case, manufacturers run tests to make sure these engines withstand unforeseen incidents ("George, 14 Sept 2017").
3. **Wing Structural Integrity Failure**: Ultimate wing load testing is standard procedure for any new airplane design and has been done on airplanes large and small almost since the beginning of aviation. Wings often face the brunt of air pressure during turbulence and are required to be strongly attached to the fuselage of airplane. Wings also bear the jet fuel within therefore any failure in wing structural integrity can be disastrous.

4. **Landing Gear Test Failure**: Landing gear is the support system of an airplane. Testing the landing gear of commercial airplane involves two types of tests. Gear drop testing includes static and fatigue tests designed to ensure landing gear can withstand worst-case landing conditions, and will not fail prematurely during the expected life of the airplane. The second type of test makes sure the landing gear apparatus (doors, locks, retraction and extension systems) performs as expected for the life of the airplane ("Landing gear, Wikipedia").
5. **Prototype flight test crash**: A prototype is an early sample, model, or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. Airplane manufacturers are responsible for prototype flight testing. Commercial flight testing is conducted to certify that the airplane meets all applicable safety and performance requirements of the government certifying agency.
6. **Flight Software test failure**: To fly most modern commercial airplanes nowadays, a lot is dependent on the use of avionics software. Auto-pilot systems use flight computers and so-called flight management systems that can fly the airplane without the pilot's active intervention during certain phases of flight. A failure in avionics software system while flying mid-air with hundreds of passengers on board could lead to major catastrophe.
7. **Virtual flight simulation test failure**: To incorporate airworthiness requirements for flight characteristics into the entire development cycle of electronic flight control system (EFCS) in commercial airplanes, a virtual flight simulation testing is conducted to study pilot controlling model, airplane motion, and atmospheric turbulence model, which is then used to simulate the realistic process of a pilot controlling an airplane to perform assigned flight tasks.
8. **Critical Component Delay**: Building airplanes nowadays include involvement of multiple vendors manufacturing and delivering components for airplane from different countries across the globe. Since global trading is such a boom, manufacturers prefer to order components from top vendors or the best vendors. Communication is the key to avoid any kind of delays which could jeopardize delivery schedule of an airplane and could cost the airplane manufacturer millions of dollars in penalty.
9. **Missing Customer Contractual Milestones**: Time and money are the key essences for any customer. Multi-million-dollar penalty agreements are contractually signed between the airplane manufacturer and the customers. Therefore, any delay in delivering these multi-million dollar airplanes by the manufacturer to a customer would lead to substantial penalties on airplane manufacturer and enormous losses to a customer.
10. **Safety Equipment Failure**: To ensure airplane is safe for passengers, CO detectors, and Oxygen Systems are installed in an airplane. In the event of an incident, there are Life Vests, Floatation Devices, First-Aid & Medical Kits, Flashlights, Survival Preparedness Tools and Rescue Devices. A failure in operation of any such safety devices could endanger life of travellers.
11. **FAA Component Approval**: The Federal Aviation Administration (FAA) engages in a variety of activities to fulfil its responsibilities. One vital activity is safety regulation. The FAA issues and enforces rules, regulations, and minimum standards relating to the manufacture, operation, and maintenance of airplanes. In the interest of safety, the FAA

also rates and certifies people working on airplanes, including medical personnel, and certifies airports that serve air carriers.

12. **Lack of Orders**: Lack of orders can easily be the biggest nightmare for any company. The manufacturer would lack funding for developing newer planes. It could also lead to loss of jobs. Lack of orders could lead the company to financial turmoil and ultimately closure. Therefore, it is very important to get constant orders for the airline manufacturer company to sustain.
13. **Source Material Scarcity**: It has been often seen that when newer products or devices are invented there is always an issue or scarcity of material sourcing. It is so very essential for procurement personnel to have the knowledge and network of sourcing the right material from the right place on time. Sourcing material scarcity is a big issue when it comes to airplane manufacturing because of the stringent manufacturing and delivery deadlines.
14. **Assembly Delay**: Assembly delays is one of the biggest fears a manufacturing company can have. Assembly delays could lead to massive financial penalties. It could also lead to lack of future orders as customers would lose faith in airline manufacturing company. Delays could also lead to loss of company reputation in a competitive market and could lead to loss of major market share to competitors.
15. **Component Damage during Transportation**: In recent years, airline manufacturers prefer to manufacture different parts of an airplane in different locations across the globe. These components or parts are then shipped and assembled at one main location. While delivering exceptionally large and heavy components either by land, sea or air, there is always a danger or risk of the material or the product getting damaged due to unforeseen circumstances during transportation.
16. **Death on Duty**: Safety of its employees working in manufacturing units has become the primary objective of many airline manufacturing companies recently. It is the company's responsibility to provide its employees with comfortable working environments, creating a work safety team, encouraging safe working areas for all workers, providing proper equipment, visual aids, and continuous training. A death on duty could lead to major loss of personnel and knowledge to an airline manufacturing company.

Sources



In our project, Next generation commercial airliners, we have created 5 main categories of Sources or Threats. These 5 main categorical sources are further sub-divided into specific threats which we have explained further in detail below.

1. **Personnel**: For any commercial airline manufacturing company, looking after their employees' safety and well-being is of utmost importance. Motivated and dedicated

employees lead to major success of companies. Some of the following threats need to be periodically monitored to avoid threats to an event that could lead to a loss.

a. **Lack of Training**: Airline manufacturers must make sure that their workers are given continuous appropriate training to avoid any kind of manufacturing delays due to lack of training. Lack of training could lead to human errors in assembling of an airplane which will be fatal for the manufacturing company, their passengers, and customers.
b. **Lack of Recruitment**: Airline manufacturing requires specific skilled labours. It is possible that airline manufacturing companies might find it difficult to find such skilled labours. Lack of skilled labours or personnel could majorly hamper production progress which could affect airplane delivery schedules.
c. **Vacation Time**: In a large employee organization, it is often the case that employees will go on vacation. The company must make sure that they plan their resource allocation in advance and smartly. Lack of resource allocation planning could lead to halt in production progress which directly effects airplane delivery schedules.
d. **Work Overload**: During peak periods it is often the case that employees must work overtime to meet specific deadlines or milestones. Work overload could lead to employee fatigue and depression which could result in certain tasks getting neglected or delayed due to lack of employee time available.
e. **Staff mishandling/mistakes**: Due to lack of training or work overload there are possibilities that a workers output could create some kind of mistake, or he has mishandled certain component or documents. This could result in major setback on production progress which directly effects airplane delivery schedules.

2. **Economic**: Economic stability of a country or region is very important and is directly proportional to blossoming of businesses in the region. Economic growth of certain countries or regions results in more people travelling for business reasons. To satisfy this need, more airplanes will be required in the region which will lead to a boost in airplane orders. There are some following threats that need to be periodically monitored to avoid threats to an event that could lead to a loss.

a. **Economic crash**: If the economy of a certain country or region plummets, then there is great loss to business. In an economic crash, customers hesitate to invest or buy new things. This could lead to a massive drop in airplane orders which could financially affect the airline manufacturing company. It will be tough for the manufacturing company to keep its employees busy, eventually leading to job cuts.
b. **Client Expectations**: Customer service is about expectations. And the expectations that customers have today were shaped by their previous experiences. Businesses need to meet or exceed these customer expectations. Service is praised or criticized because of expectations. If an airline manufacturing company does not meet client expectations, then this could lead to no future orders and could hamper their relationship with customer for future business.
c. **Market Disruptor**: A situation where markets cease to function in a regular manner, typically characterized by rapid and large market declines. Market

disruptions can result from both physical threats to the stock exchange or unusual trading. In either case, the disruption creates widespread panic and results in disorderly market conditions. Therefore, a stable market condition is very crucial for airline manufacturing company.

d. **Geopolitical Issues**: Geopolitics and the global economy interact in multiple and complex ways. Linkages among national economies through flows of trade and investments cannot exist outside the global geopolitical context. Therefore, a stable geopolitical situation is essential for airline manufacturers to sell their airplanes in different countries and regions.

3. **Communication**: Communication is an important factor within a business especially airline manufacturing where communication is the crux in creating flawless airplanes. Even using the latest communication technologies available, there are some threats that need to be periodically monitored to avoid threats to an event that could lead to a loss.

    a. **Multiple Blueprint Versions**: There is a certain possibility of having multiple blueprints of airplane designs or its components during design phase. This situation could result in lot of confusion in interpreting the designs and assembly projects causing the airline manufacturing company immense time in cases of re-design and assembly delays. Any sort of delay in delivering airplanes to its customers would mean loss of time and money for airplane manufacturing company and its customers.
    b. **Failure to detail requirements**: Sometimes time pressure can lead to a failure in detailing requirements. Human errors are major factors in failing to detail requirements. Especially in airplane manufacturing, tiny details of even physical nuts and bolts are of the utmost importance and any error or failure to correctly indicate requirements could result in major delays for airline manufacturing company.
    c. **Language/Unit Confusion**: As seen in recent years manufacturing of airplanes require involvement of different contractors located in different countries or continents, a failure in indicating correct unit or using of a language not intended to be used in the country the airplane will be delivered could result in unsatisfied customers. Therefore, constant communication between various contracting parties and the main office is of utmost importance.

4. **Quality**: Delivering high quality product to a customer is the prime objective of every company. When it comes to airplane manufacturing there needs to be no compromise in quality, as any relegation in quality could cost passenger death which is absolute unacceptable. With stringent quality procedures in place there are still some following threats that need to be periodically monitored to avoid threats to an event that could lead to a loss.

    a. **Meeting Licence requirements**: Before an airplane can be sold to a customer by the manufacturer, there are numerous licensees and approvals required. For example to operate an airplane in flight, an Airworthiness certification is authorized

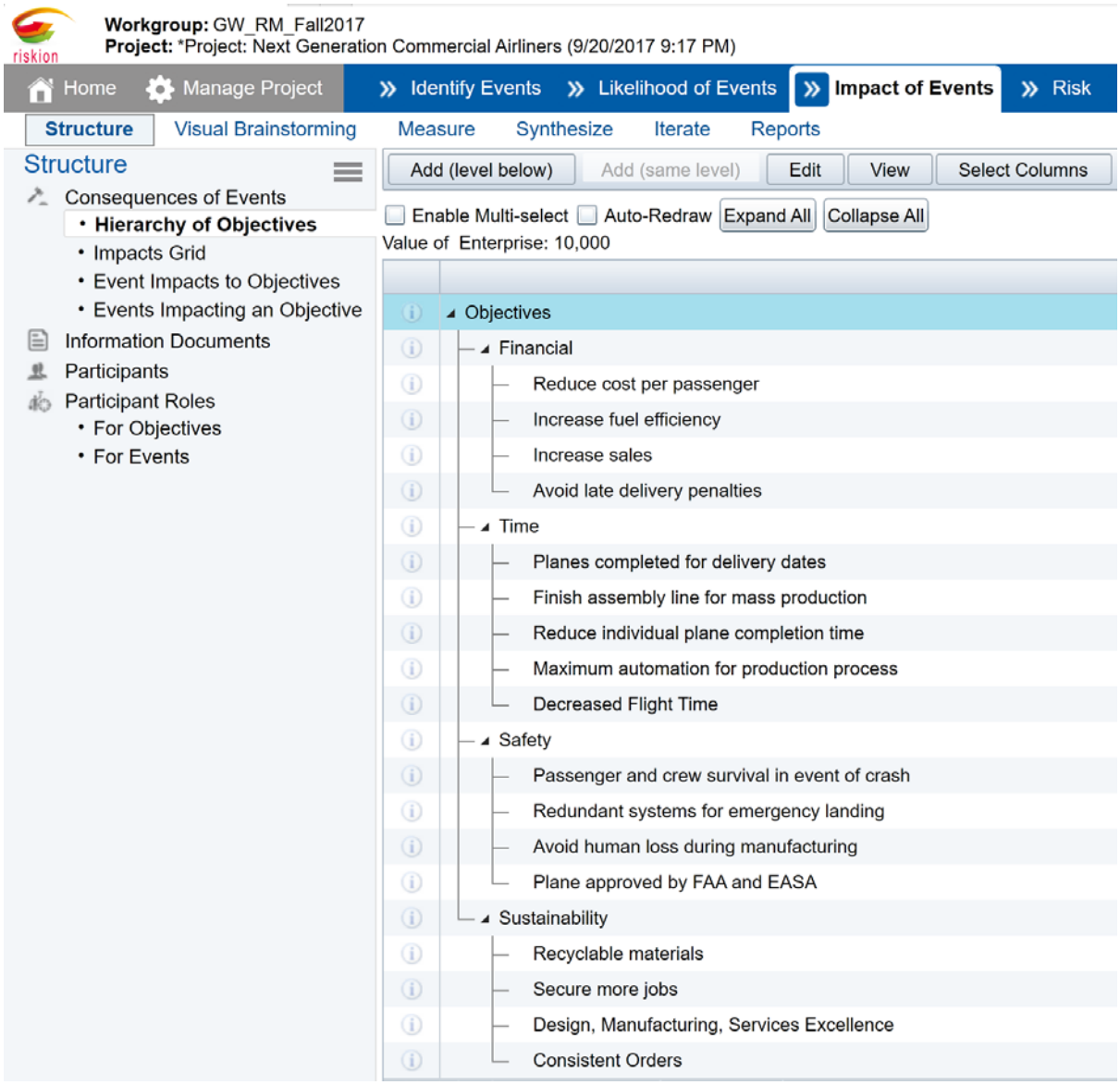
by the Federal Aviation Administration (FAA). Only after all licensees and approvals are obtained by the manufacturer for a particular airplane, the airplane can be sold to a customer.

b. **Material Flaws**: As building an airplane requires millions of components to be manufactured and assembled to build a flawless airplane, it is of utmost importance that each and every material is flawless and of prime quality. Any flaw in a material could lead to catastrophic incident.
c. **Periodic Maintenance**: Airplane maintenance checks are periodic inspections that must be done on all commercial airplane after a certain amount of time or usage. Airlines and other commercial operators of large or turbine-powered airplane follow a continuous inspection program approved by the Federal Aviation Administration (FAA) in the United States. Failure to follow periodic maintenance regime could result in disastrous incidence.

5. **Logistics**: Supply chain management and logistics handling of airplane material plays a vital role in timely manufacturing of spectacular airplanes. In recent years, airplane manufacturers have adopted the method of outsourcing, manufacturing various airplane components located in different countries or continents and then shipping it to main assembly centre where every part of an airplane is amalgamated before its maiden test flight. Even with high level of coordination, there are some following threats that need to be periodically monitored to avoid threats to an event that could lead to a loss.

   a. **Special Transports for large components**: An airplane requires various sizes of components that are manufactured and shipped from across the globe. There are certain airplane parts such as Wings, Fuselage etc which are large, heavy and requires special logistical calculations leading to requirement of special transport vehicles such as specifically built boats or trucks or even airplanes. These are used for transportation of airplane parts from various continents to the main assembly centre. Sometimes a shortage of such special or customized vehicles could lead to delays in manufacturing of airplanes.
   b. **Increased Cost**: Sometimes procuring a specific type of material required by the airplane on demand by the customer, could lead to increased cost due to unavailability of such a material in the region. This leads to procuring of such a special material from other countries or continent resulting in increased cost of goods due to transportation.
   c. **Different transportation modes**: The mode of transportation of airplane components are decided depending on certain parameters such as size, weight, time, manufacturing locations in far off country or continent. Different modes of transportations could be Air, Sea or by Road.
   d. **Weather Conditions**: When it comes to logistics, the weather is a vital factor that is considered before scheduling a major delivery of a product or material. Weather can cause major havoc leading to shipment delays causing a major loss to the airplane manufacturer.

Objectives



We have created 4 main categories for Objectives in our project of Next generation commercial airliners. These 4 main categorical objectives are further sub-divided into specific objectives which we have explained further in detail below.

1. **Financial**: Every company strives for business benefits. Business benefit is an outcome of an action or decision that contributes towards reaching business objectives. Airplane manufacturing companies too strive for financial gains so that they can use this money on research and development of more advanced commercial airplanes for the future. Following are certain objectives that airplane manufacturers are striving for with regards to financial gains both for the company and its customers.

    a. **Reduce cost per passenger**: As the demand for flying has sky rocketed, the demand for reduced air fares has also increased. Due to large number of airline companies operating there is a big competition to attract passengers. Airlines are also inventing

newer ways of reducing the weight of airplane to reduce fuel consumption which will directly benefit cost of flying per passenger.

b. **Increase fuel efficiency**: Air traffic worldwide is increasing so rapidly that global carbon dioxide emissions from aviation, which now represent just 2 to 3 percent of all carbon dioxide CO2 pollution, could jump as much as 500 percent by 2050 (Nationalgeographic.com). The increase is why the aviation world is looking at technologies, shapes, and materials that would transform flight far more dramatically.
c. **Increase Sales**: One of the main objectives of airplane manufacturing companies is to sustain in a competitive airplane manufacturing market. And this can be achieved if there are constant sales of airplanes.
d. **Avoid late delivery penalties**: As late delivery of airplanes to customers leads to heavy financial penalties, airplane manufacturers constantly monitor delivery schedules. Various communication technologies and progress evaluation tools are used to monitor progress in assembly lines.

2. **Time**: As it is said that "Time is Money", airplane manufacturing companies implement various time management methods to make sure they deliver flawless airplane on schedule and with exceptional quality. Following below are certain objectives that airplane manufacturers are striving for with regards to time to achieve timely delivery of airplanes and attain customer satisfaction.

   a. **Planes completed for delivery dates**: Gaining Customer satisfaction by delivering airplanes on time has always been the main focus of airplane manufacturing companies. To make this objective possible, constant communication among different departments and constant monitoring of production progress is required.
   b. **Finish assembly line for mass production**: Assembly lines are common methods of assembling complex items such as an airplane. The objective of the work stations is always to maintain a smooth flow of assembly line because any hinderance in assembly line could jeopardize complete assembly of multiple airplanes which could lead to on-time delivery issues for multiple airplanes.
   c. **Reduce individual plane completion time**: Airplane manufacturers always aim for performance excellence and innovations to improve manufacturing or assembly methods of each and every airplane. To achieve this objective, airplane manufacturers make sure that they provide continuous training to their skilled workers and constantly monitor production progress.
   d. **Maximum automation for production process**: Increasingly the manufacturing of complex products and component parts involves significant automation functions. With increased use of robotics in production lines, a lot can be fabricated, inspected and assembled with perfection nowadays. The use of robotics has increased drastically in recent years which has led to automation in production process resulting in quality output within scheduled time span.
   e. **Decreased flight time**: The aim of airplane manufacturing companies has always been on how to improve in reducing flight time of passengers. With research and development process undertaken by airplane manufacturing companies, newer

innovations in improving speed of airplane has helped in reducing passenger air travel time between various travel destinations.

3. **Safety**: Safety should always be a top priority for any airplane manufacturing company. Air travel is one of the safest modes of transportation and that is made possible by producing flawless airplanes. Following below are certain objectives that airplane manufacturers are striving for with regards to safety to achieve safe passenger travel and avoid any catastrophic incidents.

    a. **Passenger and crew survival in event of crash**: Many in-flight survival kits are installed in a commercial airplane, like oxygen masks in case of air pressure within cabin drops or safety vests are provided under the seat in case the flight lands on water in an event of crash. The objective is to save as many passengers and crew in an event of mishap.
    b. **Redundant systems for emergency landing**: There are numerous ways in which this is done depending on the size and complexity of the airplane. The emergency extension system lowers the landing gear if the main power system fails. Some airplanes have an emergency release handle in the flight deck that is connected through a mechanical linkage to the gear up locks. Large and high-performance airplane are equipped with redundant hydraulic systems. This makes emergency extension less common since a different source of hydraulic power can be selected if the gear does not function normally ("Aviation Stack Exchange, 2017").
    c. **Avoid human loss during manufacturing**: Airplane manufacturing and assembling can be a complex and stressful work. Some assembly sections could lead to mishaps causing human loss. Airplane manufacturers are responsible to create safe working environment and provide safety gear or equipment wherever needed.
    d. **Planes approved by FAA and EASA**: Before a newly developed airplane model may enter operation, it must obtain a type certificate from the responsible aviation regulatory authority. Federal Aviation Administration (FAA) is responsible for certification of airplanes in US and European Aviation Safety Agency (EASA) is responsible for certification of airplanes in European union.

4. **Sustainability**: In recent years, airplane manufacturing companies are striving for sustainable future by building cleaner, quieter and smarter commercial airplanes. Sustainable Aviation is a long-term strategy which sets out the challenge of ensuring a sustainable future for airline industry. Following below are certain objectives that airplane manufacturers are striving for with regards to sustainability.

    a. **Recyclable materials**: Airplane recycling pertains to the process of harvesting parts and materials from end-of-life airplane. As the airline industry looks to become more eco-friendly as well as to cut costs, one area of increasing interest is that of airplane recycling. The most valuable components are typically the engines. Parts which can be reused or refurbished have the most value, and provide the profitability of recycling operations, especially if the plane has detailed maintenance records about the history of those parts ("The balance, 2017").

b. **Secure more jobs**: To sustain in a competitive market, airplane manufacturers are required to secure more sales to keep jobs for their employees. Competition is too high in the airplane business, so job security is a must. Highly skilled and experienced employees are always needed. More jobs can be secured by providing good packages to employees, training newly hired people, and giving company benefits to employees.
c. **Design, Manufacturing, Services Excellence**: Design, Manufacturing and Services are three key processes in the airplane business. Airplane design is a compromise between many competing factors and constraints for existing designs and market requirements to produce the best airplane. Service excellence is the ability of the provider to consistently meet and manage customer expectations.
d. **Consistent Orders**: Consistence in orders is a must to run the business. Knowing the customer better is important and can be done by conducting weekly pipeline reviews, monitoring the sales cycle, streamlining the process if needed, and securing and approaching new clients. Consistent orders create accountability, establishes the company's reputation, and maintains good client relationships.

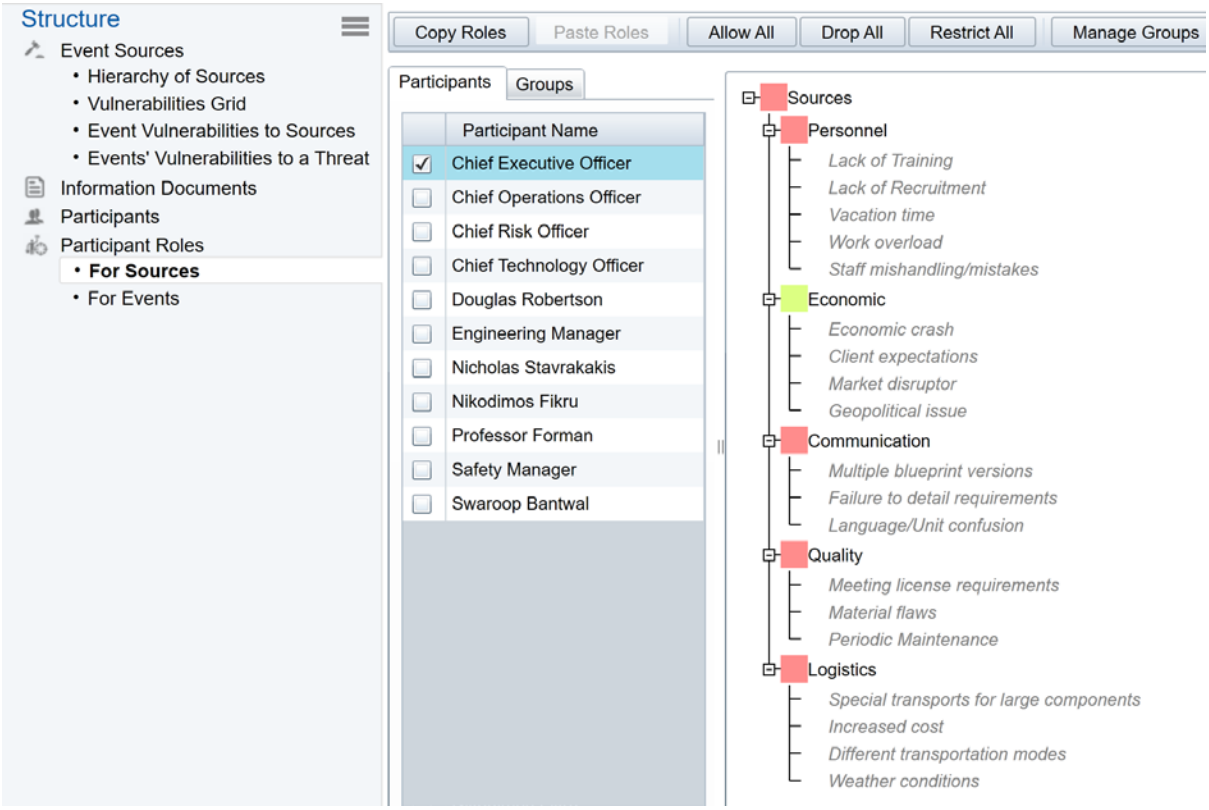
Participants:

In our project, Next generation commercial airliners, we have added participants as indicated below who are fictional characters based on the organizations management hierarchy. Several participants and roles were identified. We have divided participants into two categories 1. C-level executives and 2. Managers. C-level executives are the Chief Executive Officer-CEO, Chief Operations Officer-COO, Chief Risk Officer-CRO, and Chief Technology Officer-CTO. Managers are the Engineering Manager, Safety Manager, and Project Manager.

List of Participants and Roles:

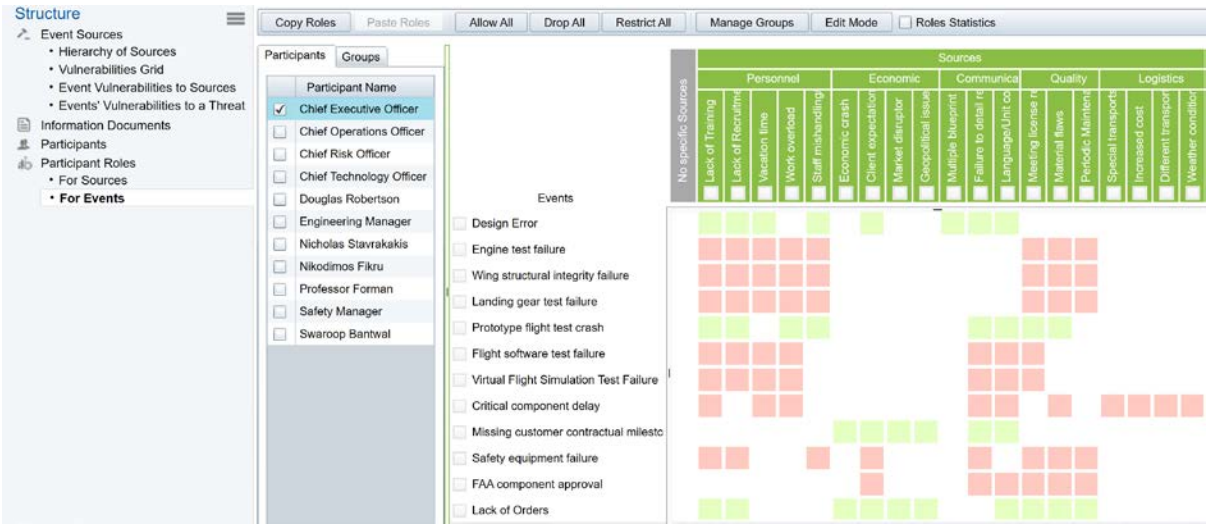
Email Address	Participant Name	Permission	Has Data?
ceo@gwu.edu	Chief Executive Officer	Evaluator	Yes
COO@gwu.edu	Chief Operations Officer	Evaluator	Yes
cro@gwu.edu	Chief Risk Officer	Evaluator	Yes
CTO@gwu.edu	Chief Technology Officer	Evaluator	Yes
drobertson86@gwu.edu	Douglas Robertson	Project Manager	No
EngineeringManager@gwu.e	Engineering Manager	Evaluator	Yes
nstavrakakis@gwu.edu	Nicholas Stavrakakis	Project Manager	No
ethio@gwu.edu	Nikodimos Fikru	Evaluator	No
forman@gwu.edu	Professor Forman	Project Manager	No
SafetyManager@gwu.edu	Safety Manager	Evaluator	Yes
swaroop82@gwu.edu	Swaroop Bantwal	Project Manager	No

Example of participant's role in evaluation of Sources (Likelihood of Events)

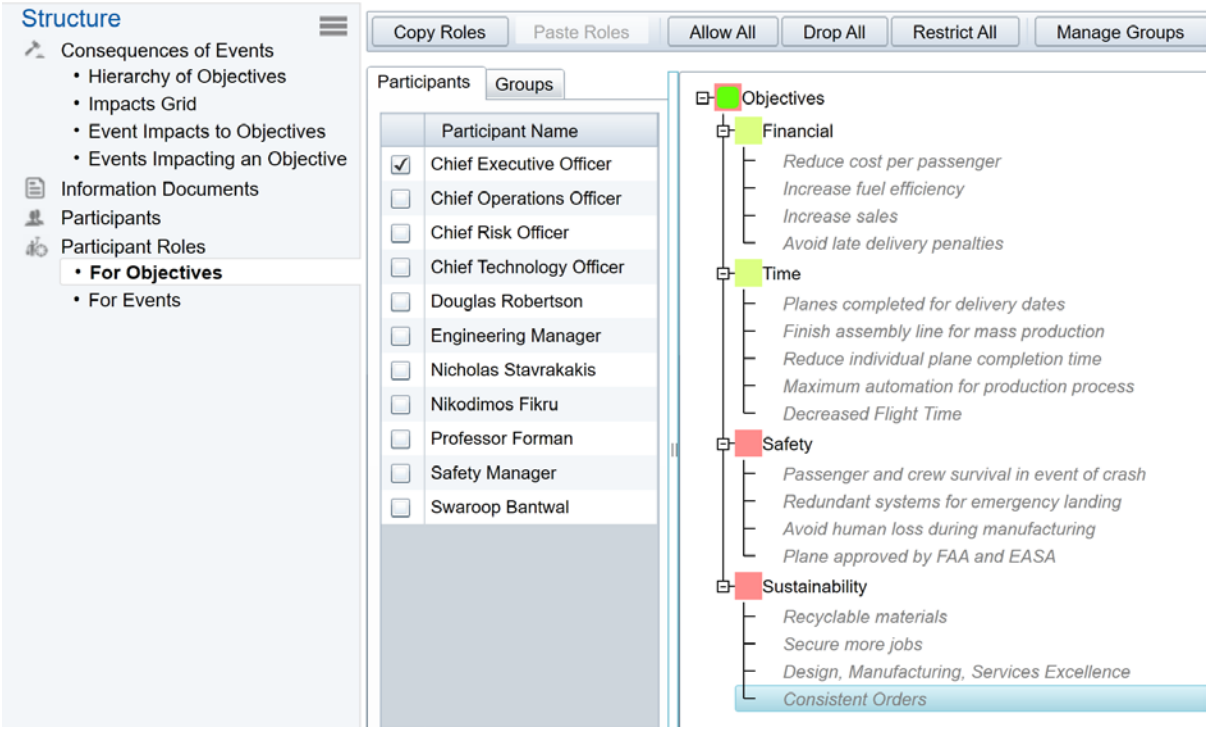


Not all participants have the same role in evaluating sources and events. Their roles are limited with regards to their expertise and business areas. The green highlighted box in above evaluation of Sources (Likelihood of Events) shows Chief Executive Officers evaluating the business area. The red boxes cannot be evaluated by the Chief Executive Officer.

Example of participant's role in evaluation of Events (Likelihood of Events)

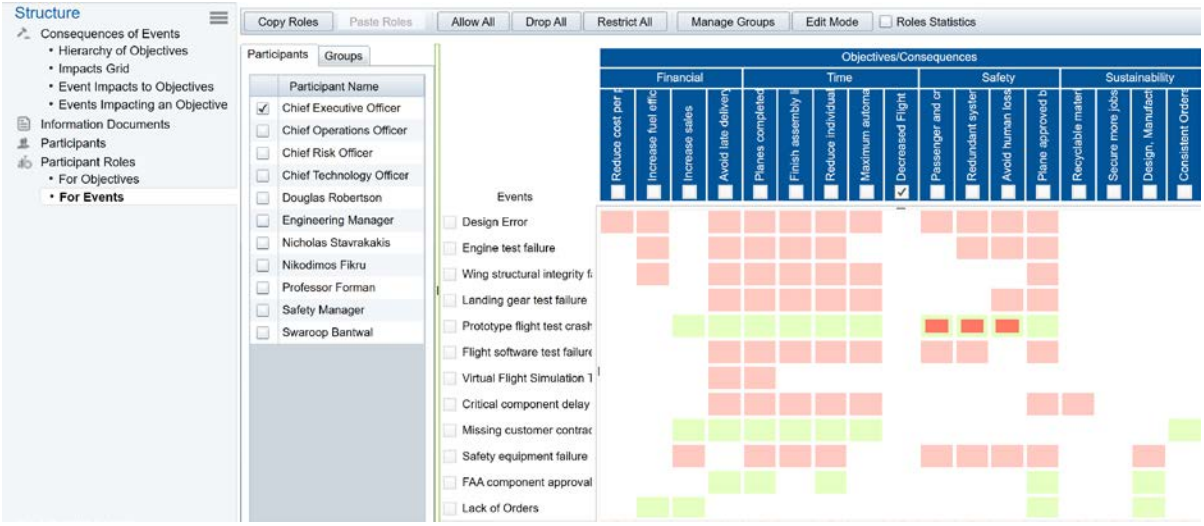


Example of participant's role in evaluation of Objectives (Impact of Events)

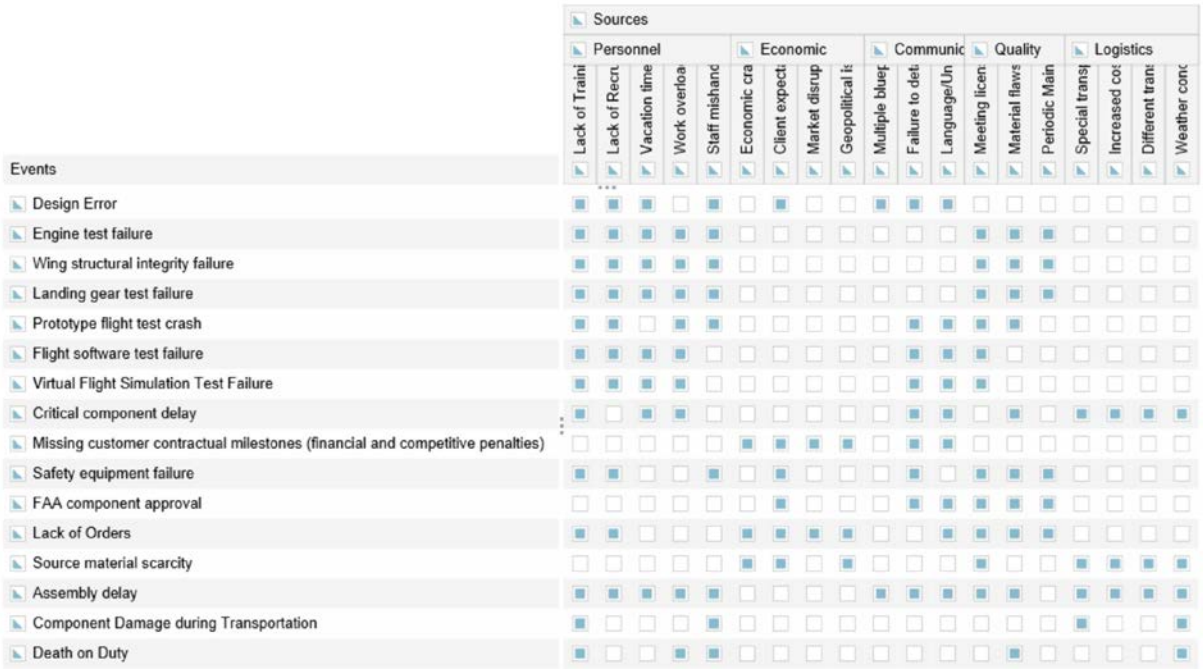


The green highlighted box in above evaluation of Objectives (Impact of Events) shows Chief Executive Officers evaluating the business area. The red boxes cannot be evaluated by the Chief Executive Officer.

Example of participant's role in evaluation of Events (Impact of Events)

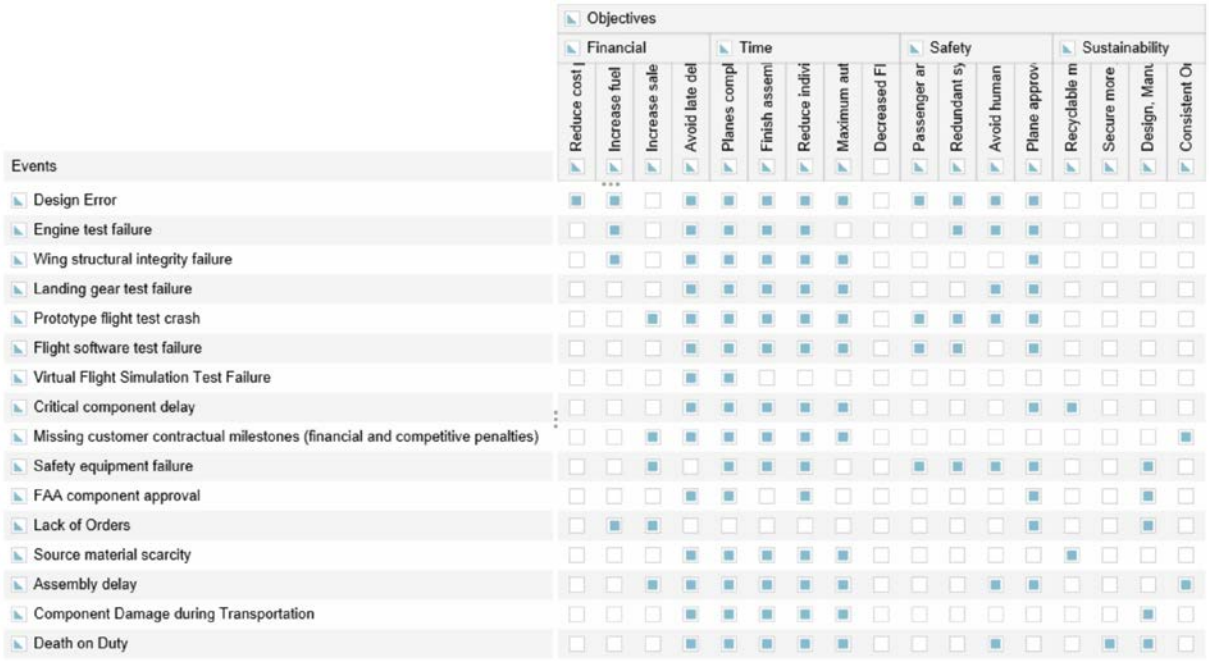


Vulnerability Grid of Events to Sources



Understanding and identifying how Sources contribute to Events is an important aspect. The above figure illustrates that we have carried out a logical exercise in Riskion to correctly assign each source's contribution to an identified event. Not all sources contribute to all events. As an example, one can see "Lack of Training" and "Lack of Recruitment" are the Sources for an Event like "Design Error" to happen.

Impact Grid of Events to Objectives



Events	Financial				Time					Safety				Sustainability			
	Reduce cost	Increase fuel	Increase sale	Avoid late del	Planes compl	Finish assem	Reduce indivi	Maximum aut	Decreased Fl	Passenger ar	Redundant sy	Avoid human	Plane approv	Recyclable m	Secure more	Design, Manu	Consistent O
Design Error	■	■		■	■	■	■	■		■	■	■	■				
Engine test failure		■		■	■	■	■				■	■	■				
Wing structural integrity failure		■		■	■	■	■	■					■				
Landing gear test failure				■	■	■	■	■				■	■				
Prototype flight test crash			■	■	■	■	■	■		■	■	■	■				
Flight software test failure				■	■	■	■	■		■	■		■				
Virtual Flight Simulation Test Failure				■	■												
Critical component delay				■	■	■	■	■					■	■			
Missing customer contractual milestones (financial and competitive penalties)			■	■	■	■	■	■									■
Safety equipment failure			■		■	■	■			■	■	■	■			■	
FAA component approval				■	■		■						■			■	
Lack of Orders		■	■										■			■	
Source material scarcity				■	■	■	■	■						■			
Assembly delay			■	■	■	■	■	■				■	■				■
Component Damage during Transportation				■	■	■	■	■								■	
Death on Duty				■	■	■	■	■				■			■	■	

The above impact grid illustrates how different events impact different organizational objectives. With the help of Riskion, we have carried out a logical exercise to correctly assign each event to objectives. Please note that not all events contribute to covering objectives. As an example, one can see a “Design Error” could impact organizational objective of “Reduce cost per passenger” and “Increase fuel efficiency”.

Controls – Threats, Vulnerabilities, and Consequences

Index	Control Name	Control for
1	Flight Instructor Required Education Hours	Threat
2	FAA Inspector Special Training	Threat
3	Hire FAA component vendor	Threat
4	Mandated Work Breaks	Threat
5	Mandated Company Holidays	Threat
6	Metric Unit Conversion Checks	Threat
7	Blueprint Version Control	Vulnerability
8	Individual Onboard Parachutes	Vulnerability
9	Engineering Quality Control	Vulnerability
10	Wind tunnel modelling	Vulnerability
11	Government Liaison Council	Vulnerability
12	Virtual Aircraft Modelling	Vulnerability
13	Detachable Passenger Cabin	Consequence
14	Backup onboard software system	Consequence
15	Heavy Equipment Training	Consequence
16	Multi-country Sourcing	Consequence
17	Safety Equipment Weekly Checks	Consequence
18	FAA and EASA Licensed Vendor Check	Consequence

Risk can be managed by identifying, measuring, and controlling them. The purpose of applying controls is to reduce potential harm that could occur due to occurrence of event. In our project, we have selected 18 Controls. The above table illustrates the list of controls implemented for Threats, Vulnerabilities, and Consequences.

Controls for Threat Likelihoods

Control Name	Personnel					Econo	
	☑ Lack of Training	☐ Lack of Recruitment	☑ Vacation time	☑ Work overload	☑ Staff mishandling/mistakes	☐ Economic crash	☐ Client expectations
☑ 1. Flight Instructor Required Education Hours	☑	☐	☐	☐	☑	☐	☐
☑ 2. FAA Inspector Special Training	☑	☐	☐	☐	☑	☐	☐
☑ 3. Hire FAA component vendor	☐	☐	☐	☐	☐	☐	☐
☑ 4. Mandated Work Breaks	☐	☐	☐	☑	☑	☐	☐
☑ 5. Mandated Company Holidays	☐	☐	☑	☑	☑	☐	☐
☑ 6. Metric Unit Conversion Checks	☐	☐	☐	☐	☐	☐	☐

The above grid shows example of Controls applied for threat likelihoods. For example, the threats like “Lack of Training” and “Staff mishandling/mistakes” can be controlled by applying controls like “Flight instructor required education hours.” This application will make sure that mandatory continued education for pilots with certain number of hours per year will reduce threats.

Controls for Vulnerabilities of event "Design Error" to threats

Select an event: 01. Design Error ☐ Enable Multi-select

Control Name	No specific Threat	Personnel				
		☑ Lack of Training	☑ Lack of Recruitment	☑ Vacation time	Work overload	☑ Staff mishandling/mistakes
☑ 7. Blueprint Version Control		☑	☑	☑		☑
☐ 8. Individual Onboard Parachutes		☐	☐	☐		☐
☑ 9. Engineering Quality Control		☑	☑	☑		☑
☑ 10. Wind tunnel modeling		☑	☑	☑		☑
☐ 11. Government Liason Council		☐	☐	☐		☐
☑ 12. Virtual Aircraft Modeling		☑	☑	☑		☑

The above grid shows example of Controls applied for Vulnerabilities of events to threats. For example, threats like “Lack of Training” and “Staff mishandling/mistakes” can be controlled by applying Controls like “Blueprint version control” for an event of “Design Error.” This application will make sure that threats can be reduced for a particular event.

Controls to mitigate consequences of event "Component Damage during Transportation" to objectives

Select an event: 17. Component Damage during Transportation ☐ Enable Multi-select

Control Name	Financial				Time		
	Reduce cost per passenger	Increase fuel efficiency	Increase sales	▣ Avoid late delivery penalties	▣ Planes completed for delivery dates	▣ Finish assembly line for mass production	▣ Reduce individual plane completion time
☐ 13. Detachable Passenger Cabin				☐	☐	☐	☐
☐ 14. Backup onboard software system				☐	☐	☐	☐
☑ 15. Heavy Equipment Training				☑	☑	☑	☑
☐ 16. Multi-country Sourcing				☐	☐	☐	☐
☐ 17. Safety Equipment Weekly Checks				☐	☐	☐	☐
☐ 18. FAA and EASA Licensed Vendor				☐	☐	☐	☐

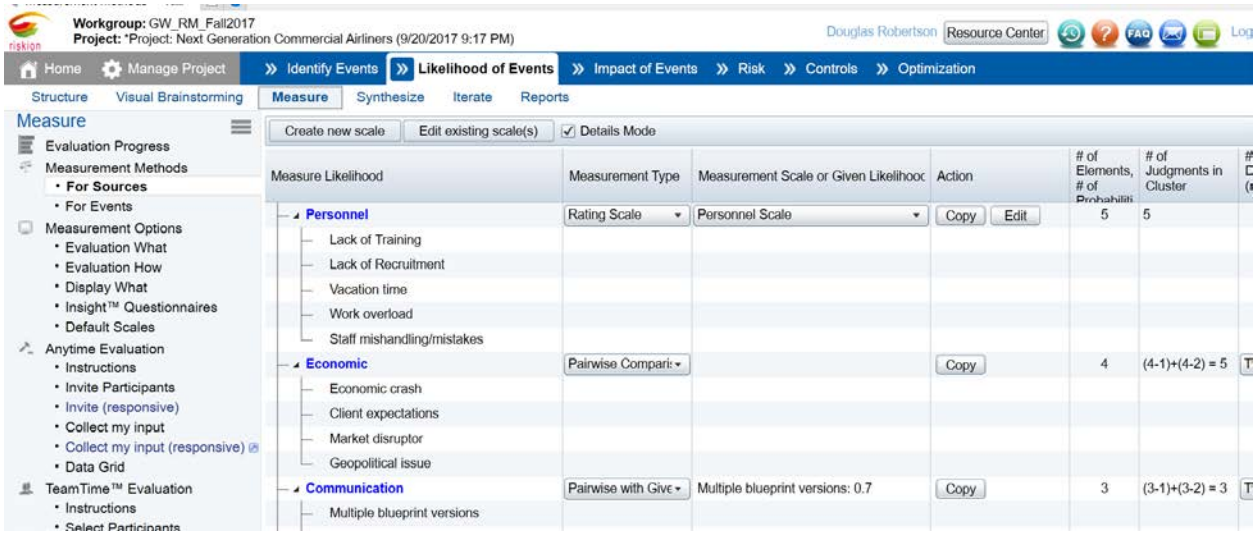
The above grid shows example of Controls applied to mitigate consequences of events to objectives. For example, objectives like "Avoid late delivery penalties" and "Planes completed for delivery dates" can be controlled by applying controls like "Heavy Equipment training" to avoid an event of "Component damage during transportation." This selection will make sure that objectives are achieved by applying proper controls.

Risk Model Measurement Methods

Different ways exist to measure risks, but most Risk Models are hindered by using nominal, ordinal, or interval data. Classifying External and Internal risks, Low-Medium-High rankings, 1 to 5 scales, or Risk Matrices with different colors are all examples of models that do not produce ratio scale numbers where the ratio of one measure to another is mathematically meaningful. A color of "Red" has no verifiable ratio to a color "Yellow" and could be two, three, or four times worse. Some Risk Models can even exacerbate risk measurements such as multiplying a 1 to 5 scale by numerical weights that appear to produce a mathematical result. The error of using non-ratio numbers is compounded and can result in worse outcomes that seem scientific.

Riskion by Expert Choice uses Analytic Hierarchy Process measurement methods that result in ratio numbers which then can derive meaningful values for Likelihood, Impact, and Risk. The math is based off the same Eigenvector principles that Google uses in its PageRank function (Bryan, Leise 2006). The verbal comparisons used are based off the Analytical Hierarchy fundamental verbal scale which uses verbal judgements to derive priorities and creates ratio data from these judgements. Some of the difference measurement methods for Next Generation Commercial Airliners are detailed below.

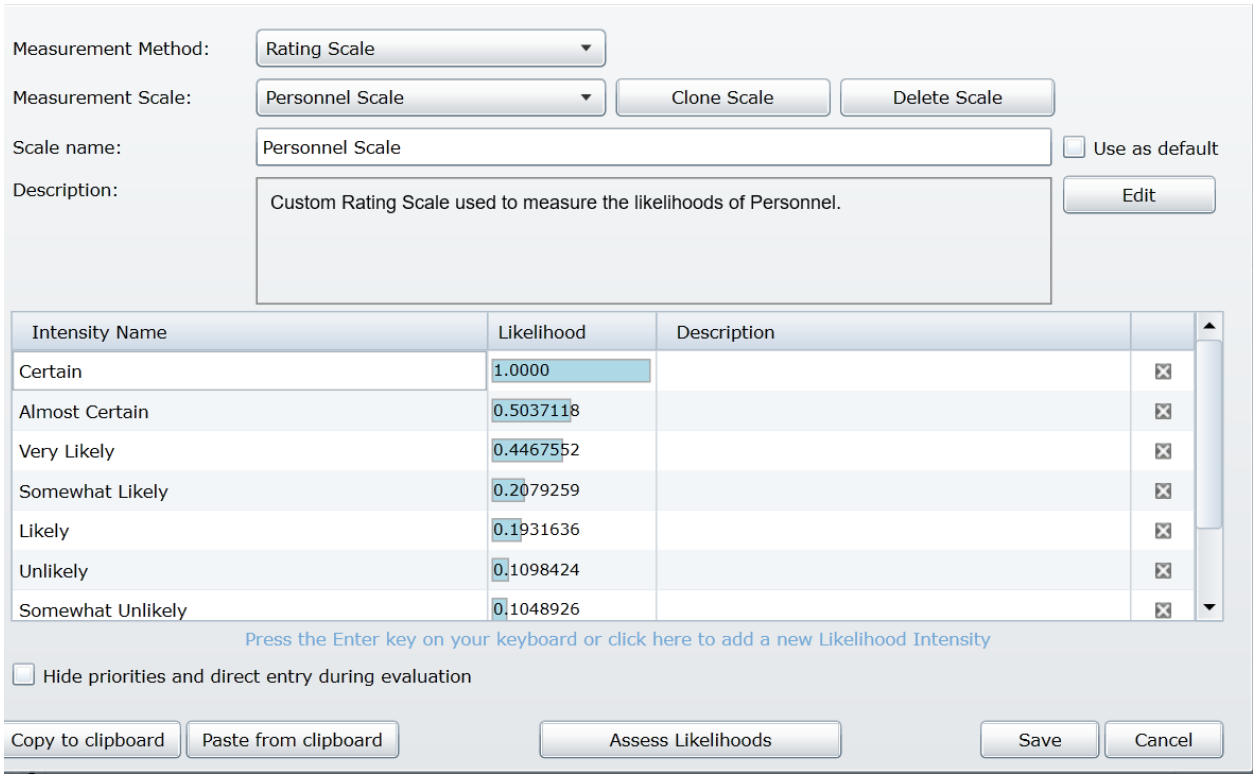
Measurement of Likelihood for Sources



In the figure above, three of the different methods used for calculating the likelihood of sources are shown. Personnel sources used a custom-made Rating Scale, Economic factors used a Pairwise Comparison, and Communication sources used Pairwise with a Given Likelihood.

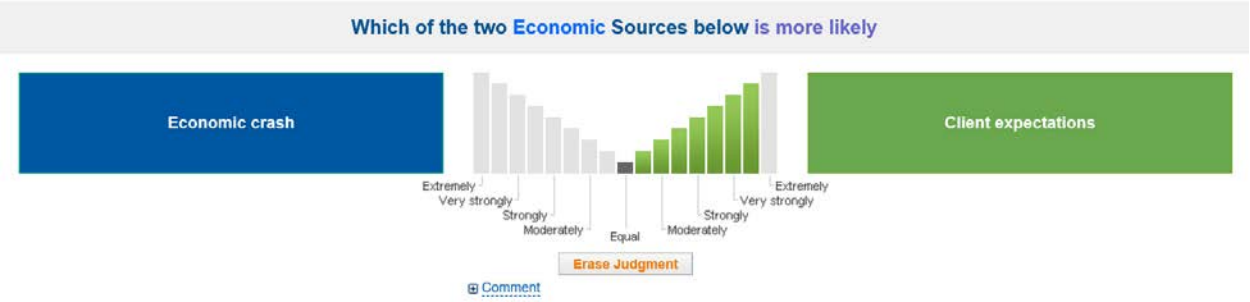
Rating Scale

A specific rating scale was created for Personnel sources between Lack of Training, Lack of Recruitment, Vacation time, Work overload, and Staff mishandling/mistakes to account for the variations in judgements between participants. A default rating scale could have been used, but instead a scale of 9 ratings shown in the figure below was assessed for the differences between words like “Almost Certain” and “Very Likely”.



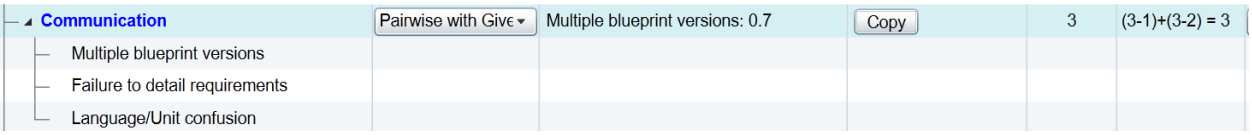
Assessing Likelihoods for a Rating Scale like this one allows a scale to more accurately reflect the differences between intensities. Another scale could be created with different language such as “Fairly Likely” or “Fairly Unlikely” that could have different likelihoods from another assessment. Assessing the different intensities to one another is also a Pairwise Comparison.

Pairwise Comparisons



Pairwise Comparisons like the figure above were used for various measurement methods such as the Economic likelihoods for Sources which included Economic Crash, Client Expectations, Market Disruptor, and Geopolitical Issues. The purpose of these comparisons was to establish ratio scale likelihoods using verbal scales through the Analytic Hierarchy Process. Pairwise Comparisons were also used for Sources in Quality for Meeting License Requirements, Material Flaws, and Periodic Maintenance.

Pairwise Comparison with Given Likelihood

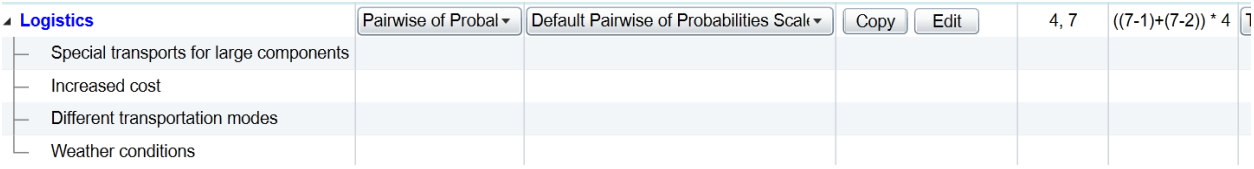


A slightly different measurement method was used for Sources under Communication like multiple blueprint versions, failure to detail requirements, and language/unit confusion which is shown above. Pairwise with Given Likelihood includes the same Pairwise Comparisons but also has a Given Likelihood that is manually entered in Riskion. This Given Likelihood can be calculated from historical data or in this case was directly entered through judgement.

Once the participant goes to rate using Pairwise with Given Likelihood, the participant sees the one given and can rate their own priority. If this measure is too different from the given likelihood, the given may need to be re-evaluated. In the figure above, the Pairwise Comparison with Given Likelihood is shown as numerical comparisons. Riskion shows pairwise comparisons with less than four options in number format because the verbal comparisons are too few to make meaningful sense.

Pairwise of Probabilities

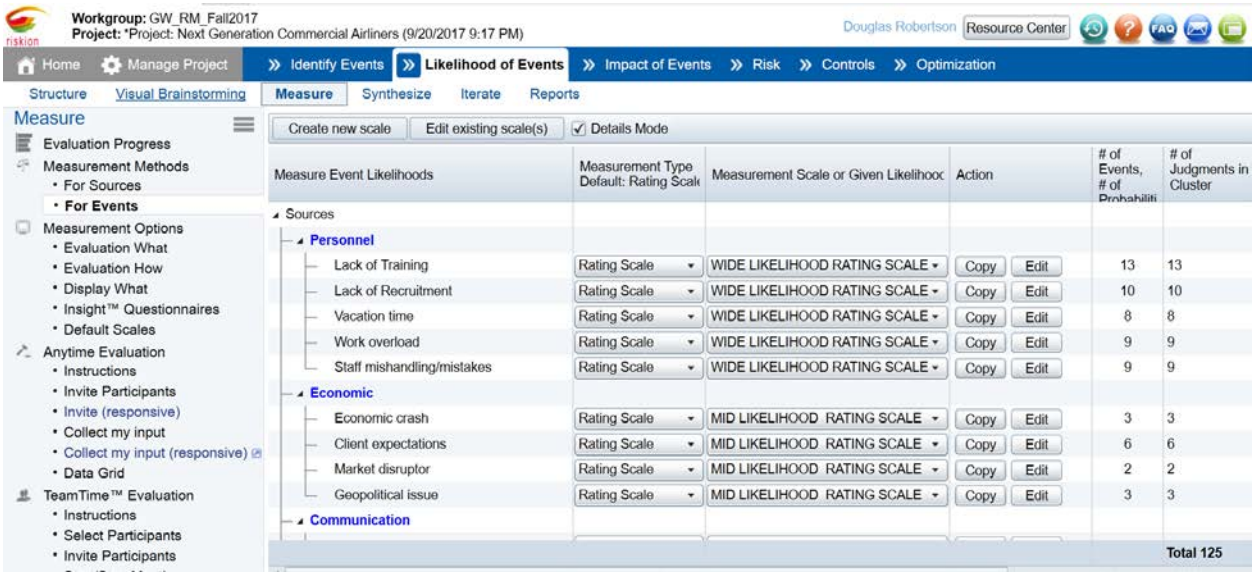
The final method used for rating the Likelihood of Sources was Pairwise of Probabilities as seen in the figure below. This comparison was used for the Logistics category concerning special transports for large components, increased cost, different transportation modes, and weather conditions.



Pairwise of Probabilities compares different Likelihoods for Sources to each other using relative probabilities. An example is seen in the below figure.

The advantage of this method is that it can produce more consistent results of likelihoods if the general range of the likelihood is known. If the likelihood is between 1-10%, then participants rating the Sources can determine to a greater degree where it falls between the relative probabilities. Through multiple participants the likelihood will then be determined.

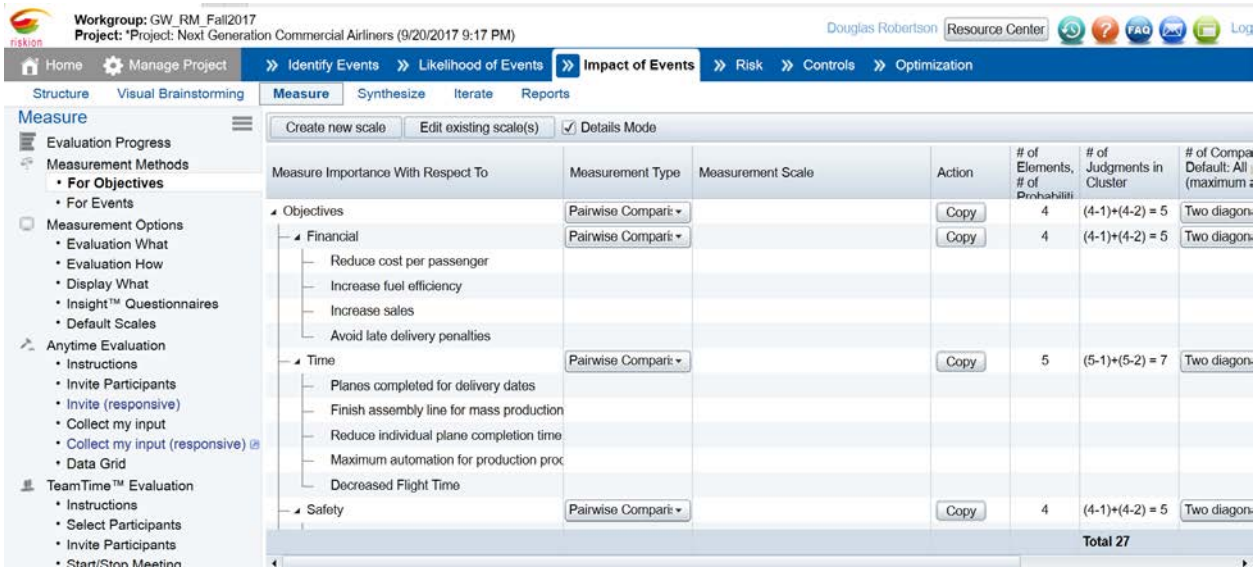
Measurement of Likelihood of Events



In the figure above, the measurement of Event Likelihoods was assessed through using Rating Scales. The Wide Likelihood Rating Scale has a larger gradient between likelihoods, so participants can rate from Almost Certain to One in 10 million. The Mid Likelihood Scale

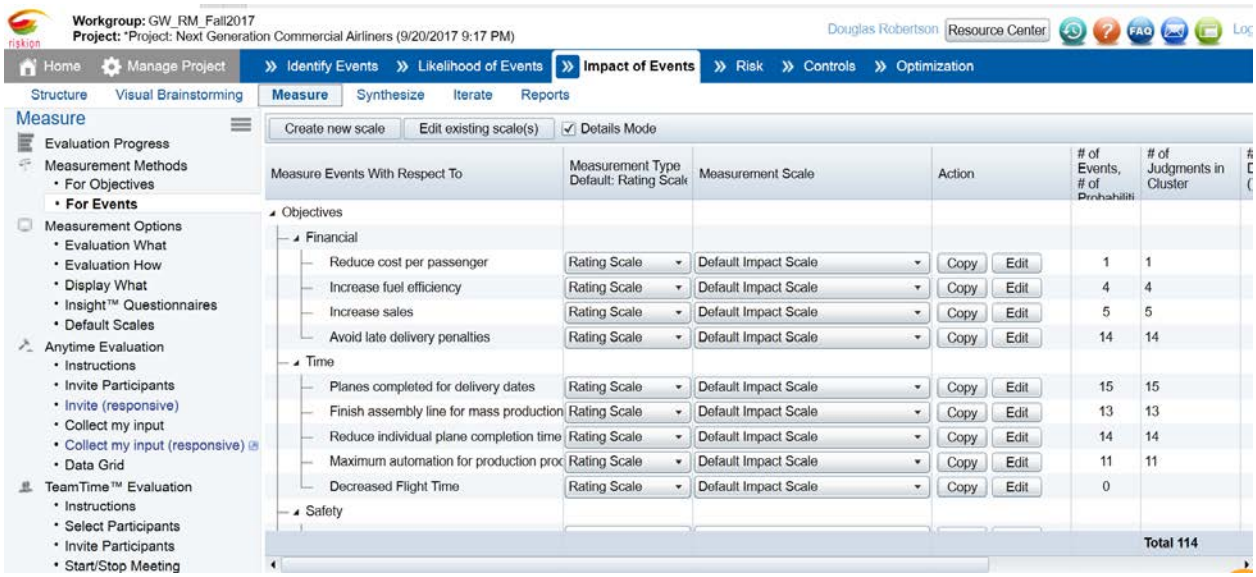
focuses on likelihoods closer to 50% and does not have all the extreme options of the Wide Likelihood Rating Scale as the Mid Likelihood Scale only goes from Highly Likely to One in 10 thousand.

Measurement of Importance with Respect to Objectives



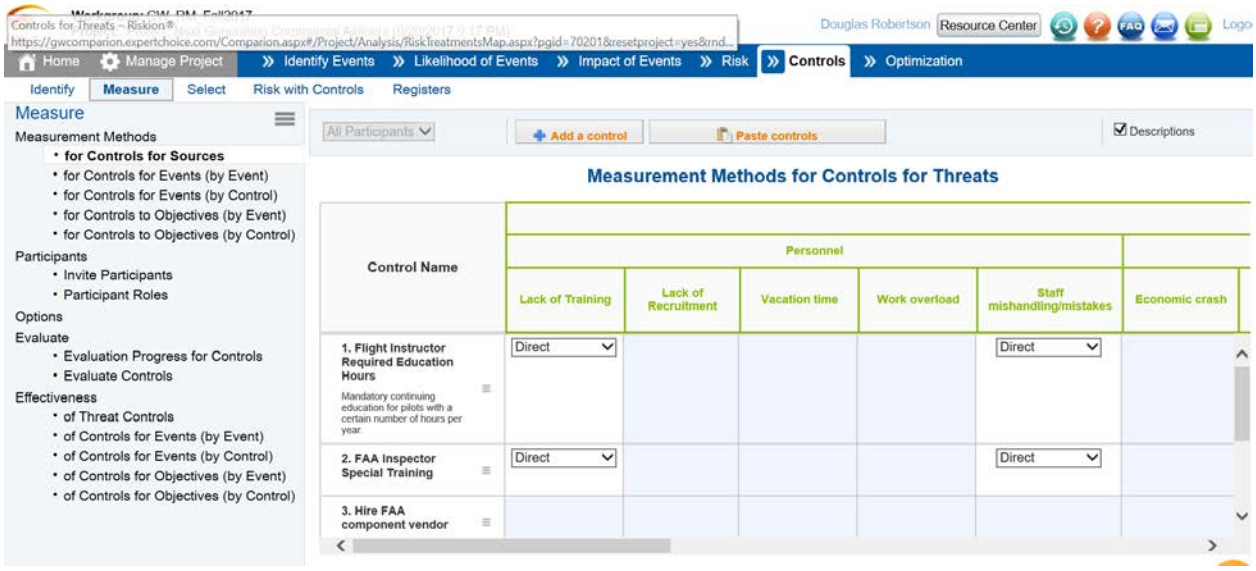
In the figure above, the measurement of importance with respect to Objectives is measured from Pairwise Comparisons like the Likelihood of Sources for Economic Threats.

Measurement of Events with Respect to Objectives



In the figure above, the measurement of events with respect to objectives is calculated from a rating scale. The Default Impact Scale was used to determine the impact of events on objectives.

Measurement of Controls



In the figure above, Controls are measured though Direct ratings by participants. Participants enter the 0-1 likelihood when comparing how a control would affect Sources, Vulnerabilities, and Objectives.

Risk Analysis

Overall Likelihoods, Impacts, and Risks without Controls

Overall Likelihoods, Impacts, and Risks for «*Project: Next Generation Commercial Airliners (9/20/2017 9:17 PM)»

No.	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[16]	Assembly delay	55.00%	2,190	1,204
[08]	Critical component delay	21.70%	957	207
[15]	Source material scarcity	23.00%	735	169
[13]	FAA component approval	69.70%	962	670
[17]	Component Damage during Transportation	75.50%	1,131	854
[01]	Design Error	30.10%	3,022	909
[05]	Prototype flight test crash	42.40%	2,140	907
[07]	Virtual Flight Simulation Test Failure	43.20%	122	52
[09]	Missing customer contractual milestones (financial and competitive penalties)	29.40%	1,953	574
[12]	Safety equipment failure	15.30%	1,436	219
[14]	Lack of Orders	24.20%	999	241
[02]	Engine test failure	23.40%	764	178
[04]	Landing gear test failure	21.10%	606	128
[03]	Wing structural integrity failure	20.60%	641	132
[06]	Flight software test failure	30.20%	502	151
[18]	Death on Duty	0.00%	0	0
	Total Risk (Computed)			**$55,918**
	Total Loss (Simulated)			**$6,604**

Risk is calculated as the Likelihood multiplied by the Impact of an event. The Likelihoods and Impact were rated by participants using the measurement methods detailed before. In Riskion, Total Risk is computed as $55,918 million for all the events. This value does not make sense as the entire monetary value of the Enterprise is $10,000 million. The mismatch occurs because multiple likelihoods and events are double counted as the Events, Sources, and Objectives are not independent from one another. Solving this problem is done through the simulation of

events where random numbers are generated which then fire based on the random number being higher than the priority of a source or event as shown below.

Threats (without controls)
Number of threats that fired: 11

Threat Name	Threat Random()	Priority
[6] Lack of Training	0.0178115	0.1098424
[7] Lack of Recruitment	0.26977518	0.10489263
[8] Vacation time	0.64563683	0.10489263
[9] Work overload	0.8255635	0.20792589
[10] Staff mishandling/mistakes	0.86976311	0.20792589
[12] Economic crash	0.0060359	0.15986995
[13] Client expectations	0.46089608	0.67263317
[14] Market disruptor	0.9780856	0.05724655
[15] Geopolitical issue	0.06332051	0.1102503
[16] Multiple blueprint versions	0.05562951	0.69999999
[17] Failure to detail requirements	0.38118097	0.68436241
[18] Language/Unit confusion	0.60669849	0.2213226
[19] Meeting license requirements	0.41506027	0.4592101
[20] Material flaws	0.42650247	0.29252666
[21] Periodic Maintenance	0.46484867	0.24826322
[22] Special transports for large components	0.11071821	0.60114914
[23] Increased cost	0.38319829	0.57966459

Total loss of simulation: 0.57307
Number of Events that fired: 5

Event Name	Random()	Vulnerability	Impact	Risk
Design Error T_{ID}=[6]	0.44559447	0.383340001106262	0.40828741	0.54674
Engine test failure T_{ID}=[6]	0.53228892	0.100000001490116	0.24956276	0.14219537
Wing structural integrity failure T_{ID}=[6]	0.73012078	0.0199999995529652	0.24509582	0.13191182
Landing gear test failure T_{ID}=[6]	0.92998354	0.0199999995529652	0.23553546	0.13289031
Prototype flight test crash T_{ID}=[6]	0.88034098	0.413199990987778	0.41626605	0.33503664
Flight software test failure T_{ID}=[6]	0.97345577	0.00999999977648258	0.18223281	0.094395
Virtual Flight Simulation Test Failure T_{ID}=[6]	**0.08383558**	**0.333000004291534**	**0.0404629**	**0.02860689**
Critical component delay T_{ID}=[6]		0.00100000004749745	0.30654442	0.71472164
Safety equipment failure T_{ID}=[6]		0.176500007510185	0.26001731	0.15851715
Lack of Orders T_{ID}=[6]		0.0425000004470348	0.1815716	0.104455
Assembly delay T_{ID}=[6]		0.200000002980232	0.50453764	1.56628036
Component Damage during Transportation T_{ID}=[6]	**0.23143568**	**0.333000004291534**	**0.32132837**	**0.4545045**
Death on Duty T_{ID}=[6]		0	0.12182105	0
Missing customer contractual milestones (fina... T_{ID}=[12]	**0.60341123**	**0.841674983501434**	**0.49919698**	**0.31462641**
Source material scarcity T_{ID}=[12]	**0.40697724**	**0.666700005531311**	**0.2332952**	**0.39684081**
FAA component approval T_{ID}=[13]	**0.38755097**	**0.666700005531311**	**0.28305605**	**0.47011069**

Controls Optimization

Controls were optimized through Riskion using a budget of $150 million with an Enterprise valuation of $10,000 million. In the optimization below, the controls are selected for the greatest risk reduction given the budget. Total Risk is reduced from $55,918 million to $32,062 million which still has double counting. Total Selected controls were 11 which did not include all the controls by Stand Alone Reduction from largest to smallest as combinations of controls can have a higher reduction than selecting them alone.

Controls optimization for "*Project: Next Generation Commercial Airliners (9/20/2017 9:17 PM)"

(•) Budget ( ) Risk ( ) Risk Reduction
Budget Limit: $ 150

Total Risk: $55,918
Risk With Selected Controls: $32,063 (Δ: $23,854)
Risk With All Controls: $28,962 (Δ: $26,956)
Total Risk Reduction: $4,265

Selected controls: 11
Cost Of Selected Controls: $150 (unfunded: $254)
Total Cost Of All Controls: $404

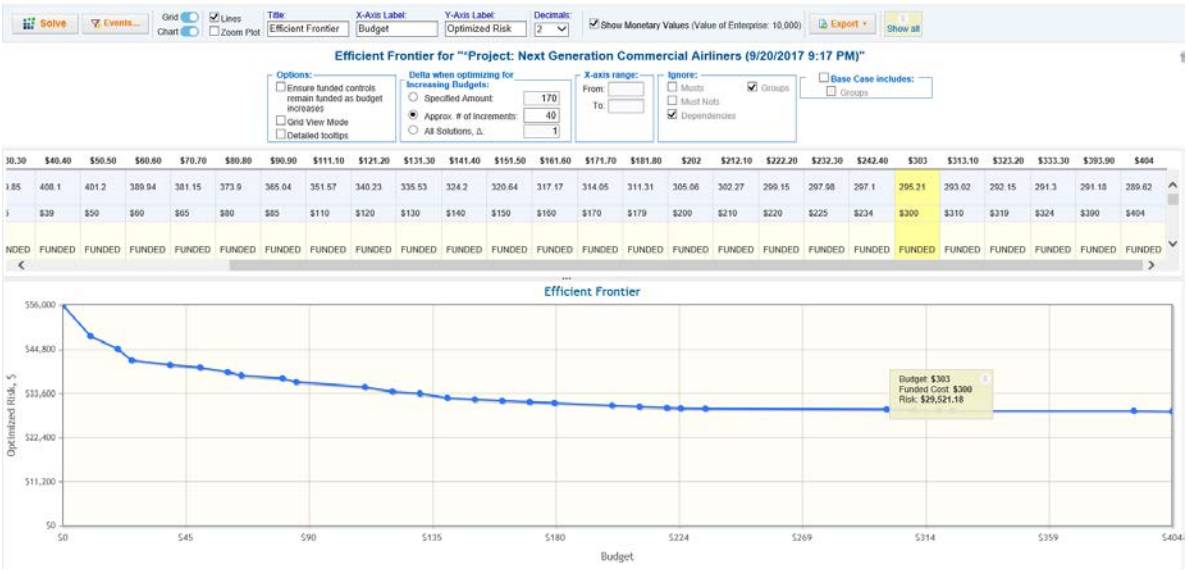
Ignore: [ ] Musts [ ] Must Nots [x] Dependencies [x] Groups

Index	Control Name	Control for	Selected	Cost	Applications	Categories	S.A. Reduction	Must	Must Not
01	Flight Instructor Required Education Hours	Threat	Yes	1	2		$2,085.44	☐	☐
02	FAA Inspector Special Training	Threat	Yes	2	3		$4,564.07	☐	☐
03	Hire FAA component vendor	Threat		20	1		$3,037.27	☐	☐
04	Mandated Work Breaks	Threat	Yes	1	2		$2,760.92	☐	☐
05	Mandated Company Holidays	Threat	Yes	5	3		$1,693.01	☐	☐
06	Metric Unit Conversion Checks	Threat	Yes	1	1		$434.03	☐	☐
07	Blueprint Version Control	Vulnerability	Yes	40	9		$6,521.66	☐	☐
08	Individual Onboard Parachutes	Vulnerability		5	13		$246.85	☐	☐
09	Engineering Quality Control	Vulnerability		9	8		$3,496.98	☐	☐
10	Wind tunnel modeling	Vulnerability	Yes	10	16		$4,111.82	☐	☐
11	Government Liason Council	Vulnerability		30	6		$946.35	☐	☐
12	Virtual Aircraft Modeling	Vulnerability		20	15		$3,878.67	☐	☐
13	Detachable Passenger Cabin	Consequence		80	9		$1,507.35	☐	☐
14	Backup onboard software system	Consequence		90	18		$1,010.91	☐	☐
15	Heavy Equipment Training	Consequence	Yes	20	13		$1,901.26	☐	☐
16	Multi-country Sourcing	Consequence	Yes	50	13		$3,890.43	☐	☐
17	Safety Equipment Weekly Checks	Consequence	Yes	10	9		$573.36	☐	☐
18	FAA and EASA Licensed Vendor Check	Consequence	Yes	10	5		$3,526.72	☐	☐

Efficient Frontier for Controls Optimization

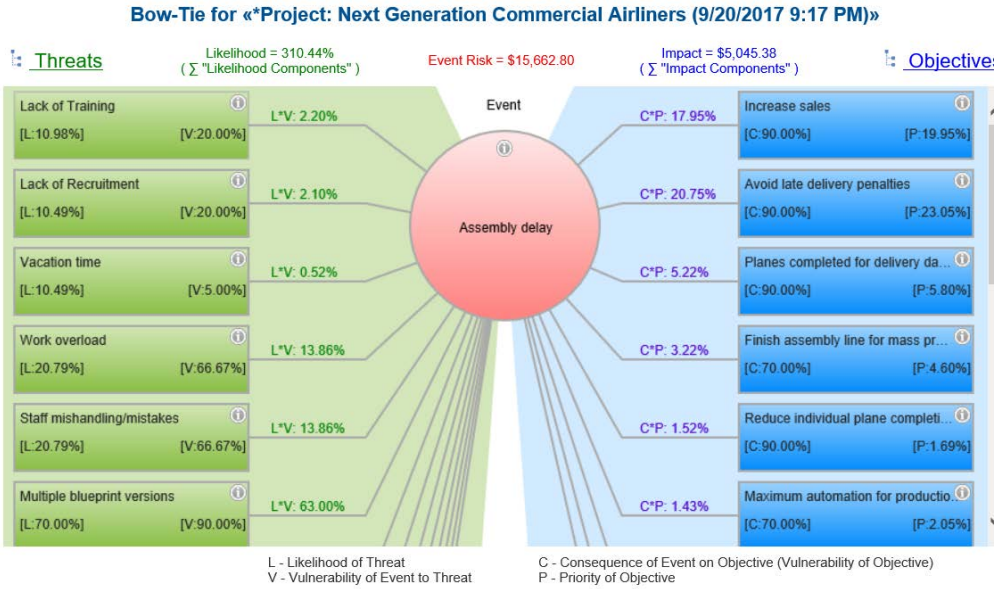
Another method that could be used to select controls is from the Efficient Frontier option in Riskion software shown below. Efficient Frontier shows the Optimized Risk an organization

faces based on the increasing amount of funding for Controls. The graph flattens quickly for Next Generation Commercial Airliners as Control Effectiveness decreases quickly per budget increases. Other projects could have a sharper distinction showing an ideal budget.

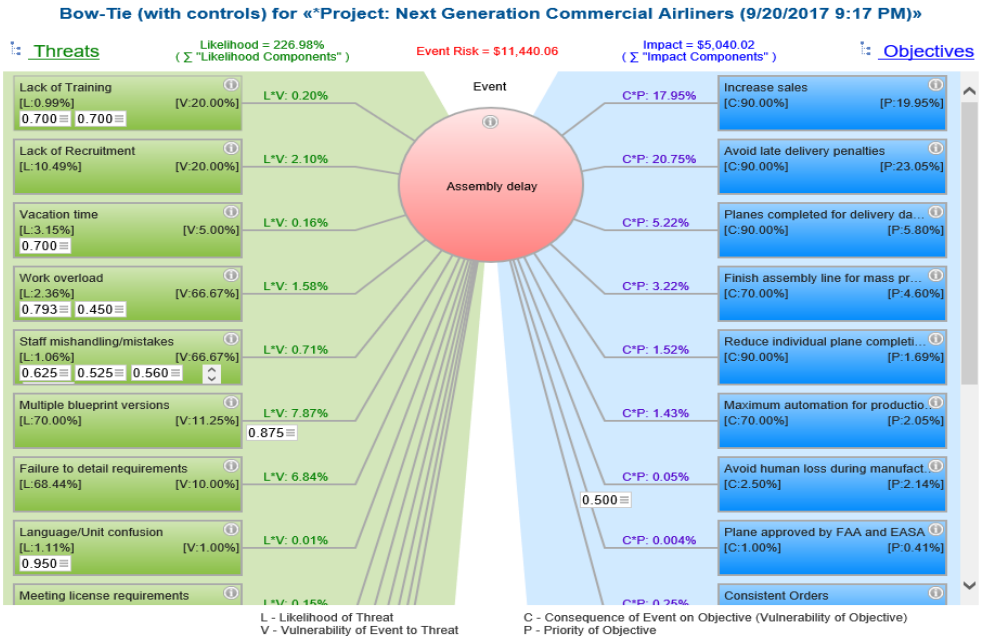


Bow Tie Diagrams with and without Controls

For any specific event, the Bow-Tie Diagram shows all threats leading into an event and the event's impact on the objectives. Below, the likelihood being greater than 300% and Impact being $5,045.38 million for the Event "Assembly Delay" is from the dependent nature of multiple threats and multiple objectives impacted showing an Event Risk of $15,662.80 million.

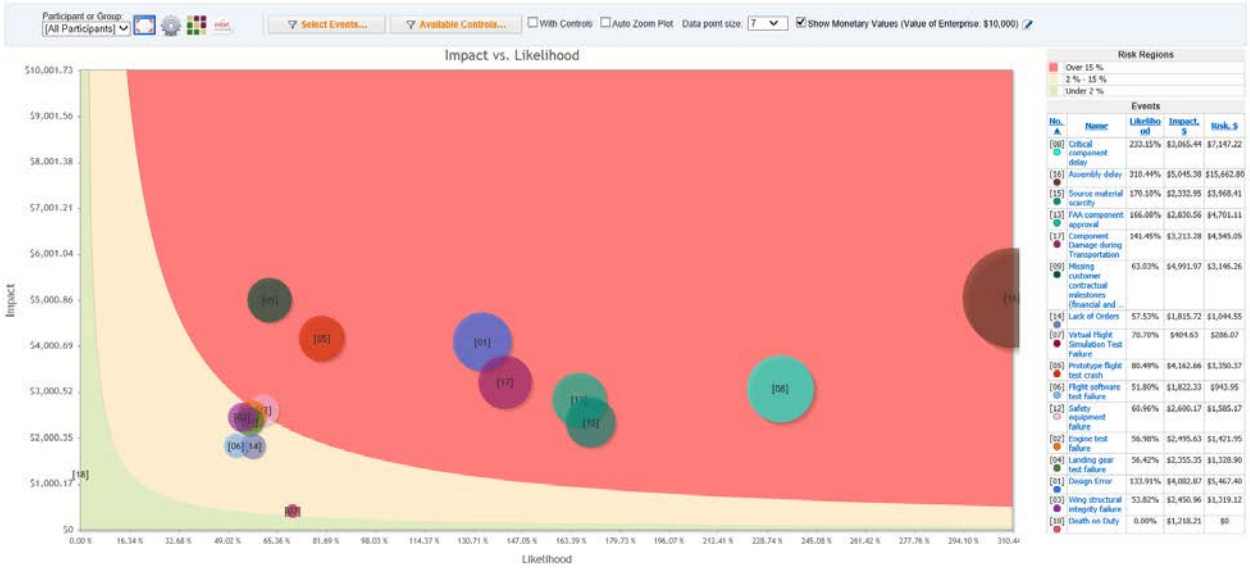


Once controls are applied, the effect can be viewed in the Bow-Tie Diagram with controls as shown below. The white boxes show the effect of different controls on their Threats, Vulnerabilities, and Objectives. This information is useful as it shows the reduction in risk for a single event based on different controls applied. The different controls can also be turned on and off to show how an additional control could reduce event risk.

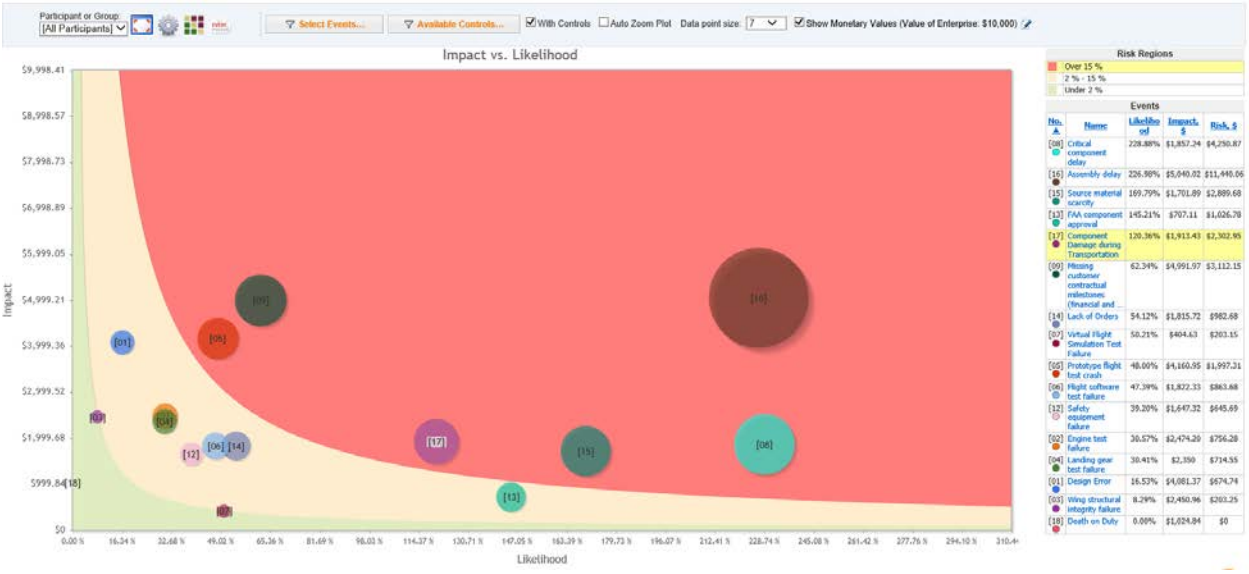


Heat Maps with and without Controls

A heat map is a visual representation of the Risk Events with relative circle sizes based on the calculation of Impact multiplied by Likelihood. This diagram has Risk Regions of Over 15%, 2%-15%, and Under 2% which can be changed based on the Risk Tolerance of an organization. For Next Generation Commercial Airlines, the Heat Map without Controls shows a very risky overall project as most events are Over 15%.



Once controls are added, another Heat Map is created to show how the selected controls affect different events and overall project risk. Below, the new Heat Map with the selected Controls shows significant reductions in Risk even though many events are still Over 15% risk. Additional controls could then be added to mitigate the events Over 15% until they are reduced to acceptable levels for the organization.



Overall Likelihoods, Impacts, and Risks with Controls

The final product of all the Events, Threats, Objectives, Controls, different measurement methods, and Control Optimization is the Overall Likelihoods, Impacts, and Risks with Controls. The figure below shows the Simulated Risks for Next Generation Commercial Airliners with a Total Loss Reduction of $1,170 million with $5,236 million in Risk remaining based on investing $150 million in Controls with a Total Enterprise Value of $10,000 million.

Select Events... | Available Controls... | ☑ With Controls | ☑ Show Monetary Values (Value of Enterprise: $10,000)

Overall Likelihoods, Impacts, and Risks (With Controls) for «*Project: Next Generation Commercial Airliners (9/20/2017 9:17 PM)»

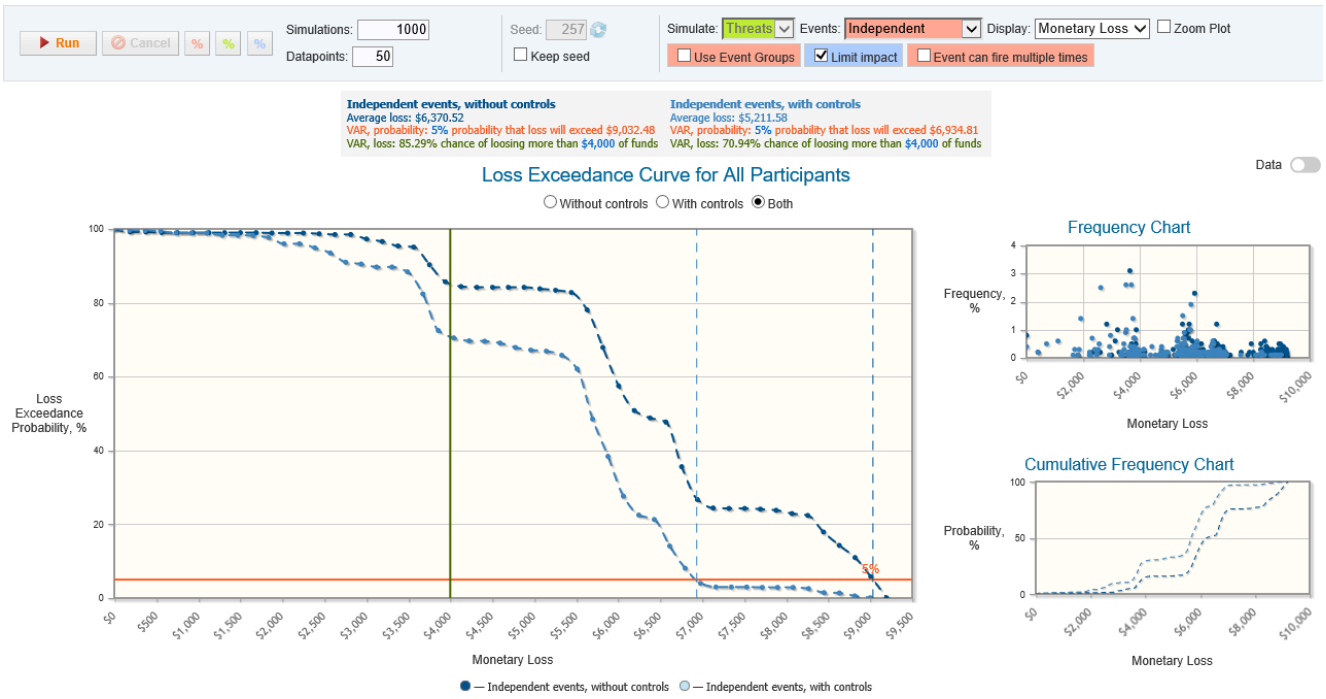
No.	Event	All Participants Likelihood Simulated	Impact, $ Simulated	Risk, $ Simulated
[08]	Critical component delay	32.10%	1,019	327
[16]	Assembly delay	17.40%	2,669	464
[15]	Source material scarcity	27.50%	803	221
[13]	FAA component approval	67.60%	380	257
[17]	Component Damage during Transportation	79.40%	1,077	855
[09]	Missing customer contractual milestones (financial and competitive penalties)	28.80%	2,466	710
[14]	Lack of Orders	26.40%	1,284	339
[07]	Virtual Flight Simulation Test Failure	41.10%	196	80
[05]	Prototype flight test crash	31.70%	2,723	863
[06]	Flight software test failure	39.60%	866	343
[12]	Safety equipment failure	10.70%	1,094	117
[02]	Engine test failure	25.70%	1,001	257
[04]	Landing gear test failure	25.00%	869	217
[01]	Design Error	3.70%	3,368	124
[03]	Wing structural integrity failure	6.70%	861	57
[18]	Death on Duty	0.00%	0	0
	Total Risk Reduction (Computed)			**$23,854**
	Total Residual Risk (Computed)			**$32,063**
	Total Loss Reduction (Simulated)			**$1,170**
	Total Residual Loss (Simulated)			**$5,236**
	Cost of Selected Controls			**$150**

Loss Exceedance Curve with and without Controls

Another option to show the simulated Risk of the project is the Loss Exceedance Curve. The Loss Exceedance Curve is the mirror of the Cumulative Frequency Chart showing the probability that a loss to the organization will be above a given value. The curve below shows

a 5% probability that loss will exceed $9,090.47 million without Controls for the Next Generation Commercial Airliner project.

Adding in Controls, the Loss Exceedance curve below shows a 5% probability that losses will exceed $6,934.81 million and a 70.94% chance of losing more than $4,000 million during the project.



Conclusion

Using Riskion by Expert Choice, Next Generation Commercial Airliners have a very high loss of $6,370.52 without Controls. With a budget of $150 million, Controls reduced the risk of the project to $5,211.58 million. The project still has a 70.94% chance of losing more than $4,000 million with a 5% probability of losing $6,934.81 million. Recommendations for this project would be to add additional controls and budget a higher amount for controls. If the losses cannot be reduced by controls, then the likelihood and impact of events may need to be re-

baselined and reassessed. Otherwise, the risks facing the project are too high for the project to be viable unless the profit or future opportunities are extremely high as well.

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