DOT/FAA/AR-12/3

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Freighter Airplane Cargo Fire Risk and Benefit Cost Model

March 2012

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

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NOTICE

This research was commissioned by the Federal Aviation Administration and Transport Canada by means of their respective Memorandums of Cooperation regarding Civil Aviation Research and Development with the Civil Aviation Authority of the United Kingdom. This activity has been carried out in cooperation between the Federal Aviation Administration, Transport Canada, and the UK Civil Aviation Authority under the auspices of the International Cabin Safety Research Technical Group whose goal is to enhance the effectiveness and timeliness of cabin safety research.

Technical Report Documentation Page

1. Report No. DOT/FAA/AR-12/3	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

FREIGHTER AIRPLANE CARGO FIRE RISK AND BENEFIT COST MODEL

5. Report Date

March 2012

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

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10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Fire Safety Branch
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

ADG-200

15. Supplementary Notes

Jointly funded by the Federal Aviation Administration and Transport Canada. The Federal Aviation Administration Aviation Research Division Technical Monitor was Richard Hill.

16. Abstract

The Federal Aviation Administration (FAA), Transport Canada, and the United Kingdom Civil Aviation Authority requested a Risk and Benefit Cost Model be developed to assess the likely number of U.S.-registered freighter fire accidents, and the benefit/cost ratio associated with seven mitigation strategies identified by the FAA. This report explains the data used by the Model, its algorithms, and the way in which the Model may be used.

The Model addresses the potential fire threat from all forms of cargo, including the bulk shipment of lithium batteries (primary and secondary) because they likely contributed to two of the five freighter fire accidents that have occurred on U.S.-registered airplanes. The Model displays the number of accidents through 2020 and costs, benefits, and the benefit/cost ratios through to 2025.

The Model prediction of the average number of accidents likely to occur from 2011 to 2020, if no mitigation action is taken, is approximately 6—with a 95-percentile range of approximately 2 to 13. If no mitigation action is taken, accident costs are likely to average approximately $44 million (U.S.) per annum over the period 2011 to 2025. The primary contribution to freighter fire accident costs is the value of the airplane—with values of approximately 90% of the total accident cost for the larger freighter airplanes. However, the Model predictions of accident costs are based on the assumption that the composition of the U.S.-registered freighter fleet will be largely unchanged from 2010 through 2025 in terms of the size and value of airplanes.

The costs of implementing the proposed mitigation strategies are currently not known to a sufficient level of accuracy to make accurate determinations of benefit/cost ratios. However, the Model has been constructed to allow user inputs of costs once they become available.

17. Key Words Cargo fire, Risk and benefit cost model, Lithium battery	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 73	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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CFR	Code of Federal Regulations
CSRTG	Cabin Safety Research Technical Group
FAA	Federal Aviation Administration
MAIS	Maximum abbreviated injury scale
MTOW	Maximum takeoff weight
NTSB	National Transportation Safety Board (U.S.)
RTM	Revenue ton-miles

EXECUTIVE SUMMARY

Following the accident at Dubai International Airport in the United Arab Emirates of a Boeing 747 freighter airplane on September 3, 2010, the Federal Aviation Administration (FAA), Transport Canada, and the United Kingdom Civil Aviation Authority requested that a Risk and Benefit Cost Model be developed to assess the likely number of U.S.-registered freighter fire accidents, and the benefit/cost ratio associated with seven mitigation strategies identified by the FAA. This report explains the data used by the Model, its algorithms, and the way in which the Model may be used.

The Model addresses the potential fire threat from all forms of cargo, including the bulk shipment of lithium batteries (primary and secondary), because they likely contributed to two of the five freighter fire accidents that have occurred on U.S.-registered airplanes. The Model displays the number of accidents from 2011 to 2020 and costs, benefits, and the benefit/cost ratios through 2025.

The Model prediction of the average number of accidents likely to occur between 2011 and 2020, if no mitigation is taken, is approximately 6, with a 95-percentile range of approximately 2 to 13. If no mitigation is taken, accident costs are likely to average approximately $44 million (U.S.) per annum between 2011 and 2025. The primary contributor to freighter fire accident costs is the value of the airplane—with approximately 90% of the total accident cost for the larger freighter airplanes. However, the Model predictions of accident costs are based on the assumption that the composition of the U.S.-registered freighter fleet will be largely unchanged from 2010 through 2025 in terms of the size and value of airplanes. However, larger freighter airplanes may change the composition of the fleet. This is likely to result in the potential for higher accident costs and higher benefits for accidents that are mitigated.

The cost of implementing the proposed mitigation strategies are currently not known to a sufficient level of accuracy to make accurate determinations of benefit/cost ratios. However, the Model has been constructed to allow user inputs of costs once they become available. If reliable data does not become available with regard to the costs of the proposed mitigation strategies, an alternative approach to determine the installation costs, weight, and effectiveness would be necessary for the mitigation to be cost-effective.

Some mitigation strategies, although they may be shown to be cost beneficial, may not have the desired reduction in the number of accidents. To make a significant impact on the number of accidents, a way to address the threat from cargo carried in containers, pallets, or as loose cargo needs to be determined. This may be accommodated by a compartment suppression system or a combination of mitigation means aimed at addressing all types of shipment.

Subsequent phases of this study will develop the Model to assess the likely number of Canadian-registered freighter fire accidents, and the benefit/cost ratio associated with the seven mitigation strategies considered in this study.

1. INTRODUCTION.

Following the accident at Dubai International Airport in the United Arab Emirates of a Boeing 747 freighter airplane on September 3, 2010, the Federal Aviation Administration (FAA), Transport Canada, and the United Kingdom Civil Aviation Authority (referred to as the Authorities) requested that a Risk and Benefit Cost Model (herein referred to as the Model) be developed to assess the likely number of fire accidents on U.S.-registered freighters together with the cost and benefit that could be afforded by certain mitigation strategies. The Model displays the number of accidents through 2020 and costs, benefits, and the benefit/cost ratios through 2025.

Since the bulk shipment of lithium batteries (primary and secondary) likely contributed to two of the five freighter fire accidents that occurred on U.S.-registered freighter airplanes, the Model addresses the potential threat from lithium batteries and other cargo separately. All references to batteries should be taken to mean secondary or primary lithium battery packs or individual cells.

This report explains the data[1] used by the Model, its algorithms, and potential uses for the Model. The data in the Model were appropriate to the U.S.-registered freighter fleet in 2010, and all costs are in 2010 U.S. dollars.

Subsequent phases of this study will develop the Model to assess the likely number of Canadian-registered freighter fire accidents, and the benefit/cost ratio associated with seven mitigation strategies considered in this study, including

- Container suppression-external
- Container suppression-internal
- Pallet covers
- Battery boxes primary
- Battery boxes secondary
- Fire-hardened containers
- Compartment suppression

2. MODEL OVERVIEW.

The Model, which was constructed in Microsoft® Excel®, has three separate submodels—a Risk Submodel, a Benefit Submodel, and a Cost Submodel. The Risk and Benefit Submodels were based on the Monte Carlo simulation methodology using statistical distributions derived from data on in-service airplanes and accidents. The Monte Carlo simulation is a method in which variables are randomly chosen based on their probability of occurrence. The variables are then combined to determine the required output, in this case, the number of U.S.-registered freighter cargo fire accidents likely to occur, the annual cost of such accidents, and the benefit that might accrue from the implementation of certain mitigation strategies. The Risk and Benefit

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[1] It should be noted that the number of significant digits contained within any data presented in this report is not indicative of the accuracy of the data. The number of digits contained within the data sets used are retained for ease of cross reference and to prevent rounding errors.

Submodels are run many thousands of times to obtain these predictions and associated distributions.

In broad terms, the Model predictions are as follows:

- The likely number of cargo fire accidents, together with a confidence range.

- The annual cost incurred as a result of these accidents.

- The annual benefit and cost that might accrue from the implementation of the mitigation strategies.

- The annual benefit/cost ratio that might result from these mitigation strategies.

The Model outputs (data and graphs) are located on the Control Panel tab, which also contains the basic settings of the Model that can be varied by the user. Other Model inputs, primarily related to cost data, are located on the User Data Input tab, which contains a user input facility to vary the data. The user input data have default settings that are used by the Model, unless overwritten by the user.

Instructions on how to use the Model are contained in section 13.

3. FREIGHTER CARGO FIRE ACCIDENTS.

The Cabin Safety Research Technical Group (CSRTG) Accident Database [1] was searched to identify all cargo fire-related accidents on U.S.-registered freighter cargo operations from 1967[2] to 2010. The following criteria were used for the selection of accidents:

- U.S.-registered freighter airplane (N registration)
- Cargo-only operation
- Fire-related accidents involving fire or smoke from the cargo

Only airplane accidents conforming to the International Civil Aviation Organization Annex 13 [2] definition were included in the analysis since the prevention of occurrences in which there were no serious or fatal injuries to personnel, or any substantial damage to the airframe, is unlikely to incur significant costs.

The National Transportation Safety Board (NTSB) Database [3] was also searched for cargo fire accidents, and the Boeing Aircraft Company supplied a list of accidents involving cargo fires.

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[2] While the study period was from 1958 to 2010, reference 1 does not contain data prior to 1967.

These data sources identified the following five cargo fire accidents to U.S.-registered freighter airplanes between 1958 and 2010.

- Accident 1

Accident Reference 20100903A [1]
Date: September 3, 2010
Operator: United Parcels Service (UPS)
Airplane: B-747-44AF (Registration N571UP)
Location: Dubai, United Arab Emirates
Airplane Damage: Destroyed
Crew Injuries: All Fatal—2 Crew Members

“At about 7:45 pm local time (1545 UTC), United Parcel Service (UPS) Flight 6, a Boeing 747-400F (N571UP), crashed while attempting to land at Dubai International Airport (DXB), Dubai, United Arab Emirates (UAE). Approximately 45 minutes after takeoff, the crew declared an emergency due to smoke in the cockpit and requested a return to DXB. The two flight crew members were fatally injured. The airplane was being operated as a scheduled cargo flight from Dubai, UAE to Cologne, Germany.” (Source: NTSB DCA10RA092)

- Accident 2

Accident Reference 20060207A [1]
Date: February 7, 2006
Operator: United Parcel Service (UPS)
Airplane: DC-8 (Registration N748UP)
Location: Philadelphia, Pennsylvania, USA
Airplane Damage: Destroyed
Crew Injuries: None

“The cause of the in-flight fire could not be determined in the UPS accident. However, the presence of a significant quantity of electronic equipment in the containers where the fire most likely originated led the Safety Board to closely examine safety issues involving the transportation of rechargeable lithium batteries on commercial aircraft, including batteries in airline passengers’ laptop computers and other personal electronic devices.”

- Accident 3

Accident Reference 20040427A [1]
Date: April 27, 2004
Operator: Mountain Air Cargo
Airplane: F27-500 (Registration N715FE)

Location:	Melo, Uruguay
Airplane Damage:	Destroyed
Crew Injuries:	None

“A FedEx flight operated by Mountain Air Cargo. The flight diverted after discovery of a fire in the cargo bay. The cause of the fire was unknown.”

- Accident 4

Accident Reference	19960905B [1]
Date:	September 5, 1996
Operator:	Federal Express Corporation (FedEx)
Airplane:	DC-10-10CF (Registration N68055)
Location:	Newburgh/Stewart, New York, USA
Airplane Damage:	Destroyed
Crew Injuries:	None

“The National Transportation Safety Board determines that the probable cause of this accident was an in-flight cargo fire of undetermined origin.”

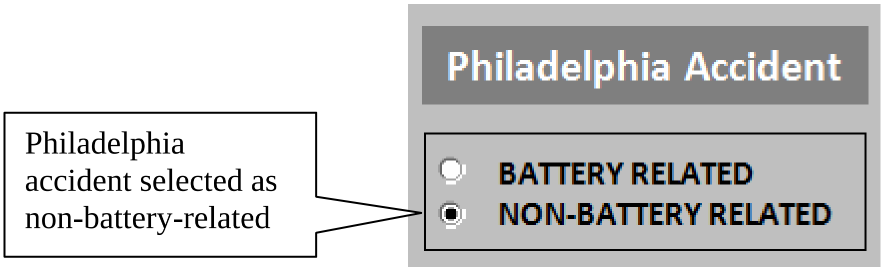
- Accident 5

Accident Reference	19731103B [1]
Date:	November 3, 1973
Operator:	Pan American World Airways
Airplane:	B-707 (Registration N458PA)
Location:	Boston, Massachusetts
Airplane Damage:	Destroyed
Crew Injuries:	All Fatal—3 Crew Members

“About 30 minutes after the aircraft departed from JFK, the flight crew reported smoke in the cockpit. The flight was diverted to Logan International Airport where it crashed just short of runway 33 during final approach. Although the source of the smoke could not be established conclusively, the NTSB believes that the spontaneous chemical reaction between leaking nitric acid, improperly packaged and stowed and the improper sawdust packing surrounding the acid’s package initiated the accident sequence.”

For the majority of these accidents, the precise cause of the fire was not determined. However, it is known that for both the Dubai accident (accident reference 20100903A) and the Philadelphia accident (accident reference 20060207A), lithium batteries were being transported and could have contributed to the onboard fires, resulting in catastrophic accidents.

The Model was based on these five accidents that were categorized as either battery-related or non-battery-related. The Dubai accident was assumed to be battery-related, and the Model allows the user to select either battery or non-battery related from the Philadelphia accident switch. To select these options, click on the appropriate button in the Philadelphia accident switch in the Model Control Panel tab, as shown in figure 1.



Philadelphia Accident

○ BATTERY RELATED
● NON-BATTERY RELATED

Philadelphia accident selected as non-battery-related

Figure 1. Philadelphia Accident Switch

4. REVENUE TON-MILES.

This section describes the way in which the predicted number of revenue ton-miles (RTM) has been derived for battery and nonbattery cargo.

The Model was based on the assumption that the risk of a cargo fire accident occurring is a function of RTMs of cargo carried. This has been used in favor of hours or number of flights as it seems reasonable that the probability of a cargo fire occurring is related to the quantity of cargo carried. RTMs gives a representation of cargo quantity and is a usage value that is routinely recorded and used by the air transport industry.

Since the threat from cargo fires is limited to Class E[3] and Class D[4] cargo compartments (on the assumption that fire threats in Class C cargo compartments are adequately accommodated by the current protection means), it is necessary to determine the proportion of the total RTMs carried in these compartments.

4.1 TOTAL RTMs, 1958 THROUGH 2010.

Assessments of non-Class C cargo compartment RTMs (Class E and Class D) were made for each airplane type in the U.S.-registered freighter fleet in 2008 though 2010 based, in part, on the data contained in reference 4.

Using data contained in references 4 through 6, assessments were made of the annual total RTMs for the U.S.-registered freighter fleet prior to 2008. These totals were factored to assess the non-Class C cargo compartment RTMs based on the proportions of the total derived from the 2010 data. By way of reference, the assessed proportion of total RTMs carried in non-Class C cargo

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[3] See appendix A for cargo compartment classifications.

[4] There are a limited number of Class D cargo compartments on U.S.-registered airplanes. They are no longer accepted as adequate for newly certificated airplanes and, as such, are no longer specified in Title 14 Code of Federal Regulations (CFR) 25.857. On this basis, it is pessimistically assumed that the protection afforded by Class D cargo compartments is similar to Class E cargo compartments.

compartments is 80%. Based on these data sources, the best estimate of the annual non-Class C cargo compartment RTMs accumulated by the U.S.-registered freighter fleet is shown in figure 2.

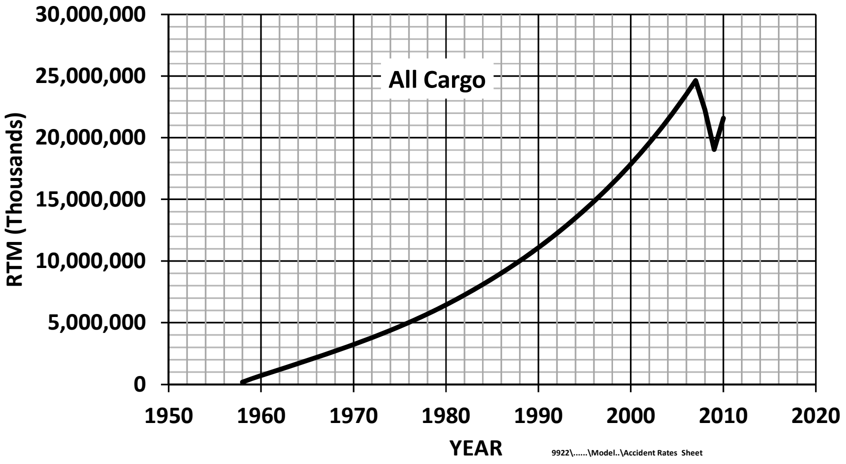

Figure 2. Assessment of the Annual Number of RTMs Carried in Non-Class C Cargo Compartments per Annum for the U.S.-Registered Freighter Fleet—1958 to 2010

Using the data illustrated in figure 2, the RTMs carried by U.S.-registered freighter airplanes in non-Class C cargo compartments was assessed to be:

- 518,741,654,641 RTMs from 1958 to 2010
- 21,451,597,998 RTMs for 2010

The RTMs carried by U.S.-registered freighter airplanes in non-Class C cargo compartments in 2010 were sorted by freighter types, as shown in table 1.

Table 1. Revenue Ton-Miles (2010) in Non-Class C Cargo Compartments by Freighter Type—All Cargo

Freighter Type	RTMs (2010)
A300	1,576,654,045
A310	284,581,190
ATR42 and 72	3,793,052
B-727	386,148,133
B-737	16,356,450
B-747-100, 200 and 300	2,084,601,533
B-747-400	4,330,981,395
B-757	824,387,992
B-767-200	409,623,487
B-767-300	1,979,964,159

Table 1. Revenue Ton-Miles (2010) in Non-Class C Cargo Compartments by Freighter Type—All Cargo (Continued)

Freighter Type	RTMs (2010)
B-777	566,721,213
CV-580	6,932,577
DC-8	183,618,371
DC-9	6,631,049
DC-10	2,398,854,543
L-100	7,877,889
MD-11	6,383,870,922
Total	21,451,597,998

4.2 DIVISION OF RTMS—LITHIUM BATTERY AND OTHER CARGO.

Since accident rates need to be derived for both lithium battery fire-related accidents and those attributable to other cargo, the RTMs in non-Class C cargo compartments needed to be divided into these two cargo categories. All assessments relate to the bulk shipment of lithium batteries and may be conservative since no account has been taken of the potential threat from the secondary shipment of batteries, for example, those contained in electronic devices (laptops, cell phones, etc.)

Based on data contained in reference 7, an assessment of the increase in production of secondary lithium battery cells was made. Figure 3 shows the annual number of secondary lithium cells estimated to have been produced from 1995 to 2010 worldwide, with a future extrapolation through 2025.

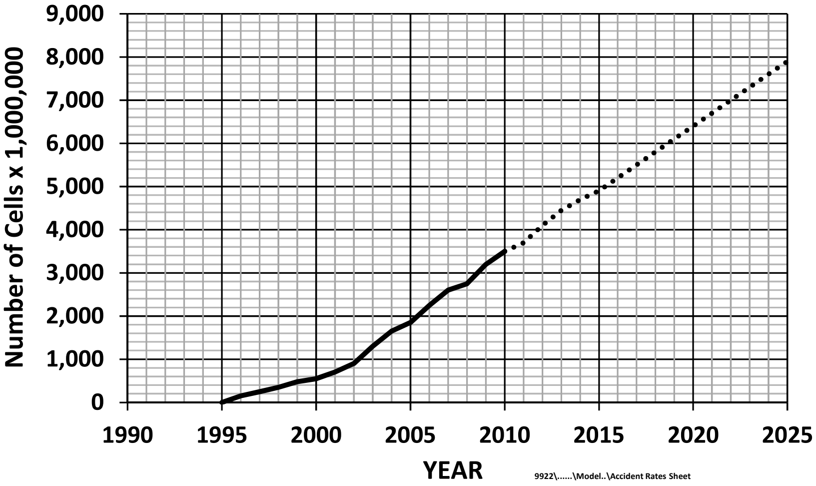

Figure 3. Estimated Annual Number of Secondary Lithium Battery Cells Produced Worldwide

The type of data shown in figure 3 was not available for primary lithium batteries. However, based on information contained in reference 8, it was estimated that primary lithium battery cell production was approximately 25% of secondary lithium battery cells, which is taken as the default value. However, it is a user input variable that can be changed on the User Data Input tab.

The annual number of secondary lithium battery cells produced worldwide, as shown in figure 3, can be multiplied by 25% to obtain an estimate of the total number of primary lithium battery cells produced annually, i.e., secondary lithium battery cells represent 80% of the total lithium battery cell production.

It was further assumed that 100% of secondary battery production and 20% of primary battery production are carried by freighter airplanes, and 50% of all batteries carried by freighter airplanes are carried by the U.S.-registered freighter fleet. However, these are user input variables that can be changed on the User Data Input tab. Using these values, an assessment may be made of the number of cells carried by U.S.-registered freighter airplanes.

The annual lithium battery RTMs carried on U.S.-registered freighter airplanes was estimated by multiplying the number of cells carried, by the weight of a typical cell[5], and the average stage length of a flight[6]. Based on this assessment, in 2010, battery (secondary and primary) RTMs accounted for 0.64% of the total RTMs carried in non-Class C cargo compartments on U.S.-registered freighter airplanes. Based on this assumption, the total RTMs for battery (secondary and primary) and nonbattery cargo, for each freighter type, would be as shown in table 2.

Table 2. The RTMs (2010) in Non-Class C Cargo Compartments by Freighter Type (Battery (Secondary and Primary) and Nonbattery Cargo)

Freighter Type	RTMs (2010)		
	Battery Cargo	Nonbattery Cargo	All Cargo
A300	10,157,793	1,566,496,251	1,576,654,045
A310	1,833,450	282,747,739	284,581,190
ATR42 and 72	24,437	3,768,615	3,793,052
B-727	2,487,808	383,660,325	386,148,133
B-737	105,379	16,251,071	16,356,450
B-747-100, 200, and 300	13,430,309	2,071,171,224	2,084,601,533
B-747-400	27,902,896	4,303,078,498	4,330,981,395
B-757	5,311,224	819,076,768	824,387,992
B-767-200	2,639,051	406,984,436	409,623,487

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[5] The common 18650 lithium battery cell, weighing 0.1 lb, was considered typical for the purpose of this assessment. This cylindrical cell is used widely within laptop battery packs and other consumer items.

[6] The average stage length for U.S. freighter airplanes in 2010 was 1889 miles.

Table 2. The RTMs (2010) in Non-Class C Cargo Compartments by Freighter Type (Battery (Secondary and Primary) and Nonbattery Cargo) (Continued)

	RTMs (2010)		
Freighter Type	Battery Cargo	Nonbattery Cargo	All Cargo
B-767-300	12,756,170	1,967,207,989	1,979,964,159
B-777	3,651,173	563,070,040	566,721,213
CV-580	44,664	6,887,913	6,932,577
DC-8	1,182,985	182,435,386	183,618,371
DC-9	42,721	6,588,327	6,631,049
DC-10	15,454,924	2,383,399,619	2,398,854,543
L-100	50,754	7,827,135	7,877,889
MD-11	41,128,897	6,342,742,025	6,383,870,922
Total	138,204,637	21,313,393,361	21,451,597,998

Based on the growth in lithium battery cell (secondary and primary) production and the assumptions for the proportion carried by the U.S.-registered freighter airplane fleet, an assessment could be made of the battery RTMs for all years prior to 2010. The battery RTMs were then subtracted from the total RTMs (all cargo) to determine the nonbattery RTMs, appropriate to non-Class C cargo compartments, for each year between 1958 and 2025. The cumulative RTMs for both battery (secondary and primary) and nonbattery cargo through 2010 were derived by summing each of the preceding years, as shown in table 3.

Table 3. Assessed Cumulative RTMs in Non-Class C Cargo Compartments for the U.S.-Registered Freighter Fleet Through 2010—Battery (Secondary and Primary) and Nonbattery

Cumulative Battery RTMs Through 2010	Cumulative Nonbattery RTMs Through 2010
887,668,638	517,853,986,003

Table 4 shows the predicted RTMs in non-Class C cargo compartments for both battery (secondary and primary) and nonbattery cargo for each year between 2011 and 2025.

Table 4. Assessed Annual RTMs in Non-Class C Cargo Compartments for the U.S.-Registered Freighter Fleet 2011 to 2025—Battery (Secondary and Primary) and Nonbattery

Date	Annual Battery (Secondary and Primary) RTM	Annual Nonbattery RTMs
2011	146,102,045	23,303,024,187
2012	161,896,860	24,379,644,594
2013	175,717,324	25,511,075,533
2014	185,589,084	26,702,685,045
2015	193,486,491	27,956,117,514
2016	205,332,603	29,269,277,365
2017	217,178,715	30,650,169,092
2018	229,024,827	32,103,104,523
2019	240,870,938	33,632,620,533
2020	252,717,050	35,243,510,034
2021	264,563,162	36,940,831,758
2022	276,409,273	38,729,911,884
2023	288,255,385	40,616,340,786
2024	300,101,497	42,605,992,591
2025	311,947,609	44,705,044,759

The assessed annual number of RTMs carried in non-Class C cargo compartments for the period 1958 to 2025 is shown in figure 4.

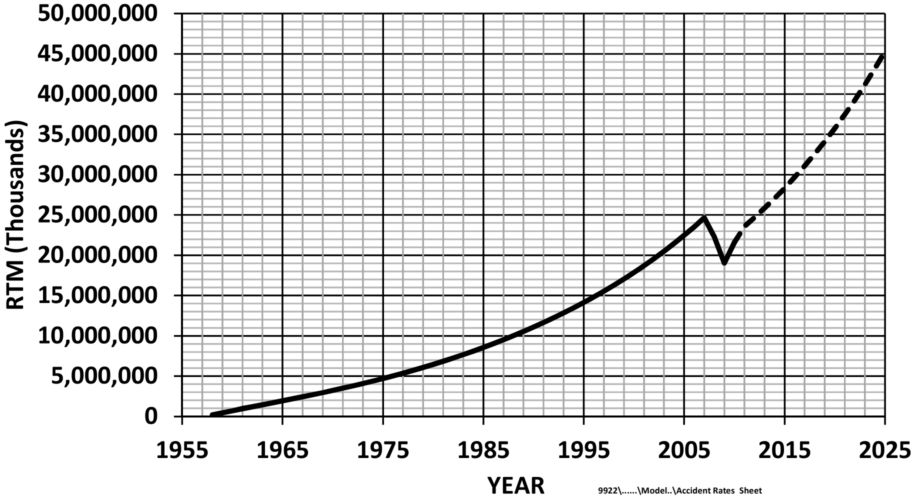


Figure 4. Assessment of the Annual Number of RTMs Carried in Non-Class C Cargo Compartments per Annum for the U.S.-Registered Freighter Fleet—1958 to 2025

5. ACCIDENT RATES AND ACCIDENT RATE DISTRIBUTIONS.

The average accident rate attributable to cargo fires may be determined using the following formula:

$$\textit{Accident rate} = \frac{\textit{Number of cargo fire accidents}}{\textit{Cumulative RTMs}}$$

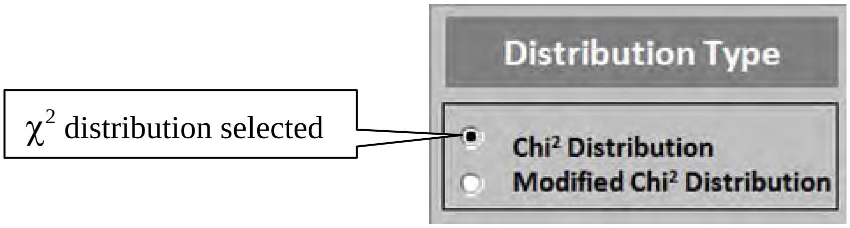
This formula can be used to determine the average accident rate attributable to battery and non-battery-related cargo by dividing the number of accidents attributable to each cause by the associated cumulative RTMs, as shown in table 3. Therefore, assuming that the Philadelphia accident was related to lithium batteries, the associated accident rates can be derived by dividing the applicable number of accidents by the associated cumulative RTMs up to and including 2010:

$$\text{Battery accident rate} = 2 \div 887{,}668{,}638 = 2.25 \times 10^{-9} \text{ per RTM}$$
$$\text{Nonbattery accident rate} = 3 \div 517{,}853{,}986{,}003 = 5.79 \times 10^{-12} \text{ per RTM}$$

However, with such small datasets, it is more realistic to develop distributions that indicate a confidence level in a range of accident rates rather than determining an average value.

The χ^2 (chi^2) distribution may be used to derive the confidence level in any given accident rate based on the number of accidents experienced over a given time period. Two accident rate distributions are derived using the χ^2 distribution; one for battery fire accidents and the other for nonbattery fire accidents. Using the RTM values shown in table 3 and the number of battery fire accidents and nonbattery fire accidents, probability distributions may be derived for the associated accident rates.

While the χ^2 distribution has a sound mathematical basis, it tends to give answers that are overly conservative than be expected. Therefore, a switch was added on the Control Panel tab, as shown in figure 5, that modifies the χ^2 distribution to provide confidence ranges closer to what might be expected. This modifier multiplies the accident rate derived from the χ^2 distribution by $x/(x+1)$; where x is the number of occurrences experienced (in this case, the number of accidents).



● Chi² Distribution
○ Modified Chi² Distribution

Figure 5. The χ^2 Distribution Switch

At each iteration of the Model, random selections were made on the χ^2 distribution (or the modified χ^2 distribution, whichever is selected) to derive an accident rate. This process was done for both the battery fire accident rate and the nonbattery fire accident rate.

It is unknown whether primary and secondary batteries present the same level of threat in terms of their potential to cause or contribute to a cargo fire. The Model contains a variable that quantifies the relative threat from primary and secondary batteries known as the Hazard Ratio. The Hazard Ratio represents the ratio of the primary battery fire accident rate to the secondary battery fire accident rate. The primary and secondary battery fire accident rates may be derived from the Hazard Ratio, the associated battery RTMs, and the expected number of battery accidents (primary and secondary). By default, the Hazard Ratio is set at 1, i.e., primary and secondary batteries have the same level of threat. However, it is a user input variable that may be changed in the User Data Input tab.

6. NUMBER OF ACCIDENTS PRIOR TO MITIGATION.

The assessed number of secondary battery, primary battery, and nonbattery fire accidents per annum, prior to mitigation, was derived by multiplying the derived accident rates by the appropriate RTMs. The assessed RTMs for battery and nonbattery cargo are shown in table 4 for 2011 to 2025 inclusive.

The average number of accidents that might be expected over a given period can be assessed by multiplying the RTMs for the period by the associated accident rate.

For example, the expected number of battery fire accidents for the period 2011 to 2020 would be:

$$\text{Battery Accident Rate} = 2.25 \times 10^{-9} \times \text{Battery RTMs 2011 to 2020} = 2{,}007{,}915{,}936$$
$$= 4.5 \text{ (Approximately equal to accidents)}$$

The proportion of these accidents attributable to secondary and primary batteries is dependent on the Hazard Ratio and the relative number of RTMs associated with primary and secondary batteries. Algorithms are contained within the Model to accommodate the user-assigned values for both variables in deriving the division of accidents.

The process of randomly selecting the χ^2 distributions and multiplying by the appropriate RTMs is repeated many thousands of times to derive a distribution of the annual predicted number of accidents for each year from 2011 to 2020. The average prediction is derived for each year through 2020. The predicted number of accidents are sequentially added to the five accidents that occurred up to year 2010 to derive a prediction of the cumulative number of accidents through 2020, as illustrated by the bold curve in figure 6.

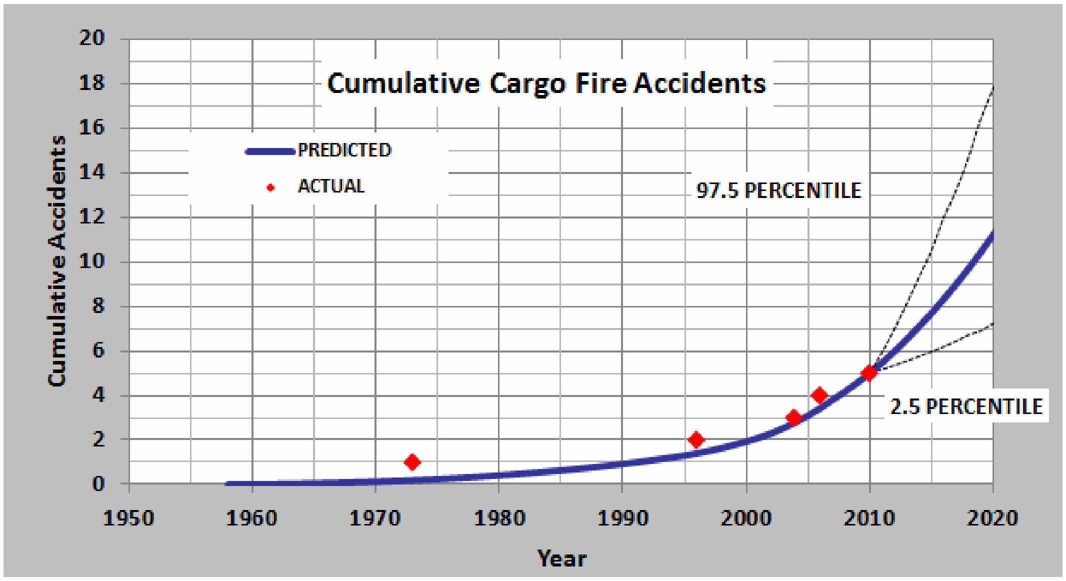
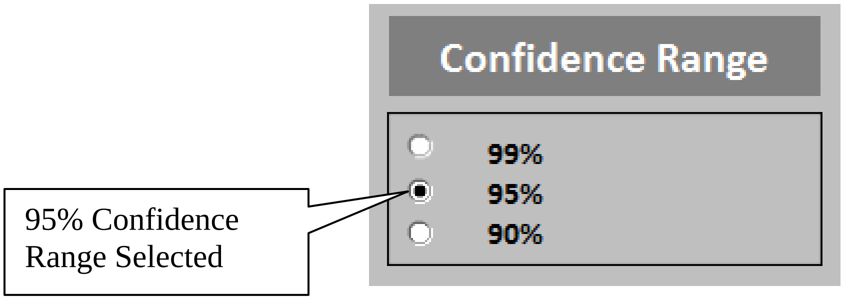


Figure 6. Predicted Number of Freighter Airplane Cargo Fire Accidents Through 2020

The Model prediction of the annual number of accidents for each year between 2011 and 2020 allows a confidence range to be established, as shown in figure 6. This confidence range is variable and can be selected by clicking the Confidence Range switch, as shown in figure 7. The Confidence Range switch is contained in the Control Panel tab. (The figure 8 predictions are based on the modified χ^2 distribution, assuming that the Philadelphia accident was attributable to a lithium battery fire.)


Confidence Range

○ 99%
● 95%
○ 90%

95% Confidence Range Selected

Figure 7. Confidence Range Switch

Accidents Predicted Over 10 Years (2011 - 2020)			
	2.5 %	Ave	97.5 %
Battery Fire Accidents		4.5	
Non-Battery Fire Accidents		1.7	
Total Accidents	2.2	6.2	12.6

Figure 8. Predicted Average and 95-Percentile Range of the Number of Cargo Fire Accidents Through 2020

For example, figure 8 shows the average prediction of the number of cargo fire accidents from 2011 to 2020 divided into accidents caused by batteries and those caused by nonbattery cargo. Figure 8 also shows the 95-percentile range (from the 2.5 percentile to the 97.5 percentile) of the predicted total number of accidents from 2011 to 2020.

The predictions shown in figure 8 are based on the modified χ^2 distribution, assuming that the Philadelphia accident was attributable to a lithium battery fire.

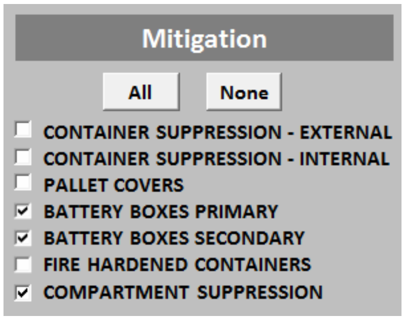
7. ACCIDENT MITIGATION.

The mitigation strategies proposed by the Authorities are those most likely to be feasible as a means of protection against fires in all freighter airplane non-Class C cargo compartments. The Model was developed so that it could accommodate any one, or combination, of these strategies. Each mitigation means will incur an associated installation and operational cost. They will, of course, also have an impact on the future prediction of the number of freighter fire accidents and the associated benefit. As such, the selected mitigation means will have an impact on the risk, benefit, and cost models.

Section 11 describes how the Model addresses the cost of each mitigation strategy, the primary algorithms used by the Model, and using of the User Data Input facility.

7.1 MITIGATION SELECTION.

From the Control Panel tab, the user can select the mitigation strategy, or combination of mitigation strategies, to be addressed by the Model. This can be done by clicking the relevant check boxes on the Control Panel tab, shown in figure 9.



☐ CONTAINER SUPPRESSION - EXTERNAL
☐ CONTAINER SUPPRESSION - INTERNAL
☐ PALLET COVERS
☑ BATTERY BOXES PRIMARY
☑ BATTERY BOXES SECONDARY
☐ FIRE HARDENED CONTAINERS
☑ COMPARTMENT SUPPRESSION

Figure 9. Selection of Mitigation Strategies

7.2 SELECTION OF FREIGHTER TYPE FOR MITIGATION.

The freighter types considered in this study are those appropriate to the 2010 U.S.-registered freighter fleet[7], as shown in table 5.

---

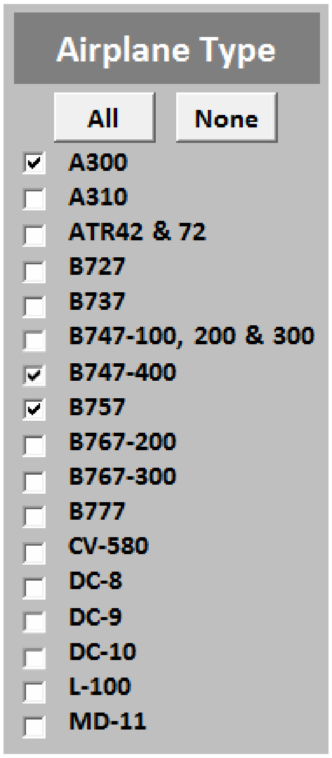
[7] Small turboprops were excluded from this study because they constitute an extremely small proportion of the RTMs carried by the U.S. fleet.

Table 5. Freighter Types in the 2010 U.S.-Registered Fleet

Freighter Type
A300
A310
ATR42 and 72
B-727
B-737
B-747-100, 200, and 300
B-747-400
B-757
B-767-200
B-767-300
B-777
CV-580
DC-8
DC-9
DC-10
L-100
MD-11

The chosen mitigation means can be applied to all the freighter types in the U.S.-registered freighter fleet, as shown in table 5, or limited to selected types. To select specific freighter types for mitigation, the user simply selects the Control Panel tab and then clicks on the check boxes to select the airplane type for mitigation. For example, figure 10 shows that the A300, the B-747-400, and the B-757 have been selected for mitigation. All other freighter types will not be subjected to the selected mitigation.

Note that the Model was constructed so that secondary and primary battery box mitigation is applied to the entire fleet when selected for mitigation. For example, if mitigation by secondary battery boxes and container suppression—external were selected, the Model would apply secondary battery boxes to the entire fleet and container suppression—external to only the selected airplane freighter types.

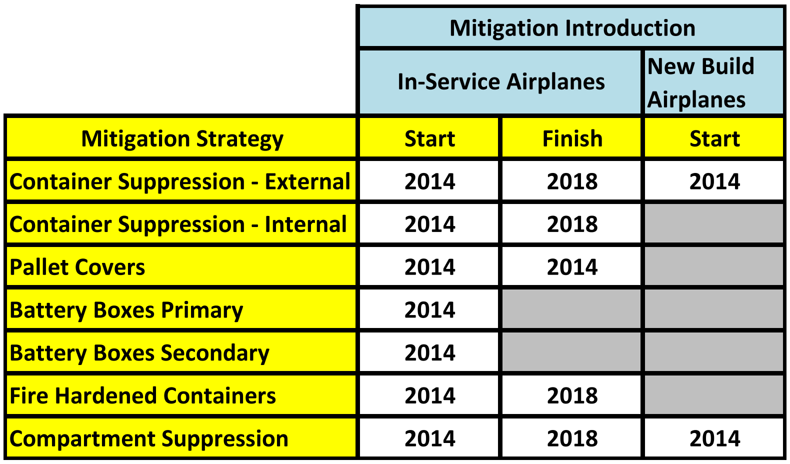


☑ A300
☐ A310
☐ ATR42 & 72
☐ B727
☐ B737
☐ B747-100, 200 & 300
☑ B747-400
☑ B757
☐ B767-200
☐ B767-300
☐ B777
☐ CV-580
☐ DC-8
☐ DC-9
☐ DC-10
☐ L-100
☐ MD-11

Figure 10. Selection of Freighter Types for Mitigation

7.3 MITIGATION INTRODUCTION PERIODS.

For each mitigation strategy, the Model has user input selections for the introduction and completion dates on in-service airplanes and, where appropriate, on new-build airplanes. Variations in these dates may be made by the user from the User Data Input tab by entering the desired value from dropdown menus in the appropriate cell. There are no default values for the introduction and completion dates. Figure 11 shows the mitigation introduction dates on the User Data Input tab.



	Mitigation Introduction		
	In-Service Airplanes		New Build Airplanes
Mitigation Strategy	Start	Finish	Start
Container Suppression - External	2014	2018	2014
Container Suppression - Internal	2014	2018	
Pallet Covers	2014	2014	
Battery Boxes Primary	2014		
Battery Boxes Secondary	2014		
Fire Hardened Containers	2014	2018	
Compartment Suppression	2014	2018	2014

Figure 11. User Data Input Tab—Mitigation Introduction Dates

7.3.1 In-Service Airplanes.

Where applicable, the user may enter a mitigation start and finish date for in-service airplanes. The Model then determines the number of accidents, the benefit, and the installation cost to in-service airplanes appropriate to the selected period.

For in-service airplanes, the Model is based on the mitigation being introduced at a constant rate over the required period. For example, if the mitigation was introduced over the 4-year period 2013 to 2016, the benefit and mitigation cost is applied at a constant rate throughout the period, starting at the beginning of 2013 and being fully implemented by the end of 2016.

If the mitigation strategy is restricted to new-build airplanes only and not introduced to in-service airplanes, the user should select the year 2026 as the start and finish dates from the dropdown menus for in-service airplanes against the associated mitigation strategy.

7.3.2 New-Build Airplanes.

Where applicable, the user may enter a mitigation Start date for new-build airplanes. The Model then determines the number of accidents, the benefit, and the installation cost for new-build airplanes appropriate to the selected period.

If the mitigation strategy is restricted to in-service airplanes only and not introduced to new-build airplanes, the user should select the year 2026 as the start date from the dropdown menus for new-build airplanes against the associated mitigation strategy.

7.4 FIRE MITIGATION IN CONTAINERS, PALLETS, AND LOOSE CARGO.

Cargo is carried on freighter airplanes in containers on pallets, or as loose cargo. The relative quantities of cargo carried in containers and pallets are significant because some of the proposed mitigation strategies only provide protection for one of these means, e.g., pallet covers only provide protection to fires originating within pallets.

Based on an evaluation of the available non-Class C cargo compartment volumes on U.S.-registered freighter airplanes, the percentage of cargo carried as loose cargo was assessed for each airplane type in the U.S.-registered freighter fleet. Within the Model, the overall percentage of cargo carried as loose cargo is a variable dependent on the airplane types selected for mitigation. For the entire U.S.-registered freighter fleet, the percentage of cargo carried as loose cargo is approximately 4.8%.

For cargo that is carried in containers or pallets, 60% is carried in containers. This is the default value, but it may be changed on the User Data Input tab.

These data inputs to the Model are summarized in table 6.

Table 6. Base Data for Cargo Carriage Methods

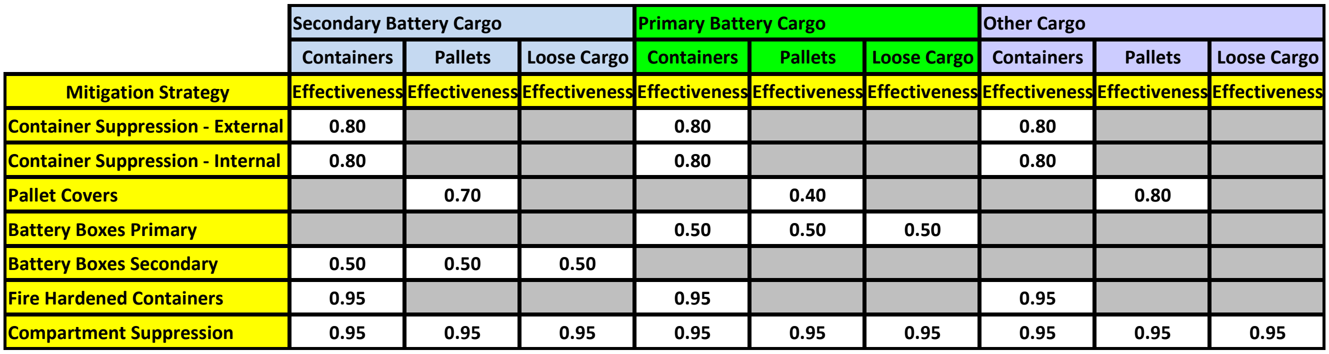
Data	Units	Default Value	User Input Variable
Percentage of cargo carried as loose cargo in non-Class C cargo compartments	-	Dependent on airplanes selected for mitigation	No
Percentage of palletized or containerized cargo carried in containers	-	60%	Yes
Percentage of palletized or containerized cargo carried on pallets	-	40%	No

7.5 MITIGATION STRATEGY EFFECTIVENESS.

Mitigation strategy effectiveness is a function of the ability of the proposed mitigation to combat the fire threats that they are likely to encounter in service. Factors influencing effectiveness include system reliability (accommodating issues relating to incorrect operation or installation of the system) and the probability of encountering fire threats beyond the design intent. Effectiveness is expressed as a numerical value ranging from 0 to 1, with 1 being a system that is always fully effective in combating any fire that is encountered in service that it is intended to suppress. For example, a 0.95 effectiveness value indicates that the mitigation system will function and be fully effective in combating the specified fire threat on 95% of occasions.

There are no in-service data regarding the effectiveness of any of the strategies considered. The effectiveness is a user input variable. The default values are shown in table 7. These values were derived by assessments made by R.G.W. Cherry and Associates engineers and can be changed in the User Data Input tab.

Table 7. Mitigation Strategy Effectiveness—Default Values



	Secondary Battery Cargo			Primary Battery Cargo			Other Cargo		
	Containers	Pallets	Loose Cargo	Containers	Pallets	Loose Cargo	Containers	Pallets	Loose Cargo
Mitigation Strategy	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness
Container Suppression - External	0.80			0.80			0.80		
Container Suppression - Internal	0.80			0.80			0.80		
Pallet Covers		0.70			0.40			0.80	
Battery Boxes Primary				0.50	0.50	0.50			
Battery Boxes Secondary	0.50	0.50	0.50						
Fire Hardened Containers	0.95			0.95			0.95		
Compartment Suppression	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

The Model addresses both mitigation of the fire threat by one mitigation means or by any combination of mitigation means. Secondary battery cargo, primary battery cargo, and other cargo must be treated separately since they have different accident rates and RTMs. Therefore, the Model selects the appropriate values, depending on the selected mitigation means. For example, considering the mitigation effectiveness values contained in table 7, if Container Suppression—External was the mitigation means selected, the proposed mitigation effectiveness value for secondary battery cargo in containers would be equal to 0.8. However, if Container Suppression—External and Battery Boxes Secondary was the mitigation means selected, then the mitigation effectiveness value for secondary battery cargo in containers would be equal to:

$$1- (1 - 0.8) \times (1- 0.5) = 0.9$$

The Model uses this principle to derive the appropriate mitigation effectiveness value for any combination of mitigation means. Sections 7.6 and 9 describe how the Model addresses the calculation of the number of accidents and the derived benefit, taking into account the mitigation means, the RTMs and the accident rates applicable to secondary battery, primary battery, and other cargo.

7.6 REDUCTION IN THE NUMBER OF ACCIDENTS.

Freighter types can be selected for mitigation, as described in section 7.2. For those airplanes not subject to mitigation, there will be no reduction in the number of accidents. The number of accidents expected on these freighter types is derived from the general expression shown in equation 1.

$$\lambda_0 \times RTM_U \tag{1}$$

where

λ_0 = the accident rate associated with the cargo type (Secondary Batteries, Primary Batteries, or Other Cargo) under consideration (Accidents per RTMs)

RTM_U = the RTMs for the freighter and cargo types not selected for mitigation during the year under consideration

The total number of accidents for all freighter types, which are not subjected to mitigation, is the sum of all the derived number of accidents for all three cargo types for all freighter types.

In addition to these accidents, the freighter types that are subjected to mitigation may also experience accidents, since no mitigation means can be 100% effective. The general expression for the number of accidents expected on the freighter types that are subject to mitigation is given by equation 2:

$$\lambda_0 \times RTM_M \times (1-M) \tag{2}$$

where

M = the Mitigation Factor appropriate to the cargo type under consideration and the mitigation means selected (see section 7.4)

RTM_M = the RTMs for the freighter types and cargo type selected for mitigation during the year under consideration

The Model will generate:

- The mitigation factor, M, for Secondary Battery, Primary Battery, and Other cargo, as described in section 7.4.
- The annual RTMs for freighter types not selected for mitigation (RTM_U) for Secondary Battery, Primary Battery, and Other cargo, as described in section 4.
- The annual RTMs for freighter types selected for mitigation (RTM_M) for Secondary Battery, Primary Battery, and Other cargo, as described in section 4.

Using these data, the Model then generates the number of accidents from equations 1 and 2 for each cargo type and year under consideration.

The annual total number of accidents, for each cargo type, for the entire fleet is the sum of the annual number of accidents for the freighter types that are subjected to mitigation and those that are not.

8. ACCIDENT COSTS PRIOR TO MITIGATION.

This section describes how the annual accident costs are derived by the Model prior to mitigation. (The derivation of the residual accident cost following the introduction of mitigation strategies is described in section 10.)

The annual cost of cargo fire accidents on U.S.-registered freighter airplanes is the predicted number of accidents per year multiplied by the cost per accident.

$$\frac{Cost}{Year} = \frac{Accidents}{RTM} \times \frac{RTM}{Year} \times \frac{Cost}{Accident} \tag{3}$$

These costs per year are derived separately for battery and nonbattery cargo for each freighter type from 2011 to 2025. The accident rates for battery and nonbattery cargo are distributions and are derived as described in section 5. The RTMs per year for battery and nonbattery cargo are fixed values for each freighter type, as specified in table 4.

The costs per accident are determined separately for each freighter type based on the assessed costs associated with the following areas:

- Crew injuries
- Airplane damage
- Cargo damage
- Collateral damage (damage to persons and property on the ground)

These costs per accident are a separate distribution for each freighter type.

The extent of the damage and injuries incurred will be a function of the nature or characteristics of the accident. Section 8.1 describes how the Model assesses the likely characteristics of accidents.

8.1 ACCIDENT CHARACTERISTICS.

Freighter fire accidents are categorized as either controlled or uncontrolled accidents. Controlled accidents are those in which following the fire, the flight crew had some degree of control and landed the airplane on the ground. Uncontrolled accidents are those in which, following the fire, the flight crew lost control in flight and the airplane impacted the ground. In instances in which control was lost on final approach and the airplane stopped within the airport perimeter, the accident was considered controlled.

A distinction between these two categories is required since uncontrolled accidents are more likely to incur collateral damage and to result in more severe consequences to the airplane and occupants than controlled accidents. Furthermore, accidents involving ground collateral damage are also likely to affect the extent of the primary damage (crew injuries, airplane damage, and cargo damage).

8.1.1 Probability of an Accident Being Controlled or Uncontrolled.

Data for the cargo fire accidents to the U.S.-registered freighter fleet from 1958 to 2010 inclusive, as described in section 4, were assessed to determine whether the accidents were controlled or uncontrolled. All were controlled, except for the B-747 accident on September 3, 2010, which was an uncontrolled accident.

For accidents that may occur in the future, the proportion that are likely to be controlled (or uncontrolled) may be assessed (from the division of accidents shown in table 8) for any particular confidence level by using a binomial distribution.

Table 8. Division of Fire-Related Accidents to U.S.-Registered Freighter Airplanes From 1958 to 2010—Controlled vs Uncontrolled

Controlled	Uncontrolled
4	1

Using the binomial distribution, figure 12 shows the cumulative probability distribution for the probability of an accident being controlled.

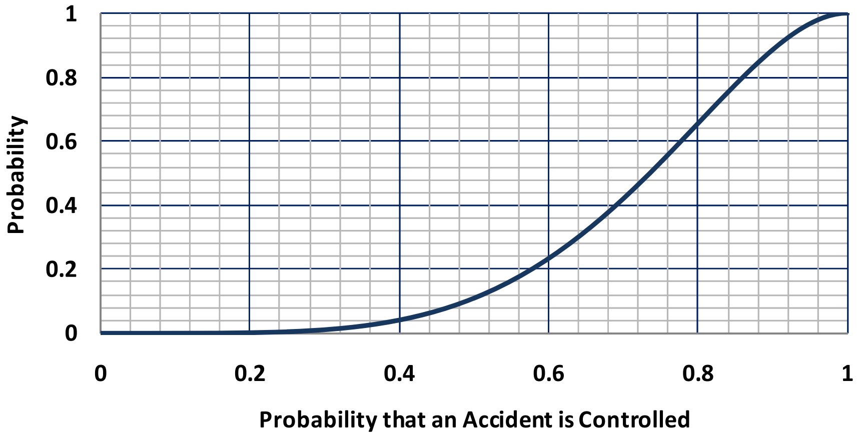


Figure 12. Cumulative Probability Distribution for the Probability of an Accident Being Controlled

The Model randomly selects a number from the vertical axis of the distribution shown in figure 11 and derives a probability that the accident is controlled.

This is illustrated in figure 13. In this example iteration of the Model, a random number generated a value of 0.4. This value equates to a 0.69 probability that the accident is controlled. The Model then selects a second random number. If its value is less than 0.69, the accident is deemed controlled. If it is greater than 0.69, the accident is deemed to be uncontrolled at this iteration of the Model.

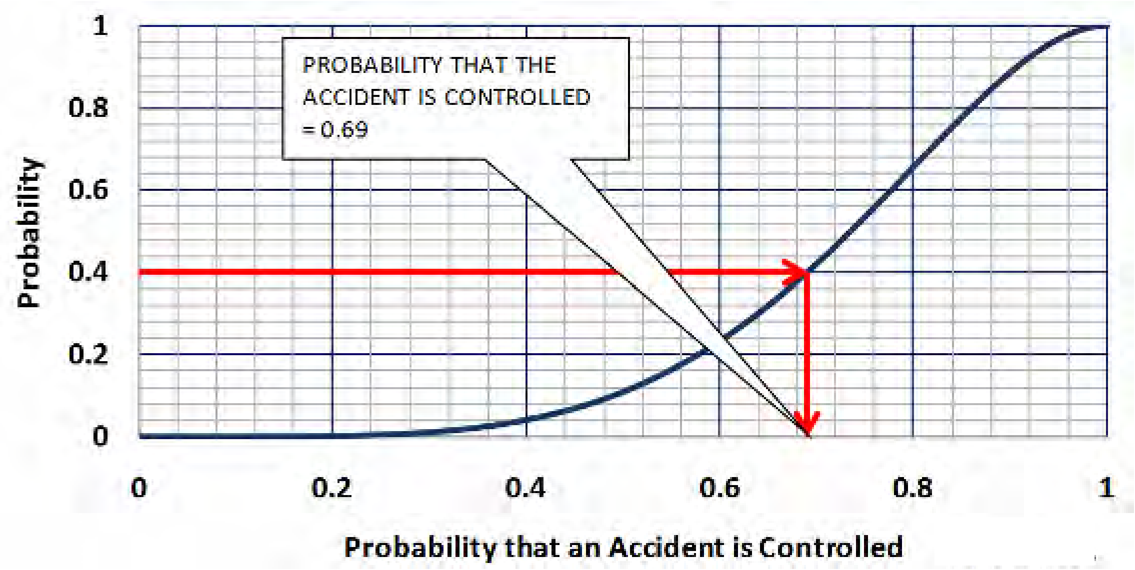


Figure 13. Example Determination of the Cumulative Probability of an Accident Being Controlled

8.1.2 Probability of an Accident Resulting in Collateral Damage.

The probability of the accident resulting in collateral damage is expected to be different for controlled and uncontrolled accidents. The CSRTG Accident Database [1] was searched for accidents to passenger-carrying airplanes and freighter airplanes that were similar in terms of their in-flight event and impact sequence to what might be expected from an in-flight cargo fire. One hundred seventy-eight passenger and freighter airplane accidents were identified as either controlled or uncontrolled.

A determination was made for each accident as to whether there was collateral damage to buildings, airplanes, or persons on the ground. This resulted in the division of accidents shown in table 9.

Table 9. Division of Accidents Collateral or No Collateral Damage

	Controlled	Uncontrolled	Total
Collateral damage	1	9	10
No collateral damage	71	97	168
Total	72	106	178

Based on these data, it could be expected that, typically, there is a 1 in 72 chance of a controlled accident resulting in collateral damage, i.e., a probability of approximately 0.014. Similarly, for an uncontrolled accident, the probability of sustaining collateral damage could be expected to be 9 in 106 or approximately 0.085. However, the Monte Carlo Simulation Model uses an assessment of the likely variation in these probabilities based on the binomial distribution using a similar process to that described in section 8.1.1 to determine if an accident is controlled or uncontrolled.

8.1.3 Accident Characteristics Assessment.

At each iteration of the Model, and separately for each freighter type, two random numbers are generated. These random numbers determine whether the accident is controllable or uncontrollable, as described in section 8.1.1. The Model then determines whether the accident resulted in collateral damage. This determination is made by randomly selecting binomial distributions of the probability of there being collateral damage, as described in section 8.1.2.

The 178 accidents discussed in section 8.1.2, which had an accident sequence similar to what can be expected from an in-flight cargo fire on a freighter airplane, were placed into four data sets:

- Controlled with no collateral damage
- Controlled with collateral damage
- Uncontrolled with no collateral damage
- Uncontrolled with collateral damage

In each data set, the accidents were ranked in order of severity in terms of the proportion of injuries (Fatal and Serious) sustained by the crew, the damage sustained by the airplane, and cargo.

Table 10 shows the nature of the data used to determine primary damage (crew injuries, airplane damage, and cargo damage).

Table 10. Example Data Used to Determine Primary Damage

Uncontrolled With No Collateral Damage—Example Only—Not Real Data					
Accident Number	Proportion of Crew			Airplane Damage	Assessed Proportion of Cargo Damage
	Fatal Injuries	Serious Injuries	Minor/No Injuries		
1	1	0	0	Destroyed	1
2	0.8	0.2	0	Destroyed	1
3	0.6	0.3	0.1	Destroyed	1
4	0.5	0.5	0	Substantial	1
…	…	…	…	…	…
…	…	…	…	…	…
98	0	0	1.0	Minor	0.5

8.2 CREW INJURIES.

The cost per accident incurred from crew injuries is calculated from the product of

- the proportion of the crew sustaining Fatal, Serious, and Minor/No injuries
- the number of crew onboard
- the monetary value associated with the injuries

8.2.1 Proportion of the Crew Sustaining Fatal and Serious Injuries.

The proportion of the crew sustaining Fatal, Serious, and Minor/No injuries is determined by randomly selecting the appropriate accident data set allocated by the Model, as described in section 8.1.3.

8.2.2 The Number of Crew Onboard.

Data relating to the distribution of the number of crew[8] by freighter type are not currently available; however, data are available for freighter airplanes by airplane weight category. Freighter types considered in this analysis were assigned a weight category based on the subdivisions of maximum takeoff weights (MTOW) shown in table 11.

---

[8] The number of crew includes all personnel onboard, some of which may not be designated crewmembers.

Table 11. Airplane Weight Categories

Weight Category	Airplane MTOW (lb)
B	12,500 to 100,000
C	100,000 to 250,000
D	250,000 to 400,000
E	Greater than 400,000

The distribution of the number of crew onboard for each airplane weight category was based on data for freighter airplanes in reference 1. Only U.S.-registered freighter airplanes, type-certificated to 14 CFR Part 25 [9] and operating under 14 CFR Part 121 [10], were selected from the database. The extracted data were assumed to follow Weibull distributions, which are shown in figure 14.

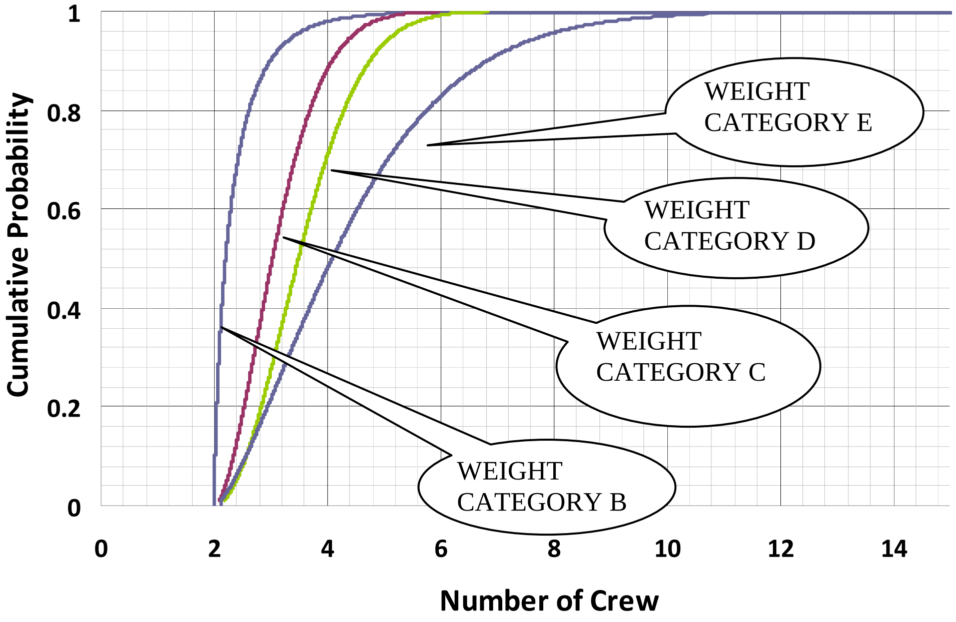


Figure 14. Distribution of Number of Crew

The weight categories of each freighter type considered in this analysis are shown in table 12.

Table 12. Airplane Weight Categories by Freighter Type

Freighter Type	Weight Category
A300	D
A310	D
ATR42 and 72	B
B-727	C

Table 12. Airplane Weight Categories by Freighter Type (Continued)

Freighter Type	Weight Category
B-737	C
B-747-100,200, and 300	E
B-747-400	E
B-757	C
B-767-200	D
B-767-300	E
B-777	E
CV-580	B
DC-8	D
DC-9	C
DC-10	E
L-100	C
MD-11	E

8.2.3 The Monetary Value Associated With Injuries.

The monetary value associated with the predicted injuries to crewmembers is shown in table 13, which is based on data obtained from the FAA [11]. Serious injuries are assigned a monetary value of $2.76 million U.S. This is the average value for injuries classified as Severe (Maximum Abbreviated Injury Scale (MAIS) 4) and Critical (MAIS 5) based on reference 11.

Table 13. Monetary Value of Injuries

Injury Severity	Monetary Value ($ millions)
Fatal	5.8
Serious	2.76

At each iteration of the Model and for each freighter type, the number of crew onboard the airplane was determined by randomly selecting on the distribution of crew numbers appropriate to the airplane weight category. The proportion of the crew sustaining Fatal, Serious, and Minor/No injuries was determined, as described in section 8.1.3, and the cost of these injuries was determined using the data in table 15. For example, the crew injury costs for accident number 4 in table 10 appropriate to a freighter airplane with four crewmembers would be

$$0.5 \times 4 \times 5.8 + 0.5 \times 4 \times \$2.76 \text{ million}$$

$$= \$11.6 + \$5.52 \text{ million}$$

$$= \$17.12 \text{ million}$$

8.3 AIRPLANE DAMAGE.

Airplane damage is a function of the value of the airplane and the extent of the damage sustained during the accident.

8.3.1 Airplane Value.

Official valuations for the airplanes in the U.S.-registered freighter fleet were unavailable. Therefore, individual airplane valuations were assessed based on freighter type and age. All the freighter types being considered in this analysis were identified, and their age was determined based on the date of first delivery.

For a freighter type still in production, the residual value of each airplane was assessed based on its 2010 list price and reduced using a compound rate of 8% per year of age.

For freighter types that are no longer in production, an artificial 2010 list price was estimated based on the MTOW. The relationship between 2010 list price and MTOW was derived from manufacturer's data and is shown in figure 15. The residual value of each airplane was assessed based on its artificial 2010 list price, as determined from the trend line in figure 15. Again, depreciation was applied at a compound rate of 8% per year of age.

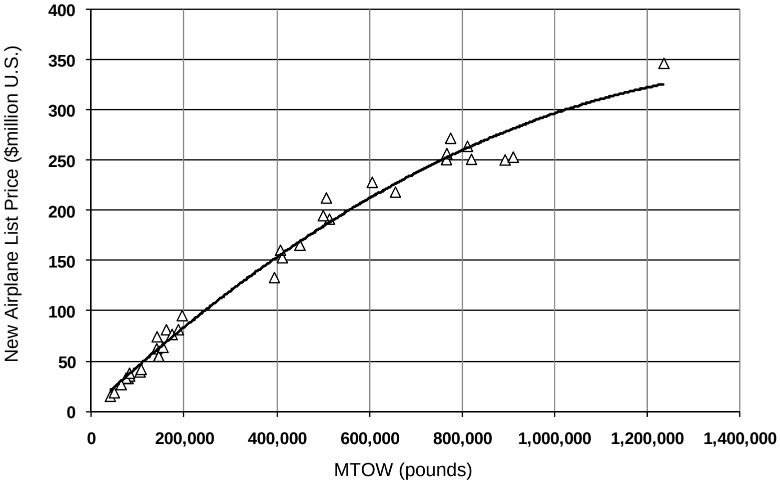


Figure 15. Relationship Between 2010 List Price and MTOW

Using this methodology, a distribution of airplane values was achieved for each freighter type. At each iteration of the Model, random selections are made on the distribution for the appropriate airplane type to derive an airplane value.

8.3.2 The Monetary Value Associated With Airplane Damage.

The extent of the airplane damage is determined by randomly selecting the appropriate accident data set allocated by the Model, as described in section 8.1.3. The damage cost as a proportion of airplane value is assumed to be as shown in table 14.

Table 14. Proportion of Airplane Value Damaged in the Accident

Airplane Damage	Damage Cost as a Proportion of Airplane Value
Destroyed	1
Substantial	0.8
Minor	0.2

This proportion is then multiplied by the airplane value, as described in section 8.3.1, to obtain the monetary value associated with the airplane damage. For example, airplane damage costs for accident number 4 in table 10 for an airplane valued at $250 million that sustained substantial damage would be:

0.8 × $250 million = $200 million

8.4 CARGO DAMAGE.

Based on reference 4, the average cargo value per ton was taken as $63,104[9]. The average number of tons of cargo carried per flight in 2010 was assessed for each freighter type based on data contained in reference 4. Using these data, the average cargo value per flight could be assessed for each freighter type, as shown in table 15.

Table 15. Average Cargo Value per Flight

Freighter Type	Average Cargo Value Per Flight ($ Millions 2010)
A300	2.0
A310	0.9
ATR 42 and 72	0.2
B-727	0.7
B-737	0.4
B-747-100, 200, and 300	2.4
B-747-400	3.3
B-757	1.1
B-767-200	1.1
B-767-300	1.6
B-777	2.3
CV-580	0.1
DC-8	1.2

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[9] 2007 data escalated at 2% per annum to 2010 levels.

Table 15. Average Cargo Value per Flight (Continued)

Freighter Type	Average Cargo Value Per Flight ($ Millions 2010)
DC-9	0.1
DC-10	2.9
L-100	0.5
MD-11	2.5

Cargo damage is assessed similarly to airplane damage. The cargo value appropriate to the freighter type is multiplied by the assessed proportion of cargo damage, which is determined by randomly selecting the appropriate accident data set allocated by the Model (see section 8.1.3) to obtain a monetary value.

For example, the cargo damage costs for accident number 98 in table 10, appropriate to a DC-8 airplane, would be:

$$0.5 \times \$1.2 \text{ million}$$

$$= \$0.60 \text{ million}$$

8.5 COLLATERAL DAMAGE.

It is assumed that the values of collateral damage that may be caused by a freighter airplane are similar to those resulting from an accident to a passenger airplane. From the accidents to passenger and freighter airplanes that were assessed to be similar in terms of their in-flight event and impact sequences to what might be expected from an in-flight cargo fire, an assessment was made of the collateral damage value. The total monetary value for each accident was determined based on the data contained in table 16. These values were based on those contained in reference 11 and advice from the FAA Office of Aviation Policy and Plans.

Table 16. Monetary Value Used in the Collateral Assessment Damage

Damage	Monetary Value ($ millions)
Fatal injury	5.8
Serious injury	2.76
Large buildings	5.0
Small buildings	0.3

The assessed collateral damage values for each accident were arranged in increasing level of monetary value and plotted as a cumulative Weibull Distribution, as shown in figure 16.

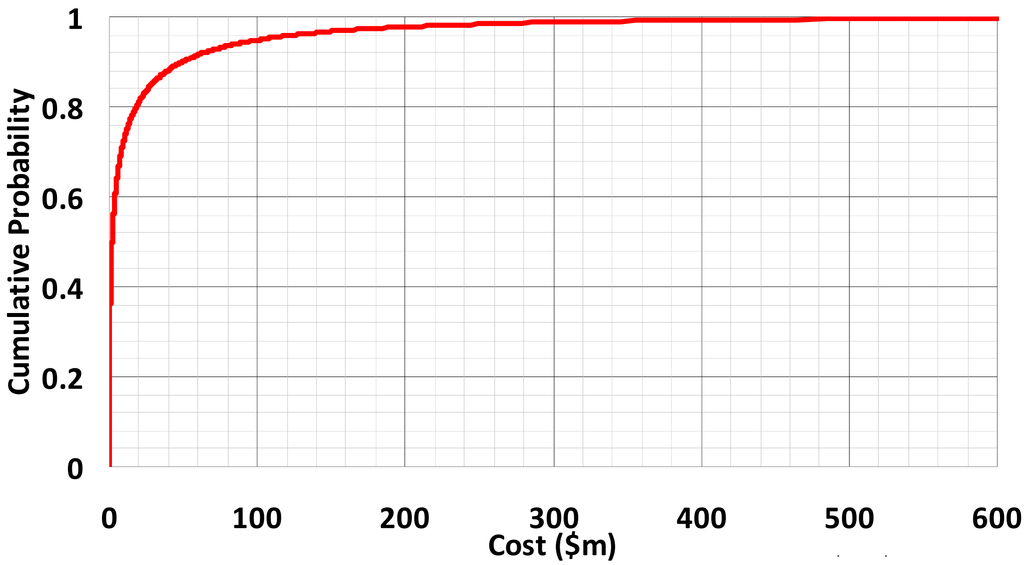

Figure 16. Probability Distribution of the Monetary Value of Collateral Damage

For accidents resulting in collateral damage, as determined by the process described in section 8.1.2, the Model selects a random number for each iteration and for each freighter type. This number is used to select the probability distributions of monetary values of the collateral damage shown in figure 16.

For accidents deemed not to result in collateral damage, the Model returns a zero value for collateral damage.

<u>8.6 TOTAL ACCIDENT COST</u>.

The total damage cost per accident is the sum of the cost of:

- Crew injuries
- Airplane damage
- Cargo damage
- Collateral damage

The resultant value is derived for each iteration of the Model and for each freighter type to obtain a distribution of the cost per accident. The annual accident cost, prior to mitigation, may then be derived for each freighter type using equation 3. At each iteration of the Model, the annual cost is summed for all freighter types to derive the distribution of the total accident cost per annum for the entire U.S.-registered freighter fleet prior to mitigation.

<u>8.7 EXAMPLE MODEL OUTPUT</u>.

The Model determines the average accident cost elements (airplane damage, crew injury, cargo damage, and collateral damage costs) for the freighter types selected and presents them as a pie chart, as shown in figure 17.

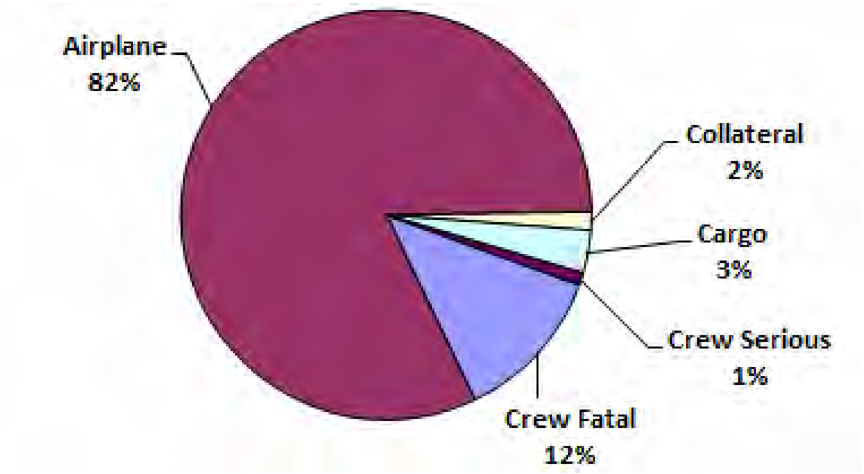

Figure 17. Example Accident Cost Elements

9. BENEFIT.

The annual benefit per freighter type, afforded by the introduction of one or more mitigation strategies, is the amount the annual accident cost prior to mitigation, C_0 (as determined by the means described in section 8), and is reduced by the mitigation. This annual benefit per freighter type, B, resulting from the introduction of mitigation, is represented by equation 4.

$$B = C_0 - C_0 \times \{\text{number of accidents expected per annum after mitigation} \div \text{number of accidents expected per annum prior to mitigation}\} \quad (4)$$

For freighter airplanes not selected for mitigation, the number of accidents expected per annum will be unchanged; hence, the benefit is zero.

The total benefit for the U.S.-registered freighter airplane fleet is the sum of the benefit for each of the freighter types selected.

10. RESIDUAL ACCIDENT COST.

The annual residual accident cost is

$$\text{annual residual accident cost} = C_0 - B$$

The annual residual accident cost is also dependent on the rate of introduction of the mitigation means. Once all airplanes have been subjected to mitigation, the annual residual accident cost varies only with the rate of change of RTMs.

All costs are derived at 2010 values. However, due to changes in the RTMs for both battery and nonbattery cargo, the predicted annual cost distributions will change. The Model assesses these costs, at 2010 values, for the years 2011 to 2025 inclusive and for any year range between 2011 and 2025. Figure 18 shows an example Model prediction of the annual residual accident cost for the period 2011 to 2020 (average prediction = $38.5 million) together with its confidence range.

For the example shown in figure 19, the cost in which one can be 95% confident of not exceeding is approximately $65 million.

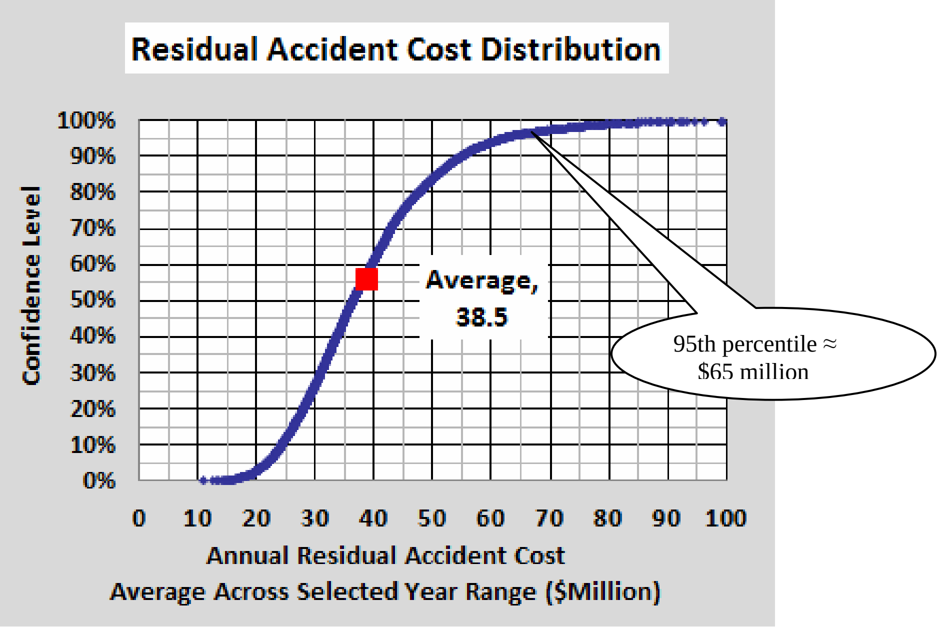

Figure 18. Example Confidence Range in the Predicted Annual Residual Accident Cost

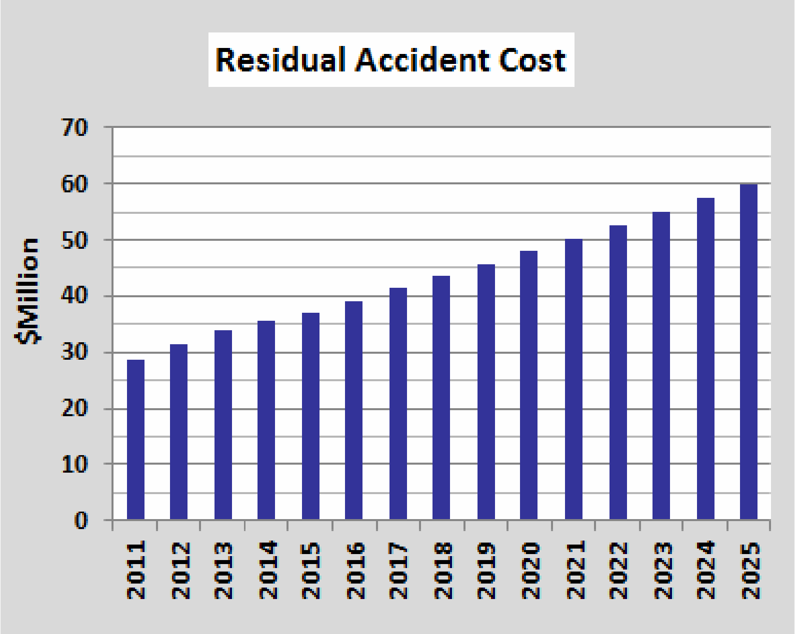

Figure 19. Example Annual Prediction of Average Residual Accident Cost

The predicted average annual accident cost is also displayed by the Model for each year from 2011 to 2025, as shown by the example in figure 19.

11. COSTS OF MITIGATION.

11.1 DATA INPUT—GENERAL.

For most of the proposed mitigation means, the precise data pertaining to the cost assessments were not available. However, the Cost Submodel was constructed to allow user input variables of certain values, as defined in this section. The Model user may change these values by clicking on the User Data Input tab and entering the desired value in the appropriate cell. Selecting the default button resets all the values to the default setting. This capability allows determinations to be made as to the sensitivity of the outputs from the Model to variations in the user input variables. It is anticipated that, as the proposed mitigation means are developed, more precise estimates of the relevant values will become available and may then be used in the Model.

11.2 OPERATING COST—INCREASED FUEL BURN.

The increase operating cost due to fuel burn is the cost associated with the increased weight of the proposed mitigation. The weight increase results in an additional fuel burn, which is freighter-type dependent.

The increased operating cost per annum, per freighter type, due to additional fuel burn resulting from the weight increase of the proposed mitigation strategy is derived from the following equation:

$$w \times g \times h \times c \tag{5}$$

where

w = the incremental weight increase associated with the proposed mitigation strategy (lb)
g = the incremental fuel burn per pound per airplane flight hour (U.S. gallons/lb flight hour)
h = the airplane flight hours per year for the freighter type (flight hours)
c = the fuel cost per U.S. gallon ($/gallon)

11.2.1 System Weight.

For each proposed mitigation strategy, assessments are made of the incremental weight increase for each freighter type.

11.2.2 Incremental Fuel Burn per Pound per Airplane Flight Hour.

The cost of the additional fuel burn incurred as a result of the increase in airplane weight associated with the proposed mitigation strategy was based on the data contained in reference 12. These values are shown in table 17.

Table 17. Incremental Fuel Burn per Pound Flight Hour by Freighter Type

Freighter Type	Incremental Fuel Burn (U.S. Gallons Per Pound Per Flight)
A300	0.004
A310	0.004
ATR 42 and 72	0.001
B-727	0.006
B-737	0.0045
B-747-100, 200, and 300	0.0045
B-747-400	0.0065
B-757	0.0055
B-767-200	0.005
B-767-300	0.005
B-777	0.004
CV-580	0.001
DC-8	0.0055
DC-9	0.004
DC-10	0.0045
L-100	0.001
MD-11	0.0045

11.2.3 Airplane Flight Hours per Annum in 2010—U.S.-Registered Freighter Fleet.

The number of flight hours accumulated by each U.S.-registered freighter type during 2010 is shown in table 18.

Table 18. Number of Flight Hours Accumulated by U.S.-Registered Freighter Fleet in 2010

Freighter Type	Flight Hours per Annum
A300	150,784
A310	34,746
ATR42 and 72	5,580
B-727	66,619
B-737	12,474
B-747-100,200, and 300	74,813
B-747-400	132,167
B-757	99,139

Table 18. Number of Flight Hours Accumulated by U.S.-Registered Freighter Fleet in 2010 (Continued)

Freighter Type	Flight Hours per Annum
B-767-200	45,666
B-767-300	101,054
B-777	20,162
CV-580	8,252
DC-8	19,191
DC-9	6,259
DC-10	121,002
L-100	4,939
MD-11	291,463

11.2.4 Fuel Cost.

Figure 20 illustrates the variation in fuel cost per U.S. gallon over the period May 2000 to March 2010, which was obtained from reference 13.

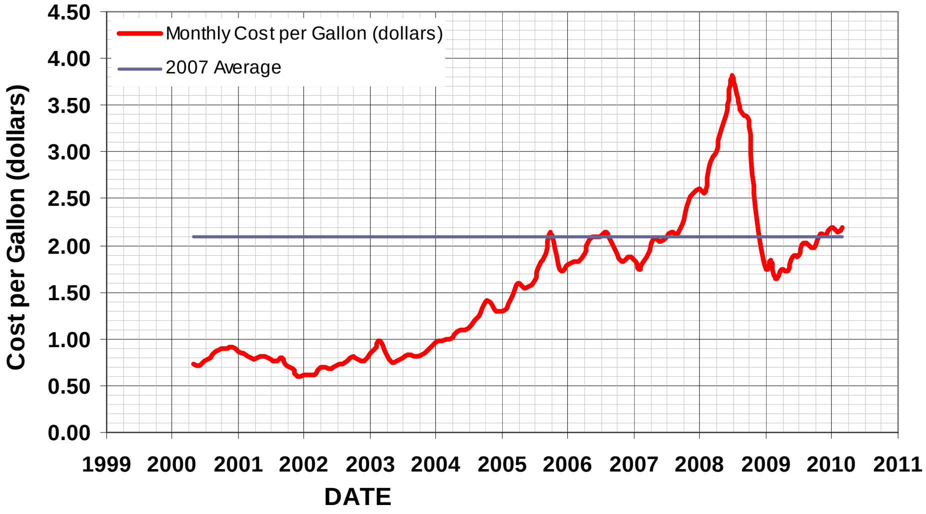

Figure 20. Variation in Fuel Cost per U.S. Gallon From May 2000 to March 2010

The fuel cost for 2010 (table 19) was typically $2.10 per gallon, which was the default value. But in the Model, it is a user input variable and may be changed from the User Data Input tab.

Table 19. Base Data for Fuel Costs

Data	Units	Default Value	User Input Variable
Fuel costs	2010 dollars per U.S. gallon	2.10	Yes

11.3 CONTAINER SUPPRESSION—EXTERNAL.

11.3.1 System Overview.

While suppression systems of this type are currently being developed, this study does not relate to any specific design but rather addresses the concept in a generic manner. Suppression systems of this type only address cargo fires originating within containers. They are assumed to be effective on existing containers. A fire suppressant, stored external to the container, is automatically applied to a container from which a fire is detected.

11.3.2 Assumptions.

The following assumptions are made regarding an external container suppression system:

- No changes are required to existing containers.
- The system is designed to combat fires in all containers located in non-Class C cargo compartments.
- System development costs are assumed to be included in the installation costs.

11.3.3 Data and Algorithms.

11.3.3.1 Base Data and User Input Variables.

The primary data used by the Model is shown in table 20. Default values for cost and weight are shown for two airplane types. The way in which these data are used by the Model is explained in the following sections.

Table 20. Base Data for Container Suppression—External

Data	Units	Default Value	User Input Variable
B-727 container suppression—external (system weight)	lb	450	Yes
B-777 container suppression—external (system weight)	lb	1,000	Yes
B-727 container suppression—external (system installation cost)	2010 dollars	$200,000	Yes
B-777 container suppression—external (system installation cost)	2010 dollars	$500,000	Yes
Ratio in-service to new-build cost	-	1.1	Yes
Annual maintenance cost as a percentage of installation cost	-	1%	Yes

11.3.3.2 Weight.

Weights for an external container suppression system are not currently available. The default values shown in table 20 were derived from estimates made by engineers involved in the project.

The Cost Submodel was developed to enable weights to be added as user input variables for two of the freighter types listed in table 5. The Model assesses the likely weights for all freighter types based on the assumption that the weight is a direct function of the non-Class C cargo compartment volume available for containers (or pallets)[10]. The non-Class C cargo compartment volumes applicable to the U.S.-registered freighter fleet are shown in table 21

Table 21. Non-Class C Cargo Compartment Volumes Available for Containers and Pallets

Freighter Type	Non-Class C Cargo Compartment Volume (ft^3)
A300	11,154
A310	8,759
ATR 42 and 72	1,121
B-727	5,280
B-737	3,520
B-747-100,200, and 300	19,154
B-747-400	21,462
B-757	6,600
B-767-200	9,500
B-767-300	15,634
B-777	18,301
CV-580	2,673
DC-8	7,820
DC-9	2,448
DC-10	13,985
L-100	4,460
MD-11	15,538

The increased operating cost per annum per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

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[10] There are certain areas of cargo compartments on some freighter airplanes that, due to their size or geometry, are not able to accommodate containers or pallets. See section 7 regarding proportion of cargo carried in containers and pallets.

11.3.3.3 Cost.

The installation cost for an external container suppression system on an in-service airplane was handled similarly to system weights in that user input variables were added for two of the freighter types listed in table 6. The default values shown in table 20 were derived from estimates made by engineers involved in the project.

The Model assesses the likely installation costs for all freighter types based on the assumption that the cost is a direct function of the non-Class C cargo compartment volume available for the containers shown in table 21. Because the cost of introducing the mitigation means on in-service airplanes is likely to be greater than on new-build airplanes, the Model has a user input variable that is the ratio of these two costs. The default value of this ratio is 1.1.

The system maintenance cost for a freighter type is assumed to relate to the installation cost of an external container suppression system on an in-service airplane. The Model has a user input variable for the percentage of the annual maintenance cost to the installation cost. The default value for this ratio is 1% (see section 11.8.3.1).

11.4 CONTAINER SUPPRESSION—INTERNAL.

11.4.1 System Overview.

Internal suppression systems are fitted to existing containers and operate independently from each other and from the airplane systems. As with external container suppression systems, they only address cargo fires originating within the containers. The system is such that the fire suppressant is automatically applied to a container from which a fire is detected.

11.4.2 Assumptions.

The following assumptions are made regarding an internal container suppression system:

- All containers used in the non-Class C cargo compartments of U.S.-registered freighter airplanes are fitted with internal container suppression systems.
- Containers with internal suppression systems are only used in non-Class C cargo compartments.
- The ratio of the number of containers used by the U.S.-registered freighter fleet is three times the number that are actually onboard airplanes (user input variable).
- The amount of suppressant carried within a container is sufficient to accommodate a fire within it.
- System development costs are assumed to be included in the installation costs.

11.4.3 Data and Algorithms.

11.4.3.1 Base Data and User Input Variables.

The primary data used by the Model is shown in table 22.

Table 22. Base Data for Container Suppression—Internal

Data	Units	Default Value	User Input Variable
System weight for LD3 container	lb	44	Yes
System weight for M1 container	lb	60	Yes
System installation cost for LD3 container	2010 dollars	$5000	Yes
System installation cost for M1 container	2010 dollars	$6000	Yes
Ratio total containers/airborne containers	-	3	Yes
Annual maintenance cost as a percentage of system installation cost	-	1%	Yes

11.4.3.2 Weight.

The installation weights for an internal container suppression system are not currently available. However, the Cost Submodel allows the weights to be added as user input variables for two of the three container types (LD3, LD9, and M1) on the User Data Input tab. The default values for the LD3 and M1 containers are shown in table 22.

The Cost Submodel assesses the average weight increase per unit volume of container and derives the likely system weights for all freighter types based on the assumption that the weight is a direct function of the non-Class C cargo compartment volume, which is available for the containers (see section 7.4) listed in table 21. The increased operating cost per annum per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

11.4.3.3 Cost.

The installation cost for an internal container suppression system is handled similarly to system weights in that user input variables are added for two of the three container types (LD3, LD9, and M1) by the user on the User Data Input tab. The Cost Submodel assesses the likely installation costs for all freighter types based on the assumption that the cost is a direct function of the non-Class C cargo compartment volume, which is available for the containers shown in table 20. The default values for the LD3 and M1 containers are shown in table 22.

It is estimated that the ratio of the total number of containers required to those actually used on an airplane is approximately 3 to 1. This ratio is a user input variable to the Model with a default value of 3.

The system maintenance cost for a freighter type is assumed to relate to the installation cost of an internal container suppression system. The Model has a user input variable for the annual maintenance cost as a percentage of the installation cost. The default value for this percentage is 1% (see section 11.8.3.1).

11.5 PALLET COVERS.

11.5.1 System Overview.

Pallet covers are applied to each pallet transported in freighter airplane cargo compartments, except those transported in Class C cargo compartments. The covers must be designed to meet a fire standard, defined by the Authorities, that requires the covers to contain and suppress a fire likely to be experienced in cargo carried on pallets. The covers must be designed and manufactured so that they are reusable, but it is anticipated that they will have a finite life.

11.5.2 Assumptions.

The following assumptions are made regarding pallet covers:

- To accommodate the required availability of pallet covers, it is assumed that freighter operators would require four times as many covers as there are pallets carried on airplanes.

- System development costs are assumed to be included in the installation costs.

11.5.3 Data and Algorithms.

11.5.3.1 Base Data and User Input Variables.

The user may input data into the Model via the User Data Input tab. Three standard pallet sizes are provided so that the user may input data pertinent to any two of the pallet sizes shown below.

- 64″ x 125″ x 96″
- 96″ x 125″ x 96″
- 118″ x 125″ x 96″

The primary data used by the Cost Submodel is shown in table 23.

Table 23. Base Data for Pallet Covers

Data	Units	Default Value	User Input Variable
Pallet cover weight for a 64- x 125- x 96-inch pallet	lb	55	Yes
Pallet cover weight for a 118- x 125- x 96-inch pallet	lb	106	Yes
Pallet cover cost for a 64- x 125- x 96-inch pallet	2010 dollars	$1700	Yes
Pallet cover cost for a 118- x 125- x 96-inch pallet	2010 dollars	$2700	Yes

Table 23. Base Data for Pallet Covers (Continued)

Data	Units	Default Value	User Input Variable
Ratio of total number of pallet covers to airborne pallet covers	-	4	Yes
Pallet cover life	Flights	300	Yes
Annual repair cost as a percentage of replacement cost	-	25%	Yes
Time taken to install and remove a 64- x 125- x 96-inch pallet cover	Hours	0.15	Yes
Time taken to install and remove a 118- x 125- x 96-inch pallet cover	Hours	0.25	Yes
Freighter operator labor rate	2010 dollars	$30	Yes

11.5.3.2 Weight.

User input variables are required for pallet cover weights taking into account any differences in net weights that result when the required fire standards are met. The Cost Submodel allows user input variables to be added for two of three pallet sizes. The Cost Submodel assesses the likely weights for all freighter types based on the assumption that the weight is a direct function of the non-Class C cargo compartment volume, which is available for the pallets (see section 7.4), listed in table 21. The default values shown in table 23 were derived from estimates made by engineers involved in the project.

The increased operating cost per annum per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

11.5.3.3 Cost.

The installation cost for pallet covers is handled similarly to the weight assessment, in that user input variables are added for two of three pallet sizes. The Cost Submodel assesses the likely installation costs for all freighter types based on the assumption that the weight is a direct function of the non-Class C cargo compartment volume, which is available for pallets listed in table 21. The default values shown in table 23 were derived from estimates by the engineers involved in the project.

However, the number of pallet covers required is more than those required to accommodate the cargo palletized on one airplane, because some are needed for cargo that is being prepared and others are in storage. It was estimated that the ratio of the total number of pallet covers required to those actually used on an airplane is approximately 4 to 1. This ratio is a user input variable to the Model with a default value of 4.

Since pallet covers are likely to have a finite life, they will require replacement after a specified period of time. This replacement cost per annum may be derived by multiplying the installation cost for the freighter type by the ratio of the total number of flights per annum to the pallet cover life in flights. The life is a user input variable to the Model with a default value of 300 flights.

Pallet covers are likely to require some repair during the course of their lives. This repair cost may be expressed as a percentage of the cost of a new pallet cover. This percentage is a user input variable to the Model with a default value of 25%.

Additional costs are incurred for installation and removal of pallet covers. This assessment of man-hours is handled similarly to the weight assessment, in that user input variables are required for any two of three pallet sizes on the User Data Input tab. The default man-hours for installation and removal are 0.15 for a 64- × 125- × 96-inch pallet and 0.25 man-hour for a 118- x 125- x 96-inch pallet. The Cost Submodel assesses the likely number of man-hours incurred for all freighter types based on the assumption that the time is a direct function of the non-Class C cargo compartment volume that is available for containers.

The labor rate assumed for U.S.-registered freighter operators is $30 per hour and is used as the default value.

11.6 SECONDARY BATTERY BOXES.

11.6.1 System Overview.

This mitigation strategy requires secondary lithium batteries that are transported on U.S.-registered freighter airplanes to be packed in boxes that have been shown to contain a fire originating from the batteries. As such, user selection of this mitigation strategy is applied to all freighter types irrespective of the selections made for other mitigation strategies, as described in section 7.2.

11.6.2 Assumptions.

The following assumptions are made regarding secondary battery boxes:

- It would not be economically feasible to reuse the boxes.
- Battery boxes would not be restricted to specific freighter types but would be adopted for all freighter airplanes in the U.S.-registered freighter fleet.
- A typical lithium battery cell, such as the 18650 cylindrical cell, weights approximately 45 grams or 0.1 pound and is 65 mm in length and 18 mm in diameter.
- System development costs are assumed to be included in the cost of the boxes.

11.6.3 Data and Algorithms.

11.6.3.1 Base Data and User Input Variables.

The primary data used by the Cost Submodel is shown in table 24.

Table 24. Base Data for Secondary Battery Boxes

Data	Units	Default Value	User Input Variable
Box life	Flights	1	No
Total box weight (cells plus box)	lb	67	Yes
Box weight (box only)	lb	0.5	Yes
Number of secondary batteries produced in 2010	-	3500×10^6	No
Proportion of worldwide secondary battery production shipped by freighter airplanes	-	100%	Yes
Proportion of batteries shipped by freighter airplanes that are carried by U.S.-registered freighter fleet	-	50%	Yes
Battery box costs	2010 dollars	10	Yes

11.6.3.2 Weight.

The total box weight, cells plus box, is likely to be constrained by weight limits associated with health and safety issues of the shipper. A typical weight limit is 30 kilograms or approximately 67 lb, which is used as the default value in the Cost Submodel. However, this limit is likely to vary in different countries and companies, therefore, it is a user input variable.

Because the box weight is dependent on the materials needed to meet any specified fire standard that may be developed in the future, this is a user input variable with a default value of 0.5 lb.

The Model derives the average number of boxes that are needed per flight for each freighter type. Based on the total box weight (cells plus box = default 67 lb) and the weight of the box (default = 0.5 lb), the weight of the cells may be derived. For the default values, the weight of the cells would be 67 minus 0.5 = 66.5 lb. The number of cells in the box, n, may then be derived by dividing the total weight of the cells in a box by the weight of one cell (0.1 lb). Thus, for the default values, based on the cell weight of 0.1 lb, the number of cells can be calculated as $66.5 \div 0.1 = 665$.

Based on data contained in reference 7, the number of secondary batteries produced in 2010 was 3500×10^6. It is further assumed that 100% of these secondary batteries were carried by freighter airplanes, of which 50%[11] were carried on U.S.-registered freighter airplanes: 1750×10^6.

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[11] These assumptions are user input variables that can be varied on the User Data Input tab.

Now, the proportion, P, of the batteries carried on each freighter type can be assessed from equation 6.

$$P = \frac{Vf}{\sum Vf} \tag{6}$$

Where V is the total cargo volume and f is the number of flights per annum for a specific freighter type. The term ΣVf represents the total capacity available for the entire U.S.-registered freighter fleet in 2010.

Therefore, the number of secondary batteries carried by a particular freighter type in 2010 is determined by

$$P \times 1750 \times 10^6$$

The number of secondary battery boxes carried for a particular freighter type in 2010 would be

$$P \times 1750 \times 10^6 \div n$$

Therefore, the number of secondary battery boxes carried per flight is given by

$$P \times 1750 \times 10^6 \div nf \tag{7}$$

The incremental increase in weight per flight can be derived by multiplying equation 7 by the weight of a battery box (nominally 0.5 lb). The increased operating cost per annum per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

11.6.3.3 Cost.

The box cost is dependent on the materials needed to meet any specified fire standard that may be developed in the future. Since boxes of this kind do not currently exist, precise cost determinations cannot be made. A default value of $10 per battery box was assumed.

11.7 PRIMARY BATTERY BOXES.

11.7.1 System Overview.

This mitigation strategy requires nonrechargeable primary lithium batteries (often called lithium-metal batteries) that are transported on U.S.-registered freighter airplanes to be packed in boxes that have been shown to contain a fire originating from the batteries. As such, user selection of this mitigation strategy is applied to all freighter types irrespective of the selections made for other mitigation strategies.

11.7.2 Assumptions.

The following assumptions are made regarding primary battery boxes:

- It would not be economically feasible to reuse the boxes.
- Battery boxes would not be restricted to specific freighter types but would be adopted for all freighter airplanes in the U.S.-registered freighter fleet.
- A typical primary lithium battery cell is similar in terms of weight and dimensions to the 18650 cylindrical cell, which is approximately 45 grams or 0.1 pound in weight and is 65 mm in length and 18 mm in diameter.
- System development costs are assumed to be included in the cost of the boxes.

11.7.3 Data and Algorithms.

The data used for primary batteries is similar to that used for secondary batteries, as described in section 11.6.3. However, based on reference 8, it was estimated that primary lithium battery cell production was approximately 25% of the secondary lithium battery cells. It was further assumed that 20% of these primary batteries were carried by freighter airplanes, of which 50% were carried on U.S.-registered freighter airplanes. These are user input variables that can be changed on the User Data Input tab. All primary battery algorithms used in the Cost Submodel are the same as the secondary batteries.

11.7.3.1 Base Data and User Input Variables.

The primary data used by the Cost Submodel is shown in table 25.

Table 25. Base Data for Primary Battery Boxes

Data	Units	Default Value	User Input Variable
Box life	Flights	1	No
Total box weight (cells plus box)	lb	67	Yes
Box weight (box only)	lb	0.5	Yes
Proportion of primary battery production to secondary battery production	-	25%	Yes
Proportion of worldwide primary battery production shipped by freighter airplanes	-	20%	Yes
Proportion of batteries shipped by freighter airplanes that are carried by U.S.-registered freighter fleet	-	50%	Yes
Battery box costs	2010 dollars	10	Yes

11.8 FIRE-HARDENED CONTAINERS.

11.8.1 System Overview.

Fire-hardened containers are designed to accommodate a fire threat defined by the Authorities. The containers prevent the fire and significant quantities of smoke and fumes from being released into the cargo compartment.

11.8.2 Assumptions.

The following assumptions are made regarding fire-hardened containers:

- All containers to be used in non-Class C cargo compartments of U.S.-registered freighter airplanes are fire-hardened.
- The ratio of the number of containers used by the U.S.-registered freighter fleet is three times the number that are actually onboard airplanes (a user input variable)
- System development costs are assumed to be included in the installation costs.

11.8.3 Data and Algorithms.

11.8.3.1 Base Data and User Input Variables.

The primary data used by the Cost Submodel for fire-hardened containers are shown in table 26.

Table 26. Base Data for Fire-Hardened Containers

Data	Units	Default Value	User Input Variable
Percentage weight increase	-	90%	Yes
LD3 existing container weight	lb	320	No
LD9 existing container weight	lb	468	No
M1 existing container weight	lb	792	No
LD3 existing container volume	ft^3	152	No
LD9 existing container volume	ft^3	371	No
M1 existing container volume	ft^3	621	No
LD3 existing container cost	2010 dollars	$1700	Yes
LD9 existing container cost	2010 dollars	$1900	Yes
M1 existing container cost	2010 dollars	$2100	Yes
Ratio: fire-hardened/standard container cost	-	1.5	Yes

Table 26. Base Data for Fire-Hardened Containers (Continued)

Data	Units	Default Value	User Input Variable
Ratio: number of containers in fleet to those onboard airplanes	-	3	Yes
Existing container life	Flights	5000	Yes
Fire-hardened container life	Flights	6000	Yes
Annual maintenance cost as a percentage of installation cost	-	1%	Yes

11.8.3.2 Weight.

The weights for the installation of fire-hardened containers are not currently available. However, the Cost Submodel was developed to enable a user input variable to be added for the percentage weight increase of fire-hardened containers beyond that of existing conventional containers. The default value for this user input variable is 90%.

Table 26 shows typical weights for existing LD3, LD9, and M1 conventional containers. Using these weights, the percentage weight increase assigned to fire-hardened containers, and the known volume of LD3, LD9, and M1 containers (shown in table 26), the Cost Submodel derives an average weight increase per unit volume.

The Cost Submodel determines the likely weight increases for all freighter types based on the assumption that the weight is a direct function of the non-Class C cargo compartment volume that is available for containers. The increased operating cost per annum per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

11.8.3.3 Cost.

The installation cost for fire-hardened containers is based on user inputs of costs for any two of three existing conventional container sizes as selected by the user. The default costs for the three containers are shown in table 26. The ratio of a fire-hardened container to a standard container is a user input variable with a default value of 1.5. The estimated cost of LD3, LD9, and M1 fire-hardened containers can, therefore, be derived by multiplying the costs of a conventional container by the default ratio (1.5).

Using these costs and the known volume of the LD3, LD9, and M1 containers, as shown in table 26, the Cost Submodel derives an average cost increase per unit volume. The Cost Submodel determines the likely cost increases for all freighter types based on the assumption that the cost is a direct function of the non-Class C cargo compartment volume that is available for the containers. However, the number of fire-hardened containers required will be more than those required to accommodate the cargo containerized on one airplane, since others are needed for cargo that is being prepared and others are in storage. It was estimated that the ratio of the total number of containers required to those actually used on an airplane, is approximately 3 to 1. This ratio is a user input variable with a default value of 3. The Cost Submodel factors the derived cost per freighter type to accommodate these additional containers.

Since the containers are life-limited, they will require replacement after a specified period of time. The number of containers that need to be replaced per year is the total number of flights per year for the freighter type divided by the container life in flights. Therefore, the increase in cost per year due to the replacement of existing containers by fire-hardened containers may be derived from the following equation:

$$f \times \{C_H/L_H - C_E/L_E\} \tag{8}$$

where

f = the number of flights per annum for the freighter type
C_H = the cost of a hardened container (2010 dollars)
L_H = the life of a hardened container (flights)
C_E = the cost of an existing container (2010 dollars)
L_E = the life of an existing container (flights)

The container cost and life assessments are based on user input variables with the default values as shown in table 26. The container costs are converted by the Cost Submodel to an annual average replacement cost per cubic foot. Since the non-Class C cargo compartment volume that is available for containers is known, the cost per annum may be derived for each freighter type.

A container is likely to require some repair during the course of its life. This repair cost may be expressed as a percentage of the cost of a new container. This percentage is a user input variable with a default value of 1% (see section 11.8.3.1), which is assumed to be applicable to both existing and fire-hardened containers. The Cost Submodel derives this cost as the difference between the repair cost of an existing container and the cost of a new fire-hardened container.

11.9 COMPARTMENT SUPPRESSION.

11.9.1 System Overview.

The system is based on using a suppressant that has the fire-extinguishing properties of Halon 1301. Existing fire or smoke detection systems already onboard freighter airplanes could be retained as part of any halon fire suppression system and, hence, do not feature in the assessment of weight and cost. Halon is stored in pressurized containers and distributed via a series of pipes and fire suppression nozzles.

It is known that halon is being phased out due to its ozone-depleting characteristics, and systems of this type are not feasible for future fire suppression systems. However, halon systems are likely to be replaced by other fire suppressants of a similar weight and cost. Thus, a halon fire suppression system was used as a baseline for this study.

11.9.2 Assumptions.

The following assumptions are made regarding a compartment suppression system:

- Compartment liners, beyond what currently exists on freighter airplanes, are not required.
- The system is operated and powered via the airplane systems.

11.9.3 Data and Algorithms.

The cost assessments and weights for the compartment suppression system were based on references 14 and 5.

11.9.3.1 Base Data and User Input Variables.

The primary data used by the Cost Submodel for a compartment suppression system are shown in table 27.

Table 27. Base Data for a Compartment Suppression System

Data	Units	Default Value	User Input Variable
Boeing-737 system weight	lb	330	Yes
Boeing-747-400 system weight	lb	2010	Yes
Boeing-737 suppression system installation costs	2010 dollars	$727,000	Yes
Boeing-747-400 suppression system installation costs	2010 dollars	$3,647,000	Yes
Ratio in-service to new-build cost	-	1.1	Yes
Annual maintenance cost as a percentage of installation cost	-	1%	Yes

11.9.3.2 Weight.

Based on reference 15, the weight of a suppression system and smoke detection system fitted to the lower deck cargo compartments of a B-737 airplane is approximately 100 lb. The lower deck cargo compartment volume on this airplane is approximately 1068 ft^3. This amounts to an average system weight of 0.094 lb/ft^3. On the assumption that system weight is directly related to cargo compartment volume, non-Class C cargo compartment weight estimates may be derived for each freighter type using the compartment volumes listed in table 28. For a B-737 airplane, this equates to a system weight of approximately 330 lb and 2010 lb for a B-747-400 freighter airplane. These two freighter types and corresponding system weights are used as the default values for the user input variables in the Model.

Table 28. Total Non-Class C Cargo Compartment Volumes

Freighter Type	Non-Class C Cargo Compartment Volume (ft^3)
A300	11,154
A310	8,759
ATR 42 and 72	1,542
B-727	6,655
B-737	3,520
B-747-100, 200, and 300	19,385
B-747-400	21,462
B-757	8,015
B-767-200	9,500
B-767-300	16,064
B-777	18,301
CV-580	2,673
DC-8	10,320
DC-9	3,048
DC-10	14,388
L-100	4,460
MD-11	15,538

The Cost Submodel was developed to enable user input variables to be added for any two freighter types in the 2010 U.S.-registered fleet from the User Data Input tab. The Cost Submodel will assess the likely weights for all freighter types based on the assumption that the weight is a direct function of the total non-Class C cargo compartment volume. The increased operating cost per year per freighter type, due to the additional fuel burn resulting from the weight increase of the proposed mitigation strategy, is derived from equation 5.

11.9.3.3 Cost.

The installation cost for a compartment suppression system is handled similarly to the weight assessment in that user input variables are added for any two freighter types in the 2010 U.S.-registered fleet from the User Data Input tab.

The study in reference 5 derived installation and development[12] costs on an in-service freighter airplane for a cargo compartment suppression system for the four freighter airplane weight

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[12] The development costs were assessed to be less than 1% of the cost of installation and, hence, are not a significant factor in the cost assessment.

categories. These costs were derived at 2007 prices and were escalated to 2010 prices for this study using an inflation rate of 2% per annum.

It was assumed that the cargo compartment suppression system cost is directly related to the cargo compartment volume for each freighter type. On this basis, an assessment may be made of the cost for each freighter airplane type using the compartment volumes listed in table 28. For a B-737 airplane, this equates to a system cost of $727,089 (2010) and $3,646,970 (2010) for a B-747-400 freighter airplane. These costs are used as the default values in the Model for these two freighter airplane types. The cost of introducing the mitigation means on in-service airplanes is likely to be greater than on new-build airplanes, the Model has a user input variable that is the ratio of these two costs. The default value of this ratio is 1.1.

Based on the FAA study [5], maintenance costs were assessed to be approximately 0.3% of the installation costs. However, for this study, it is conservatively assumed that the maintenance cost per year is 1% of the installation cost. This is the default value used by the Cost Submodel.

12. BENEFIT/COST RATIOS.

The benefit/cost ratio is the ratio of the annual benefit realized by the mitigation (see section 9) and the annual cost of implementing the mitigation (see section 11). The benefit/cost ratios are shown on the Control Panel tab for each freighter type selected for mitigation.

Figure 21 shows an example Model output of the variation in benefit/cost ratio for the U.S.-registered freighter fleet over the period 2011 to 2025.

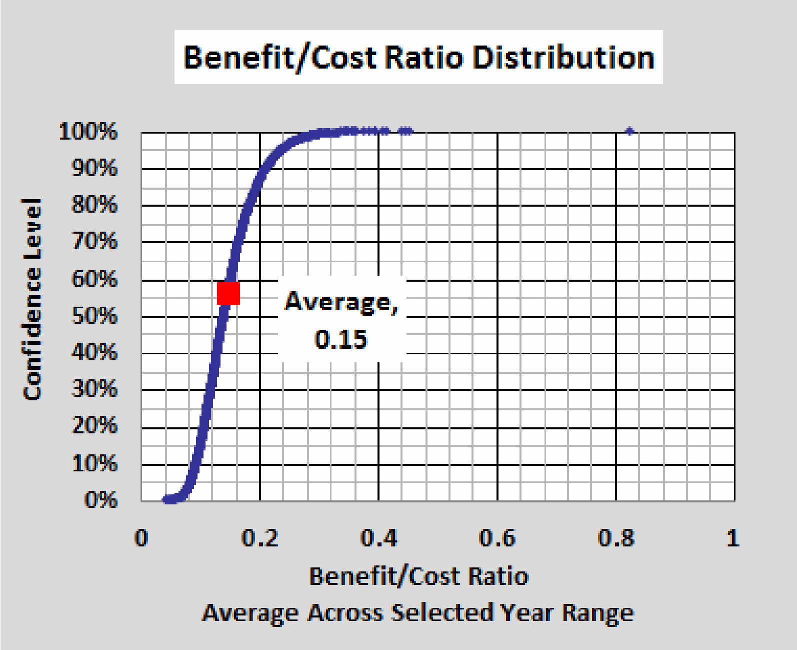
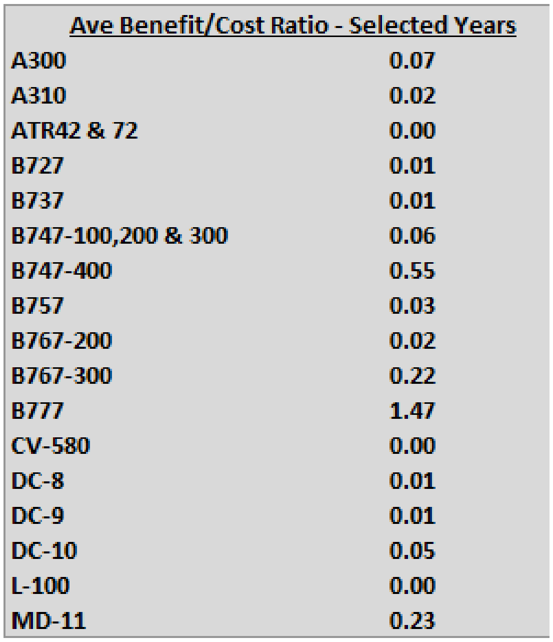


Figure 21. Example Benefit/Cost Ratio Distribution 2011 to 2025

Figure 22 shows an example of the variation in benefit/cost ratio, for each freighter type selected for mitigation.



Ave Benefit/Cost Ratio - Selected Years	
A300	0.07
A310	0.02
ATR42 & 72	0.00
B727	0.01
B737	0.01
B747-100,200 & 300	0.06
B747-400	0.55
B757	0.03
B767-200	0.02
B767-300	0.22
B777	1.47
CV-580	0.00
DC-8	0.01
DC-9	0.01
DC-10	0.05
L-100	0.00
MD-11	0.23

Figure 22. Example Average Benefit Cost by Freighter Type

Figure 23 shows an example Model output of the variation in benefit/cost ratio for the whole U.S.-registered freighter fleet over the period 2011 to 2025.

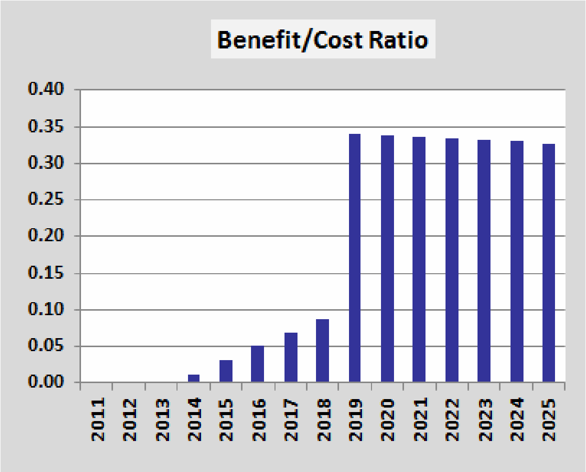


Figure 23. Example Benefit/Cost Ratio Variation 2011 to 2025

13. USING THE MODEL.

Microsoft Excel 2007 (or later) is recommended for use with the Model. Prior to opening the Model, the calculations options should be set to Manual in Excel.

13.1 TO DETERMINE THE NUMBER OF ACCIDENTS PRIOR TO MITIGATION.

To determine the number of accidents prior to any mitigation being introduced perform the following steps on the Control Panel tab:

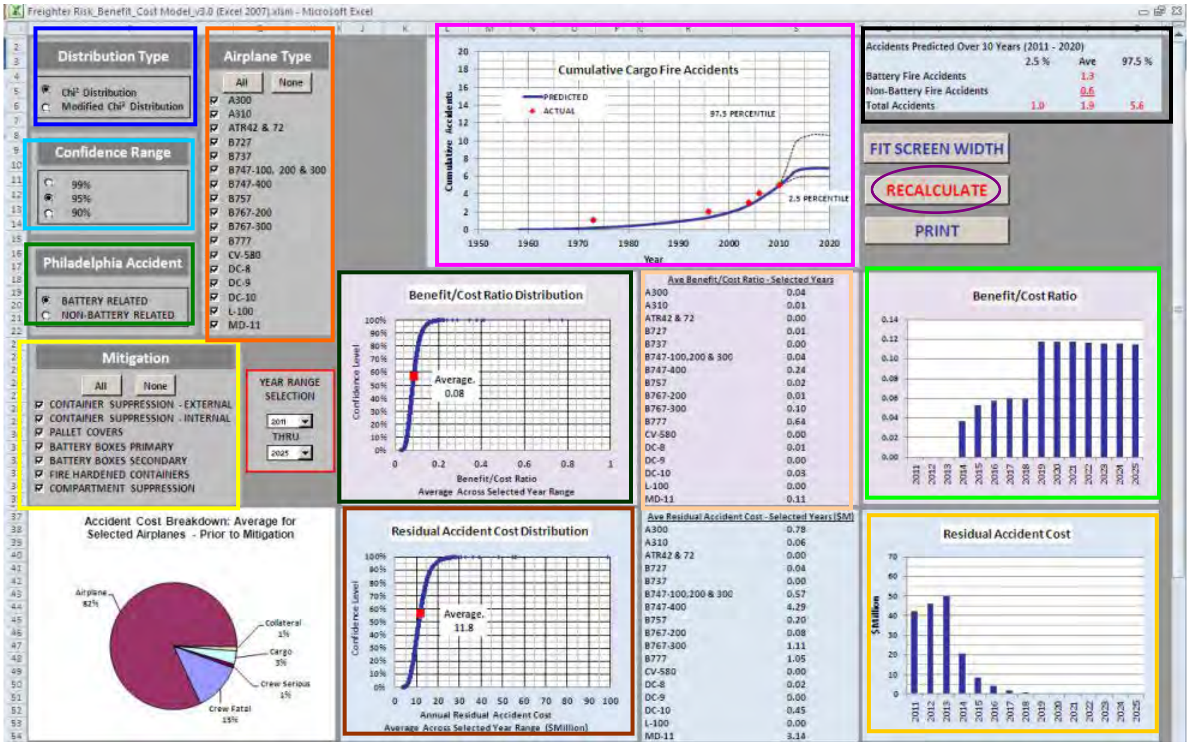
(a) Select either Battery Involvement or No Battery Involvement from the Philadelphia Accident menu (see green outline in figure 24)

(b) Select either Chi^2 Distribution or Modified Chi^2 Distribution from the Distribution Type menu (see blue outline in figure 24)

(c) Select either 90%, 95%, or 99% from the Confidence Range menu (see light-blue outline in figure 24)

(d) On the Mitigation menu, select None (see yellow outline in figure 24)

(e) Click on the RECALC button (see violet circle in figure 24)



Distribution Type
● Chi^2 Distribution
○ Modified Chi^2 Distribution

Confidence Range
○ 99%
● 95%
○ 90%

Philadelphia Accident
● BATTERY RELATED
○ NON-BATTERY RELATED

Airplane Type
All None
☑ A300
☑ A310
☑ ATR42 & 72
☑ B727
☑ B737
☑ B747-100, 200 & 300
☑ B747-400
☑ B757
☑ B767-200
☑ B767-300
☑ B777
☑ CV-580
☑ DC-8
☑ DC-9
☑ DC-10
☑ L-100
☑ MD-11

Mitigation
All None
☑ CONTAINER SUPPRESSION - EXTERNAL
☑ CONTAINER SUPPRESSION - INTERNAL
☑ PALLET COVERS
☑ BATTERY BOXES PRIMARY
☑ BATTERY BOXES SECONDARY
☑ FIRE HARDENED CONTAINERS
☑ COMPARTMENT SUPPRESSION

YEAR RANGE SELECTION
2011 THRU 2025

Accidents Predicted Over 10 Years (2011 - 2020)

	2.5 %	Ave	97.5 %
Battery Fire Accidents		1.3	
Non-Battery Fire Accidents		0.6	
Total Accidents	1.0	1.9	5.6

Ave Benefit/Cost Ratio - Selected Years	
A300	0.04
A310	0.01
ATR42 & 72	0.00
B727	0.01
B737	0.00
B747-100,200 & 300	0.04
B747-400	0.24
B757	0.02
B767-200	0.01
B767-300	0.10
B777	0.64
CV-580	0.00
DC-8	0.01
DC-9	0.00
DC-10	0.03
L-100	0.00
MD-11	0.11

Ave Residual Accident Cost - Selected Years ($M)	
A300	0.78
A310	0.06
ATR42 & 72	0.00
B727	0.04
B737	0.00
B747-100,200 & 300	0.57
B747-400	4.29
B757	0.20
B767-200	0.08
B767-300	1.11
B777	1.05
CV-580	0.00
DC-8	0.02
DC-9	0.00
DC-10	0.45
L-100	0.00
MD-11	3.14

Figure 24. Control Panel Tab

The likely number of cargo fire accidents, together with a confidence range, through the year 2020 is displayed on the Cumulative Cargo Fire Accidents graph on the Control Panel tab (see pink outline in figure 24). The Accidents Predicted over 10 Years (2011-2020) table on the Control Panel tab (see black outline in figure 24) displays the average number of battery fire accidents and nonbattery fire accidents expected over the period. The bottom row of this table displays the total number of accidents expected together with a range appropriate to that selected in (c) above.

13.2 TO DETERMINE THE COST OF ACCIDENTS PRIOR TO MITIGATION.

To determine the annual cost of U.S.-registered freighter cargo fire accidents prior to any mitigation being introduced, perform the following steps on the Control Panel tab:

(a) Repeat steps (a) to (d) in section 13.1.

(b) Select the year range over which the accident costs are to be averaged by using the Year Range Selection menu (see red box in figure 24).

(c) Click the RECALC button (see the violet circle in figure 24)

13.3 TO DETERMINE THE NUMBER AND COST OF ACCIDENTS AFTER MITIGATION.

To determine the number of accidents after any mitigation means were introduced, perform the following steps on the Control Panel tab:

(a) Select either Battery Related or Nonbattery Related from the Philadelphia Accident menu (see green outline in figure 24).

(b) Select either Chi^2 Distribution or Modified Chi^2 Distribution from the Distribution Type menu (see blue outline in figure 24).

(c) Select either 90%, 95%, or 99% from the Confidence Range menu (see light-blue outline in figure 24).

(d) On the Mitigation menu, select the mitigation strategy or combination of mitigation strategies to be applied[13] (see yellow outline in figure 24).

(e) Select the year range over which the accident costs are to be averaged by using the Year Range Selection menu (see red box in figure 24).

(f) On the Airplane Type menu (see orange outline in figure 24) select the airplane types (using the check boxes) to which the mitigation is to be applied.

(g) On the User Input Data tab, in the Mitigation Introduction panel (see red outline in figure 25), select the start dates for the chosen mitigation means for In-Service Airplanes, New Build Airplanes, and then select the finish dates for In-Service Airplanes, as appropriate.

(h) On the Control Panel tab, click on the RECALC button (see the violet circle in figure 24).

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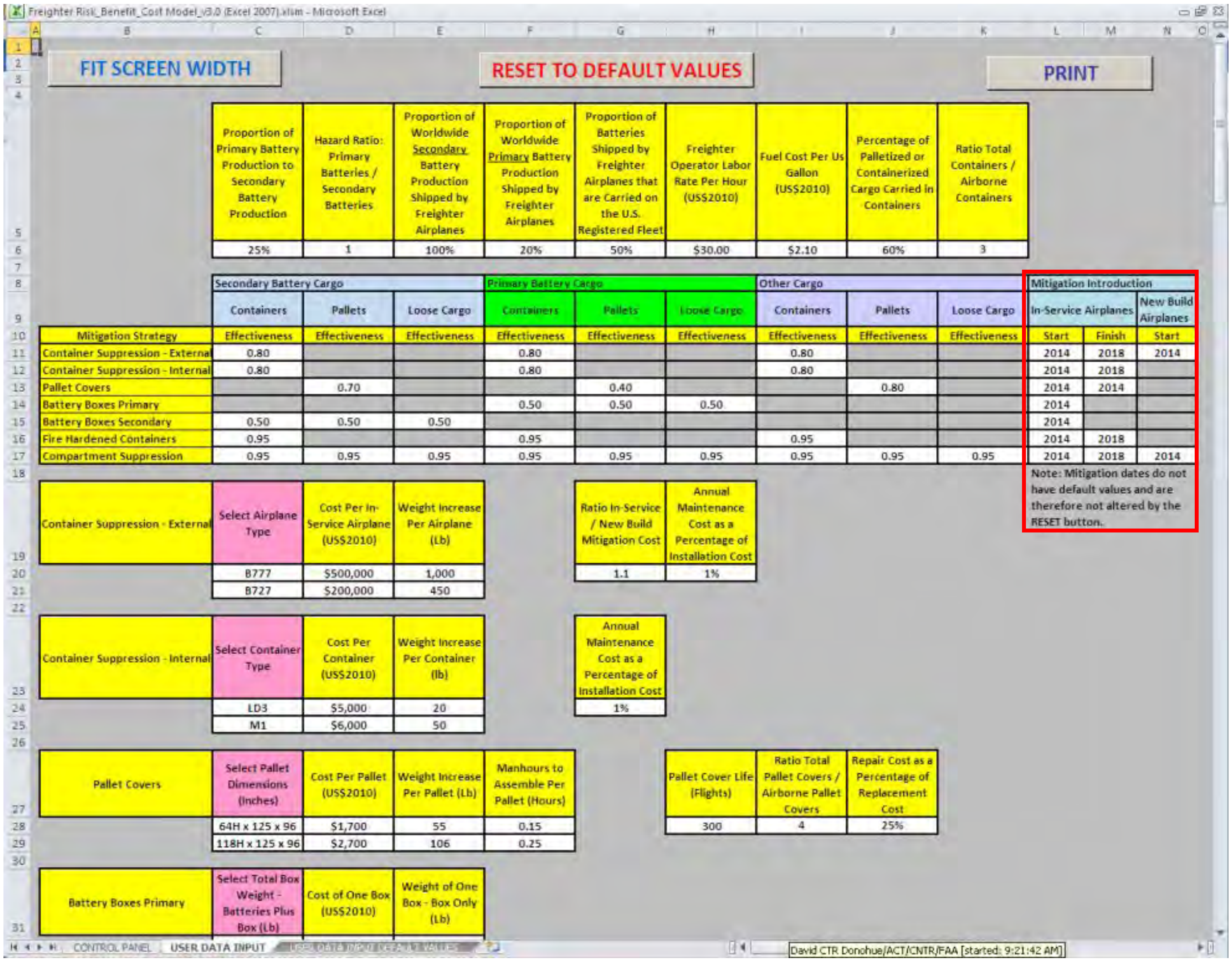
[13] Note that if the battery box primary or the battery box secondary mitigation strategy is selected, the mitigation will be applied to all freighter types irrespective of the freighter type selection made for other mitigation strategies selected, as described in section 7.2.



Proportion of Primary Battery Production to Secondary Battery Production	Hazard Ratio: Primary Batteries / Secondary Batteries	Proportion of Worldwide Secondary Battery Production Shipped by Freighter Airplanes	Proportion of Worldwide Primary Battery Production Shipped by Freighter Airplanes	Proportion of Batteries Shipped by Freighter Airplanes that are Carried on the U.S. Registered Fleet	Freighter Operator Labor Rate Per Hour (US$2010)	Fuel Cost Per Us Gallon (US$2010)	Percentage of Palletized or Containerized Cargo Carried in Containers	Ratio Total Containers / Airborne Containers
25%	1	100%	20%	50%	$30.00	$2.10	60%	3

	Secondary Battery Cargo			Primary Battery Cargo			Other Cargo			Mitigation Introduction		
	Containers	Pallets	Loose Cargo	Containers	Pallets	Loose Cargo	Containers	Pallets	Loose Cargo	In-Service Airplanes		New Build Airplanes
Mitigation Strategy	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Effectiveness	Start	Finish	Start
Container Suppression - External	0.80			0.80			0.80			2014	2018	2014
Container Suppression - Internal	0.80			0.80			0.80			2014	2018	
Pallet Covers		0.70			0.40			0.80		2014	2014	
Battery Boxes Primary				0.50	0.50	0.50				2014		
Battery Boxes Secondary	0.50	0.50	0.50							2014		
Fire Hardened Containers	0.95			0.95			0.95			2014	2018	
Compartment Suppression	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	2014	2018	2014

Note: Mitigation dates do not have default values and are therefore not altered by the RESET button.

Container Suppression - External	Select Airplane Type	Cost Per In-Service Airplane (US$2010)	Weight Increase Per Airplane (Lb)
	B777	$500,000	1,000
	B727	$200,000	450

Ratio In-Service / New Build Mitigation Cost	Annual Maintenance Cost as a Percentage of Installation Cost
1.1	1%

Container Suppression - Internal	Select Container Type	Cost Per Container (US$2010)	Weight Increase Per Container (lb)
	LD3	$5,000	20
	M1	$6,000	50

Annual Maintenance Cost as a Percentage of Installation Cost
1%

Pallet Covers	Select Pallet Dimensions (Inches)	Cost Per Pallet (US$2010)	Weight Increase Per Pallet (Lb)	Manhours to Assemble Per Pallet (Hours)
	64H x 125 x 96	$1,700	55	0.15
	118H x 125 x 96	$2,700	106	0.25

Pallet Cover Life (Flights)	Ratio Total Pallet Covers / Airborne Pallet Covers	Repair Cost as a Percentage of Replacement Cost
300	4	25%

Battery Boxes Primary	Select Total Box Weight - Batteries Plus Box (Lb)	Cost of One Box (US$2010)	Weight of One Box - Box Only (Lb)

Figure 25. User Input Tab

The likely number of cargo fire accidents, together with a confidence range, through the year 2020 is displayed on the Cumulative Cargo Fire Accidents graph on the Control Panel tab (see pink outline in figure 24). The Accidents Predicted over 10 Years (2011-2020) table on the Control Panel tab (see black outline in figure 24) displays the average number of battery fire accidents and nonbattery fire accidents expected over the period. The bottom row of this table displays the total number of accidents expected together with a range appropriate to (c) in section 13.3. The average annual accident cost over the selected period and the predicted confidence range is displayed on the Residual Accident Cost Distribution graph on the Control Panel tab (see brown outline in figure 24). This average annual accident cost over the period is divided into each freighter type in the Ave. Residual Accident Cost—Selected Years ($M) table (see tan outline in figure 24). The average accident cost per year through 2025 is displayed on the Residual Accident Cost graph (see gold outline in figure 24).

13.4 TO DETERMINE BENEFIT AND BENEFIT/COST RATIO.

To determine the benefit and benefit/cost ratio for any mitigation strategy or any combination of mitigation strategies:

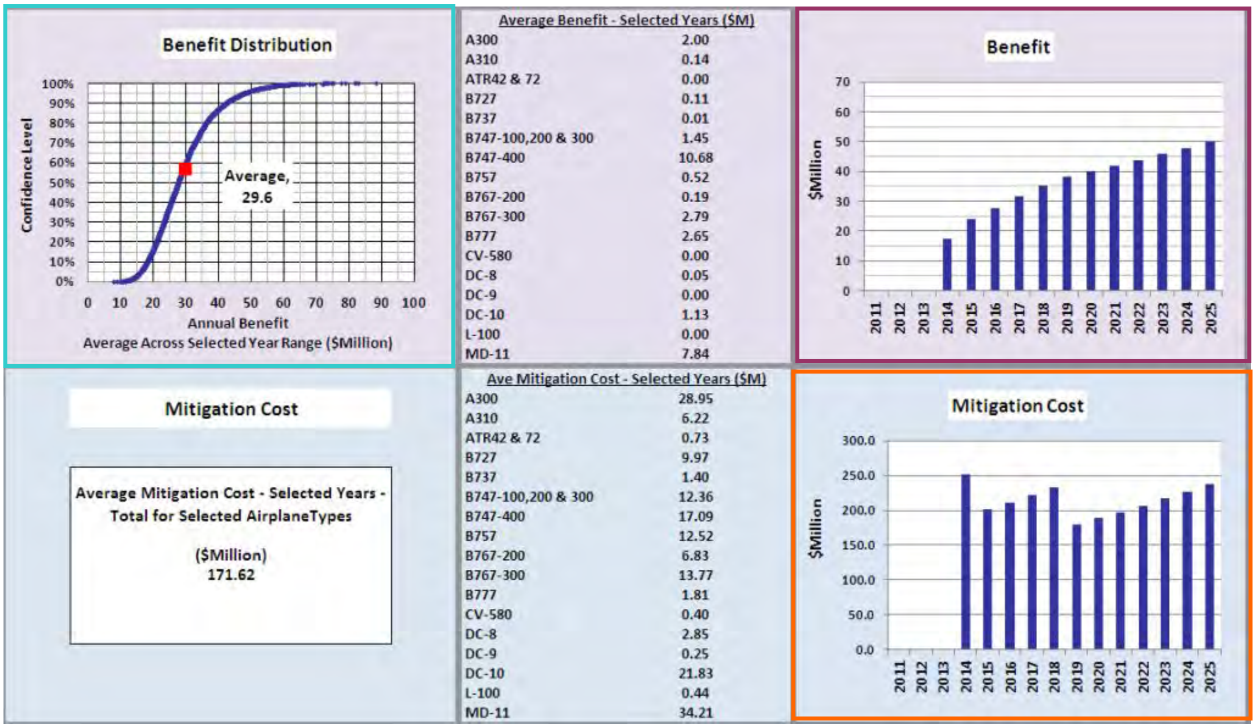
(a) Repeat steps (a) through (g) in section 13.3.

(b) On the User Input Data tab, either

- set data to the default values by clicking on the Reset to Default Values button (see figure 25) (All default values are contained in section 11) or
- review the data appropriate to the mitigation selected and change any of the values in the cells on this tab by clicking on the appropriate cell and typing in the required value.

(c) On the Control Panel tab, click the RECALC button (see figure 24)

The average annual benefit over the selected period and the predicted confidence range is displayed on the Benefit Distribution graph (see aqua outline in figure 26) on the Control Panel tab. This average benefit over the period is subdivided into each freighter type in the Average Benefit—Selected Years ($M) table (see figure 26). The average benefit per year through 2025 is displayed on the Benefit graph (see figure 26).



Average Benefit - Selected Years ($M)	
A300	2.00
A310	0.14
ATR42 & 72	0.00
B727	0.11
B737	0.01
B747-100,200 & 300	1.45
B747-400	10.68
B757	0.52
B767-200	0.19
B767-300	2.79
B777	2.65
CV-580	0.00
DC-8	0.05
DC-9	0.00
DC-10	1.13
L-100	0.00
MD-11	7.84

Average Mitigation Cost - Selected Years - Total for Selected AirplaneTypes

($Million)
171.62

Ave Mitigation Cost - Selected Years ($M)	
A300	28.95
A310	6.22
ATR42 & 72	0.73
B727	9.97
B737	1.40
B747-100,200 & 300	12.36
B747-400	17.09
B757	12.52
B767-200	6.83
B767-300	13.77
B777	1.81
CV-580	0.40
DC-8	2.85
DC-9	0.25
DC-10	21.83
L-100	0.44
MD-11	34.21

Figure 26. Graphs and Tables on the Control Panel Tab

The average mitigation cost over the selected period is divided into each freighter type in the Average Mitigation Cost—Selected Years ($M) table (see figure 26). The average mitigation cost per year through 2025 is displayed on the Mitigation Cost graph (see orange outline in figure 26).

The average annual benefit/cost ratio over the selected period and the predicted confidence range is displayed on the Benefit/Cost Ratio Distribution graph (see dark-green outline in figure 24) on the Control Panel tab. This average benefit/cost ratio over the period is subdivided into each freighter type in the Average Benefit/Cost Ratio—Selected Years table (see figure 24). The average benefit/cost ratio per year through 2025 is displayed on the Benefit/Cost Ratio graph (see bright-green outline in figure 24).

14. SUMMARY.

14.1 FUTURE PREDICTION OF THE NUMBER OF ACCIDENTS.

The Model predictions of the average number of cargo fire accidents and the associated confidence range likely to occur from 2011 to 2020 are shown in figure 27.

Accidents Predicted Over 10 Years (2011 - 2020)			
	2.5%	Ave	97.5%
Battery Fire Accidents		4.5	
Nonbattery Fire Accidents		1.7	
Total Accidents	2.2	6.2	12.6

Figure 27. Predicted Average and 95-Percentile Range of the Number of Cargo Fire Accidents From 2011 to 2020

This prediction is dependent on the forecasted RTMs from 2011 through 2020, which cannot be predicted with accuracy, and the assessment of the threat from lithium batteries.

However, if it was assumed that there was no increase in threat due to the shipment of lithium batteries, then it would still be expected that there would be an additional three accidents over the period. Even if it were assumed that there was no increase in threat due to the shipment of lithium batteries and the annual RTMs for the U.S.-registered freighter fleet was constant through 2020 (at 2010 annual levels) an additional two accidents would be expected.

Since it appears likely that there is a real threat from lithium batteries, and that the RTMs for the U.S.-registered freighter fleet will also continue to increase, the Model predictions are considered reasonable.

The fire threat may be related to flight cycles in some way as well as the volume of cargo and distance carried. For example, the fire risk may be influenced by storage, handling, and loading prior to a flight. It is recommended that further consideration be given to this aspect to ascertain whether the fire threat might have a flight cycle element and, if so, develop the Model to accommodate this issue.

14.2 FUTURE PREDICTION OF BENEFIT AND ACCIDENT COST.

If no mitigation action is taken, accident costs are likely to average approximately $44 million per annum over the period 2011 to 2025. The primary contribution to freighter fire accident costs is the value of the airplane—with values of approximately 90% of the total accident cost for the larger freighter airplanes. The Model predictions of accident costs are based on the assumption that the composition of the U.S.-registered freighter fleet will be largely unchanged from 2010 through to 2025 in terms of size and value of airplanes. However, larger freighter airplanes may change the composition of the fleet. This is likely to result in the potential for higher accident costs and higher benefits for those accidents that are mitigated.

It is recommended that consideration be given to attempting to accommodate this potential change to the composition of the U.S.-registered freighter fleet in any future cost and benefit assessments.

14.3 FUTURE PREDICTION OF BENEFIT/COST RATIO.

The costs of implementing the proposed mitigation strategies are currently not known to a sufficient level of accuracy to make accurate determinations of benefit/cost ratios. Furthermore, it is likely that some mitigation strategies, even though they may be shown to be cost beneficial for certain airplane types, may not have the desired effect in terms of reducing the number of accidents. For example, it is feasible that the cost of battery boxes could be sufficiently low to make this mitigation means cost beneficial. However, they are unlikely to be 100% effective in mitigating the threat and will have no impact on the fire threat other than from lithium batteries.

To significantly impact the number of accidents, it is likely that a means of addressing the threat from cargo carried in containers, pallets, and as loose cargo would be needed. This may be accommodated by a compartment suppression system or by a combination of mitigation means aimed at addressing all means of shipment.

If reliable data was not available regarding the costs of the proposed mitigation means, an alternative approach could be to determine the installation costs, weight, and effectiveness that would be needed for the mitigation to be cost-effective.

15. REFERENCES.

1. RGW Cherry & Associates Limited, “The Cabin Safety Research Technical Group Accident Database,” prepared for Transport Canada, the Federal Aviation Administration, and the United Kingdom Civil Aviation Authority, http://www.rgwcherry-adb.co.uk/ January 2011 (last visited July, 2011).

2. ICAO, “ANNEX 13—Aircraft and Incident Investigation,” 10th edition, July 2010.

3. The National Transportation Safety Board Accident Database, http://www.ntsb.gov/ (last visited July 2011).

4. U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, http://www.bts.gov (last visited July 2011).

5. RGW Cherry & Associates Limited, “A Cost-Benefit Analysis for the Installation of Fire Suppression Systems in Cargo Compartments of Cargo Airplanes,” FAA report DOT/FAA/AR-09/17, April 2009, http://www.fire.tc.faa.gov/pdf/09-17.pdf

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7. Hideo Takeshita, Cited in: Klein, V., “Safety and Transportation Issues—Lithium Batteries,” *Proceedings of the ICAO Working Group on Lithium Batteries on October 4-5, 2007*, Montreal, Canada, International Civil Aviation Organization, Folio 9, 2007

8. Saxman, D., “Lithium Batteries: Markets and Materials,” bcc Research, United States, http://www.bccresearch.com/report/lithium-batteries-markets-materials-fcb028e.html (last visited July 2011).

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10. 14 CFR Part 121, “Operating Requirements: Domestic, Flag, and Supplemental Operations.”

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APPENDIX A—TITLE 14 CODE OF FEDERAL REGULATIONS 25.857 CARGO COMPARTMENT CLASSIFICATION

14 CFR 25.857 Regulation – Current Standard

(a) *Class A;* A Class A cargo or baggage compartment is one in which—
(1) The presence of a fire would be easily discovered by a crewmember while at his station; and
(2) Each part of the compartment is easily accessible in flight.
(b) *Class B.* A Class B cargo or baggage compartment is one in which—
(1) There is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher;
(2) When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent, will enter any compartment occupied by the crew or passengers;
(3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.
(c) *Class C.* A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which—
(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;
(2) There is an approved built-in fire extinguishing or suppression system controllable from the cockpit.
(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers;
(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.
(d) [Reserved]
(e) *Class E.* A Class E cargo compartment is one on airplanes used only for the shipment of cargo and in which—
(1) [Reserved]
(2) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station;
(3) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment;
(4) There are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight crew compartment; and
(5) The required crew emergency exits are accessible under any cargo loading condition.

14 CFR 25.857 Regulation - Amendment 60 Standard for Class D Cargo Compartments

(d) Class D. A Class D cargo or baggage compartment is one in which--
(1) A fire occurring in it will be completely confined without endangering the safety of the airplane or the occupants;
(2) There are means to exclude hazardous quantities of smoke, flames, or other noxious gases, from any compartment occupied by the crew or passengers.
(3) Ventilation and drafts are controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits;
(4) [Reserved]
(5) Consideration is given to the effect of heat within the compartment on adjacent critical parts of the airplane.
[(6) The compartment volume does not exceed 1,000 cubic feet.]