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Atlantic City International Airport
New Jersey 08405

Freighter Airplane Cargo Fire Risk, Benefit and Cost Model (Model Version 5)

April 2013

Final Report

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NOTICE

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16. Abstract

The FAA, Transport Canada, and the UK CAA jointly developed a Risk and Benefit Cost Model 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 is structured to explain the data used by the Model Version 5, its algorithms, and the way in which the model may be used.

Model Version 5 is a development of earlier models. Extra functionality has been added and data are now appropriate to the U.S.-registered freighter fleet in 2011.

The model addresses the potential fire threat from all forms of cargo, including that from the bulk shipment of lithium batteries (primary and secondary) since it is considered they are likely to have had a contribution to two of the five freighter fire accidents that have occurred on U.S.-registered airplanes. The model displays the number of accidents through to 2021, and costs, benefits and the benefit cost ratios through to 2026.

The model predicts that the average number of total accidents likely to occur during the next 10 years, 2012 to 2021, if no mitigation action is taken, is approximately 6, ranging from 2 to 12, at 95% percent confidence interval. If no mitigation action is taken, accident costs are likely to average approximately $50 million (U.S.) per annum over the period 2012 to 2026. 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 2011 through 2026 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.

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LIST OF ACRONYMS

CAA	Civil Aviation Authority
CSRTG	Cabin Safety Research Technical Group
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
ICAO	International Civil Aviation Organization
MAIS	Maximum Abbreviated Injury Scale
MTOW	Maximum Take-Off Weight
NTSB	National Transportation Safety Board (U.S.A)
RTM	Revenue Ton Miles

EXECUTIVE SUMMARY

Following the accident at Dubai International Airport in the United Arab Emirates, to the Boeing 747 freighter airplane on September 3, 2010, the FAA, Transport Canada, and the UK CAA requested that a Risk and Benefit Cost Model be developed to assess the likely number of U.S.-registered freighter fire accidents in a 10-year period (2012-2021), and the Benefit Cost Ratio associated with seven mitigation strategies identified by the FAA. This report is structured to explain the data used by the Risk and Benefit Cost Model Version 5, its algorithms and the way in which the model may be used.

Model Version 5 is a development of earlier models, which are described in references 1 and 2. Extra functionality has been added and data are now appropriate to the U.S.-registered freighter fleet in 2011.

The model addresses the potential fire threat from all forms of cargo, including that from the bulk shipment of lithium batteries (primary and secondary) since it is considered that they are likely to have had a contribution to two of the five freighter fire accidents that have occurred on U.S. -registered airplanes. The model displays the number of accidents through to 2021, and costs, benefits and benefit/cost ratios through to 2026.

The model predicts that the average number of total accidents likely to occur during the next 10 years, 2012 to 2021, if no mitigation action is taken, is approximately 6, ranging from 2 to 12, at 95% percent confidence interval. If no mitigation action is taken, accident costs are likely to average approximately $50 million (U.S.) per annum over the period 2012 to 2026. 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 2011 through to 2026 in terms of the sizes and values of airplanes. However, it might be expected that 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 which are mitigated.

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. Should reliable data not become available regarding the costs of the proposed mitigation strategies, an alternative approach might be to determine the installation costs, weight and effectiveness that would be needed in order that they might be cost effective.

Some mitigation strategies, even though 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 it is likely that a means would need to be found of addressing the threat from cargo carried in containers, pallets and as loose cargo. This might be accommodated by a Compartment Suppression system or by a combination of mitigation means aimed at addressing all means of shipment.

1. INTRODUCTION.

Following the accident at Dubai International Airport in the United Arab Emirates, to the Boeing 747 freighter airplane on September 3, 2010, the FAA, Transport Canada and the UK CAA (referred to as the Authorities) requested that a Risk and Benefit Cost Model be developed to assess the likely number of U.S.-registered freighter fire accidents together with the cost and benefit that might be afforded, by certain mitigation strategies. The model displays the number of accidents through to 2021 and costs, benefits and benefit cost ratios through to 2026.

Since it is considered that the bulk shipment of lithium batteries (primary and secondary) are likely to have had a contribution to two of the five freighter fire accidents that have occurred on U.S.-registered airplanes, the model addresses the potential threat from lithium batteries and other cargo separately. All references in this report to batteries should be taken to mean secondary or primary lithium battery packs or individual cells.

This report is structured to explain the data[1] used by the model, its algorithms and the way in which the model may be used. The data in the model are appropriate to the U.S.-registered freighter fleet in 2011 and all costs are in 2011 U.S. dollars.

2. MODEL OVERVIEW.

The model, which is constructed in Microsoft® Excel®, may be considered as three separate sub-models – a Risk sub-Model, a Benefit sub-Model and a Cost sub-Model. The Risk and Benefit sub-Models are based on the Monte Carlo Simulation methodology utilizing statistical distributions derived from data on in-service airplanes and accidents. Monte-Carlo simulation is a method where 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 sub-Models are run many thousands of times, to obtain these predictions and the 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.

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

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

Instructions on the way in which the model may be used are contained in section 13.

3. FREIGHTER CARGO FIRE ACCIDENTS.

The CSRTG Accident Database (reference 3) was searched to identify all cargo fire related accidents on U.S.-registered cargo operations over the period 1967[2] to 2011. The following criteria were used for the selection of accidents:

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

Only airplane accidents conforming to the ICAO Annex 13 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 (reference 4) was also searched for cargo fire accidents and Boeing Aircraft Company supplied a listing of accidents involving cargo fires. These data sources identified the following five cargo fire accidents to U.S.-registered airplanes between 1958 through 2011:

Accident Ref:	20100903A
Date:	September 3rd, 2010
Operator:	United Parcels Service (UPS)
Airplane:	B747-44AF (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)"

[2] While the study period is from 1958 to 2011, reference 3 does not contain data prior to 1967.

Accident Ref:	20060207A
Date:	7th February 2006
Operator:	United Parcel Service (UPS)
Airplane:	DC8 (Registration N748UP)
Location:	Philadelphia, Pennsylvania, U.S.A
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 Ref:	20040427A
Date:	27th April 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 Ref:	19960905B
Date:	5th September 1996
Operator:	Federal Express Corporation (FedEx)
Airplane:	DC10-10CF (Registration N68055)
Location:	Newburgh/Stewart, New York, U.S.A
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 Ref:	19731103B
Date:	3rd November 1973
Operator:	Pan American World Airways
Airplane:	B707 (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 five accidents the precise cause of the fire was not determined. However, it is known that for both the Dubai accident (Accident Ref: 20100903A) and the Philadelphia accident (Accident Ref: 20060207A) lithium batteries were being transported and could have contributed to the on-board fires resulting in catastrophic accidents.

The model is based on these five accidents which are categorized as either battery related or non-battery related. The Dubai accident is assumed to be battery related and the model accommodates user selection of the Philadelphia accident as battery or non-battery related. The user may select on these options by mouse clicking on the appropriate button in the Philadelphia accident switch on the Model Control Panel tab as shown in figure 1.

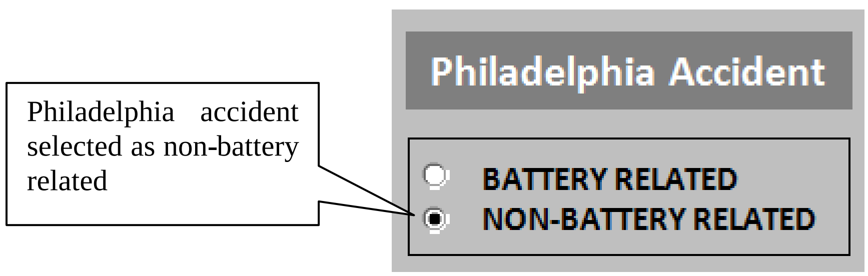

Figure 1. Philadelphia Accident Switch

Figure 1 shows the Philadelphia accident selected as non-battery related.

4. REVENUE TON-MILES.

This section of the report describes the way in which the predicted number of revenue ton-miles has been derived for battery and non-battery cargo.

The model is based on the assumption that the risk of a cargo fire accident occurring is a function of the revenue ton-miles (RTM) 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. Revenue ton-miles 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 compartments are adequately accommodated by the

[3] See Appendix A for cargo compartment classifications

current protection means) it is necessary to determine the proportion of the total revenue ton-miles carried in these compartments. Non-Class C compartments include compartments below the main cargo deck not equipped with halon fire suppression systems.

4.1 TOTAL REVENUE TON-MILES 1958 THROUGH 2011.

Assessments of non-Class C revenue ton-miles (Class E and Class D) were made for each airplane type in the U.S.-registered freighter fleet in 2008, 2009, 2010 and 2011 based, in part, on data contained in reference 5.

Using data contained in references 5, 6 and 7 assessments were made of the annual total revenue ton-miles for the U.S.-registered fleet prior to 2008. These totals were factored to assess the non-Class C revenue ton-miles based on the proportions of the total derived from the 2011 data. By way of reference the assessed proportion of total revenue ton-miles carried in non-Class C compartments is 79%. Based on these data sources the best estimate of the annual non-Class C revenue ton-miles accumulated by the U.S.-registered freighter fleet is shown in figure 2.

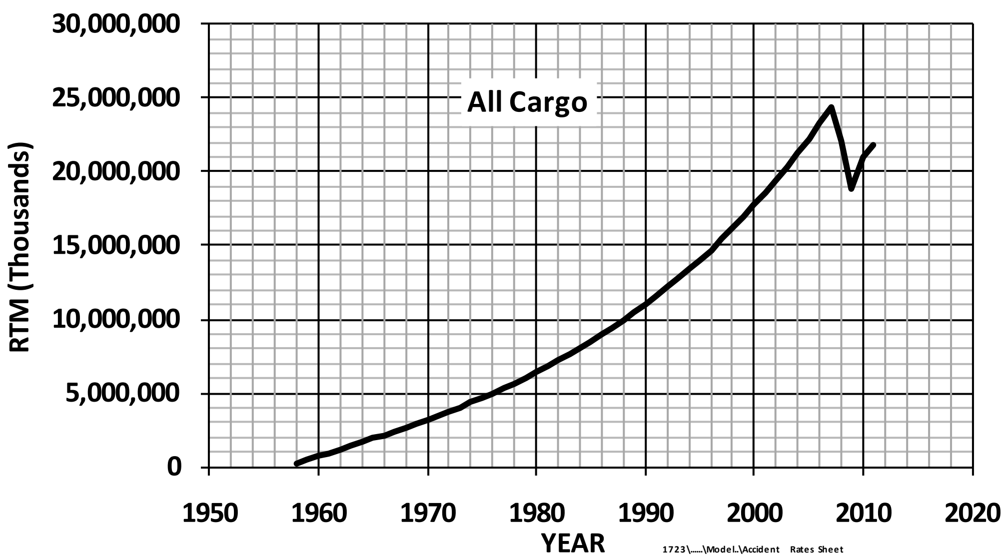

Figure 2. Assessment of the Annual Number of Revenue Ton-Miles Carried in Non-Class C Cargo Compartments per Annum for the U.S.-Registered Freighter Fleet – 1958 to 2011

[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 14 CFR 25.857. On this basis it is pessimistically assumed that the protection afforded by Class D compartments is to a similar level to that for Class E compartments.

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

536,744,004,808 revenue ton-miles for the period 1958 to 2011 and

21,846,693,792 revenue ton-miles for 2011

The revenue ton-miles, carried by U.S.-registered freighter airplanes in non-Class C cargo compartments in 2011, are divided into freighter types as shown in table 1, using data contained in reference 5.

Table 1. Revenue Ton-Miles (2011) in Non-Class C Cargo Compartments by Freighter Type – All Cargo

Freighter Type	Revenue Ton-Miles (2011)
A300	1,411,508,724
A310	278,844,391
ATR42 & 72	4,078,007
B727	292,205,620
B737	16,902,303
B747-100, 200 & 300	1,615,722,437
B747-400	5,016,594,330
B757	684,795,899
B767-200	481,038,624
B767-300	2,139,787,149
B777	1,732,401,008
CV-580	6,553,868
DC-8	141,751,511
DC-9	6,306,188
DC-10	1,886,204,512
L-100	7,526,793
MD-11	6,124,472,428
Total	21,846,693,792

4.2 DIVISION OF REVENUE TON-MILES – LITHIUM BATTERY & OTHER CARGO.

Since accident rates need to be derived for both lithium battery fire related accidents and those attributable to other cargo, the revenue ton-miles carried in non-Class C cargo compartments needs to be subdivided 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 8 an assessment was made of the growth in production of secondary lithium battery cells.

Figure 3 shows the annual number of secondary lithium battery cells estimated to have been produced from 1995 to 2011 worldwide, with a future extrapolation through to 2026.

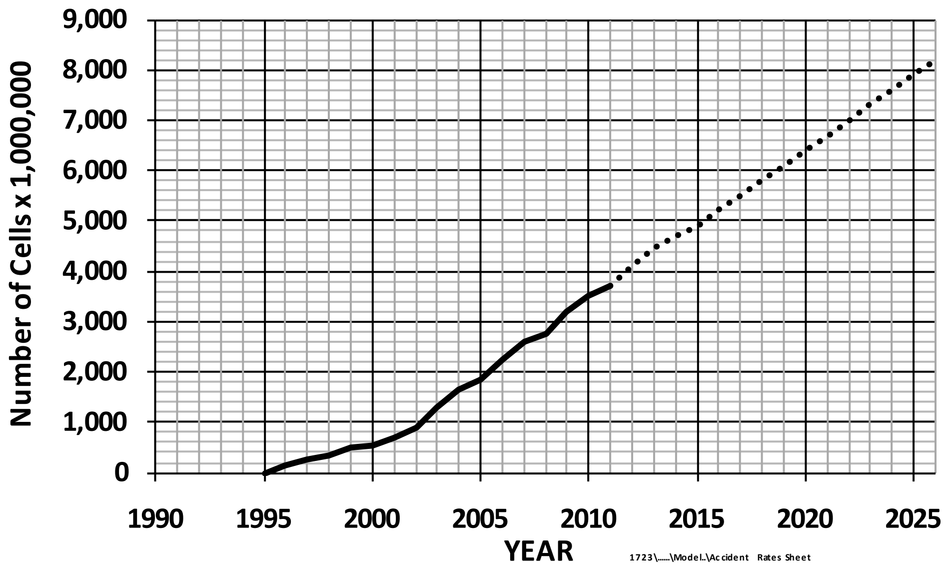

Figure 3. Estimation of the Annual Number of Secondary Lithium Battery Cells Produced Worldwide

Data of the kind shown in figure 3 are not currently available for primary lithium batteries. However, based on information contained in reference 9, it is estimated that primary lithium battery cell production is approximately 25% of that for secondary lithium battery cells. This is taken as the default value however it is a User Input Variable which may be altered on the User Data Input tab.

The annual number of secondary lithium battery cells produced worldwide, as indicated by figure 3, may 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 fleet. However, these are User Input Variables which may be altered 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 revenue ton-miles 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 2011, battery (secondary and primary) revenue ton-miles accounted for 0.65% of the total revenue ton-miles carried in non-Class C Compartments on U.S.-registered freighter airplanes. Based on this assumption, the total revenue ton-miles for battery (secondary and primary) and non-battery cargo, for each freighter type, would be as illustrated in table 2.

Table 2. Revenue Ton-Miles (2011) in Non-Class C Cargo Compartments by Freighter Type – Battery (Secondary and Primary) and Non-Battery Cargo

	Revenue Ton-Miles (2011)		
Freighter Type	Battery Cargo	Non-Battery Cargo	All Cargo
A300	9,161,678	1,402,347,046	1,411,508,724
A310	1,809,895	277,034,496	278,844,391
ATR42 & 72	26,469	4,051,538	4,078,007
B727	1,896,619	290,309,001	292,205,620
B737	109,708	16,792,596	16,902,303
B747-100,200 & 300	10,487,168	1,605,235,269	1,615,722,437
B747-400	32,561,203	4,984,033,127	5,016,594,330
B757	4,444,804	680,351,095	684,795,899
B767-200	3,122,277	477,916,347	481,038,624
B767-300	13,888,714	2,125,898,435	2,139,787,149
B777	11,244,493	1,721,156,514	1,732,401,008
CV-580	42,539	6,511,329	6,553,868
DC-8	920,066	140,831,445	141,751,511
DC-9	40,932	6,265,256	6,306,188
DC-10	12,242,785	1,873,961,727	1,886,204,512
L-100	48,854	7,477,939	7,526,793
MD-11	39,752,106	6,084,720,322	6,124,472,428

The model incorporates a facility to alter the distribution of battery cargo among aircraft types. This is because on some international routes operated by the larger freighters, a greater proportion of the total cargo might be batteries compared with smaller freighters operating internal routes. A weighting factor, having a default value of 1, is selectable within the range 0 to 10 for each aircraft type. A weighting factor of 1 signifies that battery cargo, as a proportion

[5] The common '18650' form 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 2011 was assessed to be 1846 miles.

of total cargo, is equal to the average for the U.S.-registered fleet. Weighting factors of 0.1 and 10 signify that battery cargo, as a proportion of total cargo, are one-tenth and 10 times the average for the U.S.-registered fleet respectively. Using a best-fit calculation, the model derives the battery revenue ton-miles for each airplane type within the model, according to the weightings applied. Non-battery cargo for each airplane type is adjusted accordingly.
The weighting factor is selected via the drop down menus in the Control Panel tab as shown in figure 10. A weighting must be selected for all airplane types, regardless of whether they are to have mitigation applied.

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 revenue ton-miles for all of the years prior to 2011. The battery revenue ton-miles is then subtracted from the total revenue ton-miles (All Cargo) to determine the non-battery revenue ton-miles, appropriate to non-Class C cargo compartments, for each year from 1958 to 2026. The cumulative revenue ton-miles for both battery (secondary and primary) and non-battery cargo through to 2011 is derived by simply summing each of the preceding years as shown in table 3.

Table 3. Assessed Cumulative Revenue Ton-Miles in Non-Class C Compartments for the U.S.-Registered Fleet Through to 2011 – Battery (Secondary and Primary) and Non-Battery Cargo

Cumulative Battery Revenue Ton-Miles Through to 2011	Cumulative Non-Battery Revenue Ton-Miles Through to 2011
1,003,333,001	535,740,671,807

Table 4 shows the predicted revenue ton-miles in non-Class C cargo compartments for both battery (secondary and primary) and non-battery cargo for each year from 2012 to 2026.

Table 4. Assessed Annual Revenue Ton-Miles in non-Class C Cargo Compartments for the U.S.-Registered Freighter Fleet 2012 to 2026 – Battery (Secondary and Primary) and Non-Battery Cargo

Date	Annual Battery (Secondary and Primary) RTM	Annual Non-Battery RTM
2012	157,130,073	23,133,131,501
2013	170,543,616	24,204,732,216
2014	180,124,718	25,332,643,593
2015	187,789,599	26,518,320,109
2016	199,286,922	27,759,607,325
2017	210,784,244	29,064,139,229
2018	222,281,566	30,435,944,135
2019	233,778,889	31,879,304,659
2020	245,276,211	33,398,726,938
2021	256,773,534	34,998,971,415
2022	268,270,856	36,685,062,546
2023	279,768,178	38,462,290,431
2024	291,265,501	40,336,207,565
2025	302,762,823	42,312,648,282
2026	314,260,145	44,397,748,189

The assessed annual number of revenue ton-miles carried in non-Class C cargo compartments over the period 1958 to 2026 are shown in figure 4.

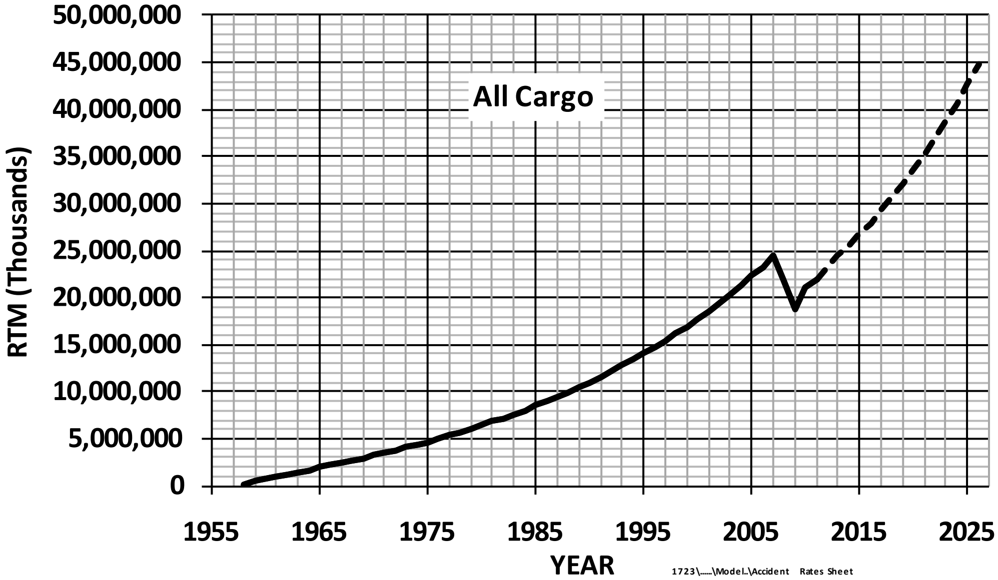

Figure 4. Assessment of the Annual Number of Revenue Ton-Miles Carried in Non-Class C Cargo Compartments per Annum for the U.S.-Registered Fleet – 1958 to 2026

5. ACCIDENT RATES & ACCIDENT RATE DISTRIBUTIONS.

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

$$\text{Accident Rate} = \frac{\text{Number of Cargo Fire Accidents}}{\text{Cumulative revenue ton-miles}}$$

This formula may be used to determine the average accident rate attributable to battery related cargo and to non-battery cargo simply by dividing the number of accidents attributable to each of the causes by the associated cumulative revenue ton-miles as shown in table 3. Therefore assuming that the Philadelphia accident was related to lithium batteries the associated accident rates may be derived by dividing the applicable number of accidents by the associated cumulative revenue ton-miles up to and including 2011:

Battery Accident Rate = $2 \div 1{,}003{,}333{,}001 = 1.99 \times 10^{-9}$ per RTM
Non-Battery Accident Rate = $3 \div 535{,}740{,}671{,}807 = 5.6 \times 10^{-12}$ 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 simply an average value.

The χ^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 non-battery fire accidents. Using the revenue ton-miles values illustrated in table 3, and the number of battery fire accidents and non-battery 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 more pessimistic than might be expected. Therefore, an option has been provided that may be selected using the switch, in the Control Panel tab, illustrated in figure 5. This switch modifies the χ^2 distribution to provide confidence ranges closer to what might be expected. This modifier simply 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).

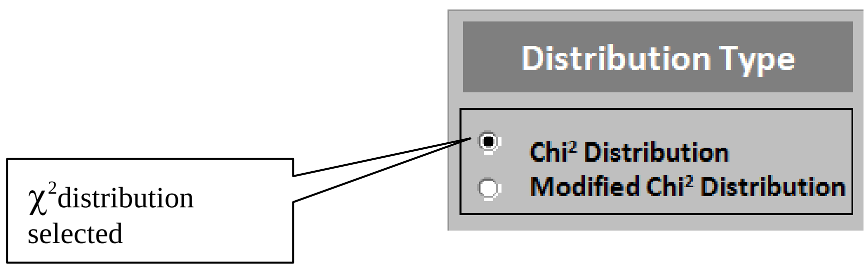

Figure 5. The χ^2 (Chi ^{2}) Distribution Switch

At each iteration of the model, random selections are made on the χ^2 distribution (or the modified χ^2 distribution, whichever is selected) to derive an accident rate. This process is carried out for both the battery fire accident rate and the non-battery fire accident rate.

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 revenue ton-miles 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 which may be altered on the User Data Input tab.

6. NUMBER OF ACCIDENTS PRIOR TO MITIGATION.

The assessed number of secondary battery, primary battery, and non-battery fire accidents per year, prior to mitigation, are derived by simply multiplying the derived accident rates by the appropriate revenue ton-miles. The assessed revenue ton-miles for battery and non-battery cargo are shown in table 4 for years 2012 to 2026 inclusive.

The average number of accidents that might be expected over a given period may be assessed by simply multiplying the revenue ton-miles for the period by the associated accident rate.

For example, the expected number of battery fire accidents over the ten year period 2012 to 2021 would be:

Battery Accident Rate x Battery revenue ton-miles 2012 to 2021

$$= 1.99 \times 10^{-9} \times 2{,}063{,}769{,}370$$

Approximately equal to 4.1 accidents

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

The process of randomly selecting on the χ^2 distributions and multiplying by the appropriate revenue ton-miles is repeated many thousands of times to derive a distribution of the annual predicted number of accidents for each year from 2012 to 2021. The average prediction is derived for each year through to 2021. These predicted numbers of accidents are sequentially added to the 5 accidents that occurred up to year 2011 to derive a prediction of the cumulative number of accidents through to 2021 as illustrated by the bold curve in figure 6.

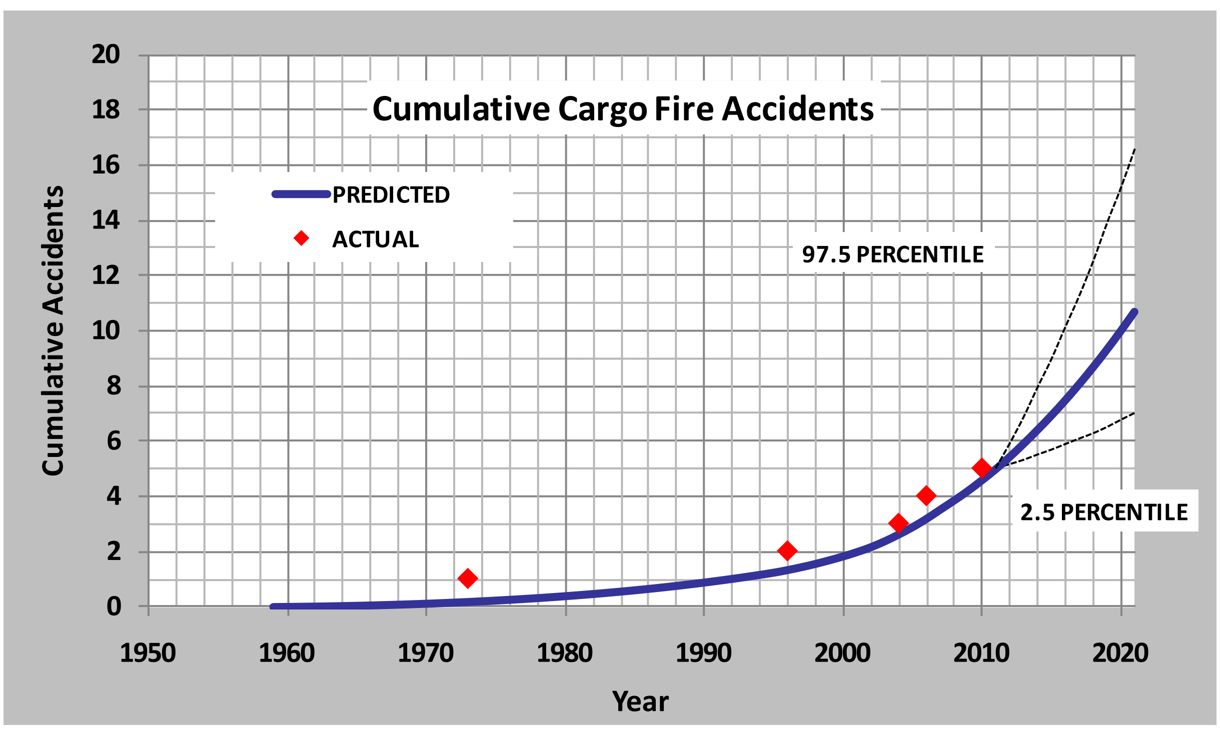

Figure 6. Predicted Number of Freighter Airplane Cargo Fire Accidents Through to 2021

The model prediction of the annual number of accidents for each year from 2012 to 2021 allows a confidence range to be established as illustrated in figure 6. This confidence range is variable and may be selected by the user by means of the Confidence Range switch illustrated in figure 7. The Confidence Range switch is contained in the Control Panel tab. (The figure 6 predictions are based on the modified χ^2 distribution assuming that the Philadelphia accident was attributable to a lithium battery fire.)

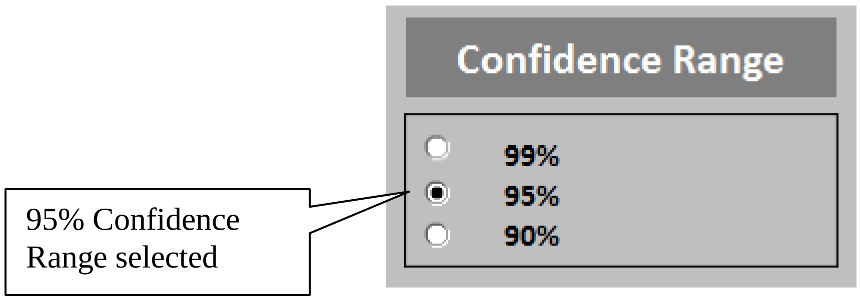

Figure 7. Confidence Range Switch

For example, figure 8 shows the average prediction of the number of cargo fire accidents from 2012 to 2021 subdivided into those accidents caused by batteries and those caused by non-battery cargo. Also shown in figure 8 is the 95 percentile range (from the 2.5 percentile to the 97.5 percentile) of the predicted total number of accidents from 2012 to 2021.

Accidents Predicted Over 10 Years (2012 - 2021)			
	2.5 %	Ave	97.5 %
Battery Fire Accidents		4.1	
Non-Battery Fire Accidents		1.6	
Total Accidents	2.1	5.7	11.6

Figure 8. Predicted Average and 95 Percentile Range of the Number of Cargo Fire Accidents Through to 2021

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.

Mitigation strategies have been proposed by the Authorities as those most likely to be feasible as a means of protection against fires in freighter airplane non-Class C cargo compartments. The model has been developed such that it can accommodate any one, or combinations, of these strategies. Each of these 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 sub-Model, the Benefit sub-Model and the Cost sub-Model.

Section 11 provides a description of the manner in which the model addresses the cost of each of the mitigation strategies, the primary algorithms used by the model and use of the User Data Input facility.

7.1 MITIGATION SELECTION.

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

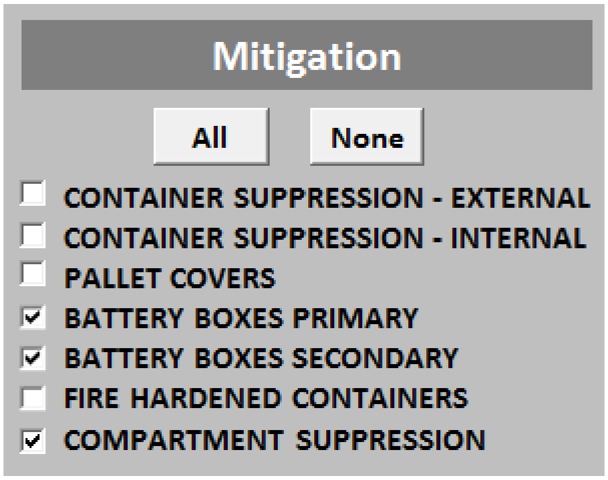

Figure 9. Selection of Mitigation Strategies

Figure 9 illustrates the selection of mitigation strategies Battery Boxes Primary, Battery Boxes Secondary and Compartment Suppression.

7.2 SELECTION OF FREIGHTER TYPES FOR MITIGATION.

The freighter types considered in this study are those appropriate to the 2011 U.S.-registered freighter fleet[7] as shown in table 5.

[7] Small turboprops have been excluded from this study since they constitute an extremely small proportion of the Revenue Ton-Miles carried by the US fleet.

Table 5. Freighter Types in the 2011 U.S.-Registered Fleet

Freighter Type
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

The chosen mitigation means can be applied to all of the freighter types in the U.S.-registered fleet, 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 airplanes for mitigation. For example, figure 10 shows only the B747-100/200/300, B747-400, B777 and the MD-11 have been selected for mitigation. All other freighter types have not been subjected to the selected mitigation.

	Reset to Default Values			
	Airplane Types Mitigated (All / None)	Proportion of In-Service Airplanes Mitigated	Proportion of Batteries Carried by Mitigated Airplanes	Battery Carriage Weighting (Proportion of Average)
A300	☐	0%	0%	1
A310	☐	0%	0%	1
ATR42 & 72	☐	0%	0%	0.2
B727	☐	0%	0%	1
B737	☐	0%	0%	1
B747-100,200 & 300	☑	50%	90%	5
B747-400	☑	100%	100%	5
B757	☐	0%	0%	1
B767-200	☐	0%	0%	1
B767-300	☐	0%	0%	1
B777	☑	100%	100%	5
CV-580	☐	0%	0%	0.2
DC-8	☐	0%	0%	1
DC-9	☐	0%	0%	1
DC-10	☐	0%	0%	1
L-100	☐	0%	0%	0.2
MD-11	☑	100%	100%	5

Figure 10. Selection of Freighter Types for Mitigation

It should be noted that the model has been constructed such 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.

7.3 SELECTION OF THE PROPORTION OF IN-SERVICE AIRPLANES MITIGATED.

The chosen mitigation means are applied to all new-build airplanes of each type selected for mitigation. However, they are applied only to a proportion of in-service airplanes of each type, as defined by the user. This is because the modification of older in-service airplanes may be significantly less cost beneficial than newer in-service airplanes. The proportion of in-service airplanes to be mitigated is selected via the dropdown menus for each airplane type within the Control Panel tab. Proportions can be selected from 0% up to the default value of 100%. The model applies the selected mitigation means to the highest value in-service airplanes of each type. For example, figure 10 shows 50% of the B747-100/200/300 in-service airplanes selected for mitigation. For this selection, only the 50% highest value in-service airplanes (and all new build airplanes) will have the selected mitigation means applied.

For airplane types that are not selected for mitigation, the proportion of in-service airplanes selected for mitigation should be set to 0%. However, if this requirement is overlooked, the model will override the proportion of in-service airplanes selected and will automatically assign a value of 0%.

7.4 SELECTION OF PROPORTION OF BATTERIES CARRIED BY MITIGATED AIRPLANES.

It is feasible that the carriage of battery cargo could be biased towards airplanes that have had mitigation means applied. The model therefore allows the user to select the proportion of the total battery cargo carried by each airplane type, to be carried by the mitigated airplanes of that type.

For each airplane type, the proportion of battery cargo carried by the mitigated airplanes is selected via the dropdown menus within the Control Panel tab. For example, figure 10 shows the proportion of battery cargo to be carried by the mitigated B747-100, 200 & 300 airplanes is selected to be 90%. The proportion of battery cargo carried by the non-mitigated B747-100, 200 & 300 airplanes would therefore be 10%.

For airplane types having 100% of in-service airplanes selected for mitigation, the proportion of battery cargo carried by mitigated airplanes should be set to 100%. However, if this requirement is overlooked, the model will override the selected value and will automatically assign a value of 100%.

7.5 MITIGATION INTRODUCTION PERIODS.

For each of the mitigation strategies the model has user input selections for their 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 illustrates 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

7.5.1 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 for 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 5 year period 2014 to 2018 the Benefit and mitigation cost is applied at a constant rate throughout the period starting at the beginning of 2014 and being fully implemented by the end of 2018.

If the mitigation strategy is not to be introduced onto in-service airplanes and is to be restricted to new-build airplanes only, the user should select the year 2027 as the Start and Finish dates on the drop down menus for In-Service Airplanes against the associated mitigation strategy.

7.5.2 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 not to be introduced onto new-build airplanes and is to be restricted to in-service airplanes only, the user should select the year 2027 as the Start date on the drop down menus for New Build Airplanes against the associated mitigation strategy.

7.6 MITIGATION OF FIRE 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 is of significance since some of the proposed mitigation strategies will only provide protection for one of these means – e.g. Pallet Covers will only provide protection to fires originating within pallets.

Based on an evaluation of the available non-Class C cargo 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 whole U.S.-registered freighter fleet, it is assessed that the percentage of cargo carried as loose cargo is in the region of 4.1%.

It has also been assessed that for cargo that is carried in containers or pallets, 60% is carried in containers. This is the default value but it may be varied from 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

7.7 MITIGATION STRATEGY EFFECTIVENESS.

The effectiveness is a function of the ability of the proposed mitigation to combat the fire threats that are likely to encountered in service. Factors influencing the effectiveness will include the system reliability (accommodating issues relating to incorrect operation or fitting of the system) and the probability of encountering fire threats beyond the design intent. The 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, an effectiveness value of 0.95 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 to the model with the default values shown in table 7. These values were derived by assessments made by engineers involved in the project. They may be altered from the User Data Input tab.

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 differing accident rates and differing revenue ton-miles. Therefore, the model will select the appropriate values depending on the mitigation means selected. For example, considering the Mitigation Effectiveness Values contained in table 7, if the mitigation means selected were Container Suppression – External it may be seen that the proposed Mitigation Effectiveness Value for Secondary Battery cargo in containers is equal to 0.8. However, if the mitigation means selected were Container Suppression – External and Secondary Battery Boxes then the Mitigation Effectiveness Value for Secondary Battery cargo in containers would be:

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

The model uses this principle to derive the appropriate Mitigation Effectiveness Value for any combination of mitigation means. Section 7.8 and section 9 describe the manner in which the model addresses the calculation of the number of accidents and the derived benefit taking into account the mitigation means, the revenue ton-miles and the accident rates applicable to Secondary Battery, Primary Battery, and Other cargo.

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		
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

7.8 REDUCTION IN THE NUMBER OF ACCIDENTS.

Freighter types may 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 that might be expected on these freighter types is simply derived from the general expression shown in equation 1.

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

Where:

$\boldsymbol{\lambda_0}$ is the accident rate associated with the cargo type (Secondary Batteries, Primary Batteries, or Other Cargo) under consideration (Accidents per revenue ton-miles), as described in section 5.

$RTM_{\mathbf{U}}$ is the revenue ton-miles for the freighter types and cargo type 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 simply 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 that might be 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 is the Mitigation Factor appropriate to the cargo type under consideration and the mitigation means selected (see section 7.6)

$RTM_{\mathbf{M}}$ is the revenue ton-miles for the freighter types and cargo type selected for mitigation during the year under consideration

The model will generate:

1. The Mitigation Factor, M, for Secondary Battery, Primary Battery, and Other cargo as described in section 7.6.
2. The annual revenue ton-miles for freighter types not selected for mitigation ($RTM_{\mathbf{U}}$) for Secondary Battery, Primary Battery, and Other cargo as described in section 4.
3. The annual revenue ton-miles for freighter types selected for mitigation ($RTM_{\mathbf{M}}$) for Secondary Battery, Primary Battery, and Other cargo as described in section 4.

Using these data the model will then generate the number of accidents from equation 1 and equation 2 for each of the cargo types and years under consideration.

The annual total number of accidents, for each of the cargo types, for the entire fleet, is simply 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 of the report describes the way in which 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 simply the predicted number of accidents per year multiplied by the cost per accident.

$$\frac{Cost}{Year} = \frac{Accidents}{RTM} \text{ x } \frac{RTM}{Year} \text{ x } \frac{Cost}{Accident} \qquad (3)$$

These costs per year are derived separately for battery and non-battery cargo for each freighter type over the period 2011 to 2025. The accident rates for battery and non-battery cargo are distributions and are derived as described in section 5. The revenue ton-miles per year for battery and non-battery 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 the manner in which 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 where following the fire the flight crew had some degree of control of the airplane onto the ground. Uncontrolled accidents are those where following the fire, the flight crew lost control in flight and the airplane impacted with the ground. In instances where control is lost on final approach and the airplane is stopped within the airport perimeter the accident is 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 over the period 1958 to 2011 inclusive, as described in section 3, were assessed to determine whether the accidents were controlled or uncontrolled. All were assessed to be controlled except for the B747 accident on September 3, 2010, which is considered to be an uncontrolled accident.

Table 8. Division of Fire Related Accidents to U.S.-Registered Freighter Airplanes Over the Period 1958 to 2011 – Controlled vs Uncontrolled

Controlled	Uncontrolled
4	1

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 the Binomial Distribution.

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

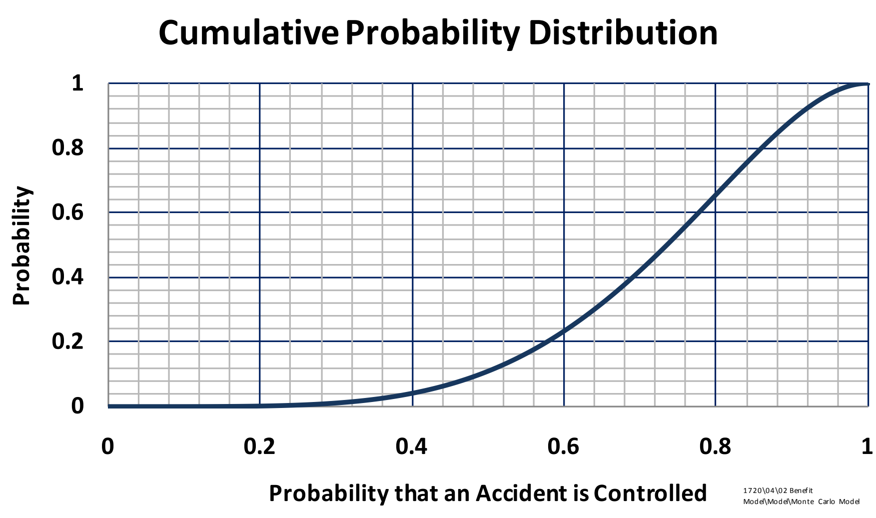

Figure 12. Cumulative Probability Distribution for the Probability of an Accident Being Controlled

The model randomly selects a number from the vertical axis of the distribution shown in figure 12 and derives a probability that the accident is controlled.

This is illustrated by the example shown in figure 13. In this example iteration of the model, a random number generates a value of 0.4. This value equates to a probability that the accident is controlled of 0.69. 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.

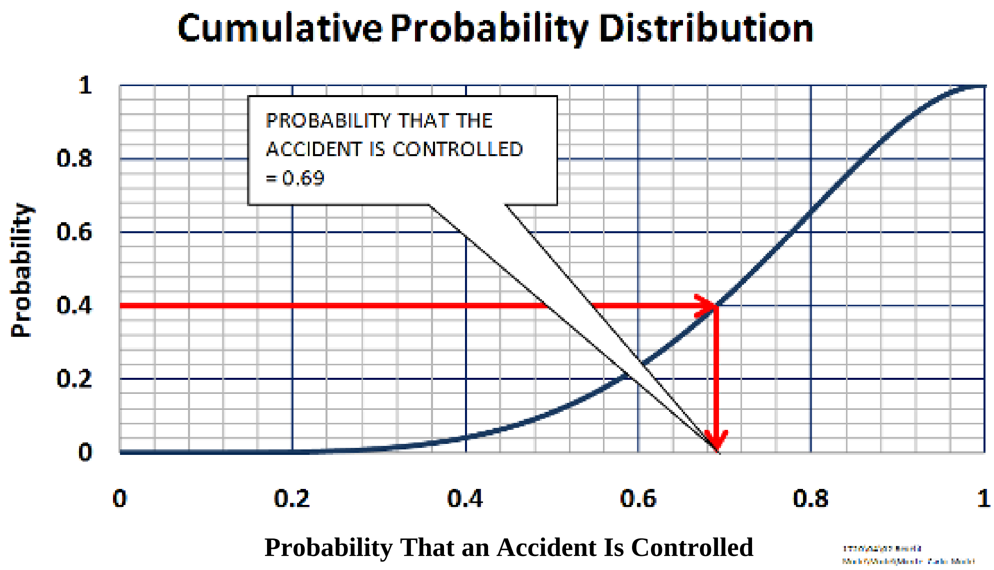

Figure 13. Example Determination of the Probability of an Accident Being Controlled

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 (reference 3) was searched for accidents to passenger carrying airplanes and freighter airplanes that were assessed to be similar in terms of their in-flight event and impact sequence to what might be expected from an in-flight cargo fire. One hundred and seventy-eight accidents to passenger and freighter airplanes were identified and divided into those that were assessed as controlled and those that were assessed as 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 following 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 might 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 might 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 9.1.1 for the determination of an accident being controlled or uncontrolled.

<u>8.1.3 Assessment of Accident Characteristics</u>.

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 results in collateral damage. This determination is made by randomly selecting on 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, that had an accident sequence similar to what might 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 illustrates the nature of the data used to determine primary damage (crew injuries, airplane damage and cargo damage).

Table 10. Illustration of the Data Used to Determine Primary Damage

Uncontrolled With No Collateral Damage – Example Only – Not Real Data					
	Proportion of Crew				
Accident Number	Fatal Injuries	Serious Injuries	Minor/No Injuries	Airplane Damage	Assessed Proportion of Cargo Damage
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	.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 on-board
- 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 on the appropriate accident dataset allocated by the model as described in section 8.1.3.

8.2.2 The Number of Crew On-Board.

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, have been assigned a weight category based on the sub divisions of Maximum Take-off Weights shown in table 11.

[8] The number of crew includes all personnel on-board – some of which may not be designated crewmembers.

Table 11. Airplane Weight Categories

Weight Category	Airplane Maximum Take-Off Weight
B	12,500 lb to 100,000 lb
C	100,000 lb to 250,000 lb
D	250,000 lb to 400,000 lb
E	Greater than 400,000 lb

The distribution of the number of crew on-board for each airplane weight category was based on data for freighter airplanes contained in reference 3. Only U.S.-registered freighter airplanes, type-certificated to FAR Part 25 and operating under FAR Part 121, were selected from the database. The extracted data were assumed to follow Weibull distributions, which are shown in figure 14.

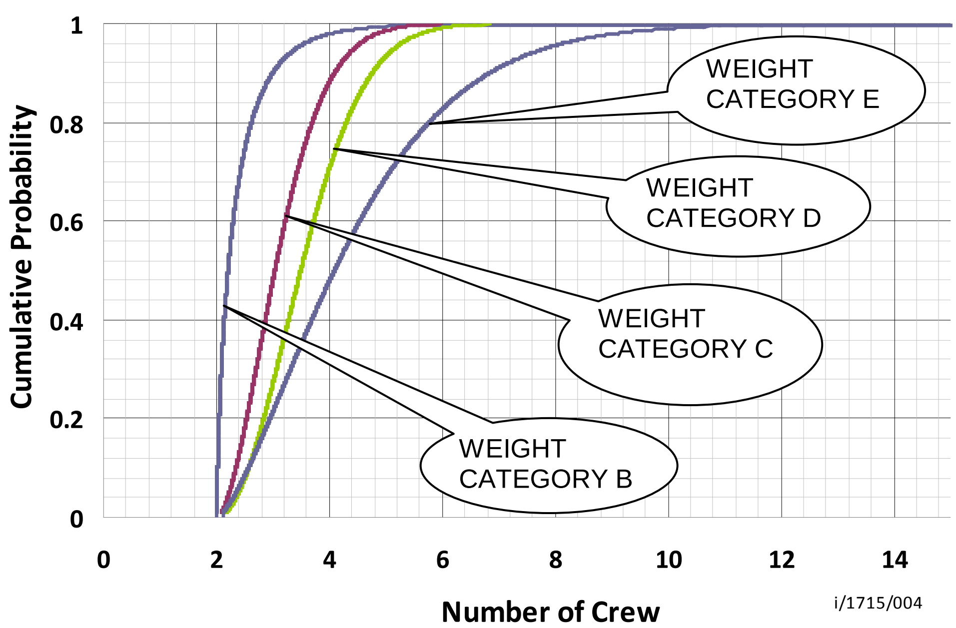

Figure 14. Distribution of Number of Crew

The weight categories of each of the freighter types 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 & 72	B
B727	C
B737	C
B747-100,200 & 300	E
B747-400	E
B757	C
B767-200	D
B767-300	E
B777	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 as shown in table 13, which is based on data obtained from reference 10. Serious injuries are assigned a monetary value of 2.66 million U.S. $. This is the average value for injuries classified as Severe (MAIS 4) and Critical (MAIS 5) based on reference 10.

Table 13. Monetary Value of Injuries

Injury Severity	Monetary Value Millions of U.S.$
Fatal	6.2
Serious	2.66

At each iteration of the model, and for each freighter type, the number of crew on-board the airplane is 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 is determined as described in section 8.1.3 and the cost of these injuries determined using the data illustrated in table 13. 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 x 4 x 6.2 + 0.5 x 4 x 2.66 million U.S. $

=12.4 + 5.32 million U.S. $

= 17.72 million U.S. $

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. Individual airplane valuations were therefore assessed based on freighter type and age. All of the freighter airplanes on the U.S. registry, of the types being considered in this analysis, were identified and their age 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 2011 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 2011 list price was estimated based on the Maximum Take-Off Weight (MTOW). The relationship between 2011 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 2011 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.

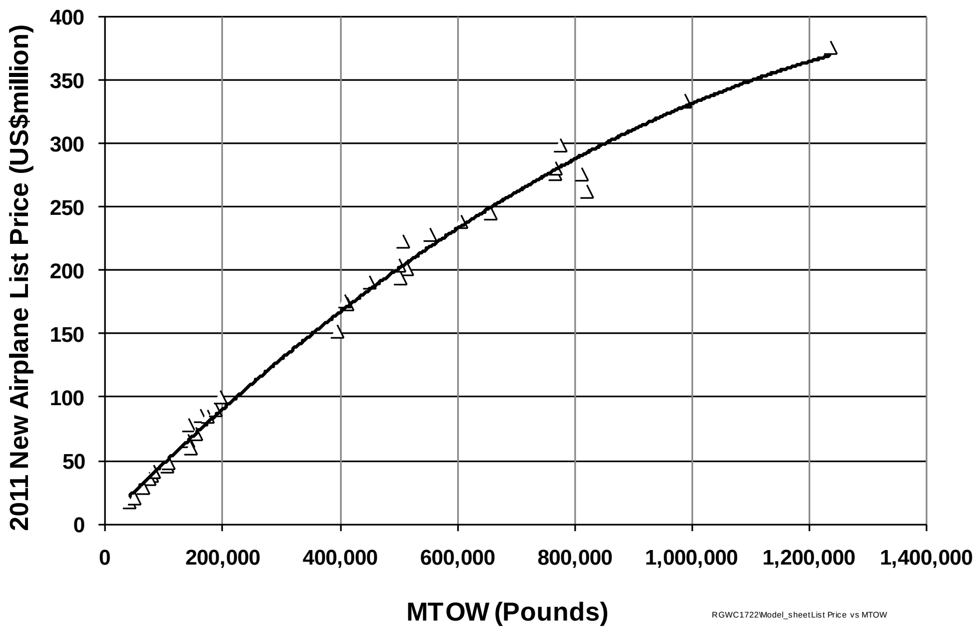

Figure 15. Relationship Between 2011 List Price and MTOW

Using this methodology a distribution was achieved of airplane values 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 on the appropriate accident dataset 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
Sustantial	0.8
Minor	0.2

This proportion is then multiplied by the airplane value derived in the manner described in section 8.3.1 to obtain 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 U.S. $ that sustained Substantial damage, would be:

0.8 x 250 million U.S. $ = 200 million U.S. $

8.4 CARGO DAMAGE.

Based on reference 5, the average cargo value per ton was taken as $64,997[9]. The average number of tons of cargo carried per flight in 2011 was assessed for each freighter type based on data contained in reference 5. 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 (U.S.$ Millions 2011)
A300	1.9
A310	1.1
ATR 42 & 72	0.2
B727	0.8
B737	0.4
B747-100, 200 & 300	2.3
B747-400	3.0
B757	1.0
B767-200	1.2
B767-300	1.6
B777	2.4
CV-580	0.1
DC-8	1.1
DC-9	0.2
DC-10	2.9
L-100	0.5
MD-11	2.5

Cargo damage is assessed in a similar manner to airplane damage. The cargo value appropriate to the freighter type is simply multiplied by the assessed proportion of cargo damage, determined by randomly selecting on the appropriate accident dataset allocated by the model (see section 8.1.3) in order to obtain a monetary value.

[9] 2007 data escalated at 2% per annum to 2010 and a further 3% to 2011 level

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

0.5 x 1.1 million U.S. $

= 0.55 million U.S. $

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 sequence to what might be expected from an in-flight cargo fire, an assessment was made of the value of the collateral damage. 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 10, and advice from the FAA Office of Aviation Policy and Plans.

Table 16. Monetary Value Used in the Assessment of Collateral Damage

Damage	Monetary Value U.S.$ Millions
Fatal Injury	6.2
Serious Injury	2.66
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.

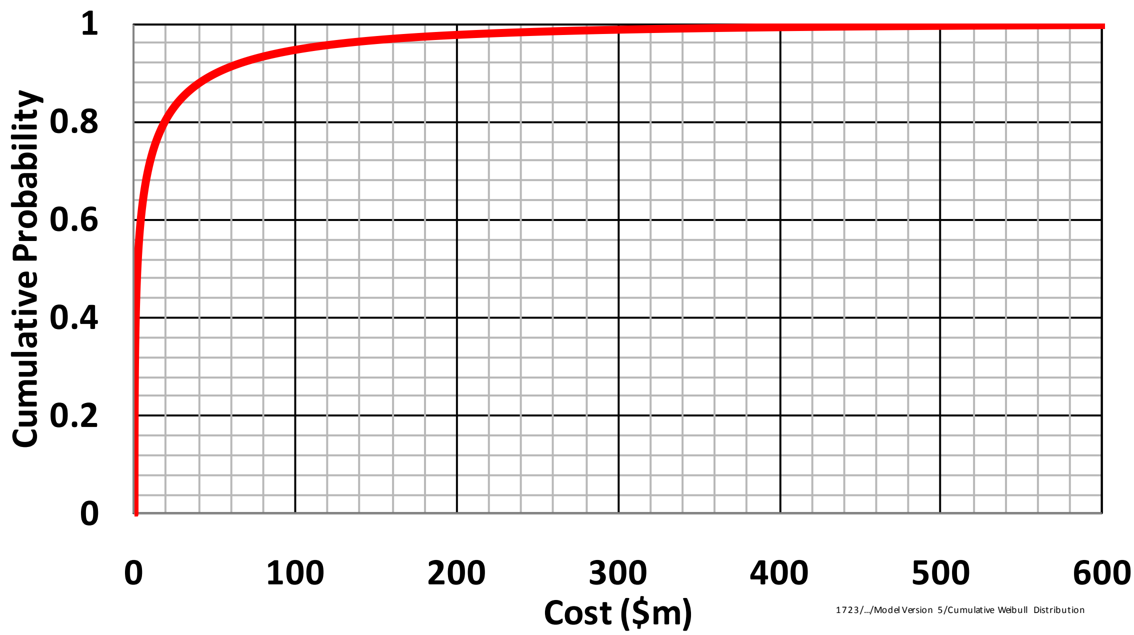

Figure 16. Probability Distribution of the Monetary Value of Collateral Damage

For accidents deemed to result 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 on the probability distributions of monetary values of collateral damage shown in figure 16.

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

8.6 TOTAL ACCIDENT COST.

The total damage cost per accident is simply 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 derive 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 on page 24. 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.

8.7 EXAMPLE MODEL OUTPUT.

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

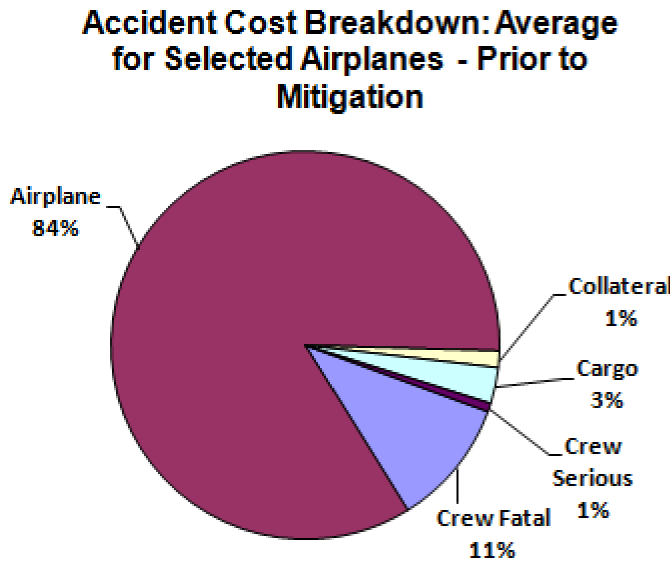

Figure 17. Example Accident Cost Breakdown

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, $\mathbf{C_0}$, as determined by the means described in section 8, is reduced by the mitigation. This annual benefit per freighter type, B, resulting from the introduction of mitigation is represented by equation 4.

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

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

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

10. RESIDUAL ACCIDENT COST.

The annual Residual Accident Cost is simply:

$$\text{Annual Residual Accident Cost} = C_0 - B$$

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 will vary only with the rate of change of revenue ton-miles.

All costs are derived at 2011 values. However, due to changes in the revenue ton-miles for both battery cargo and non-battery cargo the predicted annual cost distributions will change. The model assesses these costs, at 2011 values, for the years 2012 to 2026 inclusive and for any year range between 2012 and 2026. Figure 18 shows an example of the model prediction of the annual Residual Accident Cost over the period 2012 to 2026 (Average prediction =U.S. $16.0 million) together with its confidence range. For the example shown in figure 18 the cost in which one can be 95% confident of not exceeding is approximately U.S. $23 million.

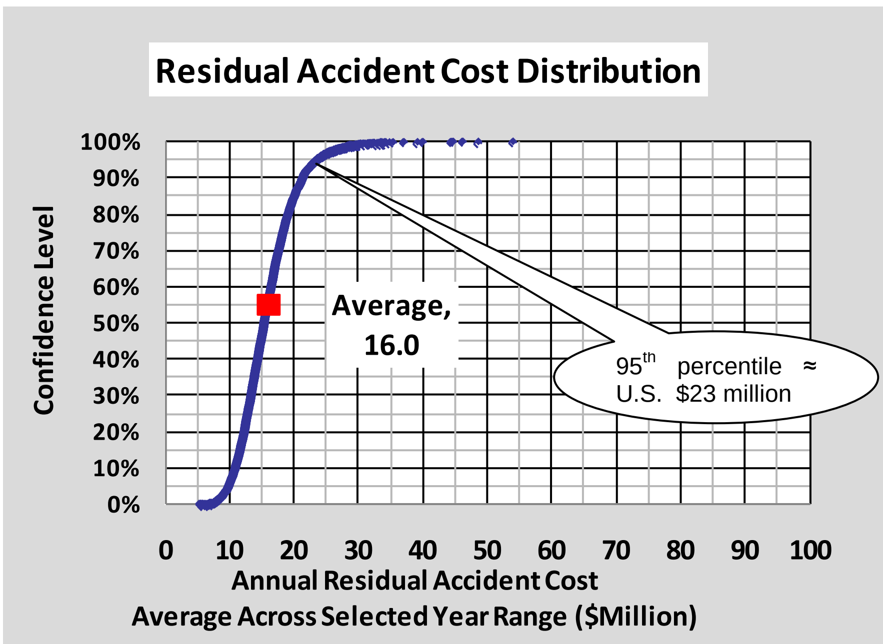

Figure 18. Example Confidence Range in the Predicted Annual Residual Accident Cost – Illustration Only

The predicted average annual accident cost is also displayed by the model for each year from 2012 to 2026 as illustrated in figure 19.

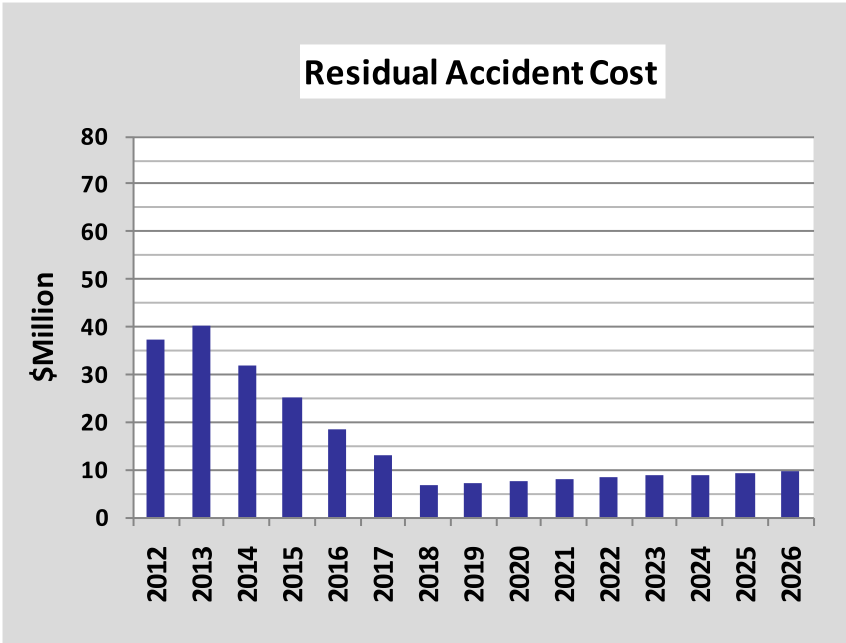

Figure 19. Annual Prediction of Average Residual Accident Cost – Illustration Only

11. COSTS OF MITIGATION.

11.1 DATA INPUT – GENERAL.

For most of the proposed mitigation means precise data pertaining to the cost assessments are not available at this time. However, the Cost sub-Model has been constructed to allow User Input Variables of certain values as defined in this section. The model user may change these values by simply clicking on the User Data Input tab and entering the desired value in the appropriate cell. Selecting the Default button resets all of the values to the default values. 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.

This 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:

$$w \times g \times h \times c \quad (5)$$

Where:

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

11.2.1 System Weight, w.

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

11.2.2 Incremental Fuel Burn per Pound per Airplane Flight Hour, g.

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 11. 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 Flight Hour
A300	0.004
A310	0.004
ATR 42 & 72	0.001
B727	0.006
B737	0.0045
B747-100, 200 & 300	0.0045
B747-400	0.0065
B757	0.0055
B767-200	0.005
B767-300	0.005
B777	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 Year in 2011 – U.S.-Registered Fleet of Freighter Airplanes, h.

The number of flight hours accumulated by each U.S.-registered freighter type during 2011 is shown in table 18.

Table 18. Number of Flight Hours Accumulated by the U.S.-Registered Fleet of Freighter Airplanes in 2011

Freighter Type	Flight Hours Per Annum
A300	141,489
A310	38,170
ATR42 & 72	5,922
B727	53,351
B737	12,840
B747-100,200 & 300	54,446
B747-400	156,534
B757	94,619
B767-200	51,094
B767-300	116,719
B777	68,719
CV-580	7,890
DC-8	16,274
DC-9	6,379
DC-10	103,216
L-100	4,386
MD-11	285,403

11.2.4 Fuel Cost, c.

Figure 20 illustrates the variation in fuel cost per U.S. gallon over the period May 2000 to June 2012 which was obtained from reference 12.

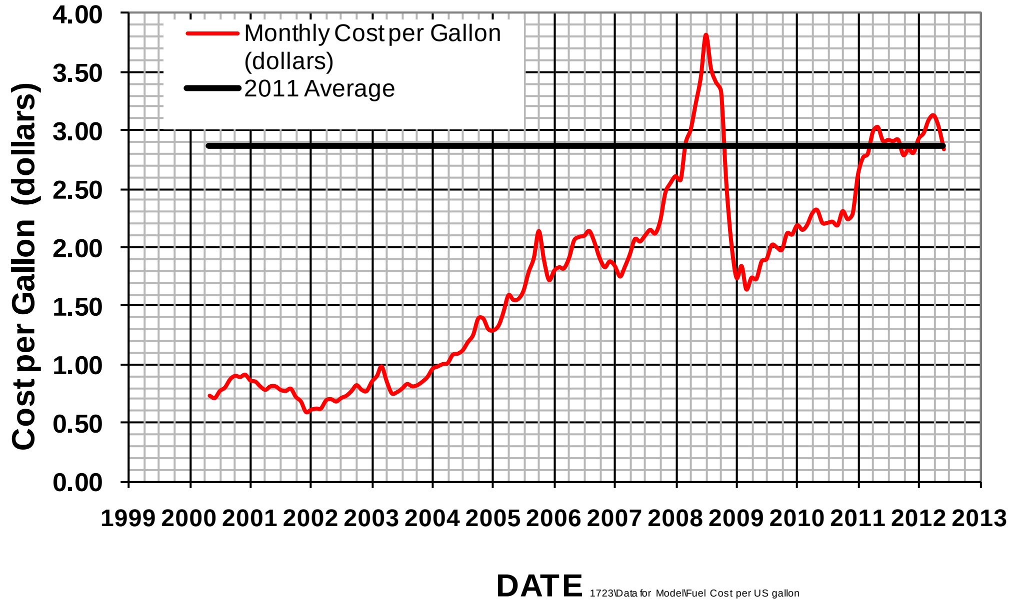

Figure 20. Variation in Fuel Cost per U.S. Gallon Over the Period May 2000 to June 2012

The fuel cost for 2011 was typically U.S. $2.86 per gallon. This is taken as the default value but is a User Input Variable and may be varied from the User Data Input tab.

Table 19. Base Data for Fuel Costs

Data	Units	Default Value	User Input Variable
Fuel Costs	U.S. $ 2011 per U.S. gallon	2.86	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 will 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 this data is 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
Boeing 727 Container Suppression – External - System Weight	lb	450	Yes
Boeing 777 Container Suppression – External - System Weight	lb	1,000	Yes
Boeing 727 Container Suppression – External - System Installation Cost	U.S.$ 2011	$206,000	Yes
Boeing 777 Container Suppression – External - System Installation Cost	U.S.$ 2011	$515,000	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 the installation of 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 sub-Model has been 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 volume available for containers (or pallets)[10]. The non-Class C volumes applicable to the freighter airplanes in the U.S.-registered fleet are shown in table 21.

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

Freighter Type	Non Class C Volume ft^3
A300	11,154
A310	8,759
ATR 42 & 72	1,121
B727	5,280
B737	3,520
B747-100,200 & 300	19,536
B747-400	21,462
B757	6,600
B767-200	9,500
B767-300	15,395
B777	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 then derived from equation 5 on page 38.

11.3.3.3 Cost.

The installation cost for an external container suppression system, on an in-service airplane, is handled in a similar manner to system weights in that User Input Variables are added for two of the freighter types listed in table 5 as selected by the user. The default values shown in table 20 were derived from estimates made by engineers involved in the project.

[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 7.6 regarding proportion of cargo carried in containers and pallets.

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 volume available for containers shown in table 21. Since it is recognized that the cost of introducing the mitigation means on in-service airplanes is likely to be greater than that on new build airplanes, the model has a User Input Variable which is the ratio of these two costs. The default value of this ratio is 1.1.

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%[11].

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 airplane systems. As with external container suppression systems, they will only address cargo fires originating within 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 to be 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 utilized by the U.S.-registered freighter fleet is 3 times the number that are actually on-board 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.

[11] See section 11.9.3.3

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	U.S.$ 2011	$5,200	Yes
System Installation Cost for M1 Container	U.S.$ 2011	$6,200	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.

Weights for the installation of an Internal Container Suppression System are not currently available. However, the Cost sub-Model has been developed to enable weights to be added as User Input Variables for two container types (LD3, M1) on the User Data Input tab. The default values for an LD3 and M1 container are as shown in table 22.

The Cost sub-Model will then assess the average weight increase per unit volume of container and derive the likely system weights for all freighter types based on the assumption that the weight is a direct function of the non-Class C volume that is available for containers[12] as shown 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 then derived from equation 5 on page 38.

11.4.3.3 Cost.

The installation cost for an Internal Container Suppression System is handled in a similar manner to system weights in that User Input Variables are added for two container types (LD3, M1) by the user on the User Data Input tab. The Cost sub-Model will then assess the likely installation costs for all freighter types based on the assumption that the cost is a direct function of the non-Class C volume that is available for containers shown in table 21. The default values for an LD3 and M1 container are as shown in table 22.

[12] See section 7.6 regarding proportion of cargo carried in containers

It is estimated that the ratio of the total number of containers required to those actually utilized on an airplane, is in the region of 3 to 1. This ratio is a User Input Variable to the model with a default value of 3.

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%[13].

11.5 PALLET COVERS.

11.5.1 System Overview.

Pallet Covers are applied to each pallet transported in freighter airplane cargo compartments other than 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 4 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 to the model via the User Data Input tab. To facilitate this, two standard pallet sizes are provided. The User may input data pertinent to the pallet sizes shown in table 23.

Table 23. Pallet Types – Dimensions in Inches

Pallet Dimensions (Inches)
64H x 125 x 96
118H x 125 x 96

[13] See section 11.9.3.3

The primary data used by the Cost sub-Model are shown in table 24.

Table 24. Base Data for Pallet Covers

Data	Units	Default Value	User Input Variable
Pallet Cover Weight for a 64H x 125 x 96 Pallet	lb	55	YES
Pallet Cover Weight for a 118H x 125 x 96 Pallet	lb	106	YES
Pallet Cover Cost for a 64H x 125 x 96 Pallet	U.S.$ 2011	$1,800	YES
Pallet Cover Cost for a 118H x 125 x 96 Pallet	U.S.$ 2011	$2,800	YES
Ratio of Total Number of Pallet Covers to Airborne Pallet Covers	-	4	YES
Pallet Cover Life	Flights	300	YES
Annual Repair Cost as a percentage of Replacement Cost	-	25%	YES
Time taken to Install and Remove a 64H x 125 x 96 Pallet Cover	Man-hours	0.15	YES
Time taken to Install and Remove a 118H x 125 x 96 Pallet Cover	Man-hours	0.25	YES
Freighter Operator Labor Rate	U.S.$ 2011	$30	YES

11.5.3.2 Weight.

User Input Variables are required of weights for Pallet Covers taking into account any differences in weights of nets that might result from meeting the requisite fire standards. The Cost sub-Model has been developed to enable User Input Variables to be added for two pallet sizes. The Cost sub-Model will then assess the likely weights for all freighter types based on the assumption that the weight is a direct function of the non-Class C volume that is available for pallets[14] shown in table 21. The default values shown in table 24 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 then derived from equation 5 on page 38.

[14] See section 7.6 regarding proportion of cargo carried on pallets

11.5.3.3 Cost.

The installation cost for Pallet Covers is handled in a similar manner to that used for the weight assessment, in that User Input Variables are added for two pallet sizes. The Cost sub-Model will then assess the likely installation costs for all freighter types based on the assumption that the weight is a direct function of the non-Class C volume that is available for pallets shown in table 21. The default values shown in table 24 were derived from estimates made by engineers involved in the project.

However, the number of Pallet Covers required will be more than those required to accommodate the cargo palletized on one airplane since others are needed for cargo that is being prepared and there will be a number in storage. It is estimated that the ratio of the total number of Pallet Covers required to those actually utilized on an airplane, is in the region of 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 simply 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.

During a Pallet Cover's life it is likely to require some repair. 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%.

A further cost incurred from Pallet Covers results from the time taken to install them on a pallet and their subsequent removal. This assessment of man-hours is handled in a similar manner to the weight assessment, in that User Input Variables are required for two pallet sizes. The default man-hours for installation and removal are 0.15 man-hours for a 64H x 125 x 96 pallet and 0.25 man-hours for a 118H x 125 x 96 pallet. The Cost sub-Model will then assess 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 volume that is available for containers.

The labor rate assumed to be typical of U.S.-registered freighter operators is 30 U.S. $ per man-hour - this is taken as the default value.

11.6 SECONDARY BATTERY BOXES.

11.6.1 System Overview.

This mitigation strategy would require that Secondary Lithium batteries that are transported on U.S.-registered freighter airplanes are packed in boxes, which have been shown to contain a fire originating from the batteries. As such user selection of this mitigation strategy in the model 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 is the 18650 Cylindrical Cell which is approximately 45 grams or 0.1 pounds in weight and has dimensions of 65 mm in length by 18 mm 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 sub-Model is shown in table 25.

Table 25. 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 2011	-	$3,700 \times 10^6$	NO
Proportion of Worldwide Secondary Battery Production Shipped by Freighter Airplanes	-	100%	YES
Proportion of Batteries Shipped by Freighter Airplanes that are carried on the U.S.-Registered Fleet	-	50%	YES
Battery Box Costs	U.S.$ 2011	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. A typical limit is 30 kilograms or approximately 67 lb.; hence this value is taken as the default value in the Cost sub-Model. However, this limit is likely to vary in different countries and within companies hence this model Input is a User Input Variable.

The box weight will be dependent on the materials needed to meet any specified fire standard that might be developed. 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 simply 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 may be calculated as 66.5 ÷ 0.1 = 665.

Based on data contained in reference 8 it is assessed that the Number of Secondary Batteries produced in 2011 was $3,700 \times 10^6$. It is further assumed that 100% of these Secondary Batteries were carried by freighter airplanes, of which 50%[15] were carried on U.S.-registered freighter airplanes – $1,850 \times 10^6$.

Now the proportion, P, of the batteries carried on each freighter type may 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 fleet of freighter airplanes in 2011.

Therefore, the number of Secondary Batteries carried by a particular freighter type in 2011 would be:

$$P \times 1,850 \times 10^6$$

And the number of Secondary Battery boxes carried for a particular freighter type, in 2011, would be:

$$P \times 1,850 \times 10^6 \div n$$

Therefore, the number of Secondary Battery boxes carried per flight is given by:

$$P \times 1,850 \times 10^6 \div nf \tag{7}$$

The incremental increase in weight per flight may therefore be derived by simply 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 then derived from equation 5 on page 38.

[15] These assumptions are User Input Variables which may be varied on the User Data Input tab.

11.6.3.3 Cost.

The Box Cost will be dependent on the materials needed to meet any specified fire standard that might be developed. Since boxes of this kind do not currently exist precise determinations cannot be made of their cost. A default value of U.S. $ 10 per battery box has been assumed.

11.7 PRIMARY BATTERY BOXES.

11.7.1 System Overview.

This mitigation strategy would require that non-rechargeable Primary Lithium batteries, often called Lithium-Metal batteries, that are transported on U.S.-registered airplanes are packed in boxes, which have been shown to contain a fire originating from the batteries. As such user selection of this mitigation strategy in the model 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 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 pounds in weight and has dimensions of 65 mm in length by 18 mm 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 information contained in reference 9, it is estimated that primary lithium battery cell production is approximately 25% of that for secondary lithium battery cells. It is 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 which may be varied on the User Data Input tab. All Primary Battery algorithms used in the Cost sub-Model are the same as for Secondary Batteries.

11.7.3.1 Base Data and User Input Variables.

The primary data used by the Cost sub-Model is shown in table 26.

Table 26. 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 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 on the U.S.-Registered fleet	-	50%	Yes
Battery Box Costs	U.S.$ 2011	10	Yes

11.8 FIRE HARDENED CONTAINERS.

11.8.1 System Overview.

Fire Hardened Containers would be designed to accommodate a fire threat defined by the Authorities. The containers will 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 utilized by the U.S.-registered freighter fleet is 3 times the number that are actually on-board airplanes (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 sub-Model for Fire Hardened Containers are shown in table 27.

Table 27. 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
M1 Existing Container Weight	lb.	792	No
LD3 Existing Container Volume	ft^3	152	No
M1 Existing Container Volume	ft3	621	No
LD3 Existing Container Cost	U.S.$ 2011	$1,800	Yes
M1 Existing Container Cost	U.S.$ 2011	$2,200	Yes
Ratio: Fire Hardened / Standard Container Cost	-	1.5	Yes
Ratio: Number of Containers in fleet to those on-board airplanes	-	3	Yes
Existing Container Life	Flights	5,000	Yes
Fire Hardened Container Life	Flights	6,000	Yes
Annual Maintenance Cost as a percentage of Installation Cost	-	1%	Yes

11.8.3.2 Weight.

Weights for the installation of Fire Hardened Containers are not currently available. However, the Cost sub-Model has been 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 27 shows typical weights for LD3 and M1 existing conventional containers. Using these weights, the percentage weight increase assigned to Fire Hardened Containers and the known volume of LD3 and M1 containers, as shown in table 27, the Cost sub-Model derives an average weight increase per unit volume.

The Cost sub-Model then 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 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 then derived from equation 5 on page 38.

11.8.3.3 Cost.

The installation cost for Fire Hardened Containers is based on User Inputs of costs for two existing conventional container sizes. The default costs for the two containers are shown in table 27. 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 and M1 Fire Hardened Containers can therefore be derived by simply multiplying the costs of a conventional container by the default ratio (1.5).

Using these costs and the known volume of LD3 and M1 containers, as shown in table 27, the Cost sub-Model derives an average cost increase per unit volume. The Cost sub-Model then 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 volume that is available for 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 there will be a number in storage. It is estimated that the ratio of the total number of containers required to those actually utilized on an airplane, is in the region of 3 to 1. This ratio is a User Input Variable to the model with a default value of 3. The Cost sub-Model simply factors the derived cost per freighter type, to accommodate these additional containers.

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

$$f \text{ x } \{C_H/L_H - C_E/L_E\} \quad (8)$$

Where:

f is the number of flights per annum for the freighter type
C_H is the cost of a hardened container (U.S. $ 2011)
L_H is the life of a hardened container (flights)
C_E is the cost of an existing container (U.S. $ 2011)
L_E is 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 27. The container costs are converted by the Cost sub-Model to an annual average replacement cost per cubic foot. Since the non-Class C volume that is available for containers is known, the cost per annum may be derived for each freighter type.

During a container's life it is likely to require some repair. This repair cost may be expressed as a percentage of the cost of a new container. This percentage is a User Input Variable to the model with a default value of 1% - which is assumed to be applicable to both existing and Fire Hardened Containers. The Cost sub-Model derives this cost as a difference between the repair cost for an existing and for a Fire Hardened Container.

11.9 COMPARTMENT SUPPRESSION.

11.9.1 System Overview.

The system is based on the use of a suppressant having the fire extinguishing properties of Halon 1301. Existing fire or smoke detection systems already on-board freighter airplanes could be retained as part of any Halon fire suppression system and, therefore, 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 recognized that Halon is being phased out due to its ozone depleting characteristics, and therefore 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. Therefore, a Halon fire suppression system has been 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 exist 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 a Compartment Suppression System are based on an Aviation Rulemaking Advisory Committee (ARAC) document, reference 13, and the study carried out for the FAA, reference 6.

11.9.3.1 Base Data and User Input Variables.

The primary data used by the Cost sub-Model for a Compartment Suppression System are shown in table 28.

Table 28. 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	U.S.$ 2011	$749,000	Yes
Boeing 747-400 Suppression System Installation Costs	U.S.$ 2011	$3,756,000	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 14 the weight of a suppression system and smoke detection system fitted to the lower deck cargo compartments of a Boeing 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 illustrated in table 29. For a Boeing 737 airplane this equates to a system weight of approximately 330 lb. and for a Boeing 747-400 freighter airplane 2,010 lb. These two freighter airplane types and corresponding system weights are used as the default values for the User Input Variables in the model.

The Cost sub-Model has been developed to enable User Input Variables to be added for any two freighter airplane types in the 2011 U.S.-registered fleet as selected by the user from a dropdown menu. The Cost sub-Model will then 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 volume. 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 then derived from equation 5 on page 38.

Table 29. Total Non-Class C Cargo Compartment Volumes

Freighter Type	Non Class C Volume ft^3
A300	11,154
A310	8,759
ATR 42 & 72	1,542
B727	6,805
B737	3,520
B747-100,200 & 300	19,825
B747-400	21,462
B757	7,602
B767-200	9,500
B767-300	15,797
B777	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

11.9.3.3 Cost.

The installation cost for a Compartment Suppression System is handled in a similar manner to that used for the weight assessment, in that User Input Variables are added for any two freighter airplane types in the 2011 U.S.-registered fleet as selected by the user from a dropdown menu.

The study carried out on behalf of the FAA (reference 6) derived installation and development[16] costs, on an in-service freighter airplane, for a Cargo Compartment Suppression System for each of the four freighter airplane weight categories. These costs were derived at 2007 prices so were escalated to 2011 prices, for this study, using an inflation rate of 2% per annum up to 2010 and 3% for 2011.

It is assumed that the Cargo Compartment Suppression System cost is directly related to the cargo compartment volume for each of the freighter airplane types. On this basis an assessment may be made of the cost for each freighter airplane type using the compartment volumes

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

illustrated in table 29. For a Boeing 737 airplane this equates to a system cost of U.S. (2011) $748,800 and for a Boeing 747-400 freighter airplane U.S. (2011) $3,756,400. These costs are used as the default values in the model for these two freighter airplane types. Since it is recognized that the cost of introducing the mitigation means on in-service airplanes is likely to be greater than that on new build airplanes, the model has a User Input Variable which is the ratio of these two costs. The default value of this ratio is 1.1.

Based on the FAA study (reference 6) maintenance costs were assessed to be approximately 0.3% of the installation costs. However, for this study it is pessimistically assumed that the maintenance cost per annum is 1% of the installation cost. This is the default value used by the Cost sub-Model.

12. BENEFIT COST RATIOS.

The Benefit Cost Ratio is simply 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 illustrated on the Control Panel tab for each freighter type selected for mitigation.

Figure 21 illustrates a typical model output of the variation in Benefit Cost Ratio for the fleet over the period 2012 to 2026.

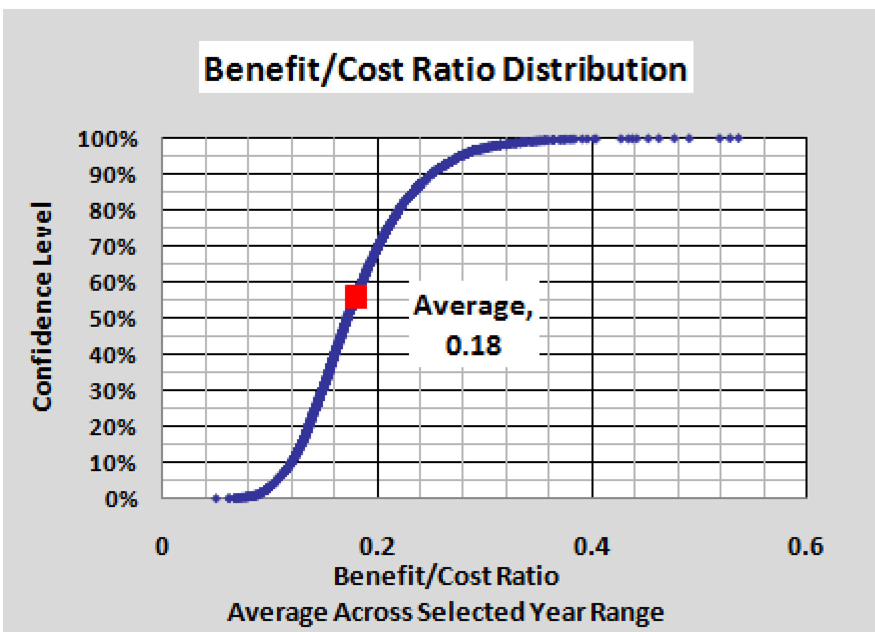

Figure 21. Benefit Cost Ratio Distribution 2012 to 2026 – Illustration Only

Figure 22 illustrates the variation in Benefit Cost Ratio, for each freighter type selected for mitigation.

Ave Benefit/Cost Ratio - Selected Years	
A300	0.07
A310	0.03
ATR42 & 72	0.00
B727	0.01
B737	0.00
B747-100,200 & 300	0.08
B747-400	0.44
B757	0.02
B767-200	0.03
B767-300	0.23
B777	1.24
CV-580	0.00
DC-8	0.01
DC-9	0.00
DC-10	0.05
L-100	0.00
MD-11	0.20

Figure 22. Average Benefit Cost by Freighter Type – Illustration Only

Figure 23 illustrates a typical Model output of the variation in Benefit Cost Ratio for the whole U.S.-registered fleet over the period 2012 to 2026.

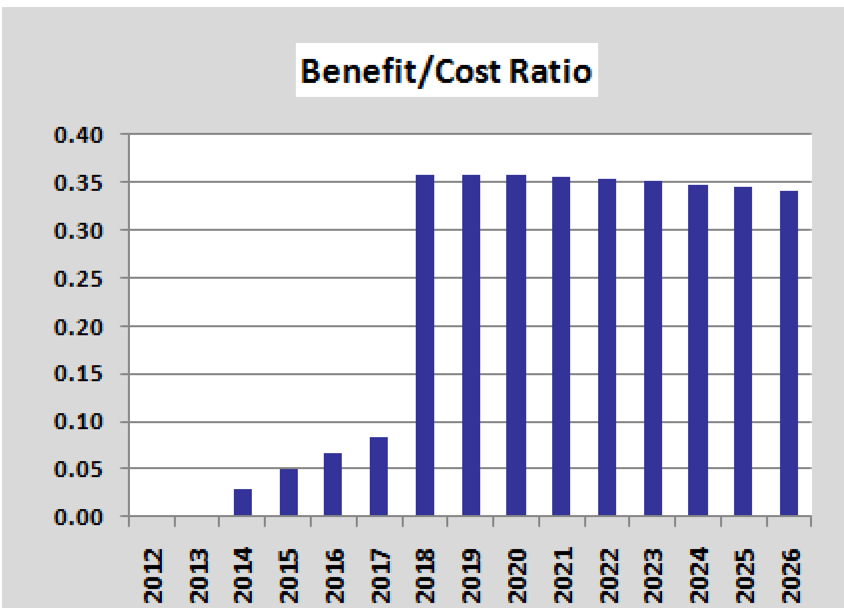

Figure 23. Benefit Cost Ratio Variation 2012 to 2026 – Illustration Only

13. USING THE MODEL.

It is recommended the model is opened in Microsoft® Excel® 2007 or later. 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 to the U.S.-registered freighter fleet, carry out the following steps on the Control Panel tab:

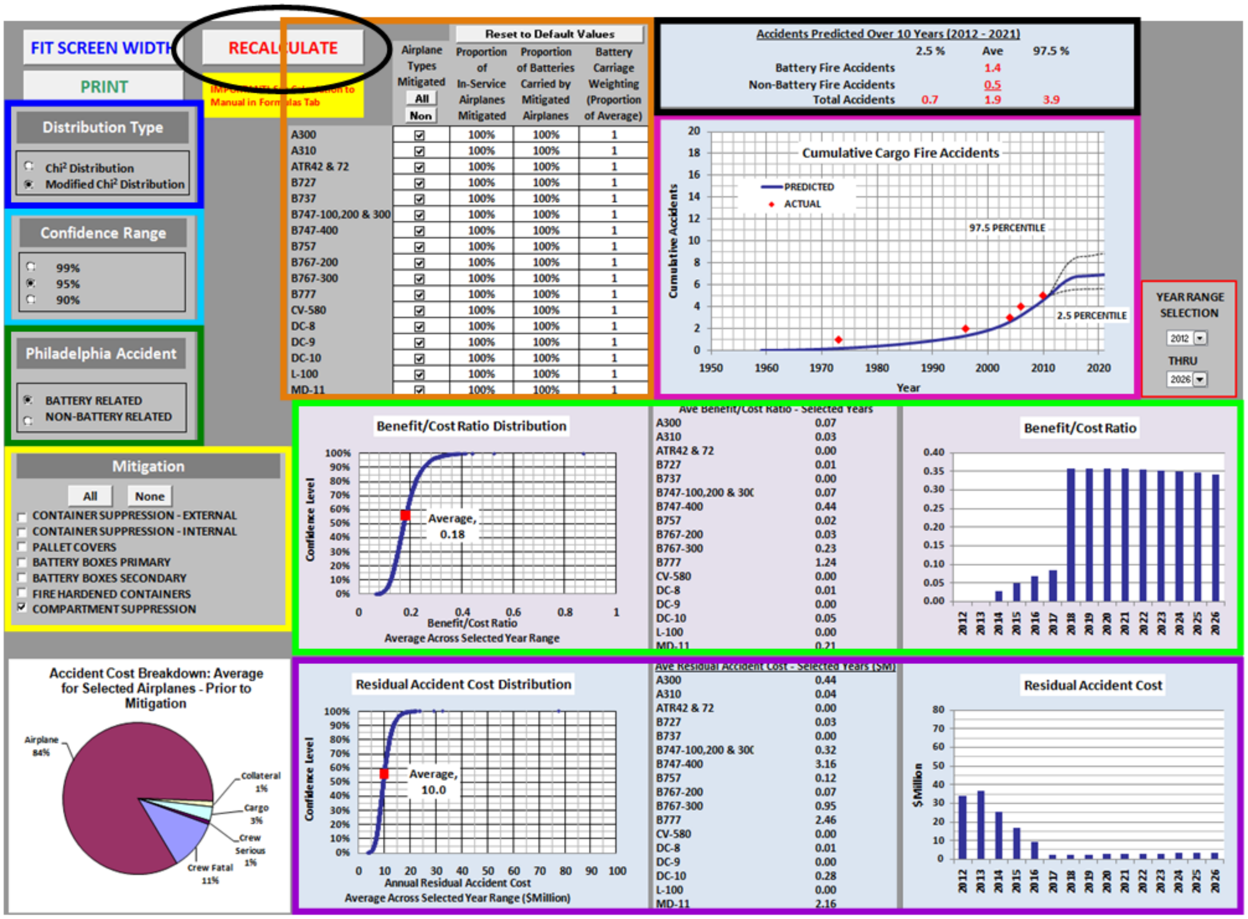

Figure 24. Control Panel Tab (Upper Section)

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

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

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

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

e) Click on the Recalculate button (see black circle in figure 24).

The likely number of cargo fire accidents, together with a confidence range, through to the year 2021 is displayed on the Cumulative Cargo Fire Accidents graph on the Control Panel tab (see pink outline in figure 24). The table headed Accidents Predicted over 10 Years (2012-2021) displays the average number of Battery Fire Accidents and Non-Battery Fire Accidents expected over the period (see black outline in figure 24). 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, carry out the following steps on the Control Panel tab:

a) Go through steps a) to d) in section 13.1.
b) On the Airplane Type menu (see orange outline in figure 24), for each airplane type, select the Battery Carriage Weighting Factor (using the dropdown menu). (Refer to section 4.2 for explanation for Battery Carriage Weighting factor.)
c) 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).
d) Click on the Recalcuate button (see black circle in figure 24).

Refer to the purple outline in figure 24. 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. This average Accident Cost over the period is subdivided into each of the freighter types in the table headed Average Residual Accident Cost - Selected Years ($M). The average Accident Cost per year through to 2026 is displayed on the graph headed Residual Accident Cost.

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

To determine the number of accidents, after the introduction of some mitigation means being introduced to the U.S.-registered freighter fleet, carry out the following steps on the Control Panel tab:

a) Select either Battery Involvement or No Battery Involvement from the Philadelphia Accident menu (see dark green outline in figure 24).
b) Select either Chi^2 Distribution or Modified Chi^2 Distribution from the Distribution Type menu (see dark blue outline in figure 24).
c) Select either 90%, 95% or 99% from the Confidence Range menu (see pale blue outline in figure 24).
d) On the Mitigation menu select the mitigation strategy or combination of mitigation strategies to be applied[17] (see yellow outline in figure 24).

[17] It should be noted 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 .

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 Airplane Type menu (see orange outline in figure 24), for each airplane type, select (using the dropdown menu) the proportion of in-service airplanes that are to be mitigated.

h) On the Airplane Type menu (see orange outline in figure 24), for each airplane type, select (using the dropdown menu) the proportion of batteries that will be carried by the mitigated airplanes of that type.

i) On the Airplane Type menu (see orange outline in figure 24), for each airplane type, select the Battery Carriage Weighting Factor (using the dropdown menu). (Refer to section 4.2 for explanation for Battery Carriage Weighting factor.)

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

k) On the Control Panel tab click on the Recalculate button (see black circle in figure 24).

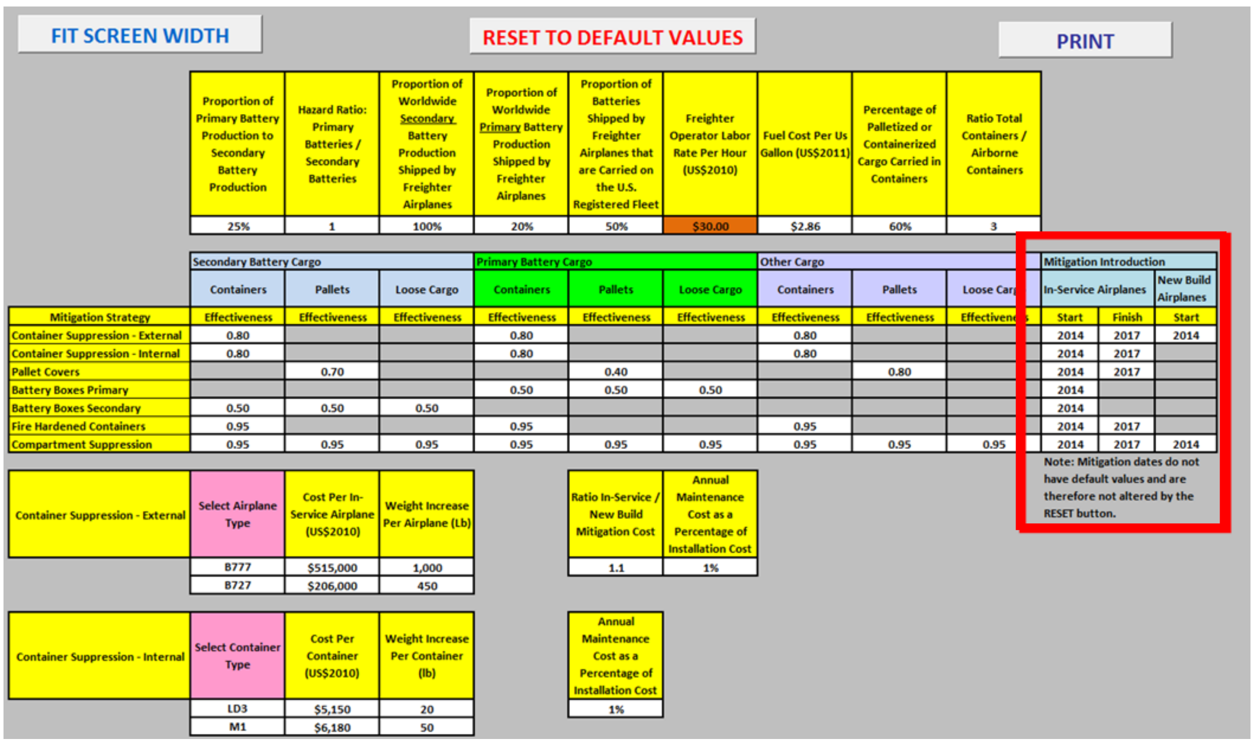

Figure 25. User Data Input Tab (Upper Section)

The likely number of cargo fire accidents, together with a confidence range, through to the year 2021 is displayed on the Cumulative Cargo Fire Accidents graph on the Control Panel tab (see pink outline in figure 24). The table headed Accidents Predicted over 10 Years (2012-2021) displays the average number of Battery Fire Accidents and Non-Battery Fire Accidents expected over the period (see black outline in figure 24). The bottom row of this table displays the total number of accidents expected together with a range appropriate to that selected in c) above.

Refer to the purple outline in figure 24. 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. This average Accident Cost over the period is subdivided into each of the freighter types in the table headed Average Residual Accident Cost - Selected Years ($M). The average Accident Cost per year through to 2026 is displayed on the graph headed Residual Accident Cost.

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) Go through steps a) to j) in section 13.3.
b) On the User Data Input tab Either
    i. Set data to the Default Values by clicking on the Reset to Default Values button. (all default values are contained in section 11 of this report), or
    ii. Review the data appropriate to the mitigation selected and change any of the values in the cells on this tab by simply clicking on the appropriate cell and typing in the required value.
c) On the Control Panel tab click on the Recalcuate button (see black circle in figure 24).

Refer to the red outline in figure 26. The average annual Benefit over the selected period and the predicted confidence range is displayed on the Benefit Distribution graph on the Control Panel tab. This average Benefit over the period is subdivided into each of the freighter types in the table headed Average Benefit – Selected Years ($M). The average Benefit per year through to 2026 is displayed on the graph headed Benefit.

Refer to the yellow outline in figure 26. The average Mitigation Cost over the selected period is subdivided into each of the freighter types in the table headed Average Mitigation Cost – Selected Years ($M). The Average Mitigation Cost per year through to 2026 is displayed on the graph headed Mitigation Cost.

Refer to the pale green outline in figure 24. The average annual Benefit/Cost Ratio over the selected period and the predicted confidence range is displayed on the Benefit/Cost Ratio Distribution graph on the Control Panel tab. This average Benefit/Cost Ratio over the period is subdivided into each of the freighter types in the table headed Average Benefit/Cost Ratio – Selected Years. The average Benefit/Cost Ratio per year through to 2026 is displayed on the graph headed Benefit/Cost Ratio.

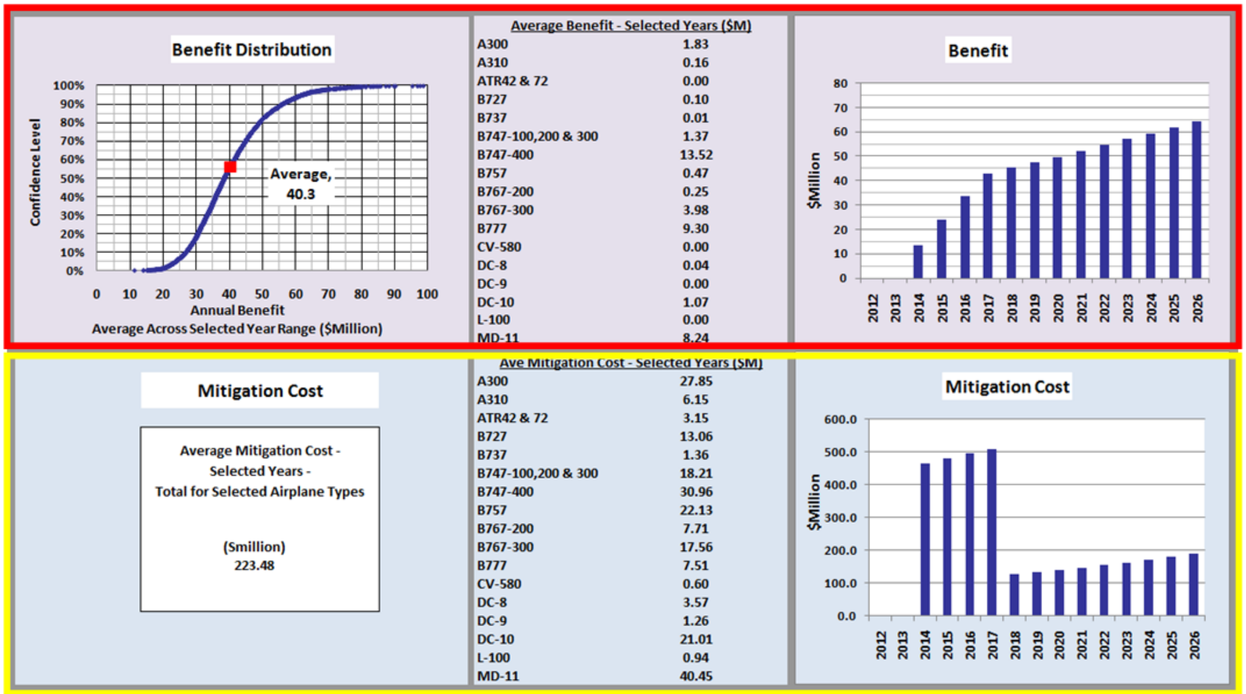

Figure 26. Control Panel Tab (Lower Section)

14. SUMMARY AND CONCLUSIONS.

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 through to 2021, are shown in figure 27.

Accidents Predicted Over 10 Years (2012 - 2021)			
	2.5 %	Ave	97.5 %
Battery Fire Accidents		4.1	
Non-Battery Fire Accidents		1.6	
Total Accidents	2.1	5.7	11.6

Figure 27. Predicted Average and 95 Percentile Range of the Number of Cargo Fire Accidents Through to 2021

This prediction is primarily dependent on the forecast of the number of revenue ton-miles through to 2021, which cannot be predicted with accuracy, and the assessment of the threat from lithium batteries.

However, if it were optimistically assumed there was no increase in threat due to the shipment of lithium batteries then it would still be expected that there would be a further 3 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 revenue ton-miles for the U.S.-registered freighter fleet was constant through to 2021 at the 2011 annual level a further 2 accidents would be expected.

Since it would appear likely that there is a real threat from lithium batteries, and it is also likely that the revenue ton-miles for the U.S.-registered freighter fleet will continue to increase, the model predictions are considered reasonable.

14.2 FUTURE PREDICTION OF BENEFIT AND ACCIDENT COST.

If no mitigation action is taken, Accident Costs are likely to average approximately 50 million U.S. $ per annum over the period 2012 to 2026. 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 that in 2011 through to 2026 in terms of the sizes and values of airplanes. However, it might be expected that 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 which are mitigated.

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 the reduction in 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 on the number of accidents it is likely that a means would need to be found of addressing the threat from cargo carried in containers, pallets and as loose cargo. This might be accommodated by a Compartment Suppression system or by a combination of mitigation means aimed at addressing all means of shipment.

Should reliable data not become available regarding the costs of the proposed mitigation means an alternative approach might be to determine the installation costs, weight and effectiveness that would be needed in order that they might be cost effective.

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APPENDIX A – 14 CFR 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.]