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ACCIDENT COSTS FOR A CAUSAL MODEL OF AIR TRANSPORT SAFETY

A.L.C. Roelen
J.W. Smeltink

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Executive summary

Accident Costs for a Causal Model of Air Transport Safety

Problem area
A causal model for air transport safety (CATS) is being developed. The purpose of the model is to describe the air traffic system and in particular its safety functions in such a way that it is possible to analyse the effects of risk reducing alternatives and to serve as a means of communication between experts and managers within the industry.

The model combines Event Sequence Diagrams (ESDs), Fault Trees and Bayesian Belief Nets into a single structure. The ESDs are used to represent accident scenarios like e.g. mid-air collision, structure overload, and fire/explosion. The scenarios terminate in one or more end states, e.g. runway overrun, collision with ground, or aircraft continues flight. For each end state, the consequence in terms of aircraft damage and occupant fatality was determined.

Description of work
The objective of this part of the study, as part of the CATS model development, is to describe accident costs for ESD end states. This information is intended as part the CATS consequence model.

Results and conclusions
Accident and incident costs have been determined for each end state. The aircraft damage percentage, the occupant fatality percentage and runway closure time are required as parameter input for the accident and incident costs. Values for these three parameters have been given for each end state.

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Author(s)
A.L.C. Roelen
J.W. Smeltink

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NLR Air Transport Safety Institute
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Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 20 511 31 13, Fax +31 20 511 32 10, Web site: www.nlr.nl

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A.L.C. Roelen
J.W. Smeltink

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Contents

1 Introduction

1.1 Background

The Netherlands Ministry of Transport has initiated a research effort to develop a causal model for air transport safety (CATS) [Ale et al 2005, Ale et al 2007]. The purpose of the model is to describe the air traffic system and its safety functions in such a way that it is possible to analyse risk reduction alternatives and to serve as a means of communication between experts and managers within the industry. The model combines Event Sequence Diagrams (ESDs), Fault Trees and Bayesian Belief Nets into a single structure. The ESDs are used to represent accident scenarios like e.g. abrupt manoeuvre, uncontrolled collision with ground, controlled flight into terrain, forced landing, mid-air collision, collision on ground, structure overload, or fire/explosion. A total of 33 generic accident scenarios were developed [Roelen and Wever, 2005]. An ESD consists of an initiating event, pivotal events and end states. Where necessary, the initiating and pivotal events are detailed in a submodel which can be a Fault Tree or a Bayesian Belief Net. In the CATS model, the ESDs were quantified by estimating the probability of occurrence of each event and end state using historical data [Roelen at al., 2006]. The consequence of each end state in terms of aircraft damage and occupant fatalities was determined. in Roelen and Smeltink [2008].

1.2 Objective

The objective of this part of the study, as part of the CATS model development, is to describe accident costs for ESD end states. This information is intended as part the CATS consequence model.

2 Accident Cost Headings

2.1 End State Consequences

The CATS model combines Event Sequence Diagrams (ESDs), Fault Trees and Bayesian Belief Nets into a single structure [Roelen and Wever, 2005] [Roelen et al, 2006]. The ESDs are used to represent accident scenarios like e.g. mid-air collision, structure overload, and fire/explosion. The scenarios terminate in one or more end states. Examples of end states are runway overrun, collision with ground, and aircraft continues flight.

The costs for end states that represent an incident or accident are different than the costs for a normal flight. Additional costs occur due to passenger injuries or fatalities, damage to the aircraft, but potentially also indirect costs for other airlines, that airport and third party (society).

In Roelen and Smeltink [2008], the consequences in terms of aircraft damage and occupant fatalities have been determined for each end state. A summary of those results is given in Appendix A.

Costs for an airport and other airlines arise when an accident or incident occurs at or near a runway, like a runway overrun, runway veer-off, collision on the runway or the aircraft stops on runway in case of a rejected take-off. In those situations the runway (or even the airport) is blocked. This will lead to delays for the other aircraft at or in the vicinity of the airport and costs for the airport operator. The consequences will be discussed in more detail in section 3.8.

Third party costs occur when an accident or incident result in third party fatalities or damage to property. The consequences will be discussed in section 3.14.

2.2 List of cost headings

To assess the costs related to accidents and incidents, 18 cost headings were identified, see Table 1. They are based on costs headings defined in the ASTER project [Roelen et al, 2001]. Each cost heading will be explained and analysed in section 3.

Table 1: An overview of all relevant cost headings related to accidents and incidents.

Nr	Cost heading
1	Aircraft physical damage (cost of repair/replacement)
2	Possible loss of resale value
3	Aircraft loss of use
4	Aircraft loss of investment return
5	Passenger and crew fatalities and/or serious injuries
6	Site contamination and clearance
7	Airline costs for delay (diversion, passenger management etc.)
8	Airport closure
9	Loss of staff investment (training, experience etc)
10	Loss of cargo and/or mail and/or passenger baggage
11	Search and rescue and cost of emergency services
12	Airline immediate response
13	Cost of accident investigation (to state, operator, manufacturer etc)
14	Third party damage (physical damage, deaths, injuries, inconvenience and loss of use)
15	Loss of airline income/value/reputation (loss of passengers, decrease in share value and market capability)
16	Societal costs (effects of road closures, general delay, loss of electrical power, loss of tax, skills etc)
17	Emergency inspections SB and AD compliance (grounding and suspension of Type Certificate)
18	Fines, punitive damages, criminal proceedings

2.3 Stakeholder allocation

Since not all accident costs are borne by the same stakeholder, the estimated costs are allocated to stakeholders. The following stakeholders are distinguished:
— Airlines
— Airport operators
— (Safety) Regulators / Authorities
— Society / Third party
— Aircraft/system manufacturers
— Insurers

In Table 2 below, the stakeholders are linked to the cost headings. The table depicts the percentages of the costs that a stakeholder has to bear. These percentages have been derived in the ASICBA project [Smeltink et al, 2006] and serve as default values. They could be modified when appropriate. In ASICBA, Passengers and Air Navigation Service Providers were also identified as stakeholders, but no costs were linked to them. Therefore, they have been removed from the list of stakeholders and Table 2.

It is assumed that in some cases all or part of the incurred accident costs are covered by insurance e.g. the cost of repairing a damaged aircraft may be covered by the airline's 'hull' insurance. Where a particular loss is covered by insurance, insurers will bear the cost in place of the insured. However, depending upon the size of the loss and other factors, some of these costs may be recovered from the insured party in the form of increased insurance premiums.

Where all or the majority of a cost would normally be expected to be covered by insurance this is indicated by an "X" in the 'Insurer' column in Table 2. This is a somewhat simplified view of the relationship between insurer and insured and of which 'stakeholder' ultimately bears the cost.

For example for 'Aircraft physical damage', 100% of the costs are allocated to the airline. The costs, however, are being covered by the airline's insurance. It is possible, depending upon the causes of the accident, that the airline's insurers may be able to successfully subrogate against other 'stakeholders' such as an overhaul agency or service provider and recover part of the money from them or, more common, from their insurers. In the case of compensation for passenger deaths and injuries it is common for (the insurers of) product manufacturers, service providers and others to end up bearing some of the cost.

Table 2: Linking of cost headings and stakeholders

Cost heading	Airline	Airport operator	Autho-rities	Society	Other airlines	Manu-facturer	Insurer
1. Aircraft physical damage	100%						X
2. Possible loss of resale value	100%						
3. Aircraft loss of use	100%						
4. Aircraft loss of investment return	100%						
5. Passenger and crew deaths and/or serious injuries	100%						X
6. Site contamination and clearance	100%						X
7. Airline costs for delay	100%						
8. Airport closure	20%	7%			73%		
9. Loss of staff investment	100%						
10. Loss of cargo and/or mail and/or passenger baggage	100%						X
11. Search and rescue and cost of emergency services			100%				
12. Airline immediate response	100%						
13. Cost of accident investigation	10%		80%			10%	
14. Third party damage				100%			X
15. Loss of airline income/value/reputation	75%				25%		
16. Social costs				100%			
17. Emergency inspections	100%						
18. Fines, punitive damages, criminal proceedings	100%						

3 ACCIDENT COST VALUES

In this section default values are specified for each cost heading. The values are default values and are estimated such that is reflects as much as possible the European situation.

The costs values for each cost heading can be computed using three input variables:

1. the percentage of aircraft damage;
2. the percentage of occupants killed; and
3. whether the accident/incident occurs at an airport.

3.1 AIRCRAFT PHYSICAL DAMAGE

Aircraft physical damage is considered one of the key determinants in categorising accidents and incidents. However, the actual costs arising from similar physical damage suffered by different aircraft can vary by perhaps as much as two orders of magnitude – consider an old Boeing 707 with a value of say $1 to $2 million and a brand new Boeing 747 valued in excess of $150 million.

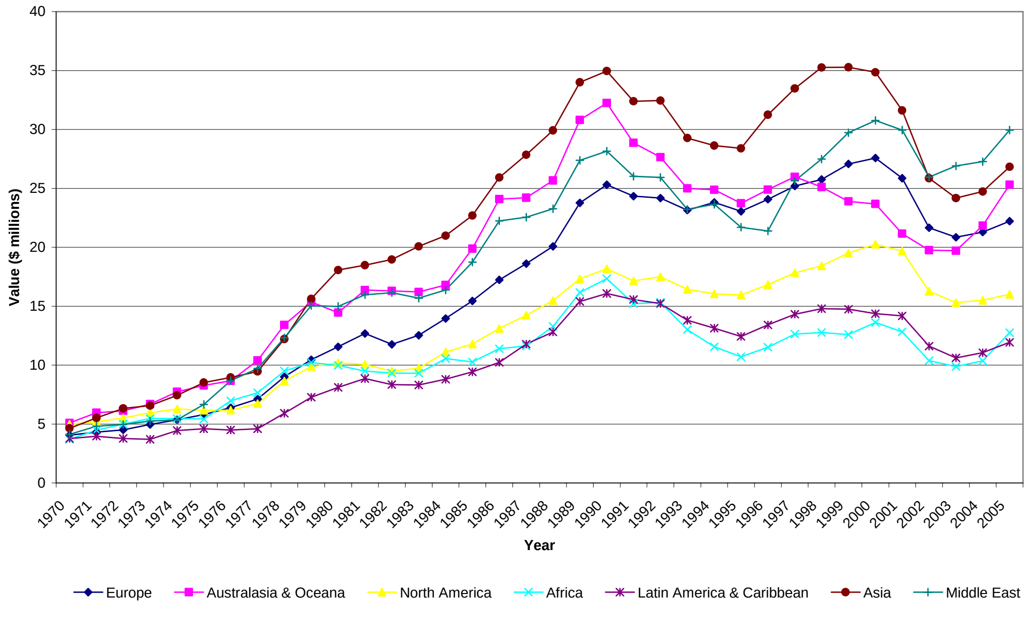

Figure 1: Average Aircraft Value (Western-Built Jets with a maximum take-off weight heavier than 5700 kg) obtained from the Airclaims database CASE (price level 2005).

An analysis of the Airclaims database CASE, presented in Figure 1, shows that since 1990, the average value of the western-built jet aircraft in the European fleet has remained at between $20 and $30 million. It would therefore seem reasonable to assume that the average value of a jet airliner in Europe is about $25 million.

Aircraft are normally insured for more than their market value and the difference between the insurance and market values normally increases with aircraft age, going from about 120% when new to about 300% of market value when thirty years old. For western-built jet airliners in the European fleet it was estimated using the Airclaims database CASE that the average age of the aircraft is about nine years. The difference between their average insurance value and their average market value is 185%. So, based on the average market value of these aircraft being $25 million, the average insurance value is 1.85 × $25 million = $46.25 million = € 70.6 million. For the conversion the rate € 1 = $1.5272 (Conversion rate on June 11, 2008) is used.
Default costs: % aircraft damage × average insurance value.

3.2 Possible loss of resale value

Any accident which causes physical damage to the aircraft can be expected to be noted in its records and it might be argued that this alone, even where the aircraft has long since been properly repaired and returned to service, could adversely influence any potential purchaser and therefore result in diminution of its value. This argument is difficult to prove and aircraft sales data which would allow any possible loss of value to be demonstrated or quantified most probably does not exist.

Nevertheless, many people do assume that damage history does have an effect on value and, in some forums, may be able to carry this argument. From Airclaims' experience, where such reduction of value is accepted, an arbitrary reduction of between 5% and 15% of the aircraft market value at the time of sale is assumed. These assumed percentages are for airliners, for business jets for example higher percentage ranges apply.

Most insurance policies allow the insured to elect to have the aircraft treated as a total loss (100%) if the estimated cost of repair is 75% or more of the hull value [Smeltink et al., 2006]. So for accidents with less than 75% aircraft damage, the loss of resale value is estimated to be 10% x average insurance value = € 7.06 million. For accidents with more than 75% aircraft damage, the cost is zero.

3.3 AIRCRAFT LOSS OF USE

Following an accident, the airline will be deprived of the use of the aircraft until it can be repaired or, if destroyed, replaced. Assuming that the airline actually had an operational need for the aircraft and did not have surplus capacity, these costs can be estimated by calculating the costs of a direct replacement for the period of repair or until a suitable permanent replacement can be found and put into service. An airline might respond to a loss of capacity as the result of an accident in the following ways:

- Immediately following the accident – delay or re-route passengers, put passengers onto other airlines and/or pay compensation for delay/cancellation. This would apply in every case but is addressed under a separate cost heading, 'Airline costs for delay' etc.
- The first week or so – buy in or charter capacity.
- Thereafter (up to periods of six months or a year) – wet-lease a replacement aircraft[1].
- Longer periods (more than six months) - possibly dry lease[2] a replacement aircraft (if available). If the aircraft is destroyed or it is uneconomical to repair it, the airline might wish to obtain a permanent replacement (depending upon the expected time to carry out repairs, this might also be a viable alternative to wet and/or dry leasing). For older aircraft it is thought that no permanent replacement (acquired through purchase/operating lease/finance lease etc) could be found and introduced into service in less than three months and also that a period of six months is perhaps more typical. If the aircraft involved was new or nearly new, a similar replacement would have to be found. Depending upon market conditions, this might take up to one or two years.

In Table 3, the estimated costs for different types of lease are depicted for Boeing 737 type of aircraft. The values in this table have been determined by searching through the various lease offers available on internet (www.globalplanesearch.com displays the search results from several sources). These costs should be considered as extra costs above the normal operational costs which would occur in case there was no accident.

1 In a wet-lease construction the lessor provides the aircraft, one or more complete crews (including engineers) including their salaries and usually allowances, all maintenance for the aircraft and insurance, which usually includes hull and third party liability. The period can go from one month to usually one to two years.

2 In a dry-lease construction the lessor provides the aircraft without insurance, crew, additional equipment and maintenance.

Table 3: Lease costs for Boeing 737 type of aircraft (price level 2005).

Aircraft Class	Range of costs per block hour	Default costs per month
Ad-hoc charter lease	$ 5,000 to $ 7,500	€ 1.9 million
Wet lease	$ 1,800 to $ 3,200	€ 0.8 million
Dry-lease	$ 900 to $ 1,600	€ 0.4 million

To calculate the default value for the costs of a loss of aircraft use it is assumed that there is ad-hoc charter capacity for 2 weeks followed by a wet lease replacement for 3 to 6 months. As a result the cost will be between € 3.2 million and € 5.5 million. The default value is hence taken to be € 4.4 million. It is assumed that the costs are proportional to the percentage of aircraft damage: Default costs = % aircraft damage x € 4.4 million.

3.4 Aircraft loss of investment return

It is believed that, although the loss of investment return is a legitimate extra cost arising from an accident, it is already taken into account elsewhere under other cost headings (notable aircraft loss of use and damage costs).

3.5 Passenger and crew fatalities and/or serious injuries

Estimating costs associated with fatalities can be difficult and controversial. A person's life is beyond price. It is, therefore, usually accepted that money cannot compensate for the loss of life itself. However, a price may be put on the material impact on others of a person's death e.g. compensation (indemnity) for loss of support etc., and, separately, on society's assumed desire to reduce the risk of a fatality.

Costs associated with fatalities are usually expressed as a Value of a Statistical Life (VOSL) where this 'value' generally includes an element of indemnity together with society's 'willingness to pay' to avoid a statistical fatality. In this context it is suggested to treat passengers and aircraft crew in the same way. In Eurocontrol [2007], the value of a fatality is estimated to be € 2.5 million.

The percentage of occupant fatalities is given for each end state in Roelen and Smeltink [2008] (see also Appendix A). Serious injuries are not taken into account. In combination with an average of 85.2 passengers per flight (see

section 3.6) and the assumption of 9 crew members per flight on average, the costs for passenger and crew fatalities can be computed:
Default cost = % occupant fatalities x (85.2 + 9) x € 2.5 million.

3.6 Site contamination and clearance

Following an accident it should be assumed that the accident site will have to be cleared of any residual wreckage, decontaminated and restored to its former condition.

This cost heading does not include damage to buildings or possible casualties and injuries. These costs are included in cost heading “Third party damage”.

Table 4: Costs of site clearance [Roelen et al., 2001]

Aircraft Class	Removal of Wreckage	Site Restoration	Total
Wide body (747, MD11 etc)	€200,000 to €800,000	€1.0m to €2.0m	€1.2m to €2.8m
Narrow body (757, MD80 etc)	€200,000 to€300,000	€0.5m to €1.0m	€0.7m to €1.3m
Smaller aircraft	€20,000 to €100,000	€100,000	€0.12m to €0.2m

Table 4, provides estimates for three types of aircraft, ranges in costs for the removal of the wreckage and the site restoration [Roelen et al., 2001]. To estimate the costs of site clearance the upper range are taken:
— Wide body: € 2.8 million
— Narrow body: € 1.3 million
— Smaller aircraft: € 0.2 million

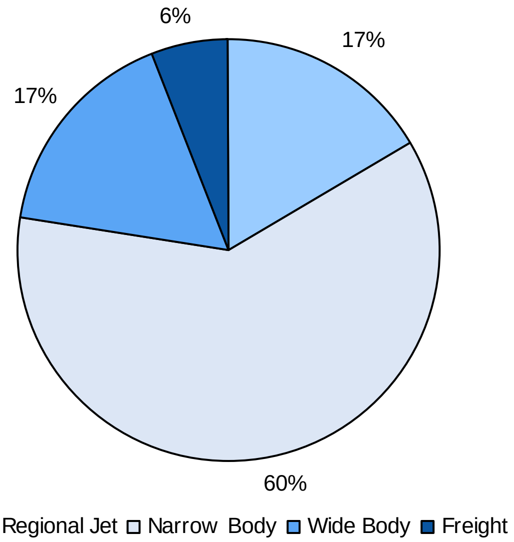

Figure 2: European fleet by aircraft category in 2006 obtained from the Airclaims database CASE.

From the Airclaims CASE database the division of the European fleet in 2006 is determined and presented in Figure 3. Using this division, the average costs are estimated to be € 1.64 million. Freight aircraft are assumed to be wide bodies.

3.7 Airline costs for delay

Airline cost for delaying consist of the direct costs due to delay and cancellation. In this case it only has a relationship with the involved airline. Indirect costs like the decreasing reputation of an airline due to delays are taken into account in cost heading "loss of reputation". Possible costs for other airlines are included in cost heading "Airport Closure".

Examples of the costs for delay and cancellation are:
— extra ground staff for managing delayed passengers;
— extra costs due to compensation of passengers (refund ticket fare, hotel costs);
— possible replacement of aircraft (also included in cost heading "loss of use"); and
— costs for extra aircraft crew (also included in cost heading "loss of use").

The value of delay costs is frequently used to quantify the benefits of investments in air transport. Eurocontrol has gathered several research sources on this topic and recommends an average value of € 99 per minute of delay [Eurocontrol, 2007].

Besides the airlines, passengers also have to cope with delays and their cost. These passenger costs are calculated by using the 'value of time'. The value of time differs by trip purpose and has a range between € 40 and € 52. In 2007 prices the average cost is €46 per hour per passenger [Eurocontrol, 2007].

The average cost of cancelling a commercial scheduled flight is valued by Eurocontrol [2007] at € 6,514.

The European Commission [2004] has defined a financial compensation for passengers in the regulation on denied boarding compensation. In the case where a flight is cancelled each passenger has the possibility to claim a compensation of € 400. We assume that this compensation equals the actual costs of a cancellation for passengers.

To estimate the average number of passengers on a flight, figures from the Association of European Airlines (AEA) are used [AEA, 2007]. In 2006, the 31 major European airlines represented by AEA executed 11,030 flights per day carrying 343 million passengers. That is 85.2 passengers per flight on average. No distinction is made between passenger flights and cargo flights, because this is also not done in the CATS risk model. The costs for cancelling a flight is € 400 x 85.2 = € 34,080.

For other airline delays only delays as a consequence of runway closure are considered. This is treated in the next section (Section 3.8). Amount of delay other than due to runway closure are difficult to estimate, since it is influenced by a number of factors such as the size of the airline, the amount of other traffic, and the response by Air Traffic Control. Therefore, these are not taken into account.

3.8 Airport closure

If an accident happens at an airport then it can be expected to have some effect on the airport's operations. The actual impact on the airport will vary considerably, depending upon circumstances. However, blockage of a runway or damage to navigation aids, runway lights etc. all have the potential to close the airport or limit its operations. Even if the runway is unobstructed, an aircraft fire attended by the Airport Fire Service will normally result in a temporary reduction in the airport's fire cover level and mean that the airport is not available for passenger flights until the necessary fire cover is restored.

It is believed that the main indicator of cost under this heading is the number of flights cancelled, delayed or diverted to other airports. This number will depend, broadly, upon the number of hours the airport is closed and the average number of air transport movements (arrivals and departures) per hour. The period of closure will depend upon the severity of the accident (assuming that the accident occurs on the airport) and might range from a few hours for a simple overrun accident where the aircraft becomes bogged down beside the runway to, perhaps, several days if the aircraft crashes on the runway with significant loss of life.

Table 5 provides estimates of the times that the runway is blocked for different events. These estimations are based on Airclaims' experience [Smeltink et al., 2006].

Table 5: Typical runway closure times for different events [Smeltink et al., 2006].

Generic Event Type	737 Class	747 Class
Tyre burst (one)	30min	30min
Tyre burst (multiple)	2 hours	6 hours
Bogged down	4 hours	12 hours
Nose gear collapse	6 hours	12 hours
One main gear collapse	1 day	2 days
On belly (repairable)	2 – 3 days	4 – 6 days
On belly (not economical to repair)	1 day	1 day
Catastrophe	Investigation + 2 days	Investigation + 2 days

There are four types of end states that result in runway closure:

1. Collision on runway
2. Runway overruns;
3. Runway veer-offs; and
4. Aircraft stops on runway damaged due to a hard landing.

Based on the values of Table 5, it is assumed that the result of a collision on the runway is equivalent to a catastrophe. It is assumed that the investigation required 12 days, so the total runway closure is 14 days (=336 hours). The result of an overrun or a veer-off is comparable to a “one main gear collapse”. As a result, the runway is closed for 1.5 days (=36 hours). An aircraft stopping on the runway damaged due to a hard landing is assumed to be equivalent to a multiple tyre burst. Hence, it will result in a runway closure of 4 hours. For all other end states, no delay due to runway closure is foreseen.

To estimate the number of flights cancelled, delayed or diverted to other airports, average traffic numbers for a European airport are used. The average number of flights per day in a European airport is about 166 flights [ACI, 2006], which corresponds to 7 aircraft per hour.

In Schmidlin et al. [1999] it was estimated that the costs for delaying an aircraft increases linearly with the amount of delay up to 180 minutes. After 180 minutes, the costs remain constant. In Section 3.6, the cost of delaying an aircraft is valued to be € 99 per minute. This implies a maximum of € 17,820. It is assumed that all affected aircraft have a maximum delay costs. The resulting costs for the groups of end states are given in Table 6.

Table 6: Default costs resulting from runway closure for different groups of end states.

End States	Runway closure time	Number of affected aircraft	Total costs
Collsion on runway	336 hours	2352	€ 41.9 million
Runway overrun	36 hours	252	€ 4.4 million
Runway veer-off	36 hours	252	€ 4.4 million
Aircraft hard landing on runway	4 hours	28	€ 0.5 million

3.9 Loss of staff investment

In the case where the crew of an aircraft is killed or unable to continue in their normal work due to an injury the involved airline will suffer a loss of investment in their employees in a number of ways including:
— The cost of recruiting and training replacements.
— A possible reduction in productivity while a suitable replacement is found because of less trained and experienced crew.

The costs of temporary wet lease (aircraft including crew) is already taken into account under the heading “Aircraft loss of use” (see section 3.3).

In Lebouille et al. [2006] for the ASICBA project, it is assumed that the recruited staff:
— need an introduction training;
— has 5 year less experience than the initial crew; and
— need, during these 5 years, extra flight training compared to the initial crew.

Training costs were assumed to be € 10,000 per year per staff member.

Table 7: Estimation of average costs of recruitment and additional training of crew [Lebouille et al., 2006].

Costs	**Amount per staff member**
Recruitment	€ 5,000
Additional training during 5 years	€ 50,000
Introduction training	€ 10,000
Total	**€ 65,000**

Hence, the total costs are: % occupant fatalities × number of crew (default = 9) × € 65,000.

3.10 Loss of cargo and/or mail and/or passenger baggage

Apart from the physical damage to the aircraft and possible deaths or injuries suffered by passengers and crew, in an accident there is also the potential for loss of the cargo and/or mail carried in the holds of passenger aircraft.

In 2006, the 31 major European airlines represented by AEA executed 11,030 flights per day carrying 6 million tonnes of cargo. That is 1.5 tonnes of cargo per flight on average. No distinction is made between passenger flights and cargo flights.

In a research study for the Dutch Ministry of Transport the value of air cargo is calculated based on Customer information from Schiphol Airport [ECORYS and Districon, 2005]. An average value of 63 €/kg is determined for cargo.

The default values in the cost model are derived from the figures above. An average value of 63 €/kg with an average cargo load of 1,500 kg, the value of the cargo per flight is estimated to be € 94,500.

In the 1999 Montreal Convention [ICAO, 1999], a maximum liability of airlines on lost or damages passenger baggage is set to 1,000 SDR[3] per passenger. This equals € 1041 per passenger. Based on a checked baggage limit of 20 kg per

[3] Special Drawing Rights (SDR), created by the International Monetary Fund (IMF), serves as a unit of account of the IMF and some other international organizations. For the conversion, the rate 1 SDR = € 1.041 (June 11, 2008) has been used.

passenger, this would imply € 52 per kg. With an average of 85.2 passengers per flight (see section 3.5), the total the value of the baggage per flight is therefore about 85.2 × € 1041 = € 88,693.

The percentage of cargo, mail and baggage lost is assumed to be equal to the percentage of aircraft damage. Using this percentage the value of the loss of cargo, mail and passenger baggage can be computed:
Default costs = % aircraft damage × (€ 94,500 + € 88,693)

3.11 Search and rescue and cost of emergency services

An aircraft accident will generally result in costs being incurred for search and rescue (SAR) and/or the operation of emergency services. These costs may include such things as fire service and ambulance attendance and on-site medical aid, police, civil defence or assistance from military personnel in the search and rescue operation, recovery and transportation to safety of survivors, recovery of bodies etc. In general, the cost should include all actions during the immediate response to the accident or to the report of an aircraft going missing, up until all occupants are accounted for and brought to safety and the accident site stabilised (fire extinguished etc). The costs of laying a foam carpet on a runway prior to an emergency landing are also normally included under this heading for insurance purposes.

Costs for wreckage recovery, accident investigation, ongoing medical care etc. are not included under this heading. They are included in cost heading 5: “Site contamination and clearance” (section 3.5).

A large part of the SAR costs are the daily operational costs. Rescue organisations intended to have enough rescue capacity during 365 days a year. This results in large amounts of fixed costs of which the labour cost is the majority. The capacity of SAR organisations is not determined on aviation accidents alone but also such calamities as forest fires, traffic accidents and many other rescue operations.

In Roelen et al [2001], the average SAR cost claim was assessed to be € 0.6 million per accident. They stated that only catastrophic and disaster events lead to SAR operations. Catastrophic and disaster events were defined in Roelen et al [2001] as events with 100% aircraft damage. It is assumed that the € 0.6 million is proportional to the percentage of aircraft damage: costs = € 0.6 million × % aircraft damage.

3.12 Airline immediate response

A disaster, especially one involving loss of life or serious injury to passengers, could be expected to trigger an exceptional response by the airline. An airline's immediate response to a 'disaster' depends to a certain extent on the airline's company policy with respect to accident responses. However, typical actions of the airline include the set up of a crisis management centre, a passenger information centre, a local control centre, media information activities and specific centres for families of the victims. The costs related to this crisis management vary strongly with the size of the accidents and the airline's policy.

Minor accidents may result in additional airline management and staff costs e.g. rescheduling aircraft, calling in standby crews etc., it might be argued that these should not be included as they represent the normal work of the departments concerned – they would need to take the same action if flights were disrupted due to adverse weather or some other operational problem. Other 'legitimate' costs arising from such an accident would be covered under the heading 'Airline Costs for Delay etc'.

An average estimate of costs related to the airline's immediate response might involve the full time diversion from normal duties of perhaps 200 or 300 management and staff, including board level executives for some 24 to 48 hours. This might then reduce to about 50 people, full time, over the next three to four days. After this period the airlines' response might be considered to change from the 'immediate' phase to a longer-term effort in support of the investigation. The decision of the airline to dispatch an aircraft to the accident site and the setting up of centres to cope with the media and the victim's relatives might add to this cost picture.

As an example the direct crisis management costs related to the Swissair crash in 1998 were reported to be in excess of 12 million USD (price level 1998) [Roelen et al., 2001].

Based on this information, the maximum costs (all occupants killed) are estimated to be € 3 million [Roelen et al., 2001]. Most of these costs are uninsured; therefore it is assumed that these costs must be borne by the airline itself. The cost heading "Airline Immediate Response" is assumed to be proportional to the percentage of occupant fatalities:
Default costs = € 3 million × % occupant fatalities

3.13 Cost of accident investigation

Most 'reportable' accidents and major incidents, especially those in Western Europe, North America and Australia, can be expected to be investigated by the State where the accident happened with assistance as required from other parties including the State where the aircraft was registered, the aircraft operator, aircraft manufacturer etc. depending on the circumstances The actual level of effort will normally reflect the severity and/or significance of the accident, with some relatively minor 'more routine' accidents attracting only 'routine' investigation. However, a 'disaster' or some other significant accident will generate very considerable investigative effort, especially when the wreckage is located at a site which is difficult to access, e.g. in sea.

Costs for accident investigation range from € 0.1 million to € 100 million [Roelen et al., 2001]. Accident investigation costs of € 100 million, however, will occur only in exceptional cases, e.g. when the aircraft's black boxes (flight data recorder and voice cockpit recorder) or parts of the wreckage need to be recovered from the ocean. It is assumed that the average investigation cost is about € 2.5 million.

It is assumed that the costs of accident investigation are proportional to the aircraft damage percentage: costs = € 2.5 million × % aircraft damage.

3.14 Third party damage

This cost heading includes three categories of cost:
1. Third party material damage on the ground (buildings, infrastructure, etc.).
2. Third party deaths and injuries.
3. Business interruption due to material damage and/or investigations.

The cost of site decontamination and restoration is already covered under the "Site Contamination and Clearance".

Third party deaths and injuries are rare and not the usual outcome of an accident. In spite of the rarity of third party deaths and injuries, they can be substantial:
— In 1996 on 8 January in Kinshasa, Congo an Antonov AN32 failed to get airborne on take-off and overran into a crowded open-air market just beyond the end of the runway. The accident resulted in a reported 297 deaths and 253 serious injuries.

— On 4 Oct 1992 an El Al Boeing 747 went out of control on approach to Schiphol Amsterdam Airport and crashed into two blocks of apartments. 43 people on the ground were killed and a further 11 seriously injured. The apartment buildings were demolished and the total costs were estimated to be $ 62million.

The costs of material damage to buildings, infrastructure, etc. can differ a lot. At one end, damage may only be occasioned to crops or grassland, which will result in relatively minimal costs, equal to the market value of the damaged crop. But at the other end, the costs can rise to several millions because of serious damage to buildings.

In Roelen and Smeltink [2008] it was determined that in 3% of the accidents and incidents used in their analysis, there have been third party fatalities. An average of 0.3 third party fatalities per accident end state was computed. Using the value of a fatality (see section 3.8), a value can be assigned for third party fatalities: Default costs: 0.3 × € 2.5 million (for all accident end states).

3.15 LOSS OF AIRLINE INCOME/VALUE/REPUTATION

Immediately following an accident, the airline involved and possibly also other airlines may experience a drop in passenger traffic and bookings. This may, in part, be off set by using lower promotional fares to draw passengers back but this will result in a reduction in yield and therefore in income.

Beside a drop in number of passengers, the airline has probably also to cope with a loss of reputation. This damage to the airline's 'brand' will have impact on the number of passenger during a longer period.

In the ASICBA project the number of passengers has been analysed before and after an accident for different airlines [Lebouille et al., 2006]. However, no convincing argument or magnitude was found to represent this loss of income. There was no evidence found for a significant decrease of number of passengers during the months directly after an accident.

However, not passenger data but data containing the monthly yield of an airline should give an insight in the (temporary) decrease in profit. The problem is that this kind of data is not available and therefore the costs cannot be estimated.

3.16 Societal costs

Apart from the direct costs arising from the effects of an accident to third parties (see Section 3.14), there are possible additional costs associated with general disruption. Depending upon the circumstances this might include road closures during the search and rescue phase with resultant congestion and delay, loss of electrical power if the aircraft destroyed power-lines, loss of access and so on. Also people killed or injured to such an extent that they can no longer work normally could have an impact on the overall wealth of society.

However, it is felt that these general 'societal costs' are perhaps too ill defined and too far removed from the accident that, if an attempt is made to include them, the risk exists of not knowing where to stop. Each delay, missed meeting etc., can spawn further delays ad infinitum. Real life does not run like clockwork and, unfortunately, is full of minor problems, delays and other inconveniences. Therefore, unless the accident, for some reason, produces exceptional 'social costs', which stand out from the general background noise of every day life, it is suggested that these potential costs are ignored.

3.17 Emergency inspections

As the result of an accident, costs may be incurred through the need to comply with Service Bulletins or Airworthiness Directives published to address a deficiency discovered during the accident investigation. In extreme situations aircraft may be grounded temporarily until inspections/fixes can be made or even as a result of the suspension of their Type Certificate. However, by definition, it could be argued that these are pre-existing deficiencies. They have always existed and were not caused by the accident. Therefore, the cost of compliance is not a cost resulting from the accident. Only the exceptional cost of complying 'suddenly' or perhaps the costs caused by the unexpected and unplanned temporary suspension of operations might legitimately be included. In summary, it is suggested that no costs are included for this cost heading.

3.18 Fines, punitive damages, criminal proceedings

It is believed that for fines or other such sanctions to be taken against people and/or concerns following an accident, there is generally a presumption of wrong doing either by omission or deliberate commission. Fines might be regarded as a punishment for 'doing wrong' and therefore an 'encouragement' to do the 'right thing'. Using this argument, it might be said that punishment is part of the 'safety effort'[4] not an accident cost. There are several examples of fined Airlines.

[4] It is not suggested that punishment can be an effective part of a 'safety effort'

Nevertheless there is a wide range of fine proportions and there is also very uncertain relationship between the costs of fines and accidents. Therefore no value is suggested for this cost heading.

3.19 Summary

The estimates for the different cost headings are summarised in Table 8. The percentage of aircraft damage, the percentage of occupant fatalities, and the runway closure times are required as input. The estimates presented in this table are default costs.

Table 8: Summary of the default cost estimates for the different cost headings.

Cost heading	Default costs
1. Aircraft physical damage	= % aircraft damage × average insurance value = % aircraft damage × € 70.6 million
2. Possible loss of resale value	if % aircraft damage >= 75% costs = 0 if % aircraft damage< 75% costs = € 7.06 million.
3. Aircraft loss of use	= % aircraft damage x € 4.4 million
4. Aircraft loss of investment return	= 0
5. Passenger and crew fatalities and/or serious injuries	=% occupant fatalities x (85.2 + 9) x € 2.5 million
6. Site contamination and clearance	= € 1.64 million (for all accident end states)
7. Airline costs for delay	= 0
8. Airport closure	Collision on runway € 41.9 million Runway overrun/veer-off: € 4.4 million Aircraft hard landing on runway: € 0.5 million
9. Loss of staff investment	= % occupant fatalities × number of crew (= 9) × € 65,000
10. Loss of cargo and/or mail and/or passenger baggage	= % aircraft damage × (€ 94,500 + € 88,693)
11. Search and rescue and cost of emergency services	= € 0.6 million × % aircraft damage.
12. Airline immediate response	= € 3 million × % occupant fatalities
13. Cost of accident investigation	= € 2.5 million × % aircraft damage
14. Third party damage	= 0.3 × € 2.5 million (for all accident end states)
15. Loss of airline income/value/reputation	= 0
16. Societal costs	= 0
17. Emergency inspections	= 0
18. Fines, punitive damages, criminal proceedings	= 0

4 Conclusions and Recommendations

In this study, as part of the model development within the CATS project, the accident and incident costs for all end states of the CATS model have been determined. This information is intended as part of the CATS consequence model. The aircraft damage percentage, the occupant fatality percentage and runway closure time are the three input values required to compute the accident and incident costs. These three inputs have been given for each end state.

Insufficient data was available to make an estimate of Airline costs for delay, Loss of airline income/value/reputation, Societal costs, Emergency inspections, and Fines, punitive damages, criminal proceedings. It is recommended that these cost headings are studied in more detail and that more data is collected.

Furthermore, in a number of situations assumptions or rough estimates have been made due to a lack of data. It is recommended that more data is collected to improve the credibility of these assumptions and estimates.

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Appendix A AIRCRAFT DAMAGE AND OCCUPANT FATALITIES

Table 2: Summary results for each end state: the average damage percentages and the average percentage of onboard fatalities. This table was obtained from Roelen and Smeltink [2008].

End State		Average damage (% of hull value)	Average fatalities (% of occupants)
TO01d1-01	Runway overrun (V>V1)	31%	0%
TO01e1-02	Runway overrun (V<V1)	47%	0%
TO03d1-01	Runway overrun (RTO)	100%	0%
TO03e1-02	Runway veer-off (RTO)	100%	0%
TO03d4-05	Runway veer-off (no RTO)	65%	4%
TO04d1-01	Runway overrun (V>V1)	72%	0%
TO04e1-02	Runway veer-off	58%	0%
TO04f1-03	Runway overrun (V<V1)	54%	0%
TO05e1-01	Runway overrun (V>V1)	59%	0%
TO05e7-07	Collision with ground	100%	61%
TO06d1-01	Collision with ground	100%	85%
TO07d1-01	Collision with ground	100%	97%
TO08d1-01	Collision with ground	100%	0%
TO09d1-01	Runway overrun (V>V1)	61%	2%
TO09e1-02	Runway veer-off (V<V1)	48%	0%
TO09f1-03	Runway overrun (V<V1)	77%	0%
TO09d4-05	Runway veer-off (V>V1)	100%	1%
TO10d1-01	Runway overrun (V>V1)	73%	0%
TO10f1-03	Runway overrun (V<V1)	100%	0%
TO10d4-05	Runway overrun(no RTO)	100%	95%
ER11e1-01	Collision with ground	100%	100%
ER12c1-01	Collision with ground	95%	79%
ER13c1-01	Collision with ground	100%	98%
ER14c1-01	Collision with ground	100%	88%
ER15e1-01	Collision with ground	94%	63%
ER16c1-01	Collision with ground	100%	100%
ER17d1-02	Collision with ground	100%	93%

ER18d1-01	Collision with ground	100%	79%
ER18e1-02	Aircraft lands off runway	94%	6%
ER18d3-03	Aircraft continues landing	58%	0%
ER18e5-07	Collision with ground	100%	52%
AL19d1-01	Collision with ground	87%	25%
AL19f1-02	Runway overrun	70%	3%
AL19h1-04	Runway veer-off	82%	6%
AL19h2-05	Aircraft continues landing roll damaged	46%	0%
AL19f5-06	Aircraft continues landing roll	32%	0%
AL19e5-08	Collision with ground	98%	57%
AL19f4-09	Aircraft lands off runway	100%	53%
TF21c1-01	Collision with ground	100%	50%
AL23f1-01	Runway veer-off	72%	29%
AL23f2-02	Aircraft continues landing roll damaged	33%	0%
AL23f3-04	Runway overrun	62%	0%
AL25d1-01	Runway overrun	36%	0%
AL25d2-02	Aircraft damaged	47%	1%
AL25f1-03	Runway veer-off	80%	0%
AL26c1-01	Runway veer-off	46%	0%
AL26d1-02	Runway overrun	63%	0%
AL27c1-01	Runway veer-off	53%	1%
AL28c1-01	Runway veer-off	69%	0%
AL28d1-02	Runway overrun	100%	0%
AL29c1-01	Runway veer-off	69%	0%
AL29d1-02	Runway overrun	76%	0%
AL30c1-01	Runway veer-off	54%	0%
AL30d1-02	Runway overrun	77%	4%
ER31d1-01	Collision in mid-air	77%	75%
ER32d1-01	Collision on runway	34%	9%
ER33c1-01	In-flight break up	100%	75%
AL35e1-01/f1-02	Collision with ground	97%	76%
XX37	Collision with ground	70%	67%