Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Aviation Safety Targets for Effective Regulation

Consolidated Final Report

Summary

ASTER stands for "Aviation Safety Targets for Effective Regulation". It is a project carried out on behalf of DGVII of the European Commission in 2000-2001. The ASTER project has been initiated in response to Key action 2.2 of the Fifth Framework Programme ('Competitive & Sustainable Growth') of the European Commission.

The main objective of the ASTER research is the development of a methodology that enables safety targets to be set and optimised for each of the participants in the air transport system, to achieve the optimum level of safety for the system as a whole. To support this process, means were developed for assessing the safety benefits of any changes, including changes in legislation/rulemaking, in relation to the cost of implementing those changes. Current methodologies in support of risk based regulation for the air transport system are restricted to the aircraft and its systems, do not adequately support a total aviation system approach, and do not allow effective cost-benefit assessment.

Methods that are currently being used in aerospace for setting target levels of safety were analysed. The analyses included strengths, weaknesses and developments in the current use of safety targets. A comparative analysis with the rail and nuclear power sector was performed. A major conclusion is that derivation and application of a target level of safety in aviation must take into account the problems inherent in dealing with low accident probabilities. In particular, approaches to a target level of safety that are based upon historical data must take into account the problems associated with significant fluctuations in measured risk due to the random occurrence of small numbers of discrete events. Understanding the limitations posed by this issue is critical to ensure that safety targets are properly set and that comparisons of future performance against this target are credible.

All elements of the Air Transport System (ATS) were analysed and their ownership defined, including cross relationships. The relationships between ATS elements and causal factors of accidents and incidents were investigated and subsequently modelled and parameterised into a scenario based accident risk model. The accident risk model uses a taxonomy of causal factors that is based upon the International Civil Aviation Organisation (ICAO) Accident/Incident Data Report (ADREP) standard. Accidents and incidents are described as a sequence of events with descriptive and explanatory factors. The identification of relationships between causal factors is supported by a functional model of the Air Transport System. The functional model assists in identifying affected elements in the system. The accident risk model and the functional model were combined and quantified in a Bayesian Belief Network.

The analysis of cost effects addressed both the costs of events such as accidents and incidents, and the costs of implementing changes in legislation/rulemaking or other measures to improve safety. The most significant determinants of cost arising from accidents and incidents are aircraft damage, deaths

and injuries suffered by occupants, and loss of reputation. However, cost may arise from an accident in a number of ways, both directly and immediately and indirectly, perhaps over a longer term. The ASTER cost model uses heads of cost that includes both direct and indirect factors. The model allows estimation of benefits in terms of a reduction in incident/accident probability and/or increased productivity. This benefit can then be balanced against the implementation costs of the measure.

The results of the work described above were integrated into a method that enables assessments of how the difference between the Target Level of Safety and the current level of safety can be bridged in the most cost-effective manner. A handbook that described application of the method was developed and illustrated with a case study that compares four inherently different measures to address the wake vortex hazard:

1. Wake vortex prediction, detection and warning on airports;
2. Airborne wake vortex detection and warning;
3. Wake vortex avoiding landing procedures;
4. Active wake vortex suppression system at the wing of the aircraft.

Benefits and costs of all four methods are described and compared from a European perspective.

Contents

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1 Introduction

ASTER stands for "Aviation Safety Targets for Effective Regulation". It is a project carried out on behalf of DGVII of the European Commission in 2000-2001. The ASTER project has been initiated in response to Key action 2.2 of the Fifth Framework Programme ('Competitive & Sustainable Growth') of the European Commission. This spells out the RTD objectives to promote transport sustainability from an economic, social and environmental perspective, while improving safety and security and optimising the human role and performance.

The ASTER Consortium includes the following project partners:

a) National Aerospace Laboratory (NLR)	*Project Co-ordinator*
b) EUROCONTROL	*Main contractor*
c) Meridiana	*Main contractor*
d) Airclaims	*Main contractor*
e) Netherlands Economic Institute (NEI)	*Main contractor*
f) Israel Aircraft Industries(IAI)	*Main contractor*
g) Joint Research Centre (JRC)	*Main contractor*
h) Federal Aviation Administration (FAA)	*Reviewer*
i) Joint Aviation Authorities (JAA)	*Reviewer*
j) European Commission DG-TREN	*Funding*

2 Objectives of the project

The main objective of the project is the development of a method that will enable safety targets to be set and optimised for each of the actors of the air transport system to achieve the optimum level of safety for the system as a whole. The method must allow an assessment of the safety benefit of any change (including changes in legislation and rulemaking) in relation to the costs of those changes.

3 Approach

It holds for any system that to have good performance with regard to a particular property, this property must be part of the design requirements rather than a mere spin-off of the development process of the system. For this reason, aircraft speed and fuel-efficiency are design requirements instead of the coincidental outcome of the design. The same ”design approach” should be followed with regard to the safety of air transport in order to achieve a significant improvement in relative safety.

Usually there are several ways to achieve a particular safety improvement. Also, particular safety improvements in some elements of the air transport system may be more easily (at lower costs) achieved than in other elements of the air transport system. Therefore, in view of the fact that the available resources for the improvement of safety are limited, it is imperative to establish the most effective way of spending the resources available for safety improvements. The ASTER project aims at providing methods for this need.

The ASTER project thus developed the elements required to enable a design approach towards air transport safety. These elements are:

1. A review of current methods for setting Target Levels of Safety in aviation and other industries. The assumptions, methods, models etc that are used in the setting of these targets are described in detail. The strengths and weaknesses of the different approaches are reviewed, as well as the implications for the distribution of risk throughout the air transport system.

2. A method for the establishment in a quantitative manner of the current level of safety in the air transport system, and the development of a method for the estimation of safety effects in terms of a reduction of the probability of accidents/incidents that can be expected from safety measures (including regulation).

The elements 1 and 2 together enable assessments of which gaps between actual safety levels and target safety levels are to be bridged by safety improvement measures.

3. A description of costs of unsafety, i.e. direct and indirect costs associated with accidents and incidents, and a description of the costs of the implementation of safety measures and regulation.

4. These results are combined in a quantitative method for predicting the effect of safety measures, both in terms of safety benefits (in terms of reduction of the costs of unsafety) and in terms of implementation costs, thus allowing cost-benefit analysis of proposed safety improvement measures. This method is set forth in a well structured handbook, substantiated by a case study.

4 Target level of safety

A Target Level of Safety is the amount of safety that is aimed for. It can be mandatory (it must be achieved in order to carry out some activity) or aspirational (a target that must be aimed for but not necessarily achieved).

A review was conducted on existing Target Levels of Safety (TLS) within the civil aviation community, drawing relevant comparisons with other industry sectors. The work explored the role of stakeholders and the extent of their involvement in TLS derivation processes and considered the need for greater understanding of the relevant stakeholders. Strengths, weaknesses and developments of relevance to ASTER were identified accordingly.

Before addressing TLS is was necessary to define safety. The following definition was used:

Safety is freedom from unacceptable risk

Risk is a combination of the probability of occurrence of harm and the severity of the harm.

Harm is physical injury or damage to the health of people either directly or indirectly as a result of damage to property or the environment.

Specifying the persons (or groups, or classes of persons) exposed to risk is necessary to ensure that risks are properly identified and evaluated.

It is important to establish what type of target is being, or should be, used in a target level of safety. Consideration of the different types of safety target used in the ‘As Low As Reasonably Practicable’ (ALARP) approach to safety will show the main types of target and their uses.

ALARP identifies three risk regions. Above a certain level (the Maximum Tolerable Risk), the level of risk is so great as to be intolerable (unacceptable). The activity giving rise to the risk is not permitted until the risk is reduced below the Maximum Tolerable Risk. At and below another, lower, level (the Negligible Risk Level) the level of risk is so small as to be broadly acceptable. Between the Maximum Tolerable Risk and the Negligible Risk Level, the risk is only tolerable (acceptable) if a benefit is gained from the activity and either risk cannot be reduced or the cost of risk reduction is grossly disproportionate to the improvement gained. The three regions are shown in Figure 1.

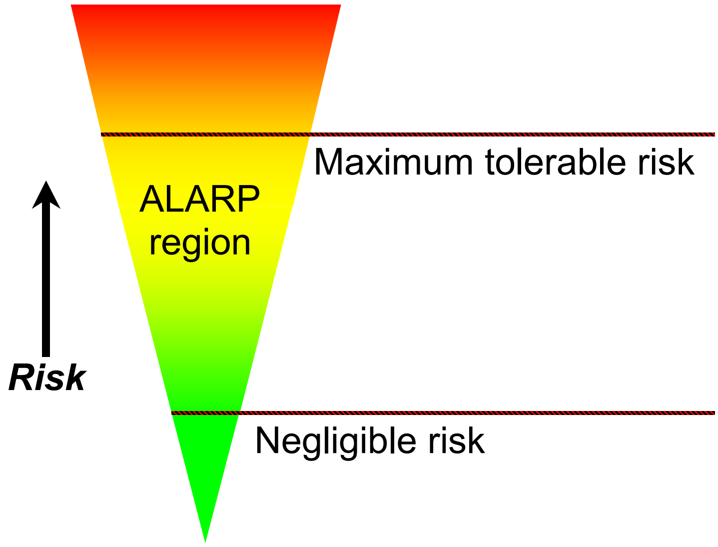

Figure 1: ALARP regions

If the Maximum Tolerable Risk is used as a Target Level of Safety then it is clearly a mandatory target since a higher level of risk is not acceptable under any circumstances. Similarly, the Negligible Risk Level is normally considered to be an aspirational target since higher levels of risk can be tolerated, albeit with some conditions attached. Target Levels of Safety set in the ALARP region may be either mandatory or aspirational. This arises because of the way in which the ALARP principle works to improve safety and drive down risk. Risk is considered tolerable if either the risk cannot be reduced or the cost of risk reduction is disproportionate to the improvement gained. Although a target may be set, failing to meet it would be tolerable if all reasonable options for risk reduction have been investigated and either the reduction cannot be achieved or the associated costs are disproportionate. Mandatory targets may be set, however, if it is clear that a particular level of risk can be achieved. For instance, a target might be set that is equal to an industry average or the best that is achieved within an industry sector. It is clearly reasonable and practicable to achieve it. Similarly, historical performance can be used to set a mandatory target. Again, it is clearly reasonable and practicable to achieve it because it has been achieved.

4.1 Existing TLS – air transport industry

There are wide arrays of mandatory safety targets that must be achieved for the air transport industry, as defined by international aviation regulators and other organisations. While these are largely mandatory targets, the ALARP concept is commonly reflected in the derivation methods.

Strengths of TLS in aviation are that airworthiness requirements are generally applicable, providing a unified set of requirements. Due to the large history in airworthiness certification, there is much experience with the application and many proven guidelines are available.

An inherent weakness is that the TLS approach sets a single value dividing acceptable from unacceptable risk, whereas risk predictions have significant uncertainty bands. The TLS approach does not encourage risk reduction below the TLS.

4.2 Existing TLS – rail

TLS for the rail industry are commonly based upon safety-related data, derived via the utilisation of risk profiling techniques. This provides historical data for specific time periods, which are then categorised in accordance to the average yearly number of occurrences and key causal factors that lead to an undesired event – such as a fatality. This approach is taken in order to prioritise effectively in relation to how resources and efforts are deployed within the industry.

TLS for the rail industry have been derived subject to qualitative judgement regarding fatalities and injuries avoided and equivalent fatalities (10 major injuries being the equivalent to one fatality and 200 minor injuries being the equivalent to one fatality). This approach is relevant to the aviation industry, for example, that ‘x’ number of level busts = ‘y’ number of fatal accidents might prove to be a valid equivalent fatality for ATM. The equivalent fatality approach is not widely applied in the aviation sector and would have to be justified if utilised.

Factors in TLS for the rail industry that are not addressed in aviation TLS relate to stakeholders such as freight operators and infrastructure contractors. These categories of stakeholder are accounted for in relation to the impact they may have on passenger safety. It illuminates the significant role that can be played by all stakeholders to ensure that a safety target is met once it is set.

4.3 Existing TLS – nuclear power

Nuclear accidents generally cause harm to people through the effects of radiation. Large doses of radiation can cause death within a short time. However, this is uncommon in accidents at nuclear plants. Death after a long period of time (years or decades) may, however, occur due to cancers induced by lower doses of radiation. These are very difficult to quantify precisely.

The nuclear industry has therefore developed the use of surrogates for harm in developing TLS. These are linked to deaths from radiation through a causal chain but are considerably easier to calculate with reasonable certainty. Credible models are used to link the different stages with the ultimate harm, ensuring that the use of such TLS correspond to reasonable TLS for harm.

Nuclear TLS are the responsibility of national regulatory authorities and consequently different TLS exist across different countries. In aviation this is much more problematic due to the international nature of air travel.

4.4 Stakeholders

People who are affected by risk either directly or indirectly have a legitimate interest in Target Levels of Safety. They are generally known as stakeholders. Such parties fundamentally can be considered at core and secondary levels:

Core / Institutional

- Regulatory
- Military
- European Union
- Trade Unions
- International Bodies
- Legal
- Economy

Secondary / Society & Other Industries

- Public
- Passengers
- Family Members
- Media
- Rail
- Nuclear
- Biotechnology

Solution Providers

- Commercial Airlines
- Airport authorities
- Contractors
- Crew
- Owners (Shareholders)
- Manufacturers (aircraft and systems)
- ATM Providers

4.5 Final point on TLS

No single process for establishing TLS is best in all situations. The process should be appropriate for the commercial, legal and political situations of the industry concerned and should take into account technical issues and timescales. The process should be acceptable to at least the most important stakeholders, should be clearly defined and should result in a TLS that is both achievable and not open to significant dispute. While approaches to TLS are more developed in ATM, there is a recognised need for a framework to establish and control how TLS are (or are not) being achieved, in view of the entire aviation system.

5 Assessing safety levels and determining the effect of changes

One of the objectives of the ASTER project is to provide a means to determine the level of safety in the air transport system and to predict effects of proposed safety measures on this level of safety.

One of the reasons for determining levels of safety is so that safety can be compared. This requires careful consideration of statistics. Measurements of safety inevitably contain some random, fluctuating element.

Quantifying safety for an industry with a good safety record inevitably leads to safety being expressed in terms of small numbers. It is important that the corresponding limitations are understood and properly handled. Quantification requires the choice of units in which risk is expressed. Units must be chosen carefully and justified in terms of the end use and target audience. As well as direct safety data (deaths, hull losses, etc), data must be collected that enables the appropriate numbers to be used. For example, 'per flight' means that the number of flights must be counted, 'per km flown' means that distance must be determined. The accuracy of the measured safety will depend upon the accuracy of all the data, not just the direct safety data.

The safety level can be estimated by using historical accident and incident data, or it can be estimated by using mathematical models that represent (parts of) the air transport system. In ATM, mathematical modelling for the assessment of mid-air collision risk is significant as a tool for determining the extent to which TLS are being achieved. Both approaches have inherent advantages and disadvantages. The disadvantage of using historical accident data is that is always provides a picture of the past rather than the present, and the fact that accidents are rare, which limits the statistical reliability of the estimates. Mathematical modelling results are limited by the quality of the model, the validity of which often requires comparison with statistical data with all associated difficulties.

In ASTER a mixed approach was followed by developing a simple mathematical model that relies heavily on historical data for quantification. In doing so the model remains as transparent as possible, making it easy to understand and allowing a better understanding of the limitations of the model. Most importantly, the modelling approach facilitates straightforward adaptation of the model to user needs and operational context.

To achieve such a model it is necessary to identify the elements of the air transport system and the causal factors that affect the safety of each element. Elements and factors must be linked to be able to determine the overall level of safety of the air transport system.

In ASTER this is done by a combination of accident scenarios representing typical combinations of causal factors. Such generic accident scenarios have been constructed for the following accident types:

- Loss of control
- Controlled flight into terrain
- Collision with another aircraft
- General disintegration
- Landing gear related
- Runway veer-off/overrun

The scenarios have initially been developed by analysis of a sample of accidents for which detailed information was available. Individual event trees were established and combined into generic accident scenarios for specific types of accidents. The trees were further developed by combining them with a functional model of the air transport system. This functional model systematically describes functional relationships between different actors. Combining the initial accident trees with the functional model has the advantage that factors that could play a role but have not materialised in an accident are exposed. In addition, it directly identifies 'ownership' of causal factors.

To describe the scenarios, the model uses a taxonomy of causal factors that is based upon the International Civil Aviation Organisation (ICAO) Accident/Incident Data Report (ADREP) standard. The ADREP system describes an accident or an incident chronologically by listing the events that led to this occurrence together with causal factors that triggered these events. Causal factors can be both technical (Descriptive factors) and non-technical (Explanatory factors). In ASTER a simplified classification was used, with less elements than the original ADREP list. To enable a better representation of ATC related factors, elements of the 'Harmonisation of European Incident Definition Initiative for ATM' (HEIDI) taxonomy, which has a structure that is similar to ADREP, were added to the classification.

Generic accident scenarios were integrated into a nodal network, with the top event "fatal accident". The nodes of the network consist of the elements of the classification scheme that were used to build the scenarios. States were defined for each of the nodes, indicating the status of that node. The number of possible states for each of the nodes was intentionally minimised to keep the network as simple as possible. To allow probabilistic causal analysis, a Bayesian Network is constructed.

A Bayesian Network is a combination of causal relations without closed loops in which relations between variables are represented through conditional probabilities. The Bayesian Network forms a representation of a joint probability function of the system, which allows a computation of the probability of any combination of values for the parameters in the model. A Bayesian Network allows easy representation in a graph, which can be helpful to provide more insight during the analysis.

Hugin is used in ASTER as a Bayesian Network programming environment for modelling and calculations. Hugin is software for the construction of causal probabilistic networks where the underlying model is Bayesian probability theory. The software was developed as part of a European ESPRIT project on neuromuscular diseases.

A very pragmatic approach to quantification of the model was followed. Although the size of the model is kept modest (it consists of 49 nodes), full quantification requires more than 500 conditional probabilities to be determined. While a strong effort was made to justify all of the probabilities that are used in the model, limitations in available time and data required that some assumptions had to be made. It is important that users of the model are aware of those assumptions.

The model can be used to determine the potential of safety improvement alternatives. As an example, the effect of each of the ‘base nodes’ on the overall accident rate was calculated. The base nodes were ‘eliminated’ by setting their probability of occurrence at 0, and subsequently the relative improvement of the accident rate was calculated. The result is presented in Figure 2. It shows that the largest improvement (20%) in safety is obtained when ‘crew aircraft handling’ is always according to procedures. This corresponds with results from other research.

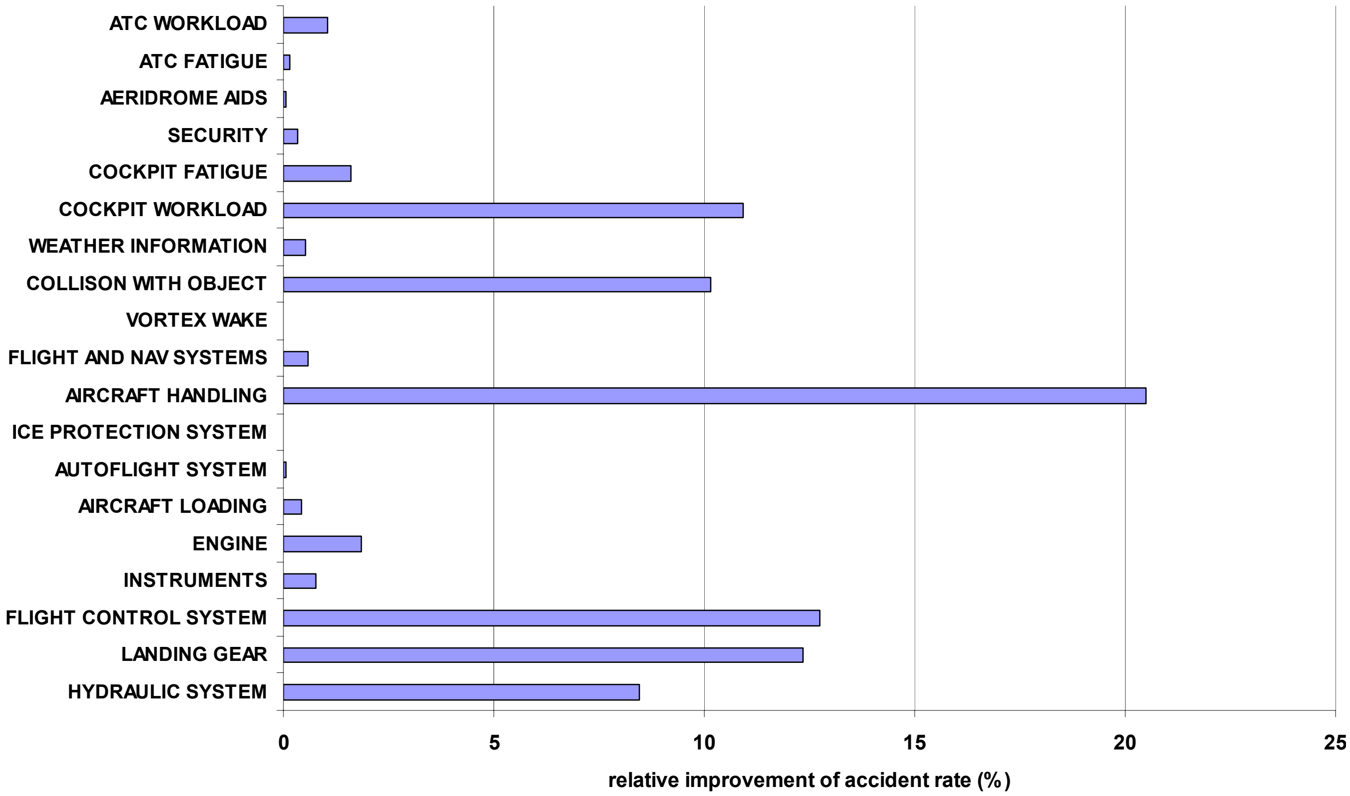

Figure 2: Relative influence of the base nodes on the overall accident rate

Availability of data remains a problem. The best sources of data are aircraft manufacturers and airlines. IAI provided very detailed reliability data the Galaxy business jet. This included mean time between failure and failure mode description on part number level for all major systems. While this illustrates that manufacturers are potentially a very important data source, the translation of this detailed reliability data into more generic data proved to be impossible within the scope of this study.

In the context of Flight Operational Quality Assurance (FOQA), airlines collect and analyse in flight recorded data using systems such as the British Airways Safety Information System (BASIS). After a comparison of the ASTER classification scheme and BASIS, it was concluded that both BASIS and FOQA data can be successfully exploited as sources of technical information. The ASTER classification could be modified so as to interface better with BASIS, but this would imply a reduction of the classification and consequently a lower precision for similar categories. As far as non-technical (human factors) data are concerned, neither BASIS nor FOQA are capable to provide relevant data at the moment.

Availability of in-flight recorded data is difficult. Data is not generally shared with other operators. Often an agreement has been made with the pilot unions to keep in-flight recorded data within the Flight Safety Department.

6 The costs of unsafety

The main objective of ASTER is the development of a method to optimise safety targets across the air transport system. This optimisation has to be based on a number of criteria, one of which is the balance between safety benefits and costs. The method used by economists to appraise (government) policies and projects and to optimise costs and benefits across all parties is cost-benefit analysis (CBA). In CBA, all effects are expressed in monetary terms. Not all effects are priced on an economic market however. Non-priced effects must be valued by using surveys, behavioural data or shadow prices. CBA can be used in a systematic comparison of alternatives and to supply information to facilitate the evaluation of these alternatives. Therefore, CBA can be used for safety budget allocation as meant in ASTER.

6.1 Limiting the scope

Although in theory all costs should be considered in a socio-economic CBA the question arises if really all costs should be considered, specifically costs related to third party risk and costs associated to minor events and incidents.

While accidents with *third party* casualties are not typical, they do happen and costs can be very high. Given the high costs which can be associated with third party risk it is proposed that in ASTER a risk assessment together with some kind of expected costs should be incorporated.

With respect to damage related to incidents it is important to make a distinction between two type of incidents:

Non-Operational (No intention of flight)
Events where the aircraft was damaged or even destroyed but there had been no intention of flight e.g. a hangar fire, or events during ground handling. These events are sometimes referred to as ‘non-operational accidents’. These accidents and incidents may in some cases cause delays and cancellations but do not directly relate to any air safety issue. Therefore, these costs are not considered relevant for ASTER.

Operational
Two categories of operational events can be considered:

- Events, which are similar to accidents but where there were no injuries and aircraft damage fell below that defined as ‘substantial’ in Annex 13. These events might include minor runway/taxiway excursions, hitting animals or birds, minor ground collisions etc. These are minor damage events, with the cost of repairs not exceeding a few hundred thousand dollars but normally probably much less. Other costs may also arise such as delay but, again, they could normally be expected to be relatively minor.

- Events where an accident 'almost' happened but where there was no damage or injury and no other disruption. Such events might include loss of separation between aircraft, descent below a safe height, equipment/system failures etc. This type of 'incident' may be investigated ('Serious incidents' as defined in ICAO Annex 13 may be investigated by the State while other incidents may be investigated internally by the airline, manufacturer, ATM provider etc.). However, it is suggested that these investigations and their costs should be regarded as a safety action, a cost of safety rather than unsafety. The work is undertaken to avoid accidents.

6.2 Accident cost factors

The most significant determinants of cost arising from accidents and incidents are aircraft damage, death and injury suffered by occupants, and loss of airline reputation. However, costs may arise from an accident in a number of ways, both directly and immediate and indirectly, perhaps over a longer term.

Analysis of accident data shows a direct link between aircraft damage and number of occupants killed. It also suggests that for many other heads of cost the level of cost is largely dependent upon the accident severity. The accident severity scheme presented in Table 1 is used to model the effect of accident severity on the level of cost.

Table 1: Accident severity classification scheme

Level	**Damage**	**Death**
Catastrophic	100%	80%
Disaster	100%	30%
Major	80%	0%
Moderate	50%	0%
Minor	20%	0%

For each accident type a typical severity level was established. The correlation between some accident types and their 'typical' severity level was found to be very strong, e.g. 98% of 'collision with high ground' accidents matched the definition of catastrophic. However, others showed considerably less strong correlations. Where no typical severity level could be established (more than 50% of the accidents in the sample meeting the level definition), the average damage level was used. For the accident types included in the model, this provided the following results:

Table 2: Typical accident severity

Loss of control	catastrophic
Controlled flight into terrain	catastrophic
Collision with another aircraft	disaster
General disintegration	major
Landing gear related	moderate
Runway veer-off/overrun	moderate

6.2.1 Aircraft physical damage

Under the cost model, aircraft physical damage is one of the key determinants in categorising accidents. 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 $1 to $2 million and a brand new Boeing 747 valued in excess of $150 million. The destruction of these aircraft will produce very different resulting costs for aircraft physical damage. Costs will also vary with time as inflation causes new prices and costs for repair to gradually rise.

Therefore, rather than using actual cost figures for individual aircraft, these figures are normalised so that an 'index' for relative degree of damage is obtained. The index is expressed as a percentage of the aircraft damaged. The average loss of aircraft value with age, as determined by Airclaims, across all Western-built jet airlines types for all years of manufacture and all market conditions is provided to help estimate aircraft damage costs.

6.2.2 Passenger and crew deaths and serious injuries

Human life is precious and beyond price and it is, therefore, not possible, nor indeed desirable, to attempt to put a price on it. Nevertheless, attempts are made to indemnify for the purely material losses arising from deaths and serious injuries. Cost benefit models increasingly use a Value of Statistical Life in their calculations where this 'value' generally includes an element of indemnity together with society's 'Willingness to Pay' (WTP) to avoid a statistical fatality.

WTP values are based on individual preferences, which include perception and attitude to risk. It is not necessary that these preferences, perceptions and attitudes are the same for all types of risks. The WTP for a given reduction in number of deaths can vary by a factor of more than three for different contexts. Even accidents in different transport modes seem to have different values for the individuals; reduction in underground accidents has been found to be valued one and a half times the value placed on road accidents. From the WTP a Value of Statistical Life (VOSL) can be derived. Proposed VOSL for different European countries are presented in Table 3.

Table 3: Proposed VOSL by Country (Consumer value - € 1998) Source: UNITE project

Country	**VOSL (M €)**
Austria	1.68
Belgium	1.67
Denmark	1.79
Finland	1.54
France	1.49
Germany	1.62
Greece	1.00
Ireland	1.63
Italy	1.51
Luxembourg	2.64
Netherlands	1.70
Norway	1.93
Portugal	1.12
Spain	1.21
Sweden	1.53
Switzerland	1.91
United Kingdom	1.52
Hungary	0.74
Estonia	0.65

6.2.3 Loss of reputation

A major accident may change the way the general public and, directly and indirectly, how business views the airline or the aircraft manufacturer which may be associated with the crash. This can have both short term and longer term implications for the company. A very important factor is the view of the public on ‘who is to blame’ in the accident. This public perception is largely determined by the media. It should be noted that although the airline involved may suffer a substantial loss of turnover, other airlines might profit from the crash, merely leading to a redistribution of revenue. From a (societal) economic point of view this offsets the impact of a crash suffered by the airlines involved.

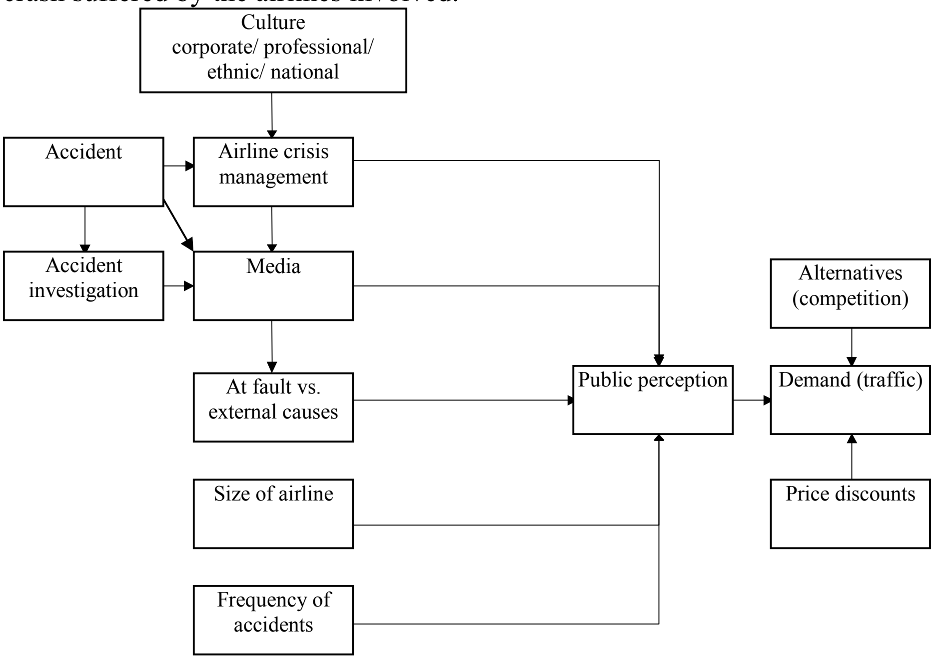

Figure 3: Interrelation of accidents and reputation.

6.3 Insurance and commercial aviation

Probably because of the potentially catastrophic nature of air accidents and the large amounts of money at risk, insurance plays a large part in commercial aviation, removing most of the possible direct loss resulting from such accidents. In typical airline accidents the following insurance covers play a part in mitigating losses resulting from an accident.

INSURED	COVER
Airline (Operator)	Hull – Insurance against loss or damage to the aircraft.
	Loss of Use (Consequential loss resulting from accidental damage to the aircraft)
	Deductible
	Business Interruption Insurance
	Passenger Liability
	Third Party Liability
	Cargo Legal Liability
Owner (Lessor/Financier)	Diminution of value/Residual Value Insurance
Crew	Personal accident etc.
Passengers	Various personal insurances
Third parties	Various personal insurances
Manufacturers(aircraft)	Various personal insurances
Airports	Liability insurance
Other suppliers of products and services (ATM, Fuel etc.)	Liability insurance

It may be assumed that, in most cases, it is the airline's insurance which responds first to a loss with other parties becoming involved through subrogation or contribution. Separately, personal insurances e.g. life insurance, may also be expected to respond.

Insurance, hull, passenger liability etc, removes most of the direct costs of an accident from the airline and other parties which may be involved (the insureds) so that the monetary impact of an accident falls more immediately on insurers and re-insurers.

However, in undertaking the work for both DESIRE and ASTER, when discussing 'the cost of accidents' with anyone outside of insurance, a common response to the suggestion that most of the cost of an accident is taken away by insurance is, 'well of course if you have an accident, although insurers will pay the claim, you end up paying it all back in a couple of years in increased premiums.'

In most cases this is not true. A major loss, all else being equal, may result in an increased premium for two or three years but the insured would not be expected to 'pay back' the loss in higher premiums.

But, if it is assumed that the cost of all claims paid by the insurers are eventually recovered from the insureds as a whole through the general level of premiums paid plus any additional loading placed on the premiums of those insureds which have suffered losses, then the cost of the loss will end up back with the airline community as a whole.

Therefore, if it would be double counting if the cost of insurance premiums are included in the cost of accidents, even if it is only the expected additional premium cost incurred following a loss.

An overview of all heads of cost related to aircraft accidents is presented in Table 4.

Table 4: Overview of accident heads of cost

Cost category	**Costs**	**Assumptions / remarks**
Aircraft physical damage	Minor, 15% damage	Aircraft market value depends on type and age. Estimates provided in deliverable.
	Moderate, 50% damage	
	Major, 80% damage	
	Disaster, 100 % damage	
	Catastrophic, 100% damage	
Possible loss of resale value	5-10 % of aircraft market value for partial losses	It is assumed that this cost item is only applicable for aircraft with partial loss damage. Aircraft market value depends on type and age.
Aircraft loss of use	Monthly lease cost x assumed months to replace = cost of 'loss of use'	ACMI lease cost estimates provided in deliverable
Aircraft loss of investment return		Part of aircraft loss of use.
Site contamination and clearance	Wide body 1.2m-2.8 m €	
	Narrow body 0.7m-1.3m €	
	Smaller aircraft 0.13m-0.2m €	
Airline costs for delay	Wide body: 22 € per seat per hour	
	Narrow body: 20 € per seat per hour	
Airport closure	Airport disruption depends on severity of the accident, estimates provided in deliverable	Only applicable if accident occurs on or close to the runway.
Deaths and injuries	Value of Statistical Life (VOSL) 1-2.64 m €	VOSL differs per country. Value of injury is 13% of VOSL.
Loss of staff investment	Replacement cost per pilot 45,000 €	Only for catastrophic and disaster events.
Loss of baggage	Underfloor cargo carried on passenger flights 110,000 €	Only for catastrophic and disaster events.
	Personal baggage on passenger flights 45,000 €	Only for catastrophic and disaster events.
SAR costs	Average SAR cost claim 0.6m €	Only catastrophic and disaster events lead to SAR operations; estimation costs: 50% of policy limit

Airline immediate response	Average costs per accident 0.5-3m €	Only for catastrophic and disaster events.
Cost of accident investigation	State 0.1-100m €	Only for catastrophic and disaster events. Huge range, depends among others on effort needed for wreckage reconstruction.
	Airline 1m	Only for catastrophic and disaster events
	Manufacturer 1m €	Only for catastrophic and disaster events
Third party damage	Third party death and injury: use similar VOSL as in passenger death and injury.	
	Third party physical damage	
Loss of investment income		These costs are reflected in insurance premiums.
Increased cost of insurance	Loss of 20% insurance discount for airline involved	Only for catastrophic and disaster events. The loss of the no-claim premium reflects the payment of the insurance company for the aircraft physical and liability. Including these costs in a CBA would be double-counting.
Loss of income		Part of 'loss of reputation' costs
Loss of reputation	Airline loss of turnover 0-380m €	Huge range. Loss to society is far less than to airline, since major part of reduced demand will shift to other airline. Hence should not be incorporated in CBA from societal perspective.
	Manufacturer	Likely that airlines will buy aircraft from other manufacturers. Hence from societal point of view this should not be incorporated in CBA.
Loss of company value		Not included because of double counting
Social costs		These costs are ignored since they are considered too far removed from the accident.
Loss to society		Not included, for displacement reasons
Special situations		Too ill defined: not included
SB and AD compliance		Not included: not a direct accident cost factor
Fines, punitive damages		Not included: not a direct accident cost factor

7 The costs of safety measures and regulation

Air safety has improved considerably over the years, possibly by a 1,000 fold since the very early days of air travel in 1930 and 50 to 100 times since 1950. If air safety had not improved, insured airline losses (hull and passenger liabilities) today would average $2,250 billion at 1930 safety levels and between $50 and $100 billion at 1950 levels. Average expected insured losses per year today total $2 billion.

Based on an estimated 2,000 million passenger trips per year, $1,150 is now saved per passenger trip as the result of improvements in safety since 1930. However, this reduces to $40 per passenger trip for improvements since the start of the jet age and only 12 cents for improvements in the last 10 years. The money (insured loss) which could be saved by reducing the accident rate to zero is about $1 per passenger per flight or, less than 1% of the average ticket price (but 15-20% of the notional profit per ticket).

7.1 Life cycle costs

Cost can arise at all stages of a lifecycle: design, manufacturing, operation, disposal. The lifecycle can be applicable to products, but also regulation and procedures. In the case of regulation, life cycle stages are research & development[1], implementation, compliance and termination. Within each phase, particular types of activities take place. The relative size of costs and the duration associated to each of the phases depends on the nature of the (safety) measure. The (safety) benefits will in general only appear during the operational stage.

Major heads of cost for each of the life cycle phases are the following:

- Equipment
- Consumables
  - Consumable materials
  - Energy and utilities
- Spares and support equipment
- Facilities[2]
- Personnel costs
  - Salaries and wages
  - Training
    - Initial training
    - Recurrent training

7.2 Estimating cost of safety measures and regulation

Necessary steps in making a cost estimation are the following:

<u>1) Identify type of measure</u>

Classify the proposed safety measure or safety regulation. This will help in identifying additional reference material for cost estimation (e.g. data on similar measures).

<u>2) Identify scope (geographic, within each type of actor)</u>

What is the scope of the intended safety measure? Is it restricted to a particular geographical region? A specific type of operation? A specific fleet of aircraft, etc. Specify as detailed as possible.

<u>3) Identify type of actors involved.</u>

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[1] Research & Development costs are often excluded from cost benefit analysis.

[2] Facilities consist primarily of buildings and other real property. Included are costs for new construction and ongoing costs such as real property lease payments.

Even in those cases where the costs or benefits to society as a whole are investigated, it is important to identify the actors involved in some detail. It will allow making use of more detailed cost information (with respect to labour rates for instance) and will provide a structure that will assist in determining all relevant cost elements.

4) Identify applicable life cycle period(s)

Usually different life cycle phases will result in different cost distributions. As opposed to benefits, costs are generated during all life cycle periods. Estimate the duration of each of the life cycle periods using available information on similar projects.

5) Identify time scale (start, finish for each of the applicable life cycle periods)

Expected start and finish data for each of the life cycle periods should be estimated.

6) Identify relevant cost elements (equipment, consumables, spares, facilities, personnel)

Identify relevant heads of cost, stratified by life cycle period and actor involved.

7) Collect reference material.

The information that is provided in ASTER deliverables can be used as a starting point. It is also expected that potential users of the ASTER methodology will have own sources of data that they might want to consult.

8) Discounting

Establish the discount rate that will be used in the cost-benefit analysis. This discounting rate must be similar to the rate that is used to calculate benefits.

7.3 The rulemaking process

In order to help estimating costs associated with rule making, the rulemaking process was described in some detail for different organisations (ICAO, FAA, JAA, and Eurocontrol). In general, the process of rulemaking comprises the following steps:

- Initiation
- Drafting
- Consultation
- Review of comments
- Adoption
- Publication.

The total effort involved in rulemaking is highly dependent on the size and the subject of a particular regulation or amendment.

8 ASTER Handbook

8.1 Purpose of this handbook

Within the ASTER project several tools have been developed and useful information has been collected to assist in each of the steps of a cost benefit analysis of safety measures. The purpose of this handbook is to provide a guide on how to conduct a cost benefit analysis of safety measures and how to use the tools in each of the necessary steps. As a further illustration of the method, a case study that addresses the problem of wake vortices has been worked out in detail.

8.2 Potential users of this handbook

The prime user of the ASTER method is expected to be a pan European regulator, such as JAA and EUROCONTROL, and in particular the proposed European Aviation Safety Agency (EASA). The development approach was to include the whole aviation system from the beginning and to use a top down approach. As a result the method, and in particular the ASTER accident probability model that is a part of the method, describes the air transport system at a fairly generic level.

8.3 Overview of the process

The ASTER process comprises the following steps:

1. Define scope
2. Set target level of safety
3. Determine actual level of safety
4. Identify areas of improvement and improvement alternatives
5. Define base case
6. Estimate costs and benefits
7. Comparison of alternatives

The underlying work packages of ASTER are the basis for this process. In Figure 4, the relationship between the general ASTER process and the underlying work packages are visualised. This immediately provides a reference for further reading.

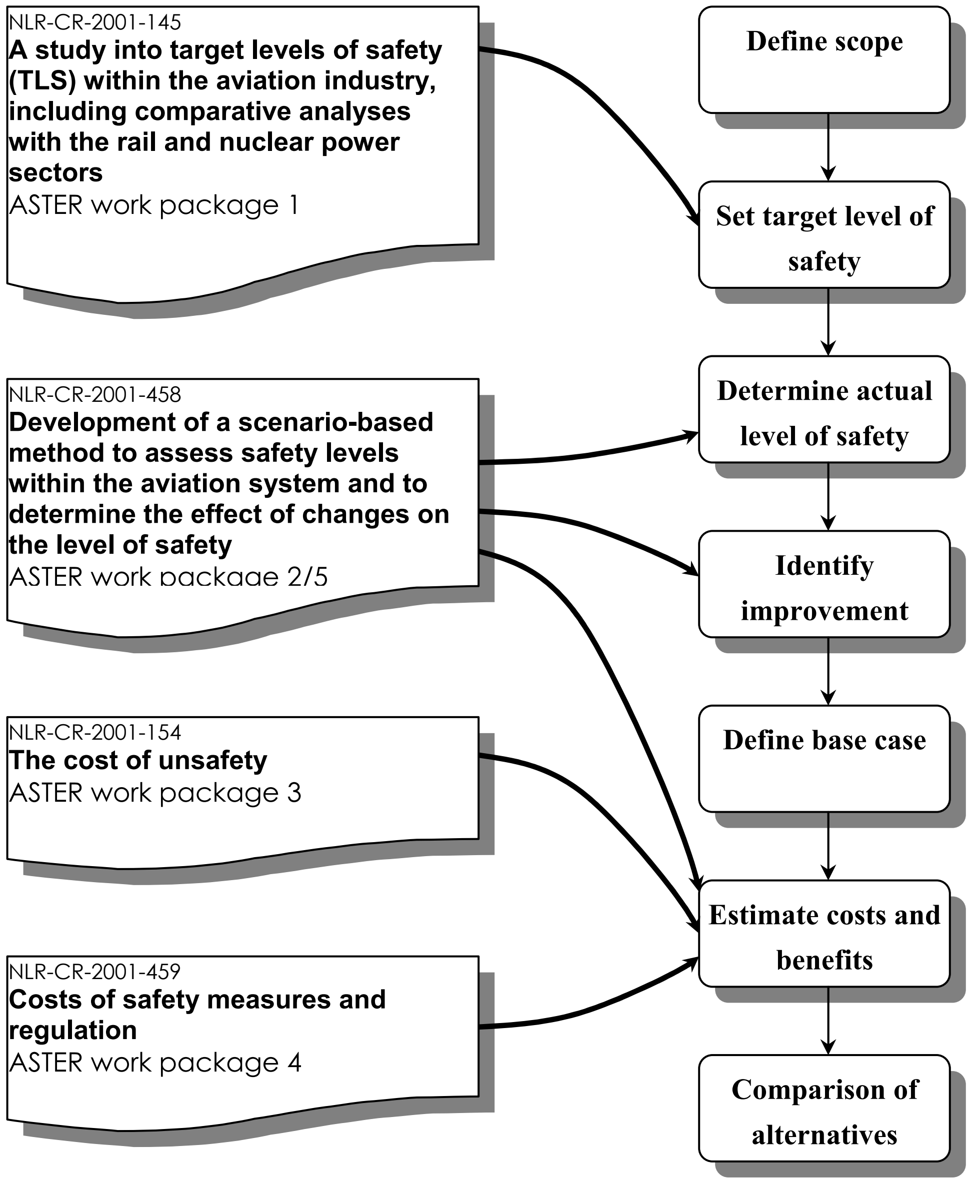

Figure 4: ASTER process flowchart

A first step in CBA is to define the scope of the assessment. An aspirational or mandatory target needs to be set. The actual level of safety must be determined by analysing historical data, using mathematical models, or a combination of both. Comparison of the actual level of safety with the target may lead to the conclusion that improvement is necessary. Improvement alternatives may be identified by using (a combination of) expert judgement, common sense, literature review, research results, accident and incident investigation and operational experience.

The expected costs and benefits of alternatives are considered in relation to a base case. The base case is the situation that would exist if the alternative were not undertaken. In identifying impacts it is necessary to carry out a stake holder analysis. If costs and benefits of alternatives have been assessed, the actual CBA can be carried out. A frequently applied measure in CBA is the Net Present Value (NPV). The NPV is defined as the cash equivalent now of a sum receivable or payable at a future date. In order to calculate the NPV, it is necessary to discount future benefits and costs. This discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner. The higher the discount rate, the lower is the present value of future cash flows. Hence the value of the discount factor reflects the preference of society for today's income versus income later in time. The discount rate represents also the cost associated with diverting investment resources from alternative investments or from consumption. The following equation is used for calculating the NPV:

$$\text{Net Present Value (NPV)} = B_o - K_o + \frac{B_1 - K_1}{1+r} + \frac{B_2 - K_2}{(1+r)^2} + \frac{B_n - K_n}{(1+r)^n}$$

$$= \sum_{t=0}^{t=n} \frac{B_t - K_t}{(1+r)^t}$$

Where:

n is the project life;

B is the present value of cash inflows;

K is the present value of cash outflows;

r is the annual discount rate.

It must be kept in mind that in conducting any cost benefit analysis a number of assumptions have to be made, for instance with respect to the efficiency of certain measures, expected traffic growth, future technological developments, displacement effects, hardware costs, etc. The amount of uncertainty in such assumptions can be substantial. For this reason it is recommended to perform a sensitivity analysis.

In a sensitivity analysis, the effects of systematic variations of key parameters on the economic measures of the project viability (NPV, IRR and Benefit/Cost Ratio) are determined. The following list contains factors generally important for such an impact analysis:

- Projected traffic growth in absolute terms and with respect to the traffic mix;
- Safety effects;
- Capacity effects;
- Investment costs (purchase prices, installation/introduction);
- Staff costs;
- Discount rates;
- Project time scales

The results of the sensitivity analysis identify the most critical parameters and their degree of impact.

9 Wake vortex case study

As a demonstration of the ASTER approach for setting and optimising safety targets, a case study was conducted on wake vortex measures.

9.1 Define scope

The analysis is conducted from the viewpoint of the proposed European Aviation Safety Agency (EASA) and is limited to flights in ECAC airspace.

9.2 Set target level of safety

The current level of safety with respect to wake vortex is considered to be acceptable. In face of the system-wide effort to reduce the accident rate to such a level that the total number of accidents does not increase in spite of the prospected growth in air traffic, an increase of the wake vortex related accident risk is not acceptable. The target level of safety for wake vortex related accident risk is therefore set at 1×10^{-8} accidents[3] per flight.

9.3 Determine actual level of safety

From 1970 to 2000, no accidents due to wake vortex are known to have occurred where ICAO minimum longitudinal separation standards have been achieved. Therefore it is not possible to estimate an accident probability from past events. It does suggest however that the wake vortex related accident probability is at least two orders of magnitude lower than the overall accident probability, i.e. 10^{-8} or lower.

The ASTER accident probability model can be used to estimate the wake vortex related accident probability. The model contains the node "wake vortex", which represents the probability of a wake vortex encounter. If this probability is set at 0 (representing total elimination of the wake vortex problem) the overall fatal accident probability drops with 1.7×10^{-9}, which represents the current wake vortex related accident probability according to the model. This supports the earlier estimate.

9.4 Identify areas of improvement and improvement alternatives

The current level of safety meets the target. However, for the purpose of increasing airport capacity a safe reduction in separation of aircraft compared to current flight rules is desirable. Several alternative measures are proposed to enable such a reduced separation. The following measures are included in this case study:

- Ground based wake vortex prediction and detection

[3] 'Accident' in this case refers to the ICAO definition of an accident.

- On-board wake vortex detection
- Alternative approach procedures (HALS/DTOP)
- Wake vortex reduction at the wing of the aircraft.

9.5 Define base case

The base case is the air transport system in Europe in 2002-2020 with no additional wake vortex measures. The current fatal accident rate is considered to remain constant at 0.46 accidents per million flights. Traffic growth within the ECAC region and the 10 major European airfields is according to the 'accommodated growth' scenario of an ECAC/Eurocontrol study on constraints to growth.
Future fleet distribution is according to the Airbus Global Market Forecast 2000.

9.6 Estimate costs and benefits

Ground based prediction and detection will be introduced on the currently 10 busiest fields (by number of movements) in Europe from 2006 onwards. The system will be operational for all runways that are normally used for landing. Capacity increase for the same level of safety as the base case is estimated at 6%.

An airborne wake vortex detection and warning system will be required by EASA for all newly built large aircraft from 2008 onwards. Retrofits will be required on the existing fleet from 2015 onwards. Airbus global market forecast data is used to estimate the number of aircraft involved. It is estimated that this will not lead to a capacity increase. The accident rate is estimated to reduce to 4.54×10^{-6} per flight.

Displaced Threshold Operations will be conducted on those of the 10 busiest airports of Europe (2001 situation, ranked by number of movements) where it will lead to increased capacity. It will be operational from 2005 onwards. Capacity effects vary between airports and are expected to total 38,400 movements per year for the whole of Europe with the same level of safety as the base case.

A wake vortex reduction system will be required by EASA for all newly built heavy aircraft (over 255,000 lbs MTOW) from 2010 onwards. No retrofits will be required on existing aircraft. Airbus global market forecast data is used to estimate the number of aircraft involved. Yearly capacity improvements due to reduced average separation have been estimated, where it is assumed that the accident rate will be similar to the base case.

Detailed costs estimates of each of the four proposed measures have been calculated.

9.7 Comparison of alternatives.

The calculation results in the highest NPV for wake reduction on the aircraft, followed by ground based prediction and detection and HALS DTOP. Airborne detection and warning has a negative NPV (Figure 5).

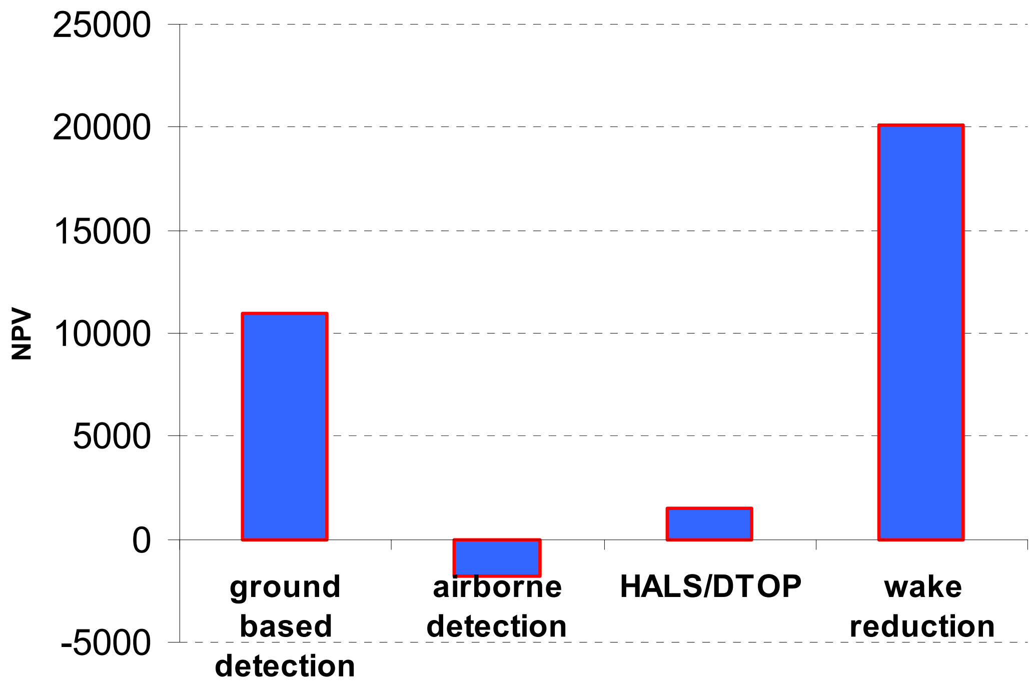

Figure 5: Net Present Value comparison of the alternatives

The wake vortex reduction system is also the alternative with large uncertainties as regards technical feasibility, total costs and overall effect on capacity.

The uncertainties related to the 'second best' alternative, ground based prediction and detection, are less (experimental set-ups have been successfully tested and capacity effects have been measured).

Based on these results, a good decision for EASA would be to initiate more detailed studies on the installation of ground based wake vortex prediction and detection systems at major European airports, while simultaneously encouraging further research in the field of wake vortex reduction.

It is emphasised however that the results of this analysis depend on the assumptions that have been made. A sensitivity analysis has not been carried out. Furthermore, combinations of measures, such as a combination of ground based and airborne detection of vortices, were not considered.

10 Workshop

A workshop was held at Meridiana in Olbia, Italy. The objective of the workshop was to obtain feedback on the development approach and the model itself from a potential user of the model[4]. Participants included the managers of the Technical and Operations Division, the Flight Safety Department and the Quality Assurance Department of Meridiana.

Meridiana is a relatively small airline, operating mainly domestic routes in Italy with a fleet of 21 aircraft.

The Safety Department does not have an own budget. Technical issues fall under the budget of the Technical Department, training issues under the budget of the Training Department. The task of the Safety Department is to monitor and observe.

The Human Factor activities within the airline involves review of the system functions and identification of human tasks that may be critical to the performance of those functions early in the acquisition process of a new system (or in the implementation of a new organisation or activity) and analysis of in-service events, identification of critical issues and providing recommendations to the responsible manager for human factor design.

Flight data relevant for training issues is collected and analysed for exceedances with the FLIDRAS system[5]. The system itself is capable of presenting statistics, these are used for training. The system is used to analyse the impact of training. Data is not shared with other operators. An agreement has been made with the pilot unions to keep in-flight recorded data within the Flight Safety Department. An updated version of FLIDRAS is available from Teledyne, but this is not being bought because a fleet renewal is expected shortly.

An ideal system would relay in-flight information real time to the ground. This would be particularly helpful to the maintenance organisation.

According to Meridiana, ASTER is a tool for the regulator. The majority of safety investments made by the company are because of regulatory requirements. Many of the decisions that are being made are based on qualitative rather than quantitative data. However it was also stated that the 'signature' of the company in terms of flights safety is what they do *in addition* to the

[4] A similar workshop was scheduled at IAI but this was cancelled because the Netherlands Ministry of Foreign Affairs advised against travelling to Israel.

[5] FLIDRAS = Flight Data Replay & Analysis System

minimum requirements. In order to make a decision on which additional requirements would be useful, a tool such as ASTER can be very relevant.

Tools such as ASTER could be useful for the Maintenance Department in making decisions with respect to non-mandatory modifications (Service Bulletins). It is sometimes very difficult to make a decision on whether or not to implement a SB.

With respect to the case study subject is was mentioned that wake vortex is not considered to be a problem. Wind-shear and mountain waves are considered to be more problematic. Acceptance of reduce longitudinal separation minima by the pilot community is considered to be similar to RVSM acceptance: When it can be demonstrated that there will be no safety implications there will be no problems with respect to acceptance of the new standards.

11 Review and dissemination of project results

During the course of the project, dissemination of project results was considered important to obtain feedback from other parties. An important role was played by the review committee with representatives from FAA, JAA Eurocontrol and Airbus. The review committee received all (draft) deliverables before publication and was able to comment. In addition, the project manager discussed the project and the results with members of the committee personally.

Representatives from FAA's Risk Analysis Section AAR-424 came over to Europe to attend ASTER progress meetings and to describe the process of aviation rulemaking in the US. In addition FAA made reference material available to the ASTER study team.

A representative of JAA's Regulation Division attended ASTER progress meetings and actively participated in explaining the rule making process within JAA.

A visiting scientist from NASA's Langley Research Center actively participated in the development of generic accident scenarios as part of work packages 2 and 5 and attended one ASTER progress meeting.

The Safety Manager of NATS' New En-Route Centre at Swanick attended one progress meeting and provided additional information on the use of Safety Cases.

Two presentations were made at the Human Issues in Aviation System symposium, held at the Ecole Nationale de l'Aviation Civile in Toulouse, France on 26-28 September 2001.

A presentation was made at the Probabilistic Safety Assessment and Management PSAM 6 Conference in San Juan, Puerto Rico, on 24 June 2002.

A presentation was made at the 4th Workshop on Risk Analysis and Safety Performance Measurements in Aviation in Atlantic City, NJ, USA on 29 August 2002.

A presentation was made to the JAA Regulatory Impact Assessment group at JAA Headquarters in Hoofddorp, the Netherlands, on 25 April 2002.

The ASTER method is mentioned in the draft NPA to JAR 11, version 20-06-02:
"*Safety*

All safety impacts of the option(s) being evaluated should be identified and wherever possible and necessary be quantified e.g. in terms of incident/accident probability and severity. This should, if appropriate, include Human Factors and Operational aspects.

A method of quantifying the safety impact is included in the ASTER ‘Handbook for conducting cost benefit analysis of safety measures in air transport’, NLR-CR-2001-609. (ASTER is a research project carried out under a contract awarded by the European Commission, DG-TREN, contract number GMA1-1999-10024.)”.

12 Conclusions and recommendations

The main objective of ASTER, the development of a method to set and optimise safety targets in the aviation system, has been met. A step by step guide on the process of setting and optimising safety targets is described in a handbook and further illustrated with a case study.

No single process for establishing TLS is best in all situations. The process should be appropriate for the commercial, legal and political situations of the industry concerned and should take into account technical issues and timescales. The process should be acceptable to at least the most important stakeholders, should be clearly defined and should result in a TLS that is both achievable and not open to significant dispute.

TLS for the rail industry have been derived subject to qualitative judgement regarding fatalities and injuries avoided and equivalent fatalities (10 major injuries being the equivalent to one fatality and 200 minor injuries being the equivalent to one fatality). This approach is relevant to the aviation industry, for example, that ‘x’ number of level busts = ‘y’ number of fatal accidents might prove to be a valid equivalent fatality for ATM. Further research on the use of ‘equivalent fatalities’ for TLS in aviation is recommended.

An important element of the method is the ASTER accident probability model, a fully quantified Bayesian Network developed in a HUGIN software environment. This model is used to assess the effect of changes in the air transport system on the level of safety, expressed an accident probability. While the model can be used directly for calculations, in many cases expert knowledge from the user will be required to tailor it to the specific circumstances that are under consideration. Similarly, although considerable care was taken in selecting the factors, the interconnections, the probabilities and the financial equations and data, it is expected that users of the method will have their own sources of data that they would want to use.

It is recommended to further develop the ASTER approach to tailor it to specific users. One of the possibilities is to further develop the ASTER method into a decision support tool for a airline Maintenance Department for assistance in making decisions on non-mandatory modifications (Service Bulletins).

13 List of deliverables

T. Joyce, G. Graham, S. Kinnersly, M.J.A. van Eenige, A.L.C. Roelen, A study into Target Levels of Safety (TLS) within the aviation industry, including comparative analyses with the rail and nuclear power sectors, ASTER WP 1, NLR-CR-2001-145, April 2001.

A.L.C. Roelen, Y.S. Cheung, M.H.C. Everdij, E.A. Bloem, M. Pedrali, P. Hayes, Development of a scenario-based method to assess safety levels within the aviation system and to determine the effect of changes on the level of safety, Part 1: ASTER WP 2/5 main report, NLR-CR-2001-458-PT-1, NLR Amsterdam, October 2001.

A.L.C. Roelen, Y.S. Cheung, M.H.C. Everdij, E.A. Bloem, M. Pedrali, C. Mauri, P. Hayes, Development of a scenario-based method to assess safety levels within the aviation system and to determine the effect of changes on the level of safety, Part 2: Appendices to the main report, NLR-CR-2001-458-PT-2, NLR Amsterdam, 2001.

W. van Dijk, R.J. Molemaker, P. Hayes, A.L.C. Roelen, The cost of unsafety, ASTER WP3, NLR-CR-2001-154, April 2001.

A.L.C. Roelen, G.W.F.M. van der Nat, A. Joyce, G. Graham, P. Hayes, Costs of safety measures and regulation, ASTER WP 4, NLR-CR-2001-450, NLR Amsterdam, October 2001.

A.L.C. Roelen, R.J. Molemaker, R. Piers, P. Hayes, A. Joyce, G. Graham, A cost benefit analysis of wake vortex measures, Demonstration of the ASTER approach for setting and optimising safety targets, NLR-CR-2001-610, NLR Amsterdam, December 2001.

A,L.C. Roelen, R. Piers, R.J. Molemaker, Handbook for conducting cost benefit analysis of safety measures in air transport, NLR-CR-2001-609, NLR Amsterdam, December 2001.

Appendix A

Handbook for conducting cost benefit analysis of safety measures in air transport

NLR A.L.C.Roelen

NEI R. Piers, R.J. Molemaker

Airclaims P. Hayes

Summary

Within the ASTER project several tools have been developed and useful information has been collected to assist in each of the steps of a cost benefit analysis of safety measures. The purpose of this handbook is to provide a guide on how to conduct a cost benefit analysis of safety measures and how to use the tools in each of the necessary steps:

- Define scope,
- Set target level of safety,
- Determine improvement alternatives,
- Determine costs,
- Project effects and benefits,
- Comparison of alternatives.

Contents

1 Introduction

1.1 Background

Whilst EU member states have been maintaining a high level of safety of air transport in the face of increasing demands, the pressure for continued improvement will not diminish. The costs of safety improvements are ultimately borne by the passengers. If the investments that are needed to achieve the desired level of safety become excessive, the growth in air transport volume will reduce or even reverse. Therefore methods are needed to ensure that safety targets are being set and optimised for all parts of the aviation system by balancing safety against costs.

1.2 Objective of the ASTER project

The objective of the ASTER project is to develop a method to set and optimise safety targets to achieve the optimum level of safety for the aviation system as a whole by distributing the safety burden more evenly among the different stakeholders. This includes the development of a method for cost benefit analysis to assess safety benefits of any change, including changes in legislation and rulemaking, in relation to the costs of implementing those changes.

The ASTER method is a decision support tool. It provides information and facilitates a systematic comparison of various alternatives to assist in the evaluation of those alternatives.

1.3 Purpose of this handbook

Within the ASTER project several tools have been developed and useful information has been collected to assist in each of the steps of a cost benefit analysis of safety measures [Ref. 1-5]. The purpose of this handbook is to provide a guide on how to conduct a cost benefit analysis of safety measures and how to use the tools in each of the necessary steps. As a further illustration of the method, a case study that addresses the problem of wake vortices has been worked out in detail [Ref. 6].

1.4 General principles of cost-benefit analysis

Project appraisal in general, and cost-benefit analysis (CBA) in specific, is the formal process that provides and formulates a framework within which investment decisions can be made. Projects are assessed according to criteria such as costs, revenues, socio-economic benefits and risk. Within ASTER the focus is on safety measures in air transport. This generally means aviation projects with a European dimension. When conducting or reviewing a CBA, it is important to bear in mind that different sectors/stakeholders will often have different objectives. Since the analysis necessarily should reflect the appraiser’s objectives, the impacts included in the analysis, the importance given to the various impacts as well as the discount factor used are determined by the interest of the appraiser. It follows that the outcome of an analysis may differ, depending upon which stakeholders viewpoint is taken. For instance, the outcome of a CBA may be different for an airline than for an airport. Furthermore, benefits of a certain measure could fall very unbalanced compared to cost for an stakeholder: it may be possible that an airline bears the cost of an alternative, but that benefits fall largely at other stakeholders.

Cost-benefit analysis involves the identification of all effects of a project on the welfare of all members of the community. In welfare economic theory this is expressed in utility, which is a rather intangible measure. A common unit of measurement is required to establish whether aggregate benefits outweigh aggregate costs given a certain discount rate during the lifetime of the project. Generally, the common unit is money reflecting the money transfer which would make an individual indifferent with or without the project.

Impacts are evaluated if possible on the basis of prices observed in the market place, with certain necessary adjustments. Where impacts lack an appropriate market price or cannot be directly measured in money units, it is sometimes possible to estimate unit money values indirectly through some form of shadow pricing. Nonetheless, some impacts that cannot be valued in money (intangibles) remain in principle outside the analysis.

1.5 Potential users of this handbook

The prime user of the ASTER method is expected to be a pan-European regulator, such as JAA and EUROCONTROL, and in particular the proposed European Aviation Safety Agency (EASA). The development approach was to include the whole aviation system from the beginning and to use a top down approach. As a result the method, and in particular the ASTER accident probability model that is a part of the method, describes the air transport system at a fairly generic level.

The ASTER method itself can be used by all stakeholders in the aviation system, but because of the generic nature of the ASTER accident probability model users may need to detail the model to their specific situation. Also the trade-off between costs and benefits might need adjustment, since the focus will shift to those costs and benefits which are borne by the specific stakeholder. In section 3.4 this aspect is further explained.

1.6 Words of caution

A cost benefit analysis can not and should not be used to readily provide answers to the question on what investment is appropriate to protect life and health. In a cost benefit analysis, it is inescapably necessary to compare costs and benefits that can be quantified with relative certainty to costs and benefits that can not. This requires expert judgement on certain matters and consequently includes subjective elements, rather than being rock solid science.

The air transport system is incredibly complex and interdependent. In addition, the subjective qualitative judgements of those working within the air transport system have an important role to play in relation to safety.

A potential danger of cost-benefit analysis can be that it overestimates readily quantifiable variables and disregards variables that are less readily subject to quantitative valuation.

Nevertheless, a thoughtful cost benefit analysis, including explanations of the critical assumptions behind the analysis of scientific evidence, will improve the information relied on in the decision making process. A proper cost-benefit analysis is a useful tool for getting an understanding of the gain and loss associated with safety investments.

2 Overview of the ASTER approach

The ASTER process comprises the following steps in general, which are dealt with in the next chapters:

8. Define scope
9. Set target level of safety
10. Determine actual level of safety
11. Identify areas of improvement and improvement alternatives
12. Define base case
13. Estimate costs and benefits
14. Comparison of alternatives

The underlying work packages of ASTER are the basis for this process. In the following figure, the relationship between the general ASTER process and the underlying work packages is visualised. This immediately provides a reference for further reading.

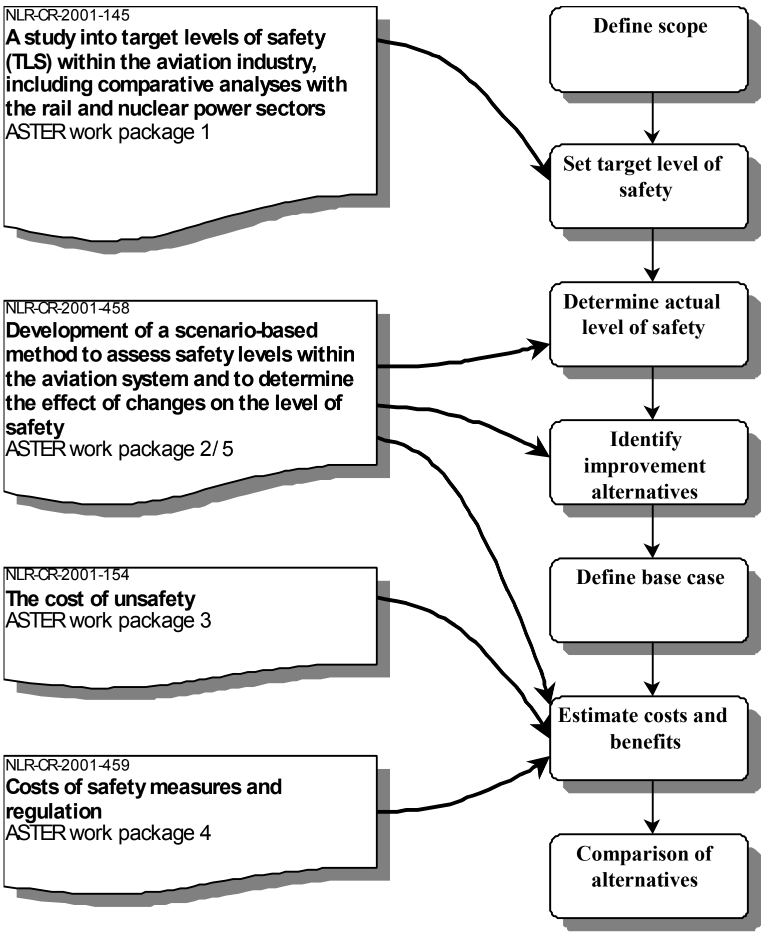

Figure 1: ASTER process flowchart

The starting point for ASTER has been safety. This has resulted in the development of a basic ASTER approach for the assessment of measures that aim at improving the level of safety in aviation. The basic approach is depicted in Figure 2.

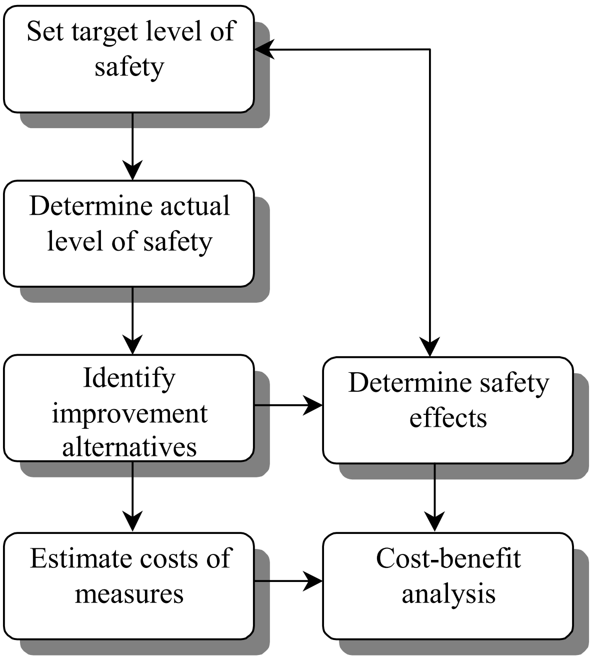

Figure 2 ASTER basic approach: addressing safety measures

The basic ASTER approach is not limited to the assessment of safety measures but can be applied to evaluate any change to the system. This is visualised in Figure 3 below. Safety measures to improve capacity have an impact on the actual level of safety. This actual level is safety is compared with the set target level of safety. If the target is met, the capacity effects of the measures are input to the CBA, as well as the costs of the measures. If the target is not met, the measures have to be adapted or compensation measures have to be taken.

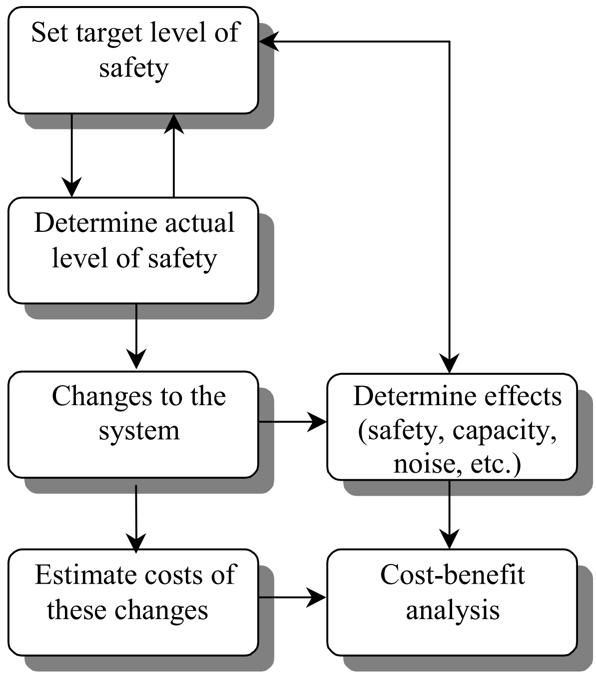

Figure 3: ASTER extended application.

3 Scope

3.1 Introduction

A first step in project appraisal in general, hence also in conducting a CBA, is to define the problem area. The scope of the assessment needs to be determined, before starting to calculate effects and benefits.

3.2 Evaluation framework

If the problem has been defined, it is important to design a framework including all:

- stakeholders to the project;
- cost categories for each stakeholder;
- benefit categories for each stakeholder;
- specifications of transfers between stakeholders.

A thorough set-up of such a framework avoids double counting of costs and benefits.

CBA is usually undertaken from the perspective of the society within which the particular project is located and focuses on the net benefits to society as a whole from implementing the project. As such, it is conducted in terms of resource costs, i.e., the real net costs to society of the impacts it has. Taxes and transfer payments are excluded. Also excluded in many national CBA applications is valuation of impacts outside the country concerned. For appraisal from a Europe-wide perspective the geographical impact area must be agreed upon. An important omission is often any direct reference to the distribution through society of the costs and benefits, although it is possible up to a point to explore distributional consequences if the overall evaluation framework is carefully designed. The ASTER approach has been designed for evaluating from a European societal perspective of e.g. a European Aviation Safety Agency. Nevertheless, ASTER is applicable for other perspectives as well.

In general, a well-substantiated CBA will have the following structure:

1. It starts with a definition of what has to be evaluated: base case, project case(s), geography, time horizon, other practical issues.
2. Furthermore, an extensive stakeholder analysis is carried out, which identifies all stakeholders that are affected by implementing the project(s).
3. For each stakeholder, the costs of the project have to be calculated: R&D-costs, implementation costs, operation- and maintenance costs, termination costs. It is important to be aware of double-counting in this respect.

4. Next, the effects of the projects are quantified for all stakeholders, and subsequently valued in monetary terms. This results in the benefits of the project. If quantification of the project effects is not possible, the effects should be described qualitatively.
5. Finally, the trade-off between costs and benefits is made, the various alternatives are compared, and the consequences for the various stakeholders and geographic regions is identified. Various measures for the feasibility of projects can be calculated.

Aspects 1 (definition) and 2 (stakeholder analysis) need to be addressed when drawing the scope of the analysis. *After all, these aspects have an impact on the assessment of costs and benefits.* In this chapter both aspects will be amplified. The aspects costs, benefits and trade-off will be dealt with in separate chapters.

3.3 Definition

3.3.1 Base case

The expected costs and benefits of alternative measures must be considered in relation to a benchmark or base case. The base case is the situation that would exist if the new system, procedure, facility or device were not undertaken. In cost benefit analysis, two states of the world are compared, one in which the new system is developed and one in which it is not. The state of the world without the new system or procedure is referred to as the base case. Estimates of incremental costs and benefits have meaning only relative to this base case. It is unrealistic to assume that the base case is a future state of the world unchanged from the current situation. Ongoing developments, for instance in the growth of air traffic volume, technology advances, etc, should be taken into account in the base case. The set of assumptions about the most likely future of the air transport system must be explicitly stated at the outset of the analysis. Examples are realistic assessments of future traffic, traffic management improvements, constraints on future capacity, etc.

The base case describes the scenario in which the improvement alternatives are *not* developed. Without these improvement alternatives, there are, or will be, bottlenecks. The base case comprises the best possible solutions for these bottlenecks, without the improvement alternatives. Hence the base case is different then a ‘do-nothing’ scenario or ‘existing policy’ scenario. Overestimation of the yield is a likely result when a poor base case is developed.

3.3.2 Project case(s)

The alternatives that are being evaluated in the CBA are referred to as the ‘project cases’. The project case is the translation of the improvement alternatives into CBA-terms. Depending on the number of improvement alternatives, there are one or more project cases, which can all be compared with the base case. The project case is the practical elaboration of the improvement alternatives, addressing amongst others:

- Time horizon: when is the alternative implemented? Until when is the alternative considered? An unbiased comparison of project cases and the base case requires that they be analysed over equivalent time frames.
- Geography: is the alternative developed on a national or European scale? Is it for all airports, or the top-10 airports? Is it applicable for national airlines, European airlines or all airlines?
- Other practical issues: is the alternative applied only to new aircraft or also to existing? When will retrofit take place? The air transport system is a very complex and truly global system, with many different types of stakeholders that are directly or indirectly involved. What exactly constitutes the air transport system is merely a matter of definition. System boundaries must be clearly defined for each individual case. When the boundaries are too restricted, there is the possibility that some effects that are relevant from a safety or economic point of view are not taken into account. When the boundaries are too broad, the analysis becomes impossibly complicated.

  Elements to be considered are:

  - Type of aircraft (jets, turboprop, piston, helicopters, weight category, manufacturer)
  - Type of operator, (domestic/international, commercial/military, passenger/cargo)
  - Airport type (domestic/international, number of movements, equipment, etc)
  - Airspace type

It is in this phase of the project that all cost and benefit categories need to be identified for all stakeholders.

3.4 Stakeholder analysis

In identifying impacts it is of course essential to identify the different stakeholders that play a role in determining the socio-economic feasibility of a project. Stakeholders can be classified according to their role or interest in the proposed project and the time period they are involved, whether this is in supplying input or producing output during the implementation phase, or in generating demand or supply during the operational phase. Figure 4 below provides an outline of this categorisation:

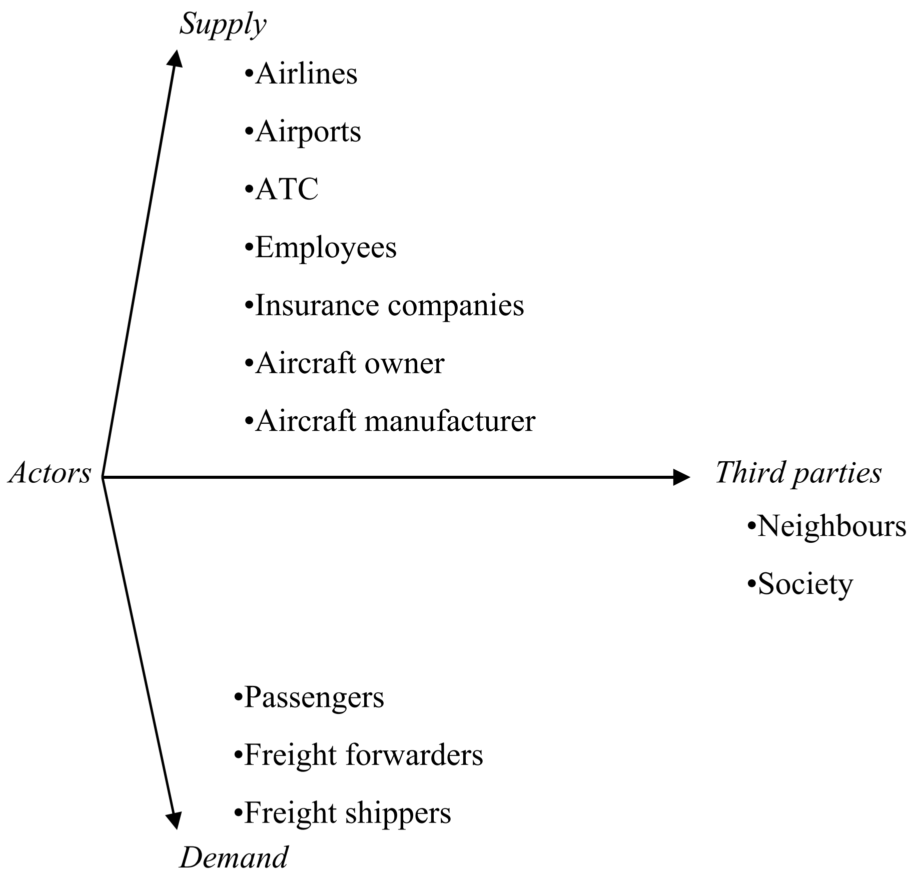

Figure 4: Stakeholder classification

In this scheme, three categories of stakeholders have been distinguished. Stakeholders on the demand side are the customers of transport services in aviation. Stakeholders at the supply side provide those customers with these services either direct, or contribute indirect. The use of these services has an impact on third parties, or non-users, such as neighbours (e.g. noise pollution) of society as a whole (e.g. other environmental impacts*). It is stressed again that one has to be careful for double counting when including various stakeholders in the CBA.*

4 Set target level of safety

The views of society have been and will continue to be a key influence that drives the decision as to what should be an adequate level of safety. Safety is defined as freedom from unacceptable risk where risk is a combination of the probability or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence [Ref. 1]

The Target Level of Safety (TLS) is the 'amount' of safety that is aimed for. A TLS should have a clear and justifiable purpose. It can be mandatory or aspirational. A mandatory TLS must be achieved in order to carry out some activity, and aspirational TLS must be aimed for but not necessarily achieved.

For the purpose of a TLS, an approach to quantifying safety is fundamental. Reproducibility and objectivity of the quantification are necessary. In the quantification of safety the limitations of working with very small numbers must be understood and properly handled.

The choice of units in which to express safety must be made. In general the number of fatal accidents per million flights can be used. It is clearly defined and allows comparison with other existing target safety levels. However, there can be situations where this is totally inappropriate. For a regional airline for example the number of fatal accidents per flight will hopefully be 0 for many years, but this does not say much about the actual level of safety.

Measuring safety includes collecting, collating, processing and analysing data from operations. Unless there is a practical way of obtaining good quality measurement of safety, or a validated way to calculate safety through mathematical models, levels of safety remain theoretical constructs of limited practical value.

When safety can not be measured directly, indirect indicators of safety may be used. Qualitative judgement has been applied in the rail industry to derive 'equivalent fatalities'. 10 major injuries are considered equivalent to one fatality and 200 minor injuries are equivalent to one fatality. More or less similarly, the nuclear industry developed the use of surrogates for harm in developing TLS. These are linked to deaths from radiation through a causal chain but are considerably easier to calculate. This equivalent fatality approach is not widely applied in the aviation sector and would have to be justified if utilised.

Specifying the sources or types of risk to be addressed is necessary to ensure that the TLS is properly focussed and that the risks to be included and excluded are properly identified. It allows to focus on specific areas and develop effective solutions rather than trying to cover disparate areas and becoming diffused and ineffective.

Identifying the contribution and risk assumed by stakeholders is a significant factor. Stakeholders should be involved in setting the TLS, failure to do so may lead to a TLS being discredited. It is equally important to ensure that responsibility for setting a TLS rests with one body so that the TLS adequately balances the priorities and opinions of the various stakeholders.

It is acknowledged that a target level of safety is already pre-set in many cases, and does not need to be calculated every time again.

5 Determine actual level of safety

5.1 Introduction

The actual level of safety must be established to determine if and how much safety needs to be improved. It must be expressed in the same units as the target level of safety to allow unambiguous comparison of the actual level of safety with the target. Comparing safety requires careful consideration of statistics, the random occurrence of small numbers of discrete events can lead to significant fluctuations in measured risk. Any difference in population can make meaningful comparison difficult.

Because aircraft accidents are rare events, historical data can not always be used to determine the level of safety. In such cases mathematical models may be used to calculate the level of safety. Eurocontrol for instance uses mathematical models to calculate en-route collision risks.

When determining the actual level of safety, either based on historical data or by using mathematical models, and especially in those cases of low probability events and small datasets, the amount of uncertainty can be substantial. The actual level of safety should not be expressed as a point estimate, but should be accompanied by upper and lower confidence levels.

The accident probability model that was developed in ASTER [Ref. 2] can also be used to determine the actual level of safety. This is explained in the next section.

5.2 The ASTER accident probability model

The ASTER accident probability model has been developed by combining generic accident scenarios in a nodal network and subsequent quantification of that network. Safety is expressed as the probability per flight of a fatal accident. The nodes of the network consist of the elements of the (revised) ADREP classification scheme for causal factors[6] of accidents and incidents.

When the ASTER accident probability model is used to assess the current level of safety in a given context, that context needs to be translated into the causal factors of the network. It may be necessary to expand the model by including more causal factors from the classification scheme listed in [Ref 3].

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[6] A revision of the original ADREP scheme was necessary to limit the complexity of the model

The ASTER accident probability model is generic, both in structure and in quantification. The nodes represent causal factors, the links between the nodes represent cause-effect relations. For each of the nodes it must be confirmed whether the estimated probabilities are applicable to the specific situation of the user. If not, they should be adapted accordingly. The same applies to the links between the nodes. These links are expressed as conditional probabilities.

During the development of the ASTER accident probability model several assumptions have been made. Users of the model should verify these assumptions for the specific case.

Users of the ASTER method may have their own sources of data that either directly describes the level of safety of the operation under consideration, or that can be used to ‘fine-tune’ the ASTER accident probability model for safety assessment. It must be kept in mind that the ASTER accident probability model is a generic model and was developed and quantified using generic data.

The output of the ASTER accident probability model is the fatal accident probability (all causes) in number of accidents per million flights. In some cases this may be the output that is needed, but in comparing actual safety with a TLS it is more likely that the accident risk related to a specific accident type or type of operation is needed. Examples are collision risk, system failure, etc. Such a specific accident risk can be obtained by identifying the elements of the model that are contributing (positively or negatively) to the specific accident risk and determining the effect of these elements on the overall accident probability.

6 Determine areas of improvement and improvement alternatives

Comparison of the actual level of safety with the target level of safety can lead to conclusion that the target is not met. Safety improvement alternatives or safety measures to improve capacity must then be identified. No protocol for identifying safety improvement alternatives is provided here. Expert judgement, common sense, literature review, research results, incident/accident investigation and operational experience could all be part of the identification process. The ASTER accident probability model can also be used here because it identifies the causal factors that are associated with the hazard. Elimination of those causal factors will improve safety. Safety improvement alternatives should therefore be aimed at the elimination of those causal factors. In addition, the ASTER accident probability model can be used to get an initial indication of the effectiveness of a measure by identifying causal factors that contribute most the accident probability. The relative contribution of each of the causal factors can easily be determined by a one by one elimination of the causal factors and assessing the effect on the accident probability.

When improvement alternatives have been identified, realistic future scenarios for each of the alternatives need to be developed. The evaluation period and system boundaries much be similar to the base case. The set of assumptions about the most likely future of the air transport system must be explicitly stated for each of the alternatives.

7 Determining the costs

Calculation of the costs of the proposed measures for improvement should be calculated for each stakeholder affected by these measures. The costs should include the complete lifecycle of the product if applicable. A life cycle consists of 4 phases, visualised in Figure 5.

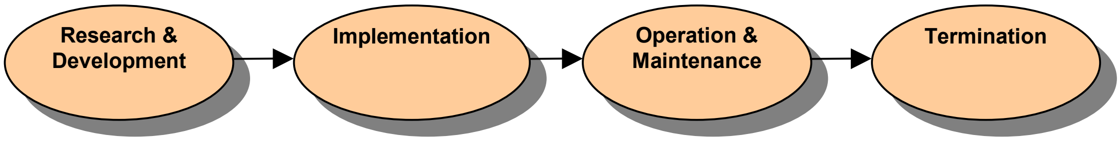


Figure 5: Life cycle phases

The costs of each phase should be included in the CBA:

- Research & Development (R&D): this is rather an elusive cost category. Costs of R&D can be made many years before implementation. It can reasonably be assumed though that the costs for R&D *made by the private sector* are included in the price of the hardware. However, strictly speaking, basic research activities sponsored by other parties, such as research performed under the EU framework programme, or research activities from NASA, should be assessed and incorporated in the CBA analysis.

  It is important to mention sunk costs in this respect. These are costs that already have been made, with or without the project. Since these are also made in the base case, they can be kept out of consideration in the CBA.
- Implementation: this cost category comprises the cost of the actual investment, plus all other cost that have to be made to get the project 'up-and-running'. This includes for example also costs for certification and initial training.
- Operation & Maintenance: this cost category comprises maintenance costs to keep the system working and costs for operation, e.g. labour costs, recurrent training costs, increased overhead costs etc.
- Termination: this cost category should only be included if at the end of the project costs have to be made to remove a system, and these costs cannot be attributed to a following project thereafter. The residual value of such a system should be taken up as a benefit at the end of the project.

8 Project effects and benefits

The implementation of the project will result in costs and effects for the various stakeholders identified. Determination of the costs has been pursued in the previous chapter. In this chapter we will deal with quantification and valuation of the effects. Valued effects are called the benefits of the project. Within the scope of this handbook, two types of effects are described in an extensive way: safety effects and capacity effects. Valuation of these two types of effects results in safety benefits and capacity benefits. These benefits are the input for the CBA. However, a CBA is usually not limited to these effects. Effects for supply side stakeholders (e.g. cost savings in operation) or for third parties (e.g. environmental effects) should be included in a CBA, but because of the broad spectrum of these possible effects, they are only mentioned here and not discussed any further.

8.1 Physical safety effects

The physical safety effects are expressed as an increase or reduction of the accident probability relative to the accident probability in the base case. The associated accident severity and the operational context determine the costs per accident. Multiplication of accident probability with the number of flights results in the physical safety effect: an increase or decrease of the number of accidents. Multiplying the physical safety effects with the accident cost provides the overall safety-related costs. Similar to the other costs and benefits, the safety related costs for each of the alternatives must be compared with the accident related costs of the base case. It is important to realise that a reduction of the accident probability, (usually the purpose of safety improvement measures), and hence a reduction of the safety related costs are a *benefit* of a project and not costs.

Calculating the cost associated with safety effects requires various steps for each of the project cases. These steps are depicted in Figure 6 below.

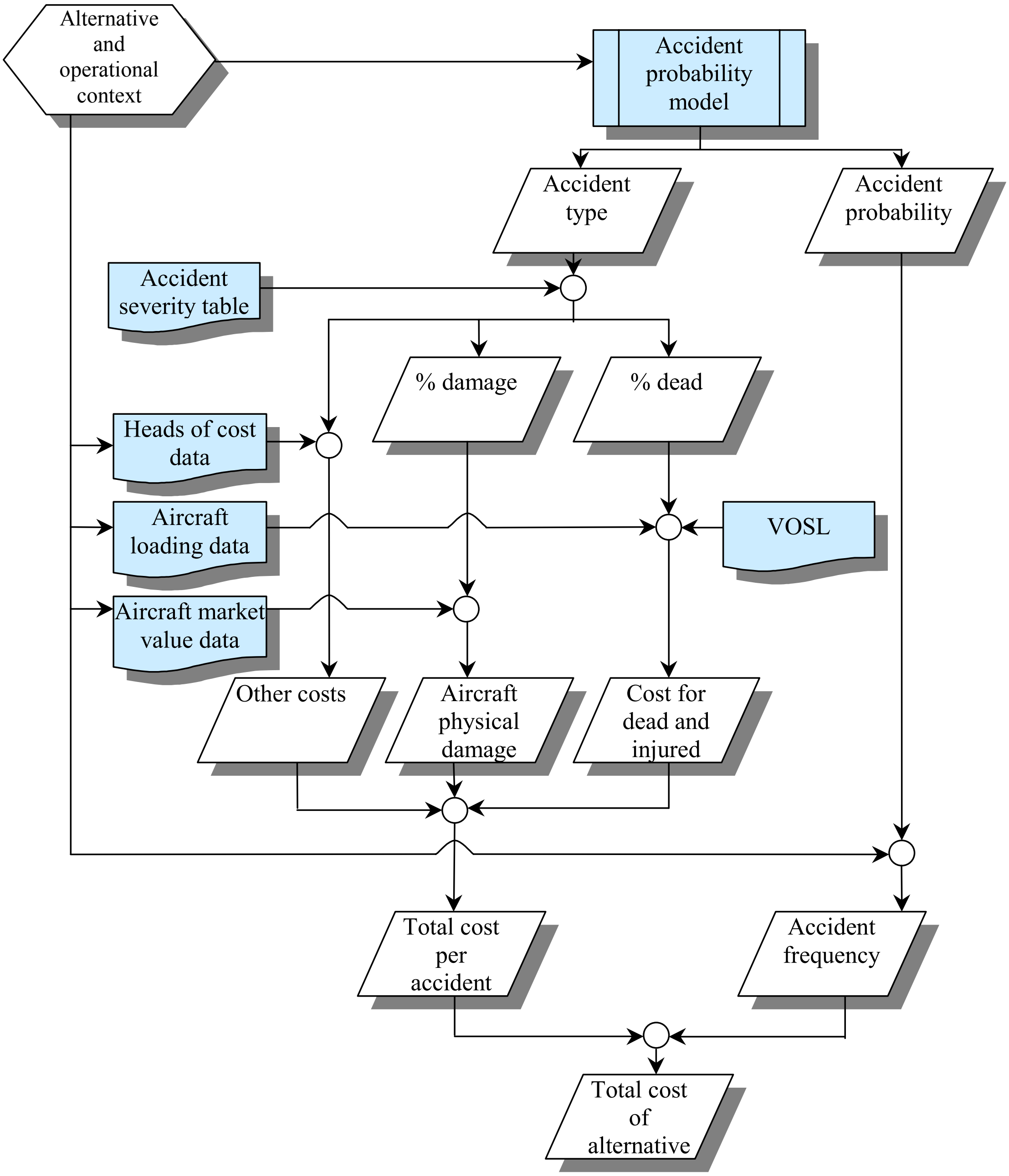


Fig 6: Accident cost calculation flowchart

The steps can be put into two categories:

- Determining the physical safety effect:
  - Calculate accident probability;
  - Determine accident type and severity;
  - Calculate accident frequency;

- Determining the safety-related benefits
  - Determine aircraft market value and aircraft physical damage cost;
  - Determine number of people on-board, number of fatalities and associated costs;
  - Determine other heads of cost;
  - Calculate total safety-related benefits.

The steps will be further elaborated below.

8.1.1 Determining the physical safety effect

Accident probability

Identify the elements (nodes and links between the nodes) of the ASTER accident probability model that are influenced by the project case. Quantify the effects in terms of probability of occurrence of each individual factor and the conditional probabilities that connect the elements (Figure 7). Calculate the accident probability corresponding with the project case.

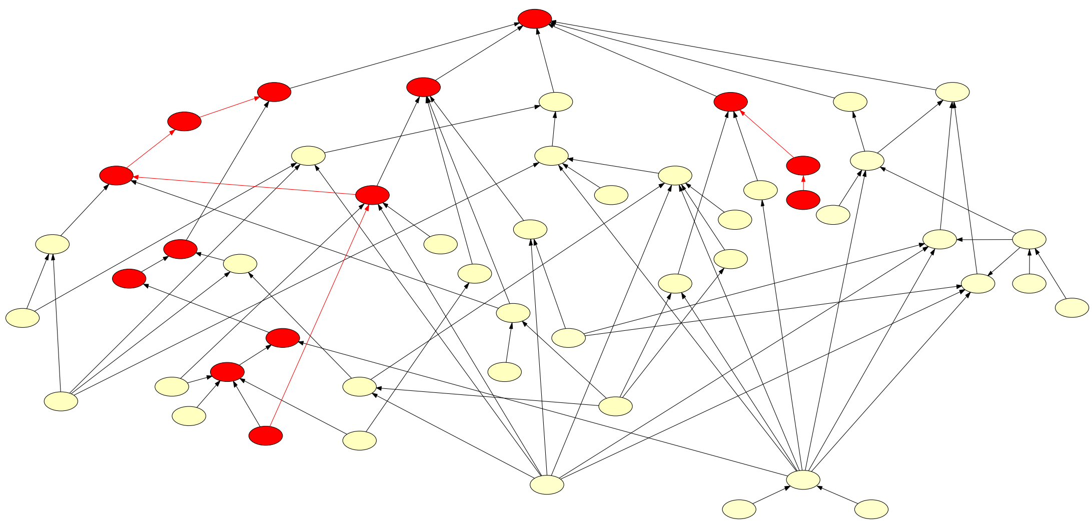


Figure 7: Example of nodes and links that are modified (in red) by the project case

The ASTER accident probability model is generic, both in structure and in quantification. A situation could occur where a particular alternative can not be expressed in a change of one of the nodes (causal factors) or links between the nodes (cause-effect relations). In these cases, the complete list of causal factors [Ref. 3, chapter 2, ASTER classification scheme] should be reviewed. Factors that are affected by the project case should then be added to the nodal network of the accident probability model.

Remember that changes are calculated relative to the base case. The accident probability of the base case must also be calculated. In cases where the accident probability model is expanded with additional nodes or links, the accident probability of the base case should also be calculated with this expanded model.

Determine accident type and severity

According to the ASTER method, the type of accident is directly liked to the accident severity. When the accident probability of the project case is different from the accident probability of the base case, the type of accident that is responsible for this difference should be identified. The ASTER accident probability model can be used for this. The main accident types are represented as the nodes in the upper level of the accident probability model (Figure 8). The frequency of occurrence of these nodes represents the frequency of occurrence of the different accident types.

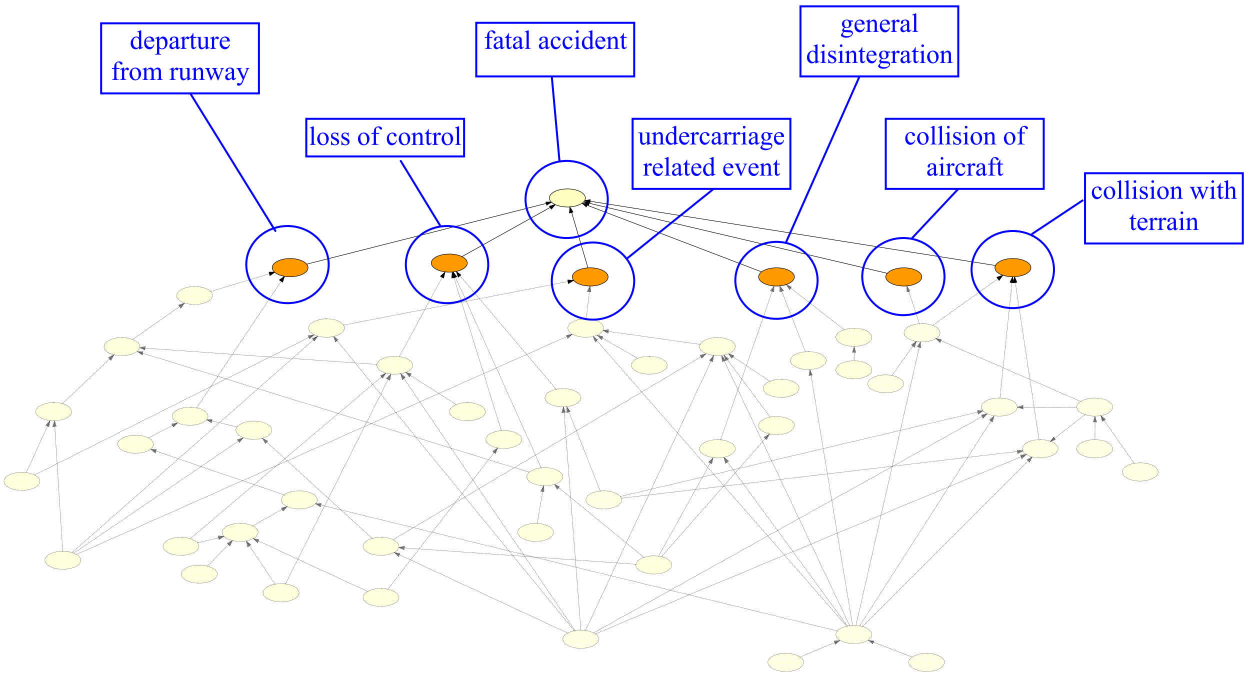


Figure 8: Main accident types in the ASTER accident probability model

Accident frequency

The accident frequency is calculated by multiplying the accident probability with the (expected) number of flights for the project case. This should be done for each year of the evaluation period.

8.1.2 Determining the safety-related benefits

Determine aircraft market value and aircraft physical damage costs

Accident type and aircraft damage (expressed as a percentage, 100% represents a hull loss) are linked according to Table 3 and 4. Translating this damage percentage into monetary terms requires an estimate of the aircraft market value, which largely depends on aircraft size and aircraft age. In most cases an *average* aircraft size and age will have to be estimated. Tables 6, 7 and 9 provide data to help estimating aircraft market values. Keep in mind that the average aircraft value may change during the reference period (e.g. due to changes to the fleet), in such cases different expected market values may be estimated for different sections of the reference period (e.g. each year).

Number of fatalities and associated costs

The number of passengers on-board the aircraft equals the number of seats multiplied by the load factor. Table 8 provides average load factors that can be used when no specific data is available. Number of crew (flight crew and cabin crew) should be added to obtain total number of occupants. Keep in mind that this number may change during the evaluation period. The accident type is linked to percentage of occupants killed according to Table 3 and 4.

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 statistical 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. It is felt that no one 'cost of life' should be 'recommended' but that, rather, it should be left to the user to decide which approach should be adopted and what monetary value should be used. Table 10 provides estimated VOSL data for different European States.

8.1.3 Other heads of cost

Other heads of cost should be determined according to the summary Table 5. Further detail for each of those heads of cost can be found in [Ref. 4].

8.1.4 Total safety related benefits.

Total benefits are estimated by multiplying the expected number of accidents with the (average) cost of a single accident. This should be done for each year of the reference period. As indicated before, it is only considered a benefit if the number of accidents is expected to decrease. However, with respect to safety-improving measures this is usually the case.

8.2 Capacity effects

Capacity effects can be expressed as increased/decreased number of flight or increased/decreased delays. In both cases it should be kept in mind that extra capacity can only be claimed if there is demand and if the extra capacity can be accommodated (hence capacity bottlenecks elsewhere in the system should be reckoned with). In ASTER it was decided to express capacity effects in number of flights only.

Estimating capacity benefits (hence the monetary value of increased/reduced capacity) can be approached from a narrow perspective and a broad perspective. Both perspectives are presented below.

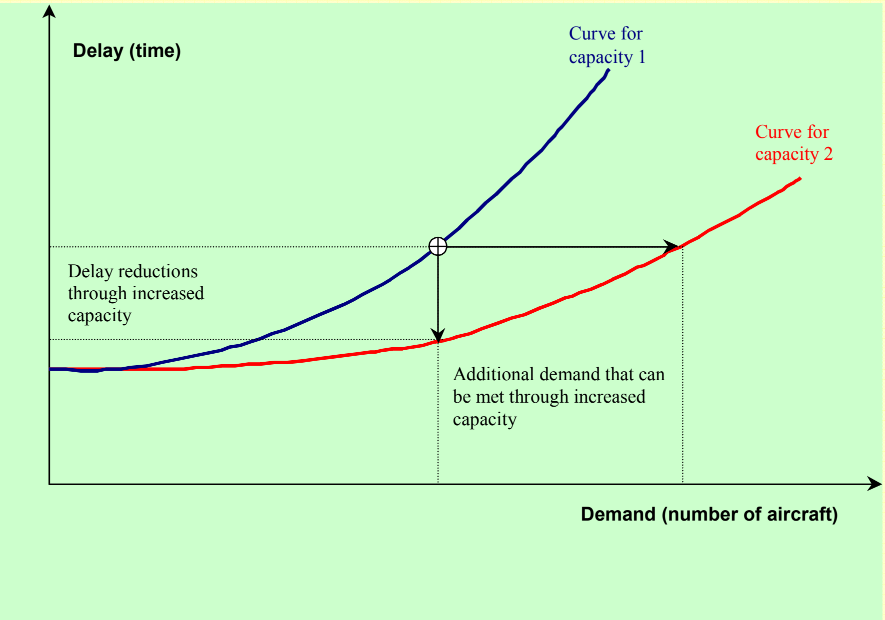
8.2.1 Narrow perspective

In the narrow perspective capacity effects are limited to revenues for airports and airlines. Revenues for airports are generated as a result of airport charges. These airport charges vary over airports, data for the major European airports are presented in the annex.

The calculation of benefits for airlines is based on the assumption that additional flights have a value to the airlines. Airlines require additional capacity in order to exploit that value. The calculation of the value is based on the requirement of each flight to cover its direct operating cost and also make a contribution to the overhead of the company. It is this contribution to overhead that is used as the average value of extra flights for an airline. Values for the benefits for airlines are presented in the Annex.

Box 1

Extra capacity can either be used to accommodate unconstrained demand or to reduce delays given the current capacity. The relationship between both entities is presented in the figure below [Ref.8].



In practice the trade-off might not be black-or-white. When including both aspects in a CBA, one should be aware of double-counting when including both aspects in a CBA.

While the cost of delay could differ between world regions, IATA has determined values for the cost of delay (on the ground and in the air) in Europe [Ref. 7]. These values are based on a detailed data collection of aircraft operators' direct operating costs. Values for delay on the ground and in the air are presented in Table 13.

8.2.2 Broad perspective

In a broad perspective, secondary economical effects of passenger movements are included. This can be expressed as the total contribution to the gross regional product of one flight movement (i.e. take-off or landing). A value for this benefit is provided in the annex.

When calculating the benefits for the regional economy, displacement aspects should be taken in mind. The extra accommodated demand as described, might have been attracted from other (regional) airports of other modes of transport (e.g. high speed trains). A decrease of demand might be expected there, accompanied by a decrease in employment and value added. Furthermore, additional passenger movements might displace other economic activities. The level of displacement is difficult to substantiate, but should always be taken into consideration.

8.3 Other effects

Apart from safety effects and capacity effects, other effects may occur. This is highly dependent from the type of improvement alternatives that are assessed. In a sound CBA, all effects should be taken into consideration. A clear example is the impact of an alternative on the environment, such as noise and emission. Assessing environmental effects requires subjective judgement to some extent. The CBA analyst may not be in a position to provide that judgement. Alternatively, environmental effects can be described quantitatively (relative to the base case) and included in the overall information presented to the decision-maker.

9 Comparison of alternatives: cost-benefit analysis

9.1 Introduction

If the costs and benefits of an improvement alternative have been assessed, the actual cost-benefit analysis can be carried out. Current and future costs and benefits of the improvement alternative are compared with the base case. General principles of cost-benefit analysis are described in section 1.4 of this handbook.

A positive outcome of the CBA indicates that the improvement alternative is economic viable, and should be implemented *from the perspective from which the CBA is carried out*. If there are more than one improvement alternatives, implementation of the alternative with the highest CBA outcome is preferable.

However, the perspective from which the CBA is carried out is important in this respect. It might be possible that from the European societal perspective, the CBA outcome for an improvement alternative is positive. But, if the analysis is carried out from the perspective of an airline, or a certain country this might not be the case. More attention to these distribution aspects is given in section 3 of this chapter.

9.2 Measures for CBA

To compare current and future costs and benefits, the annual cash inflows and cash outflows of the project, compared to the base case, have to be discounted. A frequently applied measure in CBA is the Net Present Value (NPV). The NPV is defined as the cash equivalent now of a sum receivable or payable at a future date. In order to calculate the NPV, it is necessary to discount future benefits and costs. This discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner. The higher the discount rate, the lower is the present value of future cash flows. Hence the value of the discount factor reflects the preference of society for today’s income versus income later in time. The discount rate represents also the cost associated with diverting investment resources from alternative investments or from consumption. The following equation is used for calculating the NPV:

$$\text{Net Present Value (NPV)} = B_o - K_o + \frac{B_1 - K_1}{1+r} + \frac{B_2 - K_2}{(1+r)^2} + \frac{B_n - K_n}{(1+r)^n}$$

$$= \sum_{t=0}^{t=n} \frac{B_t - K_t}{(1+r)^t}$$

Where:

n is the project life;

B is the present value of cash inflows;
K is the present value of cash outflows;
r is the annual discount rate.

If NPV: >0, accept the project
<0, reject the project

The discount rate expresses the rate of return that would have been generated in case of alternative use of the means. In European countries there is a large variation in the prescriptions for the use of the discount rate [Ref10]:

- The Netherlands: 4%
- Germany: 3%
- United Kingdom: 6%
- Danmark: 7%
- France: 8%
- The European Commission states that 5% is a 'proper starting point'.

Another measure often applied in CBA is the Internal Rate of Return (IRR). The IRR is the discount rate that equates the present value of the cash inflows with the initial investment associated with a project. The IRR, in other words, is the discount rate for which the NPV of an alternative is zero. Hence, the IRR indicates the highest level of the discount rate where the project is just profitable.

$$\sum_{t=0}^{t=n} \frac{B_t - K_t}{\left(1+i\right)^t} = 0$$

where i is the IRR.

If IRR > cost of capital, accept the project.
< cost of capital, reject the project

A last measure that is sometimes used in CBA is the Benefit/Cost Ratio. The Benefit/Cost Ratio is a simple measure of profitability used to measure the NPV per unit of capital outlay required. It is used to assist in the choice of combination of projects that would maximise the NPV generated by using the available capital.

Benefit/Cost Ratio = NPV/K

If NPV/K: >1, accept the project
<1, reject the project

The cost benefit ratio measures the NPV per unit of capital outlay which permits the decision makers to maximise the generated NPV by undertaking combinations of project portions. This is useful when capital rationing is applied. However, in practice projects are very often not divisible and the use of the ratio to measure the viability of complete projects is less accurate than other measures.

In case of more than one alternative, the general consequence of the three measures mentioned above, is that the project with the highest NPV, IRR or B/C ratio should be applied from socio-economic point of view. However, for cases with both single and multiple alternatives, it is useful to assess the cash flows behind the ratio's. Especially an analysis of the various stakeholders and regions affected is valuable in terms of differences in distribution of costs and benefits.

9.3 Stakeholders and distribution aspects

The CBA approach in this handbook is outlined from the perspective of society: if the outcome is positive, the project should be implemented from socio-economic point of view. However, the distribution of costs and benefits may very well be unbalanced. It might be possible that the costs of an alternative are borne by airlines, but the benefits are generated largely by other stakeholders. The same holds for the geographic point of view. From a European point of view implementing alternatives may be positive, but from national or regional point of view, costs and benefits may be distributed unbalanced.

Therefore it is always recommended to perform an analysis of the distribution effects with regard to stakeholders and geography. Such extra information is valuable for decision-makers when deciding about the implementation of alternatives.

9.4 Sensitivity analysis

It must be kept in mind that in conducting any cost benefit analysis a number of assumptions have to be made, for instance with respect to the efficiency of certain measures, expected traffic growth, future technological developments, displacement effects, hardware costs, etc. The amount of uncertainty in such assumptions can be substantial. For this reason it is recommended to perform a sensitivity analysis.

In a sensitivity analysis, the effects of systematic variations of key parameters on the economic measures of the project viability (NPV, IRR and Benefit/Cost Ratio) are determined.

The most significant parameters to be considered in the conduct of a sensitivity analysis will vary from project case to project case. However, the following list contains factors generally important for such an impact analysis [Ref. 9]:

- Projected traffic growth in absolute terms and with respect to the traffic mix;
- Safety effects;
- Capacity effects;
- Investment costs (purchase prices, installation/introduction);
- Staff costs;
- Discount rates;
- Project time scales

The results of the sensitivity analysis identify the most critical parameters and their degree of impact.

10 References

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11 Annex: Reference data

Table 1: Descriptive and explanatory factors included in the ASTER accident probability model

Accident	Flight crew
	Crew aircraft handling
ATC	Cockpit fatigue
ATC fatigue	Cockpit workload
ATC related event	
ATC workload	Collision of aircraft
Altitude related event	Collision with terrain
Navigation related event	Collision with object
Aerodrome aids	
	Departure from intended moving area
Weather related event	Runway excursion to the side
Weather information	Overrun
Aircraft encountered turbulence	
Aircraft encountered unexpected wind	General disintegration
Vortex wake	
	Hard landing
Aircraft loading	Landing gear
Cargo related event	Gear collapse
	Nose wheel steering
Aircraft flight control	Undercarriage related event
Flight and navigation systems	Wheels up landing
Flight control system	
	Loss of control
Aircraft system related event	Loss off directional control
Autoflight system	Stall
Hydraulic system	
Ice rain protection system	Rejected take off
Instruments	
	Security
Engine	Unlawful act damage
	Unstabilised approach

Table 2: Accident cost factors

No.	Cost element	Stakeholder
1	Aircraft physical damage (cost of repair/replacement)	Airline/owner (airline's insurance)
2	Possible loss of resale value	Airline/owner
3	Aircraft loss of use	Airline (poss. airline's insurance)
4	Aircraft loss of investment return	Airline/owner (airline's insurance indirectly)
5	Site contamination and clearance	Airline, airport, society (airline's insurance)
6	Airline costs for delay (diversion, passenger management etc.)	Airline
7	Airport closure	Airline, airport and auxiliary stakeholders
8	Passenger and crew deaths and/or serious injuries	Society (insurance)
9	Loss of staff investment (training, experience etc)	Airline
10	Loss of cargo and/or mail and/or passenger baggage	Sender/receiver (insurance)
11	Search and rescue and cost of emergency services	Society (airline's insurance)
12	Airline immediate response	Airline
13	Cost of accident investigation (to state, operator, manufacturer etc)	State, airline (manufacturer, airport operator)
14	Third party damage (physical damage, deaths, injuries, inconvenience and loss of use)	Third party stakeholders (mainly airline's insurance)
15	Loss of investment income (to insurers on monies paid out on claims)	Airline (and indirectly other insureds)
16	Increased cost of insurance	Airline (and other insureds)
17	Loss of income (airline avoidance specific and generally)	Airline, airport
18	Loss of reputation (airline, manufacturer etc)	Airline, airport, manufacturer etc
19	Loss of company value (decrease in share value and market capability)	Airline, airport, manufacturer etc
20	Social costs (effects of road closures, general delay, loss of electrical power etc)	Society (some from airline's insurance)
21	Loss to society (tax, skills etc)	Society
22	Special situations	Airline, airport, society
23	Emergency inspections SB and AD compliance (grounding and suspension of Type Certificate)	Airline, regulatory bodies, manufacturer
24	Fines, punitive damages, criminal proceedings	Guilty stakeholders

Table 3: Accident severity classification

Level	Damage	Death
Catastrophic	100%	80%
Disaster	100%	30%
Major	80%	0%
Moderate	50%	0%
Minor	15%	0%

Table 4: Severity classification of the most frequent accident types (Ref. DESIRE Final Technical Report]

Accident type	**Class**
Loss of control in flight (not recovered)	Catastrophic
Collision with high ground	Catastrophic
Collision with another aircraft (air or ground)	Disaster
Doors or windows failures	Minor
Uncontained engine failure	Major
Hard landing (on runway)	Moderate
Undershoot	Catastrophic
Overruns (take-off or landing)	Moderate
Wheels up landing	Moderate
Gear retracted, collapsed or substantially damaged	Moderate

Table 5: Accident cost estimates

Cost category	Costs	Assumptions / remarks
Aircraft physical damage	Minor, 15% damage	Aircraft market value depends on type and age, it can be calculated using tables 6, 7 and 9.
	Moderate, 50% damage	
	Major, 80% damage	
	Disaster, 100 % damage	
	Catastrophic, 100% damage	
Possible loss of resale value	5-10 % of aircraft market value for partial losses	It is assumed that this cost item is only applicable for aircraft with partial loss damage. Aircraft market value depends on type and age, it can be calculated using tables 6, 7 and 9.
Aircraft loss of use	Monthly lease cost x assumed months to replace = cost of 'loss of use'	ACMI lease cost estimates provided in Table 11.
Aircraft loss of investment return		Part of aircraft loss of use.
Site contamination and clearance	Wide body 1.2m-2.8 m €	
	Narrow body 0.7m-1.3m €	
	Smaller aircraft 0.13m-0.2m €	
Airline costs for delay	Wide body: 22 € per seat per hour	
	Narrow body: 20 € per seat per hour	
Airport closure	Airport disruption depends on severity of the accident, estimates provided in table 12.	Only applicable if accident occurs on or close to the runway.
Deaths and injuries	Value of Statistical Life (VOSL) 1-2.64 m €	VOSL differs per country (Table 10). Value of injury is 13% of VOSL.
Loss of staff investment	Replacement cost per pilot 45,000 €	Only for catastrophic and disaster events.
Loss of baggage	Underfloor cargo carried on passenger flights 110,000 €	Only for catastrophic and disaster events.
	Personal baggage on passenger flights 45,000 €	Only for catastrophic and disaster events.
SAR costs	Average SAR cost claim 0.6m €	Only catastrophic and disaster events lead to SAR operations; estimation costs: 50% of policy limit
Airline immediate response	Average costs per accident 0.5-3m €	Only for catastrophic and disaster events.
Cost of accident investigation	State 0.1-100m €	Only for catastrophic and disaster events. Huge range, depends among others on effort needed for wreckage reconstruction.
	Airline 1m €	Only for catastrophic and disaster events
	Manufacturer 1m €	Only for catastrophic and disaster events
Third party damage	Third party death and injury: use similar VOSL as in passenger death and injury.	
	Third party physical damage	
Loss of investment income		These costs are reflected in insurance premiums.
Increased cost of insurance	Loss of 20% insurance discount for airline involved	Only for catastrophic and disaster events. The loss of the no-claim premium reflects the payment of the insurance company for the aircraft physical and liability. Including these costs in a CBA would be double-counting.
Loss of income		Part of 'loss of reputation' costs

Loss of reputation	Airline loss of turnover 0-380m €	Huge range. Loss to society is far less than to airline, since major part of reduced demand will shift to other airline. Hence should not be incorporated in CBA from societal perspective.
	Manufacturer	Likely that airlines will buy aircraft from other manufacturers. Hence from societal point of view this should not be incorporated in CBA.
Loss of company value		Not included because of double counting
Social costs		These costs are ignored since they are considered too far removed from the accident.
Loss to society		Not included, for displacement reasons
Special situations		Too ill defined: not included
SB and AD compliance		Not included: not a direct accident cost factor
Fines, punitive damages		Not included: not a direct accident cost factor

Table 6: Unit value of new aircraft (1999), based on average published list prices. Source: Airclaims

Type	Unit Cost €m's
Avro RJ	€27.4
Canadair RJ	€21.4
Dornier 328J	€12.7
Embraer 135	€13.3
Embraer 145	€17.0
	€19.3
Airbus A319	€36.6
Airbus A3230	€44.7
Boeing 717	€22.8
Boeing 737 CFM	€34.3
Boeing 737NG	€40.5
Boeing MD-80	€30.5
Boeing MD-90	€28.3
	€39.1
Airbus A321	€50.7
Boeing 757	€52.8
	€52.1
Airbus A300	€85.5
Boeing 767	€81.9
	€82.5
Airbus A330	€98.7
Airbus A340	€110.3
Boeing 777	€123.5
Boeing MD-11	€109.3
	€114.1
Boeing 747	**€148.4**

Table 7: Hypothetical 'new values' (1999) for types no longer in production (source: Airclaims)

Aerospatial Caravelle	€20 m
BAe One Eleven	€24 m
Boeing 707	€57 m
Boeing 727	€34 m
Boeing (MDC) DC-8	€56 m
Boeing (MDC) DC-9	€23 m
Boeing (MDC) DC-10	€105 m
Fokker F28	€20 m
Lockheed Tristar	€100 m

Table 8: Average Passenger Load per Flight[7] - 1998

Manufacturer	Type	Passenger load	Manufacturer	Type	Passenger load
Airbus	A300	138	Boeing	747 (Classic)	165
Airbus	A310	91	Boeing	747-400	248
Airbus	A319	73	Boeing	757	203
Airbus	A320	96	Boeing	767	236
Airbus	A321	124	Canadair	RJ	30
Airbus	A330	294	Embraer	145	27
Airbus	A340	161	Fokker	F28	54
Avro	RJ	60	Fokker	70	44
BAe	146	46	Fokker	100	62
BAe	One Eleven	53	Lockheed	L1011	145
BAe	Concorde	49	MDC (Boeing)	DC-9	58
Boeing	727	67	MDC (Boeing)	MD80	85
Boeing	737 (JT8D)	69	MDC (Boeing)	DC-10	135
Boeing	737 (CFMI)	99	MDC (Boeing)	MD-11	165
Boeing	737 (NG)	99			

Source: Airclaims Airliner Loss Rates 1999

[7] Data is based on the total operations of the aircraft type including cargo flights. Although this provides a good estimate for the average exposure across the whole fleet, it can considerably underestimate the average passenger load on passenger flights by those types which have a large percentage of cargo flights

Table 9: Used aircraft, Average loss of value with age (Source:Airclaims)

Age (yr)	Value (%)	Age (yr)	Value (5)
0	100	16	39
1	92	17	38
2	86	18	38
3	81	19	37
4	76	20	36
5	71	21	36
6	66	22	32
7	62	23	26
8	58	24	20
9	54	25	15
10	52	26	12
11	49	27	12
12	46	28	14
13	44	29	14
14	41	30	14
15	40	31	13

Table 10: Proposed VOSL by Country (Consumer value - € 1998) Source: UNITE project

Country	VOSL M €
Austria	1.68
Belgium	1.67
Denmark	1.79
Finland	1.54
France	1.49
Germany	1.62
Greece	1.00
Ireland	1.63
Italy	1.51
Luxembourg	2.64
Netherlands	1.70
Norway	1.93
Portugal	1.12
Spain	1.21
Sweden	1.53
Switzerland	1.91
United Kingdom	1.52
Hungary	0.74
Estonia	0.65

Table 11: Estimated monthly ACMI[8] lease rates expressed as % of current market value (Source: Airclaims)

Age (yr)	Narrow-bodied	Wide-bodied	Age (yr)	Narrow-bodied	Wide-bodied
0	1.8	1.6	16	3.1	3.0
1	1.8	1.6	17	3.2	3.1
2	1.9	1.7	18	3.3	3.3
3	1.9	1.7	19	3.5	3.5
4	2.0	1.8	20	3.6	3.7
5	2.1	1.9	21	3.8	3.9
6	2.1	1.9	22	4.0	4.1
7	2.2	2.0	23	4.1	4.4
8	2.3	2.1	24	4.3	4.7
9	2.3	2.2	25	4.6	5.0
10	2.4	2.3	26	4.8	5.3
11	2.5	2.3	27	5.0	5.6
12	2.6	2.5	28	5.3	6.0
13	2.7	2.6	29	5.5	6.4
14	2.8	2.7	30	5.8	6.8
15	2.9	2.8			

Table 12: Estimated airport closure relative to accident severity (Source: Airclaims)[9]

Catastrophic	5 days
Disaster	5 days
Major	4 days*
Moderate	2 days*
Minor	2 days*

* *assumes undercarriage unusable*

Table 13: Cost per minute of delay per aircraft (1998)

	€/min
Ground cost of delay	22.0
Cost of additional flight time/delay in the air	33.0

Source: IATA Cost Benefit Task Force, Report of the 7th ICBTF meeting (extract), Brussels, 8 April 1997.

[8] ACMI = Aircraft, Crew, Maintenance, Insurance
[9] These figures are estimates prepared by Airclaims' surveyors based on their experience

Capacity benefits narrow perspective

- Airport charges: in Europe, average airport charges for the 10 major airports vary between €1,684 and €4,656, with an average of €2,846 per aircraft movement (1999 values) [Ref. 4].
- Benefits for airlines: this benefit is expressed as the contribution to overhead of an additional flight. The figure commonly used is € 1,570 per extra flight [Ref. 9].

Capacity benefits broad perspective

In a broad perspective, secondary economical effects of additional passenger movements are also included. NYFER[10] has carried out an analysis on the economic impact of airports in Europe. In this study, an analysis has been made of the employment- and economic effects of extra passenger movements.

The direct employment, employment directly related to passenger movements, generated by 1 million passenger movements varies between 750 and 2,000 jobs, depending on the specific local situation. Total employment, hence direct employment plus indirect employment, which can be described as the employment generated at suppliers of companies that form the direct employment, varies between 2,500 and 8,500. This is presented in Table 14.

Table 14 Economic effects of airports in literature[11], jobs per million passenger movements**.**

Study	**Year**	**Character**	**Direct employment**	**Indirect employment**	**Total employment**
York Consulting	1998	International hub	1,450-1,600		
		Large regional airport	850-1,100		
		Small regional airport	850		
		Holiday destination airport	350-400		
Bennel and Prentice	1993	Canada, small regional airports	1,130		
ACI	1998	Europe	1,410		
	1997	Europe	1,100	2,900	4,000
ATAG	2000	low	750	1,750	2,500
		middle	1,500	4,500	6,000
		high	2,000	5,500	7,500
NYFER	2000	Schiphol	1,500		
		Europe	1,000	7,600	8,600
		USA	600		

10 NYFER, 2000, *Hub- of spokestad?*, Breukelen (in Dutch).

11 Sources: York consulting, 1998, *The economic impact of airports*; ATAG, 2000, *The economic benefits of air transport*, Geneva; NYFER, 2000, *Hub- of spokestad* (in Dutch, cit. Benell, D.W. and B.E. Prentice, 1993, A regression model for predicting the economic impacts of Canadian airports, in: *Logistics and transportation review*, 29-2, pp. 139-158.; ACI, 1999 and 1998, *ACI Airports Economic Survey-1998 and 1997,* Brussels).

The NYFER study has been based on three types of data files: airport data, economic-and demographic data and enterprise data. This approach is much broader than applied in the other studies mentioned (mostly airport surveys). Therefore the NYFER figures are used in this case study.

The economic impact can be expressed in employment and gross regional product growth. The latter is applicable for cost benefit analysis. As described above, the employment that is related with an increase of one million passenger movements amounts to 8,600 on average in total, of which 1,000 jobs are direct employment and the rest, 7,600, are indirect employment. The total contribution to the gross regional product of one million extra passenger movements amounts to € 499 million.

According to the NYFER study the average number of passenger movements per flight movement in Europe is 70. The total contribution to the gross regional product of one flight movement (i.e. take-off or landing) then amounts to € 34,930. The values presented here should be considered the very maximal capacity-benefit. It should be realised that to generate this benefit additional costs have to be made.