EUROCONTROL

Feasibility study on the integration of third party risk near airports into IMPACT

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EXECUTIVE SUMMARY

The aim of this report was to study the feasibility of integrating or interfacing EUROCONTROL's environmental impact assessment platform, IMPACT, with a third party risk modelling tool. Currently, the IMPACT platform contains noise and fuel/emissions assessment tools. Though third party risk is not yet viewed as central as noise and air quality issues, it is one of the key environmental impacts created by airports and air traffic. Third party risk is also bound to go up on the policy agenda, creating new requirements to operational stakeholders and constraining future airport developments. Although the European Directive 85/337/EEC on Environmental Impact Assessment and its subsequent amendments do not explicitly mention third party risk, its assessment can be taken as an implicit requirement as all significant effects on the local population and the environment are to be assessed.

Third party risk in aviation is defined as the risk posed by aircraft accidents to the health and safety of persons on the ground. Third party risk generated by the air traffic system is at its highest in the proximity of airports. This is due to two factors: airports are hubs for air traffic with hundreds or even thousands of operations per day for the biggest airports and, secondly, most aircraft accidents and incidents take place at either take-off or landing phases of flight. Third party risk issues are in many ways similar to noise impacts created by air traffic as the population living in the vicinity of airports is involuntary exposed to these negative externalities. Two different metrics are used to measure third party risk: individual risk and societal risk. Individual risk is location dependent and it can be visualized in the form of risk contours. Societal risk, on the other hand, is not location specific and is determined based on the number of inhabitants found inside given individual risk contours. Third party risk is at its greatest in the immediate proximity of the runways and the extended runway centreline while the risk levels decrease when moving away from the runway and tracks. Individual and societal risk values can also be used to define Public Safety Zones restricting existing and new developments around airports.

The importance of risk around airports was recognised in the UK in the 1950s and Public Safety Zones were introduced in 1958. In the 1990s, the method for third party risk assessment around airports and the definition of appropriate risk assessment criteria was presented in a NATS report for the UK Department of Transport. As in the UK, the development of third party risk assessment and Public Safety Zones in the Netherlands was greatly accelerated by the Bijlmer disaster in 1992 when an El Al cargo aircraft crashed into high-rise residential buildings near the Amsterdam Schiphol Airport. The Dutch risk assessment methodology was even inscribed in the country's aviation law in 2003. According to this policy, new buildings are not allowed within the 10^{-5} individual risk contours and only small-scale businesses are allowed within the 10^{-5}–10^{-6} risk contours. This is similar to the UK where no new buildings are allowed within the 10^{-5} risk contour (exceptions may be made for developments involving a low population density).

There are two major European third party risk models, namely the UK and the Dutch models, developed respectively by NATS and NLR. In addition to these models, the US DOE model, the Italian model (developed by Sapienza University of Rome for ENAC) and the Ukrainian model (3PRisk developed by the National Aviation University) were reviewed in this report. Third party risk models are generally composed of three sub-models: an accident probability model, an accident location model and an accident consequence model. The accident probability model allows the calculation of accident probabilities for different aircraft classes. Based on accident rates and the number of movements, accident probabilities for different flight phases (landing, take-off) and accident types (undershoot, overshoot, veer-off) can be calculated. The accident rates (usually

given per 10^6 movements) are generally determined based on historical accident data. The central element of the accident location model is a probability density function determining the accident distribution in the proximity of runways and tracks. The accident location functions generally differ for different aircraft classes and accident types. The accident consequence model allows the calculation of the impact area and the lethality of the accident; the impact usually depends on the aircraft size and the quantity of fuel on board.

The NLR and NATS third party risk models share the same basic approach and structure. The main difference between the models lies in the fact that the UK model has been calibrated using global accident data whereas the Dutch model has different formulations for large airports (developed for the Schiphol Airport) and regional airports. In addition, the Dutch and UK models differ with respect to the aircraft grouping: in the NATS model, the classification is based on the operation type (passenger, non-passenger) and aircraft classes defined by the engine type and various other characteristics (Western Class I–IV jets, Eastern jets, executive jets, etc.). In the NLR model, on the other hand, accident probabilities are based on a heavy/light weight classification, operation type and aircraft generation. It should also be taken into consideration that the accident location model of UK risk model is based on extended runway centrelines whereas the NLR model takes the different aircraft tracks or routes into account.

EUROCONTROL's IMPACT platform currently contains calculation modules for noise and aircraft emissions assessment at airports. Both the noise and fuel/emissions models run on common input data generated from user inputs and data in various reference and mapping tables. Notably, in noise modelling aircraft types are mapped to ANP codes whereas in emissions modelling the mapping involves AEM and BADA codes. The input data and database structures of IMPACT were analysed in order to investigate how a third party risk calculation module might be integrated into the platform. The data requirements of third party risk modelling are covered by existing IMPACT input data as the platform users are already providing information on the airspace (airport, runways and tracks) and aircraft movements. However, in third party risk modelling information on the individual flight trajectories it is not required; only data on nominal tracks is exploited. This is due to the fact that the accident distribution is already taken into account in the distribution functions of accident location models. The integration of a third party risk module into IMPACT would require a third party risk database (containing reference data on accident rates) and a mapping table linking aircraft types from the movements file to aircraft classes with recorded accident rates. The aircraft classes should also be linked to aircraft weight categories used in determining the accident impact area. European aircraft accident data could be combined from various international, European and other sources (either public or private), notably ECCAIRS, a European aircraft accident reporting system, and from the European Aviation Safety Agency. In addition, EUROCONTROL itself collects data on ATC/ATM-related accidents and incidents.

There are two different possibilities for adding third party risk calculation capabilities to EURONCONTROL's IMPACT platform: interfacing the platform with an existing third party risk model or integrating a third party risk calculation module into IMPACT. This study recommends the development of an IMPACT-specific third party risk calculation module integrated directly into the platform. This approach would give EUROCONTROL full control over its third party risk model; in addition, this would also allow the development of a hybrid model, combining aspects of both NLR and NATS third party risk models. For instance, it would be possible to define the aircraft classes using a combination of NATS and NLR categories. Both the UK and Dutch risk models have been described extensively in various public reports and scientific articles and the calculation formulas could therefore be fairly easily implemented in IMPACT. Third party risk calculations are somewhat simpler compared for instance with the calculation of noise contours, and the required effort should therefore not be excessive. In addition, various tools already existing in IMPACT, such as the airport grid used in noise calculations, might be reused in the third party risk module.

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Acronym	Description
AAIB	UK Air Accidents Investigation Branch
ACARE	Advisory Council for Aeronautics Research in Europe
ACRAM	Aircraft Crash Risk Analysis Methodology
ADREP	Accident/Incident Data Reporting
AEM	Advanced Emissions Model
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
ALPA	Airline Pilots Association
ANP	Aircraft Noise and Performance database
ANSP	Air Navigation Service Provider
AR	Accident Rate
ATC	Air Traffic Control
ATM	Air Traffic Management
BADA	Base of Aircraft Data
BEA	Bureau d'enquêtes et d'analyses pour la sécurité de l'aviation civile (French Bureau of Enquiry and Analysis for Civil Aviation Safety)
CAA	Civil Aviation Authority
CBA	Cost-Benefit Analysis

CFIT	Controlled Flight into Terrain
CID	Common Input Data (IMPACT)
DB	Database
DETR	UK Department of the Environment, Transport and the Regions
DOE	US Department of Energy
DOEDP	Department of Energy Office of Defense Programs
EC	European Commission
ECCAIRS	European Coordination Centre for Accident and Incident Reporting System
ECR	European Central Repository
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statements
EEC	European Economic Community
ENAC	Italian Civil Aviation Authority, L'Ente Nazionale per l'Aviazione Civile
ETSC	European Transport Safety Council
EVAIR	EUROCONTROL Voluntary ATM Incident Reporting
FAA	US Federal Aviation Administration
FSU	Former Soviet Union
GS	Ground Safety
GSIE	Global Safety Information Exchange

GUI	Graphical User Interface
HSE	UK Health and Safety Executive
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPR	Intellectual Property Rights
IR	Individual Risk
JRC	Joint Research Centre
KPI	Key Performance Indicator
LOC-I	Loss of Control in-Flight
LPG	Liquefied Petroleum Gas
MORS	Mandatory Occurrence Reporting Scheme
MS	Member State
NATS	UK air navigation service provider, formerly National Air Traffic Services
NAU	National Aviation University, Ukraine
NLR	National aerospace laboratory, Netherlands
NP	Non-Passenger
NTSB	US National Transportation Safety Board
OD	Operational Damage
PAX	Passenger

PDF	Probability Density Function
PRA	Probabilistic Risk Assessment
PRISME	Pan-European Repository of Information Supporting the Management of EATM
PSZ	Public Safety Zone
QRA	Quantified Risk Assessment
RAMS	Reliability, Maintenability and Safety
RS	Runway Safety
SAFER	Safety Analysis Function EUROCONTROL and associated Repository
SAFREP	Safety Data Reporting and Data Flow Task Force
SMI	Separation Minimum Infringements
SR	Societal Risk
STAPES	SysTem for AirPort noise Exposure Studies
TPR	Third Party Risk
TSB	Transportation Safety Board of Canada
VROM	The Ministry of Housing, Spatial Planning and the Environment, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu
WAAS	World Airline Accident Summary
WHO	World Health Organization

1 INTRODUCTION

1.1 Context

1.1.1 Third Party Risk as an Environmental Issue

In the air transportation system, air traffic is centred on airports. For the population living in the vicinity of airports, this implies involuntary exposure to a number of impacts, including the risk of aircraft accidents. Current inventory of environmental problems in the aviation sector groups the issues into seven categories [1]: aircraft noise, air pollution near airports, global phenomena (global warming and climate change), airport/infrastructure construction (landscape-transforming factor), water/soil pollution near airports, airport waste management, and aircraft accidents/incidents.

Before taking a closer at risk generated by aircraft accidents, it is useful to consider environmental safety issues in general. Environmental safety is a state of the environment which ensures the prevention of degradation (risks to ecosystems' health) and mitigates risks to human health [2]. Environmental safety is a component of the national safety and security, providing protection for the vital interests of individuals, society, the state and the environment from real or potential threats posed by man-made or natural factors (hazards) in the environment [3]. At current stage of human development, the main real and potential threats to the national security of any country in the environmental domain are significant anthropogenic disturbances and technological (man-made) overloads, and increased risks of anthropogenic and natural disasters [4].

Article 3 of the EU Directive 2011/92/EU (later amended by 2014/52/EU) on the assessment of the effects of certain public and private projects on the environment declares [5]: “The environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case and in accordance with Articles 4 to 12, the direct and indirect effects of a project on the following factors: (a) human beings, fauna and flora; (b) soil, water, air, climate and the landscape; (c) material assets and the cultural heritage; (d) the interaction between the factors referred to in points (a), (b) and (c).” In addition, “Member States shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue, inter alia, of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects.” These projects are defined in Article 4 and Annex I. Annex I of the [5] covers the “Construction […] of airports with a basic runway length of 2,100 m or more”; this means that airports and specific runways are considered as potentially dangerous objects for the environment and that they are subject for environmental impact assessment in case of their construction and/or extension.

The risk of anthropogenic environmental disasters is to a considerable extent determined by the state of ‘potentially dangerous objects’, or, in other words, ‘hazardous sites’, ‘critical objects’, ‘critical infrastructures’ or according to the definitions of the Seveso III Directive (2012/18/EU) [7] ‘establishments’ (which mean the whole location under the control of an operator where dangerous substances are present in one or more installations, including common or related infrastructures or activities). Prevention of emergency situations involving critical objects should be provided by the implementation of a system of measures to reduce risks at these critical sites. Given the possibility of environmental emergencies associated with critical objects and the threats they pose to environment and particularly to people living closely to these objects (health effects, including injuries and fatalities), facilities bearing powerful man-made threats require special attention with regard to their operation and development [6].

The main requirements of emergency prevention with regard to protection from the negative impact of critical objects and infrastructures include the development of executive and organizational documents on emergency prevention and environment protection; development and implementation of action plans for emergency prevention at facilities; forecasting emergency situations, determining the risk of emergencies for occupational personnel and population in the surrounding area; collection, processing and delivery of information in the field of emergency prevention; protection of populations and territories from dangerous effects; declaration of safety, licensing and liability insurance for injuries when hazardous facilities are operating; and creation of reserves of material and financial resources for emergency response [6]. Several of the outlined requirements are directly linked to risk of aircraft accidents/incidents around airports.

In particular, Article 13 “Land-use planning” of the Seveso III Directive [7] requires the Member States to ensure that their land-use policies or other relevant policies aim at limiting the consequences of major accidents for human health and the environment. This objective should be pursued by controlling the siting of new establishments and developments including transport routes, locations of public use and residential areas at locations where such developments may be the source of or increase the risk or consequences of a major accident. The Directive [7] also states that “Member States shall ensure that their land-use or other relevant policies and the procedures for implementing those policies take account of the need, in the long term: (a) to maintain appropriate safety distances between establishments covered by this Directive and residential areas, buildings and areas of public use, recreational areas, and, as far as possible, major transport routes; (b) to protect areas of particular natural sensitivity or interest in the vicinity of establishments, where appropriate through appropriate safety distances or other relevant measures; (c) in the case of existing establishments, to take additional technical measures in accordance with Article 5 so as not to increase the risks to human health and the environment.”

According to the definition of the UK Department for Transport definition [8], “Public Safety Zones are areas of land at the ends of the runways at the busiest airports, within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing”. Public Safety Zones (PSZs) around the runways of airports are particular examples of the Seveso policy requirements in the EU Member States. The UK Department for Transport [8] also states that “The basic policy objective governing the restriction on development near civil airports is that there should be no increase in the number of people living, working or congregating in Public Safety Zones and that, over time, the number should be reduced as circumstances allow.”

Environmental safety is considered as a dynamic component of the regional system, which ensures harmonious development of protection of the environment from real and potential anthropogenic impacts and threats. Managing environmental safety effectively is possible only based on the study of the conditions of formation and manifestations of environmental threats and hazards, and analysis of specific threats and hazards to identify regionally significant components of danger and their sources. Environmental risk has in general a complex hierarchical structure (Figure 1) [9]. Technogenic (technological or man-made) safety, linked to human impact on the environment, is a part of environmental safety. The technogenic component of environmental threats and hazards describes the impact of technological facilities and activities on people and the environment (landscape, fauna and flora, etc.). One of the anthropogenic impacts with its specific types of threats and hazards is concentrated around airports.

The main objective of environmental safety management systems is the creation and maintenance of a necessary level of protection of vital interests to guarantee favourable conditions for the safe and sustainable development of individuals, society and the environment. The main element of modern environmental safety evaluation is an assessment of risk and of the probability of negative impacts of various anthropogenic factors and their consequences. Therefore, in aviation context the primary objective of the study of environmental safety is the identification of all anthropogenic factors that can lead to the violation of environmental safety, particularly for the population in the vicinity of airports.

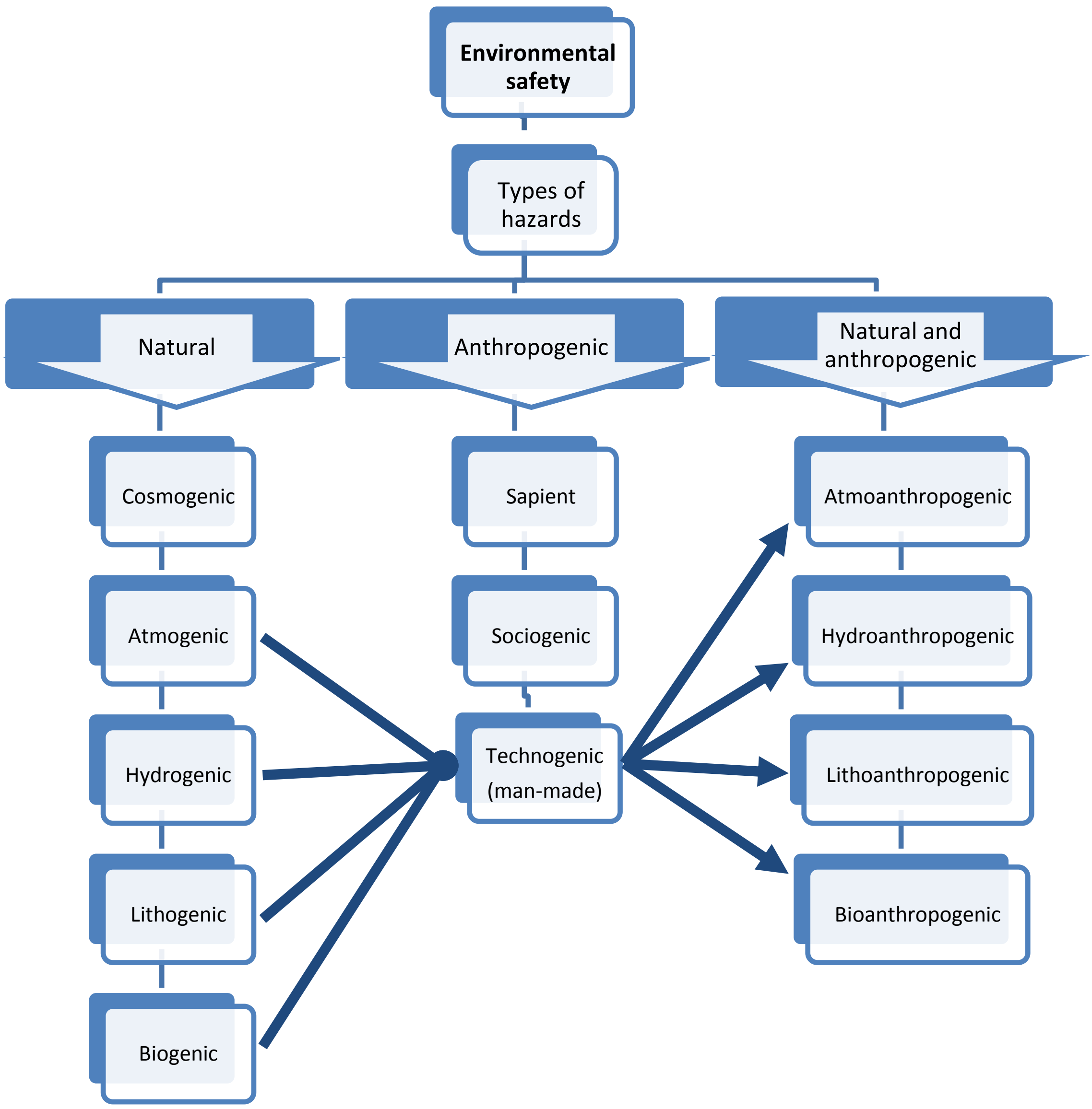


Figure 1 General hierarchical structure of environmental safety, hazards and risks [9]

Civil aviation airports create anthropogenic pressure on environment due to the simultaneous presence of hazardous constituents of different genesis and the unfavourable positioning of their sources. Placement and functioning of different stationary objects (mechanical and galvanic stations, storages for fuels and lubricants, painting stations and pumps for petroleum products transportation, boiler installations), vehicles, etc. in the powerful commercial aviation systems cause the convergence in time and place of a significant number of hazardous factors (threats), and significantly enhance their negative impact on the population around airports. Among the dominant environmental hazards specific to airports are traffic accidents, notably aircraft accidents and incidents.

In [9], a hierarchical structure of man-made hazards is proposed, highlighting threats generated by operating factors, with a limited number of subtypes. Based on investigations, this hierarchical system of threats and hazards was extended under normal and abnormal operational conditions of **ergatic systems** or, in other words, man–machine systems. The class of anthropogenic environmental safety consists of threats and hazards produced by the following factors: chemical, physical, biological, landscape-transforming, information, innovative design or operational. In particular, the operational factors are defined by malfunctions in technologies, systems and designs, insufficient human performances and their errors, and malfunction in information systems which allow the management and control of the overall ergatic systems and conditions of the outer environment, inside of which the ergatic systems are operating. Among these man-made environmental threats and hazards, there are specific factors associated for instance with the uncontrolled exploitation of lands near the highways, railways and airports for industrial and residential construction.

Abnormal conditions can lead to accidents, such as traffic or more particularly aircraft accidents, with the following impacts on the environment: risk to third parties (impairments of the health of the population and even fatal consequences for people living around airports); risk to wildlife, especially for birds (with reverse impact on safety in case of collision with aircraft); and risk associated with infrastructures surrounding the airport areas (storages of hazardous substances, pipelines, other critical objects, etc.). In such cases, both environmental and flight safety hazards lead to the genesis of new risk factors for the environment in general and human populations in particular. Only a balanced approach, similar to aircraft noise control formulated by ICAO [10], may be used to manage such a complex system efficiently. The basis for the balanced approach in environmental protection consists of the implementation of measures to reduce the adverse effects of aircraft on the environment during their operation; zoning, planning and control of land use around airports; monitoring the levels of exposure to adverse factors inside the airport area and in the vicinity of the airport; and implementation of economic regulations to environmental protection, and so on.

The ICAO Airport Planning Manual (Doc 9184), first published in 1999, includes a discussion on third party risk issues in its Part 2 on Land Use and Environmental Control [11]. Third party risk is in many ways similar to local air quality and noise issues in that it impacts mainly the population living close to airports: this population gains certain economic, employment or other benefits from air traffic but is also subject to its negative effects. Noise and third party issues also carry similar implications in terms of zoning and land use planning: different levels of protection zones with respect to noise and risk exposure can be established around airports, restricting land use and further developments. Third party risk is therefore not merely a safety issue, although the accident rates (based either on historical data or modelling and simulations) used in risk calculations are naturally related to aviation safety. Environmental problems might arise from aircraft accidents while incidents involving dangerous goods carried as cargo are likely to occur only under exceptional circumstances. The quantities of dangerous goods carried on aircraft are so small that they only pose environmental hazards of a localized nature. In the event of accidents, fuel spills could be of environmental concern but a fire is a much greater risk. Action taken to improve aviation safety helps to reduce the likelihood of these problems.

It is important to note that ICAO and ACARE targets and goals are not only to reduce noise levels and air pollution concentrations: the novelty of the approach is the idea that noise and air pollution reduction at receiver point are not the final objective for the society, but a tool to achieve the real final goal which is the reduction of the noise and air pollution effects. This effect is defined currently by ICAO as a reduction of the number of people affected by aircraft noise and air pollution [12]. The same approach is needed when analysing the effects of aircraft accident risk—the aim is to reduce the number of people affected by this risk, while there can also be damage to material assets and ecological systems [5].

Until recent years, risks to health and life were mainly analysed from a purely scientific and technical perspective, although it is becoming understood that that risks can be apprehended and interpreted quite differently by different societal groups, such as scientists, professionals, managers, the general public and decision-makers [13]. Assessment and management of risks to human health and life is a new field of study that has been on the rise since the early 1970s [13]. Originally, the focus of the field of risk assessment was on the development of scientific methods for identifying and characterizing threats/hazards and on the assessment of the probabilities associated with adverse outcomes and their consequences [13]. A great amount of attention has been given to the type and scale of the adverse consequences of risk, including mortality [13]. Early studies on risk analysis were mainly done in the US and Europe [13, 14].

In the early 1980s, risk analysis was divided into two major phases: 1) risk assessment and 2) risk management [13]. More attention was now given to how hazards or risk factors could be handled both at the individual level (**individual risk**) and at the societal level (**societal risk**) [13]. The emphasis of risk analysis was transferred from the calculation of the probability of adverse events for different risk factors to the assessment of the scale and range of possible consequences; and, at the same time, the aim was to reduce any uncertainties in the estimates [13, 15]. Mortality is naturally perceived as one of the most important consequences of adverse events [13]. New focus on individual risk factors lead to the fact that many risks were characterized as behavioural in origin and largely under individual control, which in turn gave rise to the lifestyle approach in health promotion [13].

Risk assessment can be defined as “a systematic approach to estimating and comparing the burden of disease and injury” resulting from different hazards [13]. According to [13], the first global estimates of disease and injury burden attributable to a set of hazards were reported in the first global burden of disease study [16, 17]. All the defined risk factors that were assessed were either exposures to the environment (for example, unsafe water [18]), human behaviour (for example, tobacco smoking [19]) or physiological states (for example, hypertension [20]). There was a lack of comparability between the different risk factor assessments in this study due to different degrees of uncertainty in risk factors and non-standard comparison groups [13].

World Health Organization (WHO) considers that road traffic-related injuries are a major but neglected global public health problem, requiring coordinated efforts to ensure their effective and sustainable prevention [21]. The number of persons killed in road traffic accidents is estimated at over 1 million per year worldwide, while the number injured could rise up to 50 million [21]. Although the number of people impacted by aircraft accidents is several orders of magnitude lower, this number is bound to rise due to the growth of air traffic. As a result, the importance of air traffic safety and its third party risk is bound to rise on the policy agenda. Approaches to improving traffic safety fall into three broad groups: engineering measures (e.g. airport design and air traffic management), vehicle design and equipment (e.g. seat belts for passengers) and operational measures (e.g. speed limits, and restrictions on drinking for pilots and drivers).

Since the last major WHO world report on road traffic safety issued over 40 years ago [22], there has been a major change—a paradigm shift—in the understanding of and practical approaches to traffic injury prevention among traffic safety professionals [21]. One of the main elements of this shift was the realisation that transportation safety is a multi-sectoral and public health issue: all sectors need to be fully engaged in responsibility, action and advocacy for crash injury prevention while traditionally transportation safety has been assumed to be the responsibility of the transport sector [21].

1.1.2 History of Third Party Accidents

The convergence of air traffic over areas surrounding airports implies for people living in the vicinity an involuntary exposure to a number of impacts, such as aircraft accidents [11, 23]. Whilst crashes with significant casualties are infrequent, most aircraft accidents occur on take-off or landing (Figure 2) and people on the ground near airports run a heightened risk of death or serious injury. Even though only 6% of a flight is spent in the landing or take-off phases, most fatal accidents happen in these two phases [23]. A fatal injury is defined as an injury that results in death within 30 days of the accident [23]. Fatal injuries are further sub-divided into on-board fatalities and third party fatalities. If fatalities concern persons outside the aircraft (and not involved in their operation and maintenance), then they are treated as third party fatalities. In this case, the first party is the aviation personnel (who provide the air transportation service) and the second party the passengers (for whom the air transportation is provided). Accordingly, such a risk is known as Third Party Risk (TPR) when the people exposed are there for reasons unrelated to aviation, for instance people living in the airport vicinity.

Urgent reviews of TPR around airports should be carried out and strict land use policies developed to reduce the numbers of people at risk, preferably with independent health and safety authorities (legally obliged to provide this kind of protection) taking the leading role. There are a number of ways in which the environmental impacts of airports are currently regulated. Planning regimes and policies exist at local, regional and national levels and provide a framework that allows airports to seek permission to construct and operate facilities—runways, passenger terminals and so on—and expand to meet demand. These actions are subject to scrutiny of varying degrees. A zoning policy [8] with land use restrictions applied to residential and commercial development, and transport links based on rigorous risk assessment, consequence and cost benefit analysis (including societal risk) should underpin the definition of protection zones. In the TPR context, these zones are usually called Public Safety Zones (PSZs). The stated aim of this policy is: “to minimise the number of people on the ground at risk of death or injury in the event of an air crash on take-off or landing” [8, 24].

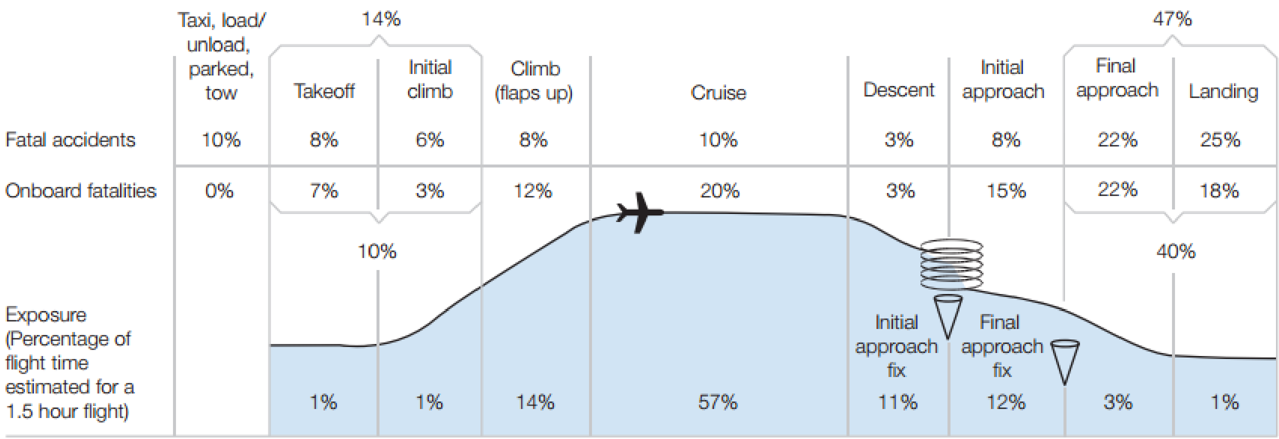


Figure 2 Percentage of fatal accidents by flight phase (worldwide commercial jet fleet, 2004–2013) [23]

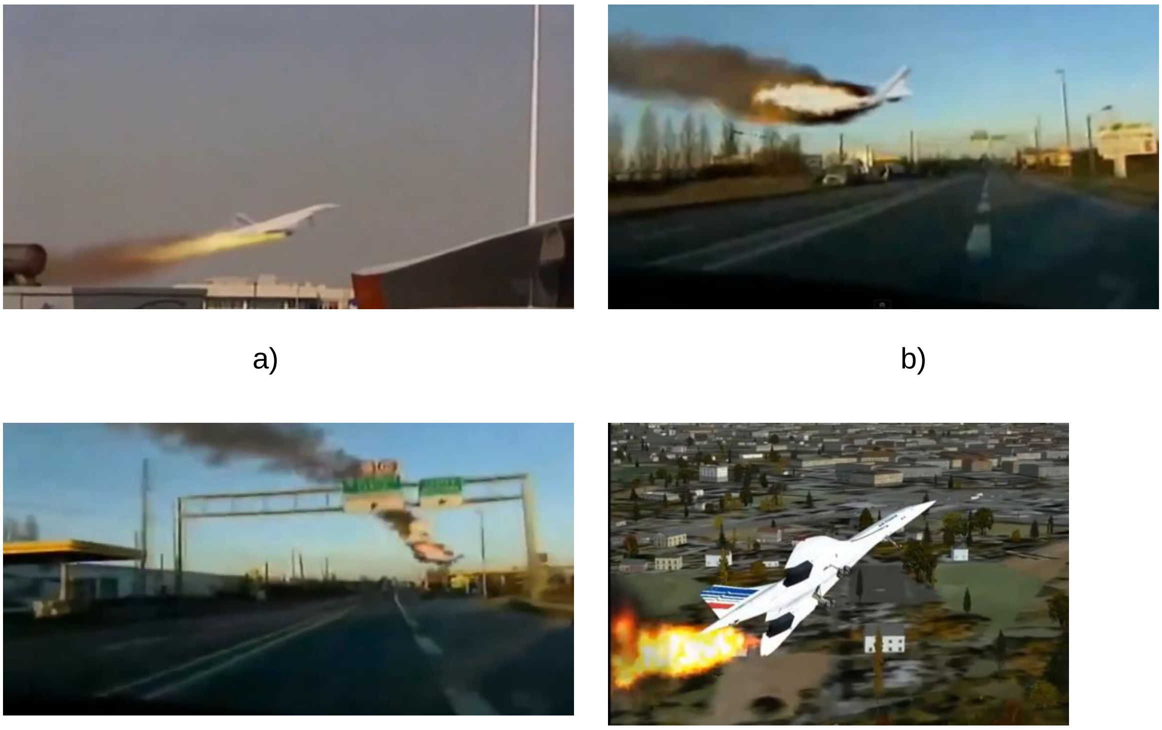
Public Safety Zones were first instituted following the 1992 El Al 747 crash near the Schiphol airport in the Netherlands (Figure 3), where the number of fatalities reached 49 and around 40 were injured. The pertinence of the PSZ approach was validated by accidents that occurred in the decade that followed: the number of fatalities in 1996 was dominated by a single accident in Kinshasa, Zaire where a Scibe Airlift Antonov 32 failed to take-off and overran into a market, killing 297 people on the ground. In January 1996, an Antonov 32 killed over 300 people when crashing on a crowded open air market at the end of the runway when shortly after take-off at Kinshasa's N'Djili Airport. On 4th May 2002 in the north Nigerian city of Kano, a Nigerian EAS Airlines BAC 1-11 500 aircraft crashed killing at least 148, including 73 persons on the ground. On April 15, 2008 a Hewa Bora Airways McDonnell Douglas DC-9 crashed after aborting its take-off from Goma, in the east of the Democratic Republic of Congo. At least 50 people were killed and more than 100 people were injured on the aircraft and on the ground. On December 5th, 1997 an airplane crashed into a department store in Irkutsk, Russia (Figure 4), killing 45 people on the ground. In 2000, four employees of the Hotelissimo hotel were killed in the crash of Air France Flight 4590, a Concorde operated by Air France scheduled to fly from Charles de Gaulle Airport near Paris to JFK International Airport in New York (Figure 5).

The following examples of aircraft accidents demonstrate the variety of ground accidents [25]:

1. An airplane crashed into a house killing its resident.
2. An airplane hit an individual walking on the runway.
3. An airplane made an emergency landing on a highway hitting an automobile and killing the driver.
4. An airplane hit someone taking pictures at the end of the runway.

Figure 3 The Boeing 747 crash into high rise flats adjacent to Schiphol airport in 1992 [26]

Figure 4 The Antonov 124 crash into residential area adjacent to Irkutsk airport in 1997 [25]



a) b)

c) d)

Figure 5 Reconstruction of the Concorde crash into residential area adjacent to Charles de Gaulle Airport near Paris in 2000: a) take-off with destroyed engines; b) initial climb; c, d) crash into the hotel [27]

Table 1 gives an indication of events where aviation related objects (aircraft, aircraft parts and ice from aircraft) have hit third parties or their property [28]. In the 10 years reported, there were two injuries as a result of these events, in 1994 and 2000. Both resulted from falling ice and/or debris created by such a fall. The term ‘Falling Aircraft’ below indicates events where a whole aircraft has struck or ended up on third party property, e.g. the Air Algeria B737 on 21 December 1994.

Table 1 Events where aviation has impinged on third parties, 1992-2001 [28]

Incident type	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Icefalls	23	25	26	23	33	36	29	34	39	34
Falling Aircraft Parts	17	13	16	10	19	14	17	7	10	5
Falling Aircraft	2	3	3	2	5	4	3	2	6	4

Table 2 below indicates the general locations for these events for 2000 and 2001 only [28]. However, it should be borne in mind that aircraft forced to land in an emergency on open ground, e.g. on private farmland, have been ignored unless a third party was directly involved because this is considered normal safe practice. In addition, icefalls onto open ground rarely leave any trace so the information is incomplete. Table 3 below indicates the general locations of these events for 1992–2011, excluding icefalls. All the data in Table 1–Table 3 indicate a constant third party hazard connected to aircraft accidents and incidents.

Table 2 General location of events from Table 1, 2000 and 2001 only [28]

Site	Only Ice	A/C Parts	A/C
Residential Buildings	32	4	3
Private Gardens/Outbuildings	19	2	-
Commercial & Other Property	-	4	2
On/near vehicles/people	20	-	-
Crossing/on Roads	2	-	5
Open Ground	-	5	-

Table 3 General location of events from Table 1, excluding 'Icefalls', 1992–2011 [29]

Site	A/C Parts	A/C
Residential Buildings	56	17
Private Gardens/Outbuildings	5	2
Commercial & Other Property	12	16
Community and socially important sites (schools, preschools, rest areas)	3	-
Crossing/on Roads	5	12
Open Ground	14	3

Local risk levels around large airports are of the same order of magnitude as those associated with road traffic. Because an increase in airport capacity usually involves changes to runway and flight route layouts, and air traffic distributions among them, which in turn affect the risk values around the airport, TPR is an important issue in decision making on airport development [11]. Wherever major terminal, runway or other capacity enhancing developments trigger Environmental Impact Assessments (EIAs) [5], mandatory third party risk assessment should also be undertaken as part of the EIA process. The European EIA Directive 85/337/EEC does not specifically require a TPR assessment; however, as it requires the assessment of the direct and indirect effects of a project on human beings, TPR aspects can be taken as implicit. (For amendments of the Directive, see 2011/92/EU and 2014/52/EU.) Although at present of less significance than noise and air quality, it is widely believed that third party risk is moving rapidly up the policy agenda. The results of this could be increased constraints on airport capacity and obligations on operational stakeholders to act to meet regulatory requirements.

Systematic assessment of risk has addressed public concerns at Public Inquiries and in EISs and has helped to produce a batter informed overall assessment of airport development plans. Hence there are a number of positive aspects that could flow from more attention to third party safety, just as has happened in major hazard industries (e.g. chemical). Public concerns over safety around airports will not go away. Therefore, in order to enable airports to develop long-term plans for the future, these concerns need to be addressed.

Third party risk models can be used for decision-making and policy purposes with regard to airport development and operations [30]. They are used to forecast the risk of an individual being killed by an aircraft crash in the airport vicinity (Figure 6); this information has also been exploited for comparing risk levels around airports and those near chemical and nuclear plants [30]. TPR models consist in general of three main building blocks: **accident probability**, **accident location** and **accident consequences.** Risk is generally defined as a combination of the probability of an adverse event and its severity. Two main measures of risk are used in TPR analyses: **Individual Risk** and **Societal Risk**. Zoning around airports based on individual risk contours and societal risk values is now undertaken in many countries.

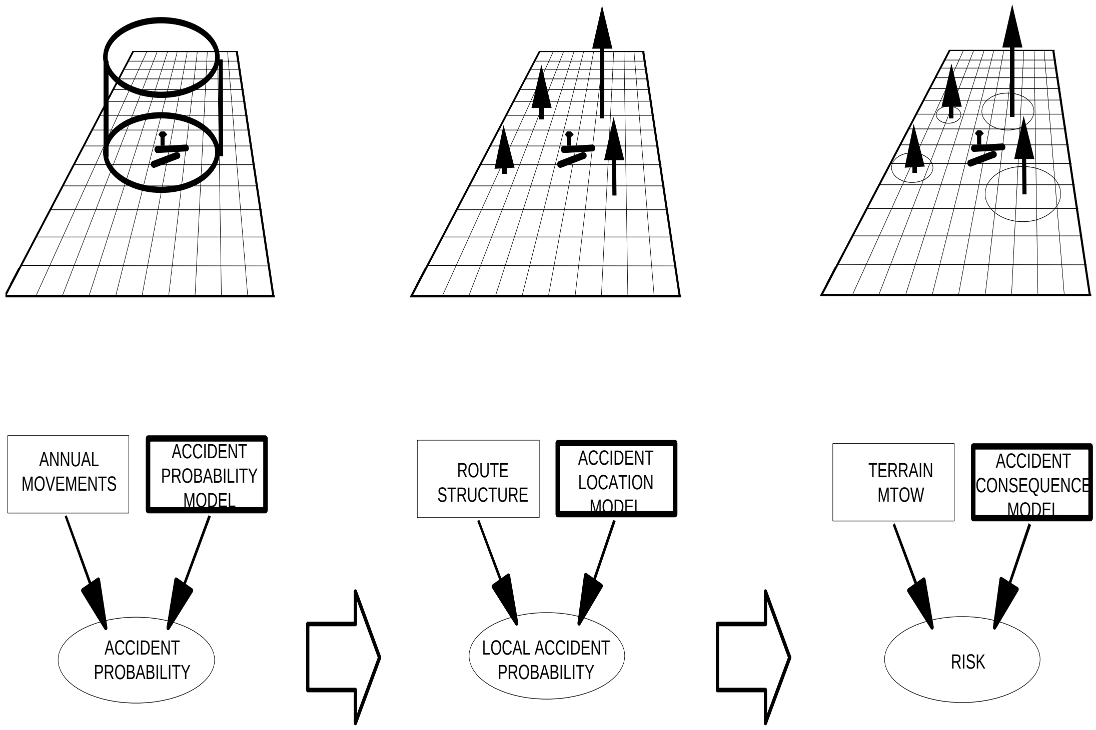


Figure 6 Third party risk methodology [11]

1.2 Project Objectives

The primary objective of this report is to study the possibility of integrating the notion of Third Party Risk in EUROCONTROL's environmental impact assessment web platform called IMPACT. In accordance with the technical specifications issued by EUROCONTROL, such a feasibility study should be able to:

- identify existing Third Party Risk models;
- determine the requirements for performing Third Party Risk modelling;
- assess whether existing Third Party Risk models could be successfully integrated with or interfaced with IMPACT;
- assess whether an IMPACT-specific Third Party Risk model is required; and
- propose credible solutions for developing Third Party Risk modelling capabilities within the IMPACT platform.

IMPACT is a web-based environmental modelling system developed by EUROCONTROL in the context of SESAR. It has been built upon the already existing EUROCONTROL fuel/emissions and noise assessment models—AEM and STAPES respectively. IMPACT allows the consistent assessment of trade-offs between noise and gaseous emissions owing to a common aircraft performance model based on a combination of the Aircraft Noise and Performance (ANP) database and the latest release of EUROCONTROL's Base of Aircraft Data (BADA). This potential extension of IMPACT's scope was recommended by the audit conducted in the context of the SESAR 16.03.01 project.

It is not obvious to evaluate if/how TPR modelling can be cross-bred with other environmental modelling. This feasibility study will highlight which TPR models are best suited for this approach and especially suitable for the IMPACT platform. A number of TPR calculation models exist today. These models are to be analysed and compared in this report, and recommendations are to be made to enable the selection of a suitable TPR model or even a composite model combining different sub-models from existing TPR models. Other aspects that are to be studied include notably input data requirements for TPR modelling, model integration vs. interfacing, available open source and proprietary software, and use of existing solutions vs. the development of an IMPACT-specific solution.

1.3 Document Structure

This document starts with an Introduction to third party risk and the history of TPR accidents in Chapter 0.

The introduction is followed by a presentation of third party risk issues around airports, a review of existing TPR models and their input data needs (Chapter 2).

A review of the IMPACT platform and its data structures is given in Chapter 3.

The feasibility of integrating/interfacing a TPR model with IMPACT is analysed in Chapter 4.

General conclusions are given in Chapter 5.

The Appendix provides a glossary of third party risk related terminology.

2 REVIEW OF THIRD PARTY RISK MODELS

This chapter presents the basic concepts of third party risk around airports and its mathematical formulation, and provides a review of existing TPR models as well as their input and output data.

2.1 Third Party Risk around Airports

2.1.1 Risk in Civil Aviation

In air transport, risk is linked to air traffic accidents resulting in significant loss of life, property and environment (ecosystems). Figure 7 offers a generic scheme for analysing air traffic accidents and their consequences [30]. Risk and safety modelling employed in civil aviation can take many different types of outcomes under consideration: failures of particular technical systems and components, aircraft collisions while airborne and/or on the ground notably due to the deterioration of ATC/ATM separation rules, incidents and accidents due to human error (notably errors made by air traffic controllers), and third party risk affecting people on the ground [30].

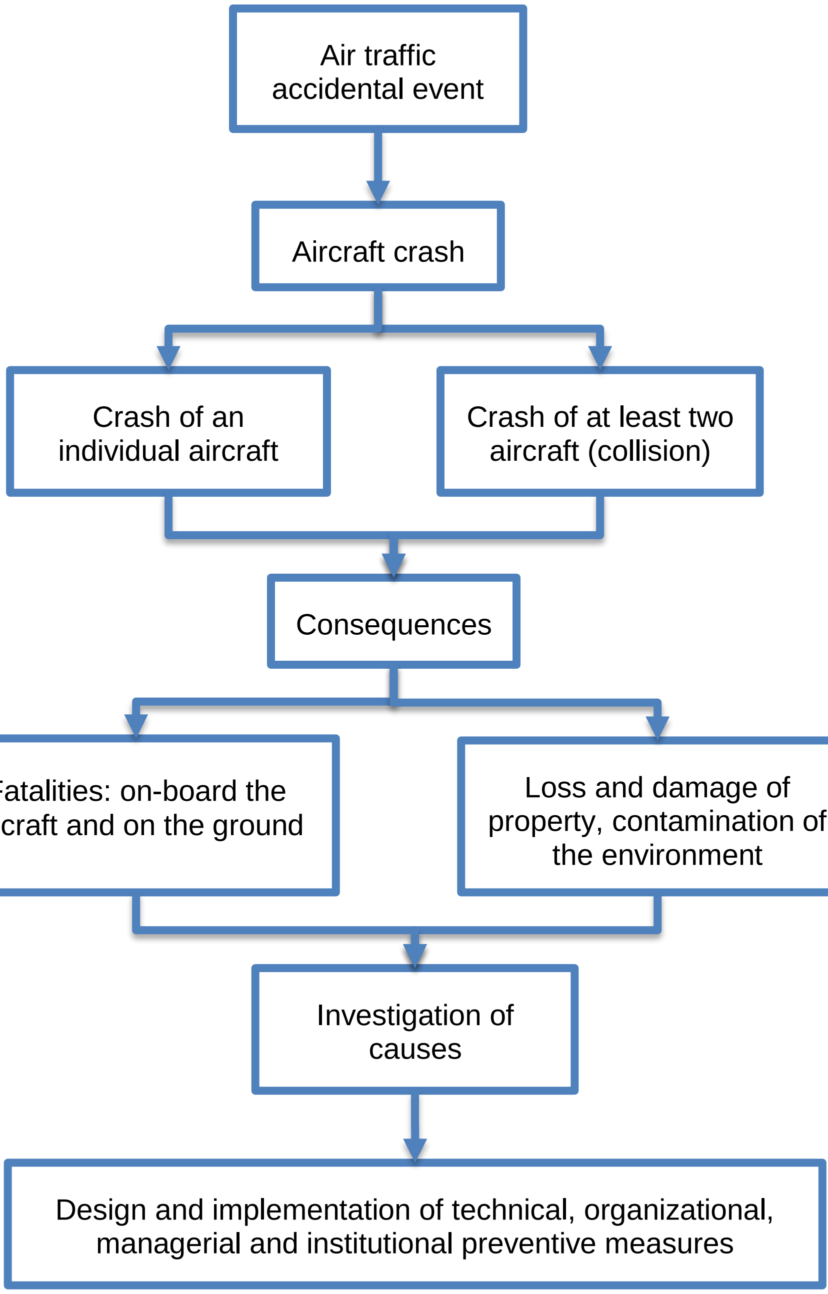


Figure 7 A generic scheme for analysing air traffic accidents and their consequences, adapted from [30]

Based on an analysis of historical accident data [31], ICAO has identified the following high-risk accident occurrence categories (Table 4): controlled flight into terrain (CFIT), loss of control in-flight (LOC-I), runway safety related events (RS), ground safety (GS), operational damage (OD) and injuries to and/or incapacitation of persons (MED). According to the ICAO report, most aircraft accidents fall in the following accident categories: 1) runway safety, 2) operational damage and 3) ground safety [31].

Table 4 GSIE Harmonized Accident Categories [31]

Category	Description
Controlled Flight into Terrain (CFIT)	Includes all instances where the aircraft was flown into terrain in a controlled manner, regardless of the crew's situational awareness. Does not include undershoots, overshoots or collisions with obstacles on take-off and landing which are included in Runway Safety.
Loss of Control in-Flight (LOC-I)	Loss of control in-flight that is not recoverable.
Runway Safety (RS)	Includes runway excursions and incursions, undershoot/overshoot, tail strike and hard landing events.
Ground Safety (GS)	Includes ramp safety, ground collisions, all ground servicing, pre-flight, engine start/departure and arrival events. Taxi and towing events are also included.
Operational Damage (OD)	Damage sustained by the aircraft while operating under its own power. This includes in-flight damage, foreign object debris (FOD) and all system or component failures including gear-up landing and gear collapse.
Injuries to and/or Incapacitation of Persons (MED)	All injuries or incapacitations sustained by anyone in direct contact with the aircraft. Includes turbulence-related injuries, injuries to ground staff coming into contact with the aircraft and on-board incapacitations and fatalities not related to unlawful external interference.
Other (OTH)	Any event that does not fit into the categories listed above.
Unknown (UNK)	Any event whereby the exact cause cannot be reasonably determined through information or inference, or when there are insufficient facts to make a conclusive decision regarding classification.

Third party risk deals with risk to an individual on the ground of being killed or injured by an aircraft; these accidents are also called groundling accidents (an aviation accident involving groundlings). The concept of TPR or *external* risk was first analysed in the nuclear and chemical industry since the risk of the release of substantial amounts of radioactive or otherwise toxic substances poses direct a threat to the environment and therefore has to be managed [32]. For the chemical and nuclear industry, the term 'external' refers to everything happening outside the nuclear or chemical plant (for example, incidents during the transport of toxic or radioactive materials of the plant or leaks from storage facilities to the environment), whereas 'internal' refers to everything inside the plant (any kind of internal accidents or incidents, for example as a consequence of technical failures and/or operator errors). The distinction between external and internal safety is pertinent as there are various additional safety measures, such as secondary containment; these measures can mitigate or even prevent the escalation of internal losses of containment to external effects [32]. For nuclear reactors, prevention measures such as concrete domes around reactors can prevent negative consequences for third parties in populated areas [32].

The concept of external risk is also relevant in transport systems, such as aviation; nevertheless, there are also notable differences [32]. Contrary to chemical or nuclear plants, aviation systems are not static: the main threats are posed by aircraft flying to and from the airport. Hence aviation risks are also produced outside the airport perimeter. Consequently, in the case of aviation risk containment at the source is not possible as for static facilities [32] Potential risks of aircraft accidents and their effects should be considered when planning activities involving large groups of people in airport proximity. As an increase in airport capacity usually involves changes to runway and route layouts, and aircraft traffic distributions within them, this in turn affect the risk levels around the airport, making third party risk is an important issue in decision making on airport development.

2.1.2 Basic Risk Concepts and Their Mathematical Formulation

Generally speaking, *safety* is defined as the property of a system not to cause damage to human health or the environment. However, in practice the safety of a system cannot be taken as a total absence of hazards and the objective is not to eliminate all risks regardless the cost; the aim is to bring the risks to an acceptable level. The concept of safety is complex and difficult to understand in all its dimensions—physical, social and psychological—and, therefore, difficult to manage [33]. Safety has been defined in [34] as "a state in which hazards and conditions leading to physical, psychological or material harm are controlled in order to preserve the health and well-being of individuals and the community. […] Safety is the result of a complex process where humans interact with their environment, including the physical, social, cultural, technological, political, economic and organisational environments." Effective safety enhancement requires the use of an integrated approach, taking into account its different facets in a comprehensive framework [33]. Major accident investigations, particularly in nuclear power production, have identified poor safety culture as a causal factor increasing the probability and severity of occurrence of accidents and their consequences [35]. A proactive approach that would allow the integration of safety culture at the organizational level is needed in order to prevent undesirable behaviours and practices in safety-related functions even before any accident occurs [36]. The safety culture concept explains how the lack of adequate knowledge and understanding of as well as the (low) priority placed on risk and safety among managers and employees can contribute to disasters.

Risk is assessed by identifying hazards and determining the probability of the consequences that arise from them. The procedure of risk assessment is essentially a probability calculation. The probability might be formulated as the average value of the realization of the event during a given time period. The basic idea of risk assessment is to identify or quantify risks, at least in comparative form (qualitatively) with respect to other risks. Risk assessments can be complex and cover a variety of risks.

The relation of risk to hazard may be formally expressed as:

Risk = $f(H \times E) = f(H \times D \times t)$, (1)

where f is a function, H is a hazard, E is an exposure, D is a dose and t is time. A risk is here defined as a measure of the probability that harm will occur under defined conditions of exposure to a stressor.

In general, the *danger* is the location of objects and combination of conditions or situations that may result in harm to human health or environment, or in material damage. *Hazard* is the potential of all or any of them to cause damage. *Stressor* (synonymous with the terms 'agent' or 'factor') is any physical, chemical or biological entity (a phenomenon, object, substance, etc.), which may cause an unacceptable response, usually called *damage*. *Receptor* is an entity that is exposed to the stressor. *Exposure* is the phenomenon of a stressor's contact with the receptor. The effect is determined by the potential consequence to the receptor, most often in the form of damage caused by a danger that exists at a particular state of the system under consideration. *Vulnerability* is used as a set of conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a receptor (community or an individual) to the impacts of hazards. In other words, vulnerability is an inability to avoid or absorb potential harm in case of exposure to risk. Conceptually, hazard and vulnerability interact producing and amplifying risk as shown in Figure 8.

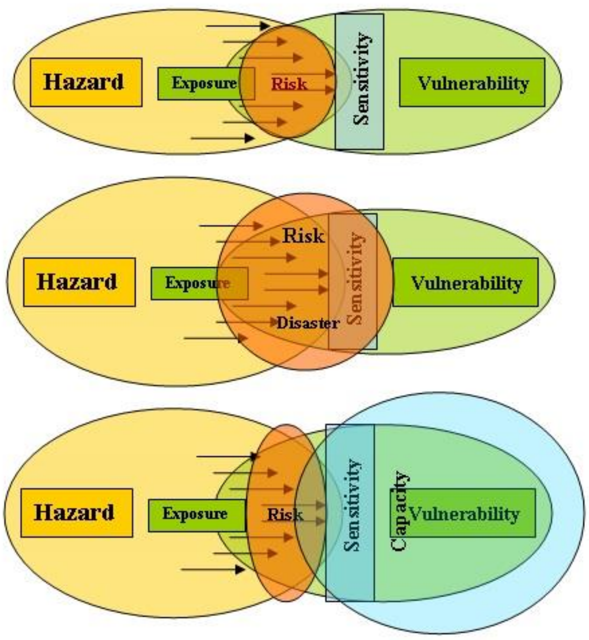


Figure 8 Hazard and vulnerability interference in risk production (source: NAU)

The severity of hazardous events is categorized as follows according to the European Space Agency standards [37]:

Catastrophic hazards

- Loss of life;
- Life threatening or permanently disabling injury;
- Occupational illness;
- Loss of an element of the interfacing manned flight system;
- Loss of launch site facility;
- Long-term detrimental environmental effects.

Critical hazards

- Temporarily disabling (not life threatening injury);
- Temporary occupational illness;
- Loss of, or major damage to flight systems, major flight system elements;
- Loss of, or major damage to ground facilities;
- Loss of, or major damage to public or private property;
- Short-term detrimental environmental effects.

The opposite characteristic to vulnerability and important criteria for risk assessment is the *capacity* of a person or group or society as a whole to anticipate, cope with, resist and recover from the impacts of a hazard [38]. First of all, capacity is defined by the knowledge of persons of possible hazards or threats, their stressors, exposures and vulnerabilities. Secondly, capacity implies the knowledge and skills of persons on how to protect themselves. It is governmental responsibility to provide these knowledge and skills to citizens and to provide the means for personal and collective protection and prevention. In some cases, the term *capacity* also means the positive managerial capabilities of a receptor (individuals and communities) to confront the threat of disasters, accidents, etc. (e.g. through awareness raising, early warning systems and preparedness planning).

Since different disciplines are working with the concepts of hazard, vulnerability and capacity, all the concepts have broadened and deepened over time. The conceptual formula for risk assessment from Eq. 1 has evolved as follows (exposure and/or dose are omitted here):

Conceptual formula for risk assessment:	Main attributes to risk assessment:
Risk = H	Hazard (H)
Risk = $H \cdot V$	+ Vulnerability (V)
Risk = $H \cdot V / C$	+ Capacity (C)
Risk = $H(V,C) \cdot V(H,C) / C(H,V)$	Complex interactions between all attributes

2.1.3 <u>Risk Assessment and Management</u>

Many approaches have been developed to assess danger and hazard, the most well-known of which include Fault Tree Analysis, Common Cause Analysis, Event Tree Analysis, the Hazard and Operability method, Failure Mode, Effects and Criticality Analysis and so on [30]. Here the risk assessment and management approach is considered as one with the most perspective for safety management as a whole, particularly including the aspects of flight safety, aviation security, fire safety, environmental safety, etc. Usually elements-at-risk are the employees or population, properties, economic activities, including public services, or any other defined values (see the list of factors from EU Directive [5] in section 1.1.1) exposed to hazards in a given area. There are different manners to quantify the elements-at-risk: for instance numbers (number of buildings, people, etc.), monetary units (reparation or replacement costs, market value, etc.), area or perception (importance of elements-at-risk).

The use of risk-based approach or risk assessment and management techniques is fairly widespread in policy and regulations in the EU in fields such as design of dike systems along rivers, chemical industry and transport of hazardous materials [35–39, 40, 41]. There have been several somewhat unsuccessful attempts to harmonize the techniques and criteria used in different fields [37]. The methodology and procedures employed in the field of major hazards are often closely related to methods applied in engineering and nuclear industry [37]. Most of the development in risk management concepts stemmed from major disasters in the chemical industry that took place in the mid-70s, although some were also introduced in public policies regulating nuclear power generation [37]. In the field of environmental policy, the introduction of this risk-based approach was somewhat at odds with the prevalent general opinion which had considered no kind of pollution or risk acceptable [37].

It is of interest to consider the EU's approach to safety at and around major hazardous industrial sites. Incidents such as the explosion at Flixborough, UK in 1974 and the release of dioxin at Seveso, Italy in 1976 lead to the formulation of the Seveso EU Directive (Directive 82/501/EEC). A review of the first Directive by the EU identified a number of problem areas, leading to the new Directives called Seveso II (Directive 96/82/EC) and Seveso III (Directive 2012/18/EU). The inventories of hazardous materials held at a site are used to classify major hazard sites. A 'top tier' site storing significant amounts of flammable or toxic materials needs to produce a safety report detailing [7]:

- The management systems in place;
- The site and its surroundings;
- A risk analysis;
- Measures for reducing risk.

The principal considerations in a risk-based approach are the following [37]:

- Risk is not zero and cannot be made zero;
- Risk policy should be transparent, predictable and controllable;
- Risk policy should focus on the largest or dominant risk;
- Risk policy should be equitable.

There are a wide range of different approaches within the industry for assessing risks [37]. A number of different methodologies for risk assessment exist, including deterministic, semi-quantitative and quantitative techniques [37]. While some companies and countries employ multiple techniques including quantitative ones, others favour the use of qualitative risk assessment [37]. For activities characterized with a significant quantitative risk assessment, a framework can be suggested for assessing the acceptability of risk. The limit of risk acceptability is determined by the level above which the risk cannot be justified except in extraordinary circumstances. Below the limit of acceptability, a risk may be allowed only in response to advantages associated with the activity, but it should be analysed with respect to the requirements of the ALARP (As Low As Reasonably Practicable) principle [42]. If the risk level is between the two bounds—intolerable and negligible, thus inside the ALARP region (Figure 9)—risk should be reduced to an economically reasonable level, or ALARP level. The term 'reasonable' is interpreted as cost-effective. With the enhancement of risk management practices, it is possible to reach the point where the cost associated with further risk reduction is high enough to justify the stop to further reductions.

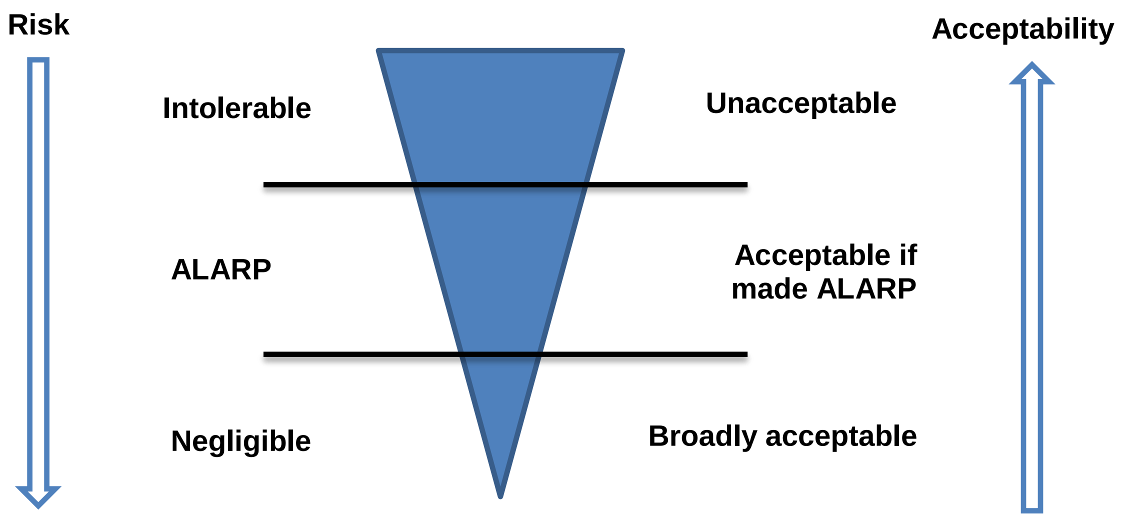


Figure 9 The ALARP principle in risk assessment and control, adapted from [43]

To demonstrate ALARP, regulations do not necessarily require the undertaking of Quantified Risk Assessment (QRA) [37]. For example, in the case of land-use planning near hazardous sites [see 39], decision-making must always be based on quantified risk criteria and a formal QRA is required to be made for the site in question [37]. The greatest added value of Quantified Risk Assessment lies in plant siting decisions and in the assessment of off-site (i.e. third party) risks. It may also be of value in assessing major on-site risks [37]. Many EU states (for instance the Netherlands, UK and Norway) often favour QRA or probabilistic risk assessment. However, some countries such as Germany and France favour a conservative deterministic approach, which can lead to the overestimation of risks [37]. With the focus on major or severe hazards, QRA is generally conducted as a top-down process for identifying hazards [37]. The major problem in probabilistic risk assessment is that is difficult to estimate the probabilities of rare events such as major accidents as data on their frequencies is scarce [37].

Safety- and risk-related matters in the EU are handled at three levels: 1) EU legislation, 2) European/international standardization, and 3) national socio-economic entities [37]. The European standardisation bodies, such as CEN, CENELEC and ETSI, are responsible for drafting technical standards meeting the requirements of EU directives [37]. Compliance with these 'harmonised standards' will provide a presumption of conformity with the directives' essential requirements [37]. As compliance with the harmonised standards remains voluntary, manufacturers can also employ other technical solutions in compliance with the directives' requirements [37].

Particularly in the UK with respect to land-use planning, Health and Safety Executive's initial approach was to promote the 'protection' of those exposed to a hazard [37].In this approach, 'worst events' were identified and a separation distance based on a defined level of injury or impact was determined [37]. This approach was later criticized for number of reasons, including [37]:

1. the protection provided might be overly conservative and beyond what can be considered 'reasonable' and, placing excessive restrictions on land use;
2. the definition of worst event was somewhat arbitrary, leading potentially to inconsistencies between the reference situations considered for different installations;
3. the difficulty in comparing the degree of hazard protection with the levels of protection required from other hazards in life.

Because of these criticisms, HSE's begun to use quantified risk criteria as basis for advice on land-use planning [37]. However, all QRA estimates involve their own uncertainty and judgements; decisions should only be taken in the light of these uncertainties [37]. Uncertainties of a quantified risk assessment are notably related to the following aspects [37]:

- Failure rate data: historical data are often lacking, incomplete or only partially relevant. They need to be complemented by formal analysis of potential failure causes.
- Consequences: consequence models are used to extend the available historical/empirical information. Uncertainty stems from the incomplete validation of these models as well as from the random nature of certain phenomena (e.g. turbulence).
- Impact and injury: deterministic prediction of injury and impact is difficult due to unknown differences in susceptibility.
- Human error: human action influences all aspects of risk management from project conception to design, construction, commissioning, operation, inspection, maintenance, repair and decommissioning/dismantling. All stages can potentially harbour unpredictable human errors.

QRA can be used as a tool to aid decision-makers in the determination of design and mission scenarios and technological implementation aspects [37]. While safety is always the priority, Reliability, Availability, Maintainability and Safety (RAMS) becomes crucial in QRA and an important driver for design and operations [37]. RAMS management is a comprehensive and systematic approach aimed at ensuring the availability and safety of systems over their entire life time [44]. RAMS management notably covers the performance of risk analysis, identification of hazard rates, detailed tests and safety certification [44]. RAMS should in the planning, development and implementation phases of projects as it contributes to the avoidance of failures at an early stage [44]. RAMS requirements are specified both in a deterministic and probabilistic way.

The widespread use and important advantages of risk assessments does not mean that they are the sole determinants of risk management decisions; risk managers are considering a number of factors. Although risk assessments provide critical information to managers, they are only a part of the decision making process. Reducing the risk to the lowest level can be very expensive or technically infeasible. Risk assessment provides the risk management program with its main input data. In managing risk, the following points need to be elucidated:

1. determine which adverse factor is the most dangerous;
2. consider the availability of management options;

3. perform the appropriate actions to reduce (or eliminate) unacceptable risks (programme realisation);
4. assess the remaining risk and its impacts.

2.1.4 Individual Risk and Societal Risk

Risk is generally defined as a combination of the probability of an event and the severity of that event. Two measures of risk are mainly used in TPR analyses: **Individual Risk** (IR) and **Societal Risk** (SR). In an airport context, individual risk represents the probability that a person permanently residing at a particular location in the airport vicinity is killed as a direct consequence of an aircraft accident [32]. Societal risk is defined as the probability that a given number of people are killed on the ground [32]. While individual risk is location-specific, societal risk applies to an entire area around the airport (Figure 10). Societal risk only exists when there are people residing near the airport (in an unpopulated area, societal third party risk is equal to zero by definition), whereas location-specific individual risk values can be calculated regardless of the number of inhabitants—it is a characteristic of the source of hazard [32].

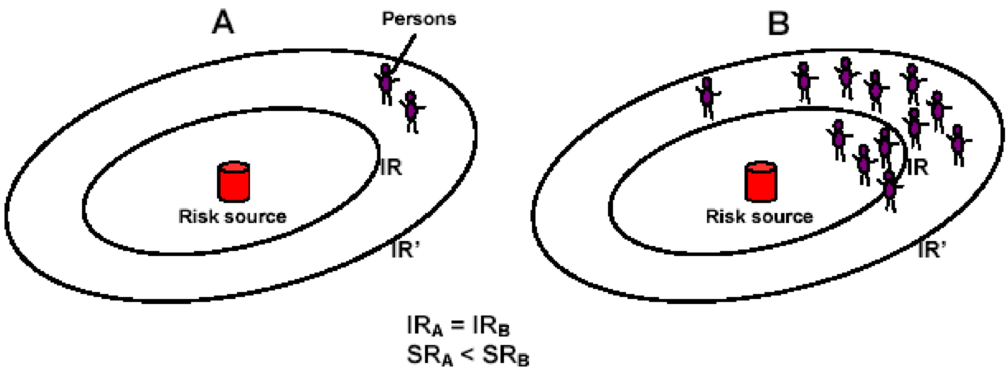


Figure 10 Difference between individual and societal risk [45]

Estimated risk values are usually given as either chances per year or chances per lifetime [37]. Particularly cancer risks (related to lifetime exposure) are often expressed as probability per lifetime [37]. With a given a life expectancy (for instance 80 years), the conversion from an annual to a lifetime risk can be calculated simply by dividing by 80, as shown in Table 5 [37].

Table 5 Individual risk conversion [37]

Lifetime risk	Equivalent individual annual risk (per year over 80 years)	Equivalent individual workplace risk (per year over 45 years)
1 in 1,000	1 in 80,000	1 in 45,000
1 in 10,000	1 in 800,000	1 in 450,000
1 in 100,000	1 in 8 million	1 in 4.5 million

1 in 1 million	1 in 80 million	1 in 45 million

The criteria for acceptable/unacceptable risk levels vary according to the type of risk and country (Table 6) [37]. Generally speaking, risks above 1 in 100,000 per year (1 in 10,000 for workers) are judged ‘unacceptable’ [37]. Risk levels of less than 1 in 100 million per year can be considered ‘acceptable’ [37]. The risk level of 1 in 1 million per year is often ‘acceptable’ [37]. The level associated with ‘unacceptable’ risk can be thought to correspond to roughly 10% of the risk level of various ‘voluntary’ risks such as driving [37]. This level is similar to the higher ‘involuntary’ risks, such as being murdered or hit by a car, as shown in Table 7 [37]. These everyday risk figures are merely averages and clearly there might be very significant variations due to different lifestyles [37].

Table 6 Examples of actual and implied risk criteria [37]

Country	Nature of risk	Limit of unacceptability	Limit of acceptability (risk of fatality per year)	Criteria applied in between
Netherlands	Residents close to hazardous facilities	1 in 1 million	None, but until recently: 1 in 100 million	ALARA*
Netherlands	Cancer risks	Not given	1 in 100 million	N/A
UK	Residents close to hazardous facilities	1 in 100,000	0.3 in a million	ALARP**
Australia (some states)	Residents close to hazardous facilities	Not given	1 in 1 million	N/A
Hong Kong	Residents close to hazardous facilities	1 in 100,000	1 in 100,000	N/A

*As low as reasonably achievable
**As low as reasonably practical

Table 7 Everyday risks in the UK [37]

Level of individual risk	‘Voluntary’ activities	‘Involuntary’ activities
1 in 10,000 per year	Driving, working in non-office environment, being at home	

1 in 100,000 per year		Being murdered, being run over
1 in 10 million per year		Being struck by lightning

As stated earlier, risk analysis can be done for the two types of risk: individual and societal. Individual risk is the average probability of death, injury and ill health per year for any individual located (residing or performing activities) near the source of danger (e.g. power plant or other critical object) and as a result of exposed to a risk (e.g. the crash of an airplane into a power plant). Individual risk levels at a given location remain the same regardless the presence and number of people there. The purpose of estimating IR is to ensure that individuals who may be affected by an accident involving a critical object are not exposed to excessive levels of risk (Table 6). IR is determined by the source of danger and the terrain around it and is therefore location-specific. For this reason, IR levels may be drawn using contours around the critical object on a map; these contours can be used further for land use planning and zoning purposes [46].

Societal Risk represents the risk to a (large) group of people. It is the annual probability that N or more people may die, become injured and/or ill as a result of risk exposure. Societal risk is not person and location-specific. The F_N-curve or F_N-diagram depicts the cumulative distribution of multiple fatality events and is therefore useful in the representation and assessment of societal risk. Two criteria lines divide the F_N-diagram space (Figure 11) into three regions: the region where risk is intolerable, the region where it is broadly acceptable and lastly the region where it requires further assessment and risk reduction as far as is reasonably practicable. The F_N-diagram allows the assessment of the average number of fatalities for all accidents. In addition, it can be specifically used to assess the risk of a catastrophic accident with multiple casualties. F_N-diagrams can be used to depict at least three different types of information: the historical record of incidents, the results of a quantitative risk analysis, and criteria for judging the tolerability of risk [47]. For instance, in the Netherlands the advised limit for societal risk of industrial facilities is $10^{-3}/N^2$ where N is the number of fatalities [46]. For new and existing industrial facilities, the limits for individual risk have been set at 10^{-6}/year and 10^{-5}/year respectively [46]. Again in the Netherlands, the individual risk level of 10^{-6}/year also applies to the transport of dangerous goods [46]. For societal risk of this same activity, the limit is defined per kilometre route and is set at $10^{-2}/N^2$ [46].

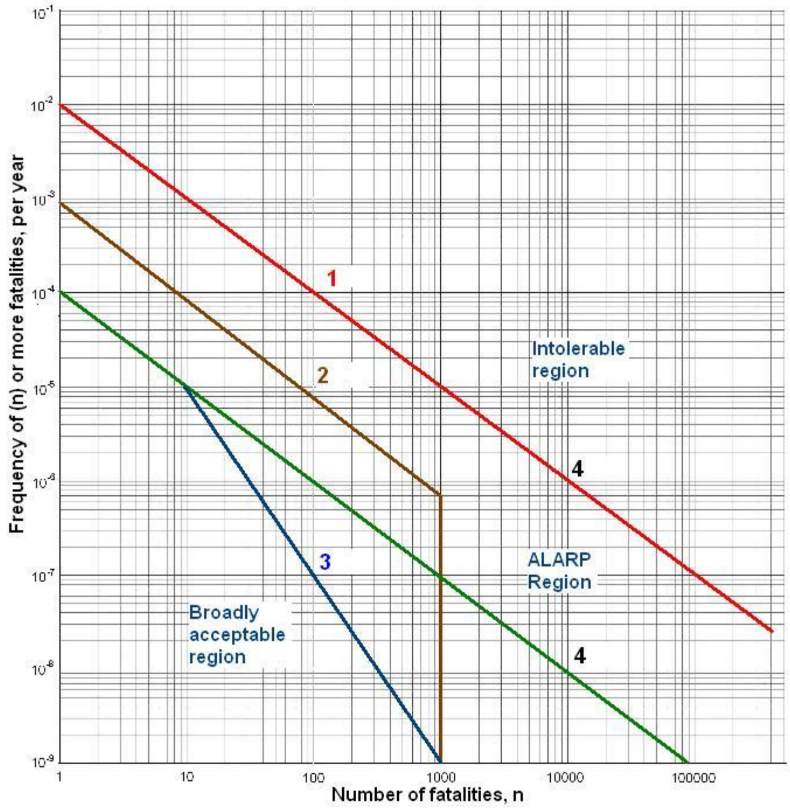


Figure 11 F_N-diagram as a social risk criterion: 1) UK risk rule; 2) Hong-Kong risk rule; 3) Netherlands risk rule; 4) upper and lower bounds of the ALARP region, upper bound coincides with the UK risk rule (source: NAU)

There are no single criteria for societal risks agreed on by operators and regulators in the major hazard industries world-wide. The variation in regulatory criteria is especially wide, as shown by the upper tolerability criterion lines in Figure 11, which span a factor of over 100. The Dutch criterion is so restrictive that it raises questions about its practicability. Societal risk is difficult to use in risk reduction, especially because it is multidimensional. It is therefore necessary to look at both SR and IR to get a full risk picture.

The F_N-curve (function of the number of fatalities N) displays the probability of exceeding a given number of fatalities on a double logarithmic scale [48]:

$$1 - F_N(x) = P(N > x) = \int_0^\infty f_N(x) x dx \qquad (2)$$

where $f_N(x)$ is the probability density function (pdf) of the number of fatalities N per year; $F_N(x)$ is the probability distribution function of the number of fatalities per year, representing the probability of less than x fatalities per year.

On the other hand, societal risk can also be expressed as the first moment of the *pdf* of fatalities, which is the expected number of fatalities $E(N)$ [48]:

$$E(N) = \int_0^\infty f_N(x)xdx \quad (3)$$

Severity of a hazard (risk of consequences of a danger) is combined with an estimate of its probability. First, we need to determine how often there may be a danger. Usually, a probability function of a combination of causes (factors) should be considered. Then, the likelihood of the worst state of the system must be assessed. This evaluation can be quantitative or qualitative. For example, let us assume that the probability of the worst system state (low altitude or airspeed, a large total mass of the aircraft) is equal to 0.001 during the operation. The probability of any effects for this system worst state can be determined by multiplying the probability of this state with the probable of consequences (effect), for example, which is also equal to 0.001. In this case, the risk of damage for investigated factor exposure during the system operation is calculated as 0.001 x 0.001 = 0.000001 = 10^{-6}. In quantitative terms, risk is often expressed as a probability: for example, the number of casualties per 1 million of population. A risk less than 10^{-6} is usually not a subject of concern for society.

Criteria of individual risk to life have a certain range of numerical values [42]:

- accidents with a death rate 10^{-6} are not usually noticed by the society; however, accidents with a frequency of 10^{-3}–10^{-4} are regarded as something to be prevented;
- the permitted level of individual risk, for which regulatory action is taken to reduce public risk, is identified in a range between 10^{-4}–$5{\cdot}10^{-5}$ per year. In some cases, the regulatory effect can be applied at lower values of risk depending on the number of population, which is exposed to a hazard;
- the minimum level of individual risk, which does not require regulatory action to reduce public risk, can be given at 10^{-7};
- the upper limit of acceptable risk to a third party in the vicinity of a power plant or transport network is around 10^{-4} per year (usually it is predefined legally from how the risk is perceived by society and hence regulatory authorities: it reflects the culture of the society and changes with time as more information becomes available);
- the upper limit of acceptable/perceived risk to working staff may be one order higher, around 10^{-3} per year.

Risk is usually associated with the probability of adverse events and their consequences. For individual risk, this basic condition may be expressed by the formula:

$$IR = P_f P_{d/f} \quad (4)$$

where P_f is the probability of an accident (e.g. aircraft accident); $P_{d/f}$ is the likelihood of the consequences (effect or damage), particularly the fatal consequences caused to individuals in the absence of protection from (or resistance to) a danger. In more general form, the probability of an accident P_f may be divided to the probability scenario p_{Sc} and the probability of hazard exposure p_{Ex}:

$$P_f = p_{Sc} p_{Ex} \quad (5)$$

The effects are usually described in terms of various types of damage *k* (e.g. fatality, injury, physical damage, loss of income, etc. depending on what are the elements-at-risk) and their vulnerability v_k (for example, a person's vulnerability can be defined as mortality):

$$P_{d/f} = k \cdot v_k \, . \quad (6)$$

An overview of different types of consequences from a power plant accident is given in Table 8. The damage is divided into tangible and intangible types, depending on whether the losses can be assessed in monetary terms. Another distinction is made between direct damage, caused by physical contact with the aircraft crash, and damage following indirectly from the crash. Indirect damage can be defined as damage that occurs outside the affected area [45]. For example, local businesses can lose supply and demand in the affected area.

Table 8 General classification of damage, based on [45]

	Tangible	Intangible
Direct	Residences Airport facilities and inventory Vehicles Agriculture Infrastructure and other public facilities Business interruption (inside affected area) Evacuation and rescue operations Clean-up costs	Fatalities Injuries Animals Utilities and communication Historical and cultural losses Environmental losses
Indirect	Damage for business outside affected area Substitution of business/production outside impacted area Temporary housing of evacuees	Societal disruption Damage to government

The individual risk at location (*x, y*) may be found by integrating all initial stressors that impact this location:

$$IR(x,y) = P(Z(x,y) < 0) = \int_0^{\infty} p_f \, f_{I_0|f}(I_0) F_D^*(I_0, x, y) dI_0 \quad (7)$$

where the probability of death at location (*x, y*) for a certain initial release (I_0) and for dispersed value of this release at location $I(I_0,x,y)$ is:

$F_D(I) = F_D(I_0,x,y)$ (8)

which is the combined dose response function. The probability density function of the intensity of initial effects $f_{Io}(I_0)$ is used as the load term. For the assessment of societal risk, the actual presence of the people (represented by the population density) is taken into account.

Calculation of individual risk basically involves the multiplication of the probability of failure and the mortality rate for the given failure. As the mortality fraction is never greater than 1, it is therefore logical that *IR* can never become larger than the probability of failure of a system.

By integrating *IR* and the population density *m*, the expected value of the number of fatalities *E(N)* inside population *N* can be determined:

$E(N) = \iint_A IR(x, y)\, \mathrm{m}(x, y)\, dxdx$ (9)

where all the contributing values are defined at location (x, y) inside area *A* per year. The number of people exposed to a certain accident (N_{EXP}) can be found by integrating the population density over the exposed area *A*:

$N_{EXP} = \iint_A m(x, y)\, dxdy$ (10)

The number of fatalities *N* is a certain function of the scenario exposure (I_0). It can be found by combining the dose response function, dispersion model and number of people exposed. Thus, the number of fatalities for one scenario yields:

$N = \iint_A F^*_D(I_0,x,y)\, m(x, y)\, dxdy$ (11)

Area under the F_N-curve (see Figure 11), which reflects the ratio of frequency of fatal consequences with their number per year, is also equal to the expected number of fatal consequences of the activities under investigation:

$$\int_0^{\infty} [1 - F_N(x)]dx = \int_0^{\infty}\int_x^{\infty} f_N(u)dudx = \int_0^{\infty}\int_0^{x} f_N(u)dxdu = \int_0^{\infty} uf_N(u)du = E(N) \qquad (12)$$

where f_N is a probability density of accidents.

The expected number of fatal consequences for the cumulative density function F_{Nij} of fatal consequences that arise during the implementation of the *i*-th activities at the *j*-th site during the year is:

$$E(N) = \int_0^{\infty} [1 - F_{Nij}(x)]dx \qquad (13)$$

Determination of individual and societal risk is shown schematically in Table 9.

Table 9 Schematic view of individual and societal risk determination (source: NAU)

Pdf of initial effects $f_{Io}(I_0)$		**Individual risk**	**Societal risk**
Dispersion modelling for	$F^*_D(I_0,x$		

exposure assessment $I(I_0,x,y)$			
Dose response function $F_D(I)$			

Determining the risk integral *RI*, as appropriate measure of social risk (Eq. 9):

$$RI = \int_0^{\infty} x[1 - F_N(x)]dx \qquad (14)$$

It is possible to show that [45]

$$RI = 0.5 \cdot [E^2(N) + \sigma^2(N)] \qquad (15)$$

where $\sigma(N)$ is the standard deviation of the number of fatalities , which is relatively high in comparison to the number of fatalities for low probability cases with high risk of consequences; generally, $\sigma(N) > E(N)$.

At the national level of hazard management, a societal risk can be estimated by limiting the total number of fatalities during the year [49]:

$$E(N_{di}) + k\sigma(N_{di}) < \beta 100 \qquad (16)$$

where $k = 3$ is the index of risk prevention; β is a factor of the current regulatory policy of the risk of danger (for the risk value $R_i = 10^{-4}$ a factor $\beta = 1$; for the lower and upper limits of risk management the factor β is equal to 0,001 and 10 respectively).

For example, for community areas around a large airport with the total number of flights (arrivals, departures) per year of about 200,000, and the probability of accident in flight (according to statistics) equals $5{\cdot}10^{-7}$ and the expected number of accidents is equal to 0.1. The number of expected victims on ground (third party risk victims only—with the exception of passengers and crew) in the event is estimated as 50 people. Because of the huge number of flights, an expected average assessment and standard deviation of the total number of accidents should be very significant [50]:

$$E(N_{di}) = N_{Ai}\, p_{fi}\, N_{d\ ij|f} = 200{,}000 \cdot 5{\cdot}10^{-7} \cdot 50 = 5.0$$

$$\sigma(N_{di}) = (N_{Ai}\, p_{fi})^{1/2}\, N_{dij|f} = (200{,}000 \cdot 5{\cdot}10^{-7})^{1/2} \cdot 50 = 15.8$$

Societal risk and the expected total number of victims of the accident at this airport in accordance with the Eq. 16 will be expected equal to 52.5. Therefore, to comply with existing EU legislation, for example, with Netherlands risk rule (see Figure 11), it is necessary to improve flight safety. A policy factor should be chosen from the condition (Eq. 16) with value $\beta \geq 0.5$. This means that the described situation is not acceptable without public debate [51] (because the value of acceptable risk to a third party will be higher than 10^{-4} per year).

2.1.5 Risk Assessment of Accidental Releases

Accidental release of an impact factor (chemicals, radiation, biological agents or any other hazardous material) may happen at a power plant of specific type for many reasons, one of them being aircraft crash on the plant [42]. Let us assume the plant as a target facility is contained inside one of the grid units, which are defined under the aircraft flight trajectory on ground surface. Let us also assume that a number of events must occur if a release should take place due to impact from aircraft crash on this target facility: the aircraft impacts the ground in the grid unit containing the target (G); the aircraft has a ground-impact accident (I); aircraft strikes the target (T); the facility is damaged by the aircraft (D); a release occurs as a result of an aircraft impact (R). In this case, the release phenomenon is written symbolically as:

$$R \subseteq D \subseteq T \subseteq G \subseteq I, \qquad (17)$$

and the probability of a release as a result of an aircraft accident is the probability of the intersection of all five previously mentioned events $R = R \cap D \cap T \cap G \cap I$, and employing Bayes' rule the release occurs with probability $P(\mathrm{R})$:

$$P(R) = P(R|D) \cdot P(D|T) \cdot P(T|G) \cdot P(G|I) \cdot P(I), \qquad (18)$$

where $P(R|D)$ is the conditional probability of a release of hazardous materials, given damage to the facility; $P(D|T)$ is the conditional probability of damage, given that the target facility is impacted; $P(T|G)$ is the conditional probability that the target facility is impacted, given that the grid unit containing it is impacted; $P(G|I)$ is the conditional probability that the grid unit containing the target facility is impacted, given that the aircraft has a ground-impact accident; and $P(I)$ is the probability that the aircraft has a ground-impact accident.

Eq. 18 defines the probability of the release for one particular aircraft flight with appropriate to the type of aircraft i and type of the flight j along the route k. If we consider a scenario of flights with a total number of flights N_{ijk}, the number of releases $E[Z_R]$ per year should be defined as:

$$E[Z_R] \approx \sum N_{ijk} \cdot P(R)_{ijk} \qquad (19)$$

Let us assume that both the probabilities of damage given impact of the target facility and of a release given damage are equal to 1.0, then Eq. 19 will be simplified to the following formula for annual number of impacts per year:

$$E[Z_I] \approx \sum N_{ijk} \cdot P(T|G)_{ij} \cdot P(G|I)_{ijk} \cdot P(I)_{ij} \qquad (20)$$

Eq. 20 is identical to one in the DOE Standard 3014-96 (Accident Analysis For Aircraft Crash Into Hazardous Facilities) [52] if we assume that the probability of the aircraft impacting the grid unit containing the target facility, given that a ground impact occurs with probability $P(G|I)_{ijk}$, is associated with aircraft crash location conditional probability $f_{ijk}(x,y)$ and the probability $P(T|G)_{ij}$ is represented by effective target area A_{ij} in the DOE Standard.

Keeping in mind the principle of conservative estimates, this mathematical model was used to define the annual probability of an aircraft crash (accounting for civilian and military aircraft) on a power generating unit of a nuclear power plant (within the area of 10,000 m^2) in Ukraine; the calculated probability does not exceed $2 \cdot 10^{-8}$/year. This is less than the criterion 10^{-7}/year and such a small anthropogenic impact does not require an analysis of the consequences [53].

2.1.6 Third Party Risk Model Structure and Public Safety Zones

The approach described in the previous section is used to calculate third party risk around the airports and manage its impact on public safety. As the majority of jet aircraft accidents occur during take-off and landing, people on the ground near airports run a heightened risk of death or serious injury. Two main measures of risk are used in TPR analyses: individual risk and societal risk. The results of TPR models are presented with IR contours (Figure 12), which may be used for the installation of the Public Safety Zones around airports (Figure 13) as a basic component of public safety management [42, 54]. According to the original UK Department for Transport (DfT) definition [8], PSZs are "areas of land at the ends of the runways at the busiest airports, within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing".

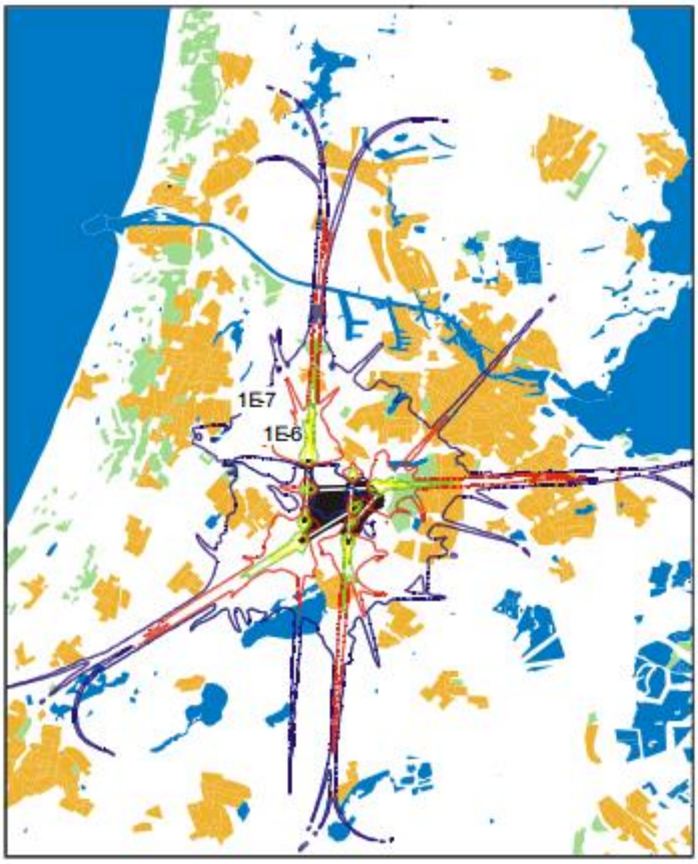


Figure 12 Individual risk contours at the Amsterdam Schiphol Airport [55]

In Figure 12, the risk levels indicated by the contours are 10^{-5}/year, 10^{-6}/year and 10^{-7}/year [55]. The highest risk levels occur in a relatively restricted area close to the runway thresholds [55]. The runways that receive the most traffic show larger individual risk contours than those that are less frequented [55]. On the other hand, the lowest risk levels occur at greater distances from the runways and flight routes [55]. Individual risk contours are used for zoning purposes at Schiphol Airport and if the maximum allowed individual risk levels are exceeded, residential buildings will actually be demolished [55]. The difference in the number of houses exposed to an individual risk level greater than 10^{-6}/year has also been used as a criterion in decision-making with respect to different runway configuration options that would allow an increase in the future capacity of Schiphol Airport [55].

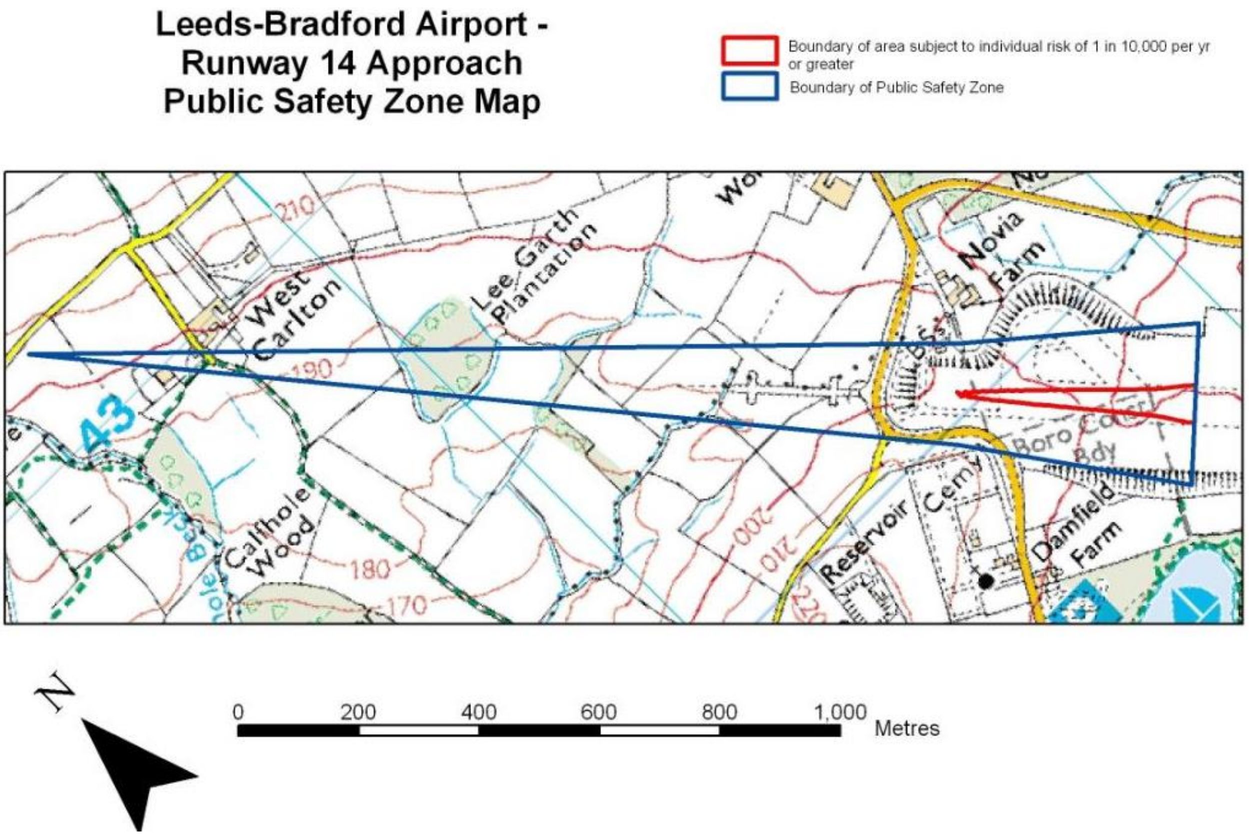


Figure 13 UK Public Safety Zones for a runway [56]

The mathematical formulation of TPR models involves three main components: accident probability $P(I)$, accident crash location conditional probability $P(G|I)_{ijk}$ and accident consequences conditional probability $P(T|G)_{ij}$ [54]. As a consequence, third party risk models rely in general on three main building blocks: **accident probability**, **accident location** and **accident consequences** (Figure 14). The probability of an aircraft accident in the vicinity of an airport is calculated based on the probability of an accident per aircraft movement and the number of movements (landings and take-offs) per year.

In principle, the probability of an accident per movement, or the **accident rate** (AR), can be derived from theoretical models that use the measured probabilities of all the possible causal factors to predict the probability of a crash for a specific type or class of aircraft [43]. The accident rate is not constant over time. Due to a steady improvement in the level of aviation safety, coupled with volume growth, the accident rate has decreased at a diminishing rate over the years. The development of the accident rate over time is derived from a statistical function which can subsequently be used to extrapolate future accident rates. This type of a theoretical approach is problematic as accidents are usually results from a combination of many different causal factors, some of them with unknown probabilities and complex interrelationships [43]. Large differences in safety levels exist between different types of operation and different regions of the world, and a careful data domain definition is required in order to provide airport-specific results. Another alternative method is to calculate crash rates using historical data on accidents and aircraft movements [43].

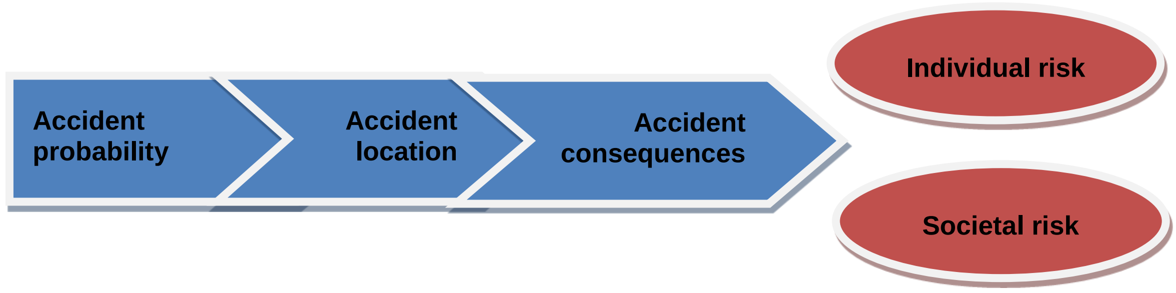


Figure 14 Third party risk calculation, adapted from [57]

Even though the probability of an accident for a given flight is very small, the local risk levels around airports can be more substantial than one might intuitively expect [55]. This stems from the fact that although the probability of an accident per take-off or landing is very small (generally around 1 in one million), major airports concentrate very large numbers of movements, typically several hundred thousand [55]. These observations are confirmed by operational experience as aircraft accidents/incidents involving third parties occur several times a year around the world [55].

The local probability of an accident is not equal at all locations around the airport: the probability is higher in the proximity of the runways than at larger distances from the runways [32]. In addition, the local probability of an accident is dependent on the proximity of the ground tracks followed by arriving and departing aircraft [32]. This risk dependence on location is represented by accident location models. The distribution of accident locations can be modelled using statistical functions taking into consideration the distance to arrival and departure routes or to the runway [32]. By bringing together the accident location model and the accident probability, the local probability of an accident can be calculated at each location in the airport vicinity [32].

With respect to the accident consequences, a person exposed to third party risk in airport vicinity is not only at risk when an aircraft accident occurs at this exact location, but also when the event takes place at a sufficiently close distance [32]. Aircraft accidents have detrimental effects inside a given radius around the epicentres of the impact [32]. The dimensions of the impact area depend on various aircraft and crash-related parameters (for instance, aircraft size, quantity of fuel on board, impact angle, etc.) and on the characteristics of the terrain [32]. The influence of these parameters as well as the impact area and the accident consequences are defined by an accident consequence model [32]. The lethality of an accident is in this respect defined as the probability of being killed inside the impact area [32].

Using data provided by the US National Transportation Safety Board (NTSB) and the 1980 US resident population, [58] estimated the risk of being killed by a crashing airplane on the ground as 0.06 per million per year; this corresponds to a 70-year lifetime risk of 4.2 per million. It was also noted that the risk was above the 1 in 10^{-6} threshold referred to by many regulatory approaches. It was therefore suggested that the risk of being killed by a plane crash could be a valuable risk communication tool, especially with regard to comparisons with chemical and physical hazards. A survey of the accident database of the NTSB provided an overview of civil aviation accidents involving fatalities to people on the ground [59]. This list was first filtered to remove occupational fatalities and fatalities due to voluntary risk exposure (such as taking photographs on the runway)

[59]. Here a groundling accident or groundling crash was defined as an aviation accident causing the death of at least one groundling [60]. The term 'groundling fatality' is usually only used to denote the fatalities on the ground linked to involuntarily exposure to the risk of a non-military aircraft crash [58].

The same risk assessment approach has been used for TPR assessment and safety zone installation for wind farms and wind turbine siting; this topic is mentioned here for the purposes of its general utility. Structural failure may cause a blade to be thrown from a wind turbine and, if the turbine was sited incorrectly, a possible consequence is a third party risk for people living or/and performing activities in the vicinity of wind farms. In this case of wind farms, the safety distance is usually called a setback [61].

2.2 Third Party Risk Models

This section presents different existing TPR models used in airport settings.

2.2.1 US DOE Model

The US has done various assessments on aviation third party risk. Generally, the risk for an individual at a given distance from an airport during the period of a year is assessed [30]. The US National Transportation Safety Board (NTSB) also collects official statistics on fatalities: NTSB estimates the number of ground fatalities by multiplying the number of crashes around airports by the number of fatalities per crash [30]. When extrapolating these estimates to the entire US air transport network, they have shown that the probability of groundling fatalities around airports is $1.3{\cdot}10^{-8}$ [30]. When converted to a 70-year lifetime risk, the risk level equals $9{\cdot}10^{-7}$ [30].

The **DOE-STD-3014-96** standard [52] provides its users with "sufficient information to evaluate and assess the significance of aircraft crash risk on facility safety without expending excessive effort where it is not required". The Aircraft Crash Risk Analysis Methodology (ACRAM) [62] Panel has been formed by the US Department of Energy Office of Defense Programs (DOEDP) for the purpose of developing a standard methodology for determining the risk from aircraft crashes onto DOE ground facilities. Like all transportation risk analyses, the results of aircraft crash risk analysis are highly sensitive to the frequency of the initiating event, or the likelihood of the accident [62]. This stems from the fact that transportation risk analyses, unlike nuclear power plant Probabilistic Risk Assessments (PRAs), do not take into account the mitigating factors of the transportation system that might prevent or mitigate the impacts of the accident [62]. This underlines the importance of accident data, data on operations and characterization of the accident in transportation risk analyses [62]. In the US, the quality and quality of accident data and operational data at least for the general and commercial aviation, are fairly good due thanks to the data collection undertaken by the NTSB and the Federal Aviation Administration (FAA) [62].

To estimate an accident rate, one must obtain the number of accidents that occurred during the performance of some number of operational measures. Operational measures could be defined in terms of number of departures or flights, number of aircraft hours flown or the distance aircraft have flown (in terms of miles, nautical miles, kilometres, etc.). The NTSB defines an aircraft accident as [23] "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage".

For the ACRAM standard [62], the aircraft accidents of interest are those accidents which result in the destruction or substantial (major) damage to the aircraft. The reasoning behind this is that if the aircraft has not suffered destruction or major damage, then the impact forces imposed on the aircraft were probably not very substantial and, therefore, the impact forces imposed on anything the aircraft hit, such as a building, could not have been very substantial. For this reason, an accident involving serious or even fatal injuries, but in without the related destruction or substantial damage to the aircraft itself, does not meet the criteria for an aircraft crash [52]. Based on this definition for commercial aircraft crashes, the crash rate for air carriers and air taxis can be calculated based on the number of aircraft destroyed or substantially damaged per operational measure.

Generally speaking, the DOE Standard provides a robust statistical framework for the assessment of release frequencies of hazardous materials often employed in industrial operations [63]. The formulae for calculating the frequencies of the DOE Standard correspond to the (unstated) underlying six-term expression (Eq. 18) that can be used when estimating the annual number of aircraft-impact-related accidental releases [63]. In particular, aircraft crash frequencies are estimated using a 'four-factor formula' which considers 1) the number of operations, 2) the probability that an aircraft will crash, 3) given a crash, the probability that the aircraft will crash into a 1-square-mile area where the facility is located, and 4) the size of the facility [52]. The four-factor formula used in the DOE standard is implemented in two different ways, depending on the flight phase [52]:

a) For near-airport activities, involving take-offs (I = 1) and landings (I = 3), the four-factor formula is implemented through a combination of site-specific information and data obtained by the user of the standard.
b) For non-airport activities (I = 2), site-specific values for the expected number of crashes per square mile per year in the vicinity of the sites (i.e., the value of the product $NPf(x,y)$) are provided; the four-factor formula is implemented by combining these with the facility effective areas to assess frequencies.

The DOE Standard [52] presents the generally accepted method for estimating the risk from an aircraft crash on a building with radioactive or hazardous materials. The first step in this process is to estimate the frequency of the aircraft crash hitting the building. This step uses the standard 4-factor formula as shown below for facilities located in the airport flight environment.

The mathematical formulation of the four-factor formula is [52]:

$$F = \sum_{i,j,k} N_{ijk} \cdot P_{ijk} \cdot f_{ijk}(x,y) \cdot A_{ij}$$

where

F = estimated annual aircraft crash impact frequency for the facility of interest (number per year);

N_{ijk} = estimated annual number of site-specific aircraft operations (i.e., take-offs, landings, and in-flights) for each applicable summation parameter (number per year);

P = aircraft crash rate (per take-off or landing for near-airport phases and *ijk* per flight for the in-flight (non-airport) phase of operation for each applicable summation parameter;

$f_{ijk}(x,y)$ = aircraft crash location conditional probability (per square mile) given a crash evaluated at the facility location for each applicable summation parameter;

A = the site-specific effective area for the facility of interest that includes *ij* skid and fly-in effective areas (square miles) for each applicable summation parameter, aircraft category or subcategory and flight phase for military aviation;

i = (index for flight phases): *I* = 1, 2, and 3 (take-off, in-flight, and landing);

j = (index for aircraft category or subcategory): *j* = 1, 2, ..., 11;

k = (index for flight source): *k* = 1, 2, ..., *K* (there could be multiple runways, and non-airport operations);

Σ = site-specific summation over flight phase, *i*; aircraft category or subcategory, *j*; and flight source, *k*.

However, the Standard [52] offers a word of warning with respect to the uncertainties: “It should be noted that there is uncertainty associated with the frequency estimates produced using the four-factor formula, caused by the need to model complex physical processes using parameters that are based upon limited historical data.”

The methodology used to estimate the aircraft crash hit frequency generally follows the procedure given by the DOE-STD-3014-96 on Aircraft Crash Analysis [52], and its supporting technical support documents [62, 64]. Accident rate depends strongly on the flight category (e.g. general or commercial aviation, military flight). Table 10 lists the aircraft accident rates (generated from US aircraft crash statistics for the middle of 1990s) per million miles flown as a function of flight category.

Table 10 Aircraft crash rates for specific aircraft type and flight phases [52]

	Take-off	**Landing**
General Aviation		
1. Fixed wing single engine reciprocating	$1.1{\cdot}10^{-5}$	$2.0{\cdot}10^{-5}$
2. Fixed wing multiple engine reciprocating	$9.3{\cdot}10^{-6}$	$2.3{\cdot}10^{-5}$
3. Fixed wing turboprop	$3.5{\cdot}10^{-6}$	$8.3{\cdot}10^{-6}$
4. Fixed wing turbojet	$1.4{\cdot}10^{-6}$	$4.7{\cdot}10^{-6}$
Representative fixed wing	$1.1{\cdot}10^{-5}$	$2.0{\cdot}10^{-5}$

Representative helicopter	$2.5 \cdot 10^{-5}$ (on a per flight basis)	
Commercial aviation		
1. Air carrier	$1.9 \cdot 10^{-7}$	$2.8 \cdot 10^{-7}$
2. Air taxi	$1.0 \cdot 10^{-6}$	$2.3 \cdot 10^{-6}$
Military aviation		
1. Large aircraft	$5.7 \cdot 10^{-7}$	$1.6 \cdot 10^{-6}$
2. Small aircraft	$1.8 \cdot 10^{-6}$	$3.3 \cdot 10^{-6}$

One of the limitations of the model is that it does not take into consideration the spatial variability of risk resulting from changing land use patterns and aircraft flight paths around airports [59]. Figure 15 shows US groundling accident rate for 1970–1999. Aircraft crash location conditional probability for near-airport operations are provided in DOE-STD-3014-96 Tables B-2–B-13 (one example is shown in Table 11) for commercial aviation (which is relevant to both air carriers and air taxis), general aviation (applicable to all fixed wing general aviation aircraft), large military aircraft and small military aircraft.

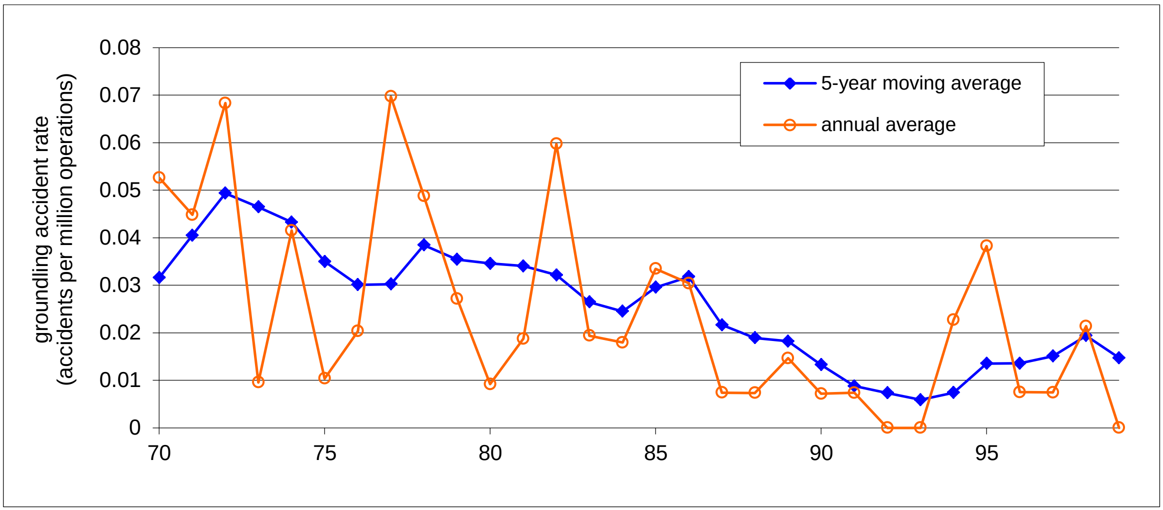


Figure 15 The US groundling accident rate, 1970–1999 [59]

Table 11 Crash location probability *f*(*x*, *y*) for commercial aircraft take-off [52]

X / Y	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10, 11	11, 12
13, 14							1.10E-05	1.10E-05					

12, 13						1.00E-05	1.40E-05	1.30E-05	1.00E-05				
11, 12						1.40E-05	1.70E-05	1.60E-05	1.20E-05				
10, 11					1.10E-05	1.90E-05	2.20E-05	1.90E-05	1.40E-05				
9,10					1.70E-05	2.60E-05	2.80E-05	2.40E-05	1.60E-05				
8,9				1.10E-05	2.60E-05	3.70E-05	3.70E-05	2.90E-05	1.90E-05	1.10E-05			
7,8				2.00E-05	4.00E-05	5.30E-05	5.00E-05	3.70E-05	2.30E-05	1.30E-05			
6,7			1.10E-05	3.70E-05	6.60E-05	7.80E-05	6.80E-05	4.80E-05	2.90E-05	1.60E-05			
5,6			2.60E-05	7.30E-05	1.10E-04	1.20E-04	9.60E-05	6.30E-05	3.60E-05	1.90E-05			
4,5		1.10E-05	6.80E-05	1.60E-04	2.10E-04	1.90E-04	1.40E-04	8.60E-05	4.70E-05	2.40E-05	1.10E-05		
3,4		4.50E-05	2.00E-04	3.70E-04	4.10E-04	3.30E-04	2.20E-04	1.20E-04	6.40E-05	3.10E-05	1.40E-05		
2,3		2.30E-04	7.30E-04	1.00E-03	9.20E-04	6.40E-04	3.70E-04	1.90E-04	9.20E-05	4.20E-05	1.90E-05		
1,2	1.00E-04	1.80E-03	3.90E-03	3.80E-03	2.60E-03	1.50E-03	7.50E-04	3.50E-04	1.50E-04	6.50E-05	2.80E-05	1.20E-05	
0,1	2.60E-02	1.80E-01	1.50E-01	7.10E-02	2.80E-02	1.10E-02	3.90E-03	1.50E-03	5.50E-04	2.10E-04	8.00E-05	3.10E-05	1.20E-05
-1,0	2.60E-02	1.80E-01	1.50E-01	7.10E-02	2.80E-02	1.10E-02	3.90E-03	1.50E-03	5.50E-04	2.10E-04	8.00E-05	3.10E-05	1.20E-05
-2,-1	1.00E-04	1.80E-03	3.90E-03	3.80E-03	2.60E-03	1.50E-03	7.50E-04	3.50E-04	1.50E-04	6.50E-05	2.80E-05	1.20E-05	
-3,-2		2.30E-04	7.30E-04	1.00E-03	9.20E-04	6.40E-04	3.70E-04	1.90E-04	9.20E-05	4.20E-05	1.90E-05		
-4,-3		4.50E-05	2.00E-04	3.70E-04	4.10E-04	3.30E-04	2.20E-04	1.20E-04	6.40E-05	3.10E-05	1.40E-05		
-5,-4		1.10E-05	6.80E-05	1.60E-04	2.10E-04	1.90E-04	1.40E-04	8.60E-05	4.70E-05	2.40E-05	1.10E-05		
-6,-5			2.60E-05	7.30E-05	1.10E-04	1.20E-04	9.60E-05	6.30E-05	3.60E-05	1.90E-05			
-7,-6			1.10E-05	3.70E-05	6.60E-05	7.80E-05	6.80E-05	4.80E-05	2.90E-05	1.60E-05			
-8,-7				2.00E-05	4.00E-05	5.30E-05	5.00E-05	3.70E-05	2.30E-05	1.30E-05			
-9,-8				1.10E-05	2.60E-05	3.70E-05	3.70E-05	2.90E-05	1.90E-05	1.10E-05			
-10, -9					1.70E-05	2.60E-05	2.80E-05	2.40E-05	1.60E-05				
-11, -10					1.10E-05	1.90E-05	2.20E-05	1.90E-05	1.40E-05				
-12, -11						1.40E-05	1.70E-05	1.60E-05	1.20E-05				
-13, -12						1.00E-05	1.40E-05	1.30E-05	1.00E-05				
-14, -13							1.10E-05	1.10E-05					

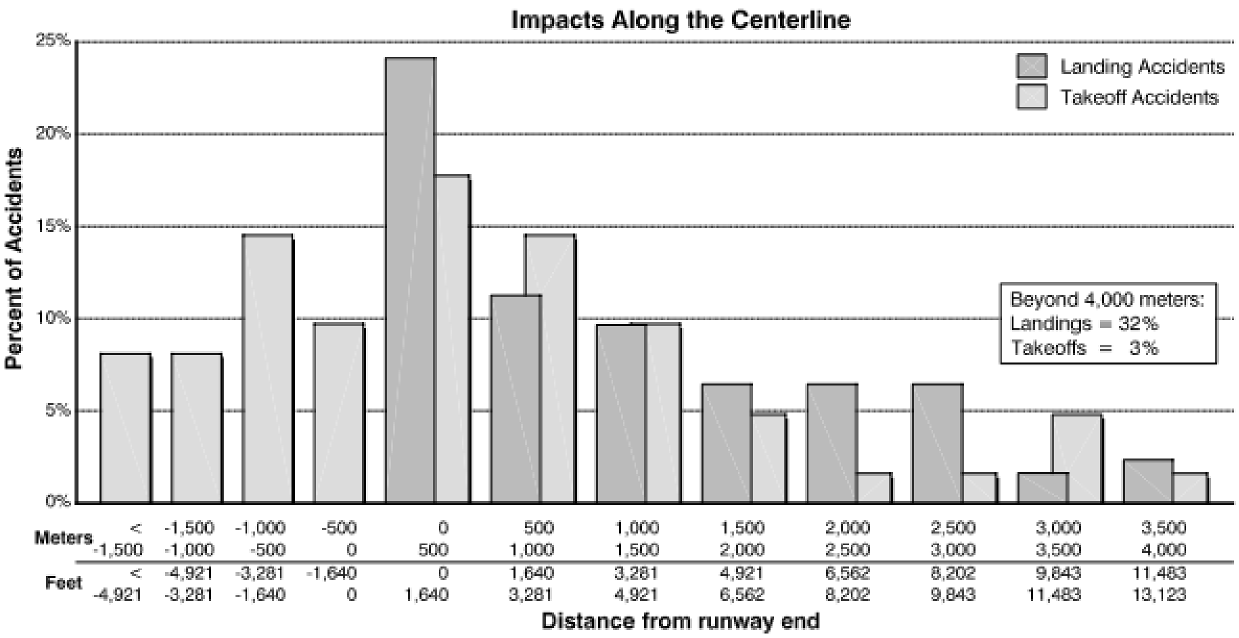
In the DOE Standard, the crash location probability values represent the conditional probability that, in the case of a crash, the crash impacts a given area of one square mile [52]. The facility's coordinates (or Cartesian distances) can be used to identify a bin in the DOE-STD-3014-96 Tables

B-2 through B-13 of in order to find the probability value of the corresponding crash location [52]. The take-off and landing crash location probability values are symmetric with respect to the *x* axis ($f(x,y) = f(x,-y)$) representing the extended runway centreline [52]. As could be expected, the crash locations are also concentrated along the *x* axis as commercial aircraft are always follow instrument flight rules and a precise directional approach during take-off and landing operations [52]. According to the conventions of the coordinate system used, all take-off crash locations (beyond the end of the runway) are in the positive *x* axis [52]. On the other hand, landing crashes have a negative *x* distance value as the aircraft approaches the runway from a negative *x* value during the landing and heads towards the origin [52]. The crash location classification and distances in the NTSB database were used to estimate the probability values [52].

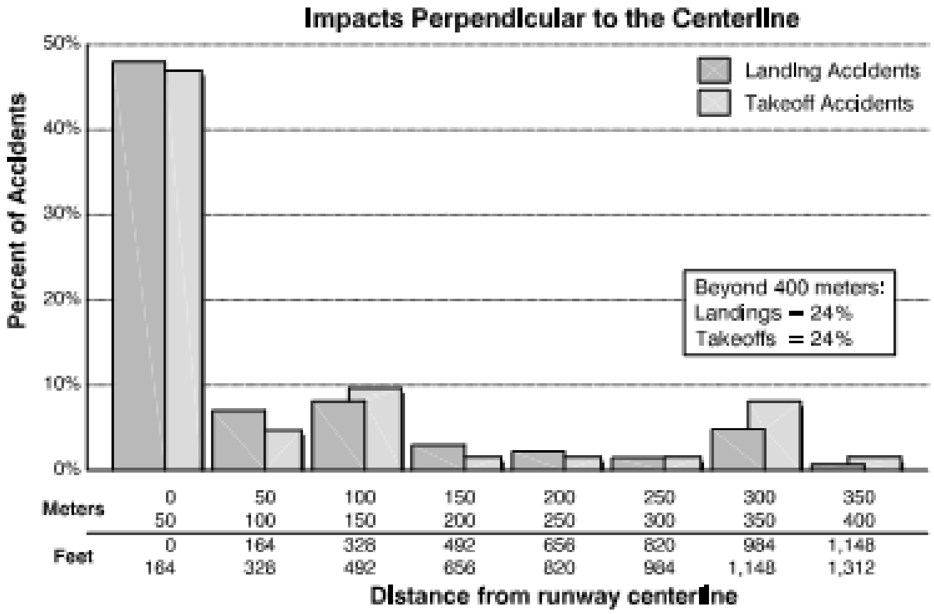
The data shows that over two-thirds of accidents in both general (68%) and commercial (67%) aviation take place at airports [65]. Only 3% of general aviation and 7% of commercial aviation accidents are en-route accidents or occur more than 5 miles from an airport [65]. The remaining 29% of general aviation and 26% of commercial aviation accidents are classified as airport-vicinity accidents (this includes potentially some en-route accidents that take place less than 5 miles from an airport) [65]. Another fairly detailed set of data on commercial aircraft accident locations was compiled by researchers in the UK [43]. In the UK report, two separate graphs are used to display the runway proximity from landing and take-off accidents in two dimensions: 1) distance from the runway end and 2) distance from the extended runway centreline (Figure 16) [65]. This was a new step forward in more accurate assessment of the location model for the aircraft crashes in airport vicinity:

$$f(x, y) = f_y(y) \cdot f_{x/y}(x, y) \qquad (22)$$

Notably, the TPR model defined by the California Airport Land Use Planning Handbook [65] is based on an axial probability density function.



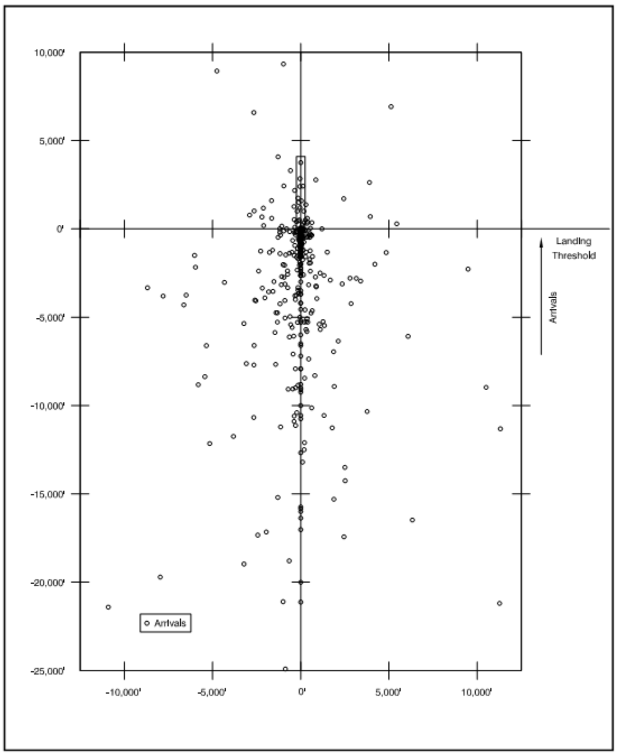
a)



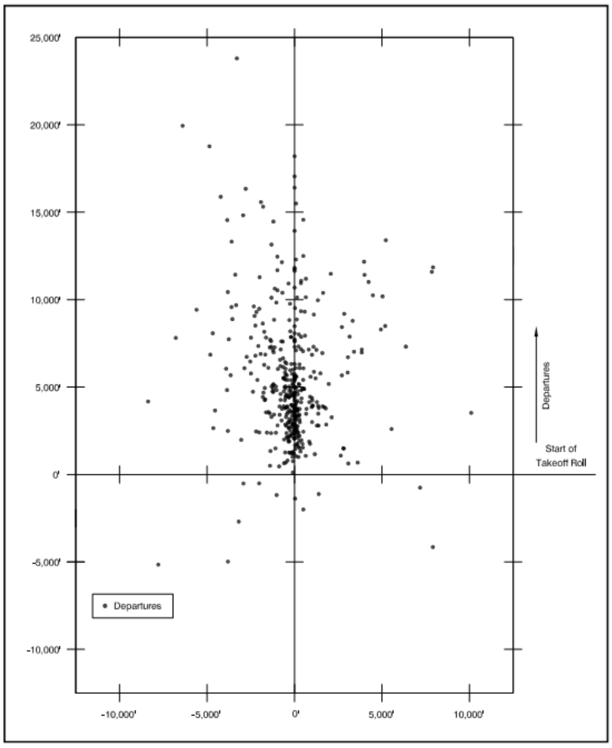
b)

Figure 16 Separate distributions of crashes: a) along the runway axis, $f_y(y)$; b) perpendicular to the runway axis, $f_{x/y}(x, y)$ [65]

In [65], it was also found that the spatial distributions of aircraft accidents at arrival and departure are quite different (illustrated in Figure 17).



a)



b)

Figure 17 Spatial distribution of aircraft accidents at a) arrival and b) departure [65]

2.2.2 NATS Model (UK and Ireland)

The importance of risk around airports was recognised in the UK in the 1950s and Public Safety Zones (PSZs) were introduced in 1958 following the recommendations of the Committee on Safeguarding Policy [43, 66, 67]. A PSZ was defined as an area at the end of a runway where the development of land is restricted if it will likely lead to an increase in the "number of persons residing, working or congregating" there [8]. The Committee of Safeguarding Policy originally suggested a longitudinal limit of 4,500 feet (or approximately 1,370 m) for the PSZs [60]. This was based on the (subjective) criteria choice 65% of landing and take-off crashes take place within the PSZ area [60].

In the 1990s, the method for TPR assessment around airports and definition of appropriate risk assessment criteria was presented in the "Third Party Risk near Airports and Public Safety Zone Policy" report [43] of the UK Department for Transport. Developments in the UK during the 1990s were influenced by the El Al crash, as would be expected. Manchester Airport's proposal for a second runway was considered by a Public Inquiry, and third party safety became a major issue. Third party safety was one of the elements he considered in arriving at an overall view, which necessitated balancing the benefits against the disadvantages of the proposal. The Inspector's overall view on this occasion was that the benefits were very significant and that the runway should be built. The developed method [43] was based on the creation of aircraft categories by manufacturer, country of origin, aircraft type (large, small, jet, turboprop) and operations type (passenger, cargo) [30]. Aircraft crash location and consequences were based on risk contours modelled using limited data sample [30]. Criteria for acceptable risk levels were established using cost-benefit analysis method [30]. In the UK study, the estimated risk remained under 10^{-4} per year, or in line with the tolerable risk level at nuclear and chemical plants while the limit of 10^{-5} was imposed on new buildings [30].

The UK National Air Traffic Service (NATS) model [68] for individual risk calculations gives the probability that an individual living permanently at a given location near an airport will be killed by an aircraft crash in a given year [69]. The NATS model exploits statistical data on crash frequency, location, impact area and accident consequences [69]. The original version of the model could only calculate the risk in a simple single runway in a runway coordinate system but using a coordinate transformation, it is also possible to perform all calculation in the same coordinate system [69]. In this case, the risk levels of different runways are added to obtain the total individual risk levels at the airport level [69].

Considerable work has gone into ensuring the robustness of the method including:

- The development of crash frequencies that distinguish between different aircraft types and/or operations. For example, Western jets are distinguished from Eastern jets and cargo operations are separated from passenger operations. This enables the specific traffic mix at an airport to be represented accurately (Figure 18, Table 12). Note that the Executive Jets crash rate detailed in [70] is significantly different from that in previous NATS and DETR reports [43].
- The crash location model is based on 559 accidents—this large number reduces statistical uncertainties surrounding this element of the analysis [68].

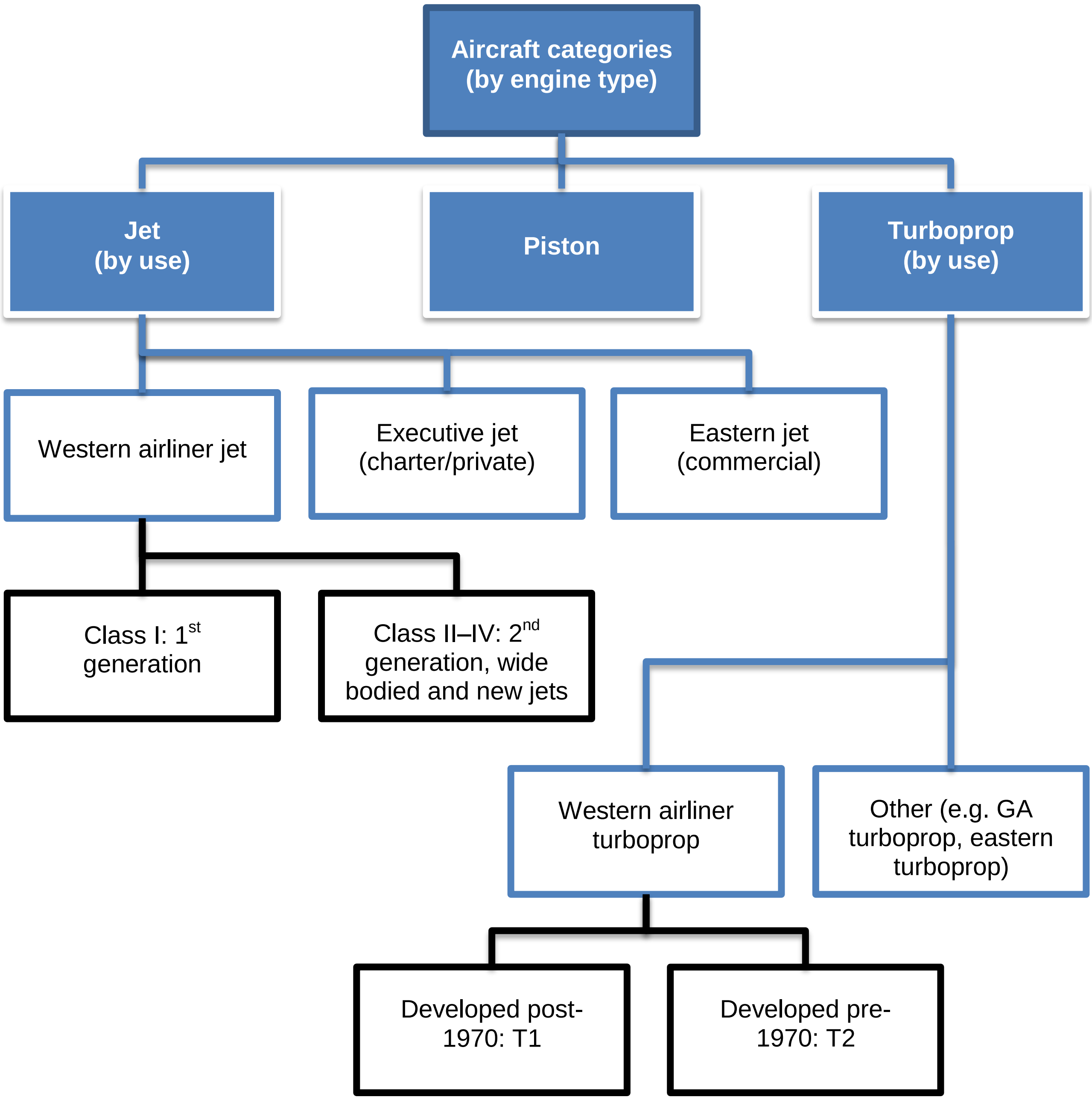


Figure 18 Aircraft type grouping for aircraft crash rates assessment, adapted from [43]

Table 12 First world aircraft crash rates by aircraft class [43]

Aircraft class	Crash rate (per 10^6 movements)

Class I jets	1.114
Class II-IV jets	0.148
Eastern jets	0.930
Executive jets	0.270
Turboprops T1	0.270
Turboprops T2	0.733
Turboprops (unclassified)	0.733
Miscellaneous, other commercial and piston engine	3.000

The pdfs for a given grid point and type of accident (Figure 19) are probability density functions in the same form as (22):

$f(x, y) = f_y(y) \cdot f_{x/y}(x, y)$

where $f_y(y)$ is a function representing the longitudinal location along the direction of the extended runway centreline, $f_{x/y}(x, y)$ is the lateral distribution perpendicular to the runway centreline. The function $f_y(y)$ is derived from y coordinate data. The function $f_{x/y}(x, y)$ is derived from x coordinate data, for which the corresponding y coordinate is known.

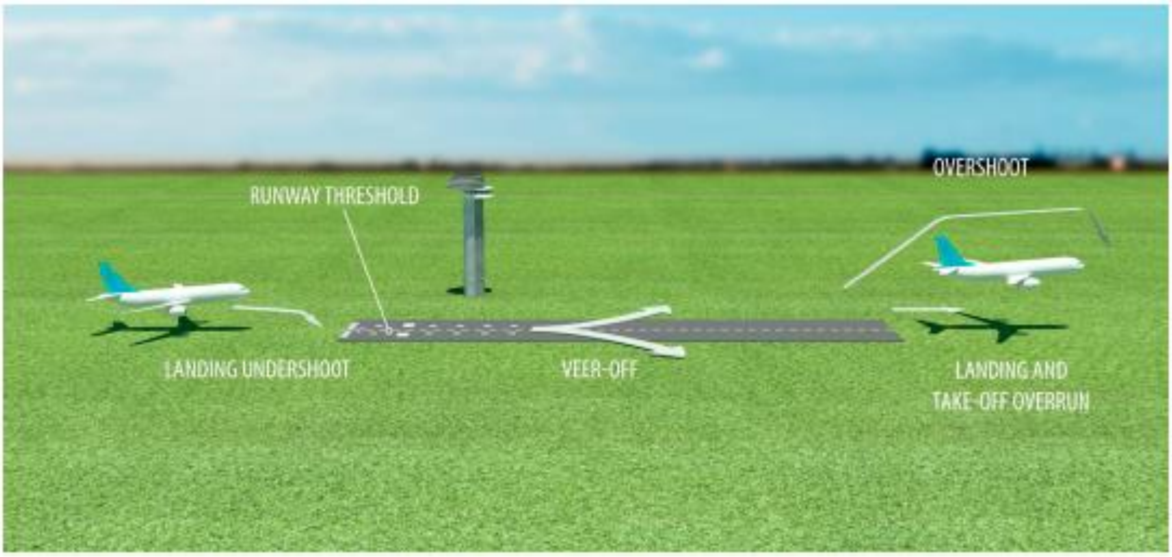


Figure 19 Accident types for landing and take-off at an airport [57]

In the NATS report, the proportions of the four types of crash were estimated as follows [70]:

- take-off crashes from flight, 20%
- take-off overruns, 8%
- landing crashes from flight, 52% and
- landing overruns, 20%.

The pdfs are based on the Gamma and Weibull distributions. The Gamma distribution for parameters *z*, *α* and *β* is [70]:

$$f(z,\alpha,\beta)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}z^{\alpha-1}\exp\left[-\left(\frac{z}{\beta}\right)\right] \quad (23)$$

The Weibull distribution for parameters *z*, *α* and *β* is:

$$f(z,\alpha,\beta)=\frac{\alpha}{\beta^{\alpha}}z^{\alpha-1}\exp\left[-\left(\frac{z}{\beta}\right)^{\alpha}\right] \quad (24)$$

For take-off overruns beyond the departure end of the runway (*y* > 0), the probability density function of the wreckage location is calculated as [70]:

for *y* > 0

$$f_{y}^{tow}(y)=p\frac{\alpha}{\beta^{\alpha}}y^{\alpha-1}\exp\left[-\left(\frac{y}{\beta}\right)^{\alpha}\right]$$

where *α* = 1.336, *β* = 342.6, *p* = 0.761 (fraction of take-off overruns with *y* > 0);

for *y* > 0, *x* ≠ 0

$$f_{x/y}^{tow}(x,y)=\frac{1}{2}\frac{\alpha}{\beta^{\alpha}}y^{\alpha c}|x|^{\alpha-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\alpha}y^{\alpha c}\right]$$

where *c* = 0.354, *α* = 0.684, *β* = 74.37.

For landing overruns (*y* > 0), the probability density function of the wreckage location was calculated as [70]:

for *y* > 0

$$f_{y}^{low}(y)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}y^{\alpha-1}\exp\left[-\left(\frac{y}{\beta}\right)\right]$$

where *α* = 4.906, *β* = 392.1,

and

$y > 0$, $x \neq 0$

$$f_{x/y}^{low}(x,y)=\frac{1}{2}\frac{\alpha}{\beta^{\alpha}}y^{\alpha c}|x|^{\alpha-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\alpha}y^{\alpha c}\right]$$

where c = 0.778, α = 0.831, β = 10313.

The probability density function of the impact location for take-off crashes from flight (non-overrun crashes) was calculated as [70]:

for $y > 0$

$$f_{y}^{tni}(y)=p\frac{\alpha}{\beta^{\alpha}}y^{\alpha-1}\exp\left[-\left(\frac{y}{\beta}\right)^{\alpha}\right]$$

where α = 0.687, β = 2863.7, p = 0.630 (fraction of take-off crashes with $y > 0$);

for $y < 0$

$$f_{y}^{tni}(y)=(1-p)\frac{1}{\beta^{\alpha}\Gamma(\alpha)}|y|^{\alpha-1}\exp\left[-\left(\frac{|y|}{\beta}\right)\right]$$

where α = 1.968, β = 570.62, p = 0.630 (fraction of take-off crashes with $y > 0$);

for $y \neq 0$, $x \neq 0$

$$f_{x/y}^{tni}(x,y)=\frac{1}{2}\frac{\alpha}{\beta^{\alpha}}|y|^{\alpha c}|x|^{\alpha-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\alpha}|y|^{\alpha c}\right]$$

c = -0.617 for $y > 0$; α = 0.668 for $y > 0$; β = 4.705 for $y > 0$;

and

c = 0.211 for $y < 0$; α = 0.485 for $y < 0$; β = 589.91 for $y < 0$.

The probability density function of the impact location for landing crashes from flight (non-overrun crashes) after the runway threshold was calculated as [70]:

for $y > 0$

$$f_{y}^{lni}(y)=p\frac{1}{\beta^{\alpha}\Gamma(\alpha)}y^{\alpha-1}\exp\left[-\left(\frac{y}{\beta}\right)\right]$$

where α = 0.283, β = 6441.9, p = 0.307 (fraction of landing crashes with impact $y > 0$), and for $y < 0$

$$f_y^{\ln i}(y) = (1-p)\frac{\alpha}{\beta^{\alpha}}|y|^{\alpha-1}\exp\left[-\left(\frac{|y|}{\beta}\right)^{\alpha}\right]$$

where $\alpha = 0.567$, $\beta = 3609.0$, and

for $y \neq 0$, $x \neq 0$

$$f_{x/y}^{\ln i}(x,y) = \frac{1}{2}\frac{\alpha}{\beta^{\alpha}}|y|^{\alpha c}|x|^{\alpha-1}\exp\left[-\left(\frac{|x|}{\beta}\right)^{\alpha}|y|^{\alpha c}\right]$$

where c = -0.877 for $y > 0$; α = 0.427 for $y > 0$; β = 0.213 for $y > 0$ and c = -0.952 for $y < 0$; α = 0.507 for $y < 0$; β = 0.158 for $y < 0$.

For light aircraft, the probability density function is defined in the NATS report [70] as follows [70]:

$$f_{<4.0}(r,\theta) = 0.08\exp(-r/2.5)\exp(-3\theta/\pi) \quad (25)$$

where the main parameters are shown in Figure 20.

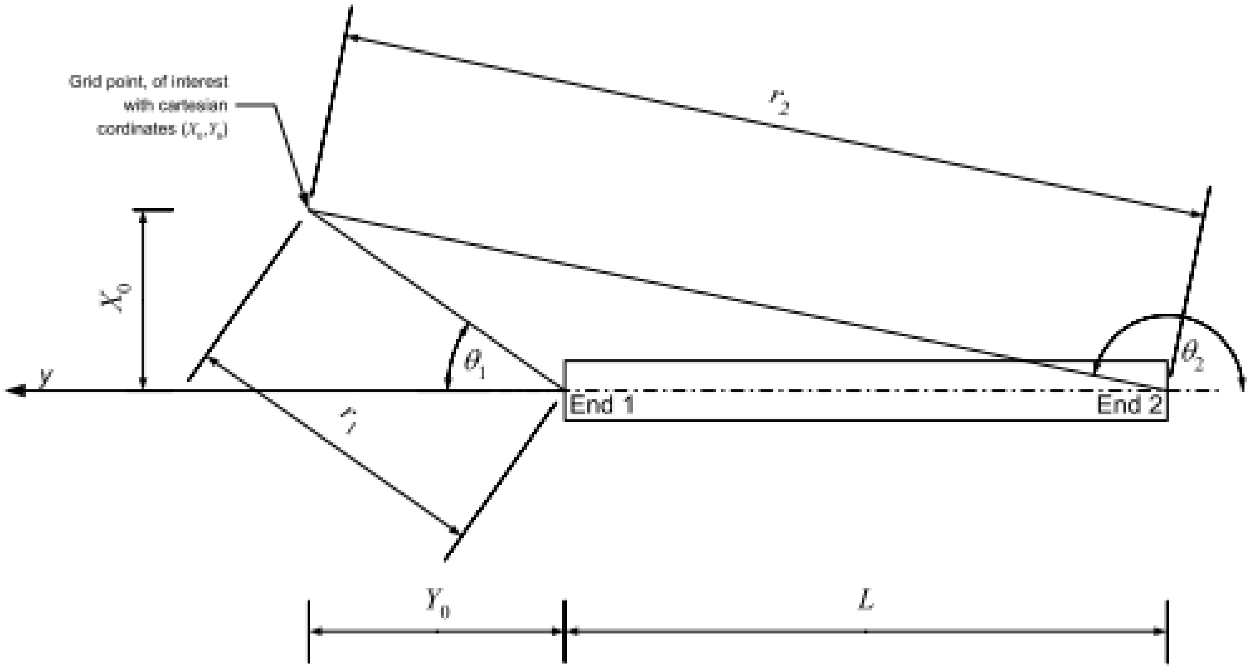


Figure 20 Geometry for probability density function definition for light aircraft [70]

The crash consequence modelling is based on 156 accidents—again, this large number improves the level of confidence associated with this element [68]. The destroyed area is calculated from the following relationship detailed in the NATS report [70]:

$$\ln(A_{destroyed}) = -6.16 + 0.474 \ln(M) \quad (26)$$

where $A_{destroyed}$ = area destroyed (hectare), $M - M_{TWA}$ (kg)

A constrained cost-benefit analysis was used to determine criteria for risk tolerability; the conclusion was that third parties should not be exposed to risks over 10^{-4} per year [44]. This is consistent with the level used to judge the tolerability of nuclear power plants, chemical plants, etc. If there are houses within this contour, it was recommended that the airport operator should buy them up [8].

Outside this contour, DETR consultants looked at the economic costs of restricting land development around airports and the benefits in terms of limiting risk. They concluded that new buildings should not be allowed within a 10^{-5} contour [8]. This effectively produces the recommended dimensions for the new PSZs using the simplified assessment techniques noted above [44]. As well as being used to develop new PSZs at UK airports, the NATS method has also been used to calculate the changes in risk that may arise from an airport development.

2.2.3 NLR Model (Netherlands)

In Dutch risk policy, two points of view are considered: the point of view of the individual, who decides to undertake an activity while weighing its risks against its direct and indirect personal benefits, and the point of view of the society, i.e. whether an activity is acceptable in terms of its risk–benefit trade-off for the general population [49]. However, in practice the risk levels of many activities, such as the Schiphol Airport, LPG stations and road safety, are above both individual and societal risk criteria [49]. This has resulted in the definition of three risk criteria: a personally (individually) acceptable level of risk, a socially acceptable level of risk and an economically acceptable level of risk [49]. It is recommended in [49] that the most stringent of these three criteria should be used as a basis for technical advice when making risk-related policy decisions.

In Dutch risk policy, risk is defined rather narrowly as the Probability of Loss of Life [49] although the concept of 'risk' is multi-dimensional and characterized by both technical and non-technical facets [49]. While in a technical approach, risk is determined by measurement and calculation, a non-technical approach to risk attributes more value to risk perception [49]. Risk perception deals with the risk judgments of people with respect to hazardous activities and technologies [49]. In the technical risk analysis approach, risk is often defined as "the product of the probability of an event and its (monetary) consequences" [49]. The probabilities and consequences of an event are used to calculate a risk number (see Eq. 4), which can be used to advise decision-makers [49].

Generally speaking, the probability of being killed in normal day-to-day activities such as driving or working in a factory appears is about two orders of magnitude lower than the overall probability of dying [49]. The highest risk levels can be found in voluntary activities such as mountaineering (Figure 21) [49]. This confirms that the public tolerance is about 1000 times greater for voluntary risks than for risks from involuntary activities [49, 71].

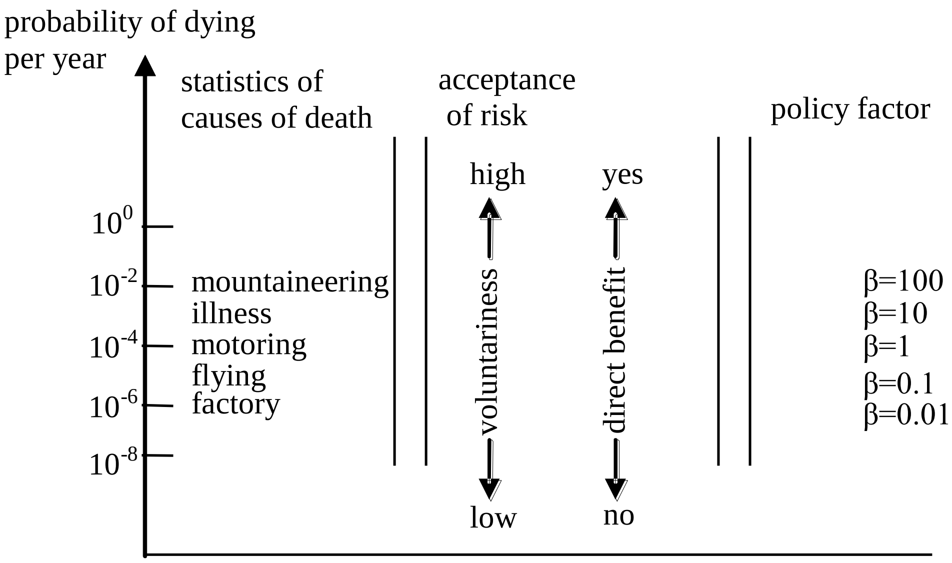


Figure 21 Personal risk in Western countries [49]

Although there has been a slightly downward trend due to technical progress, existing death risks have remained relatively stable and consistent [49]. Therefore, they might be used as a basis for decision-making with regard to the personally acceptable probability of failure [49]:

$$P_{fi} = \frac{\beta_i \cdot 10^{-4}}{P_{d|fi}} \qquad (27)$$

where P_{fi} is the yearly probability of dying and $P_{d|fi}$ denotes the probability of being killed in an accident. In this formula, the policy factor β_i varies according to the degree of voluntariness with which an activity *i* is undertaken and the perceived benefit [49]. The values of the policy factor range from 100 for complete freedom of choice like in mountaineering (P_{fi},= 0.1 = $100 \cdot 10^{-4}/10^{-1}$) to 0.01 for an risk imposed on a person without any perceived direct benefit (Table 13) [49].

Table 13 Value of the policy factor β_i as a function of voluntary character and benefit of an activity [49]

β_i	Voluntary	Direct benefit	Example
100	Completely voluntary	Direct benefit	Mountaineering
10	Voluntary	Direct benefit	Motorbiking
1.0	Neutral	Direct benefit	Car driving
0.1	Involuntary	Some benefit	Factory

0.01	Involuntary	No benefit	LPG station

Dutch TPR modelling has focused on the risk around Amsterdam Schiphol Airport following the continuous expansion of the airport near populated areas and the growth of the residential areas closer to the airport [30, 72]. However, the main catalyst for third party risk studies was the crash of the El Al freighter in the Bijlmermeer district of Amsterdam in 1992 leading to 43 fatalities (39 residents in addition to the four crew members) [30, 72].

A TPR model has been developed by the National Aerospace Laboratory (NLR) of the Netherlands. The need for such a model arose in the last decades as the amount of air traffic increased as well as the awareness of the population that they were exposed to risks caused by the traffic. The NLR third party risk model is used to evaluate the risk for people living and working close to an airport [73]. Third party risk studies are to be conducted in order to determine the impacts of new or changed air routes and runway infrastructure for risk in the airport surroundings [73]. In the Netherlands, three measures of third party risk have been defined: individual risk, societal risk and the risk of potential loss of life over a year [30, 74]. To determine IR and SR levels, the probability densities and the sizes of crash areas need to be calculated first [73]. The calculations are performed by three sub-models (Figure 22, Figure 23): the Accident Probability Model, the Accident Location Model and the Accident Consequence Model [73]. The NLR model has different formulations for large airports (the Schiphol model) and regional airports (< 150,000 movements per year) [57]. Lately, a third party risk model has also been developed for in-land heliports [57].

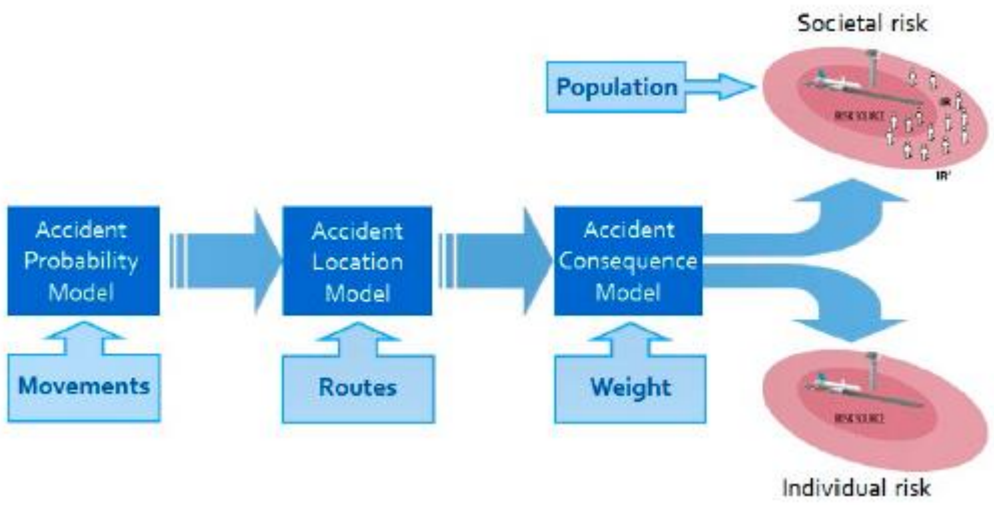


Figure 22 Flow chart of the NLR TPR sub-models [57]

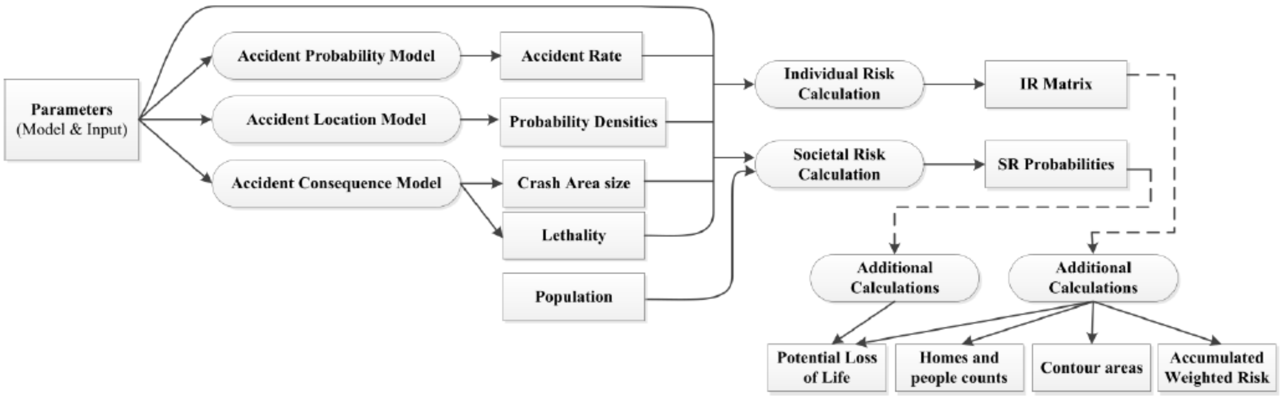


Figure 23 Design of the NLR TPR model (data is represented by rectangles and processes by rounded rectangles) [75]

The external safety requirements for Schiphol Airport have been made part of Dutch law [55]. Based on the anticipated volume of air traffic and its characteristics, NLR performs third party risk for Schiphol Airport [55]. The NLR method developed to calculate third party risk around airports consists of the following elements [55]: 1) the accident probability model, which calculates the probability of an aircraft accident in the vicinity of an airport depending on the crash rate (accident probability) per aircraft movement (landing or take-off) and the volume of airport traffic (aircraft movements) per year; 2) the accident location probability model, which calculates the probability of a given location becoming an accident scene depending on its position relative to airport runways and the incoming and outgoing aircraft trajectories; and 3) the accident consequence model, which determines the impact area and lethality of the effects of an accident. The output from these three sub-models is combined to calculate the probability of an accident at each location within the area surrounding a given airport.

The Accident Probability Model selects the accident rate (AR) of an accident type (overrun, undershoot or veer-off) based on a few parameters: the aircraft's generation, maximum take-off weight, flight type (cargo flight, passenger flight or business jet) and flight phase (whether the accident takes place during take-off or landing) [75]. The number of accidents for each of the three generations and for the six accident types (take-off overrun, landing overrun, take-off overshoot, landing undershoot, take-off veer-off, and landing veer-off) for the Schiphol model are given in Table 14. For regional airports, different accident rate values are used and the operations are further divided into passenger, cargo, business and jet categories (Table 15) [76]. The accident rate selection scheme is represented in Table 16 and accident location scheme in Table 17. The analysis of veer-offs is not supported by the standard NLR third party risk model [75].

Table 14 Accident rates per 10^6 flights by accident type for the Schiphol model [76, 77]

Accident type	Generation	Operation type and weight		
		All > 5,700 kg	General aviation 1,500–5,700 kg	General aviation < 1,500 kg
Landing overrun	1	0.251		

	2	0.200		
	3	0.146*		
Landing undershoot	1	0.753		
	2	0.145		
	3	0.073*		
Landing veer-off	1	0.879		
	2	0.181		
	3	0.093		
Take-off overrun	1	0.377		
	2	0.109		
	3	0.012*		
Take-off undershoot	1	0.126		
	2	0.046		
	3	0.037*		
Take-off veer-off	1	0.377		
	2 & 3	0.034		
Landing (all accident types)			5.53	5.53
Take-off (all accident types)			1.58	1.58

*Values updated in 2010 (source: [76])

Table 15 Accident rates per 10^6 flights by accident type for the regional airport model [76]

Accident type	Generation	Operation type and weight				
		Passenger > 5,700 kg	Cargo > 5,700 kg	Business jet > 5,700 kg	General aviation 1,500–5,700 kg	General aviation < 1,500 kg
Landing overrun	1	3.66	4.81	4.58		
	2	0.90	1.45	4.58		
	3	0.73	0.41	4.58		
Landing undershoot	1	5.24	4.81	4.58		
	2	1.95	1.45	4.58		
	3	0.17	0.41	4.58		
Landing veer-off	1	n.d.	n.d.	n.d.		
	2	n.d.	n.d.	n.d.		
	3	n.d.	n.d.	n.d.		
Take-off overrun	1	1.05	2.89	1.83		
	2	0.066	0.87	1.83		
	3	0.066	0.25	1.83		
Take-off undershoot	1	0.029	3.85	0.029		
	2	0.029	1.16	0.029		
	3	0.029	0.33	0.029		
Take-off	1	n.d.	n.d.	n.d.		

veer-off	2	n.d.	n.d.	n.d.		
	3	n.d.	n.d.	n.d.		
Landing (all accident types)					5.53	5.53
Take-off (all accident types)					1.58	1.58

n.d. = not defined

Table 16 Selection scheme of the Accident Probability Model [75, 78]

Maximum take-off weight (MTOW)	Operation-type	Generation	Flight phase	Accident rate
Light (MTOW < 5.700 kg)	n.d.	n.d.	Start	AR
			Landing	AR
Heavy (MTOW > 5.700 kg)	Business jet	n.d.	Start	$AR^{overrun}$ $AR^{undershoot}$
			Landing	$AR^{overrun}$ $AR^{undershoot}$
	Cargo	n.d.	Start	$AR^{overrun}$ $AR^{undershoot}$
			Landing	$AR^{overrun}$ $AR^{undershoot}$
	Passenger	1	Start	$AR^{overrun}$ $AR^{undershoot}$
			Landing	$AR^{overrun}$ $AR^{undershoot}$

		2	Start	$AR^{overrun}$ $AR^{undershoot}$
			Landing	$AR^{overrun}$ $AR^{undershoot}$
		3	Start	$AR^{overrun}$ $AR^{undershoot}$
			Landing	$AR^{overrun}$ $AR^{undershoot}$

Table 17 Selection scheme of the Accident Location Model [75, 78]

Maximum take-off weight (MTOW)	Flight phase	Accident type	Route dependent	Runway dependent
Light (MTOW < 5.700 kg)	Start	-	$f_{route}^{take-off\ shoot}(s,t)$	-
	Landing	-	$f_{route}^{landing\ shoot}(s,t)$	$f_{runway}^{landing\ run}(u,v)$
Heavy (MTOW > 5.700 kg)	Start	(over)shoot	$f_{route}^{take-off\ shoot}(s,t)$	$f_{runway}^{take-off\ shoot}(u,v)$
		(over)run	-	$f_{runway}^{take-offg\ run}(u,v)$
	Landing	(over)shoot	$f_{route}^{landing\ shoot}(s,t)$	$f_{runway}^{landing\ shoot}(u,v)$
		(over)run	-	$f_{runway}^{landing\ run}(u,v)$

The output of the Accident Location Model is a probability density matrix calculated for each accident rate selected in the Accident Probability Model by using one or more distribution functions (Table 18) [75]. The probability density matrix is a grid containing a probability density value for each cell [75]. The probability density in a cell represents the probability that, in the case of an accident, the crash will occur in that given cell [75]. The probability density values depend notably on the distance to the flight path or the runway threshold [75]. The distribution function is selected based on the aircraft's maximum take-off weight, the flight phase (take-off or landing) and the type of accident (overrun or undershoot) [75]. Furthermore, the choice of the distribution function depends on whether the probability density matrix should be calculated with respect to the flight route or to the runway [75, 78].

Table 18 Distribution functions used for the Accident Location Model [77]

Parameters of the overshoot distribution (n_{total} = 106, $n_{y=0}$ = 68)					
Distribution		Function	Parameters	D_{KS}	D_c
Longitudinal	$y = 0$	Weibull	η, β	0.0887	0.1649
	$y \neq 0$	Weibull	η, β	0.0884	0.2206
Lateral	$y = 0$	Gauss	σ_0, σ_1		
	$y \neq 0$	Gen. Laplace	a_0, a_1, b	0.0786	0.2206
Weight factor		p			

Parameters of the take-off overrun distribution (n_{total} = 103, $n_{y=0}$ = 72)					
Distribution		Function	Parameters	D_{KS}	D_c
Longitudinal		Weibull	η, β	0.0563	0.1340
Lateral	$y = 0$	Gauss	σ_0		
	$y \neq 0$	Gen. Laplace	a_0, a_1, b	0.0918	0.2458
Weight factor		p			

Parameters of the undershoot distribution (n_{total} = 435, $n_{y=0}$ = 353)					
Distribution		Function	Parameters	D_{KS}	D_c
Longitudinal	$y = 0$	Weibull	η, β	0.0494	0.0724
	$y \neq 0$	Weibull	η, β	0.0471	0.1502

Lateral	$y = 0$	Gauss	σ_0, σ_1		
	$y \neq 0$	Gen. Laplace	a_0, a_1, b	0.0449	0.1422
Weight factor		p			

Parameters of the landing overrun distribution (n_{total} = 255, $n_{y=0}$ = 203)					
Distribution		Function	Parameters	D_{KS}	D_c
Longitudinal		Weibull	η, β	η, β	0.0852
Lateral	$y = 0$	Gauss	σ_0		
	$y \neq 0$	Gen. Laplace	a_0, a_1, b	0.0978	0.1807
Weight factor		p			

The Accident Consequence Model determines the: crash area and lethality [75]. The size of the impact area is calculated based on the aircraft's maximum take-off weight (Figure 24) [75]. Crash areas are modelled as circles the epicentre of the crash area located at the centre of a grid cell [75]. Lethality is constant and dependent of the chosen model [75, 78]. The lethality (the sum of third party fatalities of all accidents divided by the sum of estimated population in the consequence areas) ranges from 0.13 (for aircraft with MTOW ≤ 5,700 kg) to 0.278 (for > 5,700 kg) [76].

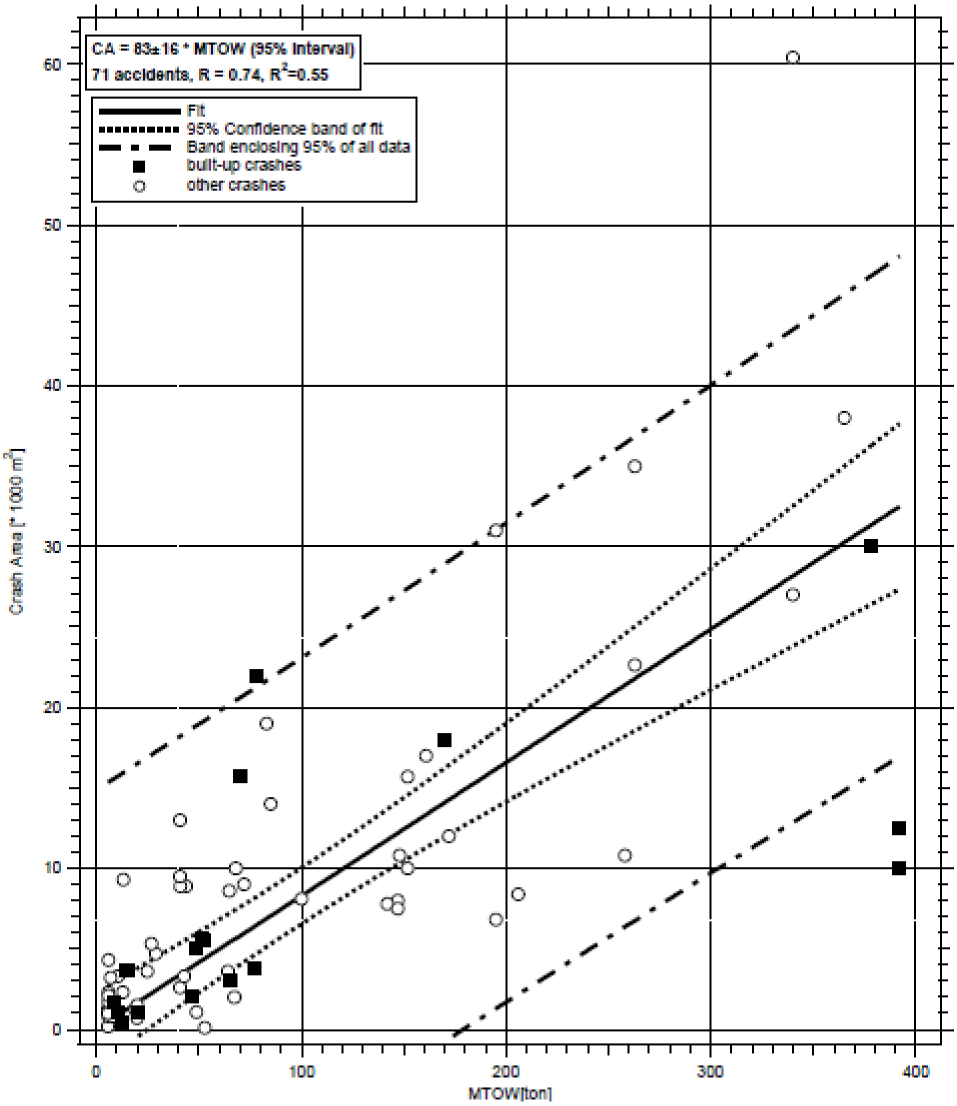


Figure 24 Data points and fit of crash area size (in 1000 m^2) against MTOW (in tons) [77]

The Dutch adapted a new policy to limit any further growth of third party risk in 2003 [49]. According to this policy, new buildings are not allowed within the 10^{-5} contours; the current situation in terms of third party risk may not worsen [49]. In addition, since 2010, no inhabitants are allowed within the $5{\cdot}10^{-5}$ contours [49]. This would lead one to conclude that the economic importance of Schiphol justifies a higher risk level in the airport vicinity than that allowed for other industrial activities [49]. Given that Schiphol is located close to inhabited areas, an important number of people are exposed to risk levels above the individual risk criterion [66, 49]. For instance, in 2001 the risk exposure of almost 4,100 people exceeded the VROM (Dutch Environmental Standard) limit of 10^{-6}/year (see Figure 11) [49]. In addition, approximately 50 people were even exposed to a risk level greater than 10^{-5}/year [49]. The societal risk criterion is exceeded as well [49]. The risk on a national level can be represented by the aggregate of the local risks originating from various hazardous installations and activities [49].

The probability of a death due to non-voluntary activities, such as working a factory or at sea, is approximately equal to $1.4 \cdot 10^{-5}$/year; this level seems good base to establish a norm for acceptable risk related to engineered infrastructures such as airports [49]. The number of casualties in car traffic, on the other hand, seems close to the verge of acceptance [49]. When adopting this observation-based frequency as the norm for assessing the safety of activity *i*, rearranging Eq. 27 and adopting a somewhat arbitrary distribution over 20 categories of activities, each claiming an equal number of lives per year, the following norm is obtained for an activity *i* with N_{pi} participants in the Netherlands [49]:

$$P_{fi} \cdot N_{pi} \cdot P_{d|fi} < \beta_i \cdot 100 \qquad (28)$$

The factor 100 is country-specific; it is based on the minimum death rate of the population, the ratio of the involuntary accident death rate (exclusive diseases) to the minimum death rate, the number of hazardous activities in a country (here 20 sectors) and the population size [49].

According to Eq. 28, an activity should be allowed as long as it is expected to claim fewer than $\beta_i \cdot 100$ deaths per year [49]. However, this does not take risk aversion into account; risk aversion is one of the factors influencing risk acceptance by a community or the society [49]. In general, relatively frequent small accidents are more easily accepted by the population than one single rare accident with an important number of victims (compare e.g. car accidents and airplane crashes), although mathematically speaking the expected number of casualties might be equal in both cases [49]. This difference will be reflected in the standard deviation of the number of casualties [49].

Figure 25 shows that at Schiphol an accident with fatalities of 100 or more should happen only once in 70,000 years [49]. However, the VROM limit corresponds to once in 1,000,000 years [49]. LPG stations in Netherlands also create risk levels that by far exceed the societal risk criterion (see Figure 25): the probability of an accident with 100 or more fatalities is once in 5000 years [49]. With almost 1100 persons dying in traffic every year and a population of 16 million people, we obtain an individual risk of $1.4 \cdot 10^{-4}$ for every citizen, which again amply exceeds the individual risk criterion of 10^{-6}/year [49]. As can be seen in Figure 25, the F_N-characteristics curve of road safety falls steeply after a given number of casualties [49].

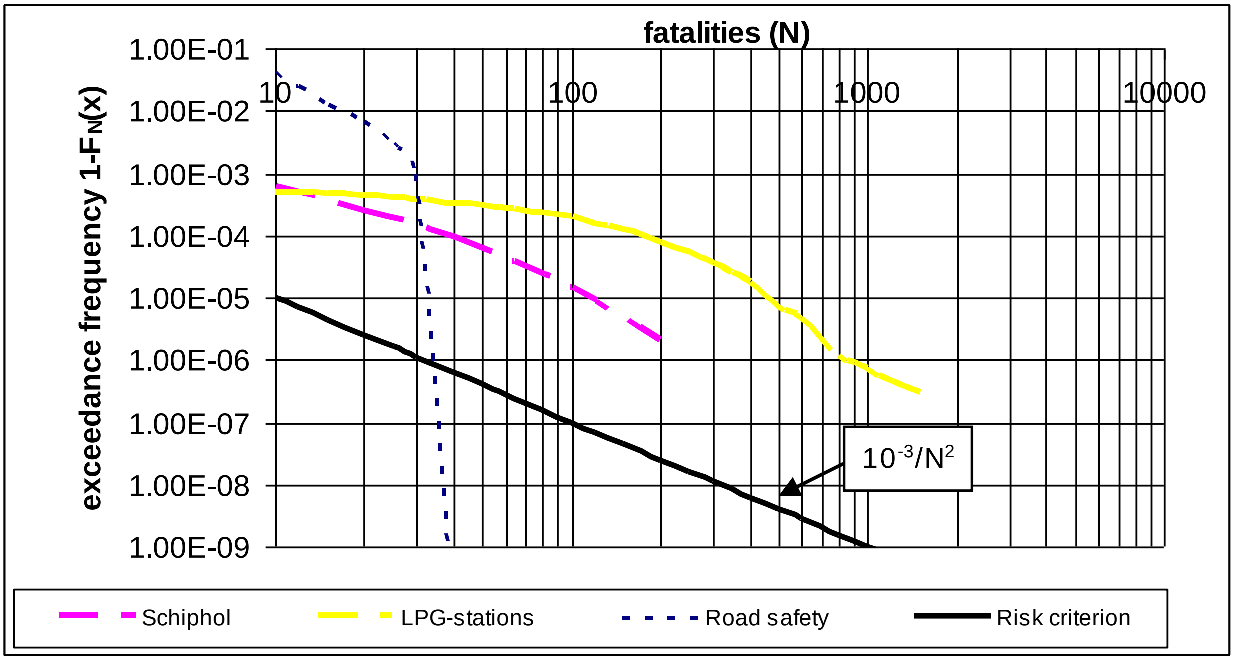


Figure 25 F_N-curve [49, 79]

2.2.4 ENAC Model (Italy)

In 2010 in Italy, ENAC issued a risk assessment implementation policy [80] that must be applied around airports [81]. The Italian Public Safety Zones are [81]:

- High Protection Zone: area included inside the 10^{-4} risk contour.
- Inner Zone: area included between the 10^{-4} and 10^{-5} risk contour.
- Intermediate Zone: area included between the 10^{-5} and 10^{-6} risk contour.
- Outer Zone: area outside the 10^{-6} risk contour.

The High Protection Zone is generally inside the airport perimeter; however, if it is located outside the airport area, the continued presence of people should be prevented [81]. In the Inner Zone, human presence is controlled by freezing the existing situation (no new constructions are permitted) [81]. If the anthropogenic load is already important, it should be assessed and containment measures put in place [81]. In the Intermediate Zone, existing buildings are tolerated; in addition, new non-residential activities can be allowed if they are characterized by the presence of only a small number of people [81]. The Outer Zone is considered outside the influence of the airport activity [81].

In the High Protection, Inner and Intermediate Zones, the following activities are to be prevented [81]:

- activities which may amplify the consequences of an aircraft crash and generate further damage to the environment (such as above ground fuel storage, chemical plants, etc.);
- public buildings such as schools and hospitals, other facilities with major population concentrations;

- traffic conditions on roads that may generate congestion and significantly increase the anthropogenic load (notably toll booths).

In 2005, a law to review the Aviation Code of Navigation [82] introduced individual risk assessment for airports in Italy [81]. This decree stipulates that the Italian Civil Aviation Authority (ENAC) is responsible for identifying airports that are to undergo risk analysis [81]. A computer program developed by Sapienza University of Rome for ENAC to allows the assessment of the third party risk [81]. The Italian model was derived from the UK/Irish and Dutch models: probability density functions (pdfs) were adopted from the first model, while the calculation of individual risk is based on the Dutch model [81]. The ENAC model for the assessment of the Public Safety Zones around airports consists of three sub-models, following the guidelines of the ICAO Airport Planning Manual [81]:

- a probabilistic model for accident occurrence;
- a probabilistic model for accident dispersion around the airport;
- an accident consequence model.

Aircraft crash risk assessment in the vicinity of an airport is done according to the following steps [81]:

- analysis of risk exposure and aircraft traffic at the airport: at this stage, present and future traffic (number of movements) is estimated;
- estimation of accident frequency: this study is based on information from international databases most relevant to the case study;
- examination of the geographic distribution of accidents around the airport;
- modelling of the probability curve that best fits the accident location patterns identified in the previous step;
- assessment of accident consequences: there consequences depend on the characteristics of the surrounding area (e.g. a high density residential area vs. uninhabited area);
- definition of the combinations of factors leading to an accident.

Via statistical treatment of airport data, linear regression curves were defined; these curves associate the product $R{\cdot}N{\cdot}A_{des}$ with the areas (A) related to the three risk individual criteria (10^{-4}, 10^{-5} and 10^{-6}) [83]:

$$A = 0.00015\, R\, N\, A_{des} + 3.095 \text{ for individual risk} = 10^{-4}\ (R^2 = 0.978)$$

$$A = 0.002500\, R\, N\, A_{des} + 60.52 \text{ for individual risk} = 10^{-5}\ (R^2 = 0.999) \quad (29)$$

$$A = 0.03380\, R\, N\, A_{des} + 849.97 \text{ for individual risk} = 10^{-6}\ (R^2 = 0.988)$$

The total area A is expressed in hectares, the number of annual aircraft movements N is expressed in millions of movements, the average crash rate R is expressed in crashes per million movements and the average destroyed area A_{des} is expressed in hectares [83].

Similarly to the NATS model, the resulting shape of the Public Safety Zones is an elongated isosceles triangle; the base of the triangle lies at the end of the runway and the sides of the triangle extend outwards beyond the airport boundaries [83].

At Catania Airport, the application of Cost-Benefit Analysis (CBA) for the determination of PSZs policy provided the following results: all the residential, scholastic and industrial activities are located outside the 10^{-6} contour in the present and also in the future (2012) scenario [83]. Table 19 shows the risk contours that should be used to control any new activities [83].

Table 19 Risk contours for limiting new activities at Catania airport [83]

Type of activity	Risk contours for limiting new activities	
	Present	Future
Residential (low population density)	10^{-4} … $1.5{\cdot}10^{-5}$	10^{-4} … 10^{-5}
Residential (high population density)	10^{-4} … $5{\cdot}10^{-6}$	10^{-4} … $4.5{\cdot}10^{-6}$
Industrial	10^{-4} … $1.5{\cdot}10^{-5}$	10^{-4} … 10^{-5}
Schools	10^{-4} … $5{\cdot}10^{-6}$	10^{-4} … $2{\cdot}10^{-6}$

2.2.5 3PRisk Model (Ukraine)

This section describes the characteristics of the 3PRisk model developed by NAU for Civil Aviation Service of the Ministry of Infrastructure in Ukraine. The current national rule for the approval of any new developments around the airports in Ukraine requires the assessment of TPR and the Air Code of Ukraine declares that any airport/aerodrome/runway must present the maps with noise zoning, sanitary zones for chemical air pollution and electromagnetic radiation, and Public Safety Zones for the approval of operation during certification procedures. TPR contours were calculated for over 20 airports in Ukraine and PSZs were defined in accordance with requirements of the Air Code of Ukraine and other national rules.

In the 3PRisk model, the TPR calculation includes an Individual Risk assessment at specific points or in the form of risk contours, while the Societal Risk and destroyed area (or other types of expected damage from aircraft accidents) outputs are optional (Figure 26). The risk assessment is based on the amount of annual aircraft traffic in the airport under consideration and takes into account the differences in accident rate (AR) values for specific classes of aircraft. An accident probability model provides a local AR for specific aircraft classes on the basis of fatal aircraft accidents (historical AR) while taking into consideration the specific conditions of aircraft operation in the airport. The aim is to cover all possible causal factors relevant in predicting the crash probability. For future scenarios of flight traffic at an airport, the available and in-development safety improvements should be included to correct the historical AR and to prevent the overestimation of the probabilities.

The aircraft classification for crash rates assessment is quite different for different countries—an analysis was done for USA, UK, Germany, the Netherlands, Italy and Australia—where PSZs are used or investigated to be used for third party risk control. The different values of crash rates stem notably from differences in aircraft fleet used for flight traffic and differences in the safety culture of aircraft and airport operators. For example, it is a known fact that scheduled and unscheduled flights, or passenger and cargo flights, even when realised with the same type of the aircraft, may differ in AR values. In addition, the crash rates for General Aviation may be 5–10 times higher when comparing with Commercial Air Transportation. Huge differences in ARs exist between flights made by civilian and military aircraft (important for mixed aerodromes), aeroplanes and helicopters, different types of flight such as private, business, sport and so on. The type of the navigation facilities, number and location of runways, specific meteorological conditions, etc., may also contribute to the local AR in an airport. Depending on all these conditions, 3PRisk can be used to incorporate various aircraft classes with different approved crash rates in its assessment.

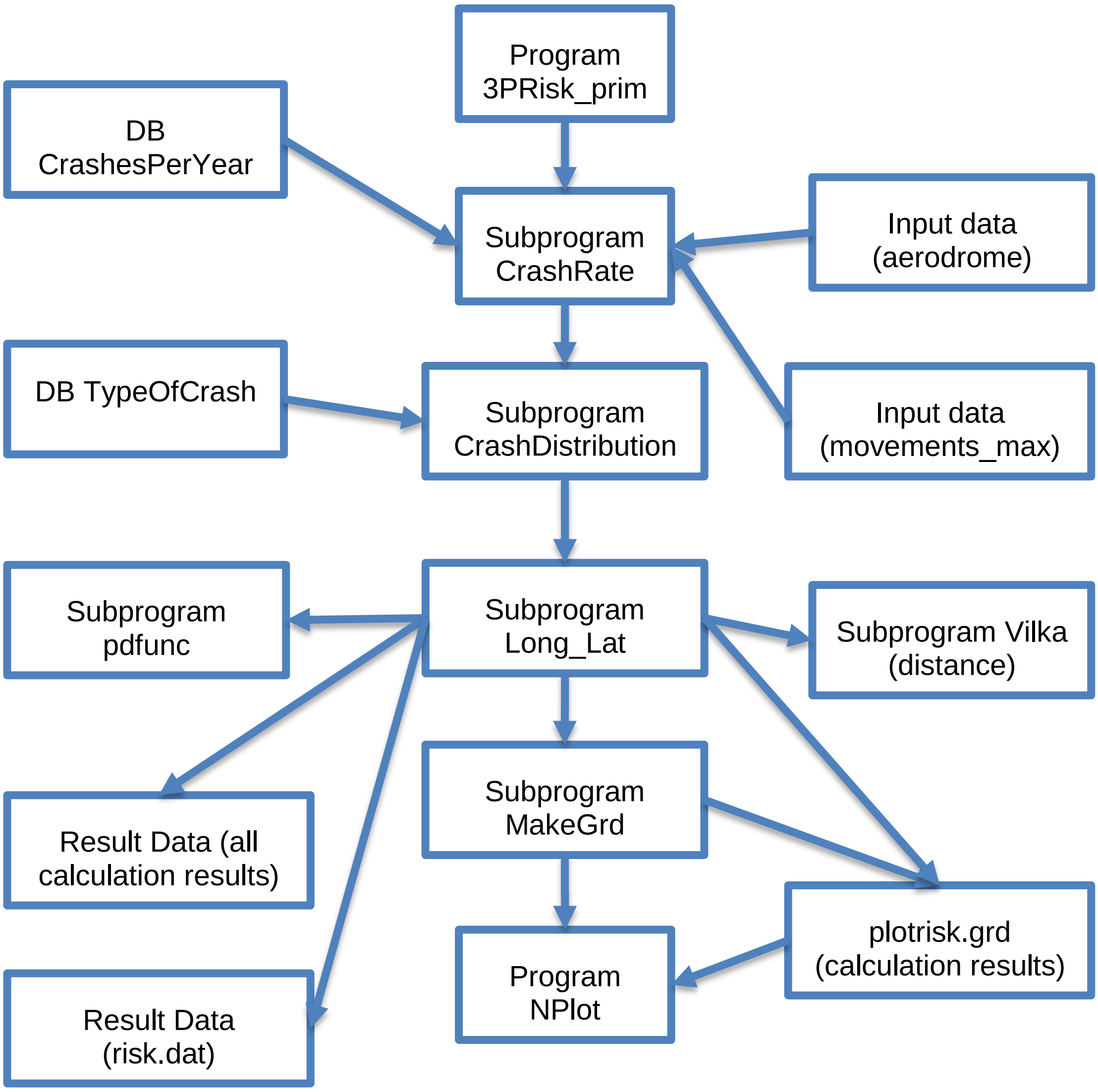


Figure 26 Flowchart of calculation algorithm of 3PRisk

In principle, aircraft crash rates or accident rates could be derived using theoretical models which would use the measured probabilities of all possible causal factors to predict the probability of a crash. Such a theoretical approach is very problematic since accidents are usually the result of a combination of many separate causal factors with unknown probabilities and complex interrelationships. An alternative method is to use historical data on accidents and on aircraft movements to calculate crash rates.

This method does assume that the historical rate of accidents will continue into the future, which, if there are future safety improvements, may lead to an overestimate for crash rate in future years. The completeness of the data is important when calculating crash rates. If any relevant crashes have been omitted, the crash rate will be underestimated, while if any relevant movements are omitted the crash rate will be overestimated. Although crashes are in general caused by a large variety of different events, different types of aircraft will have different crash rates because of variations in their design (for instance, single engine aircraft might be expected to suffer more accidents due to engine failure than multiple engine aircraft). Ideally, historical accident data could be used to calculate separate crash rates for each type of aircraft.

In 3PRisk, the predicted crash frequency (expected number of crashes per year) at any given airport for a particular group of aircraft is the product of the crash rate (crashes per movement) appropriate to that category of aircraft (same as in UK/Irish method, Figure 20) and the annual number of movements of such aircraft at the airport in question. The overall crash frequency is the sum of the crash frequencies for different categories of aircraft. The full breakdown of aircraft by type for the calculation of crash rates includes 10 aircraft classes is described in DB CLASSES, Table 20 (not shown in Figure 26).

Table 20 Details for DB CLASSES of 3PRisk

Input	CLASSES.DAT	
Parameter	**Identifier**	**Variable precision/type**
Large Jets I	L1	character
Large Jets II	L2	character
Large Jets III	L3	character
Large Jets IV	L4	character
Turboprop T1	T1	character
Turboprop T2	T2	character
Executive Jets	EJ	character
Eastern Jets	SU	character

Miscellaneous	MC	character
Light	LT	character

The accuracy and confidence of accident location models is also an important element of the TPR assessment tool. Specific models are defined elsewhere for take-off / initial climb and approach/landing flight stages in the vicinity of the airport, and they may differ depending on the runway location and length, aircraft class, type of flight, etc.; all these factors need to be taken into account. The difference is sometimes so significant and the detail in the assessment so high that, for example, in the NATS model different approaches are used for 'large' and 'light' aircraft when defining the probability density functions of specific location models. Many investigations have been made into this subject, including a PhD thesis preparation, with datasets provided by national and international Aircraft Accident Data Bases. The further improvement of accident location models is still a subject of on-going research.

The 3PRisk model calculates crash rates and crash distributions based on which an Accident Probability Analysis for the flight traffic under consideration can be made. The main input parameters are included in the initial database and scenario files: these parameters include notably aircraft classes, crashes per year and type of crash information. The design of the data flow allows the modification or extension of the number of specific aircraft classes if new accident rate values need to be taken into consideration. Scenario input files include for instance the following: traffic movement data, routes, runways, etc. For visualising the results of the calculation (contours on a map), plotting programs are used (e.g. NMPlot). Gridding programs are used to produce data in GRD format (in accordance with the NMGF standard); these data are required by NMPlot.

The target safety level adopted here and in [84] is taken as 10^{-7} or 1 in 10 million per annum. This is common in aviation. This is still not reached in world civil aviation (Figure 27) but the tendency for decrease has been observed [83]. The rate is not equal in different regions (Table 21): it is at its lowest in USA and Canada, quite similar in EU, and still very high in the FSU countries. In this region, even an increase of AR has been observed during the last 5 years (Figure 28) due to many reasons, dominantly unscheduled flights performed by small air companies [85, 86].

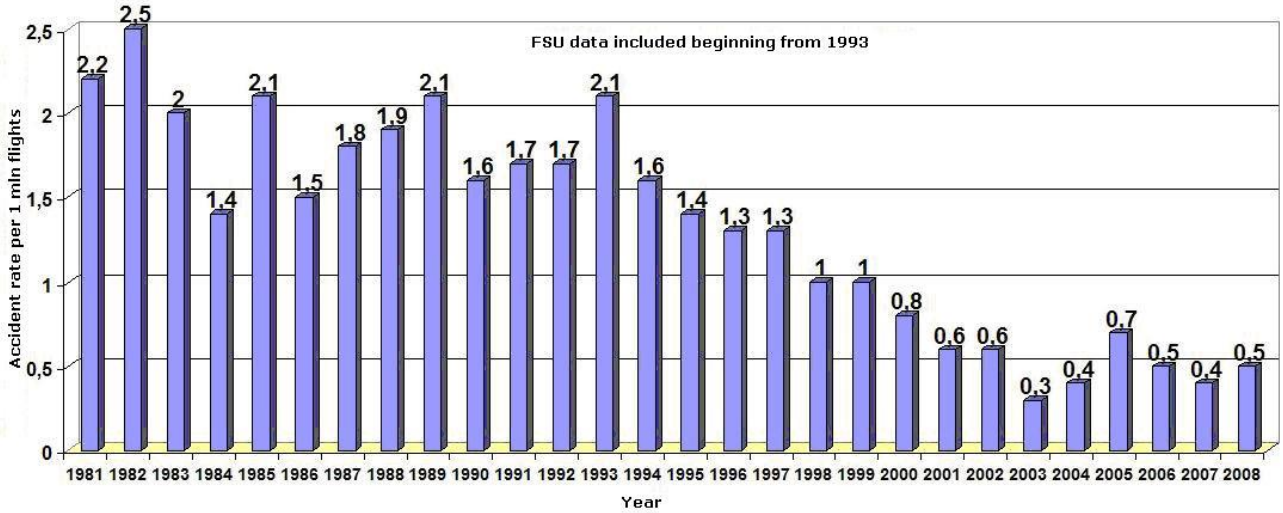


Figure 27 Average accident rate (per 10^6 movements) in the world [29]

Table 21 Average accident rates in various regions of the world, 1995–2004 [29, 53]

Region	**Averaged accident rate for 10^6 movements**
USA, Canada	0.20
South America	1.29
Western Europe	0.31
FSU	2.47
Eastern Asia	0.26
Western Asia	2.44
South and South-Eastern Asia	1.11
Australia, New Zeeland	0.33
Africa	4.77

Hence locally the probability of aircraft accident for the current year within the territory and around the airport under consideration can be estimated:

$$AR_{local} = \frac{AR_1 N_1 + AR_2 N_2 + AR_n N_n}{\left(N_1 + N_2 + N_n\right)} \qquad (28)$$

where AR_i is the assessed accident rate for *i*-th airline and N_i is number of flights realized by the airline per annum.

The location model is used to estimate the probability that the aircraft stops beyond a certain distance from the runway. The probability of an accident is not equal for all locations around the airport. The probability of an accident in the proximity of the runways is higher than at greater distances from the runways. Since this model is specific to an event, Wong et al [87, 88] distinguish four types of accident that occur at or close to airports. Overruns are 57% of the total (landing overruns, 45%; take-off overruns 12%), with landing undershoots at 28% and take-off crash at 15%. Landing accidents dominate the statistics.

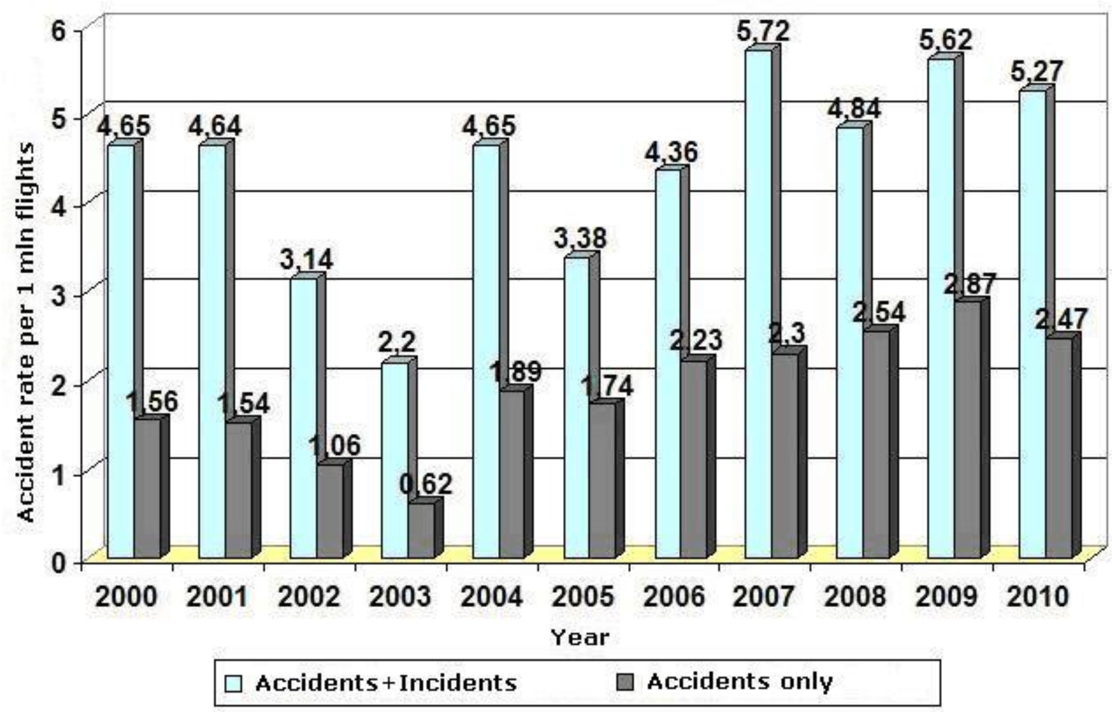


Figure 28 Average AR for aircraft movements (106 movements) in FSU countries [29]

3PRisk model sensitivity was investigated by making changes in accident rate values (on 2, 5 and 10%) and estimating the value of third party risk and the extent of risk contours from runway ends along the axis of flight. Results are shown in Table 22, they are as expected as the main formula for TPR assessment is a simple multiplication of factors (a product of four factors). The results show significant model sensitivity to AR changes, especially for high values of risk (10^{-4}).

Table 22 Results of the 3PRisk model sensitivity analysis [29]

Risk contours	Initial distance of the contour from runway end (m)	Accident rate changes (%)		
		2	5	10
10^{-4}	257.9	3.1	4.96	10.1
10^{-5}–10^{-4}	2737.6	1.4	2.8	5.6
10^{-6}–10^{-5}	11377.3	0.8	1.7	3.4

When looking at the Boryspil airport (Kyiv, Ukraine), the individual risk was estimated with respect to possible aircraft impact during accidents into different target objects within the inner risk zone between 10^{-4} and 10^{-5} contours, which are located close to the airport (Table 23). The number of fatalities depends of the character of target objects and if an object is potentially dangerous (producing chemical, biological or radiative hazards), the consequences may be expected to be one or two orders of magnitude higher.

Table 23 Estimation of individual risks for potential aircraft crashes into various objects [29]

Object type	Individual risk	Radius of the area of impact R_P (m)	Expected number of fatalities
Open area within the residential zone	$1.71 \cdot 10^{-5}$	31	13
A single-storey building area of 1000 m^2	$3.61 \cdot 10^{-5}$	82	15
Multi-storey building area of over 1000 m^2	$5.43 \cdot 10^{-5}$	100	78
Chemically hazardous object with accidental release	$1.88 \cdot 10^{-9}$	7199	2982

2.2.6 General Conclusions for TPR Models

The Netherlands, UK and Ireland have traditionally made extensive use of risk assessment in land use planning and in judging plans for industrial developments. Therefore, it is not surprising that these three countries and two modelling approaches have been leading in the area of third party risk assessment around airports. However, there are now signs that this is likely to become a major issue across Europe. The described models for TPR assessment are used not only in the countries where they were developed and currently supported, but also in other countries. TPR modelling has been for instance performed in Slovenia [89], Serbia [30, 90], Switzerland [91], Germany [92] (in addition, a national approach exists and is used there), Australia [93] and other countries.

A paper from the European Transport Safety Council (ETSC) [94] highlights notably the following issues involving third party risk:

- Growing public following the El Al crash (Amsterdam, 1992);
- The concentration of aircraft crashes in the climb and approach phases;
- Safety issues at (not just in the surroundings of) airports;
- The need for a common framework for managing risks to third parties. ETSC suggests that there is a need for comparable risk assessment methodologies and tolerability criteria to ensure fair competition between European airports;
- The need for mandatory inclusion of third party risks in Environmental Impact Statements (EISs) for airports.

Zoning around airports based on individual risk contours and societal risk values is now undertaken in many countries. Some of them use the most well-known TPR models from US, UK and the Netherlands, while others try to design their own calculation tools based on accident data from their national and international data bases, or at least combine the best features of the US, UK and Dutch model as differences between the known models exist in all parts of TPR evaluation. The general modelling approach adopted for the quantitative assessment of risks associated with third party fatalities is based on the evaluation of:

- the likelihood of the accident occurring;
- the location of the accident occurring; and
- the consequences of such an accident (fatalities, injuries and cost of damage).

In general terms, a TPR model (such as the one to be potentially developed by EUROCONTROL), should at least contain the three usual risk calculations steps together with data from a database, and allow the definition of risk contours and their visualization on a map.

There are various difficulties in third party risk modelling: third party risk models have various shortcomings, notably they can lack generality (they have to be adapted to each new airport), official and reliable data on accidents and risk exposure is often lacking, and it is difficult to set up appropriate individual and societal risk thresholds: values that are too high jeopardize airport operations whereas low values can lead to unacceptable third party risk exposure [30]. The problem of context-specific TPR models has been addressed by making the models developed for specific airports (Amsterdam Schiphol in the case of NLR) more general so that it is possible to apply them to other 'similar' airports [30]. Similitude is required notably in terms of traffic volumes, aircraft fleet, spatial layout, and land-use and population density [30]. The problem of scarcity of data on risk exposure and accidents has not yet been solved: accidents and third party fatalities are rare events and the collection of representative data remains challenging [30]. The threshold problem has been resolved by improving accuracy in setting up the thresholds for third party risk around airports [30].

2.3 Data Needs of TPR Models

TPR models, like other environmental models (e.g. noise and local air quality models), have their own input data requirements. However, a significant part of the data for third party risk calculations is common with noise and LAQ (for instance traffic information). These common input data must be adapted by TPR, aircraft noise and LAQ modellers to their local scale (airport) modelling process.

The data for TPR models, similarly to other environmental models, should be stored in a database or data warehouse. Depending on the objective of the case study to be calculated, it might not be necessary to use all information provided by the database platform (especially when a shared database is used for storing data for multiple environmental models), but instead extract the relevant data from and provide it to its model in the required format.

2.3.1 NLR Model Inputs and Outputs

The hypotheses used in the NRL model include the following:

1. The number of flights (flight traffic) should be defined in the scenario for each aircraft generation used for accident rates definitions (Table 14, Table 15 and Table 16). Flight traffic needs to be distributed between the runways and tracks before calculation with Eq. 19.
2. Accident rates and their 95% confidence limits per accident type and generation must be in accordance with data in Table 14, Table 15 and Table 16.
3. Probability distribution functions, used for the Accident Location Model, for different types of crash with appropriate coefficients must be in accordance with data in Table 17 and Table 18. The Accident Location Model and all its coefficients are usually considered as general values and they are hard coded in the subroutines (modules) of the used software.
4. The distribution of the different types of accidents (take-off crashes, landing crashes, veer-offs, overruns, undershoots) should be calculated for the set of accident data, which was analysed for the Accident Location Model, or it may be airport-specific, if the appropriate data for the airport under consideration exists.
5. The take-off mass of the aircraft must be known to calculate the accident impact area (Accident Consequence Model).
6. An IR matrix is defined for the calculation grid (steps between grid points may be assessed in accordance with the radius of the accident impact area). This matrix is further used for IR contour assessment for predefined IR values: usually 10^{-4}, 10^{-5}, $5{\cdot}10^{-5}$ and 10^{-6}. Specific contours are used for PSZs definition.
7. For every contour, an exposure analysis may be realized if the following input data is available: building locations (residential and public like schools, hotels, hospitals, etc. with large concentrations of people) and population distribution. The simplest form of output data are the contour areas.
8. If the population distribution inside the impact area is available, Societal Risk may be calculated for the predefined lethality values for every type of accident. Currently, an important type of assessment in the consequence analysis is Potential Loss of Life (recommended by WHO for ranking health injuries), which depends on SR values.

2.3.2 NATS Model Inputs and Outputs

The hypotheses of the NATS model include the following:

1. The number of flights (flight traffic) should be defined in the scenario in accordance with aircraft classes used for accident rates definitions (Figure 18 and Table 12). Flight traffic needs to be distributed between the runways and tracks before calculation with Eq. 19.
2. Accident rates per aircraft class, passenger or cargo flights must be in accordance with data in Table 12.
3. Probability distribution functions used for the Accident Location Model for different types of crash with appropriate coefficients must be in accordance with Eq. 23–25. The Accident Location Model and all its coefficients are considered as general values and they are usually hard coded in the subroutines (modules) of the used software.
4. The take-off mass of the aircraft must be known to calculate the accident impact. The radius of the average accident impact area is used as a value for the steps between grid points which are used for risk contours assessment. Eq. 26 is used for the averaged crash area calculation.
5. An IR matrix is defined for the calculation grid, which is used further for IR contours assessment for predefined IR values: usually 10^{-4}, 10^{-5} and 10^{-6}. Specific contours are used for PSZ definition.
6. For every contour, an exposure analysis may be realized if the following input data available: building locations (residential and public like schools, hotels, hospitals, etc. with large concentrations of people) and population distribution. The simplest form of output data are the contour areas.
7. Societal Risk assessment is usually an optional procedure (not required by the UK DfT circular [8]).

2.3.3 3PRisk Inputs and Outputs

Crash probabilities are subject to continuous investigations, but they must be predefined for every specific scenario with appropriate values, see an example of DB CrashesPerYear (Table 24). Some of the aircraft are passenger (PAX) and some non-passenger (NP).

Table 24 Aircraft classes and crash rates per year

Input			CrashesperYear.DAT	
Aircraft class		Probability Value per 10^6 Movements	Unit	Variable precision/type
L1	PAX	1.113	undimensioned	real
L2	PAX	0.148	undimensioned	real
L2	NP	0.444	undimensioned	real
L3	PAX	0.148	undimensioned	real

L3	NP	0.444	undimensioned	real
L4	PAX	0.148	undimensioned	real
L4	NP	0.444	undimensioned	real
SU	PAX	0.874	undimensioned	real
T1	PAX	0.288	undimensioned	real
T1	NP	0.864	undimensioned	real
T2	PAX	0.782	undimensioned	real
EJ	PAX	2.230	undimensioned	real
MC	PAX	3.270	undimensioned	real
LT	PAX	3.270	undimensioned	real

Probability distribution functions, used for the Accident Location Model, for different types of crash with appropriate coefficients must be in accordance with Eq. 23–25. Currently, the model consists of four separate distributions for different types of crash as follows:

- landing overruns (including veer-offs);
- landing crashes from flight;
- take-off overruns (including veer-offs);
- take-off crashes from flight.

DB TypeOfCrash must be predefined for every specific scenario with appropriate probability values (100% in total) for the possible type of crashes in the scenario under consideration.

Table 25 Crash types and their probabilities

Input			TypeOfCrash.DAT	
Type of crashes		Probability Value	Unit	Variable precision/type
take-off	overrun	8.0	percent	real
landing	overrun	20.0	percent	real

take-off	from flight	20.0	percent	real
landing	from flight	52.0	percent	real

File input.dat defines the type of calculation: either specific points or risk contours. If point is chosen (Input Parameter typeofcalc = 'point'), input.dat must include the data for number of points (Input Parameter numofpoints) and their coordinates in meters (Input Parameters PointY and PointX).

Table 26 Input of points for risk calculation

Input	input.DAT	
Parameter	**Units**	**Variable precision/type**
typeofcalc	undimensioned	character
numofpoints	undimensioned	integer
PointY	m	real
PointX	m	real

Input files AIRPORT.dat, RUNWAYS.dat, ROUTES.dat and MOVEMENTS_max.dat are harmonized among the NAU software 3PRisk, IsoBella and PolEmiCa with the purpose of more accurate use in any study for any airport under consideration. In principle, their structure should be the same in any known models, and differences are defined mainly by the calculation platform used in the calculation tool (for example, by data base structure implemented in calculation tool). In NAU software, the simple forms of data storage such as csv files are habitually used.

The outputs of the 3PRisk model are either risk values at a specific point (or points) of risk control or risk contours around the Runway/Track configurations. Principles for contour outputs are quite the same as for aircraft noise and LAQ (concentration) contours. For example, in 3PRisk, IsoBella (noise) and PolEmiCa (LAQ), the NMPlot module (designed by Wasmer Consulting) is used. Similar approach is used in the INM and EDMS models of the US FAA.

An IR matrix is defined for the calculation grid (steps between grid points may be assessed in accordance with radius of accident impact area), which is used further for the assessment IR contours with predefined IR values: usually 10^{-4}, 10^{-5} and 10^{-6}. Specific contours are used for PSZ definition. For every contour, an exposure analysis may be realized if the following input data available: locations of buildings (residential first of all and public like schools, hotels, hospitals, etc. with large concentrations of people) and population distribution. The simplest form of output data are the contour areas. Societal risk assessment is usually an optional procedure (it is not required by national rules).

2.3.4 General Conclusions on Data Needs of TPR Modelling

The different characteristics of TPR models under consideration are shown in Table 27. These model descriptions are used to formulate the general input data requirements for TPR modelling.

Table 27 Input data specifications for every TPR model under consideration

Model	Accident rate predefined for	Accident (crash) types	Accident location model	Consequence model	Used in
US DOE model	Aircraft classes	Arrival and departure crashes	Arrival and departure crashes for aircraft of general aviation and commercial aircraft (data table)	Accident impact area	US
US California Handbook model (see 2.2.1)	Aircraft classes	Arrival and departure crashes	Arrival and departure crashes for aircraft of general aviation and commercial aircraft (axial pdf)	Accident impact area	California
NATS model	Aircraft classes	Take-off and landing crashes, overruns	Take-off and landing crashes, overruns (area pdf) For light aircraft specific pdf at take-off and landing crashes	Accident impact area, exposure analysis results	UK, Ireland, Australia
NLR model	Aircraft generation and type of	Take-off and landing crashes,	Take-off and landing crashes,	Accident impact area, SR, exposure	Netherlands (all airports), Germany

	accident	overruns, undershoots and veer-offs	overruns, undershoots and veer-offs (area pdf)	analysis results, Potential Loss of Life	(Fraport), Italy (2 apts), Sweden (2 apts), Spain (1 apt) [95]
ENAC model	Aircraft classes	Take-off and landing crashes, overruns	Take-off and landing crashes, overruns (area pdf)	Accident impact area	Italy
3Prisk	Aircraft classes	Take-off and landing crashes, overruns	Take-off and landing crashes, overruns (area pdf)	Accident impact area	Ukraine (over 20 airports and aerodromes)

The input data required for TPR modelling includes the following main elements:

Airport data

- Airport identifier (e.g. ICAO/IATA code)
- Airport reference point coordinates (latitude and longitude)
- Topography of airport surroundings

Runway data

- Runway identifier
- Coordinates (latitude/longitude) for runway end points

Track data

- Track identifier
- Operation type (departure/arrival)
- Runway identifier
- Coordinates for track points (latitude and longitude)

Movement data

- Aircraft type
- Number of movements per route (Track)

Population data

- Population density data

Land use data

- Building locations

In addition to input data provided directly by the user, data for TPR calculations (stored in a database) should contain 1) reference data (for instance data on accident rates and consequences) and 2) mapping tables (linking aircraft types to risk categories). The user might also be given the possibility to set the values various calculation parameters or select options.

Expert users might be given the possibility to upload their own accident rate data or even define aircraft categories to replace the reference values.

A database should be used to store the results of risk calculations (risk levels and grids) for post-processing and visualization purposes.

2.4 Data for Improving TPR Model Precision

The aim of this section is to propose a 'wish list' of data that could be used to improve TPR modelling precision.

General investigation of the existing TPR models provides a few ideas for their future improvement:

Accident Rate is perhaps the most important parameter influencing the calculation results. This means that a more detailed distribution on aircraft classes with their specific ARs should be a continuous process in any TPR calculation. Past developments have shown that the number of aircraft classes in the input data tends to increase with time and this trend is expected to continue in the near future. For example, one might expect that AR data for general aviation can be specified for different types of operations usually done by general aviation, if the operational data for them also exist (defined separately); in AR definition, it is therefore appropriate to specify the AR values for every type of operation. The same is also true for scheduled flights, charters, etc., as the specific data for their AR is available and may greatly influence the final results of TPR calculation.

The same approach might be used for improving the Accident Location Models, keeping in mind that the types of accidents should be grouped more systematically and their specific probability density functions could be made more accurate (more compatible with historical data from accident sites analysis).

Accident Consequence Models might be improved in a similar manner: historical data on past accident impact areas and consequences (injuries and fatalities) could be used to better adapt the models to this statistical data.

For Accident Location Models, it is also important to consider the type of the airport under consideration (what kind of facilities are used for flight control, is the airport a hub, regional or city airport, etc.), type and length of runways, and type of flight (scheduled, charters, general aviation operation, etc.).

Other somewhat different ideas: taking into account the aircraft age, time of day at the moment of the accident, crew experience (pilots' flight hours), workload of air traffic controllers, season (for instance for bird strikes that occur during migration periods), ambient conditions (wind, visibility, etc.), actual weight of the aircraft (and not merely MTOW), etc. Perhaps some new kinds of tools such as data mining might be used to extract new information from the existing mass of multidimensional data (i.e. accident statistics and their different characteristics) and used to adjust the TPR models.

Getting access to more historical aircraft accident data and better exploiting the data therefore seems central in improving the performance of TPR models. However, we should keep in mind that historical data does not always accurately reflect future developments and the limits of its applicability in the future should be the object of expert judgement. New types of air traffic control systems and aircraft might also lead to new types of accidents not seen in the past and to the modification of accident patterns, both in terms of probability, location and consequence. Nevertheless, statistics on past accidents remain the best aid for predicting future ones.

As with all modelling, the quality of the input data (in the case of TPR models accident statistics) greatly influences the quality of the model outputs; models can only be as accurate as their input data allows them to be. Besides accident data quantity, the quality of this data of therefore of great importance for the accuracy of third party risk modelling.

3 REVIEW OF IMPACT AND ITS DATA STRUCTURES

The chapter aims to present the main aspects of the IMPACT platform, its data structures and workflow.

3.1 Presentation of IMPACT

IMPACT is a web-based environmental modelling system developed by EUROCONTROL in the context of SESAR. It has been built upon the already existing EUROCONTROL fuel/emissions and noise assessment models—AEM and STAPES respectively. It allows the consistent assessment of trade-offs between noise and gaseous emissions owing to a common aircraft performance model based on a combination of the Aircraft Noise and Performance (ANP) database and EUROCONTROL's Base of Aircraft Data (BADA).

The IMPACT platform is the front end for three major components developed and maintained by EUROCONTROL [95]:

- AEM or the Advanced Emissions Model is an aircraft emissions model. AEM that can estimate the mass of fuel burnt by aircraft engines ; this calculation is performed based on the type of the aircraft , the type of engine as well as the 4D trajectory followed by the aircraft. In addition to the fuel calculation, the amounts of gaseous and particulate emissions (CO_2, NO_X, SO_X, CO, HC, etc.) that are produced when burning of that fuel are calculated.
- ANP or the Aircraft Noise and Performance database is an online database for noise modellers. This resource supports the ECAC Doc 29 (3rd Edition) and ICAO Doc 9911 guidance documents dealing with airport noise contour modelling. The ANP database provides reference values to the STAPES model for the modelling of the noise levels of aircraft departure and approach flight phases.
- STAPES or the the SysTem for AirPort noise Exposure Studies is a multi-airport noise assessment. STAPES was originally developed by EUROCONTOL to support future policy assessments in the ICAO-CAEP context. STAPES is designed to be compliant with the best practices noise modelling guidance drafted in ECAC Doc 29 (3rd Edition) and ICAO Document 9911.

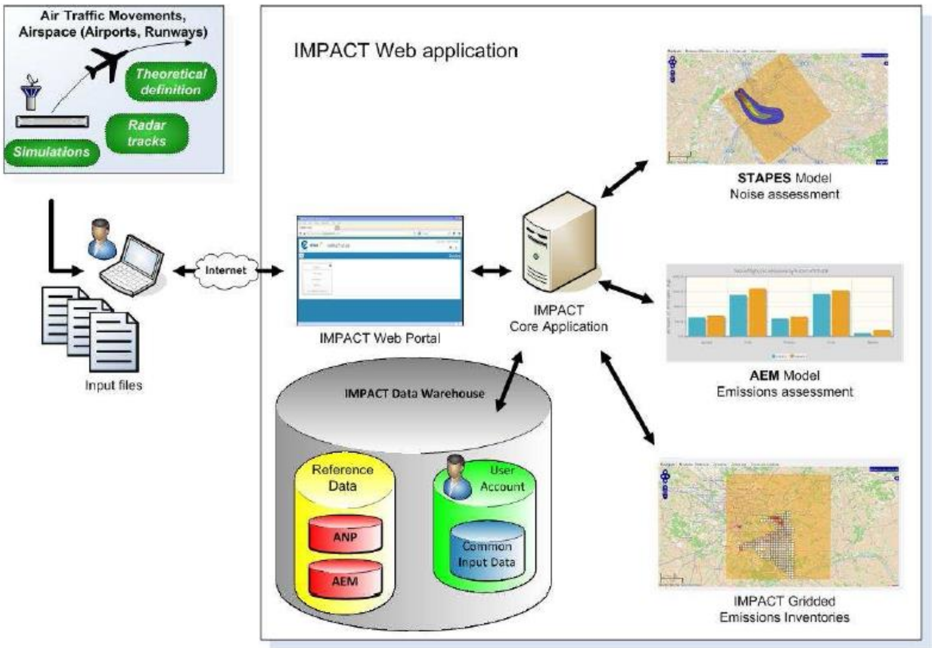


Figure 29 IMPACT web portal [95]

3.2 IMPACT Workflow

Again according to the IMPACT User Guide [95], there are six steps in the impact assessment process:

1. The first step of the environmental impact assessment is the creation and setup of **study** information. In IMPACT, this is the highest level container of the assessment information. In the study setup, the aim is to identify information that shall be used as a reference for the entire assessment (e.g. airport and runway information).
2. The second step is the creation and definition of **scenarios**. Scenarios are variants within a study, created in order to allow comparisons. IMPACT scenarios therefore contain a set of specialised information (e.g. aircraft trajectories or tracks). The scenarios can be run through the environment models.
3. **Aircraft mapping is** a mandatory step for the recognition and identification of aircraft types by the reference tables (ANP and AEM) used in aircraft performance and environmental modelling. If needed, substitution values for the aircraft types are defined.
4. The next pre-processing step is required for the generation of **common input data** or a validated set of scenario data that can be processed by IMPACT’s environmental models (AEM and STAPES).
5. After the calculation parameters of the assessments have been defined, the environmental models can be run for the selected scenarios based on the common input data.
6. The last step consists in the visualisation, download and post-processing of the assessment results.

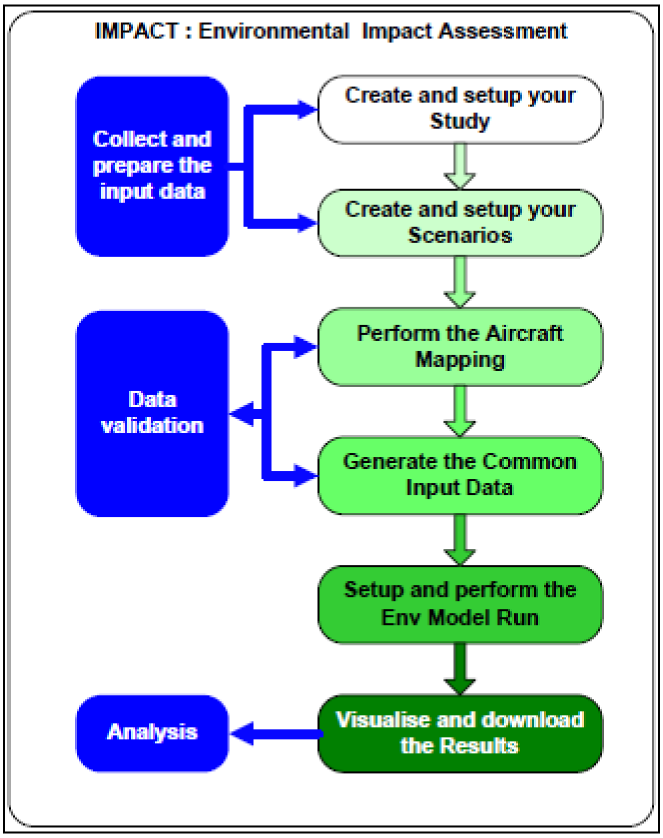


Figure 30 Assessment phases in IMPACT [95]

It is important to note that there is both **study** (i.e. airport) and **scenario** level data (some types of data can be provided in both levels). In addition, there is a specific step for **aircraft mapping** with respect to ANP and/or AEM/BADA databases. STAPES and AEM have their own separate mapping tables. The mapping can be done either based on the tables already provided in STAPES and AEM or by providing a user-defined mapping table that links an aircraft ID to both ANP, AEM, BADA3 and BADA4 ids.

3.3 IMPACT Input and Output Data

The input files for AEM & STAPES have been combined in IMPACT so that only one set of common input data (CID) is provided. These two models have distinct and different requirements in terms of input data: for example, thrust values along the aircraft trajectory are required for noise modelling whereas emissions modelling exploits information on fuel flow as well as on the ambient conditions (temperature, pressure and humidity) along the 4D trajectory. The CID is a container for the different input data (tracks, 4D trajectories, ambient conditions, etc.) and it includes also the airspace definition (airport and runways).

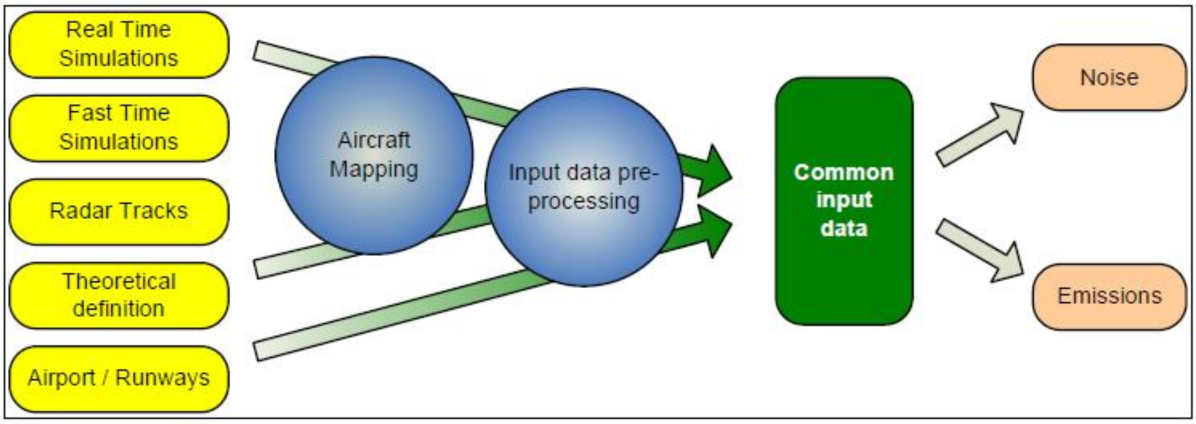


Figure 31 Common input data generation [95]

IMPACT input files are designed to describe an aircraft navigation and airspace dataset, to be processed by the chosen environmental model. Input data files are provided by the user in a single zip file uploaded in the application. Table indicates the required type of files to be inputed for a noise/emissions impact assessment with IMPACT.

Table 28 IMPACT input files types [95]

File type	Description	Input level	Input rule
Airport	The airports description	Study	Mandatory
Runway	The airports runways description	Study	Mandatory
Operations	The list of the operations (one or several flights) to analyse, with indications of associated track, profile, aircraft type, airport and runway	Study or scenario	Mandatory
Tracks 2D	The ground tracks	Study or scenario	Mandatory if no 4D trajectory nor V_Tracks
4D Trajectories	The complete trajectory description	Study or scenario	Mandatory if no Track 2D nor V_Tracks

Vector Tracks	The ground tracks expressed by vector steps	Study or scenario	Mandatory if no Track 2D or 4D trajectory
Fixed point profiles	The vertical profiles	Study or scenario	Optional. When it is not an input, IMPACT selects the operation associated ANP vertical profile

The user of IMPACT is required to upload the study default data (operations, trajectories, airports and runways to be used at the study level). The scenario edition window should remind which files are used at the scenario level. A scenario can mix files from different sources. For example, a scenario can use:

- airports and runways from the study,
- fixed point profiles from the study, and
- operations and tracks from the scenario.

The inputs and outputs of the IMPACT platform are summarized below.

Inputs

- Airport: name, location, elevation (always study-level data)
- Runways (always study-level data)
- Scenario: atmospheric conditions
- Operations: list of the operations with associated track, profile, aircraft type, airport and runway
- One of the following:
    - 2D tracks
    - 4D trajectories
    - Vector tracks (+ dispersion)
- Optional: fixed-point profiles (vertical profiles)
- Aircraft mapping to ANP database and AEM/BADA
- Optional: Landing, Take-off and Taxi times (AEM)
- Airport grid (only for STAPES)
- EEA population data: raster file (only for STAPES)

Outputs

- Calculated emissions (AEM)
- Emissions analysis (AEM)
- Gridded emission inventories (AEM)
- Log files (AEM)
- Noise contours (STAPES)
- Calculated noise grids (STAPES)
- Errors & Warnings (STAPES)

- Shapefile exports: gridded emission inventories, noise contours and tracks
- KLM files: noise contours and tracks (STAPES)
- Post-processing: noise-exposed population count (STAPES)

3.4 IMPACT Databases

IMPACT provides access to two databases that are necessary for noise and emissions calculation: ANP and AEM databases.

Aircraft Noise and Performance (ANP) reference data is used for the noise calculations; the data is mandatory. There are two ways to upload ANP data [95]:

- The IMPACT administrator can create a reference version accessible to all users of the web application. In that case, the uploaded file must contain a complete ANP version.
- Advanced noise practitioners can upload their own ANP version, either a complete version a partial one. The uploaded data will thus complete or modify the existing ANP version at the study level.

The ANP reference data contains the following tables/files:

- SPECTRAL_CLASS,
- AIRCRAFT,
- AIRCRAFT_MAPPING,
- AERODYNAMIC_COEFFICIENT,
- DEFAULT_APPROACH_PROCEDURAL_STEP, DEFAULT_DEPARTURE_PROCEDURAL_STEP,
- DEFAULT_FIXED_POINT_PROFILE,
- DEFAULT_WEIGHT,
- JET_ENGINE_COEFFICIENT,
- NPD_DATA and
- PROPELLER_ENGINE_COEFFICIENT.

The aircraft mapping is presented in more detail in section 3.5.

Similarly, AEM reference data is needed for emissions calculation. This data is also mandatory. The AEM data can be provided in the two following ways [95]:

- The IMPACT administrator can create a reference version accessible to all application users. In this case, the uploaded file should provide a complete AEM reference data version.
- Expert emissions practitioners can also provide their own AEM reference version, either a complete or a partial one. The uploaded data will replace or complete the existing AEM version at the study level.

The AEM database contains the following tables:

- ACT_PRF.AIRCRAFT_ENGINE,
- ACT_PRF.BADA_FUEL_BURN,
- ACT_PRF.ENGINE_LTO_VALUES,

- APT.AIRPORT_TIME_IN_MODE,
- AERO2K_TAXI_TIMES,
- APT.AIRPORT_DATA,
- AIRCRAFT_MAPPING,
- VOK_TOG, SYST_CONST,
- FLIGHT_LEVEL and
- AIRCRAFT_TIME.

The aircraft mapping is presented in more detail in section 3.5.

3.5 IMPACT Mapping Tables

The objective of the aircraft mapping in IMPACT is to link the input aircraft types to ANP and AEM types used in noise and emissions modelling. Only correctly mapped aircraft types can allow the pre-processing and running of environmental impact models. Mapped aircraft types are recognised by IMPACT and the platform is able to access information on the types' environmental performance.

The first step of the input data preparation process in IMPACT is to map the aircraft types present in the operation files of the study to ANP and AEM types listed in the corresponding databases. The following mappings are performed according to the study type:

- For noise studies, the input aircraft types have to be mapped to ANP types.
- For emission studies, the input aircraft types have to be mapped to AEM types.
- For studies on both noise and emissions, the input aircraft types have to be mapped to both ANP and AEM types.

Both AEM and ANP reference databases provide a default aircraft mapping table that can be used to search for aircraft types defined in the operations. Expert users can also upload a user defined aircraft mapping table to use an aircraft mapping of their own definition in the study. In this case, the aircraft types contained in the operations file are compared with the user defined aircraft mapping. A user defined aircraft mapping can be provided as a CSV file with the format shown below (Table).

Table 29 Fields of the user defined aircraft mapping table

Column Name	Definition
USER_ACFT_ID	User aircraft code
ICAO_CODE	Aircraft ICAO code
AIRFRAME	Aircraft type
ENGINE	Engine type

ANP_TYPE	Aircraft ANP code
DEP_MULT	Arrival multiplier
ARR_MULT	Departure multiplier
AEM_TYPE	Aircraft AEM code
BADA3_TYPE	Aircraft BADA3 code
BADA4_TYPE	Aircraft BADA4 code

In practice, the mapping is done by comparing successively different aircraft type descriptions (or fields) with those of the reference table; this is done in the following order: ACFT_ID, Airframe, Engine and ICAO_CODE (see Table and Table). The process is continued until a correspondence is found or until there are no more fields to compare. The aircraft mapping process is terminated when every aircraft type has been compared with types in the reference database. In case there are aircraft types for which an ANP and/or AEM code could not be found, the mapping must be completed manually by the user.

Table 30 Fields of the AEM mapping table

Column Name	Definition
User Aircraft	User aircraft code
Airframe	Aircraft type
Engine	Engine type
ICAO	Aircraft ICAO code
Aircraft	Aircraft AEM code

Table 31 Fields of the ANP mapping table

Column Name	Definition
User Aircraft	User aircraft code

Airframe	Aircraft type
Engine	Engine type
ICAO	Aircraft ICAO code
Aircraft	Aircraft ANP code
Arr Mult	Arrival multiplier for noise calculations
Dep Mult	Departure multiplier for noise calculations

4 FEASIBILITY OF DEVELOPING TPR MODELLING CAPABILITIES WITHIN IMPACT

The general requirements for a TPR model to be integrated into or interfaced with IMPACT might be formulated as follows:

- State-of-the-art European model, with components that have been proven and recognized for analysing third party risk at airports
- Adapted to general (European) airport settings and not only to one specific airport
- Feasibility of interfacing or integration with IMPACT in terms of required effort (both in terms of technical complexity and time-wise)
- In case of integration, preferably an open source TPR model or otherwise negotiable solution
- Input data readily available or at least obtainable in short -term perspective
- Model easily maintainable and adaptable to the needs of expert/advanced users
- Flexibility for instance in the choice between different modelling options, indicators to be calculated, etc.

In addition, the following aspects of TPR model characteristics remain to be defined:

- Calculation of only individual risk or both individual and societal risk
- Risk estimation at specific points in addition to the calculation of risk contours
- Functionalities for the definition and operation/management of Public Safety Zones

4.1 Existing Models vs. IMPACT-Specific Model

The results in Table 22 showed that TPR models are highly sensitive to changes in accident rate values, especially for high values of risk (10^{-4}). This means that the accuracy and confidence of input data should be as high as possible. With respect to accident rates, the optimal results may be reached by ensuring the correct grouping of aircraft with accurately predefined AR values for every group within a given level of confidence. The NATS model uses aircraft classes for grouping (see Table 12), including differences in AR for passenger and non-passenger aircraft. As a consequence, the number of groups with a specific AR value is around 20. The NATS model usually employs average AR values derived from worldwide air traffic data, but the approach also provides the possibility to use airport-specific ARs if the appropriate data exists for the aircraft fleet at the airport under consideration.

In the NATS model, the Boeing aircraft classes I–IV for jets and T1 and T2 for turboprops implement the idea that different aircraft generations need to be characterised by specific ARs. This is similar to the aircraft grouping based on generation in the NLR model. Both NATS and NLR models include a group for ‘Light aircraft’ consisting mainly of small private aircraft, the AR of which is much higher than that for commercial aviation. If military aircraft are operated in the airport under consideration, it is recommended to include a specific group for them as well, once again keeping in mind that today their AR is much higher when compared with civilian aircraft.

As the TPR methodology is primarily used to define PSZs near runways, IR contours are needed for current air traffic scenario, as for forecasted scenarios depicting the future traffic (in 5, 10 or 15 years' time depending on the requirements of national PSZ rules). It is therefore necessary to forecast AR values for these future scenarios, keeping in mind that they depend not only on historical data, but also on expected improvements in flight safety management at airlines and airports, aircraft navigation, air traffic control, etc.

The NATS model uses a specific accident location sub-model for the group 'Light aircraft' (Figure 20 and Eq. 25) different from the probability density functions that define the accident location sub-models for heavy aircraft. The accident location sub-models are based on specific coefficients for the distributions depending on the type of the accident (Eq. 23 and 24). The NLR model applies the same approach to accident location modelling as NATS does for heavy aircraft; light aircraft have the same lateral and longitudinal distribution functions in the form of Gamma, Gauss, Weibull and/or Laplace distributions as heavier aircraft. This approach is more solid from a mathematical point of view and offers more perspective for the further improvement of TPR modelling as a whole, and may be recommended for the TPR calculation module in the IMPACT platform. Historical accident data should be used for the definition of appropriate distribution functions and their coefficients for different aircraft groups.

Accident location sub-models are generally runway and track dependent as distribution functions are assessed in relation to the runways and nominal tracks (although in the UK model only the extended runway centreline is taken into account). For this reason, the correct definition of runways and nominal tracks is important for the TPR analysis results. The distribution functions are defined for nominal tracks, which are available for every airport and aerodrome, and it is not necessary to provide the data for individual flight trajectory distributions inside the flight corridors close to the airport. As the distribution functions are not dependent on flight paths at take-off and landing, it is not necessary to have information on aircraft flight details (4D trajectories) as for aircraft noise and emission calculations. For this reason, the TPR calculations are somewhat simpler than those for aircraft noise and emissions.

In IMPACT, it would be possible to use a combination of the third party risk approaches developed by NLR and NATS. This type of a hybrid approach is also used in Ukraine. The idea would be to divide the fleet into aircraft classes and, if possible, (as in the NATS methodology) to further divide the aircraft classes into smaller subgroups with specific AR values. For example, it would be possible to do this in function of the aircraft generation as in the NLR model. If there is no airport-specific data, worldwide average values could be used (as is done by NATS). As EUROCONTROL is a European organisation, the analysis might also be based on purely European accident data. On the other hand, if airport-specific data exists for any aircraft class or group (as for Schiphol in the NLR model), it might be preferable to use this data for greater precision. Perhaps the most important aspect in a third party risk model is how the accident location sub-model is defined. The accident probability sub-model is defined in accordance to aircraft classes and groups, which are in turn used in the accident location sub-model—this is the simplest solution for the TPR calculation module. In practice, the availability and quantity of data may of course limit the level of detail in terms of aircraft grouping.

It is currently too early to say which approach would be preferable (the NLR one, the NATS one or a combination of both) since the appropriate structure of the third party risk model—notably the probability density functions—require further assessment of the reference data. However, it should be noted that the general mathematical approach to defining the sub-model types used by both

NATS and NLR is the same, although the aircraft grouping is done differently. It is preferable that EUROCONTROL should define its own approach (including notably appropriate aircraft classes and probability density functions) based on the selected accident, movement and aircraft fleet data sources and accident characteristics at European airports. Ideally, the TPR model implemented in IMPACT would allow the combination of the benefits of the well-known European models, namely the NLR and NATS models. This type of a hybrid model approach would require the implementation of an IMPACT-specific third party risk model in the calculation platform.

4.2 Integration with IMPACT Workflow

The following schema (Figure 23) outlines how a TPR model might be integrated into the IMPACT workflow. The data-related aspects are further detailed in section 4.3.

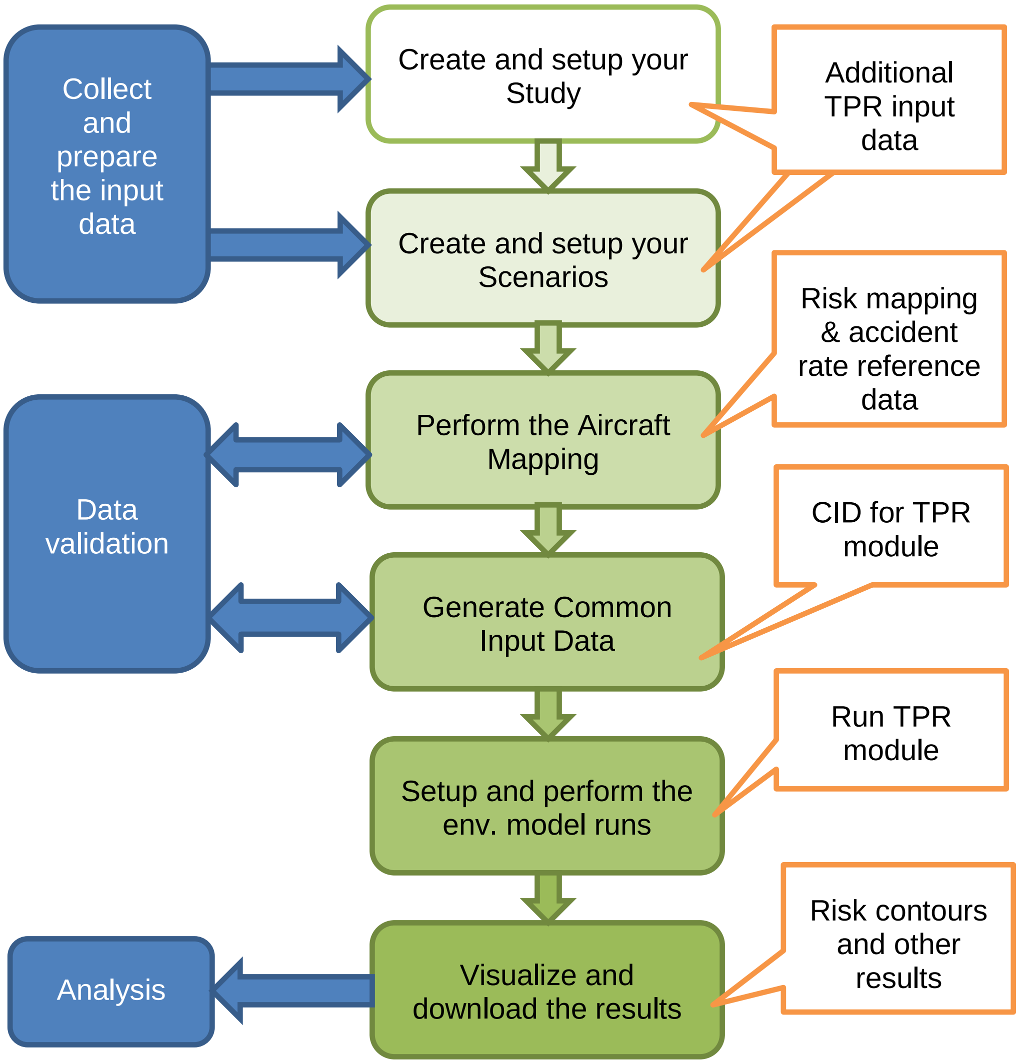


Figure 32 Integration of TPR modelling into the IMPACT workflow

Data preparation and validation is a mandatory step of any assessment in IMPACT. This consists of the two main steps:

- aircraft mapping,
- input data pre-processing for the generation of Common Input Data.

Once these two steps have been completed correctly, then the setup and runs of the environmental models can be performed for the selected scenarios.

The objective of the aircraft mapping is to perform the identification and, if necessary the substitution, of the input aircraft types by the IMPACT system. Only fully mapped aircraft types are allowed to be processed by the further assessment functions (pre-processing and model run), because IMPACT recognises them and is able to model their performances and environmental impact.

In current version of the IMPACT platform, the first step of the data preparation process is to map the aircraft types used in all the operation data files of the study to aircraft types that present in the reference databases (i.e. ANP and AEM):

- For a noise study, all aircraft types have to be mapped to ANP aircraft types.
- For an emission study, the aircraft types have to be mapped to AEM aircraft types.
- For a noise and emissions study, the aircraft types have to be mapped to both ANP and AEM aircraft types.

For TPR calculations the same principle might be proposed in order to specify the third party risk aircraft classes that the aircraft types of a scenario correspond to. The required database tables (reference tables) and mapping table are detailed in sections 4.3.2 and 4.3.3.

4.3 Required Data Structures

The generic input data requirements for TPR models can be presented as follows, when analysing them based on the general threefold model structure (accident probability, accident location and accident consequence sub-models):

Accident Probability Model

- Definition of aircraft classes (divided for passenger and non-passenger transport), generations and accident types in such a way as to combine the benefits of NATS and NLR models. (For every aircraft class, 3–4 generations' data might be defined). A database table for ARs could be presented in the general case as [class, flight type, generation, accident type], and it could be included in the database tables of IMPACT.
- Historical data on air traffic, aircraft fleet and accident types should be given for the predefined structure [class, flight type, generation, accident type]. For every class, the take-off mass is defined and included in a specific field of the DB table.
- Definition of the distribution of accident types either for all aircraft classes generally or specifically for every aircraft class: this requires the definition of a database table linking aircraft classes to accident types.

Accident Location Model

- Information on the runway and track layout: this information already exists in IMPACT (list of runways, latitude and longitude for runway ends, and list of track points).
- Coefficients for the probability density functions for every accident type and aircraft class under consideration may be presented in DB tables or directly included in the code of the calculation module of the software tool.
- Grid point coordinates, calculated in function of the radius of an average accident impact area, for which the accident crash probabilities should be calculated.
- To simplify the analysis, terrain characteristics could be excluded from the analysis.
- Dangerous installations on a ground (e.g. fuel storage) might also be excluded from the analysis.

Accident Consequence Model

- Historical data on accident consequences per type of accident and aircraft class (or weight) or a mathematical model for determining the impact area and accident lethality e.g. based on aircraft weight. If historical data is available, it should be stored in the DB on accident statistics. Information on weight (MTOW) values might be included in the AR mapping table.

Public Safety Zones

- In addition, if the TPR tool is to provide support for the definition of Public Safety Zones, the user would need to define a set of risk threshold values; a set of default values might also be proposed, e.g. 10^{-4}, 10^{-5}, $5 \cdot 10^{-5}$ and 10^{-6}.

The detailed specifications for input data, reference tables (databases) and the mapping table are presented in the following sections.

4.3.1 User Input Data

Study and scenario level data for third party risk calculations should be come from existing IMPACT files: Airports, Runways, 2D tracks and Operations. The user is simply required to upload these default data to be further exploited in TPR calculations, keeping in mind that Airport and Runways can only be uploaded at the study level.

Each scenario inherits data from the study level. The user can override some of the data, notably by uploading aircraft movement (operations) or track data at this level. The scenario-level input files include currently operations and aircraft tracks/trajectories (4D trajectories, 2D tracks or vector tracks).

It should be noted that for third party risk, it might be interesting to be able to analyse the impacts of different runway or track configurations; in the current IMPACT configuration, this can only be done by creating several studies as the runway data cannot be overridden at the scenario level. Should we wish to study the impacts of changes in population near the airport, the user might also be given the possibility to upload his own population data (at the scenario level).

The input data pre-processing generates the CID for the selected scenario as a data set corresponding to:

- airspace definition i.e. airport and runways—this data is also necessary for TRP calculations;
- operations—this data is also necessary for TPR calculations (it provides the number of movements for a given runway and track);
- description of the flight tracks expressed by in two dimensions (latitude and longitude) or flight trajectory in four dimensions (latitude, longitude, altitude, date and time) along with flight attitude and performance information (speed, thrust)—detailed flight data is not required for TPR calculations; however, a description of the airport's nominal tracks in two dimensions (latitude and longitude) is required for TPR calculations (accident location model).

The input data requirements for third party risk modelling are summarized in Table 32.

Table 32 Input data requirements of TPR modelling

Input data	Data purpose	Exists in IMPACT, name of the file	Additional information
Airport data	IR calculation (grid)	Yes, Airport	Study level; CID for environmental models
Runway data	IR calculation (accident location model)	Yes, Runways	Study level; CID for environmental models
Track/trajectory data	Actual flight data not required; nominal track data required for IR calculation (accident location model)	Yes, 2D tracks / Vector tracks	Study or scenario; level CID for environmental models
Aircraft movements (by aircraft type and track)	IR calculation (accident probability model)	Yes, Operations	Study or scenario; CID for environmental models
Population data	SR calculation	Yes, population density map (raster file)	European census data (EEA's Corine Land Cover 2000 inventory); post-processing tool
Locations of buildings	SR calculation	No	This might be either Study or Scenario level data or provided in post-processing;

			required to define the number of buildings to be relocated

With respect to the airspace definition, the following data are required for TPR calculations (see Table 33 and Table 34).

Table 33 Airport data for TPR calculations

Field name	Description	Correct values	Purpose
APT_ID	The name of the airport		Risk grid; might also be used to retrieve apt-specific accident rates
REF_POINT_LAT	Aerodrome reference point latitude (in decimal degrees)		Required for risk grid
REF_POINT_LON	Aerodrome reference point longitude (in decimal degrees)		Required for risk grid

Table 34 Runway data for TPR calculations

Field name	Description	Correct values	Purpose
APT_ID	The name of the airport		To connect the runway to an airport
RWY_ID	The runway identifier		To connect the operation to a specific runway
START_X	The runway start X coordinate in Cartesian reference system (m/ft/nm)		Runway coordinates for accident location model
START_Y	The runway start Y coordinate in Cartesian reference system (m/ft/nm)		Runway coordinates for accident location model
END_X	The runway end Y coordinate in		Runway coordinates for accident location model

	Cartesian reference system (m/ft/nm)		
END_Y	The runway end Y coordinate in Cartesian reference system (m/ft/nm)		Runway coordinates for accident location model
START_LATITUDE	The runway start latitude (in decimal degrees)		Runway coordinates for accident location model
START_LONGITUDE	The runway start longitude (in decimal degrees)		Runway coordinates for accident location model
END_LATITUDE	The runway end latitude (in decimal degrees)		Runway coordinates for accident location model
END_LONGITUDE	The runway end longitude (in decimal degrees)		Runway coordinates for accident location model

Nominal tracks could be defined in IMPACT as 2D Tracks (Table 3) or Vector Tracks.

Table 35 Nominal track data for TPR calculations

Field name	Description	Correct values	Purpose
APT_ID	The name of the airport		To connect the runway to an airport
RWY_ID	The runway identifier		To connect the operation to a specific runway
OP_TYPE	The operation type (departure or arrival)		Operation type for accident location models
TRK_ID	The track identifier		Track id for accident location model
POINT_NUM	The ordered number of the point of the trajectory		Track coordinates for accident location model
X	The X coordinate of		Track coordinates for accident

	the point in the Cartesian reference system centred on the airport (m/ft/nm)		location model
Y	The Y coordinate of the point in the Cartesian reference system centred on the airport (m/ft/nm)		Track coordinates for accident location model
LATITUDE	The point latitude (in decimal degrees)		Track coordinates for accident location model
LONGITUDE	The point longitude (in decimal degrees)		Track coordinates for accident location model

The Operations input file provides a way to provide data on aircraft movements. The following fields of the file are necessary for TPR calculations (Table 36).

Table 36 Operations data for TPR calculations

Field name	Description	Correct values	Purpose
OP_TYPE	The operation type	A, D	To define flight stage – take-off (D) or landing (A)
ACFT_ID	The aircraft type		To define aircraft type and aircraft class
ICAO_CODE	The aircraft ICAO code		To define aircraft type and aircraft class
RWY_ID	The runway identifier		To connect the operation to a specific runway
TRK_ID	The track identifier		To connect the operation to a specific runway and track
NUM_OPS_DAY	The number of identical operations in the day period		To define the number of movements
NUM_OPS_EVE	The number of identical operations in the evening period		To define the number of movements

NUM_OPS_NIGHT	The number of identical operations in the night period		To define the number of movements

The fields NUM_OPS_DAY, NUM_OPS_EVE and NUM_OPS_NIGHT can be used to calculate annual movements at the airport under consideration. A new field might also be added to provide the total number of movements.

Calculation Parameters

In addition to the input data, the user might be required to select several calculation parameters such as the risk indicators to be calculated (IR and/or SR) and/or to define Public Safety Zone criteria values.

4.3.2 Reference Tables

The table below (Table 37) contains a list of fields for the accident rate reference table. The given examples are merely illustrative; the values would have to be defined more closely based on detailed analysis.

Table 37 Reference table for accident rates

Field	Description	Examples (illustrative only)
Flight stage	Flight stage / operations type: arrival/departure	A, D
Flight type	Flight/operation type	Passenger, cargo, …
Aircraft class	Aircraft class	Jet, turboprop, executive jet, …
Aircraft generation	Aircraft generation	1, 2, 3, …
MTOW class	MTOW class	Heavy, medium, light, …
Accident type	Accident types for different accidents	Undershoot, overrun, …
Airport id	Airport id for retrieving apt-specific accident rates (potentially an option for expert users)	LPPT, LPPR
Accident rate	Historical accident rate value per 10^6 movements	

An optional accident location table is presented below (the values might also be hard coded in the TPR module). Advanced users might be given the possibility to override the default values by uploading their own data for accident location calculations (distribution function and its parameters values for a given accident type).

Table 38 Reference table for accident locations

Field	Description	Examples (illustrative only)
Accident type	Accident types for different types of take-off and landing accidents	Take-off/landing undershoot, overrun, …
Distribution	Direction of the accident distribution	Longitudinal, lateral
Function	Probability density function	Weibull, Gauss, …
Parameter list	Parameter list for the pdf	η, α, β, …
Parameter values	Parameter values for the pdf	

4.3.3 Mapping Table

The table below (Table 39) contains a list of fields for the aircraft mapping table. The given examples are illustrative; the values would have to be defined more closely based on detailed analysis.

The aircraft types should correspond to the ones given in the operations data. In the aircraft mapping step of the IMPACT workflow, the aircraft types in the movements/operations file will be matched to ones listed in this mapping table. If no correspondence is found, an additional manual mapping step could be added.

Table 39 Aircraft type mapping table

Field	Description	Examples (illustrative only)
Flight stage	Flight stage / operation type: arrival/departure	A, D
Flight type	Flight/operation type	Passenger, cargo, …
Aircraft class	Aircraft class	Jet, turboprop, executive jet, …
Aircraft generation	Aircraft generation	1, 2, 3, …

MTOW class	MTOW class	Heavy, medium, light, …
MTOW	MTOW in kg	
Aircraft type	Aircraft type corresponding to the operations data (e.g. ICAO code)	A320, B747, …

In addition to using a default mapping (set by the IMPACT administrator), it would be possible to allow users to upload their own mapping table and related reference tables. Advanced users might thus define their own aircraft categories with related accident rates for a customized study.

4.4 Post-Processing Issues

Like in noise calculations, the airport grid for risk calculations is the rectangular geographic grid around each airport on which the IR is to be computed. In noise and emission modelling, the airport grid is defined within an XY Cartesian coordinate system centred on the airport reference point as provided by the Airport input file [95]:

- The grid is divided into cells of dimension ΔX and ΔY (the units of length of the coordinate system).
- The grid dimensions are defined by Nb *X*, the number of cells of size ΔX along the X-axis, and Nb *Y*, the number of cells of size ΔY along the Y axis. (One cell has 2 points along each axis.)
- The origin of the grid is determined by the position of its bottom left corner, specified as the distance in nautical miles to the airport reference point on the X and Y axis: *OriginX* and *OriginY*.
- The grid X axis can be aligned with one airport runway by specifying the azimuth of the runway direction in “Rotated”.

For the risk grid, the same general scheme might perhaps be used but the fact that the risk grid is linked to the runway ends should be taken into account. The TPR model must compute IR values for the cells of the grid. Further cell values should be used for creating risk contours as threshold value polylines on the grid. It is helpful to anticipate where the risk contours will be located by employing the following methods:

- Identify the location of the approach and departure tracks.
- Optimise the threshold values, if possible.
- Run the scenario with a large grid and a large number of thresholds, view the results, optimise the grid and process the run again.

For risk calculations, the cell dimensions ΔX and ΔY are defined by the radius of the impact area, which is defined by the TPR model, in such way as to provide better accuracy for creating contours. The grid size is generally smaller for third party risk calculations than for noise modelling; however, IMPACT’s noise grid with a small grid size is also suitable for determining noise contours.

The final risk results display screen should provide the list of the generated contours by scenario, risk threshold value and airport. The existing noise results display might be used to display risk contours.

The population count tool in IMPACT used for determining the number of people exposed to a particular noise level might perhaps be used to calculate people inside a given risk contour.

IMPACT produces output files containing geo-references. More commonly called shapefiles, these files are designed to include the geographical coordinates, the used projection, the geographical shape as a vector and other associated information. IMPACT shapefiles are defined as a set of several files which must be used together, with the following suffixes: .dbf, .shp, .prj, .fix, .qix, .shx. They are compatible for use with TPR contours.

4.5 Potential Data Sources

4.5.1 EASA

European data on aircraft accidents could probably be provided by EASA, as this organisation notably publishes an Annual Safety Review [97]. This review differentiates between fatal and non-fatal accidents and on-board and ground (i.e. third party) fatalities (Table 40). The EASA data details the number of accidents by aircraft mass category (2,251–5,700 kg, 5,701–27,000 kg, 27,001–272,000 kg and >272 000 kg) [97]. In addition, accidents taking place at aerodromes (Figure 33) are reported based on the occurrence category (runway excursion, ground collision, ramp accidents, bird strikes, etc.) [97].

Table 40 Number of aircraft accidents and fatalities for EASA MS operators [97]

Period	Total number of accidents	Number of fatal accidents	Number of on-board fatalities	Number of ground fatalities
2002-2011 (average per year)	24.6	2.3	59	0.2
2012	33	1	0	1
2013	18	0	0	0

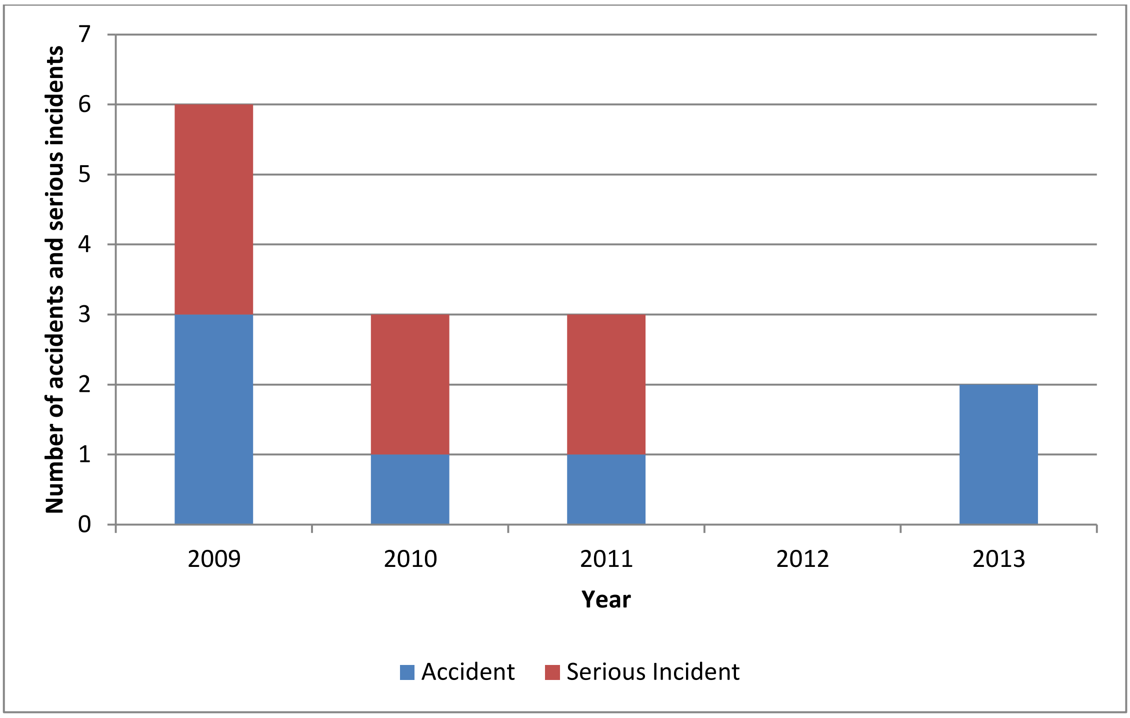


Figure 33 Number of accidents and serious incidents at EASA MS aerodromes

The EASA data is collected from various sources, notably [97]:

- Accident and serious incident data for most aircraft categories is from EASA's ADREP database,
- Light aircraft accident data is provided by EASA Member States,
- ATM data is provided by EUROCONTROL,
- Air transport statistics are provided by EUROCONTROL and by EUROSTAT,
- Exposure data for commercial air transport is provided by Ascend.

4.5.2 ECCAIRS

The European Commission promotes centralised aviation safety data collection; the data collection is done using a common information system called the European Coordination Centre for Accident and Incident Reporting System (ECCAIRS) [97]. ECCAIRS provides a standard format for the storage of accident data from European states and enables their collection in a centralised database, the European Central Repository (ECR) [97]. ECCAIRS also has a web-based portal [98].

Directive 2003/42/EC on Occurrence Reporting in Civil Aviation made it compulsory for Member States to make "all relevant safety‑related information" available to the competent authorities of other Member States and the European Commission [97]. In addition, the Member States were required to ensure the compatibility of their databases with the ECCAIRS software [97]. The Commission Regulation (EC) No 1321/2007 also later obliged the Member States to integrate their occurrence data into the ECR database [97].

4.5.3 EUROCONTROL

EUROCONTROL is currently responsible only for reporting ATM-related accidents. The Safety Analysis Function EUROCONTROL and associated Repository (SAFER) system is the principal tool of EUROCONTROL's safety data analysis work [99]. SAFER consists of a European ATM Safety Data Repository, fed by various regulatory and voluntary data flows from Member States, airspace users and ANSPs [99]. SAFER provides the ATM component of the EC's aviation-wide reporting system based on ECCAIRS [99].

EUROCONTROL also established a Safety Data Reporting and Data Flow Task Force (SAFREP) as a first step towards establishing a set of Key Performance Indicators for safety in ATM [99]. SAFREP proposed a set of 'lagging' indicators to capture a posteriori the safety performance of the ATM system [99]. These indicators are [99]:

- Accidents with direct and indirect ATM contribution,
- ATM-related incidents,
- Separation Minimum Infringements (SMI) (airborne incidents),
- Runway incursions (ground incidents).

EUROCONTROL has also established EVAIR (EUROCONTROL Voluntary ATM Incident Reporting) system as a part of SAFER [100]. This voluntary ATM incident reporting system is used by air navigation service providers, aircraft operators and airports [100].

EUROCONTROL's ATM accident data is also used as a source for EASA's Safety Review [97].

Together with accident data (either from internal or external sources), EUROCONTROL's data on European air traffic (PRISME) can be used to calculate accident rates (per million movements). Additional information on the aircraft types and operating airlines (e.g. from PRISME Fleet) can be used to determine specific accident rates for different aircraft classes and generations.

4.5.4 Eurostat

Eurostat collects data on transport safety, number of accidents and fatalities in EU Member States, EFTA and candidate countries [101]. This data covers all transport modes, namely road transport, rail, waterways and air. However, the Eurostat data does not seem to distinguish between on-board and ground fatalities. In addition, both datasets (number of injury accidents and number of fatalities in injury accidents) have incomplete data series [102]. Data is collected under a questionnaire on air transport safety statistics and is not supported by any legal acts [102].

4.5.5 ICAO

Contracting States of the Chicago Convention are required to report to ICAO information on all accidents involving aircraft of an MTOW of over 2,250 kg [103]. ICAO also gathers other information on aircraft incidents considered important for safety and accident prevention [103]. For this purpose, ICAO operates and maintains the Accident/Incident Data Reporting (ADREP) system [103]. The ADREP system (initially established in 1976) stores accident and incident occurrence data [103].

ADREP contains a data bank of world-wide accident and incident occurrences; this data allows ICAO to provide the following services [103]:

- a bi-monthly summary of reports received from States, providing an up-to-date picture of significant occurrences on a world-wide basis;
- annual ADREP statistics, presenting statistical information under broad categories such as the types of events and the phases of operation in which they occurred;
- replies to States' requests for specific information.

ICAO also publishes an annual Safety Report [31] providing information on accident rates and categories. However, the ICAO report does not single out third party fatalities.

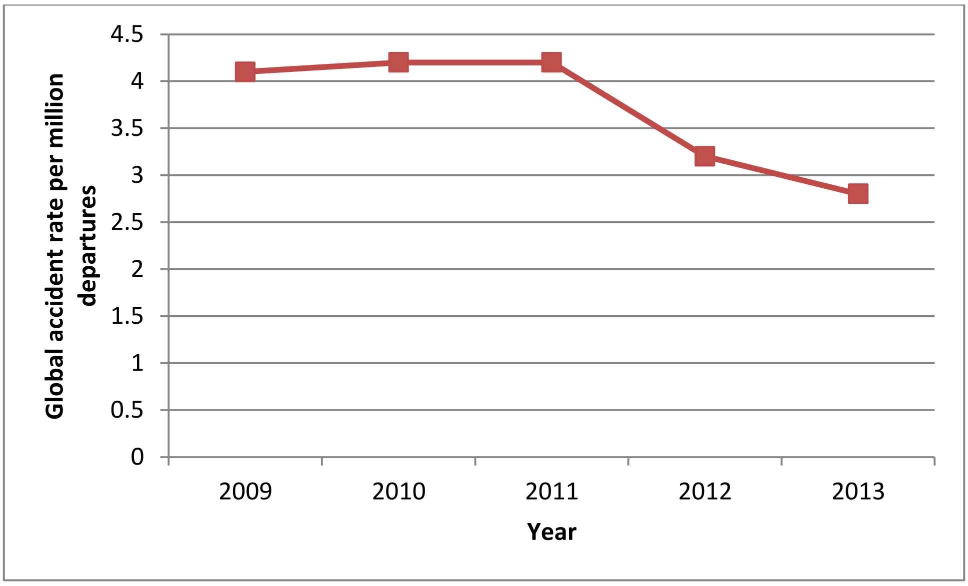


Figure 34 Global accident rate statistics [31]

The ICAO Accident/Incident Reporting Manual (ICAO Doc 9176) provides States with details on how accident reporting should be done [103]. The reporting was originally based on a manual system using forms and formats described in Doc 9176 but electronic means of reporting are now available [103].

The ADREP system operates on the European software platform ECCAIRS; this platform was adopted for ADREP use in 2004 [103]. In January 2009, 45 States and 7 international organizations had installed the ECCAIRS software and reported occurrences in the ECCAIRS format to ICAO [103].

4.5.6 National Data Sources

In addition to European and international organizations, there are also various national bodies collecting aircraft accident data. Notably, the US National Transportation Safety Board (NTSB) can be called in to investigate all accidents involving US-manufactured aircraft. NTSB also has its own aviation accident database [104]. There are also various other national authorities responsible for investigating air crashes such as the French BEA, Canadian TSB and UK AAIB. In addition, civil aviation authorities can collect accident data (the accident investigation agencies are generally independent of the CAA).

4.5.7 Other Data Sources

Accident data sources listed by NLR reports include Airclaims, ICAO ADREP, NTSB, KIMURA, Breiling and Airline Pilots Association (ALPA) [77]. The data sources listed for the NLR's accident location model include ADREP, ALPA, Airclaims, NTSB and CAA [77]. The accident consequence information was composed mainly from NTSB accident reports, completed with information from the internet, ICAO summaries and other sources [77]. Airclaims is a commercial organisation (now part of McLarens Aviation).

Accident data sources listed by the UK Department of Transport consultants include notably World Airline Accident Summary (WAAS), ICAO ADREP, CASE database maintained by Airclaims and Mandatory Occurrence Reporting Scheme (MORS) of the UK CAA [43]. WAAS is researched and published by Ascend on behalf of the UK CAA.

4.6 Intellectual Property Rights of Existing TPR Software

This section presents briefly the IPR situation for the two most well-known European TPR models, namely the NATS and NLR models. The methodologies for both models are in the public domain (they have been described in various reports and scientific articles) and could be used as a basis for an IMPACT-specific implementation. There are currently no open source software implementations that might be interfaced with the IMPACT platform. Proprietary software versions exist but the use of these would have to be negotiated with the owners of the property rights.

NATS and NLR both offer consulting services in the implementation of their TPR methodology; if required, these services might also be engaged by EUROCONTROL to assist in the development of an IMPACT-specific third party risk model.

4.6.1 NATS Model

The NATS methodology (developed for the UK Department for Transport) has been described extensively in various reports [43, 67, 70]. However, there is no commercially available software tool based the methodology. The property rights of any existing software models as well as their source code can be assumed to be the property of the UK Department for Transport. The freely available description of the NATS methodology could be exploited to implement a TPR model based on this methodology in the IMPACT platform.

4.6.2 NLR Model

The NLR model and its equations have been described in great detail in various scientific reports [57, 72, 74]. A full description of the methodology is also available in Annex 2 of the Dutch Aviation Law [105].

The following information on the NLR model is based on a personal communication with Mr Leo de Haij from NLR [106].

There are currently three software versions of the NLR TPR model. These versions were developed in different time periods by NLR and external parties but are all based on the NLR methodology formulated in appendices to the Dutch law. By prescribing the risk model by law, the Dutch Ministry of Infrastructure and Environment has invited all (public) parties to use the model and to develop software based on it.

The three versions of the NLR model are TRIPAC, GEVERS 1.0 and GEVERS 2.0. The differences between the different implementations are presented in the following table (Table 41).

Table 41 Comparison of existing software versions of the NLR model [106]

Version name	Development period	Purpose	Version used by	Risk calculation module and GUI development	Access to code
TRIPAC	2000–present	Full version for model development, model update, model analysis and national & international risk assessments	NLR	Risk calculation module developed by NLR; GUI developed by NLR	NLR
GEVERS 1.0	2008–2010	Full version for national risk assessments	Public	Risk calculation module based on NLR TRIPAC; GUI developed by external party	NLR/external party
GEVERS 2.0 (under development)	2014–present	Reduced version for national risk assessments	Public	Risk calculation module developed by external party based on open source / open data characteristics; GUI developed by external party	External parties

With the exception of TRIPAC which is a proprietary software version (the rights of which are owned by NLR), the development of the theoretical model and GEVERS software has been supported and funded by the Dutch government. For this reason, the Ministry of Infrastructure and Environment has the ownership and property rights.

5 CONCLUSION

Airports create anthropogenic pressure on environment due to the simultaneous presence of hazardous constituents of different genesis and the unfavourable positioning of their sources. Placement and functioning of different stationary objects (mechanical and galvanic stations, storage for fuels and lubricants, painting stations and pumps for petroleum products transportation, boiler installations), vehicles, etc. in the powerful commercial aviation systems cause the convergence in time and place of a significant number of hazardous factors (threats), and significantly enhance their negative impact on the population and environment around airports. One of the dominant environmental hazards specific to airports is aircraft accidents and incidents. Aircraft accidents and incidents may cause spills of toxic substances into the environment (accidental discharge of fuel and lubricants from an aircraft crash), fires or explosions, destruction of material assets and/or direct damage/injuries/fatalities involving people living or passing near the crash site. The risk of these negative consequences is called third party risk.

In the European Union, the construction of airports with a basic runway length of 2,100 m or more is according to Article 4 of the Directive 2011/92/EU subject to environmental impact assessment [5]. The ICAO Airport Planning Manual (Doc 9184) [11] includes TPR issues in its Part 2 on Land Use and Environmental Control together with local air quality and noise issues; all of these issues mainly impact the population living close to airports.

The EU Directive Seveso III [7] requires the Member States to limit the consequences of major accidents for human health and the environment in their land-use policies; this is done by controlling the siting of new establishments and developments including transport routes, locations of public use and residential areas when these developments may create or increase the risk or consequences of a major accident. In addition, appropriate safety distances should be maintained between major transport routes and residential areas, buildings and areas of public use, as far as possible. Public Safety Zones (PSZ) are defined as areas of land at the ends of runways, within which development is restricted in order to limit the number of people on the ground exposed to a risk of death or injury from an aircraft accident on take-off or landing [8, 11]. PSZs around airports are the particular examples of the Seveso policy requirements in EU Member States.

Two measures of risk are mainly used in TPR analyses: individual risk and societal risk. Individual risk represents the probability that a person residing permanently at a particular location in the airport vicinity is killed as a direct consequence of an aircraft accident. Individual risk is used in TPR contours assessment and in Public Safety Zone definition. While individual risk is location-specific, societal risk applies to an entire area around the airport. Societal risk is defined as the probability that a given number of people are killed. The F_N-curve represents the cumulative distribution of multiple fatality events and is therefore useful in the representation and assessment of societal risk.

Individual Risk to life has a range of numerical values [42]:

- Accidents with a death rate 10^{-6} are not usually noticed by the society; however, accidents with a frequency of 10^{-3}–10^{-4} are regarded as something to be prevented.

- The permitted level of individual risk, for which regulatory action is taken to reduce public risk, is identified in a range between 10^{-4}–$5 \cdot 10^{-5}$ per year. In some cases, the regulatory effect can be applied at lower values of risk depending on the number of population, which is exposed to a hazard.
- The minimum level of individual risk, which does not require regulatory action to reduce public risk, can be given at 10^{-7}.
- The upper limit of acceptable risk to a third party in the vicinity of a power plant or transport network is around 10^{-4} per year (usually it is predefined legally from how the risk is perceived by society and hence regulatory authorities: it reflects the culture of the society and changes with time as more information becomes available)

The main calculation formula of current TPR models involves three main components: accident probability $P(I)$, accident crash location conditional probability $P(G|I)_{ijk}$ and accident consequence conditional probability $P(T|G)_{ij}$. As a consequence, TPR models rely in general on three main building blocks: accident probability, accident location and accident consequence models. The probability of an aircraft accident in the vicinity of an airport is calculated based on the probability of an accident per aircraft movement and the number of movements (landings and take-offs) per year. Risk dependence on location is represented by accident location models. The distribution of accident locations can be modelled through statistical functions as a function of the distance to arrival and departure routes or to the runway. By bringing together the accident location model and the accident probability, the local probability of an accident can be calculated at each location in the airport vicinity. The dimensions (or simply a given radius) of the impact location area depend on various aircraft and crash-related parameters (aircraft size, quantity of fuel on board, impact angle, etc.) and on the characteristics of the terrain. The influence of these parameters as well as the impact area and the accident consequences are defined by a consequence model. The lethality is in this respect defined as the actual probability of being killed within the impact area.

A number of third party risk models exists and are used for SR assessment for the airports under consideration, for IR calculations in points of risk control or for determining IR contours. The most well-known and used models—and particularly the original European models created by NATS Model (UK and Ireland) and NLR—were analysed and compared.

EUROCONTROL's environmental calculation platform IMPACT was analysed in view of establishing third party risk calculation capabilities in the future in addition to the existing tools of aircraft noise, fuel burn and engine emissions assessment. The analysis of IMPACT and TPR models showed that the existing database structure could be relative easily extended to accommodate TPR input, mapping and reference data which are in many ways analogous to the existing noise and emissions data. In addition, the input data required for noise and emission calculations already covers a large share (if not all) data required for determining third party risk. Data on aircraft movements and airport (runway and tracks layout) used in noise and emissions inventories are in general similar to the data required for TPR calculations. Additional data structures are only required to provide data on the accident rates for different aircraft classes and accidents types, and to map aircraft types present in movements data to aircraft risk classes. In terms of complexity, the development of a TPR model is more comparable to an aircraft emission model that noise or local air quality models.

This report recommends the development of an IMPACT-specific third party risk model based on a mathematical analysis of historical (European) accident data. This calculation module could combine the best elements from both the NLR and the NATS methodologies. The description of these third party risk models (information on calculation formulas, distribution functions and parameter values) is available in various public documents and can therefore be freely exploited. EUROCONTOL could base the development of its own third party risk module (in terms of accident rates, accident locations as well as consequences) on historical data on aircraft accidents at European airports obtained from EASA, ECCAIRS and other sources. In addition, EUROCONTROL's own traffic and fleet data could be used to further characterize accident rates for different aircraft classes.

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7. APPENDIX: GLOSSARY

Term	Definition
Accident rate	Accident rate is defined as the ratio between the number of accidents a given year and the number of flights during that same year
Aircraft crash	Bringing the aircraft on the ground in an abnormal manner, usually causing severe damage
ALARP	As low as reasonably practical—an approach usually used for risk assessment and analysis, keeping in mind that zero risk is usually impossible to achieve
Aviation accident	An aviation accident is defined by Annex 13 of the Convention on International Civil Aviation as an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until all such persons have disembarked, and where a person is fatally or seriously injured, the aircraft sustains damage or structural failure or the aircraft is missing or is completely inaccessible
Aviation incident	An incident is defined as an occurrence involving one or more aircraft in which a hazard or a potential hazard to safety is involved but not classified as an accident due to the degree of injury and/or extent of damage
Capacity	Characteristic opposite to vulnerability: the ability of a person, group or society to anticipate, cope with, resist and recover from the impacts of a hazard; positive managerial capabilities of a receptor to confront the threat of disasters, accidents, etc.
Damage	Act or event that causes something to no longer be in good condition
Danger	Combination of conditions or situations that may result in harm to human health or the environment, or in material damage
Exposure	Phenomenon describing a stressor's contact with a receptor
Exposure assessment	Used to determine the number of people and the type of population falling under the influence of a particular stressor and the magnitude, path of action, start and duration of exposure

Fatality	Death resulting from an accident or disaster
Hazard	Potential to cause damage
Individual risk	The probability that a person permanently residing at a particular location in the airport vicinity is killed as a direct consequence of an aircraft accident; location-specific risk
Injury	Act or event that causes someone to no longer be in full health
Lethality	Causing or capable of causing death
Probability density function	Function that describes the relative likelihood for the random variable to take a given value
Public Safety Zone	Public Safety Zones are areas of land at the ends of the runways at the busiest airports, within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing
Receptor	Entity that is exposed to a stressor
Risk	Possibility of damage or loss in terms of health, human life, man-made infrastructure or natural ecosystems
Risk assessment	Systematic approach to estimate the burden of disease and/or injury resulting from different hazards
Risk analysis	Approach in which data are evaluated in order to determine the path and exposure of stressors that is most likely to occur (exposure characteristics), and, based on this exposure, to determine the type and impacts (effect) which can be expected (type of damage)
Risk characterization	Summary of the assumptions, evidence-based uncertainty, reliability and limitations of risk analysis
Risk management	Decision-making process to select the optimal steps for reducing a risk to an acceptable level
Safety	Property of a system not to cause damage to human health or the environment

Societal risk	The probability that a given number of people present around the airport are killed as the consequence of an accident; societal risk is zero if the population is zero
Stressor	Any physical, chemical or biological entity (phenomenon, object, substance, etc.) which may cause unacceptable response or damage; synonyms: agent or factor
Third party risk	Risk is known as third party risk when the people exposed are not related to the source of the danger, for instance people living in airport vicinity for aviation third party risk; synonym: external risk
Threat	Possible source of harm or danger, or the condition of being in danger or at risk
Vulnerability	Set of conditions determined by physical, social, economic and environmental factors or processes increasing the susceptibility of a receptor (a community or an individual) to the impacts of hazards; inability to avoid or absorb potential harm in case of exposure to risk

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