Dublin Airport North Runway

Relevant Action Application

Environmental Impact Assessment Report Technical Appendices (Volume I)

December 2020

daa

DublinAirport

AECOM Imagine it. Delivered.

Prepared for:

daa

Project number: PR-407849

Prepared by:

AECOM Ireland Limited

4th Floor

Adelphi Plaza

Georges Street Upper

Dun Laoghaire

Co. Dublin A96 T927

Ireland

T: +353 1 238 3100

aecom.com

Bickerdike
Allen
Partners
Architecture
Acoustics
Technology

daa

DublinAirport

AECOM Imagine it. Delivered.

Environmental Impact Assessment Report

Technical Appendices: Volume I

Table of Contents

Appendix: 8

Major Accidents and Disasters

Technical Appendix A8: Crash Risk Assessment Methodology

Table of Contents

A8.1 Introduction and Methodology Outline

A8.1.1 A variety of different models have been developed to provide quantitative estimates of the risks to third parties in the vicinity of airports, following the approach outlined in Section 9.3 of the EIAR Hazard Chapter. One such model is the UK Department for Transport (DfT) model [1,2] that was developed in the 1990s to support the development of a revised UK Public Safety Zone (PSZ) policy. That modelling approach was adopted in the study [3] of third party risks at airports in the Republic of Ireland, undertaken on behalf of the Department of Transport and the Department of Environment, Heritage and Local Government (DoEHLG), that recommended the adoption of a PSZ policy broadly similar to that in use in the UK in 2005. Taking account of the precedent set by that study and its previous use for the definition of PSZs at Dublin Airport, the DfT model has been employed as the basis for this assessment with some minor modifications.

A8.1.2 As described in the Major Accidents and Disasters Chapter of the EIAR main report, , site-specific risks to the public in the vicinity of airports can be estimated quantitatively by using an empirical modelling approach, based on historical accident data that characterises risk by reference to three key parameters as follows:

- The likelihood or probability (frequency per annum) of an aircraft crash occurring during take-off or landing operations;
- The probability of impact at any specific location at or near an airport relative to the runway end and the extended centreline;
- The severity of the consequences of an impact on the ground.

A8.1.3 Model implementation is dependent upon two key sets of input assumptions:

- The number of take-off and landing operations at each runway and the associated fleet mix which determine the probability of a crash and the severity of the consequences for the operations at a given airport;
- The geometry of the runway system concerned, in the case of Dublin Airport involving the north and south parallel runways, Runway 10L/28R and Runway 10R/28L, and the cross runway, Runway 16/34 and the associated flight paths.

The various operational and risk model assumptions employed in this assessment are set out in Section A8.2A8.2.

A8.1.4 Two distinct measures are available for characterising the risks estimated by airport-related crash risk models, as follows:

- Individual risk: the annual probability of fatality for a hypothetical resident present at any given location relative to the runway threshold and associated flight paths;
- Societal risk: the annual probability of accidents causing any given number of fatalities in any particular area of development, taking account of the nature of the development, in particular the density of occupancy.

Both measures have been employed in this assessment. Detailed accounts of the assessment of the individual risks and societal risk associated with the relevant operational scenarios are presented in Sections A8.3 and A8.4A8.4.

A8.1.5 There will inevitably be limitations to the reliability of any quantitative risk model. Some consideration has been given to the possible limitations of the DfT model, as set out in Section A8.5, and it is concluded that this modelling approach, as implemented here with some minor modifications, provides a sound basis for assessing the implications for public safety of the proposal to change permitted operations at Dublin Airport.

A8.2 Risk Model and Operational Assumptions

A8.4.1 Aircraft Crash Rates

A8.2.1 In accordance with the standard approach adopted in the UK DfT Model, historical accident rates per take-off and landing movement of different aircraft types were employed as the basis for estimating the future probability of a crash for the anticipated fleet mix operating at Dublin Airport. In the first instance, aircraft types are split according to the three engine types, as follows:

- Jet engine
- Turboprop
- Piston engine

A8.2.2 The UK DfT model identifies different crash rates according to the age of aircraft, as defined by the year of entry into service. All aircraft operating at Dublin Airport are identified as being within the latest age category with the lowest crash rates. Finally, a distinction is made between passenger and cargo operations for some aircraft types. Following a detailed reviewthe crash rates shown in **Error! Reference source not found.**A9.1 were identified as providing an appropriate basis for the risk modelling.

Table A8.1 – Modelling Assumptions for Aircraft Crash Rate per Million Movements

Aircraft category	*Crash rate per million movements*
Class IV Jets (passenger)	0.082
Class IV Jets (non-passenger)	0.531
Turboprops T1 (passenger)	0.254
Turboprops T1 (non-passenger)	1.68

A8.4.1 Crash Location Modelling

A8.2.3 The UK DfT crash location model provides for the determination of the probability, in the event of a crash anywhere in the vicinity of the airport, of the crash being centred at any given location, defined in terms of rectilinear coordinates by the distance relative to the runway end (y), as measured along the runway extended centreline, and displacement from the runway extended centreline (x), perpendicular to flight path. The model consists of a set of four probability density functions (pdfs) which represent the crash distributions associated with four separate accident scenarios as follows:

- Ground impacts from flight during take-off;
- Ground impacts from flight during landing;
- Take-off overruns; and
- Landing overruns.

A8.2.4 Following a detailed review, as described in Section A9.5.2, the standard functions identified in the latest published version of the UK DfT model [2] were identified as providing an appropriate basis for the risk modelling.

A8.2.5 The standard DfT model is based on the assumption that flight paths are runway-aligned throughout. In order to accommodate the curved departure paths employed for the earlier turns flown by Category A and B aircraft and the divergent departure paths employed by other aircraft, a revised approach was adopted for the treatment of the risk associated with take-off operations. In the case of these operations, the risk at any given point relative to the flight path was determined on the basis of the identified distribution functions where the y value (distance from the threshold) is measured along the line of the curved flight path and the x value (displacement from the flight path) is measured perpendicular to the tangent of the curve of flight path at the appropriate y value.

A8.4.1 Crash Consequence Modelling

A8.2.6 The DfT consequence model is based on the empirical relationship between the area destroyed and the size of the aircraft, characterised in terms of the maximum take-off weight allowed (MTWA), as determined by reference to the historical accident record. Following a detailed review, as described in Section A9.5.39.A9.9A8.4.59, the logarithmic function identified in the latest published version of the UK DfT model [2] was identified as providing an appropriate basis for the risk modelling. This model is as follows:

$$\log_e(\text{Area destroyed}) = - 6.16 + 0.474 \log_e (\text{MTWA})$$

A8.4.1 Annual Movements

A8.2.7 The assumed annual movements for the four different operating scenarios, covering the permitted operations and proposed operations in 2022 and 2025, are summarised in Table A9.2. These scenarios and assumptions are in line with the scenarios modelled for the noise assessment.

Table A8.2 – Annual Movements for 2022 and 2025 Permitted and Proposed Operations, excluding helicopters

Scenario	Annual movements
2022 Permitted Operations	222,902
2022 Proposed Operations	228,751
2025 Permitted Operations	232,981
2025 Proposed Operations	240,790

Source: A11267_08_CA001_4.0 Summary of Movement Data for Hazard Assessment.xslx, 6th October 2020

A8.4.1 Runway Geometry

A8.2.8 The runway threshold locations provide the primary reference points for the runway system and these are given in Irish Grid coordinates in Table A9.3. For the purposes of the assessment, it is convenient to work in terms of runway-aligned coordinates. The key reference point that has been adopted for the runway-aligned coordinate system is the Runway 10R threshold. Following the convention employed in the UK DfT model, the y direction is the direction of take-off and landing and the x direction is the lateral displacement from the runway and its extended centreline. For locations before the landing threshold (i.e. to the west of the Runway 10R threshold), y values are negative and after the threshold y values are positive. For locations to the north of the axis of the south runway, x values are negative and to the south, x values are positive. The threshold coordinates in Runway 10R threshold-aligned coordinates are also shown in Table A8.3.

Table A8.3 – Runway Threshold Coordinates

Threshold	Irish grid coordinates		10R THR aligned	
	Easting	Northing	y (m)	x (m)
10R THR	313724.501	242706.096	0	0
28L THR	316355.946	242528.360	2637.441	0
10L THR	314313.703	244360.933	476.343	-1690.680
28R THR	316688.279	244200.344	2856.343	-1690.680
16 THR	315552.728	244371.355	1711.850	-1784.677
34 THR	316422.286	242490.397	2706.188	33.406

Source: daa supplied data: "Airfield Layout 2037 Rev 1.pdf" – document no 31.6.78-003 Rev 1 dated 29/07/2016, prepared by daa Asset Management and Development.

A8.2.9 Referring to the declared distances, the displacements of the departure ends of runway with respect to the nearest thresholds have been determined. The DER locations in Runway 10R threshold-aligned coordinates have then been determined and are outlined in Table A8.4.

Table A8.4 – Take-off Runway End Displacement from Thresholds

Take-off runway end	Displacement (m)	RWY 10R THR aligned coordinates	
		y (m)	x (m)
Runway 10L DER displacement East of Runway 28R THR	450	3306.343	-1690.680
Runway 28R DER displacement West of Runway 10L THR	280	196.343	-1690.680

A8.4.1 Flight Path Geometry

A8.2.10 The approach paths are essentially runway-aligned from before the Final Approach Fix (FAF). Typical FAF to landing threshold distances for the current instrument approach procedures in the AIP at Runway 10/28 and 16/34 vary from about 13 km to about 16 km. On that basis, it is reasonable to expect that the assumption of runway-alignment will apply to at least 13 km for approach operations which is beyond the distance where risks at potentially elevated levels of relevance to this assessment are estimated to arise.

A8.2.11 Current and future departure paths supporting this assessment are based on the detailed analysis and description of current and future departure paths provided as part of the noise assessment serves. The departure paths for the current standard instrument departures (SIDs) from the Southern Runway for larger aircraft within PANS-OPS Categories C and D, which form the majority of operations at Dublin Airport, are aligned with the runway for some distance after the departure end of runway (DER) before routing to the south. In practice, radar data from 2010 has shown that some of these larger aircraft perform earlier turns than described in the SIDs. During departures from the Southern Runway, Category A and B aircraft commonly turn off the extended runway centreline to the south shortly after the end of the runway, as agreed with the IAA.

A8.2.12 In order to ensure an adequate lateral separation between aircraft using the Southern Runway and those using the North Runway, proposed future Northern Runway departure routes for larger aircraft within PANS-OPS Categories C and D include a course divergence of at least 15° to the north, shortly after take-off at 1.06 and 1.18 nautical miles for easterly and westerly take-offs, respectively. During departures from the Northern Runway, Category A and B aircraft are expected to execute an earlier turn and leave the extended runway centreline to the north shortly after the end of the runway.

A8.2.13 Data for 43 discrete departure routes for 2022 and 2025 operational forecasts has been provided by the noise consultant. Inspection of the individual departure routes determined that some individual routes diverged well beyond the expected boundaries of the 10^{-6} risk contours and for modelling of the aircraft crash risk out to areas where risk are at elevated levels of interest in this study, these routes could be combined. On that basis, 20 routes have been identified for use within the aircraft crash risk model. The track data for these routes has been provided in the form of .shp files which define a set of points along each track in Irish Transverse Mercator (ITM) coordinates. The crash risk model developed for modelling curved departures requires tracks to be defined in terms of straight elements and fixed radius turns over prescribed angles. Therefore, a best fit approach was adopted to determine a geometrically precise representation of each of the 20 identified routes. Details of the geometric specification for the modelled routes are summarised in Annex 1.

A8.4.1 Fleet Mix Assumptions

A8.2.14 Detailed fleet mix specifications have been provided in the form of busy day schedules. Fleet mixes for each individual arrival and departure route have been determined, following detailed analysis of future aircraft operations taking account of the parallel runway operational constraints. These fleet mixes were primarily generated for the noise assessment. Where applicable, analysis of the busy day schedules to determine representative crash rates and MTOW has been undertaken. Fleet mixes for the 20 combined departure routes identified for aircraft crash risk modelling purposes were determined and are reproduced in Annex 2 along with the fleet mixes for departures from the crossing runway and arrivals at all runways.

A8.3 Individual Risk Contour Modelling

A8.2.15 In the first instance, the annual average crash rate and average area destroyed was determined for the relevant arrival and departure routes. In all cases, the movement-weighted average was employed: i.e. the contribution to the average from each aircraft type was weighted in proportion to the fraction of aircraft of that type within the fleet mix. These values are summarised in Table A8.5.

Table A8.5 – Summary of Individual Risk Contour Modelling Parameters

Scenario	Annual movements	Crash rate per million movements	Crash rate per annum	Destroyed area (hectares)
2022 Permitted Operations	222,902	0.1160	0.0259	0.406
2022 Proposed Operations	228,751	0.1151	0.0263	0.408
2025 Permitted Operations	232,981	0.1145	0.0267	0.414
2025 Proposed Operations	240,790	0.1178	0.0284	0.407

A9.3.1 The individual risk at any point was then determined by reference to the crash location element of the UK DfT model, integrating over the destroyed area and determining the contributions from each relevant take-off and landing operation at each runway in accordance with the route specific fleet mix data provided in Annex 2. The risk contours determined using this approach are shown in the Hazard Chapter of the Main EIAR.

A9.3.2 The contour lengths have been assessed against the lengths out to which the modelled departure routes diverge from those routes which have not been explicitly modelled. This assessment has demonstrated that the areas across which the departure routes are modelled is adequate to provide reliable results out to the limits of the 1 in 1,000,000 per annum contours and beyond.

A8.4 Societal Risk Modelling

A8.4.1 Methodology Outline

A8.4.1 Societal risks were estimated using the same basic risk modelling approach as outlined earlier in Section A8.2A8.2 and implemented for individual risk estimation, as described in Section A8.3. However, for societal risk estimation it is also necessary to consider the various sites at potential risk specifically, taking account of the different levels of occupancy across the areas surrounding the airport. The societal risks associated with residential sites were assessed using an approach involving the following steps:

1. Identification of residential properties in the vicinity of Dublin Airport using Geodirectory data, the determination of their locations relative to the flight paths and runway ends and the estimation of the occupancy of each property.
2. Allocation of the identified residential properties to a set of 100 by 100 m grid squares referenced against the Runway 10R threshold and the determination of the density of occupation of each grid square by reference to the location and occupancy data determined under step 1.
3. Estimation of the probability of a crash in each of these 100 by 100 m grid squares containing residential properties in the event of crash somewhere at Dublin Airport during either take-off or landing, by reference to the crash location distribution model.
4. Estimation of the annual probability of a crash of each different aircraft type, by reference to the identified annual fleet mixes for operations, the annual number of movements and the crash rates applicable to each aircraft type.
5. Estimation of the area destroyed in the event of a crash of each different aircraft type, using the crash consequence model and making reference to the relevant aircraft weights.
6. Estimation of the numbers of fatalities in the event of a crash of each aircraft type in each of the 100 by 100 m grid squares, by reference to the outputs of step 2 (the densities of square occupation) and of step 5 (the area destroyed for each aircraft type).
7. Estimation of the probability of occurrence of accidents causing any specified number of fatalities, by reference to the outputs of step 6 (number of fatalities for a crash of each aircraft type in each square) and of steps 3 and 4 (together giving the annual probability of a crash of each aircraft type in each square).

A8.4.2 For commercial sites and healthcare facilities, a broadly similar approach was employed, involving the following steps:

1. Identification of relevant commercial sites and healthcare facilities in the vicinity of Dublin Airport and the determination of their locations relative to the flight paths and runway ends. By reference to the Geodirectory data, the locations of all known commercial sites were plotted on the available Google Earth satellite imagery to provide a basis for the systematic review of all commercial sites.
2. The estimation of the numbers of people present at each commercial site and healthcare facility and the estimation of the areas of occupied buildings at the sites, providing estimates for the target areas at potential risk and the densities of occupation.
3. Estimation of the probability of a crash at each commercial site and healthcare facility in the event of a crash somewhere at Dublin Airport during either take-off or landing, by reference to the site area and the crash location distribution model.
4. Estimation of the annual probability of a crash of each different aircraft type, by reference to the identified annual fleet mixes for operations, the annual number of movements and the crash rates applicable to each aircraft type.
5. Estimation of the area destroyed in the event of a crash of each different aircraft type, using the crash consequence model and making reference to the relevant aircraft weights.

6. Estimation of the numbers of fatalities in the event of a crash of each aircraft type at each of the identified commercial sites and healthcare facilities, by reference to the outputs of step 2 (the densities of square occupation) and of step 5 (the area destroyed for each aircraft type).
7. Estimation of the probability of occurrence of accidents causing any specified number of fatalities, by reference to the outputs of step 6 (number of fatalities for a crash of each aircraft type in each square) and of steps 3 and 4 (together giving the annual probability of a crash of each aircraft type at each site).

A8.4.3 The outputs of steps 7 of the approaches for residential sites, commercial sites and healthcare facilities provide the basis for describing the range of possible outcomes of aircraft accidents at residential, commercial sites and healthcare facilities and their probabilities of occurrence in quantitative terms for subsequent evaluation against the identified criteria for risk significance. These various steps of the overall assessment process are described in turn in the following sections of this appendix.

A8.4.1 Buildings Locations and Occupancy

A8.4.4 The population and dwelling data provided by BAP for use in the aviation modelling consisted of three tables as follows:

- General dwelling and population data based on Geodirectory Q2 2019 data combined with 2016 census data providing population by small area from the Central Statistics Office.
- A list of significant and relevant permitted developments based on planning submissions.
- A list of community buildings in terms of educational, religious and healthcare establishments.

A8.4.5 The general dwelling and population data within the first two categories provided by the noise consultant covers relevant residential or mixed-use sites. It is standard practice in risk modelling to assume 100% occupancy for residential buildings [4] which will be conservative. Lower occupancy factors are considered to be applicable in the assessment of commercial facilities. For mixed use buildings for which the predominant use is residential, the conservatism associated with the assumed 100% occupancy is considered to address the likely occupancy associated with commercial use.

A8.4.6 The dwelling and population data based on geodirectory Q2 2019 and permitted developments have been combined and assessed in accordance with the residential building methodology outlined above. The educational and religious establishments have not been included in the assessment, partly due to double counting as the majority of the population which would attend these facilities will have been accounted for in the residential data and also to account for the relatively low occupancies that can be expected to apply at these facilities.

A8.4.7 The healthcare facility data provided only the names of these establishments and Irish Grid coordinates for their locations. Healthcare facilities includes public and private hospitals, day care centres and nursing homes.

A8.4.3 Treatment of Residential Building Use

A8.4.8 The population within any defined area relative to the runways at Dublin Airport can be determined by reference to the coordinates of individual dwellings within that area, as given in the inventory in the Irish Grid system, and the average population data specific to each individual dwelling. In the first instance, the residential building locations were determined in runway-aligned coordinates, referenced against the 10R runway threshold. Next, the density of occupation within each 100 m x 100 m square referenced with respect to the runway threshold and runway extended centreline was determined in terms of the number of individuals per hectare.

A8.4.9 As noted earlier, in accordance with established HSA best practice, the occupants of the household are conservatively assumed to be permanently resident. In practice, the residents of these households will be subject to a lower level of risk in their homes when account is taken of the time spent at other locations. People will be subject to risks outside their homes if working at or otherwise congregating at other sites in the vicinity of the airport. To some extent at least, the assumption of permanent occupancy of residential properties will account for the risks to people at other sites. However, this balancing of the risks at residential and other locations will be dependent upon the overall distribution of residential buildings compared with the distribution of the other building uses. Where the distributions of residential and commercial buildings are well matched, the over-counting of residential buildings risks arising from the assumption of permanent occupancy may effectively address the risks associated with commercial buildings. Where the distributions are not well matched, this may not be the case and it may be necessary to give more specific consideration to the risks associated with commercial sites.

A8.4.4 Treatment of Commercial Building Use

A8.4.10 The BAP dwelling data does not include any commercial buildings and is therefore representative of the residential and general mixed-use buildings across the Dublin area. Comprehensive inclusion of all the smaller commercial buildings in the societal risk assessment is therefore not practical. That approach would provide for a level of double counting due to the assumption of permanent occupancy of residential properties and would lead to over-estimates of the risk. On the other hand, where there are commercial uses that involve relatively high densities of occupation that are located in higher risk areas close to the runway ends and extended centreline, a failure to take account of the risks associated with these commercial uses may lead to an under-estimation of the risks. The approach to the treatment of the risks associated with commercial sites has been to review the locations of the commercial sites in relation to the locations of residential sites and include identifiable areas of higher density of commercial use in areas of relatively high risk in the societal risk assessment.

A8.4.11 An initial review of the commercial building locations has shown that a large proportion are small sites that are distributed in a manner that is generally consistent with the more general pattern of development in the vicinity of the airport. It has been assumed that the risks associated with these smaller sites will be adequately addressed by the assessment of risks to residential properties, assuming permanent occupancy. In addition to those sites, a number of larger sites that are closer to the airport and potentially subject to higher than average risk levels have been identified. Specific attention has therefore been focused on these sites. Sites falling within two groups have been considered: those within the Dublin Airport Campus and those outside the Dublin Airport Campus.

A8.4.12 For sites outside the Dublin Airport Campus, the number of cars in car parks, as determined by reference to Google earth satellite images, has been employed as the basis for estimating the number of staff present during normal working hours. Central Statistical Office data for modes of travel to work for Fingal gives a value of 66.3% for the number of people driving to work. The number of cars associated with any given facility, multiplied by a factor of 1.5, therefore provides an estimate for the number of staff present. The areas covered by the different commercial buildings that represent the size of the targets at risk from aircraft crash, and the densities of occupation were determined by approximate measurements made from Google earth satellite images. Health and Safety Authority Guidance identifies the following percentage occupancy times for commercial facilities for use in risk assessments: Factories 75%, Places of entertainment 50%, Shops and supermarkets 50%, Warehouses 50%, Offices 30%. A value of 50% has been assumed for all the commercial sites outside the Dublin Airport Campus. The sites that have been included in the assessment, their locations, sizes and occupancy characteristics are summarised in Table Table 8.6.

Table 8.6 – Characteristics of commercial sites outside the Dublin Airport Campus

Site description	Latitude	Longitude	Area in hectares	Occupants	Density of occupation
Dublin Airport Business Park	53°25'33.71"N	6°13'22.47"W	2.782	515	185.09
Coachman's Inn	53°25'56.95"N	6°13'45.03"W	0.129	100	773.69
Units N of Kettle Lane	53°26'16.03"N	6°13'35.30"W	0.480	110	228.98
Swords Airside Industrial Estate	53°26'45.77"N	6°13'25.62"W	5.933	1710	288.20
Santry Retail and Business Parks	53°24'26.33"N	6°14'34.15"W	25.454	1437	56.46
Horizon Logistics Park	53°25'05.60"N	6°17'14.16"W	1.635	204	124.79
Dublin Airport Logistics Park	53°25'06.87"N	6°18'43.36"W	3.833	495	129.13
Northwest Business Park (North)	53°25'12.08"N	6°20'52.17"W	4.248	347	81.70
Northwest Business Park (South)	53°24'36.69"N	6°21'13.07"W	21.238	1735	81.70
Damastown Industrial Park	53°25'09.56"N	6°24'47.50"W	10.805	2918	270.06
Food Central	53°26'57.40"N	6°16'50.34"W	6.860	2385	347.67

A8.4.13 For the Dublin Airport Campus, an average of 6,450 staff members have been identified as working on campus on a daily basis in 2015 with a projected increase to 8,300 staff members in 2025. These staff have been allocated to different facilities within the campus. Given the hours of operation of the airport, some activities can be expected to involve two shifts per day, such that the number of staff present at any one time will be less than this daily total of 6,450. Some activities, e.g. office staff, are expected to involve a single daily shift. The campus comprises the following main areas:

- The Terminal Complex;
- The Old CTB Complex;
- The MSCP Complex;
- Cloghran West;
- Cloghran East;
- Eastlands;
- Corballis Park;
- Westland Area;
- Westpoint.

A8.4.14 For some of the more outlying areas, the numbers present can be estimated by using the method applied to commercial sites outside the Airport Campus, based on the number of cars in adjacent car parks (e.g.Corballis Park, Westland, Westpoint and Cloghran East). This approach cannot be reliably applied to other areas closer to the terminal complex where there are larger areas associated with car parking that cannot necessarily be related to staff use. For office buildings, floor area estimates are available. An average of 10.9 m² per member of office staff, based on value in a recent UK study, has been assumed to provide estimates of office staff numbers by making reference to office floor area data which was provided by daa Commercial & Asset Care Departments.

A8.4.15 Based on the staff number estimates derived in accordance with the approach set out above, the remaining number of staff was determined and these staff were allocated to the terminal areas. A small number of these staff were first allocated to the hangar areas and the remainder were allocated to the Terminal 1 and Terminal 2 complexes. Staff have been apportioned between the 2 terminals and 4 associated piers at an assumed equal density, having regard to the areas of each facility and having further regard to the number of levels in the terminal buildings, as compared to the piers. Given that all of the majority of staff can be expected to be within facilities that are in broadly similar locations, the accuracy of these allocations is considered not to be a critical factor in the reliability of the assessment. Using this approach, the locations, sizes and occupancy characteristics of sites within the Dublin Campus summarised in Table 9.7 were estimated. These values apply to 2015. They were increased by factors of 1.22 and 1.30 to give estimates for 2022 and 2025, respectively, to take account of the expected increases in staff numbers. It should be noted that these increases are expected to be conservative since they were made without taking any account of the impact of the Covid 19 pandemic.

Table 8.7 – Characteristics of Sites within the Dublin Airport Campus

Site description	Latitude	Longitude	Area in hectares	Occupants	Occupancy factor	Density of occupation
Terminal 1	53°25'37.86"N	6°14'39.19"W	2.043	496	100%	242.84
Terminal 2	53°25'32.52"N	6°14'24.85"W	3.060	744	100%	243.14
Pier 1	53°25'49.99"N	6°14'55.31"W	0.938	114	100%	121.54
Pier 2	53°25'42.38"N	6°14'49.72"W	0.450	55	100%	122.22
Pier 3	53°25'35.37"N	6°14'43.26"W	0.455	55	100%	120.88
Pier 4	53°25'25.68"N	6°14'35.35"W	1.200	146	100%	121.67
Cloghran House	53°25'29.91"N	6°13'57.60"W	0.351	447	50%	1273.50
Taxi catering	53°25'30.33"N	6°13'53.77"W	0.225	120	100%	533.33
Radisson	53°25'35.86"N	6°13'56.95"W	0.385	20	100%	51.99
Head Office Area	53°25'39.56"N	6°14'12.17"W	0.511	1282	50%	2508.81
Maldron Hotel	53°25'38.38"N	6°14'04.33"W	0.263	20	100%	76.19
Macdonalds / Topaz	53°25'44.28"N	6°14'07.77"W	0.161	15	100%	93.17
OCTB area	53°25'45.38"N	6°14'46.38"W	0.926	1303	50%	1406.82
Corballis Park	53°25'23.47"N	6°14'07.10"W	2.996	780	50%	260.31
Eastlands car rental	53°25'15.57"N	6°13'27.03"W	0.540	15	100%	27.78
ALSAA Sports	53°25'20.01"N	6°13'45.68"W	0.450	10	100%	22.22
W Hangar	53°25'49.72"N	6°14'39.59"W	0.845	10	100%	11.83
Mid Hangar group	53°25'49.38"N	6°14'26.97"W	2.500	10	100%	4.00
E Hangar	53°25'47.11"N	6°14'10.87"W	0.369	10	100%	27.14
Westland Area	53°25'46.69"N	6°15'46.83"W	1.184	240	100%	202.74
Westpoint	53°25'06.86"N	6°15'52.90"W	0.359	38	50%	105.76

A8.4.16 The values in Table 9.7 refer to staff only. The numbers of passengers present have been estimated by reference to the dwell times for departing and arriving passengers, the total annual throughput of passengers and the operating hours of the airport. On that basis, the average numbers of passengers present in the terminal complex shown in Table 9.8 have been estimated. These numbers have been assumed to be evenly distributed about the main terminal building and two piers of both terminal complexes. The same average value has been assumed to apply throughout the operating hours of the airport.

Table 8.8 – Estimates for numbers of passengers present in the terminal complex at any time

Scenario	Passengers present
2022 Permitted Operations	5,585
2022 Proposed Operations	5,760
2025 Permitted Operations	6,013
2025 Proposed Operations	6,227

A8.4.17 The Radisson and Maldron Hotels have 229 and 251 rooms, respectively. Assuming an average room occupancy of around 1.5 guests gives 345 and 377 hotel guests, respectively at these two hotels. Guests have been assumed to be present at that level for 50% of the operating hours of the airport. For the remaining period of operation, a guest occupancy of 100 has been assumed. Based on the number of cars in the car park at Kealeys of Cloghran, the number of occupants has been estimated at around 100. For the car rental facility, 50 customers collecting or returning cars has been assumed. Based on the car park occupancy in the available Google earth satellite images, the typical occupancy of users of the ALSAA Sports Fitness & Social Association facility is estimated to be 200. For the MacDonalds restaurant and Topaz petrol stations, 50 customers have been assumed. An occupancy factor of 100% has been assumed for these facilities.

A8.4.4 Treatment of Healthcare Facility Use

A8.4.18 A review of the healthcare facilities was undertaken to estimate the population and areas which would apply. The populations were estimated by reference to the number of beds at each facility with reference to hospital care quality reports or websites describing the facilities. A staffing ratio of 1:1 of beds to staff was assumed to apply. This is likely to be conservative in the majority of cases, especially in respect of smaller nursing homes. The site areas were estimated by reference to google earth satellite imagery of each facility. A table of the assumed populations and areas at each healthcare facility is provided in Annex 3.

A8.4.5 Societal Risk Estimates

A8.4.19 Societal risks were estimated separately for Airport Campus sites and all non-airport sites and for all sites combined. These estimates were characterised by a number of measures, as follows:

- The overall frequency of accidents;
- The average number of fatalities involved;
- The expectation value, representing the average number of fatalities per annum;
- The "Scaled Risk Integral" (SRI) Index, as normally employed in land-use planning in the vicinity of major hazard (COMAH) sites;
- FN curves for the full range of accident frequencies and consequences.

A8.4.20 The overall frequencies of accidents are estimated to be of the order of 0.03 per annum (about 1 in 33 years) and are predicted to rise from a baseline rate for the 2022 permitted operations of 1 in 39 years to a rate of 1 in 35 years for the 2025 proposed operations. The majority of accidents are predicted to occur at unoccupied sites and therefore not to give rise to any third party fatalities. Overall, around 4% of accidents are estimated to give rise to third party fatalities. The frequencies of accidents giving rise to third party fatalities are estimated to be of the order of 0.0012 per annum (about 1 in 870 years) and are predicted to rise from a baseline rate for the 2022 permitted operations of 1 in 947 years to a rate of 1 in 872 years for the 2025 proposed operations. This increase largely reflects the increase in the number of movements between the two cases. The average number of third party fatalities per event is estimated to be around 17-18 for locations outside the airport campus and around 22-23 on average for all locations. These key measures of the risks are summarised in Tables 8.6 and 8.9 of Hazard Chapter in the Main EIS.

A8.4.21 The societal risk FN curves corresponding with the 2022 permitted and proposed operations are shown in Figure 9-3 and those for 2025 are shown in Figure 9-6 of the Hazard Chapter in Main EIS. The FN curves for all sites and for sites excluding the Airport Campus sites are shown separately in these figures.

A8.4.22 A number of conclusions can be drawn from the data summarised in Tables 8-6 and 8-9 of the Hazard Chapter in the Main EIS and the FN curves shown in Figures 9-3 and 9-6, as follows:

- The risks for all cases are above the lower limit of negligible risk identified by the UK Health and Safety Executive.
- The risks for the 2022 and 2025 permitted and proposed operations are below the local scrutiny line and below the reference point for potentially intolerable risk identified by the UK Health and Safety Executive.
- The increases in the estimated risk for the proposed operations compared with the permitted operations in both 2022 and 2025 are relatively small (e.g. between 6.5% and 9% for 2022 and 2025, respectively, as measured in terms of the expectation value). Such differences can be considered to be negligible in the context of the overall criteria for judging societal risk significance: i.e. the risks levels all sit within the same region of the FN risk significance criteria, centrally between the identified limits defining "negligible" and "significant" risk levels.
- The levels of risk for the off-airport sites, as measured in terms of the expectation value, are roughly 2-3 times greater than levels for the airport campus and the characteristics of the risks in these different areas are substantially different. The likelihood of a crash causing fatalities at off-airport sites is around 50 times greater than the likelihood of a crash causing fatalities within the airport campus, reflecting the large area across which this risk is spread and larger number of off-airport sites at potential risk. The numbers of fatalities estimated for crashes at airport campus sites is substantially greater than the numbers expected for crashes off-airport, reflecting the generally higher densities of occupation of airport sites.

A8.4.23 Finally, the risks have been measured in terms of the Scaled Risk Integral (SRI), as identified by the Health & Safety Authority for use in respect of land-use planning in the vicinity of major hazard (COMAH) sites, and are summarised in Table 8.9Table . The 2022 baseline SRI value for off-airport sites is around 85,564, within the "moderate effects" category identified in respect of this significance criterion. These risks are expected to increase with the increase in movement numbers.

A8.4.24 For the 2025 proposed operations, the SRI value for off-airport sites is estimated to increase to around 92,473. The total SRI values for all sites are within the "moderate effects" significance category for all cases.

Table 8.9 – Scaled Risk Integral (SRI) estimates for off-airport and airport campus sites

Scenario	SRI for non-airport sites	SRI for airport campus	SRI for all sites
2022 Permitted operations	85,564	63,188	148,752
2022 Proposed operations	86,355	67,148	153,503
2025 Permitted operations	90,188	73,387	163,574
2025 Proposed operations	92,473	79,731	172,205

A8.5 Risk Modelling Assumptions Review

A8.4.25 As has been noted earlier in Section A9.1, there will be limitations to the reliability of any empirical quantitative risk model of the type employed in this assessment. Taking account of the precedent set by the previous DoEHLG study, the DfT model has been identified initially as being favoured for use in the current assessment. The potential limitations of that model have been reviewed in some detail to confirm that it can be considered appropriate for its intended use and to identify any modifications that might be made to improve its reliability. This section sets out the findings of that technical review to support the modelling approach that has been adopted, as set out in the preceding sections of this Appendix.

A8.5.1 Aircraft Crash Rates

A8.4.26 The UK DfT Model employs historical accident rates per take-off and landing movement of different aircraft types as the basis for estimating the future probability of a crash for a defined fleet mix operating at any given airport. A number of criteria are employed for characterising different aircraft types with different crash rates. In the first instance, aircraft types are split according to the three engine types, as follows:

- Jet engine
- Turboprop
- Piston engine

A8.4.27 The second main division is then made according to the age of the aircraft. Western-built jet airliners are divided into the following categories:

- Class I: First Generation Jets, e.g. Comet, Boeing 707
- Class II: Second Generation Jets, e.g. B727, VC-10
- Class III: Early Wide Bodied Jets, e.g. B747, Tristar
- Class IV: Subsequent Types, e.g. Airbus 310, B757

A8.4.28 In addition to identifying crash rates for those categories of western-built jet airliners, the UK DfT model identifies crash rates for executive jets and "eastern jets", the latter comprising those jet airliners aircraft built in the former Soviet Block. Turboprop driven aircraft are split into two categories as follows:

- Those first delivered in or after the 1970s (T1)
- Those first delivered earlier (T2)

A8.4.29 Finally, a distinction is made between passenger and cargo operations for some aircraft types.

A8.4.30 The forecast fleet mixes at Dublin Airport for 2022 and 2025, as set out in Annex 2, have been reviewed to determine which of these categories of aircraft it includes. Detailed fleet mix specifications for the scenarios, covering the key risk characteristics of the aircraft types concerned, have been developed from those specifications. The jet airliners are all in the Class IV category.

A8.4.31 All of the turboprop driven aircraft in the fleet mix have been determined to be within the T1 category. Most of these aircraft were introduced either in the 1980s or 1990s.

A8.4.32 The UK DfT model further divides the Class IV jet and T1 turboprop categories into passenger and non-passenger operations. No age-related or passenger/non-passenger subdivisions are identified for executive jets or piston engine-driven aircraft.

A8.4.33 When the UK DfT model was first developed and published in 1997, the crash rate estimates for the aircraft within the different categories were made publicly available. To take account of the improvements in the safety performance in civil aviation since those estimates were first made, the crash rate estimates have been up-dated periodically. The most recent estimates currently available for use in this assessment, identified in a 2008 study [5], are summarised in Table 8.10. Taking account of the established trends towards lower crash rates, estimates determined using the most up-to-date accident and movement statistics may be slightly lower than those identified in the table. However, the rates of decline over a ten year period can be expected to be relatively small. The available estimates given in the table are conservative and, for the most part, are considered appropriate for the assessment.

Table 8.10 – Estimates for crash rate per million movements (DfT model dataset)

Aircraft category	Crash rate per million movements
Class IV Jets (passenger)	0.082
Class IV Jets (non-passenger)	0.531
Turboprops T1 (passenger)	0.254
Turboprops T1 (non-passenger)	1.68
Executive Jets	2.23
Piston Engine	3.23

A8.4.34 There is a potential concern that the non-passenger T1 turboprop crash rate of 1.68 per million movements may be unrepresentative of those types of operations at Dublin Airport. However, there is no readily available alternative value that can be shown to be representative of these sorts of operations at Dublin Airport. T1 turboprop cargo operations make up a small proportion of the forecast fleet mix (around 0.7% or less, according to the scenario) and the aircraft involved are not large (MTOW=23 tonnes). The use of a substantial over-estimate for the crash rate of this aircraft type should therefore not have a significant impact on the overall findings of the assessment and, in the absence of a readily available alternative value, the DfT model value shown in Table 9.10 has therefore been employed in this assessment.

A8.5.2 Crash Location Modelling

A8.4.35 The UK DfT crash location model provides for the determination of the probability, in the event of a crash anywhere in the vicinity of the airport, of the crash being centred at any given location, defined in terms of rectilinear coordinates by the distance relative to the runway end and the runway extended centreline. The model consists of a set of four probability density functions (pdfs) which represent the crash distributions associated with four separate accident scenarios as follows:

- Ground impacts from flight during take-off;
- Ground impacts from flight during landing;
- Take-off overruns; and
- Landing overruns.

A8.4.36 These empirical distributions were determined by fitting mathematical functions to the crash locations identified in the historical accident record. They have been employed as described in the identified references. Some comment on the mathematical functions employed and their potential limitations and reliability is provided here.

A8.4.37 Four primary limitations in the DfT crash location model are identified as follows:

- The over-concentration of crash locations on the runway extended centreline;
- The approach to the treatment of overruns;
- The use of the departure end of runway as the coordinate system origin for take-off accidents;
- The assumption that departure routes are confined to the runway extended centreline.

These four issues are discussed in turn.

Over-concentration of crash locations on the runway extended centreline

A8.4.38 As noted earlier, the crash location model consists of probability distribution functions that fit the accident locations reported for historical accidents. A Weibull distribution was selected to fit the variation of the probability laterally from the runway extended centreline (the x direction according to the convention adopted in the DfT model) for the reported historical accident locations. The Weibull distribution tends to infinity at $x = 0$ which can be seen to be physically unrealistic. The crash location probability at the centreline can be expected to reach a maximum at $x = 0$ but must, under any physically realistic representation, be finite at that point.

A8.4.39 From the perspective of model development, there appears to be a problem associated with the nature of the reporting of accident locations. Where the historical accident locations were close to the runway extended centreline, it appears that they were often reported as being exactly on the centreline (i.e. at $x = 0$) whilst in practice they will have been displaced some distance laterally from it. The reported accident locations will therefore be over-concentrated at the centreline and, in order to fit these reported locations closely, a function such as the Weibull distribution that tends to infinity at $x = 0$ is required. The model based on these reported crash locations and associated Weibull pdfs can therefore be expected to over-estimate the crash risks along and close to the runway extended centreline. There will be a corresponding under-estimation of the crash risks across the immediately adjacent region slightly further from the runway centreline. Further still from the runway centreline the use of the Weibull distribution can be expected to provide an effective and realistic fit to the true accident location distributions.

A8.4.40 Studies of aircraft track keeping during normal operations provide a reference point for assessing the potential impact on the reliability of the predictions of the model that employs these physically unrealistic Weibull distributions. The observed tracks follow physically realistic distributions, broadly in accordance with the normal distribution function, that are finite at $x = 0$. Given the nature of the functions employed in the DfT model, there is inevitably a region across which the crash risk is more concentrated than the distribution of aircraft in flight. In effect, aircraft are predicted to crash more accurately along the runway extended centreline than they can fly.

A8.4.41 This somewhat unrealistic scenario is found to apply over a relatively limited distance from the extended centreline only. In order to determine the crash risk, account is taken of the area on the ground that is expected to be destroyed in the event of an accident, in accordance with the crash consequence model assessed further in Section A9.2.6. The values for the predicted "destruction area" for the fleet mixes under the relevant scenarios are of the order of 0.41 hectares. According to the standard approach adopted in the UK DfT model for the determination of individual risk, this destruction area is represented by a simple rectangle of around 64 m by 64 m. The risk at any single location is determined by sum of the probabilities of impact within this area. The integration of the risk over this sort of distance is expected to smooth out the effects associated with this aspect of the model, combining the areas of over-estimation of risk closer to the centreline with immediately adjacent where risk will be correspondingly under-estimated, to some extent at least. The approach adopted for societal risk estimation also involves an element of integration that will smooth out these effects. Overall, it is concluded that, whilst there may be an element of over-estimation of risk close to the runway extended centreline, this limitation of the model and reported accident location data upon which it is based is unlikely to have any significant impact on the reliability of the risk predictions of the model.

Treatment of overruns

A8.4.42 The DfT model employs the landing threshold as the basic reference point for landing accident locations. In the case of impacts from flight, the pdf describing the accident location distribution is based on the impact location. This approach is considered to be entirely appropriate. For landing overruns, the pdf describing the accident location distribution is based on the final resting location of the wreckage. There are two fundamental concerns regarding this modelling approach.

A8.4.43 The first key point to note in this respect is that landing operations are matched to the available runway length. Aircraft will land at a given runway only where they are capable of stopping, under normal circumstances and with an appropriate margin of safety, in the landing distance available, taking account of the performance characteristics of the aircraft, its weight and relevant external parameters (wind velocity, runway surface condition). In a small proportion of cases, aircraft are unable to complete the landing manoeuvre in the nominal distance required and overrun beyond the distance in which it was intended that the landing be completed.

A8.4.44 Other studies [6,7] have developed overrun models referenced against the end of the available landing runway and this approach is considered to be more appropriate than the use of landing threshold. The DfT model landing overrun dataset includes a significant number of overruns that come to rest 3,000 m or more from the landing threshold. The vast majority of these will have involved large and heavy aircraft landing on runways of around 3,000 m or more in length and typically overrunning beyond the end of the landing distance available by no more than a few tens of metres. The DfT overrun risk model is therefore not representative of landings at shorter runways. The landing distances available (LDA) at the runways at Dublin are as follows:

- Runway 10R/28L: 2,637 m;
- Runway 10L: 2,830 m;
- Runway 28R: 2,660 m;
- Runway 16/34: 2,072 m.

A8.4.45 Conceptually the DfT model is physically unrealistic and will therefore tend to over-estimate the landing overrun risk, in particular at shorter runways.

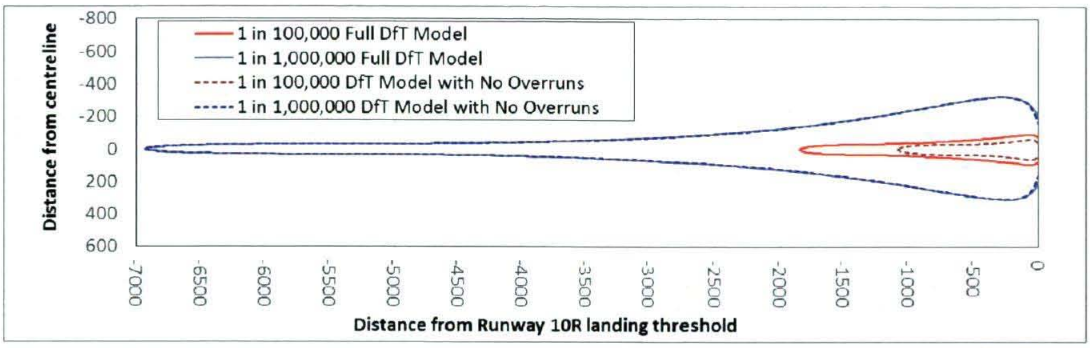
A8.4.46 The second concern is that the DfT overrun model employs accident location data without any consideration of the influence of the obstacle environment. Conceptually, this approach may be reasonably appropriate for crashes from flight but is flawed in the case of the overrun. What is observed during overrun events is dependent upon the obstacle environment and may be characterised by two primary outcomes:

- The aircraft decelerates in the open space beyond the runway end and comes to a halt before hitting any obstacle;
- The aircraft fails to stop in the available open space beyond the runway and is arrested by the first substantial obstacle it meets.

A8.4.47 Only those accidents involving a total hull loss that will fall into the second category are employed in the DfT model whilst other studies [6,7] clearly demonstrate that overrun events that do not result in major damage are common. This modelling approach is not representative of the risk scenario concerned.

A8.4.48 A preliminary assessment of the contribution of the overrun risk to the overall risk estimate was undertaken for the western end of the existing south runway, based on a now superseded but still representative movement forecasts, and the findings are illustrated in Figure A9.1. It is evident from this figure that overrun risk makes a very noticeable contribution to the 1 in 100,000 per annum risk contour but not to the 1 in a million risk contour.

Figure A8.1: Comparison of risk contours with and without overruns



A8.4.49 The large contribution to the 1 in 100,000 per annum risk contour can be seen to be unrealistic on the following basis. The 1 in 100,000 per annum risk contour without overruns extends to a distance of 1,085 m to the west of the Runway 10R landing threshold. The contour with overruns extends to a distance of 1,850 m to the west of the Runway 10R landing threshold. The available take-off overrun dataset [7] of 63 accidents and incidents identifies the longest distance travelled from the runway end as 533 m. For the landing overrun dataset of 239 accidents and incidents, the longest distance travelled from the runway end is 1,160 m and the second longest distance travelled is 624 m. In summary, out of a total of over 300 overrun accidents and incidents, just one travelled further than the 1,085 m distance to which the "no overruns" 1 in 100,000 per annum risk contour extends. That event stopped 690 m short of the limit of the "with overruns" 1 in 100,000 per annum risk contour. The DfT overrun model is evidently predicting a noticeable contribution to the estimated risk at distances that are further from the runway end than any overrun event in the historical accident dataset. The risks predicted in this region can therefore be seen to be significant over-estimates. For the 1 in a million per annum risk contour that extends considerably further from the runway end, there is essentially no noticeable difference between the two contours predicted with and without the inclusion of the overrun model (c. 1 m difference in a contour length of 6,936 m).

A8.4.50 For consistency with the previous recommendations in respect of PSZ policy in the Republic of Ireland, the standard UK DfT model, including overruns, has been employed for estimation of the risk contours but it is noted, on the basis of this analysis, that these will be over-estimates, in particular in respect of the locations closer to the runway ends where the 1 in 100,000 per annum contours are located. The UK DfT overrun model has not been employed in the determination of the societal risk estimates.

Coordinate system origin for take-off accidents

A8.4.51 The UK DfT model essentially employs the end of the declared runway as the reference point for the pdfs that describe take-off accident locations. However, the available description of the model development [1] states that the take-off accident locations are referenced against the threshold nearest the take-off end of runway. That is understood to mean that the nearest landing threshold to the departure end of runway was employed as the reference point when determining the crash locations that were used to develop the take-off accident pdfs. This reference point for take-off accidents is less unambiguous than the threshold is as a reference point for landing accidents.

A8.4.52 In some cases, there may be a displaced threshold and the chosen reference point may therefore not correspond with a specific take-off-related reference point. In some cases, clearway will be available such that take-off distance available from an operational perspective will not correspond with the paved surface. Finally, it may be noted that different aircraft have different inherent take-off distance requirements and the runway length provision in relation to those requirements will vary between different airports. Two crashes with identical operational characteristics may therefore be identified as being located at different distances from the runway end, if they were to occur at runways of different lengths. As a result, there is no clear cut reference point for use in relation to take-off accidents.

A8.4.53 When using the departure end of runway as a reference and pdfs of the type employed in the UK DfT model, a potential problem arises in relation to accidents that occur before that reference point has been reached. It is evident that there can be no crashes during take-off that occur at locations prior to the start of take-off run. This physical reality of the process is not accommodated by the model. The crash probability is not constrained to zero at locations before the start of take-off run but varies according to the pdfs selected to fit the data points before the departure end of runway: i.e. the model places a component of take-off risk behind the point at which the take-off run commences. This component of take-off risk should be accounted for somewhere by the modelling process but in a different location. In practice, this misplaced component of the risk can be expected to be relatively small and not to have a major impact on the locations of the estimated risk contours.

A8.4.54 Overall, whilst recognising these uncertainties and the possible benefits associated with using the alternative reference of the start of take-off run, the view adopted is that the departure end of runway represents a convenient and pragmatic coordinate system origin for the current purposes and the DfT modelling approach has been followed in this respect. In the case of Dublin Airport, the Departure End of Runway (DERs) are displaced from the nearest runway thresholds. The manner in which these displacements have been accounted for in the runway geometry employed in model implementation is described in Section 0.0A8.4.1.

Runway-aligned departure routes

A8.4.55 The DfT model is based on an assumption that flight paths are runway-aligned whilst some other models [8,9,10] take account of flight paths that deviate from runway alignment. Approach and landing operations are typically runway-aligned for a considerable distance before the landing threshold. In the case of operations at Dublin Airport, approaches to Runway 10 are runway-aligned prior to the final approach fix at 8.5 Nm from the runway (15.7 km) and approaches to Runway 28 are runway-aligned prior to the final approach fix at 7.1 Nm from the runway (13.1 km). The majority of accidents take place closer to the runway and the assumption that approach paths are runway-aligned is reasonable. As described in Section A8.3, the 1 in 1,000,000 per annum risk contours do not extend as far as those distances from the runway threshold.

A8.4.56 In the case of departures, turns are often initiated somewhat closer to the runway ends. For the future operation of the parallel runway system at Dublin, departures from the south runway are runway-aligned out to comparable distances. However, for the north runway, a turn to the north will be initiated shortly after take-off at 0.89 Nm from the runway end, after which aircraft may adopt a range of potential pathways at different angles offset from the runway axis. These flight paths will be runway-aligned over a limited region closer to the runway but not throughout the area of interest. Further detail concerning these offset flight paths are provided in Section A9.2.8.

A8.4.57 The description of the DfT model development states the following in relation to departure routes:

4.25 No attempt to 'bend' the distributions around the arrival and departure routes was made for this model and all crash locations were measured relative to the runway ends and the extended runway centreline. The reason for this decision was that only a small proportion of crash reports record in detail the intended route of the aircraft prior to an accident. Even when this is recorded it is not always clear how to relate the intended route of the aircraft to the eventual accident location. For example, on departure a serious problem (which ultimately causes a crash) may arise before the intended route deviates from a straight path. In this case, the pilot would not attempt to follow the intended curved route, and therefore the actual crash location would be the same irrespective of whether the intended route was curved or straight.

4.26 The fact that aircraft do not always follow straight routes will to some extent be implicit in the NATS model [i.e. the UK DfT model], as some of the historical crashes would have occurred while aircraft were on curved routes. Thus the 'average' effect of aircraft routeing on crash location is taken into account in the NATS model. The effects of curved routes are likely to be small, where the risk is greatest, close to the runway ends.

A8.4.58 Whilst the comments relating to the quality of the information concerning the intended route in para. 4.25 may be true, that does not validate the approach adopted in the DfT model. Some of the crash locations may relate to specific flight paths at certain airports that are not runway-aligned. The use of these locations in a runway-aligned model may lead to a greater degree of dispersion being predicted than would arise in practice for runway-aligned routes. The observation in para 4.26 that the "average" effect of aircraft routeing on crash location is taken into account is not helpful in this respect since the accurate prediction of areas of higher crash probability at any individual airport will be dependent on the specific details of routeing at that airport and not on the average. The observation that the effects of curved routes are likely to be small, where the risk is greatest, close to the runway, would appear to be reasonable. For the implementation of UK PSZ policy which makes reference to the 1 in 100,000 per annum risk contours which are typically located relatively close to runway ends, this modelling approach is adequate.

A8.4.59 However, for the purposes of this assessment, consideration is being given to crash risks across a wider area that extends further from the runway ends and where these effects may be more substantial. In that context, a modified approach has been employed in this assessment in which the risks at any given point relative to the flight paths were determined on the basis of the identified distribution functions where the y value (distance from the threshold) is measured along the line of the curved flight path and the x value (displacement from the flight path) is measured perpendicular to the tangent of the curve of flight path at the appropriate y value. Accordingly, the distribution functions are bent around the flight paths in use in a manner consistent with that employed in the NLR model [9]. In practice, as is evident from the predicted contours shown in the EIAR, whether straight or curved departure routes are employed makes no significant difference to the predicted risks. Whilst the effect of the use of curved departure routes is evident in the 1 in a million per annum risk contours, the areas subject to differences due to these assumptions are predominantly free from development. The more refined modelling approach may relocate areas subject to higher probability of air crash but only slightly. However, since these areas are predominantly unpopulated, the risks to people on the ground will be very similar to that using the simpler assumption of runway-aligned flight paths.

A8.5.3 Accident consequence model

A8.4.60 The DfT consequence model is based on the empirical relationship between the area destroyed and the size of the aircraft, characterised in terms of the maximum take-off weight allowed (MTWA), as determined by reference to the historical accident record. The original DfT consequence model identified the following logarithmic relationship:

$\log_e(\text{Area destroyed}) = -6.36 + 0.49 \log_e(\text{MTWA})$

This relationship was subsequently revised slightly as follows:

$\log_e(\text{Area destroyed}) = -6.16 + 0.474 \log_e(\text{MTWA})$

A8.4.61 The historical accident record indicates a clear dependence of the size of the area affected in the event of a ground impact on aircraft size. The identified logarithmic relationship lacks an element of physical realism in that it does not provide for the prediction of an area destroyed of zero for a weight of zero. However, it is found to provide a better fit to the available empirical data across the range of aircraft sizes encountered in practice.

A8.4.62 Theoretical considerations based on dimensional analysis suggest that a linear dependence is not to be expected. For simplicity, consideration is given to a simple rectilinear object of length, l, width, w and height, h. The volume will be given by $V = l \times w \times h$. Volume is proportional to mass: $V \propto M$. On impact with a surface, a constant force for deceleration per unit area over which the impact takes place is assumed. The contact area will be proportional to the square of the linear dimension. For an object sliding across a surface the contact area will be $l \times w$ and for impact with a wall, the contact area will be $w \times h$. On that basis the contact area will be proportional to Mass to the power 2/3. The kinetic energy to be dissipated will be directly proportional to mass. Accordingly, the distance travelled to arrest the Mass due to the identified deceleration force will be proportional to Mass to the power 1/3. Assuming that the consequence area is given by the object width multiplied by the distance travelled it would therefore be expected to be proportional to mass to the power 2/3.

A8.4.63 The above dimensional analysis based on a rectilinear object may not be entirely representative of aircraft behaviour in the event of an accident but it does provide some theoretical basis for the identification of the nature of the relationship between aircraft size and the scale of the impact consequences. The UK DfT logarithmic model is found to agree fairly well with the Mass to the power 2/3 relationship, although, empirically, a square root relationship appears to provide a better basis for correlation with the identified logarithmic relationship. The available accident dataset includes a limited number of accidents involving larger aircraft and there is therefore some uncertainty as to whether the observed empirical logarithmic relationship provides a sound basis for predicting crash consequences for larger aircraft. The theoretical Mass to the power 2/3 relationship would indicate somewhat larger areas destroyed for larger aircraft than the empirical logarithmic relationship of the UK DfT model. However, larger aircraft for which limited empirical crash consequence data is available (i.e. those of around 200 tonnes or more) make up a relatively small proportion of the operations (less than 7.6%). The estimated risks will be dominated by the contribution made by smaller aircraft for which the empirical logarithmic model is expected to provide reliable crash consequence estimates. Overall, it is concluded that the logarithmic UK DfT crash consequence model is an appropriate model for use in the current assessment.

References

1 Third Party Risks Near Airports and Public Safety Zone Policy: A Report to the Department by Consultants, Department of the Environment, Transport and the Regions, October 1997

2 A Methodology for Calculating Individual Risk Due to Aircraft Accidents near Airports, P.G.Cowell, P.B. Foot, R.J.Gerrard, D.Kent, S.M.Mason & A.Rivoire, NATS R&D Report 0007, 2000

3 ERM Public Safety Zones Main Report, prepared by ERM on behalf of the Department of Transport and the Department of Environment, Heritage and Local Government, February 2005
http://www.transport.ie/sites/default/files/publications/aviation/english/erm-public-safety-zones-report/erm-public-safety-zones-text-main-report.pdf

4 Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning, Health and Safety Authority, 19 March 2010
http://www.hsa.ie/eng/Your_Industry/Chemicals/Legislation_Enforcement/COMAH/Approach_to_LUP_under_Comah_Regs.pdf

5 Sydney Airport Third Party Risk Assessment. Report prepared for Sydney Airport Corporation Limited by ESR Technology ESR/D1000748/001/Issue 1 August 2008

6 Final Report on the Risk Analysis in Support of Aerodrome Design Rules, report produced by AEA Technology on behalf of the Norwegian Civil Aviation Authority, December 2001
http://www.luftfartstilsynet.no/incoming/article2032.ece/BINARY/AEA_Final_Report_Version%201A.pdf

7 ACRP Report 3: Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas, US Transportation Safety Board, 2008 onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_003.pdf

8 Manchester Airport Second Runway, Third Party Risk Proof of Evidence, Grant Purdy, DNV Technica, August 1994

9 Methods and Models for the Assessment of Third Party Risk Due to Aircraft Accidents in the Vicinity of Airports and Their Implications for Societal Risk. M.A.Piers in Technology, Risk, and Society Volume 12, Quantified Societal Risk and Policy Making pp 166-204, 1998

10 External Risk Around Airports: A Model Update, A.J.Pikaar, M.A.Piers and B. Ale, Presentation at the 5th International Conference on Probabilistic Safety Assessment and Management, Osaka, Japan, December 2000

Annex 1: Geometric Specifications for Modelled Departure Routes

Route	Turn 1 centre (local x)	Turn 1 centre (local y)	Turn 1 direction (C/AC)	Turn 1 radius (m)	Turn 1 angle (°)	Turn 2 centre (local x)	Turn 2 centre (local y)	Turn 2 direction (C/AC)	Turn 2 radius (m)	Turn 2 angle (°)
N28R_D_AB_ROTEV	2000	-500	C	2000	132	5288	3152	AC	2914	46
N28R-I_D_CD_ABB-E	4000	1700	C	4000	178	-	-	-	-	-
N28R-I_D_CD_ABBEY	3304	2185	C	3304	75	5742	2186	C	3994	106
N28R_D_CD_NEPOD	2037	2185	C	2037	30	-439	10006	AC	3994	137
N28R-I_D_CD_NEP-E	2037	2185	C	2037	30	-2484	6578	AC	4051	125
N28R_D_CD_NEP-M	2037	2185	C	2037	30	-1426	8242	AC	3967	131
N10L_D_CD_ABBEY	-757	1963	AC	757	15	-4967	7927	AC	3265	5
N10L_D_AB_ROTEV	-1984	-500	AC	1984	110	-7267	3853	C	3914	40
S10_D_AB-LIFFY	-2698	-900	AC	2698	58.2	-6886	7688	C	2396	54.8
S10_D_AB-NEPOD	2351	-700	C	2351	67.2	-	-	-	-	-
S10_D_CD-NEPOD	4108	12000	C	4108	93.3	-	-	-	-	-
S10_D_CD-LIFFY	-9419	9500	AC	9419	14.7	-	-	-	-	-
S28_D_AB-LIFFY	1961	-500	C	1961	88.5	6462	-471	C	2068	88.1
S28_D_AB-NEPOD	-1962	-500	AC	1962	118.3	-	-	-	-	-
S28_D_CD-LIF-E	3979	5000	C	3979	176.3	-	-	-	-	-
S28_D_CD-LIF-M	3979	6800	C	3979	176.3	-	-	-	-	-
S28_D_CD-ROTEV	4005	8800	C	4005	108.3	-	-	-	-	-
S28_D_CD-NEP-E	-3981	4900	AC	3981	114.8	-	-	-	-	-
S28_D_CD-NEP-M	-3983	6700	AC	3983	116.6	-	-	-	-	-
S28_D_CD-NEPOD	-3988	8800	AC	3988	118.7	-	-	-	-	-

Annex 2: Fleet Mixes

2022 Permitted Operations Fleet Mix

Aircraft Type	10L Arrivals	28R Arrivals	10R Arrivals	28L Arrivals	16 Arrivals	34 Arrivals
Airbus A306	0	0	188	455	5	2
Airbus A319	660	0	0	1592	17	6
Airbus A320	7633	0	942	20698	222	74
Airbus A320neo	377	0	0	910	10	3
Airbus A321	848	0	94	2275	24	8
Airbus A321neo	94	0	0	227	2	1
Airbus A330	1508	0	283	4322	46	15
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	2544	0	94	6369	68	23
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	94	0	0	227	2	1
Boeing 737-400	188	0	188	910	10	3
Boeing 737-700	188	0	0	455	5	2
Boeing 737-800	11684	0	377	29114	312	104
Boeing 757	188	0	0	455	5	2
Boeing 767	0	0	94	227	2	1
Boeing 777	94	0	94	455	5	2
Boeing 777X	0	0	0	0	0	0
Boeing 787	471	0	94	1365	15	5
Bombardier CS300	283	0	0	682	7	2
Bombardier Dash 8	377	0	0	910	10	3
Embraer E190/195	1413	0	0	3412	37	12
Embraer E190-E2	0	0	0	0	0	0
Other	1225	0	0	2957	32	11

2022 Permitted Operations Fleet Mix Continued

Aircraft Type	16 Dep	34 Dep	N10L Dep CD_ABBEY	N10L-I Dep AB_ROTEV	N28R-I Dep AB_ROTEV	N28R Dep CD_ABB-E
Airbus A306	5	2	0	0	0	0
Airbus A319	19	6	94	0	0	455
Airbus A320	219	73	1037	0	0	7430
Airbus A320neo	10	3	0	0	0	152
Airbus A321	24	8	94	0	0	910
Airbus A321neo	2	1	0	0	0	0
Airbus A330	46	15	0	0	0	0
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	68	23	0	1790	4322	0
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	2	1	0	0	0	152
Boeing 737-400	10	3	0	0	0	455
Boeing 737-700	7	2	0	0	0	455
Boeing 737-800	312	104	1319	0	0	10614
Boeing 757	5	2	0	0	0	0
Boeing 767	2	1	0	0	0	152
Boeing 777	5	2	94	0	0	152
Boeing 777X	0	0	0	0	0	0
Boeing 787	15	5	188	0	0	303
Bombardier CS300	7	2	0	0	0	152
Bombardier Dash 8	10	3	0	0	0	0
Embraer E190/195	34	11	0	0	0	455
Embraer E190-E2	0	0	0	0	0	0
Other	32	11	0	471	1137	607

2022 Permitted Operations Fleet Mix Continued

Aircraft Type	N28R Dep CD_ABBEY	N28R Dep CD_NEPOD	N28R Dep CD_NEP-E	N28R Dep CD_NEP-M	S10R Dep AB_LIFFY	S10R Dep AB_NEPOD
Airbus A306	0	303	76	76	0	0
Airbus A319	227	303	303	303	0	0
Airbus A320	3715	2426	2426	2426	0	0
Airbus A320neo	76	152	152	152	0	0
Airbus A321	455	227	227	227	0	0
Airbus A321neo	227	0	0	0	0	0
Airbus A330	1592	2502	0	0	0	0
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	0	0	0	0	94	754
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	76	0	0	0	0	0
Boeing 737-400	455	0	0	0	0	0
Boeing 737-700	227	0	0	0	0	0
Boeing 737-800	5307	3412	3412	3412	0	0
Boeing 757	227	227	0	0	0	0
Boeing 767	76	0	0	0	0	0
Boeing 777	76	227	0	0	0	0
Boeing 777X	0	0	0	0	0	0
Boeing 787	379	682	0	0	0	0
Bombardier CS300	76	152	152	152	0	0
Bombardier Dash 8	0	0	0	0	0	377
Embraer E190/195	227	531	531	531	0	0
Embraer E190-E2	0	0	0	0	0	0
Other	303	227	227	227	0	0

2022 Permitted Operations Fleet Mix Continued

Aircraft Type	S10R Dep CD_NEPOD	S10R Dep CD_LIFFY	S28L Dep AB_LIFFY	S28L Dep AB_NEPOD	S28L Dep CD_ROTEV	S28L Dep CD_LIFF-E
Airbus A306	188	0	0	0	0	0
Airbus A319	377	283	0	0	76	76
Airbus A320	3769	3675	0	0	76	76
Airbus A320neo	283	94	0	0	0	0
Airbus A321	377	471	0	0	0	0
Airbus A321neo	0	94	0	0	0	0
Airbus A330	188	1602	0	0	0	0
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	0	0	227	1820	0	0
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	0	94	0	0	0	0
Boeing 737-400	0	377	0	0	0	0
Boeing 737-700	0	283	0	0	0	0
Boeing 737-800	5465	5277	0	0	0	0
Boeing 757	0	188	0	0	0	0
Boeing 767	0	94	0	0	0	0
Boeing 777	0	94	0	0	0	0
Boeing 777X	0	0	0	0	0	0
Boeing 787	0	377	0	0	0	0
Bombardier CS300	188	94	0	0	0	0
Bombardier Dash 8	0	0	0	910	0	0
Embraer E190/195	1037	283	0	0	0	0
Embraer E190-E2	0	0	0	0	0	0
Other	377	377	0	0	0	0

2022 Permitted Operations Fleet Mix Continued

Aircraft Type	S28L Dep CD_LIFF-M	S28L Dep CD_NEPOD	S28L Dep CD_NEP-E	S28L Dep CD_NEP-M
Airbus A306	0	0	0	0
Airbus A319	76	0	0	0
Airbus A320	76	607	607	607
Airbus A320neo	0	76	76	76
Airbus A321	0	76	76	76
Airbus A321neo	0	0	0	0
Airbus A330	0	76	76	76
Airbus A330neo	0	0	0	0
Airbus A350	0	0	0	0
ATR 72	0	0	0	0
BAe 146/Avro RJ	0	0	0	0
Boeing 737 MAX	0	0	0	0
Boeing 737-400	0	0	0	0
Boeing 737-700	0	0	0	0
Boeing 737-800	0	986	986	986
Boeing 757	0	0	0	0
Boeing 767	0	0	0	0
Boeing 777	0	0	0	0
Boeing 777X	0	0	0	0
Boeing 787	0	0	0	0
Bombardier CS300	0	0	0	0
Bombardier Dash 8	0	0	0	0
Embraer E190/195	0	303	303	303
Embraer E190-E2	0	0	0	0
Other	0	76	76	76

2022 Proposed Operations Fleet Mix

Aircraft Type	10L Arrivals	28R Arrivals	10R Arrivals	28L Arrivals	16 Arrivals	34 Arrivals
Airbus A306	0	0	188	455	5	2
Airbus A319	660	0	0	1592	17	6
Airbus A320	8010	0	1037	21835	234	78
Airbus A320neo	377	0	0	910	10	3
Airbus A321	848	0	94	2275	24	8
Airbus A321neo	94	0	188	682	7	2
Airbus A330	1413	0	565	4776	51	17
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	2544	0	94	6369	68	23
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	94	0	0	227	2	1
Boeing 737-400	188	0	188	910	10	3
Boeing 737-700	188	0	0	455	5	2
Boeing 737-800	11779	0	283	29114	312	104
Boeing 757	188	0	0	455	5	2
Boeing 767	0	0	94	227	2	1
Boeing 777	94	0	94	455	5	2
Boeing 777X	0	0	0	0	0	0
Boeing 787	471	0	94	1365	15	5
Bombardier CS300	283	0	0	682	7	2
Bombardier Dash 8	377	0	0	910	10	3
Embraer E190/195	1413	0	0	3412	37	12
Embraer E190-E2	0	0	0	0	0	0
Other	1225	0	0	2957	32	11

2022 Proposed Operations Fleet Mix Continued

Aircraft Type	*16 Dep*	*34 Dep*	*N10L Dep CD_ABBEY*	*N10L-I Dep AB_ROTEV*	*N28R-I Dep AB_ROTEV*	*N28R Dep CD_ABB-E*
Airbus A306	5	2	0	0	0	0
Airbus A319	19	6	0	0	0	455
Airbus A320	232	77	0	0	0	7733
Airbus A320neo	10	3	0	0	0	152
Airbus A321	24	8	0	0	0	910
Airbus A321neo	7	2	0	0	0	0
Airbus A330	51	17	0	0	0	0
Airbus A330neo	0	0	0	0	0	0
Airbus A350	0	0	0	0	0	0
ATR 72	68	23	0	1790	4322	0
BAe 146/Avro RJ	0	0	0	0	0	0
Boeing 737 MAX	2	1	0	0	0	152
Boeing 737-400	10	3	0	0	0	455
Boeing 737-700	7	2	0	0	0	455
Boeing 737-800	312	104	0	0	0	10463
Boeing 757	5	2	0	0	0	0
Boeing 767	2	1	0	0	0	152
Boeing 777	5	2	0	0	0	152
Boeing 777X	0	0	0	0	0	0
Boeing 787	15	5	0	0	0	303
Bombardier CS300	7	2	0	0	0	152
Bombardier Dash 8	10	3	0	0	0	0
Embraer E190/195	34	11	0	0	0	455
Embraer E190-E2	0	0	0	0	0	0
Other	32	11	0	471	1137	607