THE AUSTRALIAN APPROACH TO GROUND POPULATION MODELLING AND RISK ASSESSMENT

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ABSTRACT

This paper describes the approach taken by Australia's range safety experts, including the Defence Science and Technology Organisation (DSTO) and Aerospace Concepts Pty Ltd, in generating reliable risk assessments considering a ground population model. This includes a discussion of the process as it is used in the Range Safety Template Toolkit (RSTT), Australia's latest capability in range safety analysis.

The Australian approach combines high-resolution data from the Australian Census with time-varying population data of high-risk areas close to a given mission. This results in a demonstratively conservative yet accurate assessment of risk which is assessed against common safety standards. Furthermore, risk to mission-essential personnel and to the general public is assessed separately and can include detail of vulnerable infrastructure and facilities.

The approach is explored through examples involving generic population data and missions, demonstrating how range safety products are generated from the RSTT and how they may be used to assess risk.

1. INTRODUCTION

Complying with range safety criteria is a major requirement of any Risk Hazard Analysis (RHA) for a given launch operation. An RHA must provide a comprehensive assessment of the risk posed to both mission-essential personnel and to the general public, as well as an estimation of the expected casualties for a given mission or set of missions. The posed risks and casualty rates should comply with safety policies defined by common standards such as RCC STD-321-07 [1] in order to ensure acceptance of a mission proposal. A common approach is to apply Geospatial Information Systems (GIS) data to a ground impact probability function produced during range safety template generation. This brief describes the process used by the Range Safety Template Toolkit (RSTT), Australia's latest capability in RHA development, in ground population modelling and its application to risk assessment. Aerospace Concepts Pty Ltd has previously presented RSTT capabilities in detail ([2],[3],[4]); what follows is a brief description to provide context.

The RSTT provides a method for rapid generation of mission-specific safety templates, achieved through the use of high fidelity nominal and failure vehicle modelling in conjunction with massive Monte Carlo simulation. This generates a large amount of ground impact data across a wide range of flight behaviours, and when statistically processed, results in a comprehensive and defensible safety template. The posed risk of a given mission is highly dependent on the intersection between the safety template and ground population, providing an overall 'Expected Casualty' level as well as showing areas of high risk. An example output is given in Figure 1, showing the posed risk at given sites near the launch area.

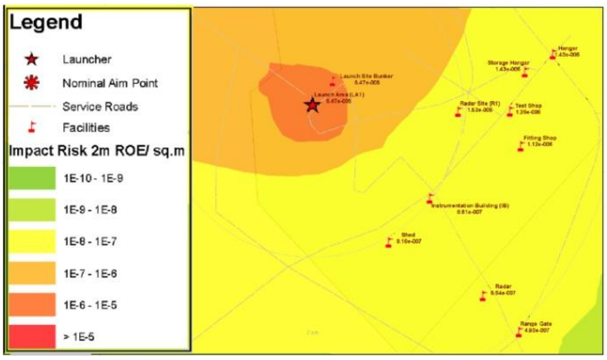

Figure 1. Casualty risk around the launch area, range facilities, and other nearby buildings

2. POPULATION DATA SOURCES

As an Australian capability, the RSTT is primarily concerned with missions taking place in and around Australia. Presently the best compromise between data accuracy, ease of access, and resolution is provided by the Australian Bureau of Statistics (ABS) in the form of the *Australian Census of Population and Housing* [5], hereafter referred to as 'the Census'. A national census activity is gathered every five years and is compulsory for all persons present on Australian territory during census night, and is publically available in multiple GIS formats (such as ESRI shapefile, MapInfo, and CSV). The data includes population estimates of varying resolution (such as city-level, electoral district, and postal code areas) which are adjusted for Census undercounting (persons missed by the Census) and estimates of Australian residents temporarily overseas.

Due to the inherent inaccuracies present in Census data (described in more detail in Section 3), other sources are sought. On-facility data is generally gathered through the organisational bodies responsible for the mission, such as the facility operators, and consists of information about facility infrastructure (such as the location of buildings, expected population, estimated building strength, etc.). Near-facility data (which consists of nearby homesteads, mines, roads, railways, culturally sensitive indigenous sites, and prohibited areas) is also gathered by the responsible bodies, generally through conservative surveys by staff or locals of the area, as well as by Geoscience Australia, the national geospatial information agency. Such supplementary data is generally modelled as points or line segments, whereas Census districts are polygons of varying sizes.

3. POPULATION DATA RESOLUTION AND ACCURACY

Given its nature, the Census provides the most accurate information for population density in Australia. The highest possible resolution is at the Mesh Block level which defines areas of approximately 30 to 60 dwellings with over 300,000 such areas across Australia[6]; an example is shown in Figure 2. The data provided at the Mesh Block level includes population and dwelling counts, as well as overall Mesh Block category (‘Residential’, ‘Commercial’, ‘Industrial’, etc.) [7].

Figure 2. Mesh Block resolution provided by the Australian Bureau of Statistics [8]

Census population data for a given Mesh Block polygon is assumed to be distributed uniformly throughout the area. The RSTT does not currently provide a means for more complex distributions, and given the nature of the data, the counts represent only the people who live in a given location, and not time-variant data such as peak working population. Furthermore, Census population numbers are impacted by respondent and processing errors. The ABS assures higher accuracy is provided by taking into account Census undercounting (failure to account for everyone in a given area and for citizens temporarily overseas), however it also introduces a small random adjustment to each population count in order to maintain general population confidentiality. This randomisation has a greater impact on Mesh Block resolution than on larger areas. Despite this the ABS strives to maintain the highest possible quality, and ensures that the Census provides a comprehensive coverage of Australia.

In order to complement the relative inaccuracies inherent in the uniform distribution used for Census data, the RSTT can also support additional independently-derived population data. This data, which is generally provided for on-facility and near-facility sources, results in a more conservative estimate by essentially double-counting the population of certain high-risk areas – for example, the population of a high-risk homestead is counted both at its location (provided by near-facility sources) as well as uniformly distributed across the Mesh Block containing it (provided by the Census). Conservative assumptions of this nature are only refined if the resulting expected casualty estimate nears the mandated mission limit, thus justifying an increase in population accuracy.

The on-facility and near-facility data also allows for some time-variant populations to be accounted for. The Census provides only data for residences, which may not accurately reflect the location of the general public during, for example, a working day. Having data of nearby infrastructure and facilities (for example mines, roads, railways, etc.) ensures that the risk assessment is accurate for high-risk areas (that is, it still assumes all residences are occupied at all times). Sources may also provide additional adjustments for Census data – for example, the seasonal peak tourist population of Broome, Western Australia, increases its count by over 30,000 people.

The accuracy of on- and near-facility data depends upon the source, whether this be the facility operators, responsible bodies, locals, or a government agency (such as Geosciences Australia).

4. RISK ASSESSMENT USING POPULATION MODELS

The RSTT is used to generate a Probability Density Function (PDF) of Ground Impact Points (GIPs) for nominal and failure behaviour. The generic example in Figure 3shows how the PDF is superimposed on geographical and topographical data for ease of reference and analysis. Note that the example shows all probabilities for GIPs, including those which are orders of magnitude below the safety requirements. The PDF represents the probability density of impact of one or more pieces of vehicle debris across the area around the launch. It is combined with population data to produce the final risk products for a given mission.

The PDF is used in three ways. Firstly, it is used to define areas conforming to Individual Risk Criteria (IRC) as defined by safety standards such as RCC STD-321-07.

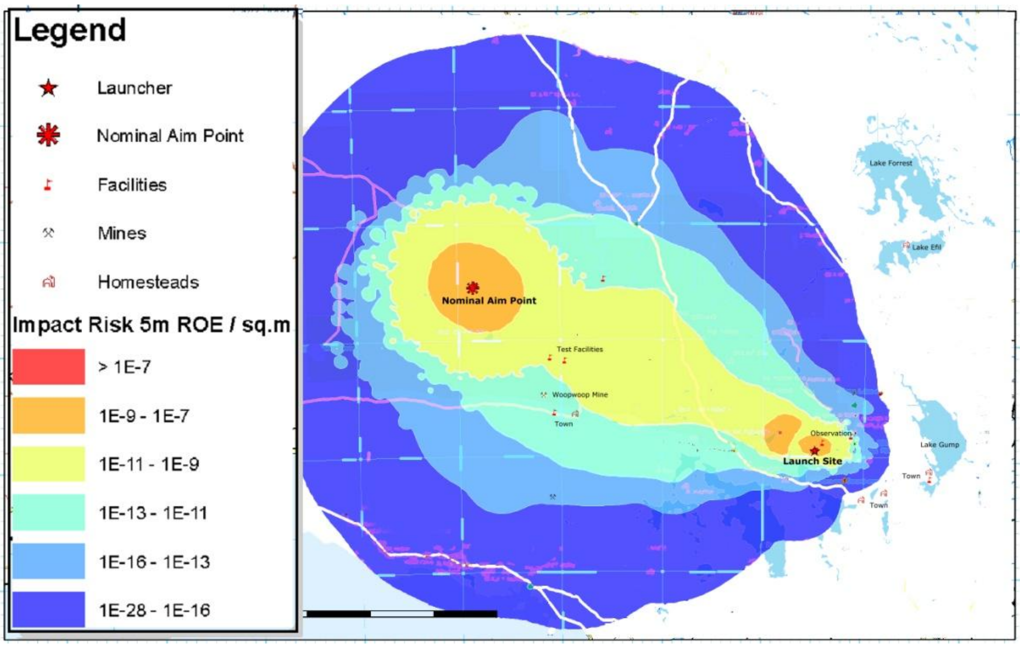

Figure 3. Generic example of PDF superimposed on geographical and topographical data

The IRC contours mark an area that should be evacuated of all individuals of a given type, depending on the criteria. An example is shown in Figure 4for risk posed to mission-essential personnel (MEP) and general population (GP) – notice that certain facilities lie outside of the MEP contours, indicating low risk to MEP, however these same facilities lie well within the IRC contours for the general population (and must therefore be evacuated of non-MEP).

The IRC contours define areas completely evacuated of non-essential personnel; thus, they are areas which can be considered to have zero population (or some small mission-essential population) for the purposes of the risk analysis. Given that these areas are usually tightly surveilled and controlled by range management authorities, this is a reasonable assumption to make.

Next, the PDFs are combined with the adjusted ground population models such that impact probability density over an area is multiplied by the population density over the area. This gives an Expected Casualty or Expected Fatality result. An excerpt of the results for an example launch RHA is shown in Table 1.

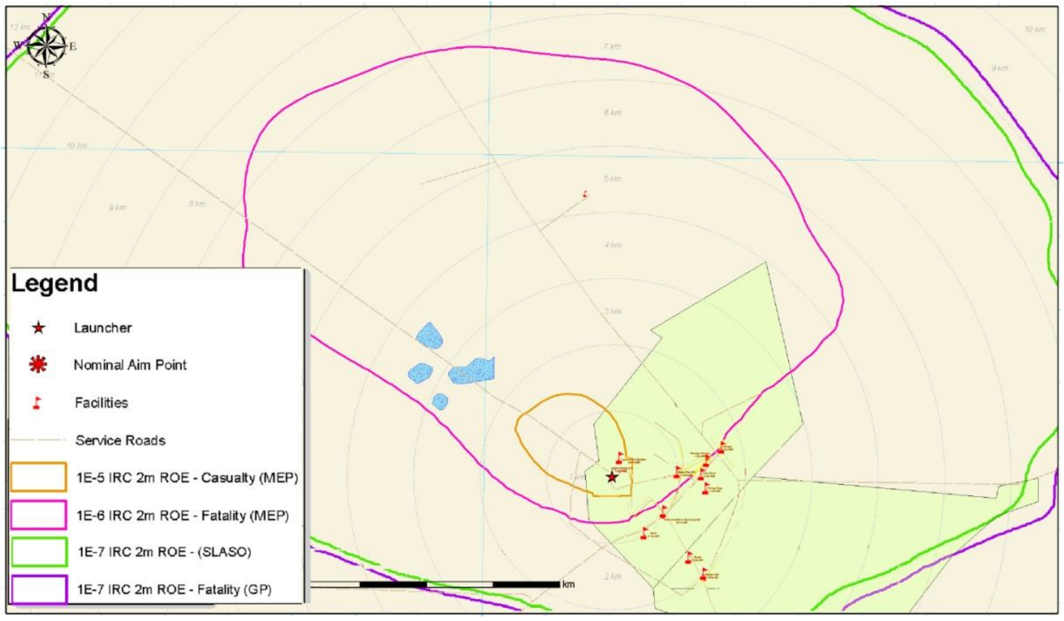

Figure 4. IRC contours for an example launch and facility, as defined by RCC STD-321-07. The green and purple IRC contours are for the GP and orange and pink are for MEP.

Table 1. General population expected casualty contributes by site

Site Name	Type	Assumed Population	E_CContribution
Small Local Town 1	Homestead	20	7.75E-06
Railway Line	Railway	2460 (along length)	4.87E-06
Highway 5	Road	1218 (along length)	3.67E-07
Suburb E	Census district	39	3.76E-08
Iron Mine	Mine	2123	1.55E-08

Table 2. Threshold values for roof penetration [9]

Class	Building purpose	Roof construction	Penetration criteria	
			Minimum mass fragment (lb)	Minimum kinetic energy (ft-lb)
A	Mobile homes & demountable offices	24 gage corrugated aluminium	0.037	17
B	Single family dwellings Small townhouses Small apartment buildings	5/8-inch plywood	0.075	30
C	Small retain commercial buildings Small office & medical buildings	Composite roof (2 inch rigid gypsum insulation on steel purlins)	0.075	30
D	Manufacturing plants Warehouses Public buildings	3½-inch Light weight concrete on 22 gauge corrugated steel decking	0.500	414

Finally, if this is required for the risk analysis, the data is also combined with infrastructure sheltering information such as building size and strength (obtained from plans and local professional judgement). This is used to form a judgement about penetration energy thresholds as per the supplement to RCC STD-321-07 which defines four classes of roof based on construction type that correspond to building purpose as listed in Table 2.

This results in different sets of IRC contours representing acceptable risks both to individuals inside buildings, as well as to the buildings themselves. This is also applicable as a measured risk on such things as culturally sensitive indigenous sites, a matter of much importance to the Australian government.

This is illustrated in the example in Figure 5 – the blue contour represents 1E-06 Class D building individual risk and the red contour represents 1E-06 'out in the open' individual risk. Personnel outside of the blue contour may be safely located inside of any Class D strength or greater building. Personnel outside of the red contour may safely be 'out in the open'. In this case, personnel at Building 1 must remain inside, assuming it is of class D strength or greater, while personnel at Building 2 may be located either inside or 'out in the open'.

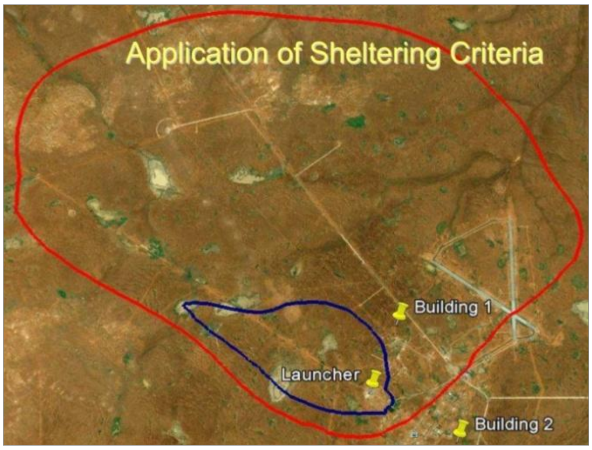

Figure 5. IRC contours combined with building strength information

One limitation of the threshold criteria in Table 2 is that there is no class defined for buildings designed to resist penetration such as bunkers, block houses and specialist buildings with additional reinforcing. This means that, unless a structural engineering assessment is done, the Class D penetration criteria must be used thus making an already conservative analysis even more so. However, we have found that this is causes only minor problems in practice.

5. RESULTING RISK HAZARD ANALYSIS

The overall outcome of the above method is to measure whether a mission is within acceptable risk levels, both for the general public and for mission-essential personnel. Similarly, if it is required, risk to buildings and other sites may also be calculated. This outcome, which is generally in the form of Expected Casualty and Expected Fatality figures, is then compared against the relevant safety standard (normally RCC STD-321-07) and conclusions are drawn.

A final example is provided in the table below of the concluding analysis of a generic sounding rocket launch. Note that, as Aerospace Concepts deals primarily with single-mission analysis, numbers are not calculated for expected yearly risk as defined in RCC STD-321-07.

Table 3. Assessed risk for example mission in comparison to RCC STD-321-07 risk criteria

Risk Criteria	Assessed Risk		Maximum acceptable as per RCC STD-321-07 criteria		Result
	General Public	Mission Essential Personnel	General Public	Mission Essential Personnel	
Individual Risk Criteria (IRC) – Casualty (I_C)			Inside range boundary		✓
Individual Risk Criteria (IRC) – Fatality (I_F)			Inside range boundary		✓
Expected Casualties (E_C)	18.99×10^{-6}	12.26×10^{-6}	100×10^{-6}	300×10^{-6}	✓
Expected Fatalities (E_F)	7.82×10^{-6}		30×10^{-6}	300×10^{-6}	✓

6. FUTURE WORK

Our currently-identified future work seeks to answer the following questions:

1. Will the Census provide data for time-variant counts such as peak commuting population? Alternatively, could the Mesh Block category (such as 'Residential', 'Industrial', 'Commercial', etc.) be used to complement the residential counts?
2. Is there a way to formalise a process for gathering data for high-risk areas?
3. What is the most appropriate way to ensure accuracy and validity of locally-sourced data?

7. CONCLUSIONS

Ground population modelling is an integral part of risk analysis for launch missions. Population and infrastructure data is required to make accurate assessments of the posed risk to the general public and to mission-essential personnel. Applying this data to the impact distributions generated by RSTT provides not only values required for meeting of safety criteria (such as Expected Casualties) but also a simple method of analysing risk to buildings, sites, roads, and any other desired features.

Australia's Census provides an accurate population count of areas throughout the country. Combined with higher resolution data for high-risk areas (close to the launch trajectory), a demonstratively conservative yet accurate assessment of risk is generated and ultimately processed into a Risk Hazard Analysis product.

8. REFERENCES

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