Quantitative and Qualitative Risk Assessments – A Highly Neglected Methodology

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1. Introduction

Fire safety engineers rely on a toolbox of familiar, reliable and well documented methodologies most of which are commonly and readily accepted by the industry. It is often recognised that authorities having jurisdiction (i.e. certifying authorities) and required referral bodies (i.e. relevant fire brigades) readily accept and are willing to support performance solutions when a performance requirement is demonstrated to be satisfied based on a validated and conventional approach. There are a wide range of deterministic methodologies which, almost by default, are adopted across the industry for certain issues, such as:

- Time equivalence burn out methodologies for reduction in FRLs;
- $RSET_{DtS} > RSET_{Performance\ Solution}$ assessments for extended travel distances in carparks;
- BCA Verification methods CV1a and CV1b for unprotected openings located closer than 3 m to the boundary for Class 2 to Class 9 buildings; and
- ASET/RSET assessments with Zone or CFD smoke and fire modelling for issues related to extended travel distances, large compartments or fire engineered smoke hazard management systems.

Majority of the time these methodologies, which are based on qualitative or quantitative and absolute or comparative "deterministic" approaches, are highly appropriate. On the other hand, there are alternative methodologies that could also be at least as appropriate (if not more) and relevant in their application to the justification of a performance solution. Risk based approaches which are often overlooked by fire safety engineers would represent such methodologies. The Fire Engineering Guidelines (1996), The Fire Engineering Guidelines (2001) and the International Fire Engineering Guidelines (2005); all identify risk assessments as a viable and relevant approach. There is a wide spectrum of qualitative and quantitative risk based methodologies available to fire safety engineers which vary from simple check lists to Failure Mode and Effect Analysis (FMEA) and from Fault/Event Trees to full blown Expected Risk to Life (ERL) assessments.

The question often is: "*Why are risk based methodologies less popular compared to other quantitative (and even qualitative) approaches?*" According to the authors of this paper there are a number of factors which may be playing a role in their unpopularity. These shall be discussed in further detail in the following sections.
To clearly understand and assess 'risk' in the built environment, it is important to understand how it is applied. This has been evaluated through firstly determining and understanding the term risk in relation to fire engineering and secondly, through identifying the key methods and approaches that are commonly undertaken locally and globally. By being able to understand fire risks and their methods of assessment, one can define and adopt alternative methods for their future application.

Verification methods, which are identified as an assessment method in the BCA, lend themselves to risk based approaches better than many other methods. With the introduction of further verification methods into the building codes there is a potential to adopt risk based approaches more frequently. This approach has been evaluated with consideration of the Building Code of Australia (BCA) within this paper.

As outlined by Watts and Hall [2], risk is the potential for realisation of unwanted adverse consequences to human life, health, property or the environment. IFEG defines risk as 'the likelihood of a hazardous event occurring'. This is further defined as being "the assessment of risk to the people and property as a result of unwanted fires" [1]. Whilst (Meacham, et al [3]) identifies the building fire risk analysis as the process of understanding and characterising the fire hazards in a building, the unwanted outcomes that may result from a fire, and the likelihood of fire and unwanted outcomes occurring. Hence, in summary it can be considered that 'risk' specific to a buildings and fires specific to occupants and property, is the occurrence of a fire and the resultant impact and consequence.

To be able to ascertain the level of risk and either quantify/qualify its impact, a number of methods and approaches can be undertaken. This can be defined as a 'fire risk analysis or assessment' which utilises the principles and methodologies of risk that are currently available and apply them in the context of the built environment. In fire safety engineering, risk analysis is most generally used to evaluate fire protection strategies for a particular application or for a class of facility or operation. And as defined by Watts and Hall [2], fire risk analysis is basically a structured approach to decision making under uncertainty.

2. Risk Based Assessment Concepts and Approaches

With respect to the fire risk analysis methodology/approach, the general concept and steps can be outlined as follows [2]:

1. Identify fire hazards:
    a. Sources of ignition;
    b. Sources of Fuel;
    c. Sources of Oxygen.
2. Identify the consequences and probabilities of the fire hazards:
    a. Identify the type of classification and use of the building/area;
    b. Review the proposed layout and internal arrangement of the building/area;
    c. Ascertain the relevant statistics influencing the building/area (e.g. area of fire origin, fatalities etc.).
3. Identify hazard control options:
    a. Determine the base building passive and active fire safety measures;
    b. Ascertain Management in use procedures or Regulatory Requirements.
4. Quantify the effects of the options on the risks of the hazards;
    a. Evaluate the identified design parameters with consideration of occupants, fire brigade and property protection (where applicable).
5. Select appropriate protection:
    a. Predicated on the effects identified, adopt appropriate fire safety measures with consideration of the cost implications in the event of a fire.

This above mentioned concept is noted to be one of a number of possible methodologies that may be undertaken by a practitioner. However, with respect to risk based assessments there is no one way to utilise and adopt them. This is as previously mentioned based on the vast number of methodologies that are available and also the fact that an approach that one practitioner may undertake, is not necessarily the same as another.

2.1 Types of Risk Assessments (Qualitative/Quantitative)

Risk assessments tend to address the physical situation and seek to measure/predict and assess the acceptability of risk in a particular place and situation [4]. As a result, various assessment methods have been developed to help address these key risk items.
As outlined by Watts and Hall, 2016 [2], the fire risk analysis may be classified into four categories: Checklists, Narratives, Indexing and probabilistic methods.
Alternatively, the types of assessments that are currently available for the purposes of fire hazard assessments can typically be defined into three (3) categories or methods. These are noted to be Qualitative, Semi-Qualitative and Quantitative methods as recognized by Ramachandran [4] as illustrated in Figure 2.1.

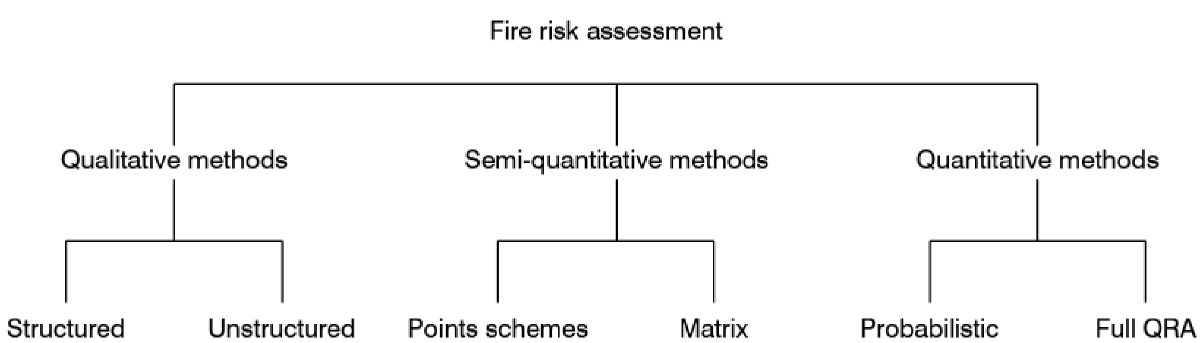

Figure 2.1: Summary of different fire risk assessment methods

The general approach that has been adopted in this paper is the application of the Ramachandran [4] definition and justification of fire risk assessments. However for simplicity, this paper has separated the assessment types into only two (2) methodologies, ‘Qualitative’ and ‘Quantitative’ with the semi-quantitative method being included into the ‘Quantitative’ methodology.

2.2 Qualitative Assessments

Qualitative assessments have typically been adopted when a simplistic issue or concern has been identified. Furthermore, they have been utilised to rationalise or identify key elements within a scenario to provide an overview of the risk that may be present within a certain situation. Through a qualitative assessment, the practitioner is able to subsequently assess those high risk elements/scenarios through a more detailed assessment, which would commonly be a Quantitative assessment. Narratives and the Failure Mode and Effect Analysis (or FMEA’s) are typical examples of qualitative risk analysis methods that are commonly adopted.

2.3 Quantitative Assessments

Quantitative assessments, as outlined in Figure 2.1, are separated into two major groups being Probabilistic Assessments and Full Quantitative Risk Assessments (QRA).

With any quantitative assessment the information or basis/assumptions of an assessment is critical. Typically the information that is relied upon for any assessment is either adopted from statistical information provided by real fire events from the past, information/data provided specific to the function and use of an environment through to the reliability and effectiveness of a systems including the input parameters that are utilised in undertaking a model or assessment. The common element and important thing to always consider from those approaches outlined above is confirming that the assumptions made and the adoption of the information is reasonable and reliable in order to achieve a suitable outcome.

Common QRA methodologies include Fault Trees, Event Trees and F-N Curves. In order to ascertain the suitability of QRAs, as part of this paper an F-N Curve assessment will be adopted. An overview has been provided in the following sections.

2.3.1 F-N Curves

Individual risk is the simply the predicted frequency of the undesired outcome. Societal risk is the risk of widespread or large scale detriment from the realisation of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response. Societal risk takes account of both the severity of the range of possible outcomes and the frequency at which they each are predicted to occur. It is usually presented as a two dimensional relationship between frequency and cumulative severity of outcome, called an F-N curve.

F-N Curves relate to the probability per year of causing N or more fatalities (F) to N. This is the complementary cumulative distribution function. Such curves may be used to express societal risk criteria and to describe the safety levels of particular facilities. F-N curves are usually used to express societal risk. Therefore, it is important to define acceptable / tolerable risk.

Acceptable risks are the risks which everyone impacted is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

On the other hand tolerable risk is defined as a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

F-N curves in the context of fires may show the number of fatalities against annual frequency. The frequency of events which causes at least N fatalities is plotted against the number N on log log scales.

F-N curves are evaluated based on the ALARP (As Low As Reasonably Practicable) principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion (depending on the level of risk) to the improvement gained.

The F-N curves concept is further discussed in Section 0.

3. Building Codes and Verification Methods

3.1 General

Verification Methods are tests or calculation methods that prescribe one way to comply with relevant Building Codes. Verification Methods can include:

- calculation methods: using recognised analytical methods and mathematical models; and
- laboratory tests: using tests (sometimes to destruction) on prototype components and systems; and

- tests-in-situ: which may involve examination of plans and verification by test, where compliance with specified numbers, dimensions or locations is required (non-destructive tests, such as pipe pressure tests, are also included).

In a number of the codes (i.e. New Zealand and Australia), there are verification methods (or prescriptive methodologies) that have been documented and provided to assist in undertaking assessments of buildings in relation to the impact of fire.

Within the Australian and New Zealand codes, these have been further documented with significant and detailed sections that have been formulated to allow for systematic approaches in combination with suitable data in order to allow for practitioners to undertake assessments with respect buildings. The methodologies and data that have been provided in both cases are specific to quantitative deterministic assessments.

3.2 Building Code of Australia

Since 1996, compliance with the code has been achieved through either Deemed to Satisfy solutions or through the performance based solution approach. As part of the assessments methods there are a number of methodologies which can be utilised as permitted and outlined in Clause A0.9 or with the most recent amendment A0.5. These are noted to be as follows [9]:

a) Evidence to support the use of a material or product, from of construction or design meets a Performance Requirement or a Deemed-to-Satisfy Provision as described in A2.2;

b) Verification Methods such as -

   i. Verification methods in the NCC; or

   ii. other such Verification Methods as the appropriate authority access for determining compliance with the Performance Requirements;

c) Expert Judgement; and

d) Comparison with the Deemed to Satisfy Provisions.

The focus of this review relates to the verification methods approach that are documented in the NCC that relate to fire. A verification method is defined as 'a test, inspection, calculation or other method that determines whether a Performance Solutions complies with the Performance Requirements' (ABCB 2016). The BCA is separated into sections that relate to key principles when constructing a building. They are noted to be as follows:

- Section B: Structure;
- Section C: Fire Resistance;
- Section D: Access and Egress;
- Section E: Services and Equipment;
- Section F: Health and Amenity;
- Section G: Ancillary Provisions;
- Section H: Special Use Buildings; and
- Section J: Energy Efficiency.

3.3 Verification methods in the Current BCA and in the Draft Summary Document

As identified above, the extent of verification methods in the BCA currently is limited. With consideration of fire safety, the only method that is currently adopted relates to fire spread between buildings on the same or different allotments. With respect to CV1 and CV2 assessment methods, it is recognized to be a combined quantitative and deterministic approach.

CV1

Compliance with CP2(a)(iii) to avoid the spread of fire between buildings on adjoining allotments is verified when it is calculated that—

(a) a building will not cause heat flux in excess of those set out in column 2 of Table CV1 at locations within the boundaries of an adjoining property set out in column 1 of Table CV1 where another building may be constructed; and

(b) when located at the distances from the allotment boundary set out in column 1 of Table CV1, a building is capable of withstanding the heat flux set out in column 2 of Table CV1 without ignition.

Table 3.1: *CV1*

Column 1 ***Location***	***Column 2*** ***Heat Flux (kW/m²)***
On boundary	*80*
1 m from boundary	*40*
3 m from boundary	*20*
6 m from boundary	*10*

CV2

Compliance with CP2(a)(iii) to avoid the spread of fire between buildings on the same allotment is verified when it is calculated that a building—

(a) is capable of withstanding the heat flux set out in column 2 of Table CV2 without ignition; and

(b) will not cause heat flux in excess of those set out in column 2 of Table CV2, when the distance between the buildings is as set out in column 1 of Table CV2.

Table 3.2: *CV2*

Column 1 ***Distance between buildings***	***Column 2*** ***Heat Flux (kW/m²)***
0 m	*80*
2 m	*40*
6 m	*20*
12 m	*10*

This principle and approach is also recognised and adopted for non-fire related verification methods within the BCA Sections E to J.

The ABCB has begun undertaking works to further update the verification methods that are present in the BCA. A draft document was issued in 2014 for public review and consideration. However, given the annual amendments of the BCA at the time, the document is yet to be introduced/uplifted to the BCA. With the recent changes to the timing associated with the amendments from the annual update to a once every three years, the ABCB in 2016 issued a draft document highlighting new verification methods and approaches that may be uplifted into the 2019 version of the BCA. The following section provides an overview and account of the changes and methods that have been proposed.

The proposed Fire Safety Verification document that has been proposed by the ABCB has adopted a design scenario concept where based on the design issues that need to be addressed a process/procedure needs to be documented to demonstrate compliance with the relevant Performance Requirements. The Figure 3.1 highlights the process as outlined in the draft document.

The basic premise associated with the process is essentially no different to the IFEG process. The steps that need to be undertaken require that a Performance Based Design Brief or Fire Engineering Brief be documented which outlines the intended approach. Once this step has been completed an analysis, modelling or testing is undertaken. The results and findings are then collated which are subsequently provided into a final report.

As part of the assessment design scenarios specific to the intent of the BCA need to be considered. These design scenarios are separated into the following factors:

1. Keeping People Safe;
2. Protecting other property;
3. Facilitating Fire Brigade Intervention.

For each of the factors mentioned above, the design scenarios that are evaluated range from blocked exits, fire starts in concealed spaces, challenging fires, robustness checks, vertical or horizontal spread and fire brigade intervention and unexpected catastrophic failure are outlined. As is currently adopted in the BCA, the methodologies and approaches that have drafted are all deterministic fire safety engineering assessments. However, contrary to the current process where engineers utilise their respective judgements and user specific input parameters, the documentation provides 'prescriptive' input parameters. This in turn will essentially provide a consistency in the assessments undertaken in the industry.

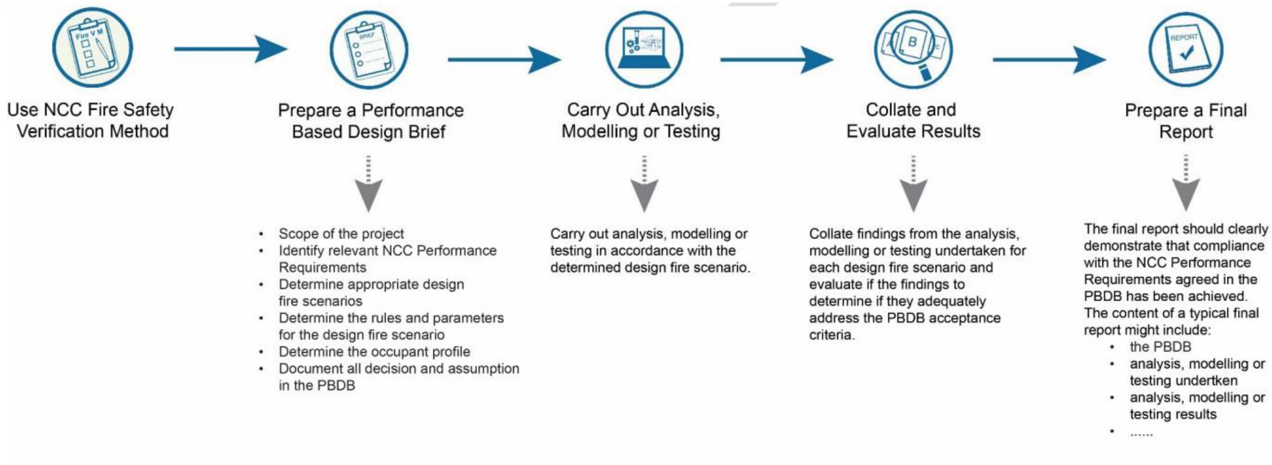

Figure 3.1: Design process for the NCC Safety Verification Method ([5], [6])

3.4 Verification Method and Design Scenario Example

To provide an understanding of the design scenario concept, an example has been provided below. The Performance Requirement that has been evaluated is CP1 which relates to building elements being able to maintaining structural stability during a fire (to the degree necessary). With reference to Tables 1.1 and Tables 1.2 of the draft document the relevant design scenarios that need to be included as part of the assessment for the relevant Performance Requirement are noted to be as follows:

Performance Requirement: CP1

Applicable Design Scenarios: BE, UT, CS, FI, UF, CF, RC, SS

Where,

BE: Fire Blocks Exit;

UT: Fire in normally occupied room threatens occupants of other rooms;

CS: Fire starts in concealed space;

FI: Fire brigade intervention;

UF: Unexpected Catastrophic Failure;

CF: Challenging Fire;

RC: Robustness Check; and

SS: Structural Stability.

With consideration to the above mentioned scenarios, the draft NCC Fire Safety Verification document in Section 4 provides a reference to the relevant Design Scenarios identified where the scenario description and method of analysis has been provided.

In order to provide an indication how probabilistic risk based methodologies could be adopted in order to enhance the assessment a fourths column has been introduced to the table. Table 3.3 provides a summary of design scenario, method and outcome that has been recommend [6] for Performance Requirement CP1.

Table 3.3: Design Scenario Methodology and Intended Outcomes (ABCB)

Design Scenario	Verification Method	Intended Outcome	Probabilistic Method Options
Fire Blocks Exit (BE)	Demonstrate by analysis to check whether or not second exit is required.	Viable Exit Route has been provided for building occupants.	Design issue dependent but can be readily applied.
Fire in normally occupied room threating occupants of	ASET/RSET analysis ; or	Demonstrate ASET>RSET.	Readily applied and is a suitable

Design Scenario	Verification Method	Intended Outcome	Probabilistic Method Options
other rooms (UT)	Adopted Active or Passive Fire Safety Measures as documented.		method/approach that can be adopted in lieu of ASET/RSET (F-N curve, Monte Carlo Simulation, ERL etc.)
Fire Stars in a concealed Space (CS)	Use of separating elements or suppression to confine fire to the concealed space ; or Include automatic detection of heat or smoke to provide early warning of fire within the concealed space	Demonstrate that fire spread via the concealed space will not endanger occupants.	Review of statistics pertaining to the type of fire with consideration of the classification can be adopted. This in turn will demonstrate compliance.
Fire Brigade Intervention (FI)	Undertake a Fire Brigade Intervention Model.	Demonstrate that fire brigade can undertake fire brigade intervention until completion of search and rescue activities.	This scenario is no different between the various methods and would be readily applied.
Unexpected Catastrophic Failure (UF)	Assessment of the building structure and critical components such that due to the fire event unexpected catastrophic failure of the entire element, or significant proportion, is unlikely to occur; and Demonstrating that if a component of the building is relied upon to carry more than 25% of the total structure a systematic risk assessment of the building is undertaken to minimise the risk during a fire event. Note: the scenario assessment should be undertaken with the structural engineer (where applicable).	Demonstrate the disproportionate failure is not likely to occur for the duration of the fire event.	Statistics in combination with a risk assessment approach could be readily applied to demonstrate the occurrence unexpected catastrophic failure of a structure.
Challenging Fire (CF)	ASET/RSET analysis; and Calculate the fire environment in the escape routes over a period of time (i.e. CFD modelling)	Demonstrate ASET>RSET for design fires in various locations within the building.	Readily applied and is a suitable method/approach that can be adopted in lieu of ASET/RSET (F-N curve, Monte Carlo Simulation, ERL etc.).
Robustness Check (RC)	Assume failure of each key fire safety system in turn as determine by the design team/stakeholders. ASET>RSET	Demonstrate that if a single fire safety system fails, the design is robust that disproportionate spread of fire does not occur. (i.e. sensitivity study)	Utilising an ascertained benchmark, the reliability of a fire safety measures can be assessed to influence

Design Scenario	Verification Method	Intended Outcome	Probabilistic Method Options
			the impact of a potential failure scenario.
Structural Stability (SS)	Practitioner needs to assess a full burn out design fire in credible worst case location with respect to the following: Prevent the building structure from failing with the design scenario; or Ensure building will collapse inwards.	Demonstrate that the building does not present risk to other property in a full burn our scenario.	Review of statistics pertaining to the type of fire with consideration of the classification can be adopted. This in turn will demonstrate compliance.

By utilising the relevant design scenario outlined above specific to the non-compliance being addressed, it is considered that the practitioner will then prepare the final report. However, a similar approach and methodology can readily be adopted for a probabilistic approach. This has been outlined in the following sections.

4. Probabilistic Approach and Verification Method Study

Within Sections 2 and 3 of the Draft NCC, Fire Safety Verification Method, detailed input parameters and rules have been provided to assist the practitioner. The parameters that have been provided include design fire characteristics, soot yields, design fire loads for classifications, time equivalent formulas, occupant movement speeds based on the characteristics of occupants in the classifications, detector criteria and so on. The following sections provide a comparison between a probabilistic approach and the verification method that has been proposed. Both of the methodologies adopted have been completed specific to Performance Requirement CP1, which states that:

> *A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to—*
>
> *(a) the function or use of the building; and*
>
> *(b) the fire load; and*
>
> *(c) the potential fire intensity; and*
>
> *(d) the fire hazard; and*
>
> *(e) the height of the building; and*
>
> *(f) its proximity to other property; and*
>
> *(g) any active fire safety systems installed in the building; and*
>
> *(h) the size of any fire compartment; and*
>
> *(i) fire brigade intervention; and*
>
> *(j) other elements they support; and*
>
> *(k) the evacuation time.*

The design issue that has been assessed is the proposed adoption of combustible materials that will form part of the external wall bounding construction within a residential building that is typically required to be of Type A construction (i.e. non-combustible).

4.1 The Probabilistic Approach

The probabilistic approach that has been undertaken specific to CP1 is the adoption of an F-N curve evaluation. With an F-N Curve it is important to be able to create the risk range/ranking that forms part of the overall evaluation.

The F-N curve risk ranking parameters can be defined by the following equation:

$F = mN + C$
Where,

F = the cumulative or non-cumulative frequency of the event
m = the slope
N = the predicted number of persons impacted
C = anchor point.
To further understand and ascertain the importance and relevance of each of the constants further explanation is provided.

4.1.1 F: The cumulative or non-cumulative frequency of an event

The 'F' value as part of an F-N curve is the key outcome or set of outcomes that determine the impact that a certain event has on society. Predicated on the manner in which an assessment has been undertaken this 'F' value can either be a single point (non-cumulative) on the graph or alternatively can provide an overall graphical output/diagram from a set of data (cumulative) outlining the frequency of an event and the associated societal risk.

For example, the 'F' value can be the data specific to the number of fatalities that occur on the roads. Where 'F' can be ascertained by calculating the total number of fatalities that have occurred by multiplying the number of events with the number of people that have been killed for that incident (i.e. 100,000 events where 1 person was killed, 10,000 events where 2 people were killed and so on).

Once these values have been calculated, the cumulative number of events start from lowest one in the table produced is ascertained summing them upwards.

The final stage is to calculate the cumulative frequency of events per year. This is achieved by dividing the cumulative number previously calculated by the number of years.

4.1.2 M: The slope of the FN Curve

The 'M' value or slope of the F-N curve is typically represented as a negative scale. This is predicated on the fact that where the lower probability of an event is likely to have a higher impact/magnitude resulting in an increased number of fatalities. A simple example can be the comparison of a place crash compared to car accidents. The probability of a plane crashing can be considered to be a lot less however the number of persons impacted upon is significant. However in the scenario of a car accident, the occurrence of an accident is much greater however the number of person impacted upon is limited and less significant.

With consideration of the assessment being undertaken, the slope that has been adopted is utilised such that it forms part of the acceptance criteria and benchmark that needs to be satisfied. The slope with respect to its application is important as the steepness of the slope defines the limits that are attributed to the acceptance criteria which are defined to be 'Acceptable', 'ALARP' (As Low As Reasonably Practicable) or 'Intolerable'.

The steepness of the slope of an FN curve is generally a user specific parameter. It assists in presenting data with respect to risk aversion. The steeper the slope provided the more risk averse is the overall profile. Typically a default slope that can be adopted is a steepness of m= -1. This is identified to be a risk neutral slope as the order of magnitude is equal as it both increases and decreases. In order to demonstrate the variations and levels of risk aversion, the slope steepness of a number of countries has been presented in Table 4.1.

Table 4.1: Slope Steepness for Societal Risk (Ref: Arup, 2014[7])

Country	Slope
Australia (NSW only)	-1.5
The Netherlands	-2
Denmark	-2
Hong Kong	-1

4.1.3 N: The Number of Persons Impacted Upon

The 'N' value represents the number of persons that have been impacted by an event. This information is either based on historical data or project specific using assumptions and a degree of engineering judgement. It is critical as it forms part of the overall FN curve assessment and presents the impact of an event on people in order to ascertain the level of risk specific to that event. Further information specific to the impact of fires and the understanding of 'N' with consideration of the events is provided in in the following sections.

4.1.4 C: The Anchor Point

The anchor point is the value which represents the sum of the frequency of ALL events for an entire population where a fatality has resulted. This value is typically derived from the number of deaths that have occurred in a year within a specific environment and compared directly with the total population for that area/country. The impact of fires over a number of years has been evaluated and documented for a number of countries and for the state of NSW in Australia. Based on this data ascertained, the following levels of risk may be utilised for the lower and upper Anchor Points for an FN curve as presented in Table 4.2.

Table 4.2: Individual Risk of Fires

Country	Individual Risk (Probability / year)
Australia	Between 3×10^{-6} and 4.6×10^{-6}
Australia (NSW Only)	Between 3×10^{-6} and 7.4×10^{-6}
Canada	Between 6×10^{-6} and 1.3×10^{-5}
New Zealand	Between 4×10^{-6} and 6×10^{-6}
United Kingdom (Wales and England Only)	Between 4×10^{-6} and 7.3×10^{-6}

4.1.5 Acceptance Criteria/Benchmark

The acceptance criteria or the range of risk that is represented is based on the data or outcomes of the assessments evaluated. For an FN curve the range in which data can be presented is noted to be either 'Acceptable', ALARP or 'Intolerable'. Acceptable and Intolerable mean where the risk has been demonstrated to be either suitable or not. However with respect to the third range and term 'ALARP' or 'As Low as Reasonably Practicable', is defined as the point where the cost of further risk reduction far outweighs the resultant reduction in risk [4]. The term 'as low as reasonably practicable has come into use through the United Kingdoms "The Health and Safety work etc. Act 1974. It has been interpreted to mean the degree of risk from any particular activity can be balanced by the cost of the measures that are present [8]. This essentially entails with respect to the built environment, that the risk or impact of a design where the introduction of fire safety measures above those typically required as a base building requirement for a solution, are evaluated against suitable benchmarks. (e.g., where an AS1670.1 smoke detection and alarm system is introduced within a building where it is only required to have an AS1668.1 smoke detection and alarm system in order to compensate for a deviation or non-compliance (Refer to Figure 4.1).

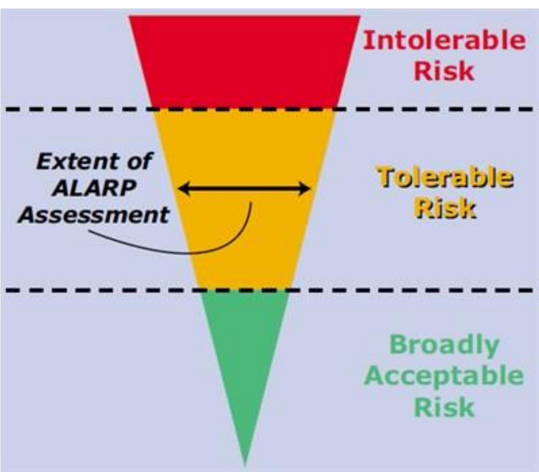

Figure 4.1: Diagram illustrating the ALARP Concept

In addition the following benchmarks have been adopted as part of the definition and outline of the FN Curve graph:

- The slope of the gradient has been assumed to be -1.
- The anchor points for the upper and lower limits are 1×10^{-5} (lower limit) and 1×10^{-4} for the upper limit.

4.1.6 Identify Limitations

The assumptions and limitations associated with the assessment undertaken have been provided below:

- The building is deemed to be a three (3) storey Class 2 (residential) development;
- The data that has been utilised is specific to NSW only from the FRNSW Annual Statistical Reports over a period of time for residential developments;

- The fire incidents and data is based on the time periods between 2002-2006;
- The number of fatalities that have occurred during the respective periods within NSW are separated into property types which are either 'One family and two family dwelling', 'Apartments', 'Units and Flats' and 'other';
- As there is no delineation between the number of people per incident, it is required that a general assumption on the number of occupants impacted upon be adopted. As such the following occupant numbers have been assumed for the assessment:
  - One family and two family dwellings: 1 person for 50% of these incidents, 2 persons for 30% of these incidents and remaining 20% of the incidents where 3 or more fatalities has occurred;
  - Apartments, units, flats: 1 Person for 65% of these incidents, 2 persons for 30% of these incidents and remaining 5 for 3 or more fatalities;
  - Other: 100% for 1 person.

4.1.7 Fire Scenarios

The fire scenarios that have been considered as part of the data and stats provided in the FRNSW Annual Statistical Reports for the periods of 2002-2006. As part of the assessment the fire scenarios have been considered based on their location and occurrence with respect to residential classification. The specific fire scenarios that have been evaluated are noted to be as follows:

- Undetermined, not reported and not applicable;
- Structural component, finish;
- Furniture;
- Soft goods, wearing apparel;
- Books, papers, recreational material, decorations;
- Supplies, stock;
- Power transfer equipment, fuel;
- General form;
- Special form; and
- Other form of material.

This data is considered specific to the design issue that is being assessed.

4.1.8 F-N Curve Parameters

In order to ascertain the level of risk that is attributed to the proposed adoption of combustible elements as part of the bounding construction of a residential building the key input parameters need to be documented. As part of the assessment the following parameters have been considered:

1. The number of fires that have occurred within residential buildings (baseline);
2. Number of fatalities that relate to those fires that have occurred;
3. Comparison of the form of material that was ignited; and
4. Confirmation of the structural components/finishes that ignited specific to the design issue (i.e. structural member, farming and thermal, acoustical insulation within the wall, partition or floor/ceiling.

4.1.9 Number of Fires within Residential Buildings

Based on the data extrapolated the following table outlines the number of fires that have occurred in NSW specific to Residential buildings between 2002 and 2006 (Refer to Table 4.3).

Table 4.3: Total Number of Fires in NSW and in Residential Buildings

Year	Total Number of Fires in Buildings NSW	Residential Fires in NSW
2002	6504	4631
2003	6388	4527
2004	6165	4321
2005	6566	4600
2006	6257	4397

4.2 Number of fatalities

The following fatalities that have occurred in NSW for the periods of 2002 and 2006 are specific to residential buildings as outlined in Table 4.4.

Table 4.4: Total Number of Fatalities

Year	Total Number of Fatalities	Residential Fire Fatalities
2002	33	27
2003	22	20
2004	50	47
2005	24	23
2006	18	17
Total:	**147**	**134**

As the data provided does not clearly identify the number of persons impacted by the fire per incident, the assumptions outlined in Section 4.1.6 have been adopted. The resultant outcomes are documented in the following Table 4.5.

Table 4.5: Number of Residential Fatalities

Year	1 Fatality	2 Fatalities	3 Fatalities
2002	14	8	5
2003	9	7	4
2004	25	13	9
2005	11	7	5
2006	9	5	3
Total:	**68**	**40**	**26**

4.2.1 Form of Material ignition (Wall Systems)

Table 4.6 provides the location of the fires where they occurred specific to the bounding wall system of a residential classification. The information extrapolated relates only to the 'One family and two family dwelling', 'Apartments', 'Units and Flats' and 'other' data provided.

Table 4.6: Form of Material Ignition (Apartments, Units and Other)

Year	Structural Member, Framing	Thermal, Acoustical insulation within the wall, partition or floor ceiling space
2002	86	22
2003	75	29
2004	70	20
2005	83	25
2006	74	20

Based on the number fires that were identified to occur within residential buildings, the structural framing and internal wall elements ignited were identified to comprise 2%-2.5% of the total fires that occurred for that period.

4.2.2 The Assessment

Based on the assumptions and input parameters that have been provided, the following F-N Curve as illustrated in Figure 4.2 has been documented for the purposes of the assessment.

As part of the assessment undertaken, the baseline or current fatalities with respect to fires has been evaluated. As outlined in Table 4.4, the total number of deaths for the period of 2002-2006 in NSW due to fires within residential buildings was in the order of 134. This value was then utilised to calculate the cumulative number of events for that period of time in order to ascertain the risk to occupants due to fires in Residential buildings.

The following Figure 4.3 outlines the risk specific to occupants in residential buildings as a benchmark (i.e. DtS compliant)

As illustrated by the results obtained, the current level of risk within NSW specific to number of fatalities is considered to be ALARP (As Low As Reasonably Practicable).

This set of values as part of the assessment specific to the timber elements has been adopted as the benchmark or accepted level of risk with respect to fatalities in residential developments. It is important to recognise that by adopting combustible elements within the wall structure of the building, the subsequent risk and impact of occupants has increased.

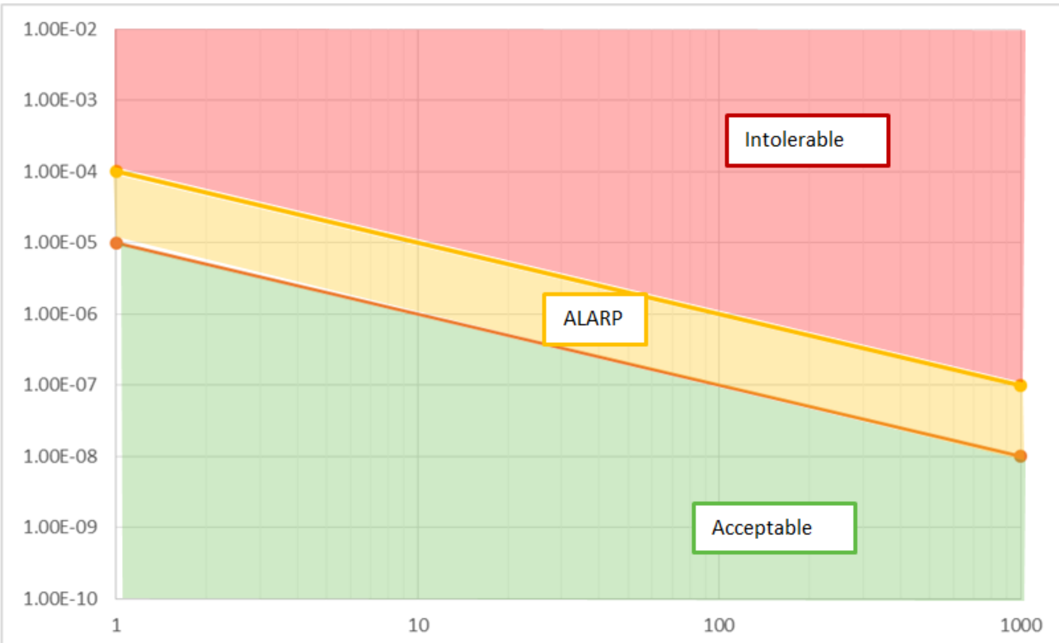

Figure 4.2: F-N Curve adopted for the Assessment

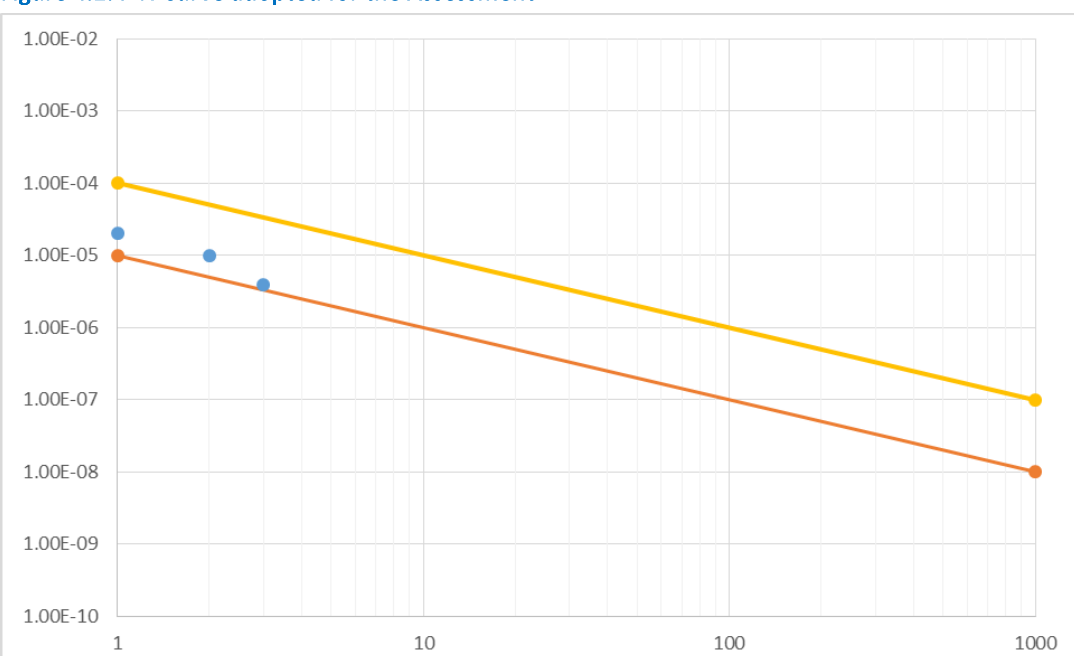

Figure 4.3: Number of Deaths due to Residential Fires (2002-2006)

Reference is made to Table 4.6, where it was identified that based on the data provided by the FRNSW stats, the impact of fires within residential developments has occurrences where the first material that was found to have ignited related to the wall structure. This was determined to be in the order of 2-2.5% of all cases recorded.

Given that the overall risk of a fire having an impact on a wall structure equates to 2.5% (worst case), the identified values as depicted in Figure 4.4 have been increased by 2.5% to represent the risk specific to the interaction of a fire and the wall systems. The following figure illustrates the outcomes:

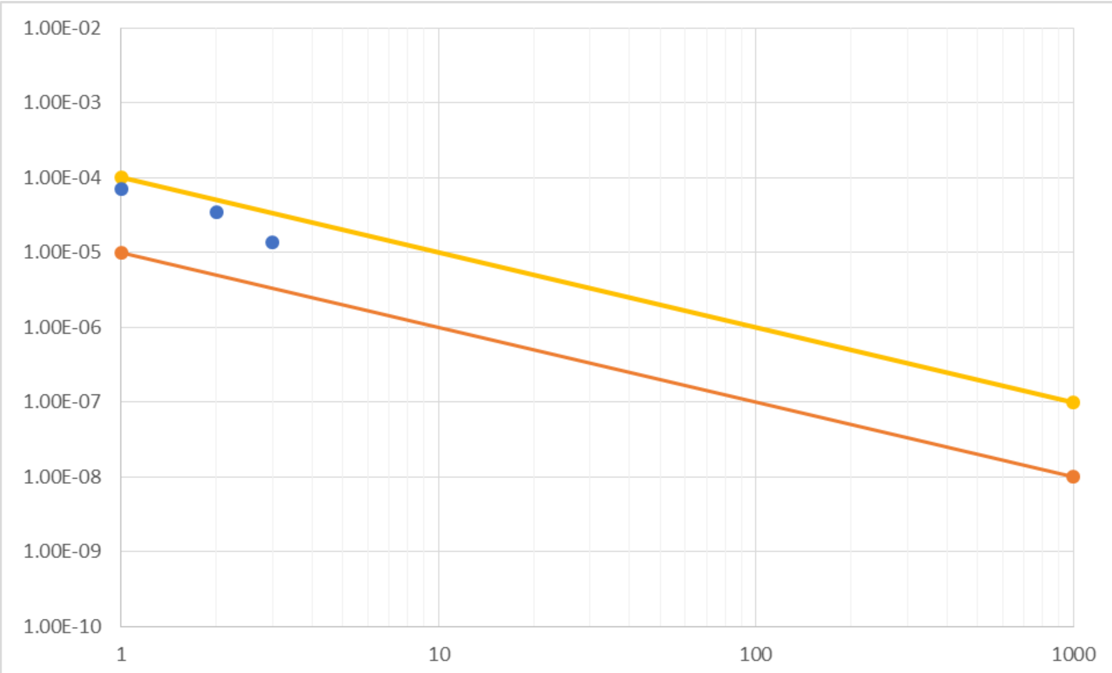

Figure 4.4: The risk of Combustible Elements in a Wall System

Based on the increased risk, it has been identified that though the results are nearing the intolerable level of risk, they have still been maintained within the stated ALARP risk ranking. Hence, are deemed to be suitable in their application and use for residential developments.

4.3 Comparison of verification method and probabilistic methodology

When a direct comparison is made between the proposed verification method and the probabilistic method it is recognised that both are readily applicable to address and achieve compliance with the Performance Requirements. Both methodologies allow with the implementation of suitable assumptions the rationalisation and justification of specific design issues (i.e. CP1). In each case whether, the parameters implemented for the assessment are dictated by the verification methods 'checklist' as outlined in the Draft NCC document, or practitioner influenced as documented as part of the probabilistic assessment, through robust and sound methodology/documentation a suitable outcome is demonstrated.

It is evident that the push by the ABCB is to move away from qualitative assessments and introduce more simplistic and to a degree prescriptive assessment methods that are easily understandable by all the relevant stakeholders and parties involved in a design/construction of a building. The overall assessment still relies upon quantitative deterministic assessments; however the variance and differences in the input parameters that is likely present between different companies and individuals will now become more consistent.

Whether this direction is appropriate and the ideal is still yet to be ascertained. However, concern is raised as checklist approach has the potential to result in the loss of innovation and unique approaches being implemented as part of a performance solution. This in turn can result in the loss of cost effective solutions which was the key influencing factor/parameter to introduce performance based assessment approaches into a prescriptive code.

5. Conclusion

As part of this paper an overall understanding into the suitability of verification methods and probabilistic assessments has been evaluated. The paper delved into previous research undertaken, review of current building codes and how they relate to the built environment internationally and the application of probabilistic assessments as part of suitably in the built environment of Australia specifically to the Performance Requirements.

A number of key findings that have been obtained from the information reviewed and assessments undertaken are noted to be as follows:

- Further education will be needed by the industry as a whole with respect to the implementation of new verification methods and further implementation of a quantitative risk based assessment method as a performance solution in the BCA;
- Where quantitative risk assessment method was implemented, it is recognised that utilising the current guidelines for risk based documentation be proposed to create a single document/guideline for both practitioners and authorities;
- Verification methods in the New Zealand and Australia may improve the level of fire engineering, however they may also create a prescriptive/performance based methodology that will result in the loss of innovation;
- In Australia, it is proposed that a single body be responsible for the collection and collation of all fire statistics in lieu of the each fire body/authority having its own individual process/procedures. Further education and update in the type of information would also need to be undertaken.
- Probabilistic risk assessments are suitable in the application to assess and achieve compliance with the Performance Requirements of the BCA. The ERL Assessments is readily able to be adopted and implemented as part of an assessment. The key factors to consider are the transparency and detailed documentation of limitation and assumptions given the variable that are required to undertake these assessments. Further works could be applied for the remainder of the Performance Requirements and also specific to buildings in lieu of single design issues/Performance Requirements.
- It will be important to achieve with fire engineering documentation a level that is readily accepted and recognised by the community to be to their expectation. This may be achieved through the implementation of Verification Methods, or this could be achieved from the implementation of quantitative risk assessment methods. Without a suitable period to review and consider their suitability once applied in the industry, it is difficult to identify whether they will have a benefit.

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