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Guidance for Validation of Models for Specific Fire Safety Design Applications

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Preface

This is a summary report prepared as part of a literature review of processes and approaches to the validation of a fire model for use in a specific design analysis.

Acknowledgments

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Note

This report is intended for fire engineers, model users and regulatory authorities.

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Reference

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Abstract

This summary report is intended for model users who are evaluating the implementation of a particular modelling approach for a particular application.

The model user is responsible for demonstrating whether the selected modelling approach is appropriate for the intended application.

A process for validating a fire model for use in a specific design analysis was presented in the context of outlining the overall flow of tasks required to adopt a modelling approach to analyse an intended building design.

The suggested overall process consisted of 12 tasks:

1. Define the design problem
2. Create the model description
3. Identify resource requirements
4. Identify potential available modelling approaches
5. Evaluate the modelling approaches
6. Select modelling approach(es)
7. Check suitability of the selected modelling approach(es)
8. Document the results of the model selection and validation process
9. Perform the analysis of the intended design
10. Interpret modelling results and check the suitability of the analysis
11. Assess the final results of the analysis
12. Document the analysis, results, interpretation and assessment

The performance of the analysis of the intended design is not the focus of this report, although this may be the initial primary focus of some users. However, the overall process from the design problem to the assessment compared to performance criteria is included in

this discussion, so that the impact of the validation of the modelling approach is clear within the overall design analysis process.

There were several check-points indicated within this process (e.g. at Task 3, Task 8 and Task 10), where a return to previous tasks would be required if additional information was attained by the user during the process or where the initial approach was found insufficient and then additional considerations would be needed to achieve an appropriate modelling approach for the design problem. When returning to an earlier task to make changes within this process, the user then continues to work through the subsequent tasks with these new additions or omissions. Therefore the process of validating a model for use in a specific design analysis may be an iterative one.

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Acronyms

BRANZ	BRANZ Ltd
C/VM2	Verification Method: Framework for Fire Safety Design for New Zealand Builidng Code Clauses C1-C6 Protection from Fire (MBIE, 2012d)
CS&E	Combustion Science & Engineering, Inc
DBH	Department of Building and Housing (New Zealand) (superceded by the Ministry of Business, Inovation and Employment)
DRU	Design Review Unit
MBIE	Ministry of Business, Innovation and Employment (New Zealand)
NRCC	National Research Council Canada
NZFS	New Zealand Fire Service
SFPE	Society of Fire Protection Engineering

Definitions

Acceptable Solution	is a design that complies with the prescriptive solutions described in Protection from Fire Acceptable Solutions C/AS1 to C/AS7 (MBIE, 2012a and MBIE, 2012b).
Accuracy	is the overall estimate of the degree of both known (precision) and unknown (uncertainty) errors of a measurement or calculated value.
Computational fluid dynamics (CFD) model	is an approach that approximates a three-dimensional space as many adjacent small control volumes, when calculating numerical solutions for either transient or steady-state fluid flow. A CFD model is also known as a field model.
Experimental uncertainty	the amount by which a measured value may differ from the true value.
Fire model	refers to a system or process that estimates fire development, fire dynamics and fire impacts (ISO/FDIS16730, 2007). A model may be an algebraic, analytical and/or empirical tool at all levels of complexity of user implementation, from hand calculations to computer software packages.
Modelling approach	is the user's construction or modification of a selected model. (ISO/FDIS16730, 2007). That is, how a particular model is used. (Several different users considering the same problem may apply the same model differently, depending on modelling expertise and experience with the particular software, resulting in an array of different model outputs).
Precision	is the degree to which a measurement or calculated value is knowingly within the true value.
Sensitivity analysis	is the comparison of the results from the systematic variation of the most influential input parameters.
Uncertainty	is an estimate of the impact of unknown errors on a measurement or calculated value on the true value.
User implementation	refers to the application of a software package by the user that includes user assumptions for model input values, selection of various model sub-modules and user assumptions for simplifying aspects or sections of the design problem, etc.
Validation	is an evaluation of the estimation of the physics by application of a model for a described situation compared to experimental results.
Verification	is an evaluation of the mathematical calculation process.
Zone model	is an approach that approximates a three-dimensional space as two or three volumes with uniform conditions, e.g. the fire compartment may consist of a lower layer, an upper layer and plume or ceiling jet.

1. INTRODUCTION

A process for validating a fire model for use in a specific design analysis was presented in the context of outlining the overall flow of tasks required to adopt a modelling approach to analyse an intended building design. The suggested overall process for using a fire model consisted of 12 tasks.

The results of an analysis of the intended design is not the focus of this report, although this may be the initial primary focus of some users. However, the overall process from the design problem to the assessment compared to performance criteria is included in this discussion, so that the impact of the validation of the modelling approach is clear within the overall design analysis process.

It is intended that this document will serve to help improve the standard and consistency of fire safety engineering in New Zealand and help eliminate current subjectivity in the use and application of various models in the design of buildings for fire safety.

1.1 Motivation

When a designer, researcher or other practitioner intends to use a fire model, initially one or more packages are selected. However, before applying the selected modelling packages to the specific application of interest, the practitioner must prove the extent of the validity of the models and the way the practitioner intends to apply them to similar scenarios to the application of interest. In practise, this important task is rarely performed and in some cases it is mistakenly assumed that it is the responsibility of the model developers to provide the measure of validation for every application.

There is widespread concern about the misuse of computer models when used in the fire safety design of buildings. Validation of the use and application of the model is one aspect of this. For example, technical audits conducted in 2006 and 2009 of the selection of designs received by the New Zealand Fire Service (NZFS) Design Review Unit (DRU) reported inappropriate use of models in 90-92% and 46-70% of instances, respectively. As noted in the technical audits, the NZFS DRU was not responsible for reviewing all New Zealand designs as only a selection of designs triggered a notification of the DRU, comments from the DRU were not mandatory and the ultimate responsibility lies with territorial authorities. The regulatory authorities play the role of gate keeper, therefore they are important stakeholders in terms of participation and promotion of good practise. Hence, promotion of good model application to fire design solutions is required for New Zealand practitioners in relation to what is needed to provide evidence of the extent of validity of the modelling packages chosen and applied by the designer to the specific application of interest. This guidance would be useful for regulatory authorities in terms of what they should be expecting from good performance-based designs.

1.2 Scope

This guide is intended for use once the decision to use C/VM2 or a specific design has been made for a fire engineering building design, to therefore assist with the selection of appropriate modelling approaches before the modelling of the intended building design has been performed.

1.3 Background

Verification and validation are fundamental elements in establishing credibility in the use of a fire model for a specific application. Verification is a process that ensures the equations and calculation methods are implemented correctly. Validation is a process that measures the accuracy of the calculation method being considered compared to real world physics (ISO/FDIS16730, 2007). Validation is the focus of this report.

When a designer, researcher or other practitioner intends to use a fire model, initially one or more packages are selected. However, before applying the selected modelling packages to the specific application of interest, the practitioner must prove the extent of the validity of the models and the way the practitioner intends to apply them to similar scenarios to the application of interest. Even though this task is described generically in such guidance documents as the Society of Fire Protection Engineer's Handbook (SFPE, 2008), International Fire Engineering Guidelines (NRCC, 2005) and further detail has been presented in the SFPE Guidelines for Substantiating a Fire Model for a Given Application (SFPE, 2011), in practise this important task is rarely performed and in some cases it is mistakenly assumed that it is the responsibility of the model developers to provide the measure of validation for every application.

Model developers do provide a measure of validation for a selection of applications to demonstrate the usefulness of the particular modelling package; however, this rarely covers all scenarios and applications that practitioners wish to apply the modelling packages to. Access to a modelling package by a potential user does not imply any level of proficiency in use and application of the specific software. Currently it is not feasible to "certify" model users and neither completion of tertiary courses nor general professional certification identify a competent model user. Therefore an approach for generic model use and application is appropriate for the current environment.

The recent publication year of the SFPE Guidelines for Substantiating a Fire Model for a Given Application (SFPE, 2011) provides a much more structured framework for approaching this problem than previously available. This work is one of the sources that formed the basis and background of the development of this document.

In recent years a number of requests by regulatory authorities to review fire safety engineering reports have brought to light instances where the assessment has misused modelling engineering techniques or applications. In virtually every case, no attempt had been made to assess the validity of the application of the model.

The ISO Working Group, ISO/TC92/SC4/WG7, for Assessment, Verification and Validation of Calculation Methods for fire safety engineering (ISO/FDIS16730, 2007) is currently in the process of developing documents on validation of fire models. In addition, a technical standard for Fire Safety Engineering – Guidance for Use of Fire Zone Models (ISO/TS13447, [to be published]) is intended for publishing in the near future. Therefore it is important to keep abreast of developments as part of ongoing professional education.

2. OVERVIEW OF THE PROCESS FOR VALIDATING A MODEL FOR A SPECIFIC APPLICATION

A schematic of the flow of tasks in the overall process of using a modelling approach to analyse an intended building design is shown in **Error! Reference source not found.**. This consists of 12 tasks:

1. Define the design problem

2. Create the model description
3. Identify resource requirements
4. Identify potential available modelling approaches
5. Evaluate the modelling approaches
6. Select modelling approach(es)
7. Check suitability of the selected modelling approach(es)
8. Document the results of the model selection and validation process
9. Perform the analysis of the intended design
10. Interpret modelling results and check the suitability of the analysis
11. Assess the final results of the analysis
12. Document the analysis, results, interpretation and assessment

The performance of the analysis of the intended design (Task 9) is not the focus of this report, although Task 9 may be the initial primary focus of some users. However, the overall process from the design problem to the assessment compared to performance criteria are included in this discussion, so that the impact of the validation of the modelling approach is clear within the overall design analysis process.

There are several check-points indicated within this schematic (e.g. at Task 3, Task 8 and Task 10), where a return to previous tasks is required if additional information is attained by the user during the process or where the initial approach is found insufficient and then additional considerations will be needed to achieve an appropriate modelling approach for the design problem. When returning to an earlier task to make changes within this process, the user continues to work through the subsequent tasks with these new additions or omissions.

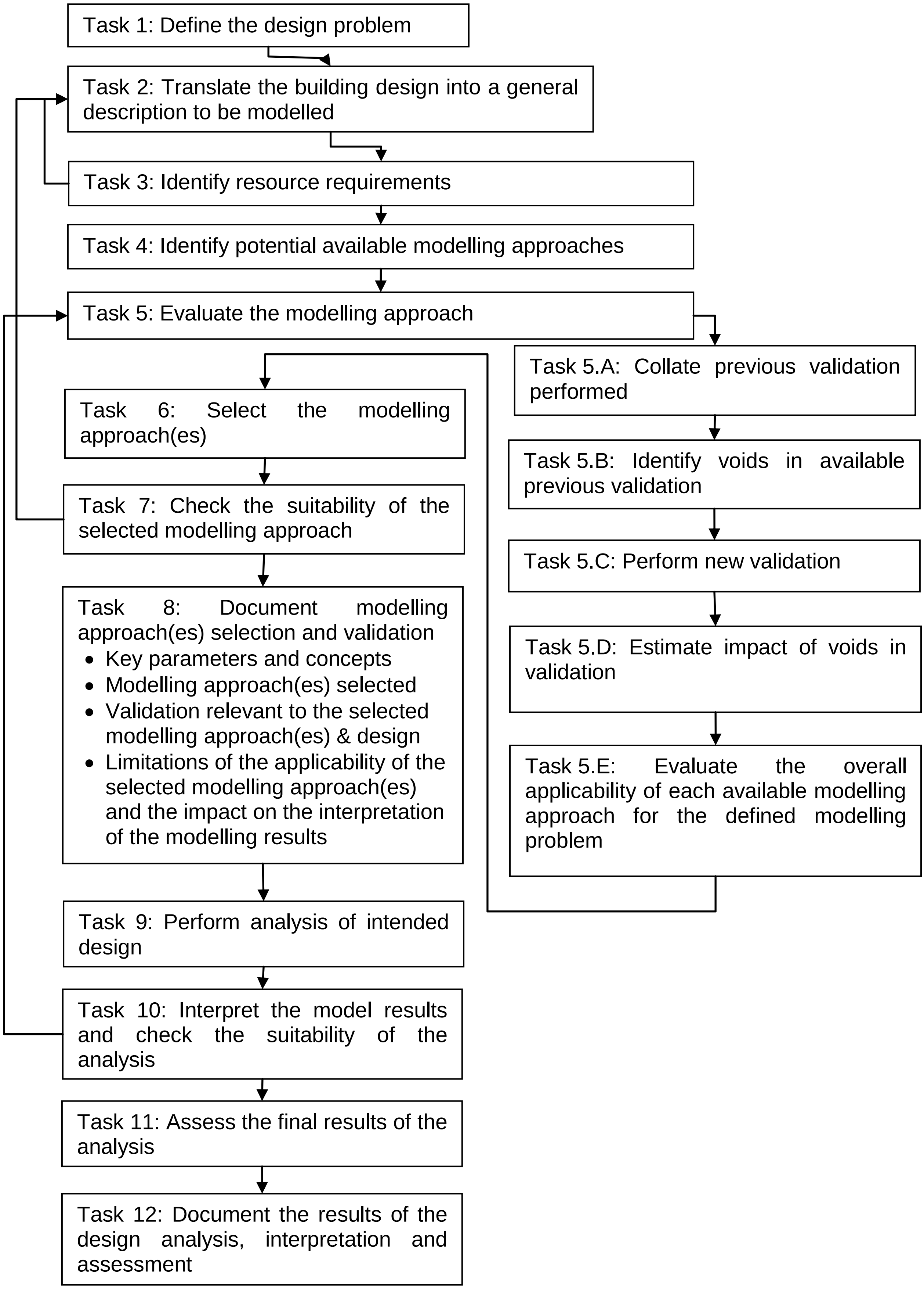

Figure 1. Schematic of the Process for Validating a Model in the Context of a Specific Fire Safety Design Analysis

2.1 Task 1: Define the Design Problem

The design of the building and the requirements for the intended regulatory path (e.g. C/VM2 Verification Method [MBIE, 2012d and MBIE, 2012c] of specific design in New Zealand) shall be taken from the Fire Engineering Brief for the project.

Identifying key concepts (including key phenomena and physics) of the building design and those for the regulatory assessment will need to be considered in the analysis of the design.

2.2 Task 2: Create the Model Description

Translate the building design and requirements for the intended regulatory path into a general description to be modelled. The detail of the model description used in the final analysis of the design might change due to the results of the selection of the modelling approach (e.g. not all key design parameters or key concepts might be available within each modelling approach finally selected or at all currently).

Identify key design parameters and engineering equations and assumptions that will need to be modelled for the:

- Building design and
- Required regulatory assessment

As a general suggestion on where to start in the identification of which parameters to include, begin with the key concepts and regulatory assessment requirements and consider which model output variables would be used to describe these, then work backwards to identify what parameters would be involved in the calculations and therefore would be influential in the results of the modelling. Examples of potential design parameters and phenomena to consider are included in the following section.

Identify the required level of accuracy for each of the key design parameters and the modelling results.

Identify the required scenarios that will be used in the analysis. Describe initial and boundary conditions for each scenario that will be modelled.

Identify aspects of the design that will not be modelled and document the reasoning for any intentional omissions and the impact on the interpretation of the modelling results.

Cross-check the identified key model parameters and phenomena and level of accuracy with the requirements set out in the design engineering brief for the project.

2.2.1 Examples of Design Parameters and Phenomena to Consider

One suggestion for a list of parameters (these may include input parameters, modelling parameters or output variables) and phenomena to consider are those mentioned directly or indirectly in the C/VM2 Verification Method (MBIE, 2012d and MBIE, 2012c), including:

- Building geometry (including floor heights, ceiling heights and shapes, intermediate floors, interconnection of floors, location of building services and penetrations, space sizes, sizes of openings, fixed versus non-fixed seating, direction of door opening, etc.)
- Fire load energy density
- Fire growth rate

- Peak heat release rate
- Species production (including CO, CO_2, water and soot)
- Radiative fraction
- Extent of fire (pre-flashover, post-flashover, full burnout)
- Location of fire (including height above floor, corner-, wall- or centre location within the room, size of the room)
- Radiant heat across at a boundary
- Heat fluxes
- Time resolution
- Vertical spread of fire
- Horizontal spread of fire
- Occupant characteristics (including intended activities, pre-travel activities and times, horizontal and vertical travel speeds, etc.)
- Occupant densities
- Available Safe Egress Time (ASET) and Required Safe Egress Time (RSET)
- Fractional effective dose for CO (including contributions from CO, CO_2 and O_2 species) and thermal effects
- Visibility
- Delayed evacuation strategies
- Fire fighter characteristics
- Structural integrity of primary elements for full burnout (e.g. time equivalent formulas, parametric time versus gas temperatures to calculate thermal boundary constitutions, or construct a Heat Release Rate [HRR] versus time history to calculate thermal boundary conditions to then use as structural response model input, etc.)
- Areas of effective openings
- Wall/room leakage and leakage around doors
- Position of doors, depending on whether they are smoke or fire doors installed with self-closers complying with a recognised national or international standard, or not, or whether they are within a route used for egress, etc.
- Glass breaking and fallout
- Maximum hot gas temperature for smoke separations, etc.
- Parameters associated with activation of installed fire safety systems
- Parameters associated with fire control for effective fire safety systems (e.g. fire growth rate, species production, peak heat release rate, etc.)
- Detection times
- Parameters associated with activation and operation of installed smoke control systems

Another list of parameters and phenomena to consider includes those associated with the list of building features or building systems outside the scope of the Acceptable Solutions (MBIE, 2012a), such as (MBIE, 2012b):

- Fire growth rate, fire load, performance of installed fire safety systems, large open spaces within the building, etc. when considering situations such as-
    - Storage height of greater than 5.0 m that are not protected with automatic fire sprinklers,
    - Foamed plastics manufacture or processing, or
    - Chemical processing plants,
- Stay-in-place procedures and the performance of fire safety systems in support of this, occupant Fractional Effective Dose (FED) threshold levels for various intended occupant types, etc. when investigating situations such as-
    - Where occupants are unable to self-rescue because of security features, such as prisons and district health board detention buildings, or treatment or care facilities, such as general anaesthetic operations/procedures, delivery rooms, intensive care units, hyperbaric chambers, etc.
- Smoke spread through large open spaces or complicated geometries within the building, performance of installed fire safety systems, egress times, occupant FED threshold levels, etc. when considering situations such as-
    - Atriums or multiple intermediate floors, such as multi-floor shopping malls, and
    - Smoke control systems
- Various egress approaches for large numbers of people in various configurations (e.g. lift evacuation in combination with stairways, staged evacuation procedures, etc.) for situations such as:
    - Buildings more than 20 storeys high from ground level, or
    - Stadia with seating for more than 2000 people, etc.

A further example of a suggested list of parameters and phenomena to consider includes those associated with the list of building features or building systems particularly important to the appropriate use of zone models (Section 8.10 of ISO/TS13447 [to be published])-

- Localised effects (e.g. interaction of fire safety systems, such as detectors, with the local conditions, etc.)
- Compartment effects (e.g. radiant feedback, etc.)
- Plume shapes (e.g. balcony spill plume, etc.)
- Stratification or not of smoke layer
- Plug-holing (e.g. during smoke extraction from a ceiling reservoir)
- Fully-developed fire conditions
- Under-ventilated fire conditions
- Post-flashover fire conditions
- Ceiling vents
- Enclosure size, dimensions and geometry

Descriptions of how the parameters or phenomena are to be handled in a modelling analysis may also be prescribed within the regulatory framework, that would provide further context for the identification of key design parameters, phenomena and implementation. For instance, requirements on how to handle the modelling of full burnout design fires or the sequence of pre-flashover and sprinkler activation, etc. are also included within C/VM2 (MBIE, 2012d and MBIE, 2012c).

The example parameters, phenomena and implementation listed here are not intended to be exhaustive, comprehensive nor wholly sufficient for a detailed analysis of a building. It is imperative for the user to fully understand the context of the intended fire safety analysis directly related to the regulatory path (e.g. C/VM2 or specific design within New Zealand) that will be used, the proper use of the modelling tools available, the limitations of the specific modelling approach, and user assumptions, implementation and validation.

2.3 Task 3: Identify Resource Requirements

Identify the resources required to achieve the analysis of the model description (Task 2). Consider this in the context of resource availability and limitations. Each limitation that is in conflict with achieving any part of the analysis of the model described in Task 2 must be listed and addressed. Means of addressing limitations may include acquiring additional resources, selection of a complementary modelling approach and describing the model in a different way. When changes need to be made to the model description of the building design, return to Task 2 of this process to ensure that changes are accounted for and impact on other aspects of the model description are also addressed.

2.3.1 Examples of Types of Resources for Consideration

Resources to consider include the availability of:

- Computational resources
    - Whether in-house or contracted resources will be employed
    - Whether several simulations be run concurrently
- Time resources
    - Aspects of time requirements need to be considered, including:
        - The time to develop any required new expertise regarding either specific modelling packages to be implemented or the applications for intended building features and systems to be analysed
        - The estimated average time to run a single simulation
        - Number of simulations that may be needed to address both individual aspects of the design, re-runs after changes to the design and sensitivity analysis
- Modelling expertise either in-house or contracted in the areas of:
    - General modelling and analysis of results and
    - Experience with specific modelling packages in relation to the intended building features and systems to be considered in the design

2.4 Task 4: Identify Potential Available Modelling Approaches

List all available relevant modelling approaches. As an initial cut, identify the most likely appropriate of these for more detailed consideration.

Modelling approaches are of the general types:

- Algebraic approaches:
    - Equations that have been developed to estimate fire behaviour for individual phenomena, such as flame height, heat release rate, plume velocity, ceiling jet velocity, gas layer temperature and gas layer depth, radiation, etc.
    - Based on empirical correlations or fundamental material properties and physics
    - Typically steady-state assumptions
    - Further information sources:
        - SFPE Handbook of Fire Protection Engineering (SFPE, 2008)
        - Sections 3 and 4 of the National Fire Protection Association (NFPA) Fire Protection Handbook (NFPA, 2008)
        - Principles of smoke management (Klote and Milke, 2002 and Milke and Klote, 1998)
        - An Introduction to Fire Dynamics (Drysdale, 2011)
        - Principles of Fire Behavior (Quintiere, 2007)
- Zone modelling or lumped parameter modelling approaches:
    - When algebraic equations will not provide the level of detail, interaction of phenomena or time dependency required, a zone modelling approach is the next level of complexity
    - Areas of interest are assumed to be broken into a small number of uniform zones, e.g. a hot layer and a cooler layer within each compartment, etc. Empirical correlations and equations estimating direct physical phenomena are used to approximate the transient state of a scenario
    - Further information sources:
        - Section 3 of the SFPE Handbook of Fire Protection Engineering (SFPE, 2008)
        - Enclosure Fire Dynamics (Karlsson and Quintiere, 2000)
        - An Introduction to Mathematical Fire Modeling (Janssens, 2000)
        - ISO/TS13447 Fire Safety Engineering – Guidance for Use of Fire Zone Models (ISO/TS13447, to be published) has useful discussion on the handling of model parameters and concepts and limitations of applicability
- Field modelling or computation fluid dynamics modelling approaches:
    - When zone modelling will not provide the level of detail or interaction of phenomena required or is not appropriate for the situation of interest (e.g. complex building geometries, large ceiling heights where gas layer stratification may occur, multi-sprinkler operation, etc.), a field modelling approach is the next level of complexity

- Areas are assumed to be broken into hundreds of thousands (or more) control volumes, for which the Navier-Stokes equations are numerically solved
- The increased complexity of potential scenarios that could be modelled using a field modelling approach is both an advantage, providing increased levels of detail, and a disadvantage, requiring understanding of the implementation of the physics and estimates within the particular modelling package, detail of data available to estimate model inputs for initial conditions and boundary conditions, and the understanding of the influence of these on the subsequent results
- Further information sources:
  - Section 4 of the SFPE Handbook of Fire Protection Engineering (SFPE, 2008)
  - Enclosure Fire Dynamics (Karlsson and Quintiere, 2000)

A suggestion on where to find summaries of a wide range of modelling software packages is an online survey of fire model software packages available at www.firemodelsurvey.com (CS&E, 2008). In addition, the summary article of An Updated International Survey of Computer Models for Fire and Smoke (Olenick and Carpenter, 2003) may also be useful in identifying available modelling approaches.

Identify the capabilities and limitations of the most likely appropriate modelling approaches, focusing on the key design parameters and engineering equations that were identified for the specific design in Task 2.

Determine whether a modelling approach is capable of providing a useable result by cross-checking the capabilities and limitations of the list of available modelling approaches with the above-described requirements for the described model and resource limitations including:

- Key design parameters
- Key engineering equations and assumptions
- Level of accuracy
- Ability to input initial conditions and boundary conditions
- Available computational resources
- Available time resources
- Level of user expertise and experience

The available models that cross-check positively with this list – that is, have capacity for each of the desired requirements, no matter how appropriately each are handled by a particular model – will form the list of most likely available models that can be used to evaluate the specific design and described fire safety scenarios or aspects of the design. These potential available models will then be considered in more detail in terms of their appropriateness to model the specific design and fire safety scenarios.

2.5 Task 5: Evaluate the Modelling Approach

A modelling approach is evaluated for a specific application by comparing experimental data sets with modelling output results for each of the key parameters and phenomena of the specific application. A single set of experiments is highly unlikely to directly relate to a specific application. Therefore a collection of various experiments may be needed to cover all parameters and phenomena of interest.

This task is intended for model users who are evaluating the implementation of a particular modelling approach for a particular application.

The model user is responsible for demonstrating whether the selected modelling approach is appropriate for the intended application.

Consider each potential modelling approach (both the software package and user implementation – there could be several alternative implementation methods for each identified software package) in terms of how the identified key design parameters, phenomena and assumptions are handled to the desired level of accuracy. The accuracy is determined by comparison with relevant experimental data sets. That is, the accuracy for each key design parameter and parameters associated with the key design phenomena in terms of the percentage difference between the model result ($p_{m,i}$), the mean experimental result ($p_{e,i}$) and the estimate of the experimental accuracy for that experimental result ($p_{e,i,accuracy} = p_{e,i,precision} + p_{e,i,uncertainty}$):

$$\Delta p_{\%,i} = \begin{cases} 0, & if\ p_{e,i,accuracy} > p_{m,i} - p_{e,i} > -p_{e,i,accuracy} \\ \dfrac{(p_{m,i} - p_{e,i}) - p_{e,i,accuracy}}{p_{e,i}}, & if\ |p_{m,i} - p_{e,i}| > p_{e,i,accuracy} \end{cases}$$

That is, if the model result ($p_{m,i}$) is within the accuracy estimate of the experimental result ($p_{e,i,accuracy}$), then the accuracy is high and the percentage difference between model and experimental results ($\Delta p_{\%,i}$) is reported to be null (0%). The reported percentage difference between model and experimental results ($\Delta p_{\%,i}$) is relative to the accuracy estimate of the experimental result ($p_{e,i,accuracy}$), therefore values for the accuracy estimate of the experimental results used in the calculation must be reported along with the percentage difference between model and experimental results to provide a context for the values. If an estimate of the accuracy of the experimental results is not included in the calculation, then it must be clearly stated which values – whether it is accuracy ($p_{e,i,accuracy}$), precision ($p_{e,i,precision}$) and/or uncertainty ($p_{e,i,uncertainty}$) of the experimental results – are assumed to be zero for the calculation.

The overall applicability for a modelling approach is reported as the list of percentage differences for the identified key parameters and phenomena, along with the associated estimated accuracy for the experimental results used in the calculation. This may be presented graphically for ease of visual comparison with different modelling approaches.

In addition, one approach to combine the estimated accuracy of the list of key parameters into a single value is to use an Euclidean mean, as described in Appendix B of ISO 16730 (ISO/FDIS16730, 2007). This is represented as:

$$\Delta p_{\%,combined} = \sqrt{\sum_{i=1}^{n} \Delta p_{\%,i}^2}$$

This evaluation task is broken into the five sub-tasks of:

- Task 5.A: Collate previous relevant validation that has been performed
- Task 5.B: Identify voids in the collected validation for the specific application
- Task 5.C: Perform new validation (collect relevant experimental data sets where needed and perform modelling)

- Task 5.D: Estimate the impact of the existing voids in validation for the specific application
- Task 5.E: Evaluate the overall applicability of the modelling approach for the specific application.

These sub-tasks are described in the following sections.

2.5.1 Task 5.A: Collate Previous Validation Performed

Validation is an evaluation of how well the physics is estimated using a modelling approach. The validation is related to the modelling approach (software package and user implementation) for a particular scenario or aspect of a scenario and the implementation of that modelling approach. Validation is evaluated by applying the modelling approach to a defined scenario that has been previously studied experimentally and then comparing the model results to the relevant experimental data sets for the scenario.

For each potential modelling approach (identified in Task 4), in turn consider whether it has been previously compared to relevant experimental data related to the identified key parameters and concepts (identified in Task 2). This may be handled visually as a matrix of modelling approaches versus key parameters and phenomena.

Where relevant validation studies to the key model parameters and concepts have previously been performed for each of the modelling approaches under consideration, collate the results. Accuracy of a modelling approach is reported in terms of comparison of the model results to the experimental results. However, it is important to note how the software package was implemented, as this forms part of the modelling approach and needs to be included in the documentation.

2.5.2 Task 5.B: Identify Voids in Available Previous Validation

Consider each of the key design parameters and phenomena in turn and identify where additional new validation must be performed in relation to each of the potential modelling approaches.

Utilising the suggested matrix of modelling approaches versus key parameters and phenomena may provide a simple visualisation of this.

2.5.3 Task 5.C: Perform New Validation

For identified key parameters and phenomena where previous validation has not been preformed (Task 5.B):

1. Collate relevant experimental data related to the identified key parameters and concepts
2. Evaluate the applicability of the available experimental data sets for comparison
3. Where available relevant data sets are not available, identify where voids in relevant data exist
    a. Identify and perform experiments to complete the sets of relevant experimental data for comparison
4. Apply the potential modelling approaches to model descriptions of the experimental situations (utilising implementation techniques intended to be used in the analysis of the building design problem)

5. Evaluate the applicability of each potential modelling approach for each key design parameter and phenomena when compared to relevant experimental data by comparison of the model output to the experimental data sets

If relevant experimental data does not exist and appropriate experiments are not performed to create the required data sets for comparison, then validation cannot be performed. Engineering judgement is not interchangeable with experimental results for comparison with modelling output.

Where validation of the modelling approach for one or more key design parameters or phenomena has not been performed, it must be clearly identified. The impact of this lack of validation on the interpretation of modelling results needs to be estimated and documented.

2.5.4 Task 5.D: Estimate Voids in Validation

Where relevant experimental data is not available and cannot be collected, estimate the impact on the applicability of model results using engineering judgement to estimate model inputs and an expected range of model output values, in combination with a sensitivity analysis.

This estimation of applicability of a modelling approach is not the equivalent of performing validation of the implementation of the modelling approach for the intended design and scenario, instead the sensitivity analysis provides an estimate of the impact of this unknown on the interpretation of the modelling results.

2.5.5 Task 5.E: Evaluate the Overall Applicability of Each Available Modelling Approach for the Defined Problem

The evaluation of these components of the overall appropriateness of the modelling approach is quantitative.

Where validation results were available, either previously published or newly performed for each modelling approach and key design parameter or phenomena:

1. Consider how closely the experimental situation describes the combination of the intended design and fire safety scenario. Identify the specific aspect(s) that are of a similar nature and the aspects that are present that are not similar to the intended design and scenarios. Also identify how the differences may affect the interpretation of the model results
2. Consider how closely the implementation method(s) used to apply the model in the validation aligns with the intended implementation for the current design problem. (Remember models can be applied by different means, e.g. different ways to input a design fire, etc. Consider that multiple users can get a range of results when trying to model the same situation)
3. Consider how accurately the model results align with the experimental results, within estimated experimental uncertainty, in the assessment of validation of the model implementation:
    a. Report the comparison as the percentage difference of the model results $(p_{m,})$ to the experimental results $(p_{e,i})$ within the estimate of the experimental accuracy $(p_{e,i,accuracy} = p_{e,i,precision} + p_{e,i,uncertainty})$ for each key design parameter and parameters associated with the key phenomena. That is, report both $\Delta p_{\%,i}$ and $p_{e,i,accuracy}$

Where there are voids in the validation of the modelling approach consider how critical the aspects that have not been validated to the design problem are:

1. Estimate the impact of the un-validated aspects using a sensitivity analysis of the modelling approach for input values based on engineering judgement.

The estimation of these un-validated components of the overall appropriateness of the modelling approach is a combination of qualitative and quantitative estimates, with a lower confidence than the validated components above. Therefore this lack of confidence must be included when estimating the overall appropriateness of the modelling approach.

The overall applicability for a modelling approach is reported as the list of percentage differences of the identified key parameters and phenomena and the sensitivity of the model results to each of the design parameters where validation was not performed.

A thorough example of validation of a zone model, specifically B-RISK, for use in situations where spill plumes are present is presented by Harrison, Wade and Spearpoint in an upcoming journal article (Harrison et al., [to be published]).

2.6 Task 6: Select Modelling Approach(es)

Based on the results of the evaluation of the overall applicability of each available modelling approach, select the modelling approach(es) that, either in isolation or in combination, have the highest overall applicability to the design problem.

2.7 Task 7: Check Suitability of the Selected Modelling Approach

Consider that the highest overall applicability from Tasks 5 and 6 do not necessarily provide an appropriate modelling approach, since these tasks have been based on the lists of key design parameters and phenomena in Task 2, and limited by the resources listed in Task 3. Therefore if appropriate modelling approach(es) have not been identified, a return to either of these tasks for reconsideration may be required.

Consider the suitability of the selected modelling approach or combination of approaches in terms of the validation process. This task is a check-point to determine whether the best overall modelling approach (as selected in Task 6) is appropriate, or whether (because of lack of validation) the design problem needs to be reconsidered. That is, could a different approach be used or are additional resources (time, cost, computing resources, expertise, etc.) required to broaden the potential modelling approaches.

How are each of the following questions addressed:

- What is the extent of the applicability, as identified during the validation process (Task 5), of the selected modelling approach for each of the key design parameters and phenomena of the intended design?
- Are any of the key design parameters and phenomena of the intended design not addressed by the selected modelling approach(es) or have a poor level of validity for the application?
- Are any voids in the validation of the modelling approach or approaches individually excessive?

For each item identified from the above questions, now consider:

- What is the influence of each of these on the modelling result?

- Are these addressed to the satisfaction of the intended regulatory authority?

If not, return to Task 2 considering what changes may be required to the approach to modelling the design problem or whether a wider selection of modelling approaches or combinations of approaches (at Task 4) is required, or whether additional validation is required for the current selection of modelling approaches (Task 5).

2.8 Task 8: Document Model Selection and Validation

Document the model selection and validation process to include:

- Model description of the intended design, specifying:
    - The key design parameters and engineering equations and assumptions for the intended design (as identified in Task 2)
    - The level of detail/resolution intended (from Task 2)
- The selected modelling approach(es), including:
    - Modelling approach limitations
    - Validation of the model for each of the key design parameters and phenomena, including comparison of the experimental set up used in the comparison to the intended application of the modelling approach
    - Any relevant aspects of the model that are not validated, including discussion on the impact of the interpretation of the modelling results relative to the intended design
- Validation of the selected modelling approach(es), including:
    - Description of the experimental studies:
        - References to published reports, etc.
        - Description of experimental set up to each of the identified key design parameters and phenomena
    - Accuracy of the modelling approach(es) for each parameter associated with the key design parameters and phenomena relative to the experimental results
    - Discussion of the applicability of the modelling approach(es) to the intended design problem, limitations and impacts on the interpretation of the model results

2.9 Task 9: Perform Analysis of Intended Design

Implement the model description of the intended design (as described in Task 2) for the required fire safety design scenarios using the selected modelling approach(es) (as documented in Task 8). For example, if the intent is to use the C/VM2 (MBIE, 2012c and MBIE, 2012d) approach, then the ten design scenarios for the problem would be worked through to provide the model results for each, ready for interpretation of the results.

Model results alone do not provide the complete story of the assessment of a design. The model results must be interpreted in the context of the limitations, assumptions and exclusions.

2.10 Task 10: Interpret Modelling Results and Check the Suitability of the Analysis

The final modelling findings are the interpretation of the modelling results with consideration of all limitations and assumptions included. Modelling results are interpreted in the context of:

- The selected modelling approach limitations listed in Task 8
- Any validation limitations, as also listed in Task 8
- Any voids in validation or information for model input values (considered in Task 5 and listed in Task 8)

When applying the interpretation to the modelling results, check the suitability of the analysis and results in terms of the key parameters and phenomena (identified in Task 2) in combination with limitations of the modelling approach(es) and user implementation.

Consider each key parameter and phenomena in turn:

1. Confirm the extent to which each has been addressed in terms of the specific design as identified in Task 2
2. Confirm the reasons for the selected modelling approach(es), user implementation and assumptions, and the subsequent impact on the interpretation of the modelling results

Although the validation process associated with the project would have identified the majority of issues for the key parameters and phenomena of the selected modelling approach(es) and implementation, if during, or as a result of, the analysis of the intended design and interpretation of modelling results it becomes evident that:

1. Additional detail (resolution or parameters) is required in the modelling result than previously estimated in Task 2
2. Additional key model parameters and phenomena to the initial list identified in Task 2 are now identified as being required for the complete analysis of the design problem

Then return to Task 2 and incorporate the additional parameters, phenomena or resolution identified.

2.11 Task 11: Assess the Final Results of the Analysis

Compare the interpreted modelling results of the analysis in the context of the limitations, assumptions and implementation with the acceptance criteria.

2.12 Task 12: Document the Analysis, Results, Interpretation and Assessment

Document:

1. Details of the design problem (from Task 1) and the model description (from Task 2)
2. Model selection and validation documentation (from Task 8), including the associated model limitations, user assumptions and implementation, and limits of validation for the specific project

3. Description of the implementation of the modelling approach(es), assumptions made about the modelling of the design and values used for initial and boundary conditions (as used in Task 9). This includes a full description of the implementation of the modelling approach(es), such that the analysis could be repeated by an unassociated party to the project. This includes identification and reasoning of all key parameters and phenomena and any aspects that were intentionally not included in the analysis, with the reasons provided for exclusion of each of these
4. Report modelling results (from Task 9)
5. Report the final analysis of the results. That is, the interpretation of the modelling results in the context of the limitations associated with the modelling approach, validation and model implementation (as performed in Task 10)
6. Report results of comparing the final analysis results with acceptance criteria (as performed in Task 11)
7. Provide an executive summary, including list of key design parameters and phenomena, key assumptions (including intentional exclusions of parameters or phenomena), description of modelling approach(es) and final analysis results

3. KEY POINTS ON THE USE OF MODELLING APPROACHES

A selection of some of the key points to keep in mind when considering various modelling approaches follow.

Models are only tools:

- Models are tools for estimating the conditions in a specific scenario, as defined by the user. The user is responsible for both selection of the tool for the problem, how the tool is applied to the problem and the interpretation of the results.

Users greatly influence the model output values:

- Choice of the scenario to model, how to describe it within a model, which model sub-routines to utilise and model input values are dependent on the user. These greatly influence the model output results.

Validation of a model must include how the user applies the model:

- Different users can get different model results from the same model because they choose different ways to describe the scenario and might use/estimate different values for the same model input parameters. Just because a model has been validated for application in a situation, it cannot be blindly applied to the same or a similar situation.

Engineering judgement is not interchangeable with experimental results for comparison with modelling output:

- Experimental data sets of similar situations and features to that which is intended to be modelled provide higher confidence compared to experimental data sets for indirectly-related situations and features combined with engineering judgement as to the applicability. The least level of confidence is associated with engineering judgement without related experimental data sets for comparison.

Model parameter preset default values are not necessarily valid for the user's intended application:

- Modelling software packages may have preset default values. These default parameter values may be included for verification purposes, may have been validated for specified conditions or may relate to the specific modelling software package. It is the responsibility of the user to understand the reasons for and application of any model parameter preset default. Model parameter values, whether default or not, must be demonstrated to be appropriate by the user for the intended application.

4. SUMMARY

A process for validating a fire model for use in a specific design analysis was presented in the context of outlining the overall flow of tasks required to adopt a modelling approach to analyse an intended building design.

The suggested overall process for using a modelling approach consisted of 12 tasks:

1. Define the design problem
2. Create the model description
3. Identify resource requirements
4. Identify potential available modelling approaches
5. Evaluate the modelling approaches
6. Select modelling approach(es)
7. Check suitability of the selected modelling approach(es)
8. Document the results of the model selection and validation process
9. Perform the analysis of the intended design
10. Interpret modelling results and check the suitability of the analysis
11. Assess the final results of the analysis
12. Document the analysis, results, interpretation and assessment

The performance of the analysis of the intended design (as summarised in Task 9) was not the focus of this report, although this may be the initial primary focus of some users. However, the overall process from the design problem to the assessment compared to performance criteria is included in this discussion, so that the impact of the validation of the modelling approach is clear within the overall design analysis process.

There were several check-points indicated within this process (e.g. at Task 3, Task 8 and Task 10), where a return to previous tasks would be required if additional information was attained by the user during the process or where the initial approach was found insufficient and then additional considerations would be needed to achieve an appropriate modelling approach for the design problem. When returning to an earlier task to make changes within this process, the user then continues to work through the subsequent tasks with these new additions or omissions. Therefore the process of validating a model for use in a specific design analysis may be an iterative one.

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The following list of bibliographic references forms suggestions for additional information related to experimental studies and model validations that may be of interest. However, this list is not intended to be exhaustive.

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5.2 Additional Resources

A suggestion for a source to assist in locating additional resources is the search engine found at: http://www.branz.co.nz/Fire_Information_Hub_Google_Search.

This is a single search location that accesses multiple repositories around the world that focus on fire research. However, the repositories included in this search location are not intended to be exhaustive and any suggestions for additional repositories should be brought to the attention of the webmaster for the search engine at Amanda.Robbins@branz.co.nz.

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