

The Fire Brigade Intervention Model

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ABSTRACT

In response to a shift towards performance-based building regulations, fire services in Australia have developed a method for quantifying their operations. This method has been released for general use by the fire safety design industry and is known as “The Fire Brigade Intervention Model”. It is an event-based methodology that considers the time taken for the various fire brigade functions to be performed. It allows for concurrent and sequential activities - an ingredient missing from previous attempts at modelling firefighting operations. Flow through the algorithm is controlled by the fireground status which is a time-evolving representation of the state-of-affairs faced by an incident controller. It incorporates quantities representing the state of the fire as provided by other models and the available fire brigade resources. The strategy to be implemented is based upon it.

Complementing the methodology is the associated data on various firefighting activities. This was collected through field testing. Results are distributed in time and depending on the margin for safety desired, a value for the time to complete a given task can be included at the appropriate point in the calculation. The final result depends on a critical time path through the range of activities that are undertaken. This final time represents the total time for fire brigade operations for the building and fire scenario under consideration. This gives designers a rational quantification of fire brigade operations to be used in the design process.

KEYWORDS: fire brigade, firefighting, performance-based design.

INTRODUCTION

The international trend for a shift from prescriptive to performance-based building codes has been embraced in Australia over recent years. This culminated with the release of a fully performance-based “Building Code of Australia” [1] published by the federal body responsible for establishing the regulatory framework - the Australian Building Codes Board (ABCB).

In an effort to provide designers with sufficient information to take advantage of the new approach to building codes, a body known as the Fire Code Reform Centre (FCRC) released the Fire Engineering Guidelines in 1996 [2]. These guidelines provide an engineering-based methodology for fire safety design in buildings so that the performance requirements of the building code may be met. The approach consists of decomposing the overall fire safety system into its logical sub-systems such as fire spread and management. These sub-systems are considered in detail and techniques of analysis are provided. One of the sub-systems considered is that of “Fire Brigade Communication and Response”.

Throughout the code development process, input from fire services was provided. However, whereas the building code is a national document, individual Australian States have responsibility for the provision of fire services and so it became clear that a more focussed and coordinated response was required. Accordingly, in May 1995, the Australasian Fire Authorities Council (AFAC) a peak national body representing the interests of various fire brigades, formed a Performance-Based Building Regulations Committee to ensure that the interests of the fire service would be properly met. These interests are essentially split into two groups:

- to ensure that high levels of fire prevention are provided to the community as is generally required under the respective Parliamentary Acts through which a fire brigade is formed, and
- to ensure that appropriate levels of safety are maintained for firefighters as they carry out their functions.

It was proposed that specific performance requirements be included in the new building code in regards to fire brigade intervention and it was apparent from the outset that a major priority of the committee was to provide a systematic approach to the quantification of the fire brigades role. Whilst this had been addressed in the fire engineering guidelines, the level of sophistication was considered insufficient with regards to the interests of the fire service and the community. Consequently, the Fire Brigade Intervention Model (FBIM) [3], as described here, was developed to bridge the gap.

Philosophy of Approach

Although the facility exists for the use of a full risk-based approach to fire engineering design, the standard practice in Australia tends to follow deterministic analysis based on a range of reasonable worst case scenarios. With this direct approach in mind, FBIM was developed as a representation of what actually takes place at a fire. This means that fire brigade operations are considered directly and decomposed into the range of activities undertaken at a fire. It is an event-based methodology. This is an intuitively appealing approach allowing for a more

ready acceptance by both design practitioners and approval authorities. It was preferred to the alternative of attempting to extract probabilities for extinguishment from available statistics. However, as will be clear when the data is discussed, the possibility exists for the integration of the FBIM into a risk-based approach.

The two fundamental aspects of the model are therefore the methodology and associated data. This paper specifically addresses the structure of the model and how that is reflected in its current release as a handbook published by the Australasian Fire Authorities Council. Software is currently being developed to streamline the process of applying the model.

METHODOLOGY

The fire brigade is involved in a myriad of activities at any fire incident. From this realistic environment there needs to be extracted a core model that represents fire brigade operations *to the extent necessary for the building design process*. The overriding issue is one of time. Many activities undertaken do not incur an accumulation of time in that they are readily completed whilst other, more time-consuming, tasks are being undertaken. For example, transmission of a radio message on the progress of a fire occurs whilst a crew is in the process of gaining entry to a structure. Such secondary activities can be neglected in analysing the time required for firefighting operations.

Driving the design process is a “Fire Engineering Design Brief” team that has responsibility for integrating all aspects of the design. They determine the parameters of the design in terms of the level of analysis and representative fire scenarios. Most importantly this includes the output from the particular fire initiation and development model being used. This fire growth curve determines detection times and consequently notification times for the fire service. From here a sequential flow through response procedures is undertaken until the first firefighting resources arrive at the fire scene. At this point, the complexity of the model escalates as it attempts to accommodate the range of options available. It is precisely in this area that previous attempts at modelling fire brigade behaviour have suffered as they fail to recognise the concurrent and interrelated nature of many firefighting activities.

A range of options exist for what might happen next and these can be conveniently arranged into the following classes of activity:

- investigation of the fire and gathering of information that will act as input to the decision process for what suppression activities to undertake,
- additional and specialist resource dispatch,
- establishment of equipment,
- search and rescue,
- control and extinguishment of the fire,
- protection of surrounding environment, and
- protection of adjoining property.

Any activity from one of the above classes may be either undertaken concurrently with an activity from another class or form a sequential chain of events with other activities. It will depend on the circumstances. For example, aspects of information gathering may be

undertaken by an officer whilst the rest of the crew begin to set-up equipment. Alternatively, all members of a crew may be required to force entry to investigate and then begin establishing the required equipment. The appropriate option is determined by the details of the particular building design and fire scenario being investigated.

Figure 1 illustrates the overall approach of the model.

The determination of precisely how many and which particular operational aspects from the range available are undertaken at any given time is made on the basis of the fireground status.

Fireground Status

The outcome of any fire will always depend upon two principal sets of variables and this needs to be reflected in any application of the Fire Brigade Intervention Model (FBIM). These sets are:

- the building/fire status which is a quantitative summary of the overall fire situation as represented by the fire growth curve and the state of all building related fire safety systems, and
- the fire brigade status which is a summary of the available fire brigade resources on the scene and the nature of their commitment.

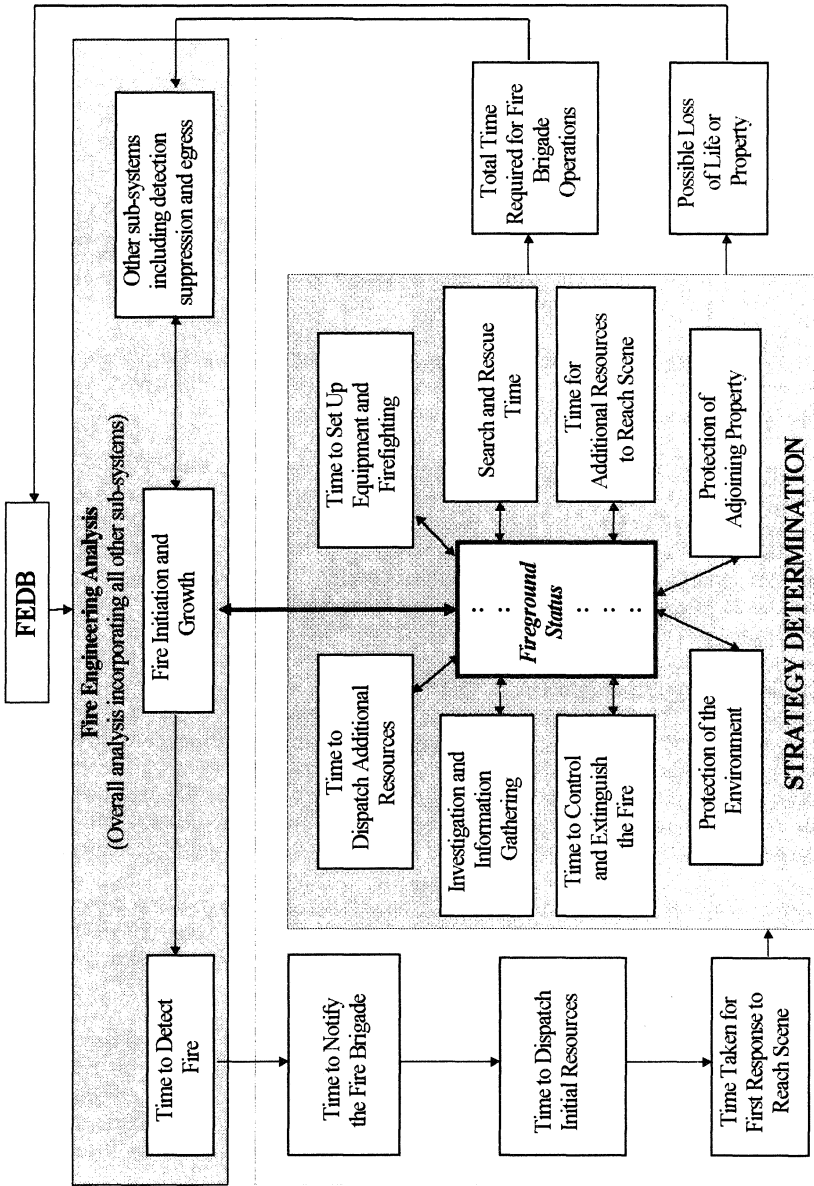
The first set is beyond the direct control of the fire brigade and so is an *externally* generated status of the fire and building. In the modelling context this would mean the information is provided by other models and constitute an input to the FBIM. The second set is directly within fire brigade control and so is internally generated by the model.

In attempting to mimic an actual operation that might be relevant to a particular fire scenario, a useful conceptual tool is that of the *fireground status*. This is a combination of the two sets of variables described above. It represents the state of affairs encountered by an incident controller that are considered pertinent to the decision making process. As such it is the centrepiece of the model algorithm in that it determines the flow of control. It is a function of time and drives the strategy determination. The adopted strategy itself determines which tasks are undertaken and hence how time for firefighting operations is accumulated with regards to the particular scenario.

Flowcharts

The activity classes described above are broken down into a series of flowcharts. Each chart forms a logical grouping of activities being either decision activities or time accumulation activities. Consequently, dependent on the decisions made, a sequential path is traced through the chart. However, at some decision points, other charts are called and this leads to concurrency of activities. Additionally, in some circumstances only part of a chart is required. This can occur for a number of reasons, the principal one being that the chain of activities needs to be suspended due to a deterioration in the state of the fire environment.

FIGURE 1: Overview of the major time components of FBIM and how the process links with the overall fire engineering analysis.



Actual flow of control through the algorithm is determined by the fireground status in conjunction with those tasks that have already been completed.

A breakdown of the flowcharts used in the model with a brief discussion about the contents of each is as follows.

1. Time taken for initial brigade notification. This includes the process of notification either automatically or via occupant cues. If automatic detection is the appropriate option then issues surrounding system performance such as sprinkler depressurisation, third-party monitoring of alarms and others are catered for.
2. Time taken to dispatch resources. This chart deals with activities from the time of receipt of a fire call by the fire brigade until the first responding resources are mobile. Consideration is given to such things as Computer-Aided Dispatch (CAD) or local response. It calls Chart 3 in its flow.
3. Time taken for firefighters to respond to dispatch call. As input to Chart 2 this chart deals with whether or not a station is staffed by permanent firefighters or not and considers internal station response procedures.
4. Time taken to reach fire scene (kerb-side). This chart covers road travel times providing various options such as allowing for a defined route if it exists or calculation based on radial distance scaled by 1.5. This factor being derived from a consideration of travel by a rectangular grid of streets. Options exist for calculating response from the station or the most remote location available in a station's response area. Flexibility is required here so that a particular fire station location does not become an integral part of a building's fire safety design. If such were the case it would impose a severe restriction on future fire service planning, adversely impacting on their ability to maintain rational standards of fire cover under a changing demographic.
5. Time taken for initial determination of fire location. Upon reaching the address of the fire, further time is taken in proceeding through a site and gaining access to secure areas. Issues surrounding pre-planning, accessing information on site such as fire indicator panels and the availability of fire wardens are also considered. This is the primary information gathering task. Charts 6 and 9 may be invoked depending on the flow through this chart.
6. Time taken to don safety equipment and gather necessary tools. The principal requirement here involves the wearing of breathing apparatus and the ancillary safety provisions that must be established such as monitoring mechanisms. These are not trivial and may require additional personnel thereby necessitating an upgraded response.
7. Time taken to assess fire. This is a nebulous quantity at best but is modelled here on the basis of reconnaissance by the incident controller who proceeds either by perimeter inspection or otherwise at appropriate travel speeds. The rationale is that this ensures a reasonable initial inspection and the decision process for further resource requirements can occur in this time. Whilst this approach constitutes a gross parameterisation, it enables a

simple and tractable analysis. Chart 2 for subsequent dispatch of resources may be invoked here.

8. Time taken to travel to set-up area. This is concerned specifically with establishing the operational location of fire appliances and equipment within or around a site after primary information has been attained. Hindrance factors to account for evacuation-in-progress are included.
9. Time taken for firefighter travel internally. The range of options considered include both horizontal and vertical travel, either by firefighter's lift or stairs. Forcibly gaining access through obstructions such as locked doors is catered for.
10. Time taken to set-up water for initial firefighter protection. This encompasses the requirements for an initial protective hose line which would be used either for immediate attack or for personnel protection when performing search and rescue. It could be either an internal hose reel or fire brigade line. Depending on water availability on site, Chart 11 for establishing water requirements may be invoked.
11. Time taken to set-up water supply requirements. The acquisition of sufficient water resources is fundamental to firefighting and so consideration is given to whether on-site supplies are adequate or whether relay pumping procedures need to be established. This may invoke Charts 2, 3, 4, 11 and 13 in order to secure appropriate resources to carry out the water supply function.
12. Time taken for search and rescue. Safety limits for firefighters in the enclosure where the search is to be conducted are of utmost importance. Full protective clothing is assumed and the criteria adopted for tenability is a radiant heat flux at a level of 1500 mm above the floor of 4.5 kW/m^2 , or the occurrence of flashover. Either of these conditions precludes searching. If a search cannot be conducted or completed, then the possible loss of life results and the process of reconsidering and adjusting the design should occur as shown in figure 1. Alternatively, a search is begun with either one or more teams of three firefighters. This team size has been adopted for Occupational Health and Safety reasons. It is based on the Australian practice of breathing apparatus teams working in pairs whilst a third firefighter provides a protective hose stream. All assembly of equipment and donning of breathing apparatus is catered for in earlier flowcharts. It is assumed that search and rescue is conducted under the constraint of 100% obscuration.

If more personnel are required, then these can be mobilised via a call to Chart 2. Searching is calculated based on the number of teams and floor area. Two search pattern options are normally adopted. The first involves a wall perimeter search generally by two firefighters moving side-by-side and hence reaching approximately 3m into the interior of the room away from the wall. The second involves an interior search with the assistance of guide lines generally criss-crossing the room. Interestingly, in the data collection trials only minor variation was found between times calculated on the basis of area for the two types of search pattern. This allowed the calculation process to be condensed and hence considerably simplified.

Individual teams may exceed the working duration of their air-sets. Allowance is made for this and the concomitant recovery time for the team before they can be utilised either in further searching or other tasks. Search of smoke-logged compartments is continued until complete or until firefighter safety limits are exceeded. This information is provided by the fireground status which tracks the time evolution of the fire.

Once fire and smoke spread has ceased and all smoke-logged compartments have been searched, a less sophisticated search of adjacent enclosures is conducted. This reconnaissance for evidence of smoke spread and remaining occupants is by definition undertaken in an environment relatively free of smoke and so is accomplished relatively quickly.

13. Time taken to protect other property. If radiant heat fluxes to adjoining properties reach threshold levels a requirement exists for establishing some measure of protection for them. This chart considers this issue and determines water requirements based on the area of exposure risk. Resource requirements, particularly in terms of specialist aerial appliances and ground-based monitors, are considered along with water availability.

14. Time taken to protect uninvolved contents (salvage operations). An important component of firefighting operations is the protection of property from the effects of fire, smoke and water damage. Consideration is here given to equipment and personnel requirements for these salvage tasks.

15. Time taken to control and extinguish the fire. This deals exclusively with the extinguishing capacity of available hose streams. Water supply is considered by Chart 11 and called if sufficient water is not available. For simplicity, one of three options is taken with regards to extinguishing capacity:

- no effect,
- control, and
- decay.

Fire size as determined from fire sub-model input is compared against the theoretical cooling capacity of available hose streams. Application of water is in discrete flow units of 5 L/s for interior hose lines and 10 L/s for exterior lines. This reflects the difference in hose size in the two regimes - smaller hoses being more manoeuvrable internally. If sufficient water is available, decay in heat output at the appropriate rate occurs. If insufficient water is available, growth is unchecked and more water must be sourced. If cooling capacity and heat output are within 10% of each other, then a constant level in heat output is assumed. Allowance is made for the efficiency of delivery of between 5 - 30 % based on observations of firefighting operations.

Although at the outset an international survey was conducted to determine what fire brigade intervention models existed, the results yielded surprisingly little. An exception to this was the work by Sardqvist [4] and much of the basis for calculation in this section has been taken from that work.

16. Time taken to protect the environment. An emerging concern for fire services in Australia is the protection of the environment, especially from the effects of contaminated water

run-off. Consideration is given to this in terms of personnel requirements and other charts are called as necessary for resource dispatch and alike.

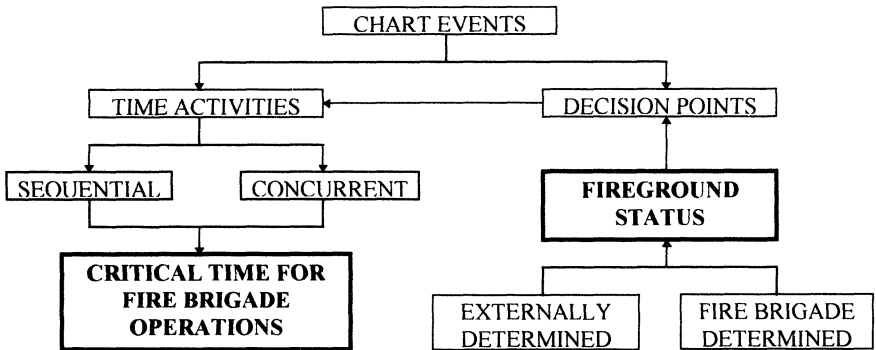


FIGURE 2: Summary representation of FBIM methodology.

DATA

Incident Reporting Statistics

At an early stage of the FBIM development a survey was made of existing sources of information, both domestically and internationally. An obvious important resource is the statistical data collected by fire services as part of their reporting procedures. By its nature, the Australian Incident Reporting System (AIRS) has a very broad scope. Generally, the level of information presently available, or potentially collectable, is insufficient when considering the analysis of a particular building design. It is simply not possible to determine fire brigade operation times for a specific design by considering the broad-band nature of the statistics. Too many specifics that may critically affect fire safety design are lost. This limits its use. There are two exceptions to this.

Response times are generic. The specific nature of the building and the fire scenario have no impact on operations until arrival. This data was analysed in the assessment of determining response times.

Quality assurance. Data can be collected which provides an overall estimate of fire service operations. This can be compared directly with FBIM output for a given situation but more importantly a statistical picture is built up over time for the various classes of building. This is important as it acts as a check on consistency, helps to isolate deficiencies requiring further work, and can be used in determining appropriate safety factors.

To this end, additional fields were included in the data collection process for AIRS. They comprise:

- *Attack time.* The time the initial firefighting attack force first places extinguishing medium on the fire.
- *Fire area at attack time.* The floor area actually involved in flaming combustion as found at the time of direct fire attack.
- *Extinguishment time.* The time at which the fire has been reduced to a smouldering stage where its continued minor heat output poses no further threat to structural adequacy.
- *Compartment size.* The size of the smallest compartment within which the fire is contained. This would be the room of origin for pre-flashover fires but would be the building dimensions if the structure had become fully involved.

These four data fields allow estimates for fire brigade performance relative to the state of development of a fire when extinguishment commences. They also allow an estimate of initial set-up times. This information has not been hitherto available but once sufficient data has been collected it will constitute a valuable resource for establishing quality control.

Collection

Acknowledging the inadequacy of relying solely on available statistics led to the development of the methodology already described. It was necessary to isolate individual functions as part of this process and consequently the collection of appropriate data corresponding to these functions consisted of determining times for the defined activities.

Eight realistic drill exercises were designed that incorporated all of the essential elements isolated in the methodology. Formulating exercises in this way allowed for collection through normal fire brigade training activities and helped to eliminate any sense of artificiality on the part of personnel undertaking the exercises. Individual data items were extracted from the exercise results.

Figure 3 shows a typical graph. It is the distribution in time for conducting safety procedures when setting up an aerial appliance such as a turntable ladder. For current application, the cumulative distribution is the most relevant. Once a percentile has been agreed to, the time for the activity is simply read from the graph of cumulative distribution.

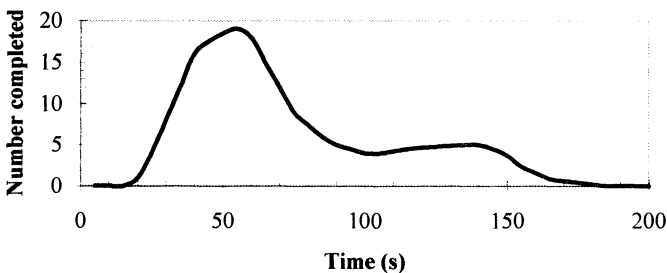


FIGURE 3: Time distribution for completion of safety procedures when establishing turntable ladders.

Margins for Safety. Deciding on appropriate safety margins is an important component of applying this model. This is agreed at the design stage and generally involves adopting a percentile level for which a majority of participants completed the given task, perhaps 80% or 90%. This can be read from graphs of the raw data. As an alternative, the samples provide estimates for means and standard deviations for the respective populations from which they are drawn and these can be used to arrive at an appropriate time in conjunction with Chebyshev's Theorem which states that the probability of randomly selecting a value more than k standard deviations away from the mean value is at most $1/k^2$. This is conservative but desirable as the distributions of the data are not well established and a high percentile level is required.

Future Plans. Whilst empirical cumulative distributions have proven convenient for the present, the long term plan involves determining appropriate distributions for each activity by hypothesis testing against appropriate theoretical models. Data collection will then provide the basis for the determination of these distributions and parameter estimates. The benefits in pursuing this lie with improved integration into risk-based modelling and improving on the levels of uncertainty inherent in the data collection. It will place the data on a more sound statistical footing so that quantitative statements can be definitively made, especially with respect to uncertainty.

As an indication of the above, much of the data is similar to that shown in figure 3 where the distribution in time for completion of a task peak and fall away with a long tail. Such a skewed distribution is to be expected. Let T be a random variable that represents the time of completion for a certain task and $F(T)$ its cumulative distribution. Then:

$$Y(t) = \text{prob}(T > t) = 1 - F(t) \tag{1}$$

represents the probability that a firefighter is yet to complete the task at time t .

The completion rate at a given time, $C(t)$, is given by the conditional probability of completion within a time interval Δt divided by that interval:

$$C(t) = \frac{1}{\Delta t} \left(\frac{F(t + \Delta t) - F(t)}{Y(t)} \right) \tag{2}$$

On taking limits a unique relationship can then be shown (see [5]) between the probability distribution and the completion rate for a given task. The point of this is that simple and intuitively appealing models for completion rates can be postulated thereby yielding the required distribution. For example, the longer the time, the greater the likelihood an individual has of completing a task and so a linear growth with time of completion rate seems reasonable. Such a model yields a Weibull distribution possessing the characteristics of an early peak with a long tail.

One problem with this approach is that it assumes identical firefighters (in a statistical sense). Clearly, different levels of training will impact on the performance of firefighters and so the anomalous behaviour of figure 3 where a second, weaker peak seems to develop, is probably

a reflection of this. To overcome this, firefighters will need to be separated into classes such as permanent, retained, etc. that reflect their level of training and data analysed on this basis. This was not done with our data as all testing was blind to individual and agency identity (many different brigades participated in the program).

Critical time. The final phase in bringing together the many disparate activities associated with firefighting operations is determining the critical time path for the overall operation appropriate to the scenario. An effective and visually revealing way of accomplishing this is to form a Gantt chart of all activities that are undertaken as determined by the strategy. Such a chart is simply an overlay of individual times against a principal time axis. As each activity is commenced, its starting time is logged on the time axis. The duration of the activity as calculated from the available data is similarly recorded. In this way an overall picture of the interrelationship and overlapping of times can be immediately seen.

CONCLUSION

We have given a brief description of the Fire Brigade Intervention Model which has been the Australian fire service response to quantifying operational firefighting in so far as it impacts upon the building design process. Many issues pertaining to firefighter safety such as structural adequacy provisions can only be properly dealt with in the prevailing performance context by having a quantitative estimate of firefighting operations. The model considers directly the range of activities undertaken at a fire and how they overlap. This leads to consideration of sequential and concurrent activities each initiating at various times. The overall outcome is then constructed via a critical path.

Defining a methodology is only part of the solution. Without reliable data no further progress can be made. Data collection across many different agencies responsible for fire suppression in Australia was undertaken and many of the results collated as empirical distributions. As more data is collected this will be refined through comparison with theoretical models.

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