Fire Research Report

Fire Loss Reduction in Industrial Buildings - Risk Cost Benefit Study

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This project investigated the cost-effectiveness of different fire protection strategies for use in industrial buildings in New Zealand, and developed a risk cost benefit model using @RISK to estimate the cost of fire in industrial buildings. Fire protection options included sprinklers, detection with manual suppression, and compartmentation.

The risk model was probabilistic and accounted for variability and uncertainty in the input data by incorporating probability distributions for inputs. Input data for the model relied on previous research on the cost of industrial fires in New Zealand carried out by Business and Economic Research Ltd (BERL) and supplemented with other data from the literature as well as engineering judgement. Latin hypercube simulation was used to generate an output distribution for the cost of fire. Twenty-five thousand iterations were conducted for each option.

Based on the upper 95% confidence level for the expected cost of fire per building per year, it is concluded that no change to the fire protection system requirements in the New Zealand building code compliance documents for industrial buildings is warranted. However, if buildings of more than 1000 m² in floor area are targeted, then it is recommended that automatic fire detection with manual suppression is the preferred option, closely followed by fire sprinklers.

The study demonstrates a methodology that addresses uncertainty and provides a more robust analysis for decision-making about Building Code requirements. It also helps identify those parameters that most affect the outcome of interest and those where better data would reduce uncertainty in the results.

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Fire Loss Reduction in Industrial Buildings – Risk Cost Benefit Study

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ABSTRACT

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Fire Loss Reduction in Industrial Buildings – Risk Cost Benefit Study

1. CLIENT

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2. INTRODUCTION

2.1 Background

The New Zealand Building Code compliance documents currently contain relatively few requirements for the fire protection of industrial buildings. In line with the focus on protecting life and neighbouring property, the potentially devastating effects of large industrial fires on the lives of those who work in them and their families, and on the surrounding community has not been a major consideration in setting the minimum requirements in code compliance documents. Given more recent changes to the Building Act (2004), in future, greater emphasis will be placed on sustainability. This study explores the cost-effectiveness of different fire protection strategies in industrial building taking a wider view of community benefit than previously considered.

2.2 Aims and objectives

The aim of this project is to develop a cost benefit model that would allow the effects (including overall benefit to the community) of increasing the level of fire protection systems in industrial buildings to be evaluated.

Specifically, the objectives of this study are to:

- Investigate the cost of a range of additional fire protection measures in industrial buildings and assess their likely impact on the fire losses.
- Develop a cost benefit model that allows these fire protection measures to be compared in financial terms. Economy-wide effects will be included as well as business costs and benefits.
- Understand the sensitivity of the results to uncertainties in the input parameters.
- Draw conclusions about the cost-benefit of providing higher levels of property protection in single storey industrial buildings.

2.3 Definition of industrial buildings

For the purpose of this study, and considering the overall objectives, it is considered that "industrial buildings" are those buildings that would fall into the "W" purpose groups of C/AS1 (DBH, 2005), but excluding business and personal services. In the main, this group of buildings would include manufacturing, processing and storage occupancies.

3. LITERATURE REVIEW

3.1 An economic assessment of industrial fires in New Zealand

BERL (2002) described an economic impact assessment (EIA) to measure the direct and indirect economic costs associated with industrial fires in New Zealand. In addition to analysis of the available fire incident records, the researchers also obtained insurance claims information from the insurance industry.

Their study was based on the year 2000 in New Zealand, where 1,100 industrial structure fires were reported. They determined that the total economic and social cost of industrial fires in Zealand (year 2000) was $86 million ($78,200 per fire). This comprised:

- Direct economic costs to business of $44M or $40,000 per fire (this included $8M for business interruption costs). This represented the value of economic losses experienced by the industry as a result of industrial fires. These costs were estimated using the value of material damage and business interruption insurance claims.
- $23M or $20,909 per fire for Fire Service costs. The cost of the fire service resource represents a share of the total expenditure on emergency response services attributed to industrial fires.
- Indirect economic costs – $10.5M or $9,545 per fire. This represented the value of the economic losses to upstream firms supplying goods or services to the business affected by fire and the resulting decline in consumption that occurs as a result of a decline in sales adversely impacting on wages and profits.
- Social costs dues to injuries and fatalities of $8.5M or $7,727 per fire. The value of a statistical life (VOSL) used was $2,469,900. The average loss of life quality due to serious and minor injuries was estimated to be 10% and 0.4% of the VOSL respectively (following LTSA (2000) methodology). In the year 2000, there were 3 fatalities, 3 life-threatening injuries and 25 non-life threatening injuries.

This study was one of the first attempts at measuring the impact of industrial fire incidents in New Zealand. One of the findings was that although industrial fires account for just 5% of all incidents, they use a disproportionately large amount of the total resource.

BERL (2002) have used a wider definition of industrial structure fires than will be used in this study. They included service and retailing industries that are not included here. Comparing the FIRS incident data (discussed later) for manufacturing and storage property uses with the dataset presented by BERL, we can see that the manufacturing and storage property uses account for around 54% of the 'industrial structure fires' based on the year 2000 fires presented by BERL. Therefore we can surmise that the expected contribution to the total economic costs for the manufacturing and storage property use subset would be $46 million per year (in year 2000 dollars).

3.2 Risk – informed, performance-based industrial fire protection

Barry (2002) discussed concepts of fire risk analysis, risk assessment and probability modelling within a performance code environment. He defined risk-informed performance-based fire protection engineering as an integration of decision analysis and quantitative risk assessment with a defined step approach for quantifying the performance success of fire protection systems. He describes various methodologies for conducting fire risk analysis in industrial buildings.

3.3 Fire protection in agricultural facilities

Research and industry practices for the fire protection of agricultural buildings (with particular reference to Canada) have been reviewed by Torvi (2003). Since these buildings are often located in remote rural areas, they present a challenge for fire protection. Large quantities of animals, crops and equipment can lead to severe fires and issues relating to animal safety and evacuation. As many agricultural facilities are located in smaller communities, the effects of a severe fire on a major employer can be devastating. There has been relatively little research carried out on fire protection in agricultural buildings (which will not be specifically addressed in the current study).

3.4 FIERAsystem

Benichou et al (2005) described a fire risk model called FIERAsystem (**FI**re **E**valuation and **R**isk **A**ssessment **System**) for evaluating fire protection systems in industrial buildings. There are various related papers e.g. Benichou et al (2002, 2003). The model is designed to conduct hazard and risk analyses related to fire protection systems in industrial buildings (it was developed primarily with warehouses and aircraft hangars in mind).

The model extends the risk assessment concepts previously developed in FiRECAM (Yung et al 1996) to industrial buildings. FIERAsystem uses time-dependent deterministic and probabilistic models to evaluate the impact of selected fire scenarios on life, property and business interruption.

The model requires the user to select the fire scenarios and their probability. For each scenario, four variants are also considered – they are sprinkler system success or failure and fire department suppression success or failure. The expected number of deaths per year and fire losses per year is calculated and summed over all the possible fire scenarios to arrive at an expected risk to life (ERL) and fire cost expectation (FCE) for the building.

It was considered that FIERAsystem may be a suitable tool for use in this current study, however it was not currently available for use. Further work is required before a beta version will be available.

The FIERAsystem Downtime Model (Benichou et al 2003) was developed to evaluate the likely business interruption as a result of fire damage to a building or its components. The calculation includes parameters such as: total capital cost ($), total replacement duration (person days), total property loss ($), total business interruption (person days).

3.5 Cost-benefit and risk analysis – basis for decisions in the fire safety design process

Lundin (2002) discusses cost-benefit analyses as a tool for the engineer to choose between alternative fire protection measures. Cost-effectiveness is relative to the perspective of the decision-maker i.e. a cost-effective solution for the building owner might not be for the building contractor. It is therefore important to define who is the decision maker? And what information is the decision to be based on?

3.6 Serious fires in industrial premises

Helm (2005) presented summary statistics for serious fires in industrial premises in the UK (serious fires are those involving fatalities or causing losses of £100,000+). Relevant statistics from 1999 to 2003 are summarised in Table 1. The average total losses per serious fire in industrial premises over the years considered was approximately £741,000, compared to approximately £539,000 per serious fire in all premises. For industrial premises, the proportion of the total losses was consistently higher than the proportion of total serious fire events for the years considered. On average, the proportion of the total losses attributed to industrial premises was 5% higher than the proportion of the number of serious fires that had occurred in industrial premises.

Table 1. Serious fires in industrial premises (extracted from Helm 2005)

Year	1999	2000	2001	2002	2003
No. serious fires in industrial premises	51	50	43	30	36
Total losses due to serious fires in industrial premises (£)	50,533,844	39,940,222	25,829,920	18,540,253	20,802,400
Total no. all serious fires	346	334	353	346	310
Total losses for all serious fires (£)	186,099,883	155,124,725	173,406,472	201,002,775	178,834,350
Serious fires in industrial premises (% of all serious fires)	14.8	14.7	12.6	8.8	12
Losses due to serious fires in industrial premises (% of $ losses for all serious fires)	27.2	25.7	16.5	9.7	12.5

3.7 Fire Sprinkler Incentive Act 2005 (USA)

The Bill H.R. 1131 was proposed to allow tax benefits through allowing a five-year depreciation of sprinkler systems. The National Fire Sprinkler Association Inc. (NFSA) published a White Paper on the Fire Sprinkler Incentive Act 2005 (NFSA 2005) that discussed the initiatives in terms of reducing the cost of fires. The estimated reduction in civilian deaths attributed to sprinklers in the USA is presented in Table 2. For industrial, manufacturing and storage premises the reduction in civilian deaths was greater than 60%. The estimated reduction in property damage attributed to sprinklers in the USA is presented in Table 3. For industrial and manufacturing premises, the reduction in property damage ($) was 43% and 67% respectively.

Table 2. Civilian deaths per thousand fires based on NFIRS and NFPA 1988–1998 survey (Extracted from NFSA 2005 and NFIRS version 5.0)

Civilian deaths per thousand fires (NFPA 1988–1998 NFIRS and NFPA survey)			
Property use	**Without sprinklers**	**With sprinklers**	**% reduction**
Industrial	1.1	0.0*	100
Manufacturing	2.0	0.8	60
Storage	1.0	0.0*	100

*Based on fewer than two deaths per year in ten-year period (may not be significant).

Table 3. Estimated reduction in property damage per fire based on NFIRS and NFPA 1988–1998 survey (Extracted from NFSA 2005)

Estimated reduction in property damage per fire (NFPA 1988–1998 NFIRS and NFPA survey)			
Property use	**Without sprinklers**	**With sprinklers**	**%reduction**
Industrial	$30,100	$17,200*	43
Manufacturing	$50,200	$16,700	67

*Based on fewer than two deaths per year in ten-year period (may not be significant).

3.8 The US fire problem overview report – storage, industrial and manufacturing properties

Ahrens (2003) reported on fire protection features in storage, industrial and manufacturing property structure fires in the US from 1994 to 1998 except dwelling garages as reported to public fire departments. Relevant summary statistics are presented in Table 4.

3.9 US experience with sprinklers and other fire extinguishing equipment

Rohr and Hall (2005) published very useful quantitative estimates of reductions in loss of life and property loss in fires where sprinklers were present based on US statistical fire incident data.

Table 5 summarises performance of automatic extinguishing systems as reported in NFIRS 5.0 to US Fire Departments for 1999 to 2002 structure fires after recoding based on reasons of failure or ineffectiveness.

Table 6 summarises the performance of all automatic extinguishing systems and sprinkler only systems respectively.

Table 7 gives the estimated reduction in civilian deaths per thousand fires in industrial, manufacturing and storage occupancies due to sprinklers.

Table 4. Storage property structure fires in the US from 1994 to 1998

Category	Storage	Industrial and Manufacturing
% of fires in buildings with smoke or other alarms present	6.4 %	32.9%
% of fires in buildings having smoke or other fire alarms in which devices were operational	68.9 %	83.0%
% of fires in buildings with operational smoke or other fire alarms (product of first two statistics)	4.4 %	27.3%
% of fires in buildings with automatic suppression system	4.0 %	41.3%
Deaths per 1,000 fires with automatic suppression system present	0.0%	0.9%
Deaths per 1,000 fires without automatic suppression system present	0.7%	1.2%
Reduction in deaths per 1,000 fires when automatic suppression systems were present	100%	30.4%
Average loss per fire when automatic fire suppression was present[1]	USD$101,711	USD$19,238
Average loss per fire with no automatic fire suppression	USD$20,051	USD$55,749
Reduction in loss per fire when automatic suppression systems were present		65.5 %

Table 5. Type of automatic extinguishing system present, excluding confined fires, 1999–2002 (extracted from NFIRS version 5.0.)

Automatic suppression systems	Manufacturing	Storage
Wet pipe sprinkler	75%	68%
Dry pipe sprinkler	15%	29%
Other sprinkler system	3%	1%
Dry chemical system	1%	1%
Carbon dioxide (CO_2) system	3%	0%
Foam system	0%	0%
Halogen type system	1%	0%
Other special hazard system	2%	1%
Total	**100%**	**100%**
Sprinkler systems	93%	97%
Other systems	7%	3%
Total	**100%**	**100%**

[1] For the storage property value: two fires within a nine-hour period in a warehouse caused $280M in direct property damage. Sprinklers were shut down after the first fire and so did not operate when wires arced as the power was restored causing a second fire.

Table 6. Automatic extinguishing system performance (extracted from NFIRS version 5.0)

	Property use	Operated and effective	Operated and not effective	Fire too small to activate	Failed to operate	Total
All automatic extinguishing systems	Manufacturing	48%	5%	43%	4%	**100%**
	Storage	44%	8%	39%	9%	**100%**
Sprinklers only	Manufacturing	48%	3%	45%	4%	**100%**
	Storage	47%	5%	38%	9%	**100%**

Table 7. Estimated reduction in civilian deaths per thousand fires due to sprinklers (extracted from NFIRS version 5.0)

Property use	Without sprinklers	With sprinklers	% reduction
Industrial	1.1%	0.0%	100%
Manufacturing	2.0%	0.8%	60%
Storage	1.0%	0.0%	100%
All buildings	7.6%	1.1%	86%

1989–1998 structure fires reported to US Fire Departments

3.10 Assessment of benefits of fire compartmentation in chemical warehouses

Houlding and Rew (2003) conducted a study that considered the benefit and cost-effectiveness of compartmentation in mitigating fire hazards in chemical warehouses in the UK, through the development of a fire risk model. Such a model was intended to aid the Health and Safety Executive (HSE) to provide advice on the design of fire protection for chemical warehouses. A summary of the work was also published elsewhere (Tyldesley, Rew and Houlding 2004). The risk model was essentially probabilistic in form, but was supported by simple deterministic analysis. An spreadsheet-based event tree approach was used as illustrated in Figure 1.

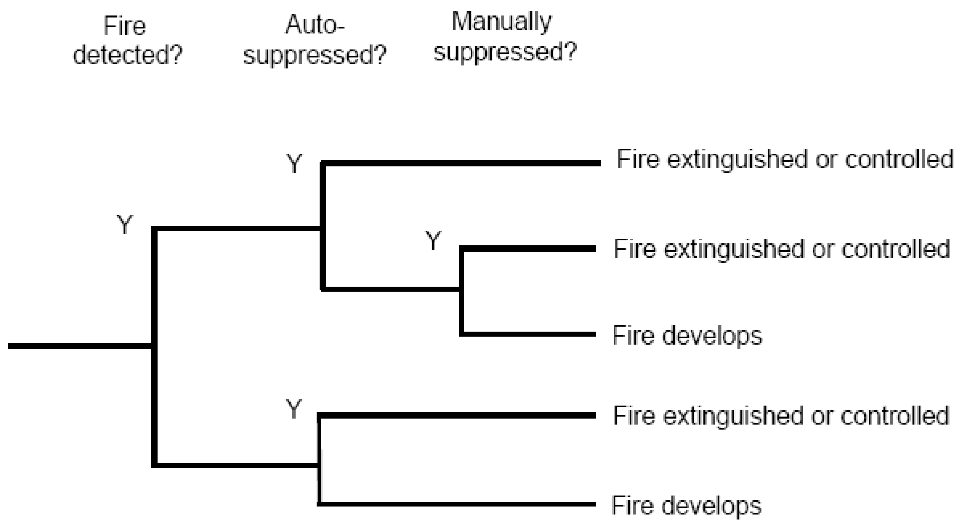


Figure 1. Fire development event tree (extracted from Houlding and Rew 2003)

The main conclusions from the Houlding and Rew study were:

- automatic fire detection is generally more cost-effective than other protection measures
- automatic suppression is more effective than compartmentation in reducing fire damage, although it is difficult to ensure the adequacy of suppression system designs for materials and storage configurations found in chemical warehouses
- reinforced concrete fire compartmentation is an effective way to prevent fire spread off-site or into high hazard areas on-site. The effectiveness reduces significantly if blockwork or stud partition walls are used or if doors or other penetrations are required in the wall.

The Houlding and Rew (2003) study is particularly relevant to the current work as the objectives of the study were somewhat similar, although it was focussed specifically on chemical warehouses whereas we are interested in industrial buildings more generally.

3.11 The ignition frequency of structural fires in Finland 1996–1999

Tillander and Keski-Rahkonen (2003) studied the ignition frequency of structural fires derived from Finnish statistics. They showed ignition frequency varied with floor area. They proposed a model for determining ignition frequency of buildings with a floor area of between 100 and 20,000 m². Figure 2 shows data relevant to industrial buildings and warehouses in Finland as taken from their paper.

The ignition frequency model has the following form where f''_m is the ignition frequency (fires per m² per annum) and c_1, c_2, r and s are constants fitted from the data. A is the floor area.

$$f''_m = c_1 A^r + c_2 A^s$$

Note that 'ignition' here is taken to mean a fire to which the public fire department is called.

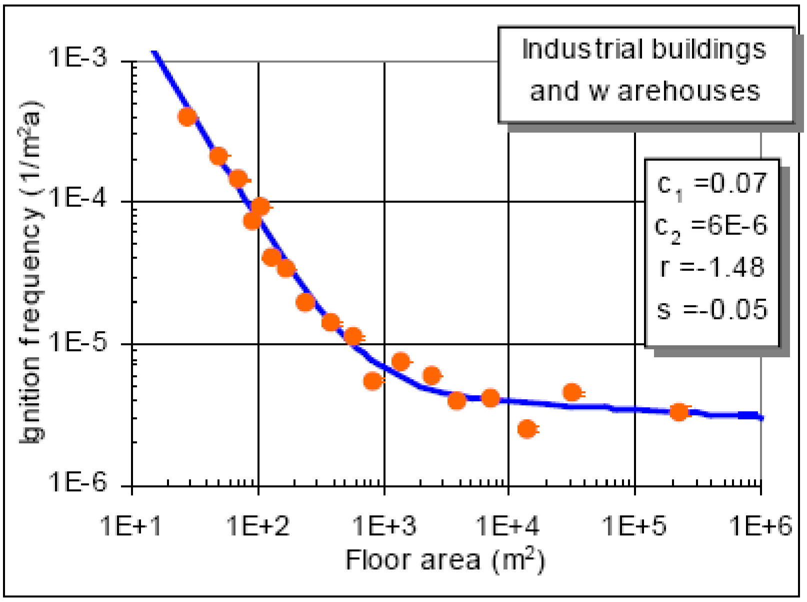


Figure 2. Ignition frequency observations (dots) in industrial buildings and warehouses 1996–1999 Finland and a generalised Barrios model fitted to the data (solid line). Extracted from Tillander and Keski-Rahkonen (2003)

3.12 Statistical determination of ignition frequency

Sandberg (2004) determined the ignition frequency in different building categories in Sweden based on data from the fire departments of Stockholm, Gothenburg and Malmö for the years 2000 to 2002 inclusive (as shown in Table 8). The average ignition frequency for industrial buildings is shown as 1.1E-05 fires per m² per annum.

Table 8. Number of premises and fires and the combined floors area in different building categories. Extracted from Sandberg (2004)

Key	Major group	Number of premises	No of fires	Floor area $[10^6\ m^2]$	Average ignition frequency $[1/y\ m^2]$
A	Hotels and restaurants	5 463 ± 253	200	6.5 ± 0.3	$3.1 \cdot 10^{-5}$
B	Offices	16 200 ± 454	123	30.7 ± 0.9	$4.0 \cdot 10^{-6}$
C	Stores and warehouses	11 065 ± 578	227	14.0 ± 0.6	$1.6 \cdot 10^{-5}$
D	Buildings for institutional care	5 884 ± 332	575	18.4 ± 1.0	$3.1 \cdot 10^{-5}$
E	Educational buildings	13 053 ± 247	422	36.2 ± 1.2	$1.2 \cdot 10^{-5}$
F	Churches/correspondin g	5 505 ± 324	20	3.6 ± 0.5	$5.6 \cdot 10^{-6}$
G	Theatres, cinemas and other assembly buildings	11 715 ± 637	52	6.0 ± 0.7	$8.7 \cdot 10^{-6}$
H	Buildings for sport activity	3 806 ± 207	59	7.0 ± 0.8	$8.4 \cdot 10^{-6}$
I	Industrial buildings	41 335*	1274	112.0**	$1.1 \cdot 10^{-5}$

*Table 6.1. Number of premises and fires and the combined floor area in different building categories the year 2002. *The number of industrial premises the year 2003. **The floor area of industrial buildings is for the year 2003.*

3.13 Decision Analysis in Fire Safety Engineering – Analysing Investments in Fire Safety

Johansson (2003) presented a summary of various decision analysis methods employed in fire safety engineering prior to 2003 (Table 9). Each of the decision analysis methods were classified as to the types of buildings (i.e. specific or general) that the method was to be applied to and the type of method (i.e. index, expected-cost or expected-utility).

Johansson (2002, 2003) described a methodology for conducting decision analysis concerned with investments in fire safety. He put forward an approach that involves decision rules based on maximising the expected utility but also including analysis of the uncertainty regarding the probabilities and consequences of different fire scenarios. This allowed conclusions to be drawn about the robustness of the decision to choose one alternative over another.

Table 9 Classification of various decision analysis methods employed earlier in fire safety engineering (extracted from Johansson, 2003)

	Index method	Expected-cost method	Expected-utility method
Buildings in general		Policy analysis (see [6], for example)	Spilberg and De Neuville [4]
Specific buildings	Watts [10], [11], and [12] Budnick *et al.* [14]	CESARE-RISK [16] FiRECAM [17]	Ramachandran [3] Cozzolino [5] Van Anne [8], [19]

4. INDUSTRIAL BUILDING STOCK IN NEW ZEALAND

Quotable Value New Zealand (QV) maintain a database of building property information. They have six categories of industrial building: heavy manufacturing (~1,000 buildings); light manufacturing (~13,000 buildings); noxious (~300 buildings); service industries (~12,000 buildings); warehouses (~7,000 buildings) and other (mainly multi-use, ~4,000 buildings).

These buildings were grouped on a floor area basis with the distributions shown in Figure 3 to Figure 7. The entire dataset comprised 40,275 buildings, with a total of 40,064,966 m² of floor area. It was decided to focus on manufacturing and storage occupancies in this study – therefore service industries were excluded, with Figure 8 showing the floor area distribution for this subset. The total number of buildings in this group is 27,273.

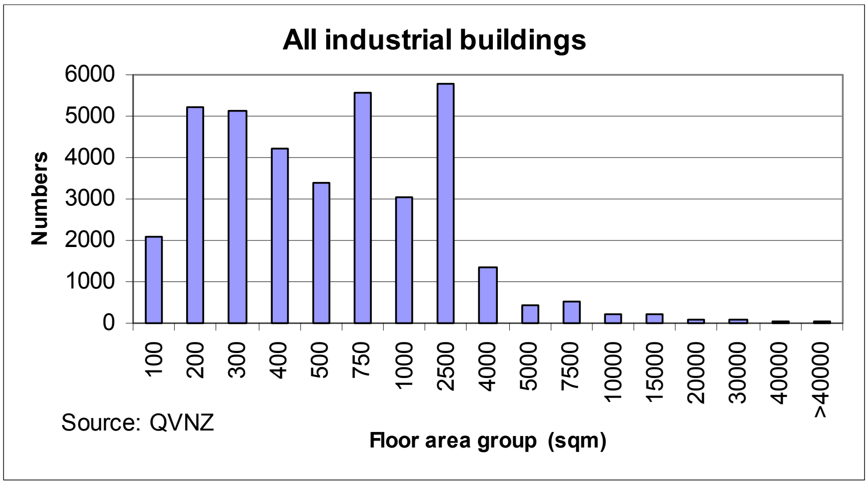


Figure 3. All industrial buildings – numbers by floor area

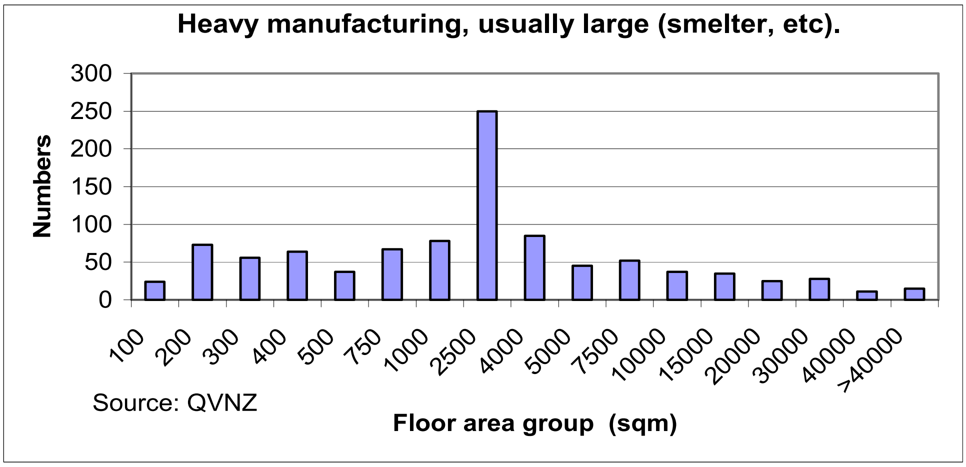


Figure 4. Heavy manufacturing buildings – numbers by floor area

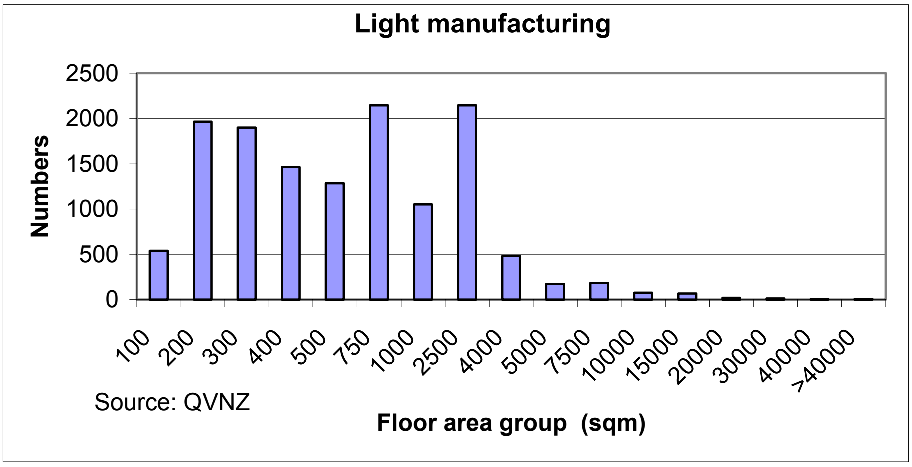


Figure 5. Light manufacturing buildings – numbers by floor area

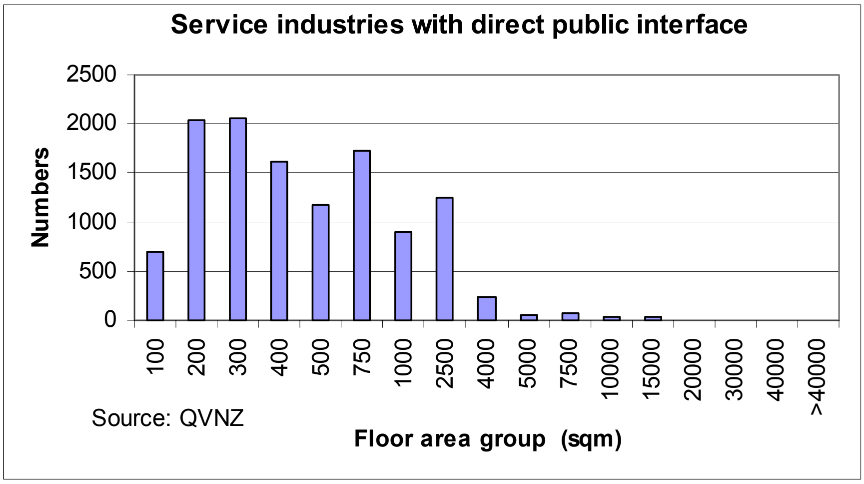


Figure 6. Service industry buildings – numbers by floor area

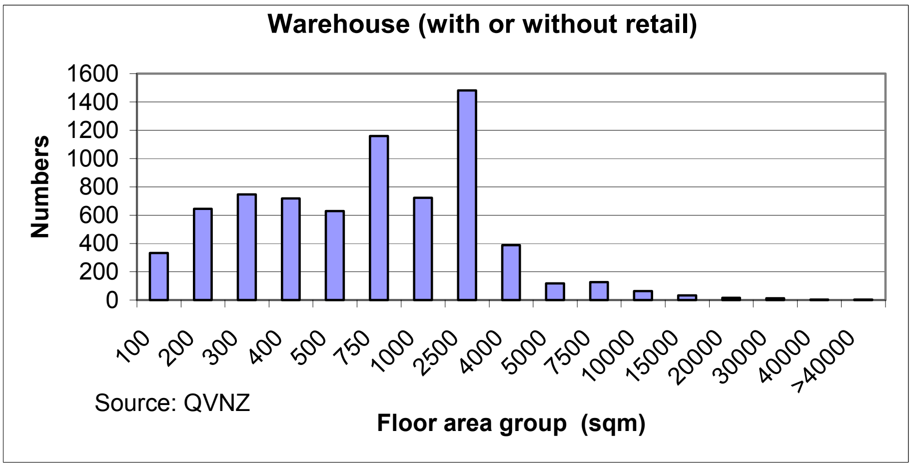


Figure 7. Warehouse buildings – numbers by floor area

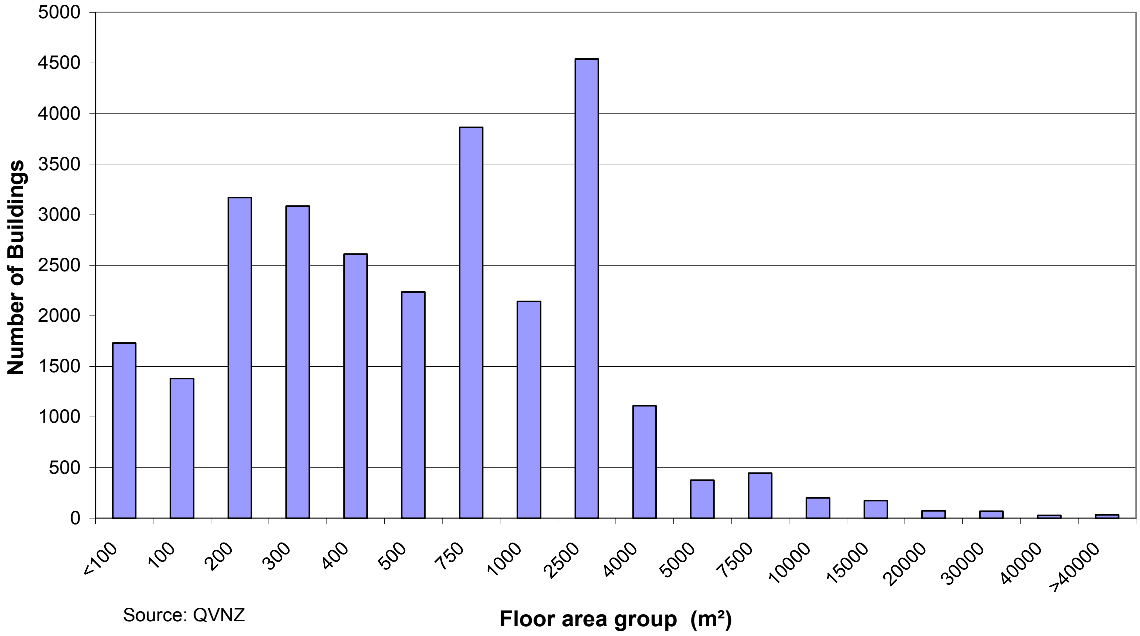


Figure 8. All industrial buildings (excluding service industries) - numbers by floor area

5. FIRE PROTECTION SYSTEMS PROBABILITY DATA

5.1 General

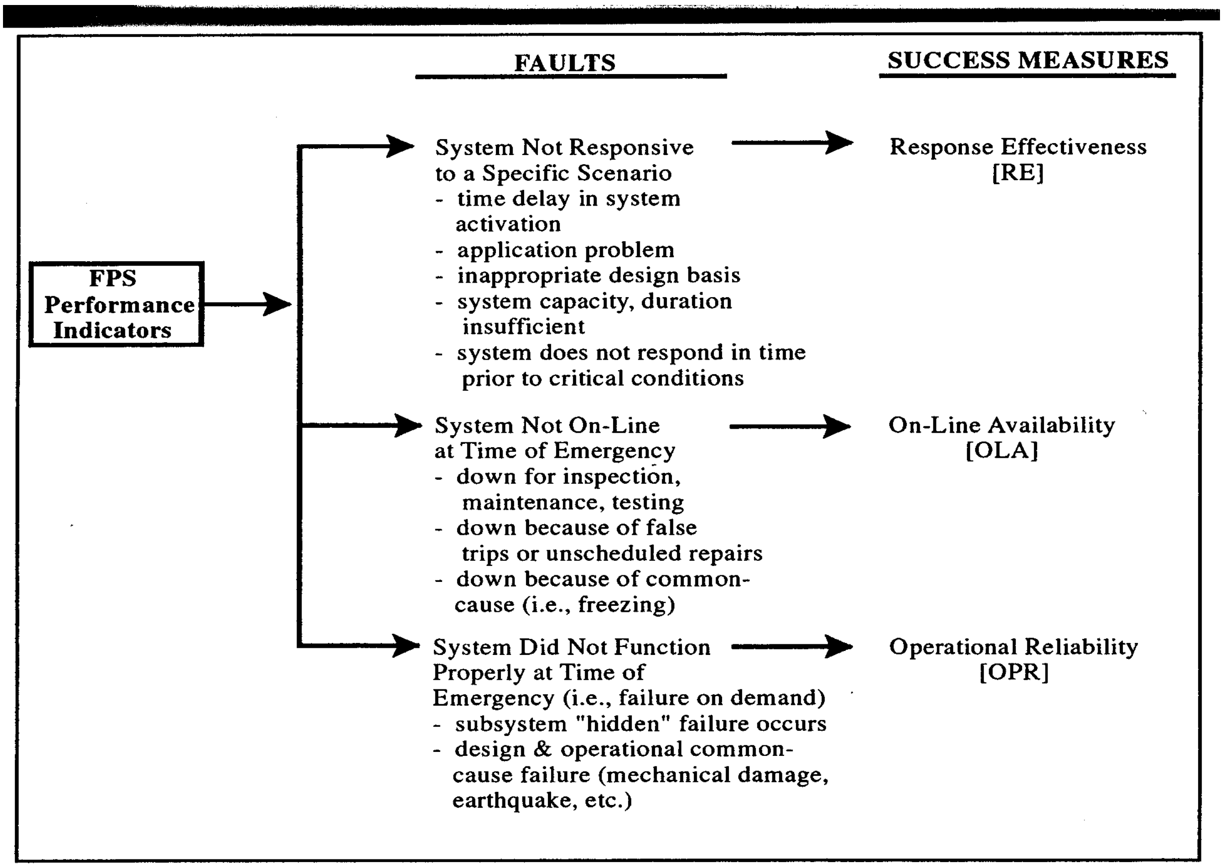
It is essential that any cost-benefit model accounts for the reliability and effectiveness of the fire protection systems. Barry (2002) provided a very good overview of the methods available for quantifying probability of success of a fire protection system.

Fire protection performance success can be considered to be the product of three probabilistic success measures:

- response effectiveness (i.e the system is responsive to a specific scenario)
- on-line availability (i.e the system is online at the time of the emergency), and
- operational reliability (the system functions properly at the time of the emergency).

Figure 9 (taken from Barry 2002) illustrates examples of some primary fire protection success measures.

In this study, the key fire protection systems intended to be included in the model are fire sprinkler systems, automatic detection systems (followed by manual suppression) and fire-rated separations or firewalls. Ideally, we would like to identify each of the probabilistic success measures for each system as input for our model, however, this level of detail was generally not found and therefore a more subjective approach was adopted, making use of the available information and the work of other similar studies.



FPS performance success is the product of these three probabilistic success measures:

Primary Performance Measure | **RE Response Effectiveness** | **OLA On-Line Availability** | **OPR Operational Reliability**

FPS Performance Success Probability (P_S) $P_S = P_{RE} \times P_{OLA} \times P_{OPR}$

P = probability

Figure 9. Example of primary FPS success measures (extracted from Barry 2002)

5.2 Fire separations

There is very little comprehensive data in the literature regarding the performance success probabilities of fire separations. The results of a Delphi study[2] done by Warrington (1996) are often quoted (e.g Bukowski et al 1999 and Houlding and Rew 2003), as given in Table 10.

[2] Based on survey of expert opinion.

Table 10. Estimates of fire separation operational reliability

Wall type	Operational reliability[3]
Masonry construction	0.81
Gypsum plasterboard	0.69

British Standard BS DD240 (1997) provided some probabilities of passive fire protection failing to operate as designed (stated to be taken from an ASTM study), as given in Table 11.

Table 11. Estimates of compartment penetrations operational reliability

Protection feature	Operational reliability
Fire door	0.70
Self-closing door to protected stairway	0.90

In a study assessing the benefits of compartmentation in chemical warehouses, Houlding and Rew (2003) adopted values for the probability of success of wall constructions as shown in Table 12 for a range of fires of the type that might be expected in a chemical warehouse. The values selected for plasterboard walls reflected their assertion that they would not perform well in conditions which were representative of liquid hydrocarbon fire exposures.

Table 12. Probabilities of success of wall construction

Wall type	Probabilities of success of wall constructions
Concrete	0.95
Masonry	0.70 – 0.80
Plasterboard	0.40 – 0.70

The probability of firewall success used in our study is given later in Section 9.2.6 of this report.

5.3 Fire detection systems and manual suppression

BS DD240 (BSI 1997) provided estimates for probabilities of fire detection systems failing to operate as designed based on earlier research by the Fire Research Station. The estimates are presented in Table 13 which is extracted from the report by Houlding and Rew (2003).

Houlding and Rew (2003) reviewed a range of automatic fire detection reliability data and concluded that an availability of 0.8 was appropriate for an automatic fire detection in a warehouse building.

Probabilities are also needed for the success of manual fire-fighting given that detection has taken place and the fire service has been notified. The success of manual fighting can be very uncertain as it depends on the fire growth rate, the availability of fire-fighters, configuration of the building etc. Again, for chemical warehouses, Houlding and Rew (2003) used values in the range 0.1 to 0.4 for the probability of success.

The probability of detection and manual suppression success used in our study is given later in Section 9.2.6 of this report.

[3] Probability that wall will have no penetrations which are fixed open.

Table 13. Estimates of detection system operational reliability

Detector type	Occupancy / fire type	Operational reliability
Smoke detector	Commercial – general	0.72
	Commercial – storage	0.68
	Commercial – industrial/manufacturing	0.80
	Institutional – general	0.84
Heat	Smouldering fire	0
	Flaming fire	0.89
Smoke	Smoldering fire	0.86
	Flaming fire	0.90
Beam smoke	Smouldering fire	0.86
	Flaming fire	0.88
Aspirated smoke	Smouldering fire	0.86

5.4 Fire sprinkler systems

There have been many studies providing reliability estimates for fire sprinkler systems with most of them having been published more than 10 years ago, so at least for industrial buildings they may not adequately reflect the performance of some of the newer sprinkler technologies (e.g. ESFR). A more recent study by Rohr and Hall (2005) based on US data (see

Table 6) indicated that for fires in manufacturing occupancies, where sprinklers were present, they either failed to operate or operated but were not effective in 7% of the cases. The value was 14% in storage occupancies.

Marryat (1988) is another often quoted source of sprinkler reliability data in New Zealand, giving reliability of 99.5%. His study was based on 9,022 fires in Australia and New Zealand over the period 1886 to 1986. However, some caution needs to be applied in the use of this value – unsatisfactory performance is defined as serious damage or destroyed by fire and/or where the damage to contents is excessive. Also, these buildings may have included other fire protection features (e.g. firewalls, smoke venting) and the effect of these is not distinguished. Nonetheless the study comprehensively illustrates the value of fire sprinklers. Australia and New Zealand are also considered to have excellent regimes for ongoing inspection and maintenance requirements for sprinklers which may lead one to argue that sprinkler effectiveness overall should be somewhat better than compared to the US, for example.

The operational reliability of sprinklers was reviewed by Bukowski et al (1999) giving a range for reported reliability data from 87.5% to 99.5%.

Houlding and Rew (2003) used values in the range 0.60 to 0.90 for the probability of fire suppression systems using water sprinklers in their study applying to chemical warehouses or a range of different fuel types (including highly flammable liquids).

The probability of sprinkler success used in our study is given later in Section 9.2.6 of this report.

6. FIRE PROTECTION SYSTEMS COSTING DATA

Considering current minimum requirements for industrial buildings based on the current compliance documents (DBH 2005) and discussed later, the most likely additional fire protection measures that might be considered for increasing the level of fire protection would be: automatic fire detectors, automatic fire sprinklers, and/or additional fire rated compartmentation within the building. The purpose of this section is to gather information relevant to the cost of including these systems within an industrial building.

The following is taken from the *2004 Rawlinsons New Zealand Construction Handbook*.

Building costs per square metre

Factories and warehouses (under 20 m clear span) \$550–650 / m²
Factories and warehouses (over 20 m clear span) \$435–485 / m²
Costs are also given for cold stores, cool stores, workshops.

Fire services (with sprinklers but excluding pumps and tanks)

Warehouse with small office	\$45–65 / m²
Factory with small office	\$35–55 / m²
Laboratory workshop	\$45–55 / m²

Detector and alarm systems

Fire Indicator Board
(Price include accessories, wiring and fire indicator board, but excludes detectors and circuits)

Medium project	\$3,000 – \$10,000
Major project	\$10,000 – \$30,000

Detector and Circuits

Thermal detectors	\$85 – 95 each
Fire bell and circuit	\$70 – 90 each

Fire-rated inter-tenancy walls

1 hour rated, non-loadbearing, plasterboard/timber	\$83–91 / m²
2 hour rated, non-loadbearing, plasterboard/timber	\$117–122 / m²

Maltbys (2005a) estimate the fire protection cost (comprising hose reels and extinguishers) for a light industrial building to be 0.6% of the total cost. This compares to 1.7% for bulk retail (smoke detection added) and 4.3% for retirement homes (sprinklers added).

From Maltbys (2005b) describing a Light Industrial Building

Single storey warehouse with mezzanine on a flat site having a gross floor area of 414 m² accommodating warehouse, office accommodation, reception and display area, staff lunchroom, kitchen and toilet facilities. Constructed of reinforced slab, reinforced concrete columns, tilt-up pre-cast concrete external walls, powder-coated external aluminium joinery, roller shutter doors, and Colorsteel roof. Timber-framed internal partitions with painted plasterboard linings. Siteworks, security and carpet are excluded.

Cost of an industrial building as at July 2005 – $1005–1074/m². The rates are per m² of gross floor area for each building type and include GST. "The unit construction costs are built up from current commercial prices of materials and labour along with current allowances for contractor's overheads and margins. Pricing is based on a model building for the region and consequently allowances will need to be made where recognition is deemed necessary for particular and specific conditions."

Estimates of the cost of an automatic fire detection and alarm system (Type 3) for industrial buildings was provided by Clark (2006). The estimates were:

Fixed cost per building of $5,000 for the alarm panel.
Variable cost of $9 per m² of floor area for the detectors, sounders and callpoints.
Annual maintenance per building of $700 for monthly testing and annual survey.
Fire service connection costs per building of $1,000 per year.

7. NEW ZEALAND FIRE INCIDENT STATISTICS

7.1 General

The data presented in this section was provided by Neil Challands of the New Zealand Fire Service from the National Fire Incident Reporting System (NFIRS) and related to fires over the period 1986 to 2005. In total there were 17,000+ incidents being "structure fires" in "primary industries and utilities", "manufacturing" and "storage" occupancies.

Figure 10 plots the number of incidents recorded each year since 1986. From the data, more incidents occurred per annum before 1995. Subsequently a downward trend exists based on the last 10–15 years. However, there was no discernable trend over the last five years (since 1999).

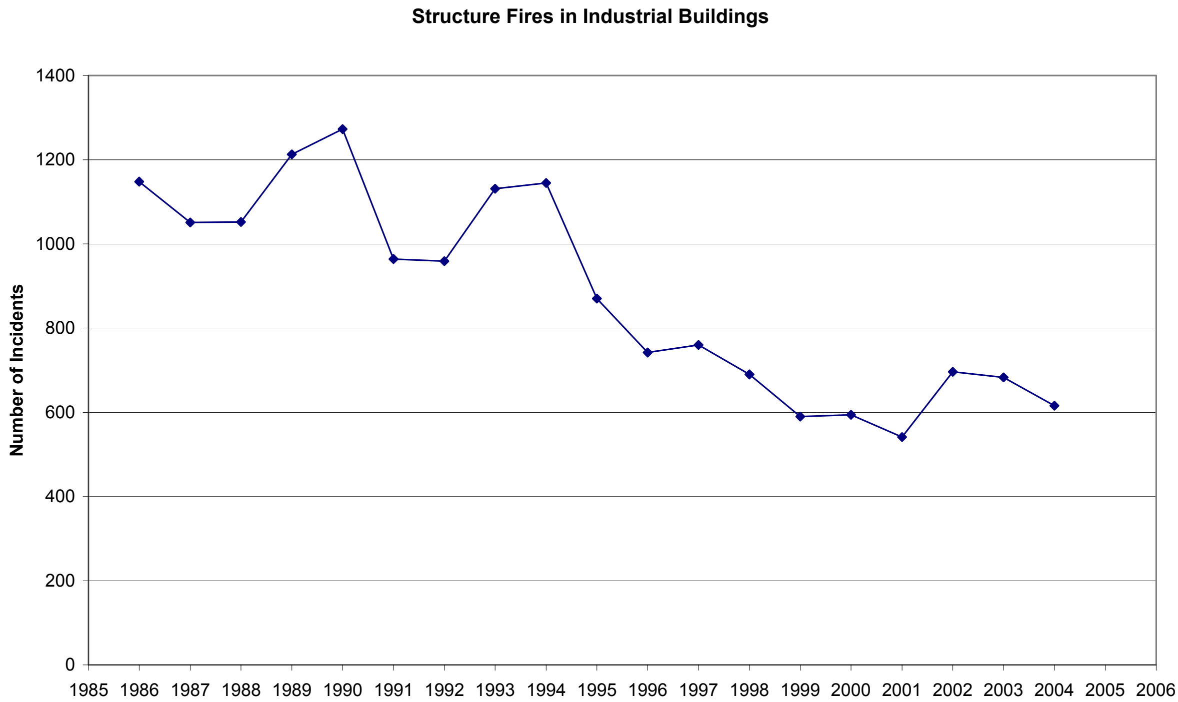


Figure 10. Structure fires in industrial buildings (Challands 2005)

Table 14 shows the automatic alarm system type that was responsible for raising the alarm in industrial buildings between 2000 and 2004. This data is not very useful for estimating the number of automatic systems because there may have been multiple systems present and this would not have been captured here. It is also not clear whether the 'not recorded' category can be interpreted as 'automatic system not present'.

Table 14. Type of automatic detection that first raised the alarm for industrial buildings 2000–2004 (Challands 2005)

Type of alarm system initiating call	No. of incidents
Other	12
Inert gas (not CO_2)	5
Deluge system	6
Domestic smoke alarms	9
Smoke sampling system	10
Water spray projection system	10
CO_2	13
Unable to classify	18
Smoke detector/security alarm system	42
Heat detector, thermal detector	55
Smoke detector system (monitored)	117
Sprinkler	172
Not recorded	2661
Total	3130

Figure 11 shows the breakdown of fire incidents in industrial buildings by the property use classification. The greatest number of fires (40%) occurred in buildings used for manufacturing purposes.

Figure 12 and Table 15 show a breakdown of fire incidents in industrial building by the extent of flame damage.

Table 15. Structure fires in industrial buildings by extent of flame damage 1986–2005 (Challands 2005) grouped into defined damage categories

No damage of this type	815	27.1%
Confined to object of origin	1,985	
Confined to part of room or area of origin	2,092	27.0%
Confined to room of origin	697	
Confined to fire cell of origin	193	3.5%
Confined to floor of origin	167	
Confined to structure of origin	3,761	42.4%
Extended beyond structure of origin	626	
Total	**10,336**	**100%**
Not recorded	6,382	

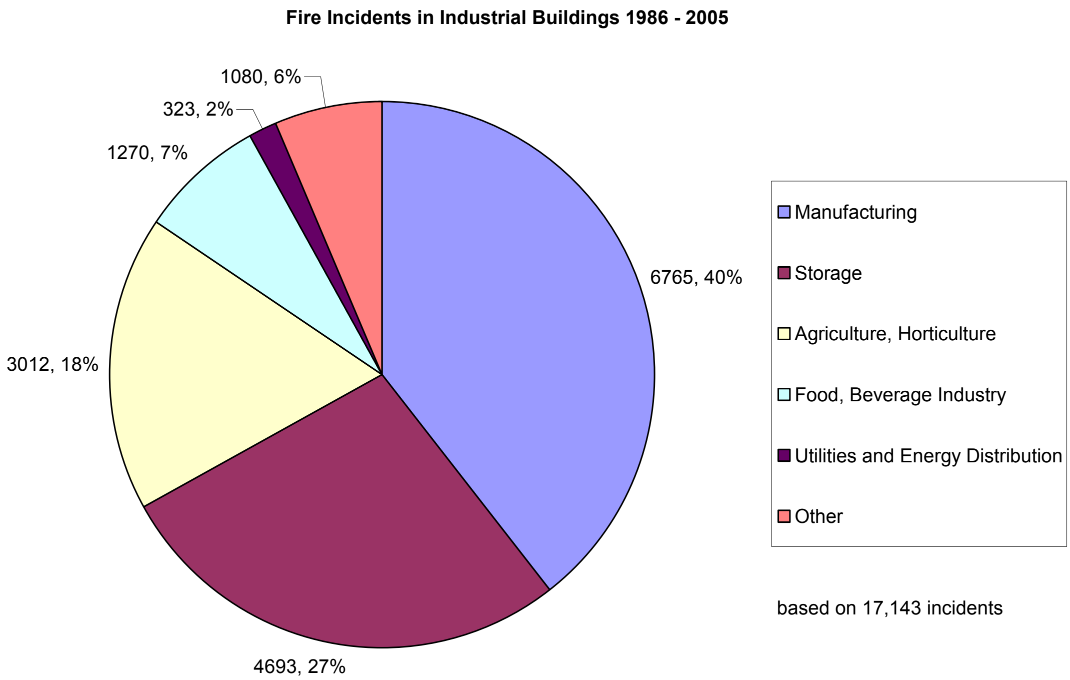


Figure 11. Structure fires in industrial buildings by property use 1986–2005 (Challands 2005)

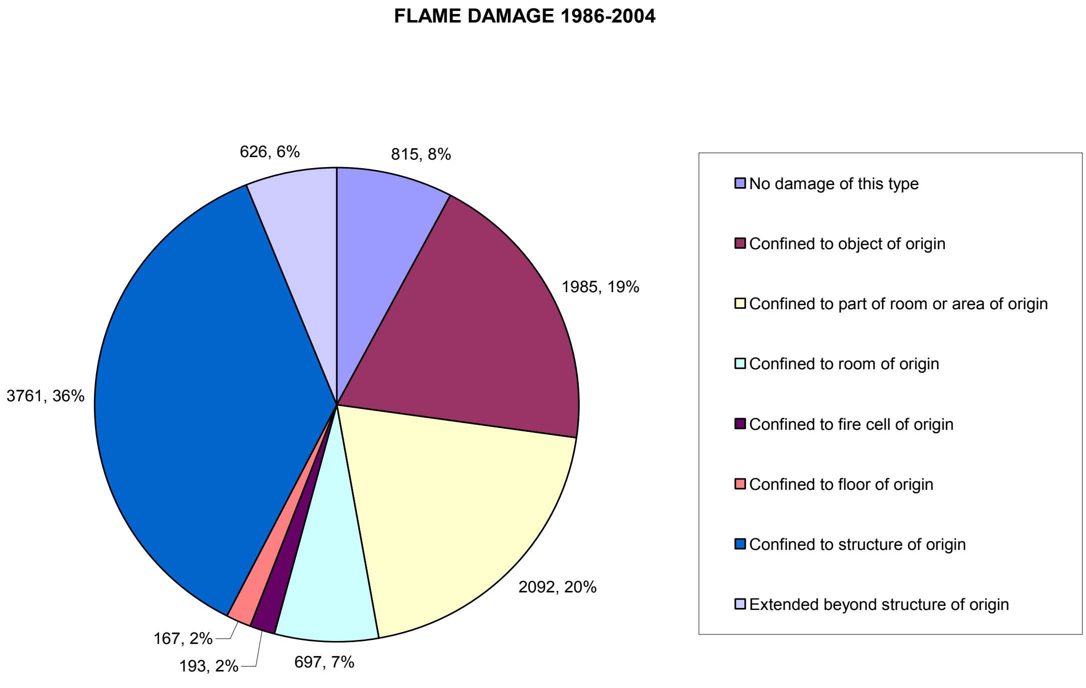


Figure 12. Structure fires in industrial buildings by extent of flame damage 1986–2005 (Challands 2005)

Table 16 shows the extent of property saved/lost as extracted from NFIRS data since 2001. The data was further summarised and presented in Table 17 for comparison with data from the year 2000, as presented by BERL (2002). The data does not agree well. It is speculated that the BERL data included the 'not recorded' category in with the 0–10 % group, and thereby over-estimated the size of that group. Since 2001, for nearly 42% of the fire incidents of interest the percent of property saved was not recorded.

Table 16. Structure fires in industrial buildings by percentage of property saved 1986–2006 (part) (Challands 2005)

Extent of damage 2001–2006 (part)

Percent of property loss	Percent of property saved	Number of records	%
91–100%	0–10%	713	22.0%
81–90%	11–20%	22	0.7%
71–80%	21–30%	13	0.4%
61–70%	31–40%	30	0.9%
51–60%	41–50%	94	2.9%
41–50%	51–60%	43	1.3%
31–40%	61–70%	59	1.8%
21–30%	71–80%	105	3.2%
11–20%	81–90%	124	3.8%
0–10%	91–100%	687	21.2%
Not recorded	Not recorded	1,344	41.6%
	Total	**3,234**	**100.0%**

Table 17. Percentage of property saved 1986–2006 (part) compared with BERL Report

Extent of damage 2001–2006 (part) – excluding those "not recorded"			
% of structure loss	Number	% of total	cf BERL Table 5.5.1 (BERL 2002) Year 2000 data
91–100%	713	27.7	9%
51–90%	159	6.2	4%
11–50%	1018	39.5	13%
0–10%	687	26.7	74%
Total	2,577	100.0	100%

Over the five-year period from 2000 to 2004, there were three fire fatalities in manufacturing property (NZFS 2004) giving an average rate of 0.6 deaths per year.

BERL (2002) presented injury data associated with industrial fire incidents derived from NFIRS for the period 1996–2000. There were a total of 169 injury incidents (fatalities excluded) giving an average rate of 33.8 injuries per year. Of the injury incidents, 160 were considered non-life-threatening and nine life-threatening. There was a total of 6,160 structure fire incidents over the period. The rate per fire for non-life-threatening and life-threatening injury incidents are calculated as 0.026 and 0.0015 injuries per fire respectively. There were also 3 fatalities for the period 1996 – 2000 corresponding to 0.0001 deaths per fire.

8. NZBC REQUIREMENTS FOR INDUSTRIAL BUILDINGS

This section summarises the fire protection requirements given by the Acceptable Solution C/AS1 compliance document for the New Zealand Building Code (DBH 2005).

The relevant purpose groups for industrial buildings are typically WM, WH or WF. Descriptions of these purpose group classifications are given in Figure 13 extracted from the NZBC compliance document (DBH 2005). The fire load density and the potential fire growth rate are the main factors determining the classification. This study will assume only single storey buildings. It is common for the inclusion of mezzanine or intermediate floors to trigger a higher level of fire protection, but this has not been considered for the purposes of this study.

Fire protection requirements for single storey industrial buildings are summarised in Table 18 and Table 19.

Table 18 Fire safety precautions required for single storey WM and WH purpose groups

		Fire Safety Precautions				
Occupant load per firecell	F-Rating	Manual Fire Alarm (2f)	Automatic Fire Alarm (heat detectors) (3f)	Automatic Fire Alarm (smoke detectors) (4)	Emergency Lighting in Exitways (16)	Fire Hydrant System, if hose run >75 m* (18c)
Up to 50 people	F0					●
Up to 100 people	F0	●				●
Up to 500 people	F0		●		●	●
Up to 1000 people	F0			●	●	●

* A fire hydrant system is required if the hose run from fire service vehicle to any point in the building is greater than 75 m.

Table 19 Fire safety precautions required for single storey WF purpose groups

		Fire Safety Precautions				
Occupant load per firecell	F-Rating	Manual Fire Alarm (2f)	Automatic Fire Alarm (heat detectors) (3f)	Automatic Fire Alarm (smoke detectors) (4)	Emergency Lighting in Exitways (16)	Fire Hydrant System, if hose run >75 m* (18c)
Up to 50 people	F0					●
Up to 100 people	F0		●			●
Up to 500 people	F0		●		●	●
Up to 1000 people	F0			●	●	●

* A fire hydrant system is required if the hose run from fire service vehicle to any point in the building is greater than 75 m.

Table 2.1: Purpose Groups *(continued)*

Purpose group	Description of intended use of the building space	Some examples	Fire hazard category
WORKING, BUSINESS OR STORAGE ACTIVITIES			
WL	Spaces used for working, business or storage – low *fire load*.	Manufacturing, processing or storage of *non-combustible* materials, or materials having a slow heat release rate, cool stores, covered cattle yards, wineries, grading or storage or packing of horticultural products, wet meat processing.	1
		Banks, hairdressing shops, beauty parlours, personal or professional services, dental offices, laundry (self-service), medical offices, business or other offices, police stations (without detention quarters), radio stations, television studios (no audience), small tool and appliance rental and service, telephone exchanges, dry meat processing.	2
WM	Spaces used for working, business or storage – medium *fire load* and slow/medium/fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Manufacturing and processing of *combustible* materials not otherwise listed, including bulk storage up to 3 m high (excluding *foamed plastics*).	3
WH	Spaces used for working, business or storage – high *fire load* and slow/medium/fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Chemical manufacturing or processing plants, distilleries, feed mills, flour mills, lacquer factories, mattress factories, rubber processing plants, spray painting operations, plastics manufacturing, bulk storage of *combustible* materials over 3 m high (excluding *foamed plastics*).	4
WF	Spaces used for working, business or storage – medium/high *fire load* and ultra fast *fire* growth rates (e.g. >1 MW in 75 sec) **(Note 1)**.	Areas involving significant quantities of highly *combustible* and flammable or explosive materials which because of their inherent characteristics constitute a special *fire hazard*, including: bulk plants for flammable liquids or gases, bulk storage warehouses for flammable substances, bulk storage of *foamed plastics*.	4 (The critical factor in this *purpose group* is the rate of *fire* growth.)
INTERMITTENT ACTIVITIES			
IE	*Exitways* on *escape routes*.	*Protected path, safe path.*	1
IA	Spaces for intermittent occupation or providing intermittently used support functions – low *fire load*.	Car parking, garages, carports, enclosed corridors, unstaffed kitchens or laundries, lift shafts, locker rooms, linen rooms, open balconies, *stairways* (within the *open path*), toilets and amenities, and service rooms incorporating machinery or equipment not using solid-fuel, gas or petroleum products as an energy source **(Note 2)**.	1
ID	Spaces for intermittent occupation or providing intermittently used support functions – medium *fire load*.	Maintenance workshops and service rooms incorporating machinery or equipment using solid-fuel, gas or petroleum products as an energy source **(Note 2)**.	3

Notes:

1. Refer to NFPA 92B for more information on *fire* growth rates.
2. Service rooms are spaces designed to accommodate any of the following: boiler/plant equipment, furnaces, incinerators, refuse, caretaking/cleaning equipment, airconditioning, heating, plumbing or electrical equipment, pipes, lift/escalator machine rooms, or similar services.

Figure 13. Purpose group definition (extracted from C/AS1)

Fire ratings (S rating) only apply to the external wall construction when required by C/AS1 Part 5 to limit fire spread to neighbouring property. In these cases, there may be a limit on fire cell floor area if the building is unsprinklered. The maximum area depends on the fire hazard category (see C/AS1 paragraph 4.2.3).

Fire hazard category (from C/AS1Table 2.1)	Maximum fire cell floor area (m²)
1	5,000
2	2,500
3	1,500
4	Specific fire engineering design required

In addition, a floor area limit does not apply if 15% of the roof area is designed for effective roof venting.

Therefore, in the event that compartmentation is required by C/AS1, it would only be provided for the purpose of limiting fire spread to neighbouring property, and not to enhance life safety or owner's property protection (although there could be flow-on benefits in that regard).

For most single-storey industrial buildings, remote from a boundary, no fire ratings are needed; no automatic detection is needed (unless more than 50 people for WF or 100 people for WL and WM purpose groups), and unlimited firecell area is often permissible. In the event of a major fire in such a building, total loss of the building and its contents could be expected.

9. RISK COST BENEFIT MODEL

The purpose of the model is to provide a methodology for comparing the risk reductions associated with the introduction of additional compartmentation, fire detection or fire suppression in industrial buildings compared to the minimum fire protection measures required by the NZBC.

9.1 Model overview

The model described in this report is intended to estimate the total cost to the nation of fires in industrial buildings (used for warehousing, manufacturing or processing), providing a tool for the regulator to evaluate the costs and benefits of different fire protection strategies for industrial buildings that are currently incorporated or may be considered in the future for inclusion in the Building Code compliance documents. The model is based on a simple event tree structure, that includes the impact of automatic and manual suppression systems, automatic fire detection and compartmentation. The model is applied to a population of industrial buildings in general rather than any specific individual building.

The model is probabilistic in nature including uncertainty by use of Latin Hypercube simulation (similar to Monte Carlo) and has been developed using Excel and the Excel add-in @Risk 4.0.5 (Palisade Corporation 2000).

Figure 14 shows the structure of the model using a simple event tree. The event tree shows possible scenarios based on the presence of automatic fire detection with manual suppression, automatic fire sprinklers, and fire compartmentation in the building. Each system has a certain probability of success and if successful (or not) a certain consequence results. When a system is not present the probability of success is forced to zero in the event tree. The consequence is expressed in financial terms ($) and comprises a summation of the expected fire-related direct and indirect losses and the cost of installing and maintaining the various fire protection systems, if present over the life of those systems.

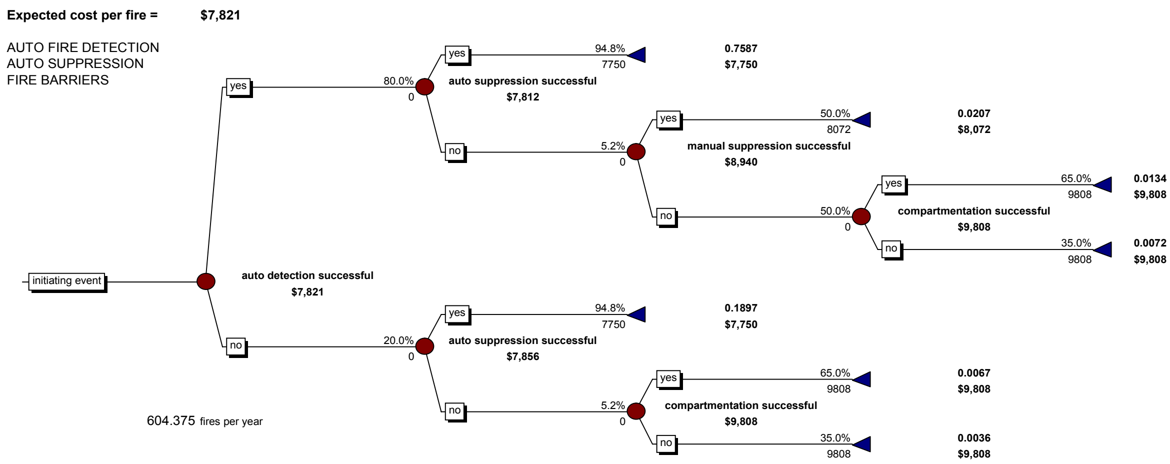


Figure 14. Event tree representation of the risk cost benefit model

The outcome or consequence of an individual fire event (including the impact of the fire protection systems if present) is assumed to result in a certain fire loss area. The derivation of the fire loss area for the various cases is described more fully in the next section.

The fire loss area is converted to a financial value with the expected loss calculated based on $/m² values derived from the analysis previously carried out by BERL (2002). The $ values (given later) have been adjusted to reflect current (2005) prices. These values include amounts for business interruption and other direct economic costs, the cost of providing the fire service response, indirect economic costs, reduced consumption and social costs (including deaths and injuries).

Determining the total financial consequence of each scenario involves summing the fire loss consequences with the installation and maintenance costs of the fire protection system. The latter was determined by adding the initial installation cost (converted to an annual payment using a real discount rate and a 50 year period) and the annual maintenance costs. The total cost of fire is expressed on a per building per year basis for comparison purposes.

The event tree allows the calculation of the expected cost of fire by multiplying the consequence of each scenario by the probability of the scenario and summing over all scenarios. The main output of the model is the expected cost of fire per building per year in the form of a distribution.

Key input parameters are expressed using probability distributions rather than single-point estimates, allowing the expected cost of fire per building per year to also be expressed as a probability distribution by virtue of running many thousands of simulations with the inputs determined from sampling the relevant distribution (Monte Carlo).

Monte Carlo simulation offers many advantages over single-value calculations including (Barry 2002):

- known distributions for input variables do not need to be approximated
- correlations and dependencies between input variables can be modelled
- the level of mathematics required is relatively simple
- the computer does all the work in determining the outcome distribution
- software is commercially available to determine the tasks involved in the simulation
- greater levels of precision can be achieved by simply increasing the number of iterations

- complex mathematics can be included with no extra difficulty
- Monte Carlo is widely recognised as a valid technique.

In this study, simulation is used and this allows for a better informed situation for any decision-making that may be based on the results of the analysis as it allows the uncertainty in the estimate to be quantified.

9.2 Model inputs and their distributions

9.2.1 Fire loss area for buildings without fire protection systems

This situation is considered to most closely represent the current situation in New Zealand for industrial buildings. The fire loss area (expressed in m² of floor area) is taken as the key measure of fire loss in the model since it has been estimated that only 7% (approximately) of industrial buildings are currently protected with an automatic sprinkler system (O'Brien 2006).

BERL (2002) analysed the composition of property damage for industrial buildings in New Zealand for the year 2000 using information contained in the FIRS database and, based on 1,100 industrial structure fires where the total area lost was 35,056 m², it was determined that the average fire loss area per fire was 32 m². Table 20 also shows the distribution of the fire loss area where in most fires (74%) the average fire loss area is quite small (7 m²).

Table 20. Composition of property damage in 2000 adapted from BERL (2002)

Extent of damage (% of structure lost)	Total incidents	% of all fire incidents	Total area lost (m²)	Area lost per fire (m²)
91 to 100%	101	9	16,181	160
51 to 90%	42	4	6,970	165
11 to 50%	140	13	6,552	47
0 to 10%	817	74	5,352	7
Total	**1,100**	**100%**	**35,056**	**32**

This data was used to propose a suitable probability distribution for the expected fire loss area for buildings without fire protection systems. A gamma distribution is used, as shown in Figure 15. The distribution is such that the fire loss area is greater than 228 m² for 5% of the fires (95th percentile); however it is also truncated at the upper end so that the fire loss area cannot be greater than the actual building floor area for any simulation (a physical impossibility). The black squares plotted on Figure 15 represent data points from Table 20.

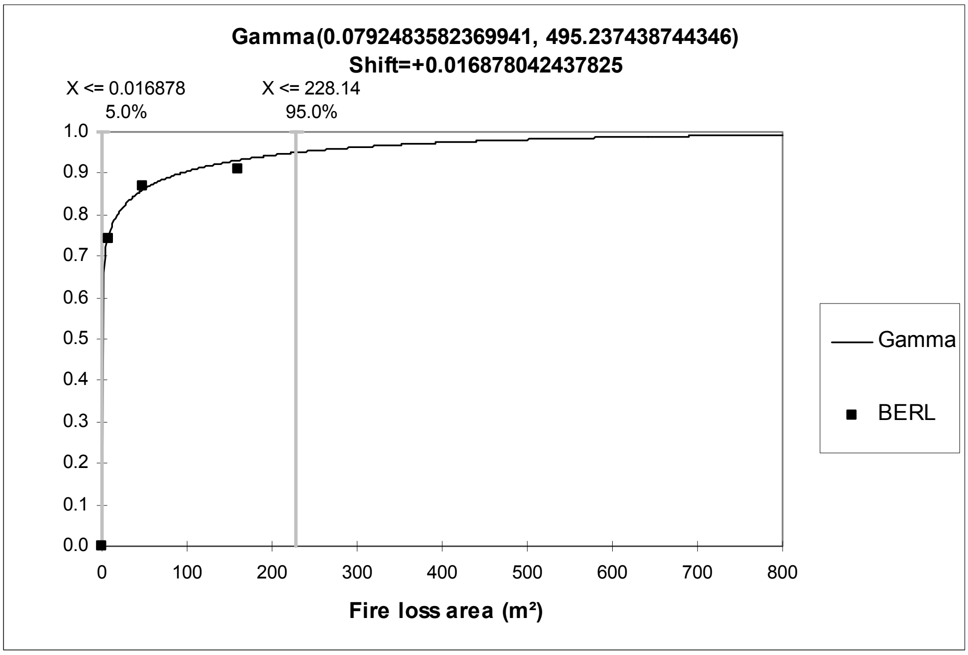


Figure 15. Cumulative distribution function of the fire loss area for an unprotected building

9.2.2 Fire loss area for buildings with automatic fire sprinkler systems

Where buildings include automatic fire sprinkler systems, and where these are assumed effective, then the fire loss area was assumed to be randomly sampled in the range 1 to 20 m². The upper end of this range was chosen to correspond with the typical maximum area of coverage of a fire sprinkler head. The development of the fire is also a stochastic process and for this study it was considered appropriate to use a uniform distribution where the probability of occurrence is uniform over the nominated range of values. The assumed probability distribution is plotted in Figure 16.

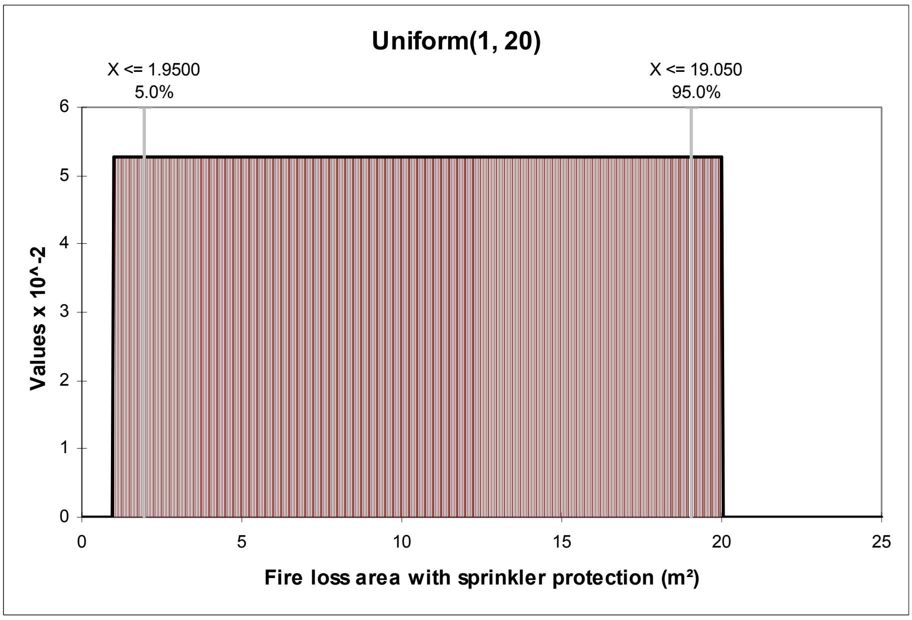


Figure 16. Probability density function for the fire loss area with sprinklers

9.2.3 Fire loss area for buildings with fire detection and manual suppression

Where buildings include fire detection and manual suppression systems then a similar uniform distribution as for the sprinklered building was selected except that a range of 0 to 30 m² was used. This reflected the fact that manual suppression could occur both earlier and later than for automatic sprinklers since human intervention may occur before conditions are reached for sprinkler operation and since the fire may be considerably larger than a sprinkler controlled fire by the time fire service personnel arrive at the building. In this model, automatic detection (and fire service notification) is assumed to be a necessary requisite for manual suppression activities. Detection alone does not result in any change to the expected fire loss area and this is reflected in the event tree (Figure 14).

The modelling of the development of the fire again used a uniform distribution where the probability of occurrence is assumed uniform over the nominated range of values, as shown in Figure 17.

9.2.4 Fire loss area for buildings with fire compartmentation

The model allows a maximum fire cell area for compartmentation purposes to be specified.

The probability distribution for the area of fire loss in a compartmented building is assumed to be the same as for the unprotected case (Figure 15), except that the maximum permitted fire loss area is constrained to not exceed the nominated maximum fire cell area for each iteration.

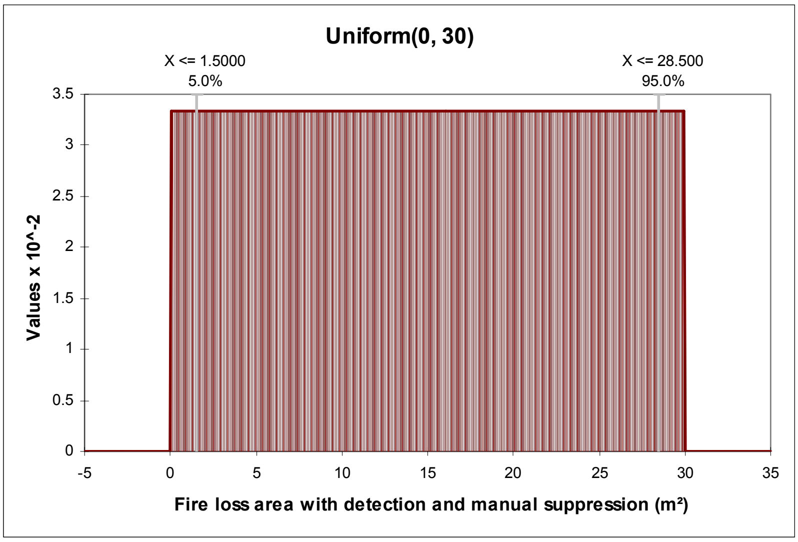


Figure 17. Probability density function for the fire loss area with detection and manual suppression

9.2.5 Fire incident rate

Figure 18 shows the number of expected fires (of the type included in this study) per year used in the model represented as a normal distribution with a mean of 604.4 and standard deviation of 91.5, based on New Zealand Fire Service incident statistics over the period 1998 to 2005.

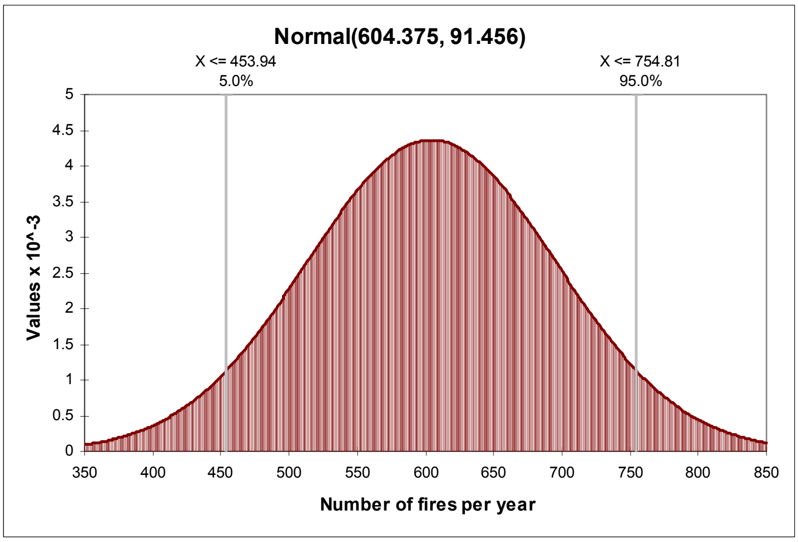


Figure 18. Probability distribution for the number of expected fires per year

A fire incident rate was calculated based on an estimated 27,130,000 m² of floor area throughout the country. This equates to a mean fire incident rate of 2.23 x 10^{-5} fires per year per square metre of floor area.

9.2.6 Fire protection system probability of success

The probability of the fire protection systems being effective (or not) are represented by pert distributions (Palisade, 2000) since detailed data is difficult to source. Pert distributions are a special form of the beta distribution and are defined with a minimum, most likely and maximum value for the parameter. The values have been selected based on reviewing the literature and the author's judgement.

The probability of a fire sprinkler system success is described by a pert distribution (shown in Figure 19) with minimum, most likely and maximum values of 0.9, 0.95 and 0.99. This distribution is considered reasonable for New Zealand industrial buildings where the fire challenge for sprinklers is 'higher than average'.

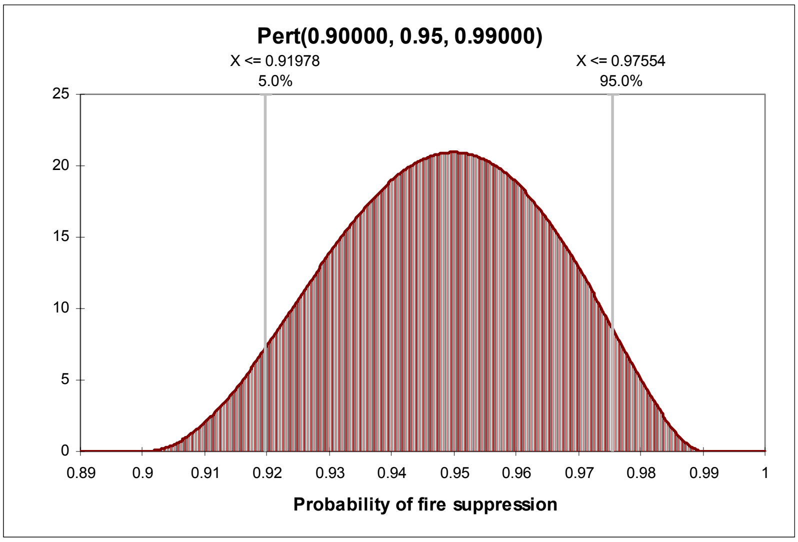


Figure 19. Probability density function for fire sprinkler success

The probability of fire compartmentation success is described with a pert distribution (shown in Figure 20) with minimum, most likely and maximum values of 0.4, 0.65 and 0.9 respectively. Houlding and Rew (2003) used values in the range 0.4 to 0.7 for the probability of success of plasterboard walls and 0.7 to 0.95 for masonry/concrete walls in their study of chemical warehouses for a range of fire types.

The probability of an automatic fire detection success is described by a pert distribution with minimum, most likely and maximum values of 0.7, 0.8 and 0.9 respectively as shown in Figure 21. These values are in the range used by Houlding and Rew (2003) for chemical warehouse buildings in the UK.

The probability of manual suppression success given that detection has taken place and fire service has been notified is described with a pert distribution (see Figure 22) with minimum, most likely and maximum values of 0.3, 0.5 and 0.7 respectively.

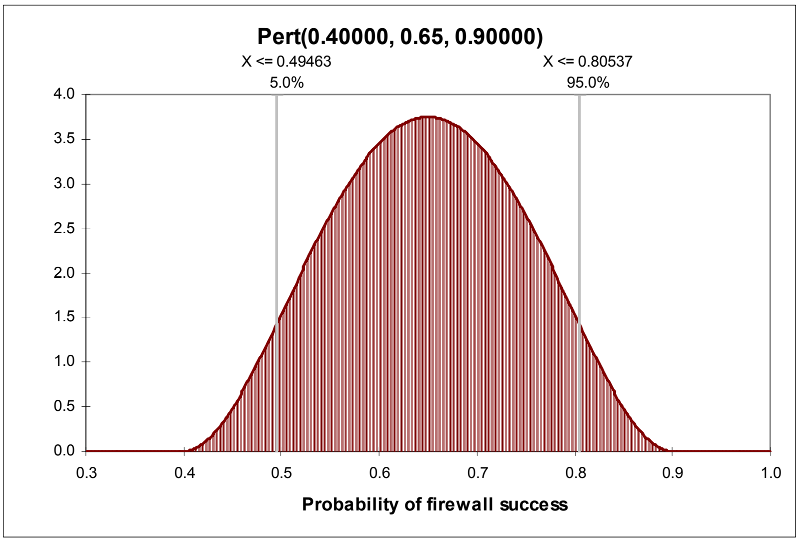


Figure 20. Probability density function for firewall success

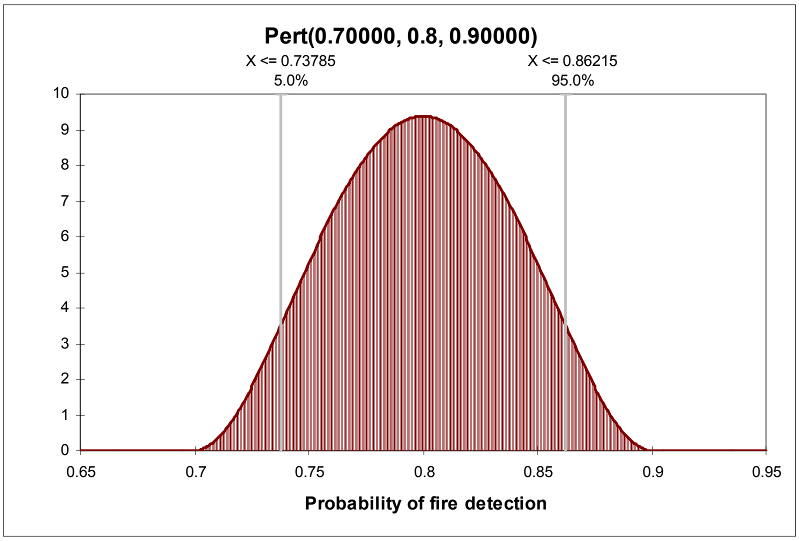


Figure 21. Probability density function for fire detection success

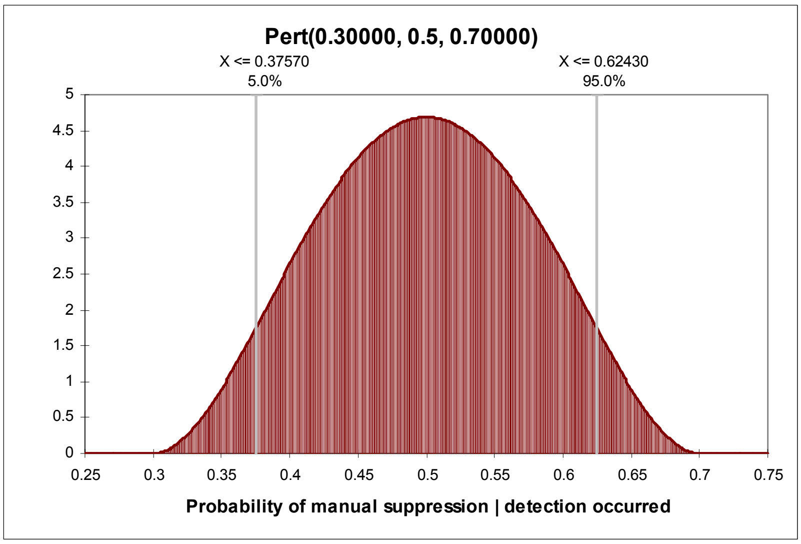


Figure 22. Probability density function for manual suppression success given detection

9.2.7 New Zealand industrial building stock characteristics

The total floor area of industrial buildings (of the sub-group covered by this study) was estimated to be 27,130,000 m², based on analysis of data obtained from Quotable Value New Zealand. The data included the building categories of heavy manufacturing (usually large), light manufacturing, noxious, warehouses (with/without retail) and other industrial. Buildings for service industries were excluded. The total number of buildings of this type was 27,273. The average floor area per building is taken as 995 m².

Figure 23 shows a graph of the cumulative density distribution for the building floor area. The QV data points (black squares) and a LogLogistic density function to best fit the QV data is also shown on the same figure. For the simulations, the probability distribution was truncated at the extreme ends such that only buildings with a floor area in the range 50 to 200,000 m² were simulated. The data also shows that 95% of all buildings of this type in New Zealand have a floor area less than 3895 m².

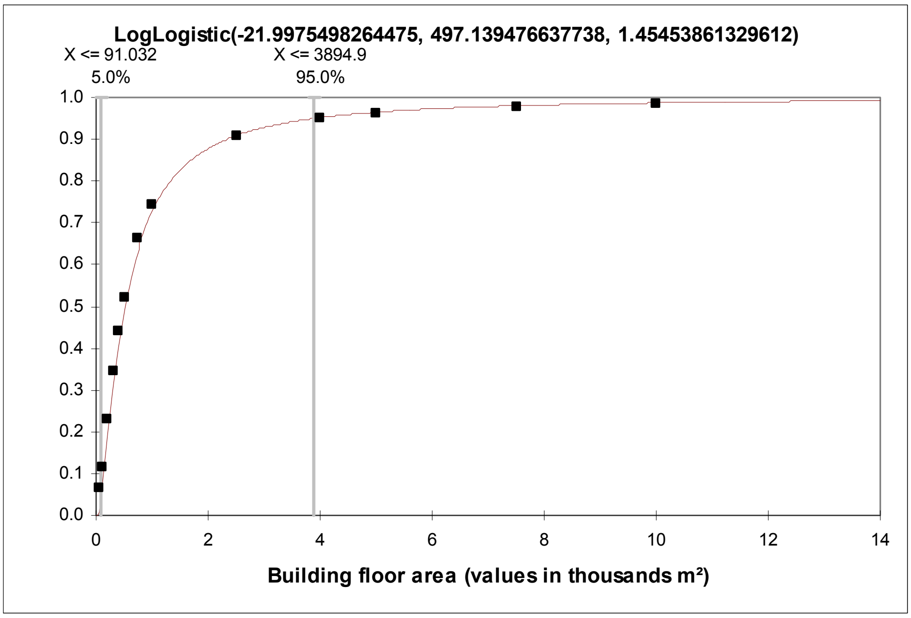


Figure 23. Cumulative density distribution for the building floor area

Figure 24 shows a graph of the corresponding probability density function.

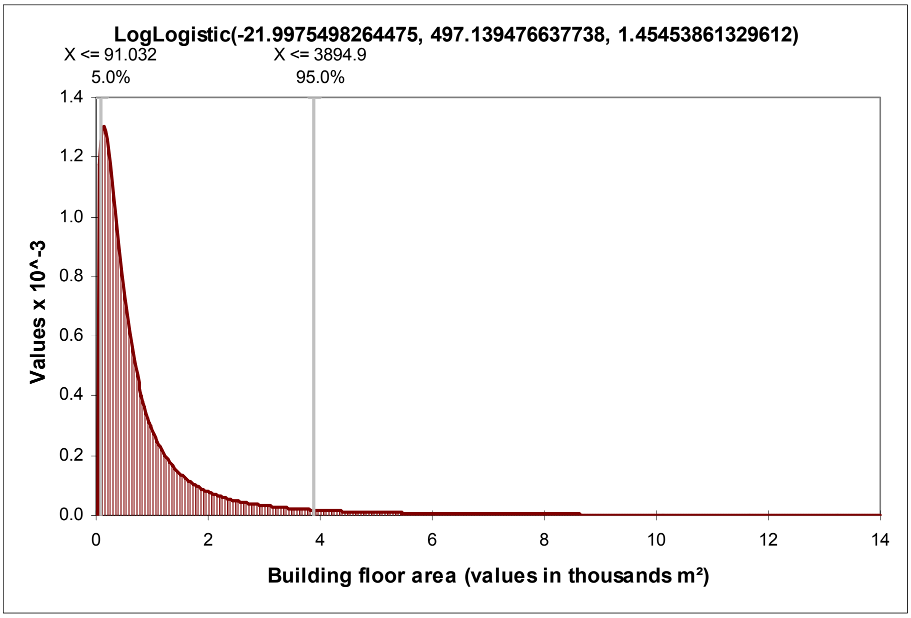


Figure 24. Probability density function for building floor area

The building height was assumed to be represented by a pert distribution with minimum, most likely and maximum values of 4, 7 and 15 m respectively as shown in Figure 25. This was estimated by the author and not based on actual data.

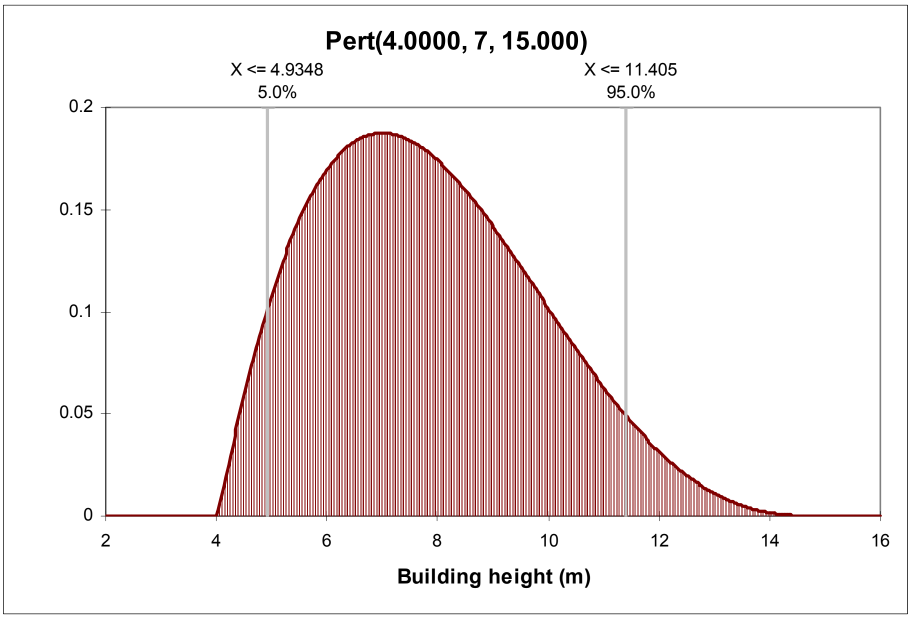


Figure 25. Probability density function for building height

The building plan aspect ratio (width:length) was assumed to be represented by a pert distribution with minimum, most likely and maximum values of 1, 3 and 6 respectively as shown in Figure 26. Industrial buildings are often long and narrow – the range selected was estimated by the author and not based on actual data. The building height and aspect ratio probability distributions both affect the calculation of the required firewall surface area for costing purposes for the case where the fire protection includes compartmentation.

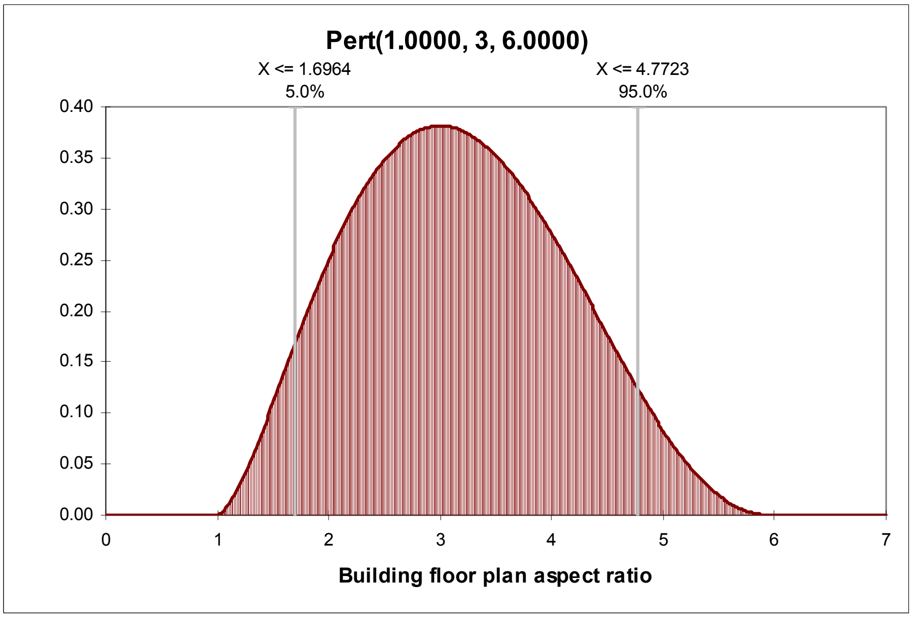


Figure 26. Probability density function for building plan aspect ratio

9.2.8 Fire detection system installation and maintenance costs

Typical costs of fire detection installations in industrial buildings were obtained from a major installer (Clark 2006). After reviewing that information it was decided to describe the detection system cost using both fixed and variable components as follows.

The probability distribution for the detection installation fixed cost is described with a pert distribution with minimum, most likely and maximum values of \$3,500, \$5,000 and \$6,500 respectively as shown in Figure 27. The fixed cost is mostly associated with providing an alarm panel in the building.

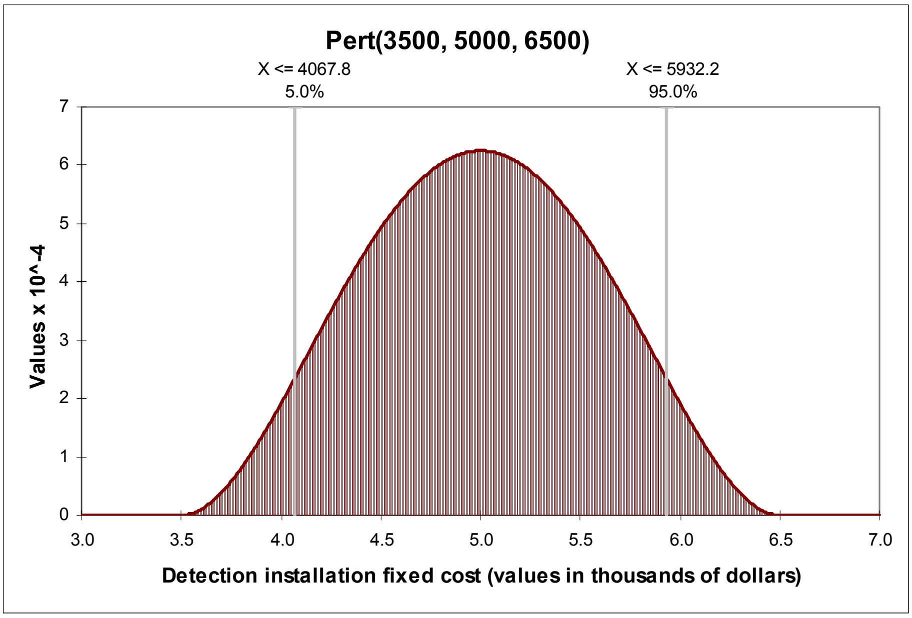


Figure 27. Probability density function for detection installation fixed cost

The probability distribution for the detection installation variable cost is described with a pert distribution with minimum, most likely and maximum values of $7, $9 and $11 respectively per m² of floor area as shown in Figure 28. The variable cost is mostly associated with providing the detectors, sounders and callpoints.

Annual maintenance was assumed to be 5% of the total installation cost each year.

The cost of providing a fire service connection was assumed to be $1,000 per year (Clark 2006).

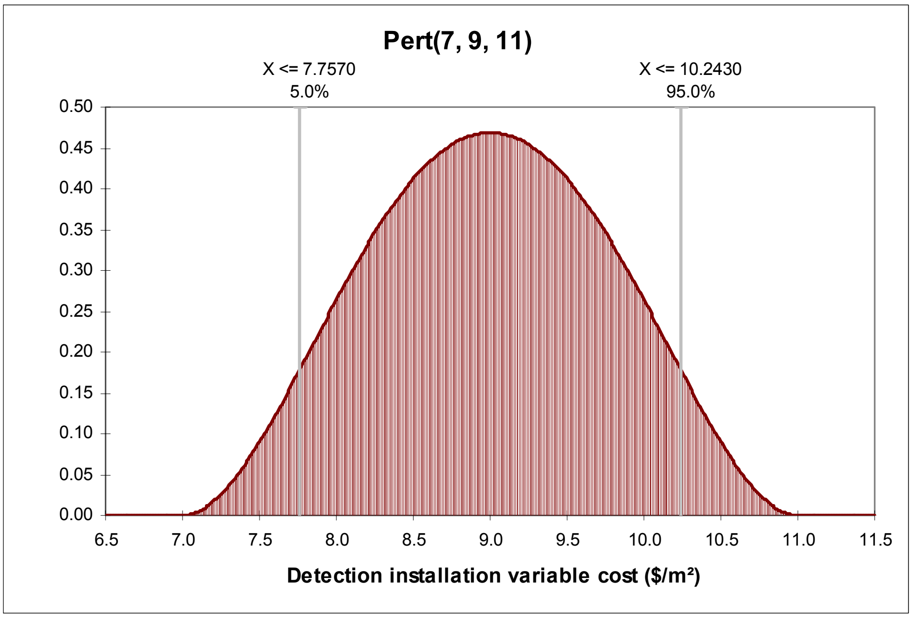


Figure 28. Probability density function for detection installation variable cost

9.2.9 Fire sprinkler system installation and maintenance costs

The cost of installing a fire sprinkler system was represented using a pert distribution with minimum, most likely and maximum values of \$25, \$45 and \$65 per m^2 of floor area respectively as shown in Figure 29. These values were selected after reviewing the estimates in the 2004 Rawlinsons New Zealand Construction Handbook for fire sprinkler systems and after seeking costing information from a major sprinkler contractor (Thompson 2006). Annual maintenance was assumed to be 1.5% of the total installation cost each year.

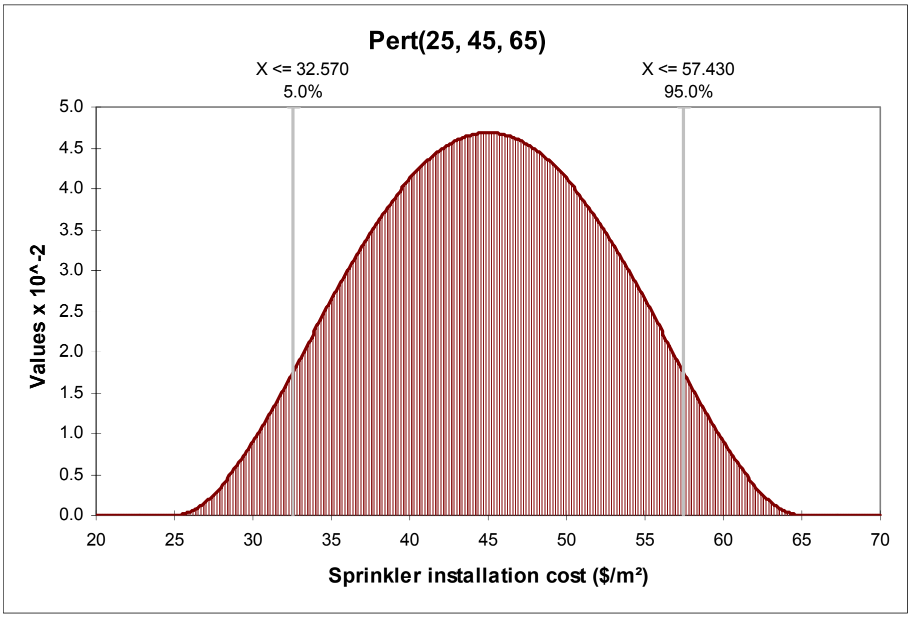


Figure 29. Probability density function for sprinkler installation cost

9.2.10 Cost of firecell compartmentation

The cost of installing fire separations in a building was represented using a pert distribution with minimum, most likely and maximum values of \$80, \$100 and \$125 per m^2 of firewall area respectively as shown in Figure 30. These values spanned the range given in the *2004 Rawlinsons* New Zealand *Construction Handbook* for fire rated inter-tenancy walls.

For each iteration of the model, the number of fire compartments in any particular building simulation is determined by the building floor area and the maximum firecell size such that:

Number of compartments = building floor area / maximum firecell area
(rounded up to the nearest whole number)

The total area of the firewall required is then determined as:

Firewall area = (number of compartments – 1) x building height x SQRT(floor area/aspect ratio).

The firewall installation cost is then given by multiplying the firewall area by the cost per unit area. Firewall maintenance costs have been ignored in this analysis, but could be included.

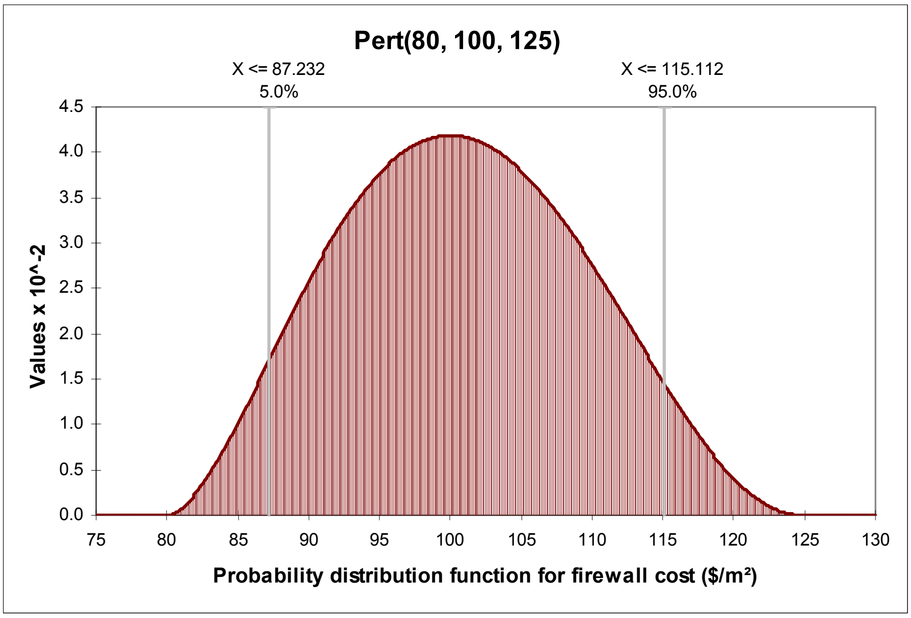


Figure 30. Probability density function for firewall installation cost

9.2.11 Cost-benefit parameters

The analysis period is taken as 50 years.

Real discount rate of 5%.

Life of a fire sprinkler system is 50 years.

Life of a fire detection system is 50 years.

Life of a fire separation is 50 years.

All the above parameters were assumed to be fixed (single-point) values in the model. They could also be treated as distributions in the model if desired.

Once the total fire protection initial installation cost (P) was calculated for each iteration in the simulation, this was converted to a regular annual payment (A) using a capital recovery formula based on the real discount rate (i=5%) and the analysis period (N=50 years) where:

$$A = \frac{P[i(1+i)^N]}{[(1+i)^N - 1]}$$

The annual maintenance cost of the system was then added to give the total cost of the fire protection system per year.

9.2.12 Cost of industrial fires

The cost of industrial fires is taken from the BERL (2002) analysis, with year 2000 dollars adjusted to 2005 dollars, using an increase of 12.5% (Page 2006).

The BERL (2002) analysis for the year 2000 was based on 1,100 industrial structure fires with an average of 32 m² of fire loss per fire. They determined that the cost to the country was a total of $86 million made up as follows:

	Total cost Y2000 $	Estimated total cost per fire in Y2005 $ (x1.125/1100)
Business interruption	$8.0 m	$8,182
Other direct economic	$36.0 m	$36,818
Fire service	$23.0 m	$23,523
Indirect economic	$8.5 m	$10,738
Reduced consumption	$2.1 m	$2,148
Social costs	$8.5 m	$8,693
Total	$86.1 m	$90,102

The cost per m² of fire loss can therefore be estimated at $2,816 per m² of fire loss based on the average of 32 m² of fire loss per fire.

The uncertainty or likely distribution of the cost per unit area of fire loss is unknown, but it is thought that it was still important to include at least some assessment of the uncertainty. It was decided to represent all these cost parameters as normal distributions with the mean value taken from the estimated above (on a per unit fire loss area basis). A standard deviation equal to 10% of the mean was arbitrarily used.

Business interruption – BERL determined this on the basis of insurance claims. A normal probability distribution with a mean of $256 per m² of fire loss area was used in the model as shown in Figure 31.

Other direct economic – this included actual property lost in fire and included both building and contents. It was also determined on the basis of insurance claims. A normal probability distribution with a mean of $1,151 per m² of fire loss area was used in the model as shown in Figure 32.

Fire service – this amount was based on the net operational expenditure on fire fighting and other fire service operations as recorded in the New Zealand Fire Service Commission's *Annual Report* in 2000, and apportioned against the relative resource required for industrial fires including false alarms and good intent calls. According to BERL, industrial fires use about 50% more resource than all fires used on average. Further details can be found in the BERL (2002) report. A normal probability distribution with a mean of $735 per m² of fire loss area was used in the model as shown in Figure 33.

Indirect economic – includes losses to upstream firms supplying goods and services to the fire-affected business. A normal probability distribution with a mean of $336 per m² of fire loss area was used in the model as shown in Figure 34.

Reduced consumption – this represents the decline in consumption as a result of employees and business owners spending less, following a decline in sales by the fire-affected business. A normal probability distribution with a mean of $67 per m² of fire loss area was used in the model as shown in Figure 35.

Social costs – costs associated with fire deaths and injuries. The value of a statistical life (VOSL) used was $2,469,900. The average loss of life quality due to serious and minor injuries was estimated to be 10% and 0.4% of the VOSL respectively (following LTSA (2000) methodology). Costs are based on year 2000 death and injury rates. A normal probability distribution with a mean of $272 per m² of fire loss area was used in the model as shown in Figure 36.

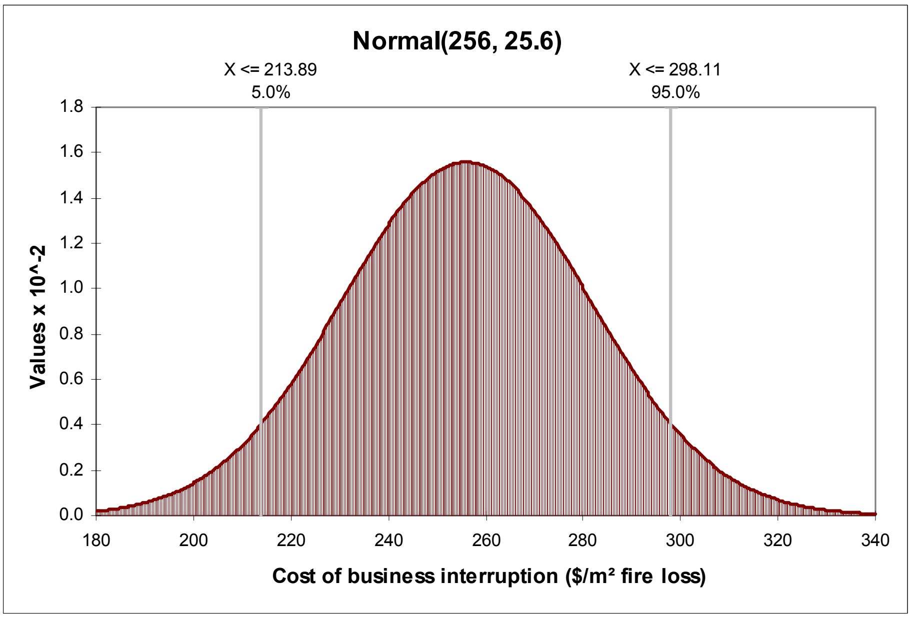


Figure 31. Probability density function for the cost of business interruption

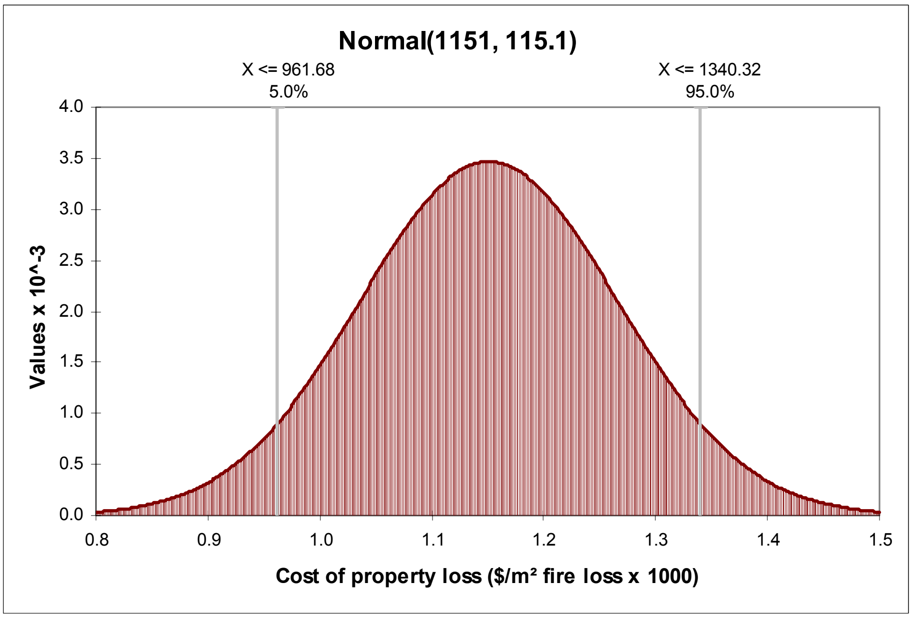


Figure 32. Probability density function for the cost of direct property losses

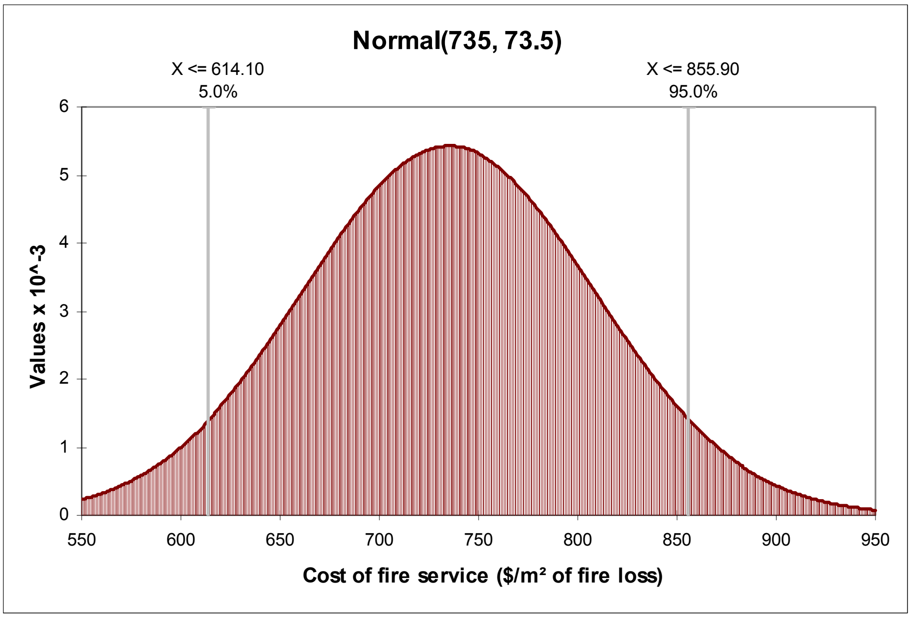


Figure 33. Probability density function for the cost of the fire service

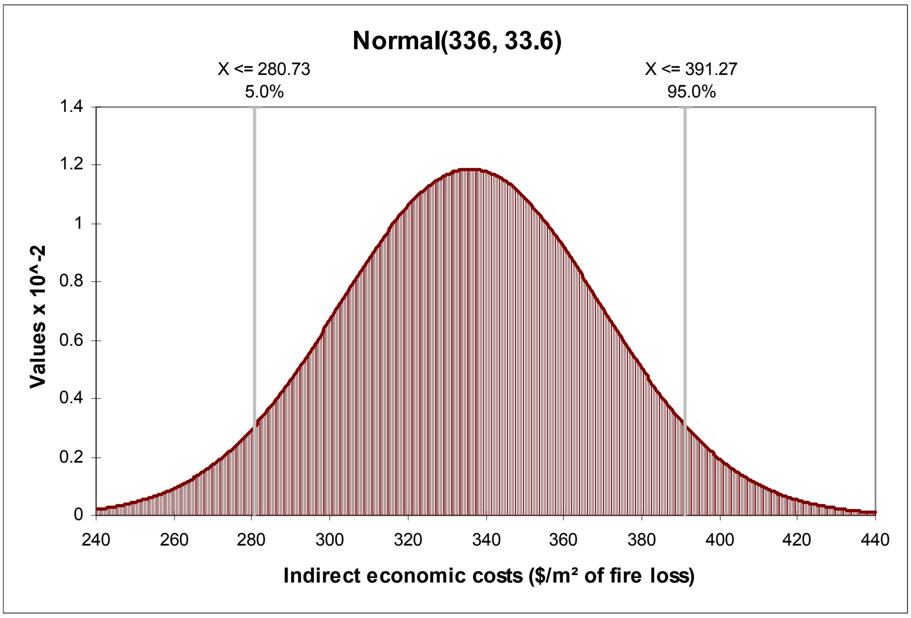


Figure 34. Probability density function for indirect economic costs

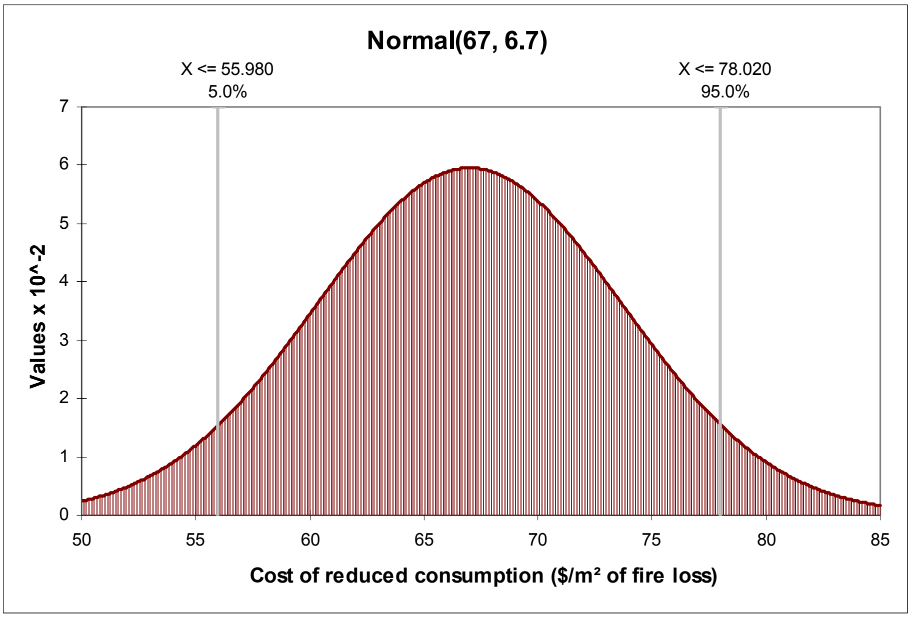


Figure 35. Probability density function for cost of reduced consumption

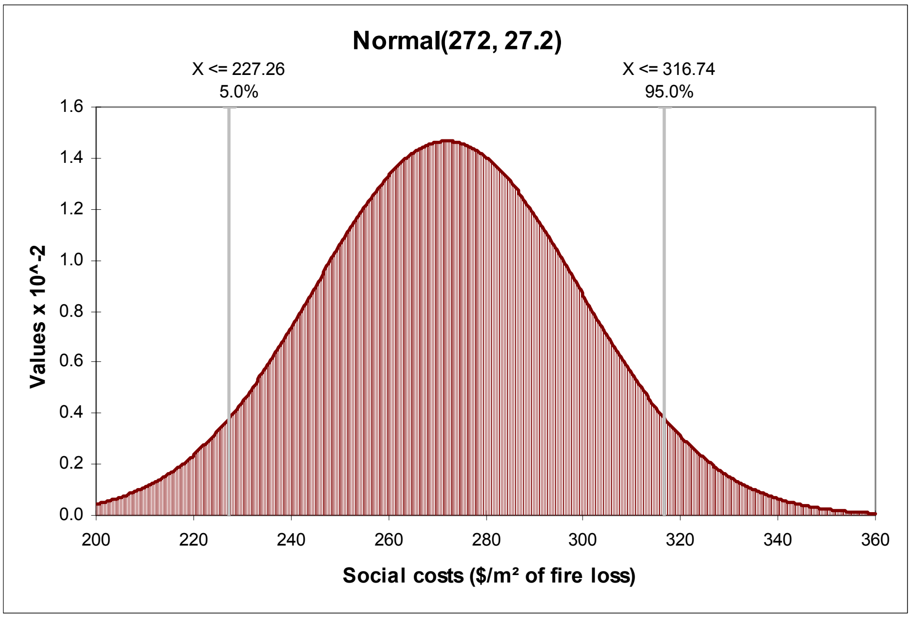


Figure 36. Probability density function for social cost

9.3 Dependencies between input variables

The @Risk software allows dependencies between input variables to be modelled. This results in more realistic sampling of input values during the simulation. The degree of correlation can fall anywhere in the range 0 to 1, with 0 corresponding to no correlation and 1 being a perfect correlation. A positive value means that an increase in the input variable results in an increase in the magnitude of the output, and a negative value means an increase in the input variable results in a decrease in the output. The actual values used for the degree of correlation are subjective as estimated by the author.

The following relationships have been assumed in the model.

1. The firewall cost ($/m²) is positively correlated with the building height. It is expected that higher walls will require larger structural members and the cost per unit area will be correspondingly greater.
2. The sprinkler installation cost ($/m²) is negatively correlated with the floor area. It is expected that economies of scale will apply in larger buildings.
3. The sprinkler installation cost ($/m²) is positively correlated with building height. It is expected that as the floor-to-ceiling height increases, that design fires will be more challenging for the fire sprinklers and the design specification will be more costly.
4. The detection system fixed cost is positively correlated with the building floor area. It is expected that the specification/complexity of the alarm panel will increase with the size of the building.
5. The detection system variable cost is negatively correlated with the building floor area due to economies of scale.

The assumed degree of correlation between inputs is described in the correlation matrix in Table 21.

Table 21. Correlation between input variables

Correlations 6x6	**Building height**	**Firewall install cost**	**Floor area**	**Sprinkler install cost**	**Detection install fixed cost**	**Detection install variable cost**
Building height	1.00					
Firewall install cost	0.55	1.00				
Floor area	0.00	0.00	1.00			
Sprinkler install cost	0.62	0.00	-0.48	1.00		
Detection install fixed cost	0.00	0.00	0.54	0.00	1.00	
Detection install variable cost	0.00	0.00	-0.45	0.00	0.00	1.00

9.4 Results

Twenty-five thousand iterations were calculated for each scenario, resulting in convergence of less than a 1% change in the calculated mean and standard deviation. Each iteration sampled the input distribution for each input variable and calculated the "cost of fire per building (pa)" as the output parameter.

The following scenarios were investigated:

1. no fire protection (the status quo)
2. fire sprinklers only
3. automatic detection and manual suppression
4. compartmentation using 1000 m² fire cells
5. compartmentation using 2000 m² fire cells
6. fire sprinklers, automatic detection and manual suppression.

The resultant output distributions are presented as histograms and are shown in Figure 37 to Figure 42.

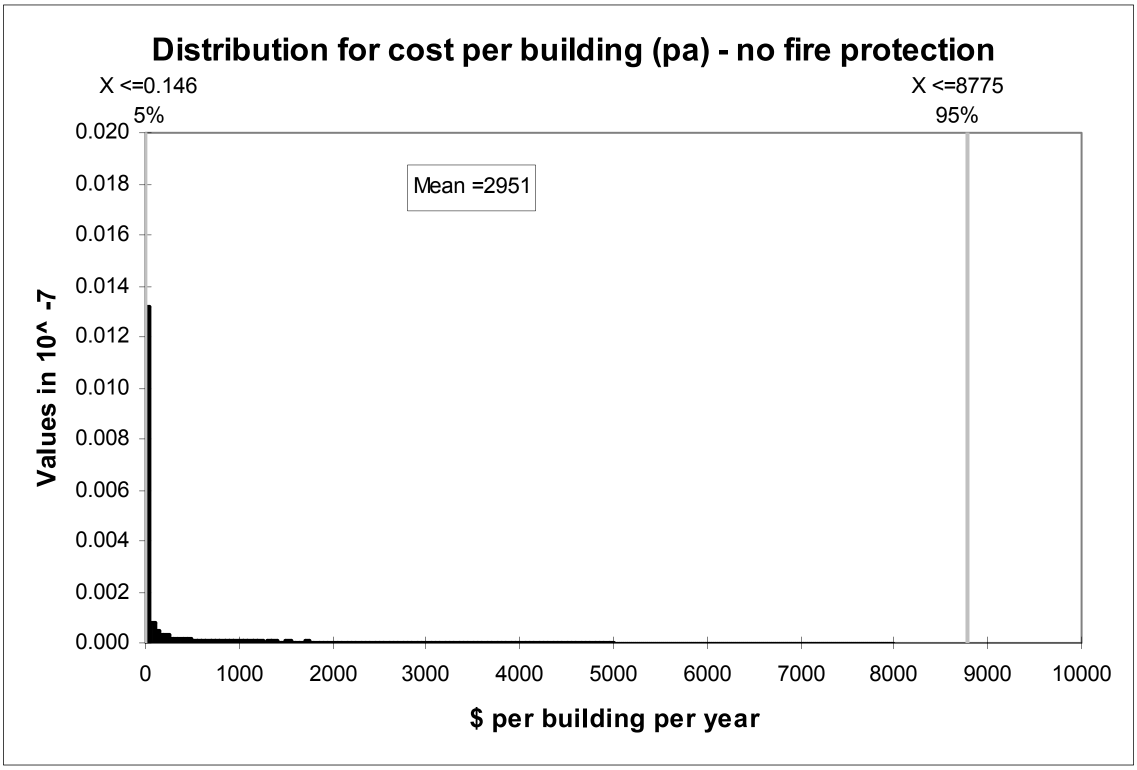


Figure 37. Model output distribution for cost of fire per building per year– unprotected building

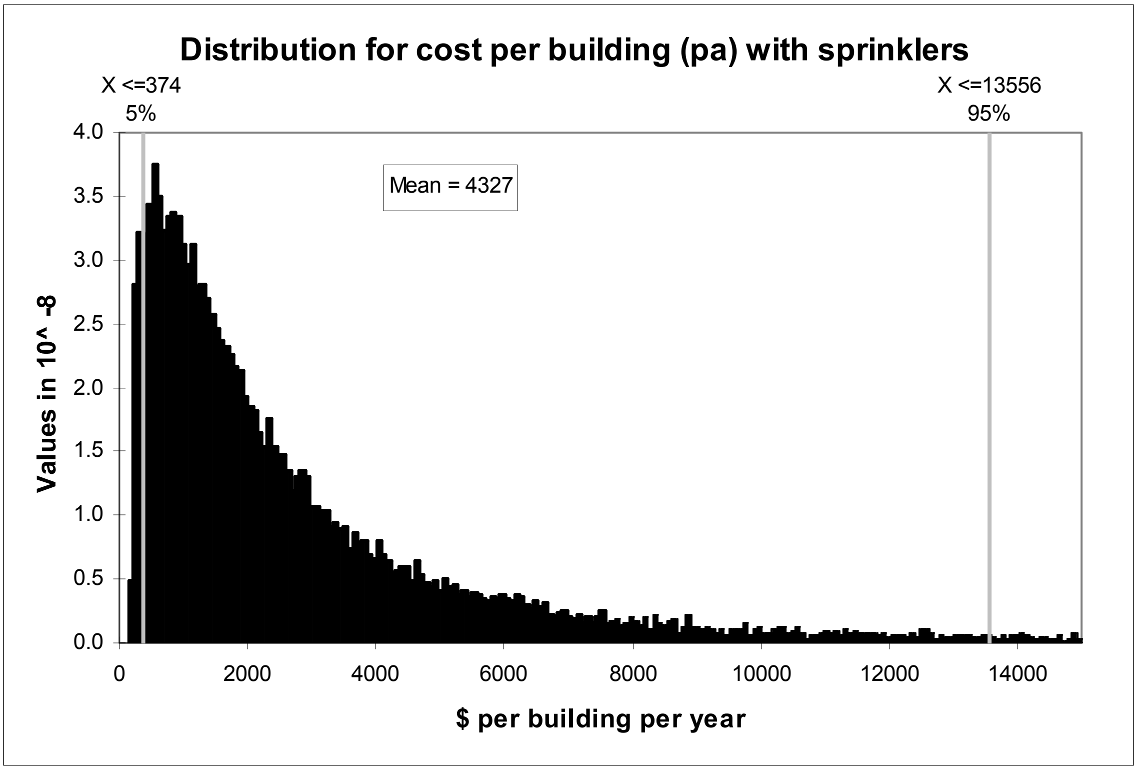


Figure 38. Model output distribution for cost of fire per building per year – sprinklered building

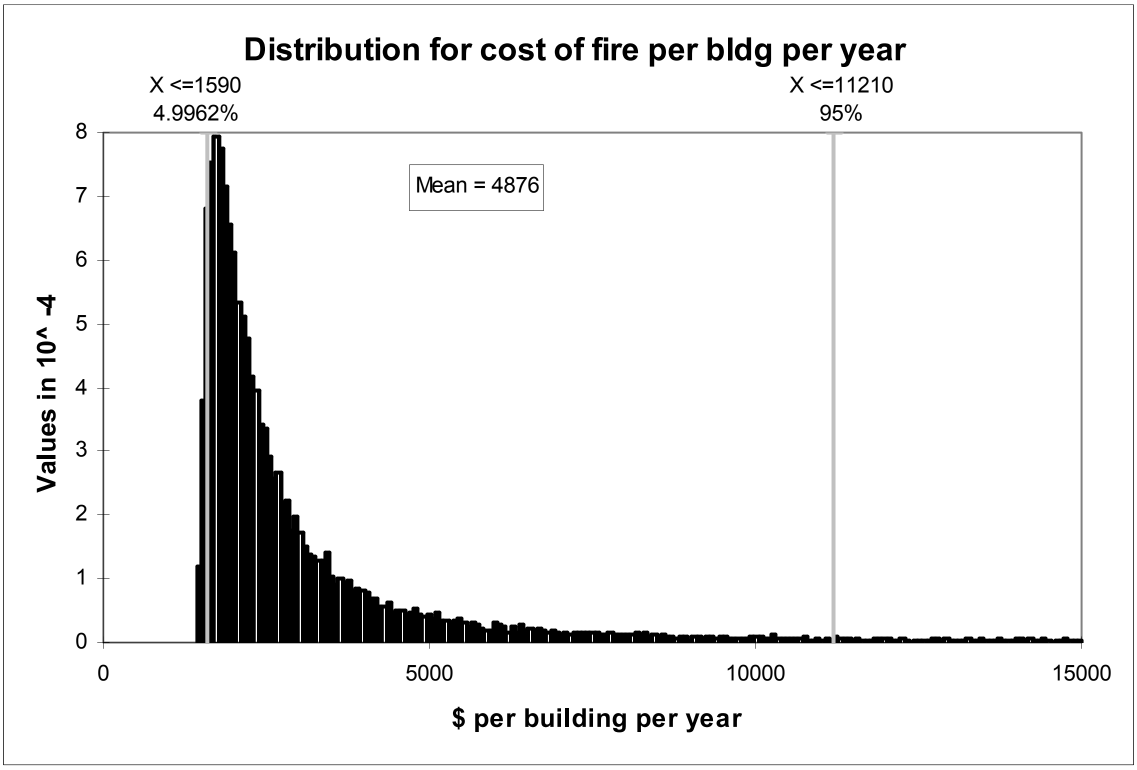


Figure 39. Model output distribution for cost of fire per building per year – with detection

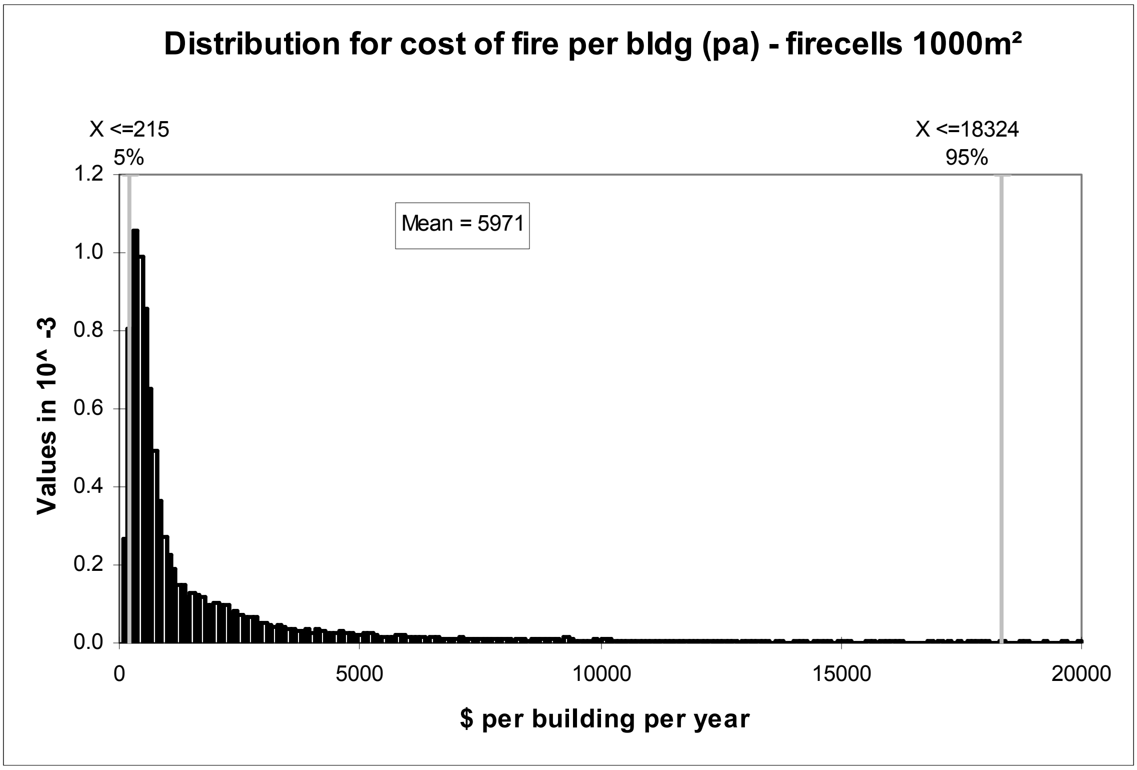


Figure 40. Model output distribution for cost of fire per building per year – with fire cells max 1000 m²

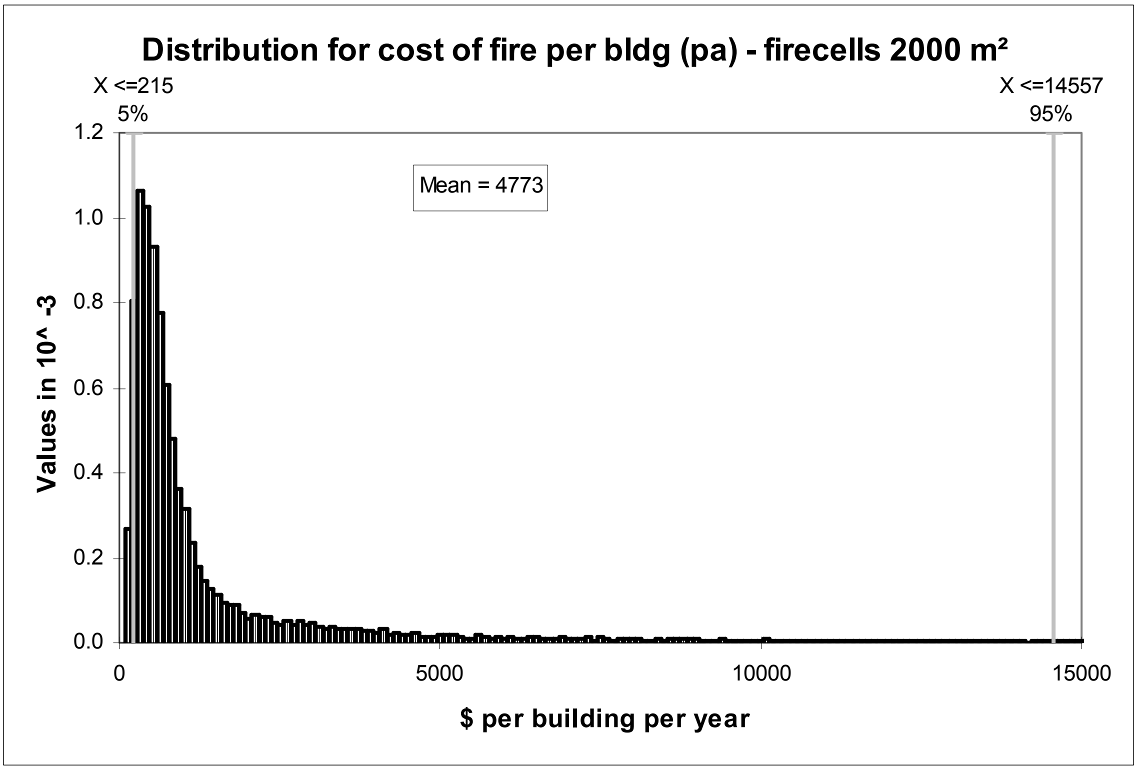


Figure 41. Model output distribution for cost of fire per building per year – with fire cells max 2000 m²

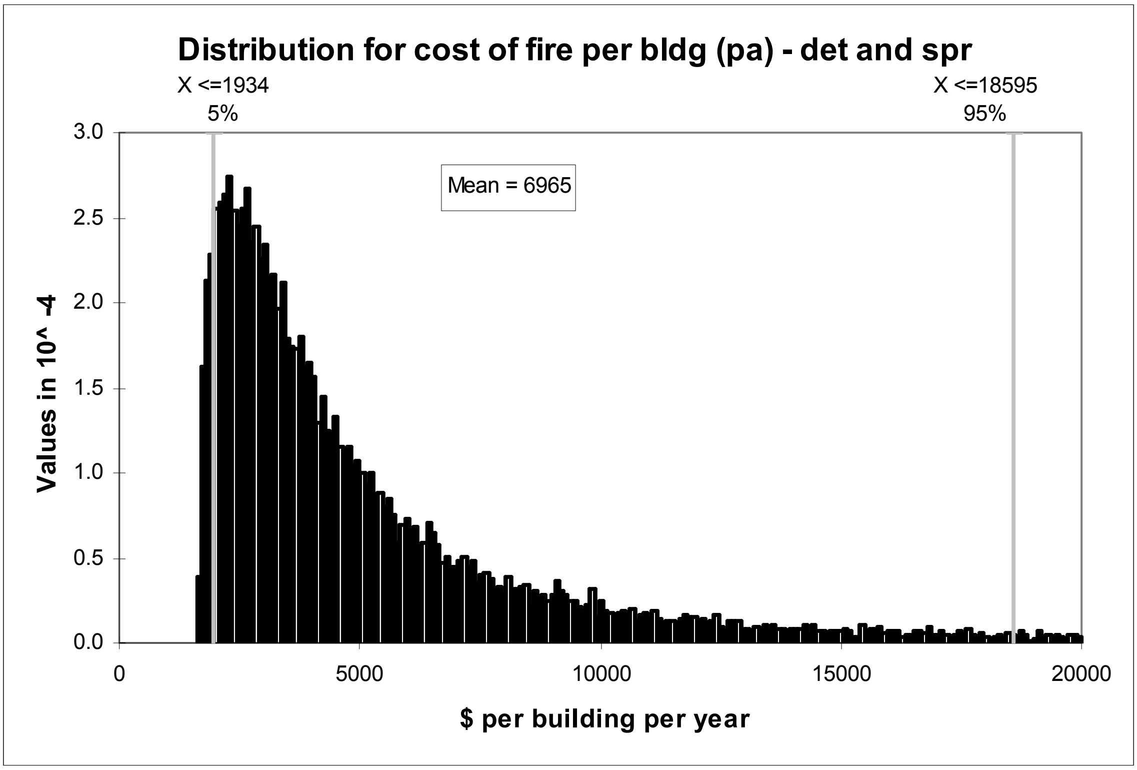


Figure 42. Model output distribution for cost of fire per building per year – with sprinklers and detection

Table 22 summarises the results in terms of the calculated total cost of fire per building (pa) assuming different fire protection options are selected.

Based on a comparison of the expected mean values, the "no protection" option gives the lowest mean cost of fire per building (pa) followed by sprinklers then firecells of 2000 m².

Using the upper 95th percentile value as the decision criterion, the "no protection" option still gives the lowest cost of fire per building (pa) followed by detection (with manual suppression) and then sprinklers. We interpret this to mean that in 95% of cases we expect the cost of fire per year to be less than $8,775 for the no protection option and less than $11,210 for the detection with manual suppression option.

Table 22. Cost of fire per building as calculated by model simulations

Scenario	**Total cost of fire per year per building per year ($)**		
	Mean & rank	median	upper 95th percentile & rank
No fire protection	$2,951 (1)	$4	$8,775 (1)
With sprinklers	$4,327 (2)	$1,925	$13,556 (3)
With detection/man suppression	$4,876 (4)	$2,300	$11,210 (2)
With fire cell area 1000 m²	$5,971 (5)	$757	$18,324 (5)
With fire cell area 2000 m²	$4,773 (3)	$701	$14,557 (4)
With sprinklers and detection/man suppression	$6,965 (6)	$3,949	$18,595 (6)

Figure 43 presents the results in the form of an ascending cumulative frequency plot for the different fire protection options.

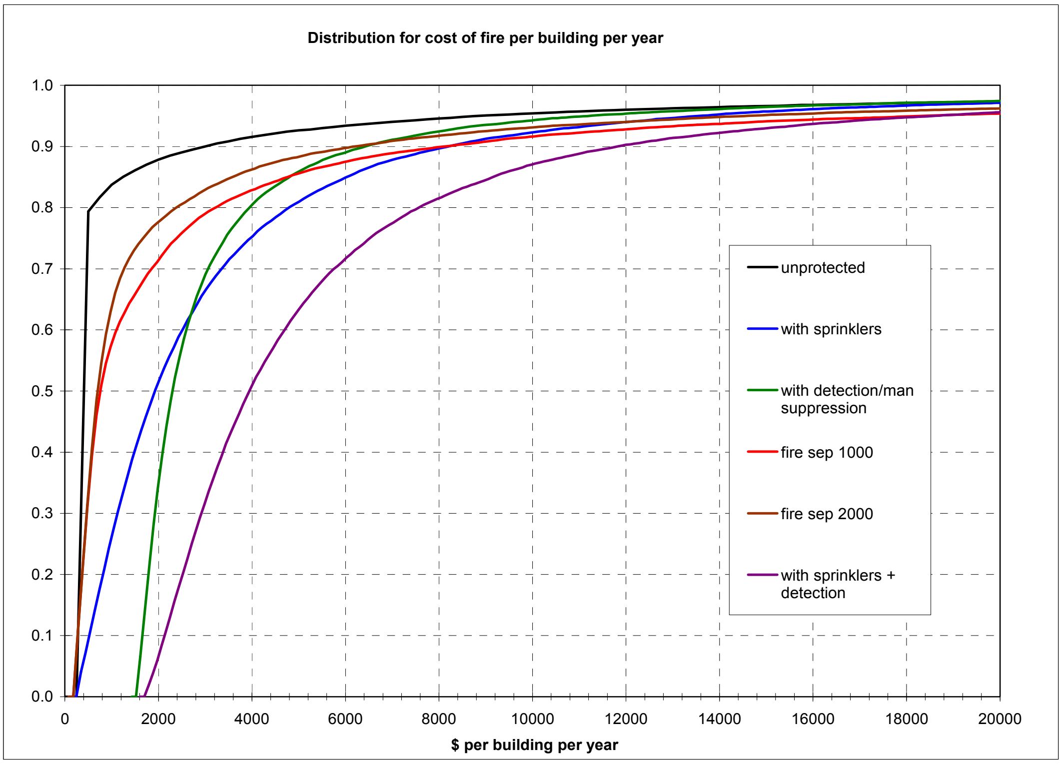


Figure 43. Comparison of ascending cumulative frequency for the cost of fire per building (pa) of different fire protection options

9.5 Comparing the model results to historical data

As a reality check, the model results can be compared to the estimated cost of industrial fires in the year 2000 as calculated by BERL (2002), and proportionally adjusted for the sub-group of industrial buildings included in this study and adjusted for inflation. On this basis, the total cost of industrial fires is $52.8 million pa. Using an estimated 27,273 buildings for this group, this equates to an average $1936 per building per year. The model predicts a mean of $2951 per building per year, about 50% higher. We attribute the difference to be partly due to the fire loss area (unprotected) where the distribution assumed had a higher mean value (39 m^2) than that determined by BERL (32 m^2). Since we are using the model for comparative assessment only we do not consider this difference to be very important.

In addition, we can compare the values of the estimated total direct property loss per year for the sprinklered and unsprinklered cases. The mean value for the direct property loss for these two cases calculated by the model was $45,080 and $12,090 respectively. This results in a 73% reduction in the expected direct property loss. If we compare this reduction to the NFPA data for industrial and storage buildings in the US, we can see that the data in Table 4 for storage occupancies gives an 80% reduction, whereas the data in Section 3.6 gives a 43–67% reduction for industrial/manufacturing occupancies. The percentage reduction in the mean from the model is of the correct order.

9.6 Sensitivity analysis

The sensitivity analysis using rank correlations is based on the Spearman rank correlation coefficient calculations. With this analysis, the rank correlation coefficient is calculated between the selected output variable and the samples for each of the input distributions. The higher the correlation between the input and the output, the more significant the input is in determining the output's value.

Figure 44 to Figure 48 show tornado plots of the correlation coefficients for the various fire protection options. The most important input variables to the model are the expected fire loss areas (with and without fire protection systems in place) and building floor area.

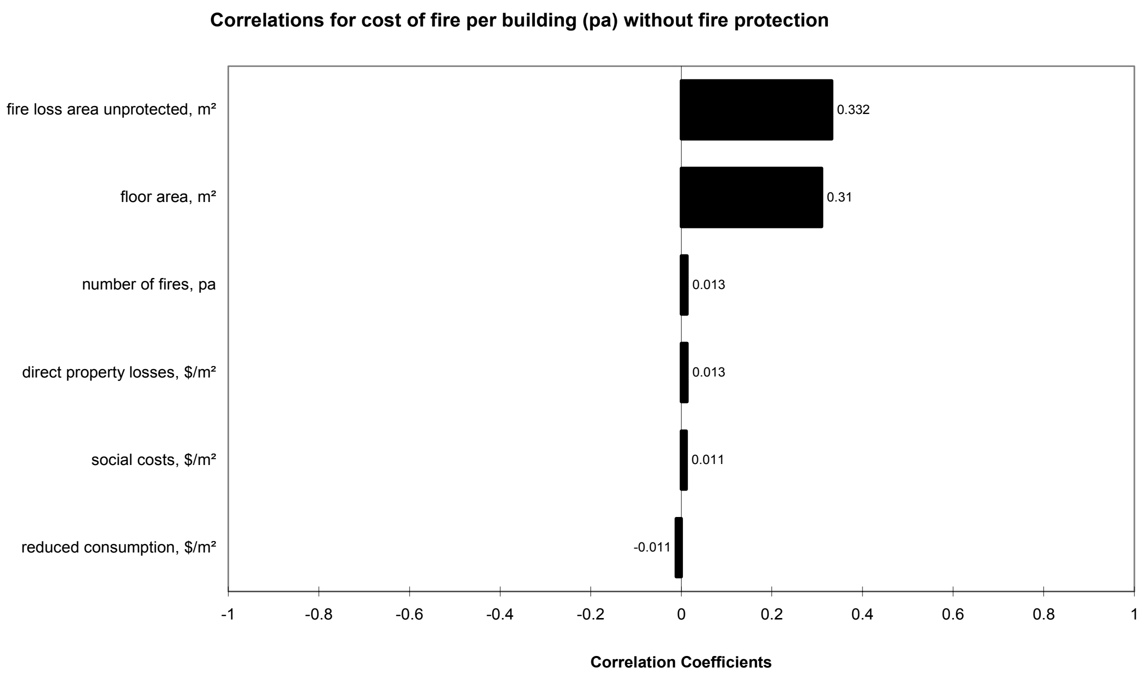


Figure 44. Tornado chart for unprotected buildings

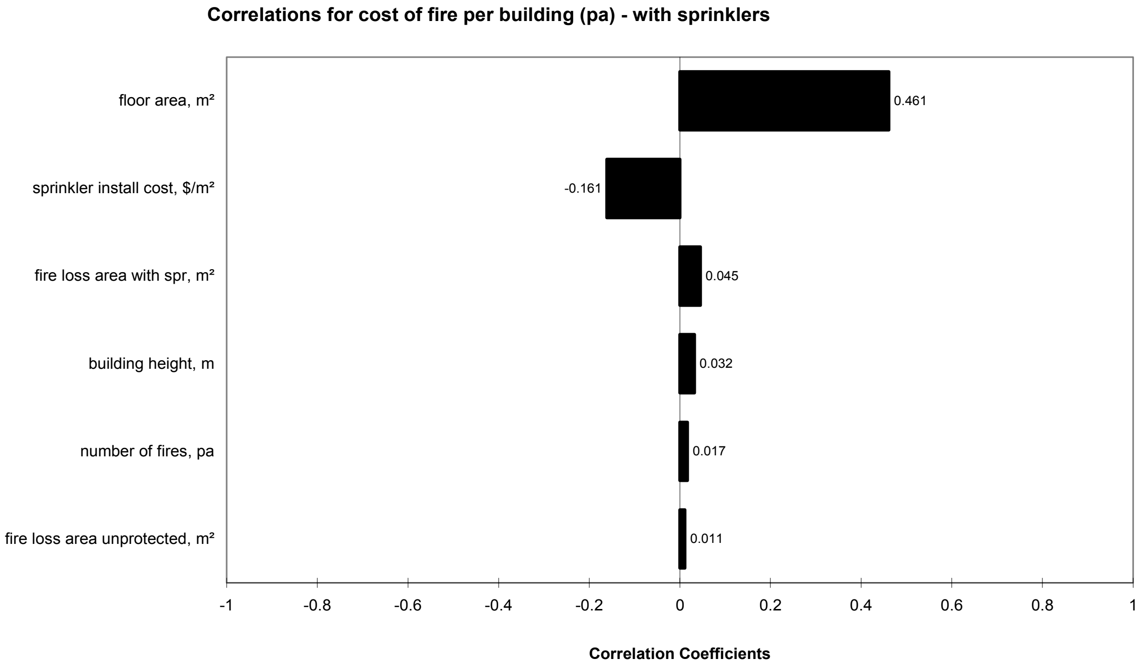


Figure 45. Tornado chart for sprinklered buildings

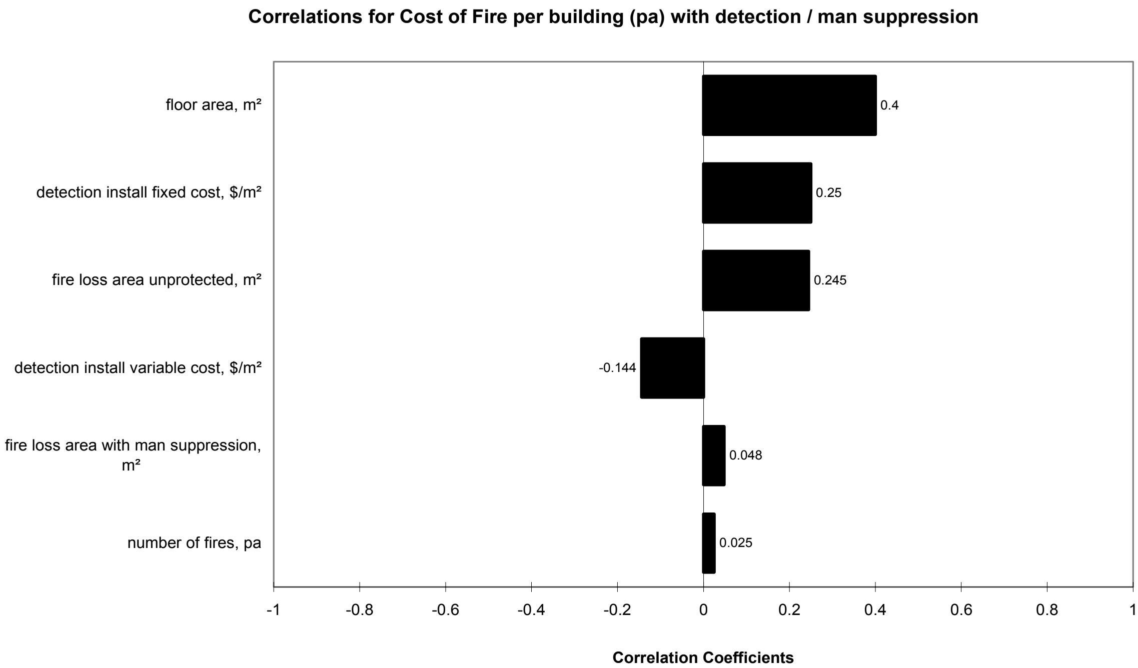


Figure 46. Tornado chart for buildings with detectors/man suppression

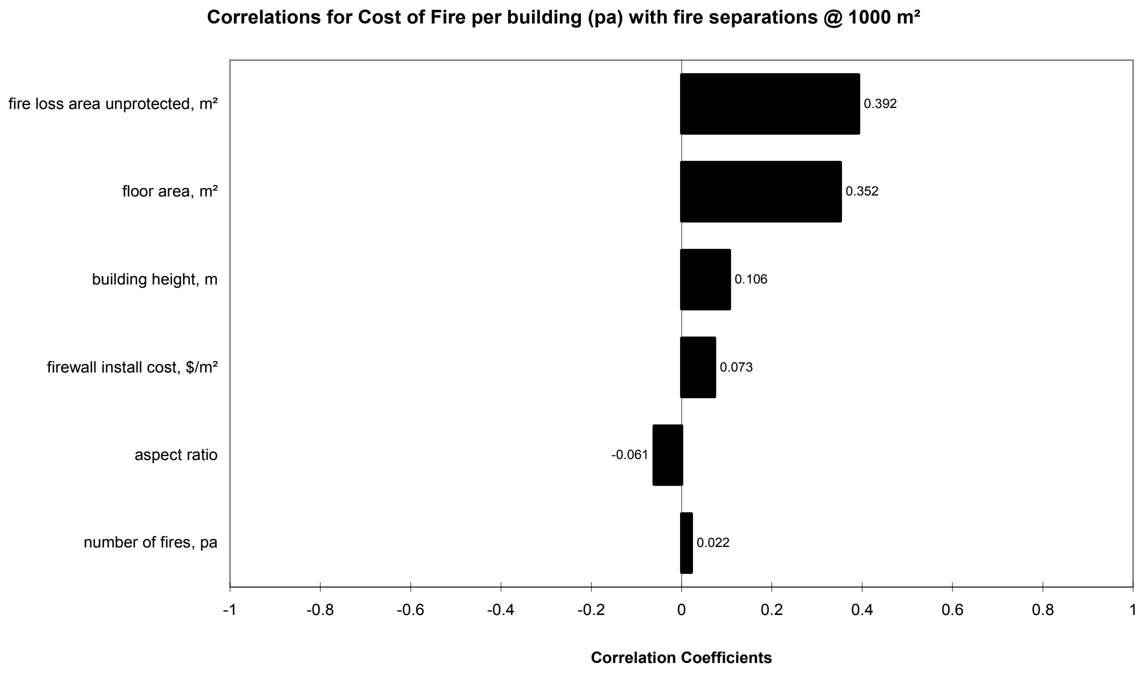


Figure 47. Tornado chart for compartmented buildings (1000 m² fire cells)

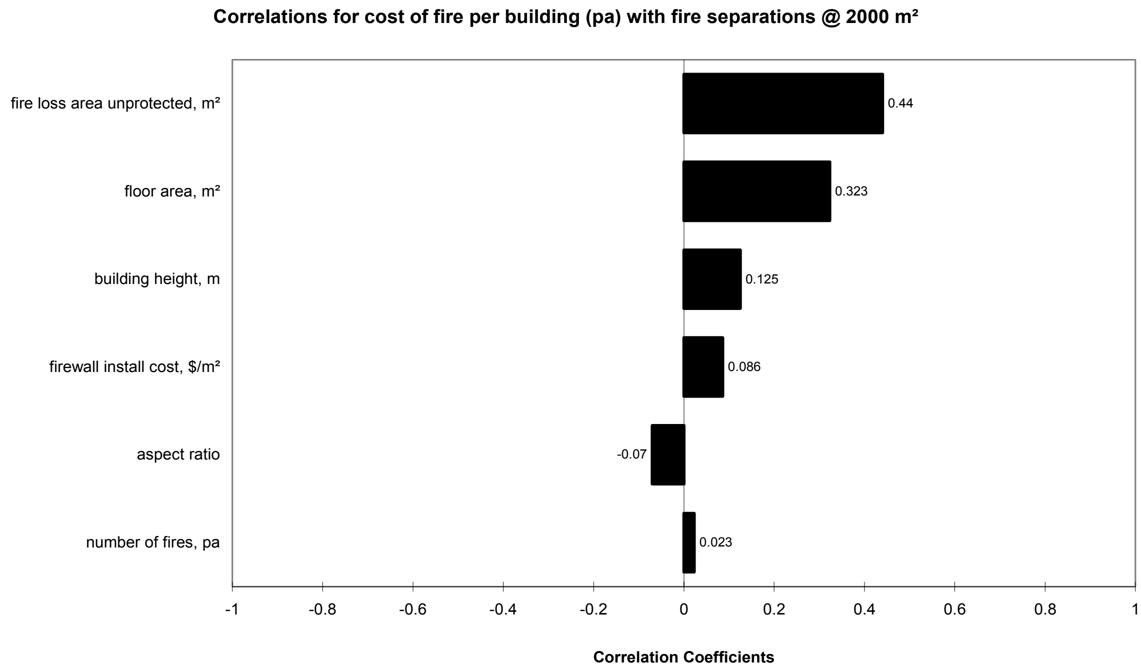


Figure 48. Tornado chart for compartmented buildings (2000 m² fire cells)

9.7 Filtering results by building floor area

In order to investigate whether the most favoured fire protection option would remain unchanged if we considered only buildings of 1000 m² or more, we applied a filter to the results based on this criteria. About 28% of the buildings considered in this study had a floor area of 1000 m² or more (see Figure 23).

Table 23 summarises the results in terms of the calculated total cost of fire per building (pa). Based on a comparison of the expected mean values the "no protection" option gives the lowest mean cost of fire per building (pa) followed by detection with manual suppression.

However, using the upper 95th percentile value as the decision criterion, the preferred option changes to detection with manual suppression (with sprinklers a close second). In 95% of cases we expect the cost of fire per year for buildings of 1000 m² or more to be less than $32,087 for the detection with manual suppression option compared to $35,600 for the no protection option.

Table 23. Cost of fire per building of 1000 m² or more as calculated by model simulations

Scenario	Total cost of fire per building per year ($)	
	Mean & rank	upper 95th percentile & rank
No fire protection	$8,597 (1)	$35,600 (3)
With sprinklers	$11,627 (3)	$32,409 (2)
With detection/man suppression	$11,075 (2)	$32,087 (1)
With firecell area 1000 m²	$18,063 (6)	$60,955 (6)
With firecell area 2000 m²	$13,652 (4)	$48,346 (5)
With sprinklers & detection/man suppression	$16,240 (5)	$42,192 (4)

9.8 Model limitations

This model and the subsequent analysis is highly reliant on the earlier BERL analysis (2002). The model parameters for the fire loss area (unprotected) and the $ losses per unit area of fire loss are intrinsically related, with the product of the two directly corresponding to BERL estimates of the cost of industrial fires. Changes made to either of these input variables in this model must consider their effect on both.

The model considers the whole population of industrial buildings to have the 'same protection' and compares the results on this basis. It does not consider the gradual change over time that would occur if changes were made to the requirement for new/altered buildings via the building consent process.

Social costs measured by the cost of deaths and injuries are based on year 2000 data. This could be revised to reflect longer term death and injury rates, although is not expected to impact much on the results, since very few deaths occur in industrial buildings. The year 2000 had a higher than average number of fire deaths in industrial buildings in New Zealand.

10. CONCLUSIONS

Based on an upper 95 percentile decision criterion for all industrial buildings of the type considered in this study, as applied to the expected cost of fire per building per year, the three preferred fire protection systems, in order of decreasing preference, are:

1. no protection
2. automatic detection with manual suppression
3. fire sprinklers

Based on an upper 95 percentile decision criterion for only industrial buildings of more than 1000 m^2 of the type considered in this study, as applied to the expected cost of fire per building per year, the three preferred fire protection systems, in order of decreasing preference, are:

1. automatic detection with manual suppression
2. fire sprinklers
3. no protection

Many regulatory-focussed cost-benefit studies that attempt to assess the implementation of new technology in our Building Code often gloss-over the quantification of the impact of the new technology usually because the impacts are often considered to be highly uncertain and there may be little data available that can be directly used. This study demonstrates the application of a methodology that addresses uncertainty and provides a more robust analysis on which to base decisions around whether to make changes to Building Code compliance documents or not. It also helps to identify those parameters that most affect the outcome of interest, and those parameters where better data would reduce uncertainty in the results.

This type of study considers a wide group of buildings and looks at the cost-benefit from a regulatory perspective. An individual building owner, considering the specific hazards in their building and their personal level of risk aversion may come to a different conclusion than given in this report.

11. RECOMMENDATIONS

Better data on the area of fire loss experienced in industrial buildings would be valuable. The fire loss areas presented by BERL (2002) were based on New Zealand fire service incident records making use of % property saved and building area estimated made by the fire officer. There is a degree of scepticism over the accuracy of these figures, and there is some conflict with the data presented in Table 17 of this report. Fire loss areas observed in buildings with different types of fire protection is also needed. In the absence of quality data, a high level of engineering judgement was used in the current study.

Better quality data for the performance and operational reliability of fire protection systems would be very helpful, although the reliability of the fire protection systems did not feature strongly in the sensitivity analysis.

The Department of Building and Housing should consider amending the minimum fire protection requirements in industrial buildings with floor areas above 1000 m^2.

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APPENDIX: MODEL SCENARIOS AND EVENT TREES

FIRE RISK - COST BENEFIT MODEL FOR EVALUATING FIRE PROTECTION STRATEGIES IN NEW ZEALAND INDUSTRIAL BUILDINGS

	min	most likely value	max	units
Fire protection systems reliability & effectiveness				
probability of detection success	0.7	0.80	0.90	
probability of auto suppression success	0.9	0.95	0.99	
prob of manual suppression success | fire detected	0.3	0.50	0.70	
probability of barrier success	0.4	0.65	0.90	
Industrial building stock characteristics				
total number of buildings of this type		27273		
floor area per building		1140		m²
assumed building height (m)	4	8	15	m²
new buildings constructed/altered per year		5%		
maximum firecell area		2000		m²
aspect ratio 1 : x	1	3.2	6	
industrial fires per year		604.375		fires
maximum floor area limit		200000		m²
Fire protection system costs				
firewall cost	80	100.8	125	$/m² wall area
firewall maintenance cost		0.0		$ per year
sprinkler installation cost	25	45.0	65	$/m² floor area
automatic fire detection installation fixed cost	3500	5000.0	6500	$ per building
automatic fire detection installation variable cost	7	9.0	11	$/m² floor area
automatic fire detection systems fire service connection		1000.0		$ per year
Cost-benefit parameters				
analysis period		50		years
discount rate		8.0%		
inflation rate		3.0%		
life of fire sprinkler system		50		years
life of automatic fire detection system		50		years
life of a fire separation		50		years
BERL data for fires in industrial buildings				
business interruption costs		$256		$ per m² of fire loss
direct property losses		$1,151		$ per m² of fire loss
fire service costs		$735		$ per m² of fire loss
indirect economic costs		$336		$ per m² of fire loss
reduced consumption		$67		$ per m² of fire loss
social costs		$272		$ per m² of fire loss
Fire Loss Areas				
fire loss area (no systems)		39		m²
fire loss area (with sprinklers eff)		11		m²
fire loss area (with man supp | detection)		15		m²
fire loss area (with firewall eff)		39		m²
Calculated values				
number of firecells		1		
area of fire compartment wall (assume short wall subdividing floor plate)		148.6		m²
real discount rate		5.0%		
total direct property loss per year (with spr)		$12,086		
total direct property loss per year (without spr)		$45,192		
automatic fire detection system maintenance cost		763.0		$ per year
sprinkler maintenance cost		769.5		$ per year
fire incident rate		2.23E-05		fires /yr / m²
Current Model Result : total cost per year per building		**$2,809**		
	Select ----->	**NO FIRE DETECTION**		
	Select ----->	**NO SUPPRESSION**		
	Select ----->	**NO BARRIERS**		
Project Number		Project FQ5014		

Scenario 1. No detection, no suppression, no barriers

FIRE RISK - COST BENEFIT MODEL FOR EVALUATING FIRE PROTECTION STRATEGIES IN NEW ZEALAND INDUSTRIAL BUILDINGS

	min	most likely value	max	units
Fire protection systems reliability & effectiveness				
probability of detection success	0.7	0.80	0.90	
probability of auto suppression success	0.9	0.95	0.99	
prob of manual suppression success | fire detected	0.3	0.50	0.70	
probability of barrier success	0.4	0.65	0.90	
Industrial building stock characteristics				
total number of buildings of this type		27273		
floor area per building		1140		m²
assumed building height (m)	4	8	15	m²
new buildings constructed/altered per year		5%		
maximum firecell area		2000		m²
aspect ratio 1 : x	1	3.2	6	
industrial fires per year		604.375		fires
maximum floor area limit		200000		m²
Fire protection system costs				
firewall cost	80	100.8	125	$/m² wall area
firewall maintenance cost		0.0		$ per year
sprinkler installation cost	25	45.0	65	$/m² floor area
automatic fire detection installation fixed cost	3500	5000.0	6500	$ per building
automatic fire detection installation variable cost	7	9.0	11	$/m² floor area
automatic fire detection systems fire service connection		1000.0		$ per year
Cost-benefit parameters				
analysis period		50		years
discount rate		8.0%		
inflation rate		3.0%		
life of fire sprinkler system		50		years
life of automatic fire detection system		50		years
life of a fire separation		50		years
BERL data for fires in industrial buildings				
business interruption costs		$256		$ per m² of fire loss
direct property losses		$1,151		$ per m² of fire loss
fire service costs		$735		$ per m² of fire loss
indirect economic costs		$336		$ per m² of fire loss
reduced consumption		$67		$ per m² of fire loss
social costs		$272		$ per m² of fire loss
Fire Loss Areas				
fire loss area (no systems)		39		m²
fire loss area (with sprinklers eff)		11		m²
fire loss area (with man supp | detection)		15		m²
fire loss area (with firewall eff)		39		m²
Calculated values				
number of firecells		1		
area of fire compartment wall (assume short wall subdividing floor plate)		148.6		m²
real discount rate		5.0%		
total direct property loss per year (with spr)		$12,086		
total direct property loss per year (without spr)		$45,192		
automatic fire detection system maintenance cost		763.0		$ per year
sprinkler maintenance cost		769.5		$ per year
fire incident rate		2.23E-05		fires /yr / m²
Current Model Result : total cost per year per building		**$3,630**		
	Select ----->	**NO FIRE DETECTION**		
	Select ----->	**NO SUPPRESSION**		
	Select ----->	**FIRE BARRIERS**		
Project Number		Project FQ5014		

Scenario 2. No detection, no suppression, barriers

FIRE RISK - COST BENEFIT MODEL FOR EVALUATING FIRE PROTECTION STRATEGIES IN NEW ZEALAND INDUSTRIAL BUILDINGS

	min	most likely value	max	units
Fire protection systems reliability & effectiveness				
probability of detection success	0.7	0.80	0.90	
probability of auto suppression success	0.9	0.95	0.99	
prob of manual suppression success | fire detected	0.3	0.50	0.70	
probability of barrier success	0.4	0.65	0.90	
Industrial building stock characteristics				
total number of buildings of this type		27273		
floor area per building		1140		m²
assumed building height (m)	4	8	15	m²
new buildings constructed/altered per year		5%		
maximum firecell area		2000		m²
aspect ratio 1 : x	1	3.2	6	
industrial fires per year		604.375		fires
maximum floor area limit		200000		m²
Fire protection system costs				
firewall cost	80	100.8	125	$/m² wall area
firewall maintenance cost		0.0		$ per year
sprinkler installation cost	25	45.0	65	$/m² floor area
automatic fire detection installation fixed cost	3500	5000.0	6500	$ per building
automatic fire detection installation variable cost	7	9.0	11	$/m² floor area
automatic fire detection systems fire service connection		1000.0		$ per year
Cost-benefit parameters				
analysis period		50		years
discount rate		8.0%		
inflation rate		3.0%		
life of fire sprinkler system		50		years
life of automatic fire detection system		50		years
life of a fire separation		50		years
BERL data for fires in industrial buildings				
business interruption costs		$256		$ per m² of fire loss
direct property losses		$1,151		$ per m² of fire loss
fire service costs		$735		$ per m² of fire loss
indirect economic costs		$336		$ per m² of fire loss
reduced consumption		$67		$ per m² of fire loss
social costs		$272		$ per m² of fire loss
Fire Loss Areas				
fire loss area (no systems)		39		m²
fire loss area (with sprinklers eff)		11		m²
fire loss area (with man supp | detection)		15		m²
fire loss area (with firewall eff)		39		m²
Calculated values				
number of firecells		1		
area of fire compartment wall (assume short wall subdividing floor plate)		148.6		m²
real discount rate		5.0%		
total direct property loss per year (with spr)		$12,086		
total direct property loss per year (without spr)		$45,192		
automatic fire detection system maintenance cost		763.0		$ per year
sprinkler maintenance cost		769.5		$ per year
fire incident rate		2.23E-05		fires /yr / m²
Current Model Result : total cost per year per building		**$4,437**		
	Select ----->	**NO FIRE DETECTION**		
	Select ----->	**AUTO SUPPRESSION**		
	Select ----->	**NO BARRIERS**		
Project Number		Project FQ5014		

Scenario 3. No detection, auto suppression, no barriers

FIRE RISK - COST BENEFIT MODEL FOR EVALUATING FIRE PROTECTION STRATEGIES IN NEW ZEALAND INDUSTRIAL BUILDINGS

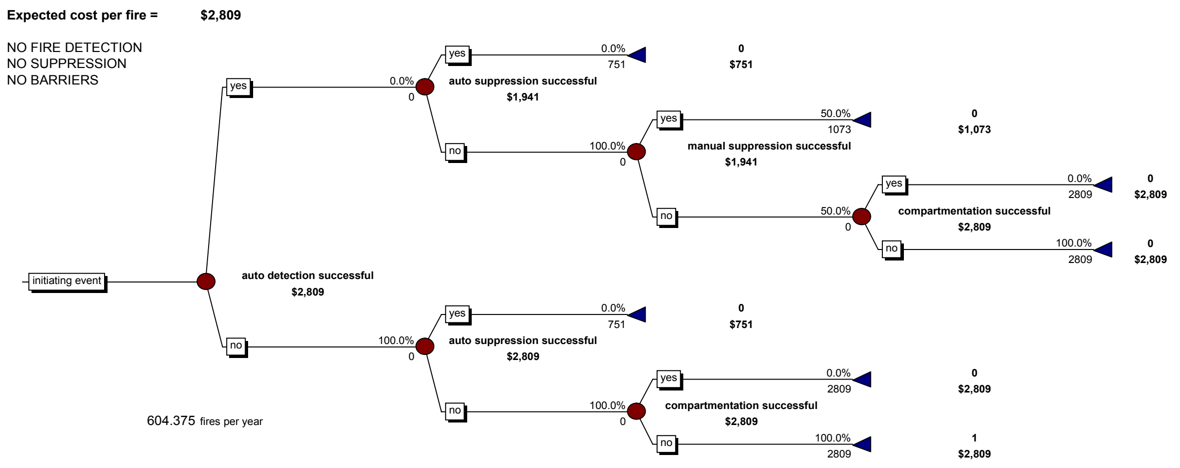
	min	most likely value	max	units
Fire protection systems reliability & effectiveness				
probability of detection success	0.7	0.80	0.90	
probability of auto suppression success	0.9	0.95	0.99	
prob of manual suppression success | fire detected	0.3	0.50	0.70	
probability of barrier success	0.4	0.65	0.90	
Industrial building stock characteristics				
total number of buildings of this type		27273		
floor area per building		1140		m²
assumed building height (m)	4	8	15	m²
new buildings constructed/altered per year		5%		
maximum firecell area		2000		m²
aspect ratio 1 : x	1	3.2	6	
industrial fires per year		604.375		fires
maximum floor area limit		200000		m²
Fire protection system costs				
firewall cost	80	100.8	125	\$/m² wall area
firewall maintenance cost		0.0		\$ per year
sprinkler installation cost	25	45.0	65	\$/m² floor area
automatic fire detection installation fixed cost	3500	5000.0	6500	\$ per building
automatic fire detection installation variable cost	7	9.0	11	\$/m² floor area
automatic fire detection systems fire service connection		1000.0		\$ per year
Cost-benefit parameters				
analysis period		50		years
discount rate		8.0%		
inflation rate		3.0%		
life of fire sprinkler system		50		years
life of automatic fire detection system		50		years
life of a fire separation		50		years
BERL data for fires in industrial buildings				
business interruption costs		\$256		\$ per m² of fire loss
direct property losses		\$1,151		\$ per m² of fire loss
fire service costs		\$735		\$ per m² of fire loss
indirect economic costs		\$336		\$ per m² of fire loss
reduced consumption		\$67		\$ per m² of fire loss
social costs		\$272		\$ per m² of fire loss
Fire Loss Areas				
fire loss area (no systems)		39		m²
fire loss area (with sprinklers eff)		11		m²
fire loss area (with man supp | detection)		15		m²
fire loss area (with firewall eff)		39		m²
Calculated values				
number of firecells		1		
area of fire compartment wall (assume short wall subdividing floor plate)		148.6		m²
real discount rate		5.0%		
total direct property loss per year (with spr)		\$12,086		
total direct property loss per year (without spr)		\$45,192		
automatic fire detection system maintenance cost		763.0		\$ per year
sprinkler maintenance cost		769.5		\$ per year
fire incident rate		2.23E-05		fires /yr / m²
Current Model Result : total cost per year per building		**\$4,713**		
	Select ----->	**AUTO FIRE DETECTION**		
	Select ----->	**NO SUPPRESSION**		
	Select ----->	**NO BARRIERS**		
Project Number		Project FQ5014		

Scenario 4. Auto detection, no suppression, no barriers

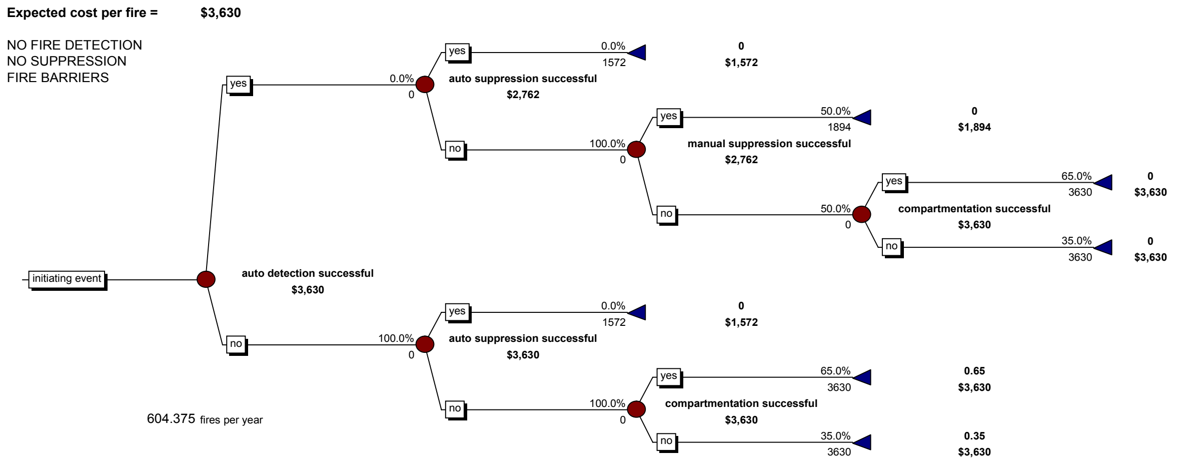
FIRE RISK - COST BENEFIT MODEL FOR EVALUATING FIRE PROTECTION STRATEGIES IN NEW ZEALAND INDUSTRIAL BUILDINGS

	min	most likely value	max	units
Fire protection systems reliability & effectiveness				
probability of detection success	0.7	0.80	0.90	
probability of auto suppression success	0.9	0.95	0.99	
prob of manual suppression success | fire detected	0.3	0.50	0.70	
probability of barrier success	0.4	0.65	0.90	
Industrial building stock characteristics				
total number of buildings of this type		27273		
floor area per building		1140		m²
assumed building height (m)	4	8	15	m²
new buildings constructed/altered per year		5%		
maximum firecell area		2000		m²
aspect ratio 1 : x	1	3.2	6	
industrial fires per year		604.375		fires
maximum floor area limit		200000		m²
Fire protection system costs				
firewall cost	80	100.8	125	$/m² wall area
firewall maintenance cost		0.0		$ per year
sprinkler installation cost	25	45.0	65	$/m² floor area
automatic fire detection installation fixed cost	3500	5000.0	6500	$ per building
automatic fire detection installation variable cost	7	9.0	11	$/m² floor area
automatic fire detection systems fire service connection		1000.0		$ per year
Cost-benefit parameters				
analysis period		50		years
discount rate		8.0%		
inflation rate		3.0%		
life of fire sprinkler system		50		years
life of automatic fire detection system		50		years
life of a fire separation		50		years
BERL data for fires in industrial buildings				
business interruption costs		$256		$ per m² of fire loss
direct property losses		$1,151		$ per m² of fire loss
fire service costs		$735		$ per m² of fire loss
indirect economic costs		$336		$ per m² of fire loss
reduced consumption		$67		$ per m² of fire loss
social costs		$272		$ per m² of fire loss
Fire Loss Areas				
fire loss area (no systems)		39		m²
fire loss area (with sprinklers eff)		11		m²
fire loss area (with man supp | detection)		15		m²
fire loss area (with firewall eff)		39		m²
Calculated values				
number of firecells		1		
area of fire compartment wall (assume short wall subdividing floor plate)		148.6		m²
real discount rate		5.0%		
total direct property loss per year (with spr)		$12,086		
total direct property loss per year (without spr)		$45,192		
automatic fire detection system maintenance cost		763.0		$ per year
sprinkler maintenance cost		769.5		$ per year
fire incident rate		2.23E-05		fires /yr / m²
Current Model Result : total cost per year per building		**$7,000**		
	Select ----->	**AUTO FIRE DETECTION**		
	Select ----->	**AUTO SUPPRESSION**		
	Select ----->	**NO BARRIERS**		
Project Number		Project FQ5014		

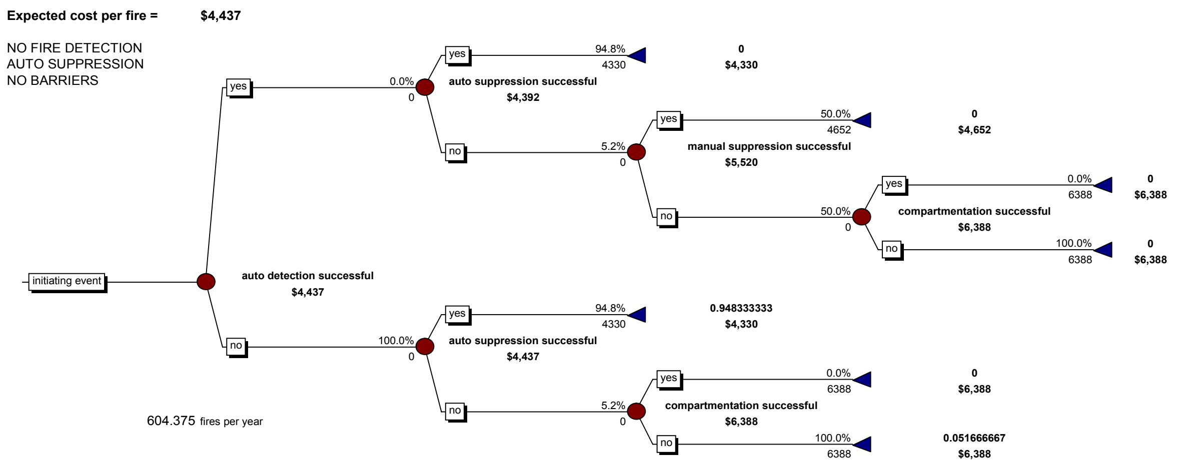
Scenario 5. Auto detection, auto suppression, no barriers



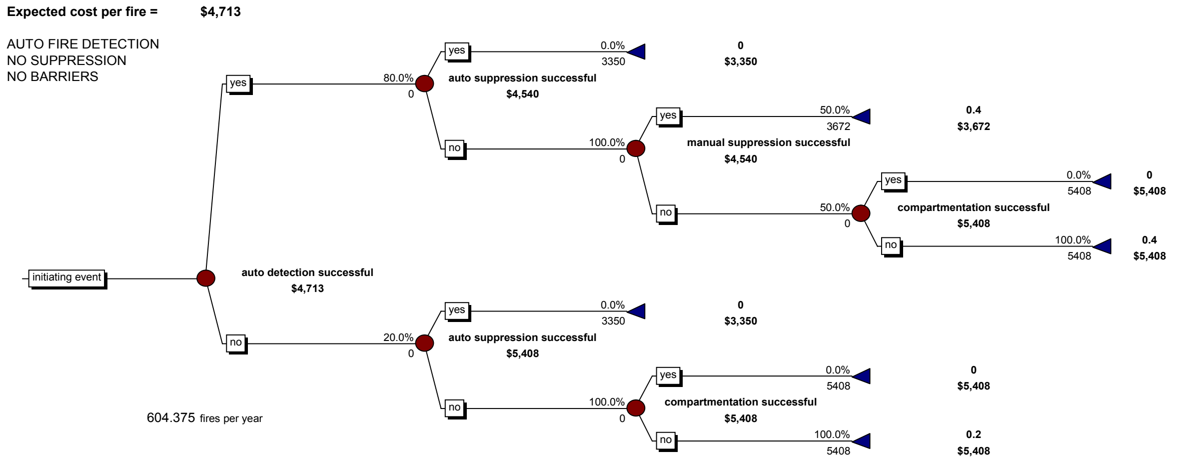
Event Tree 1. No detection, no suppression, no barriers



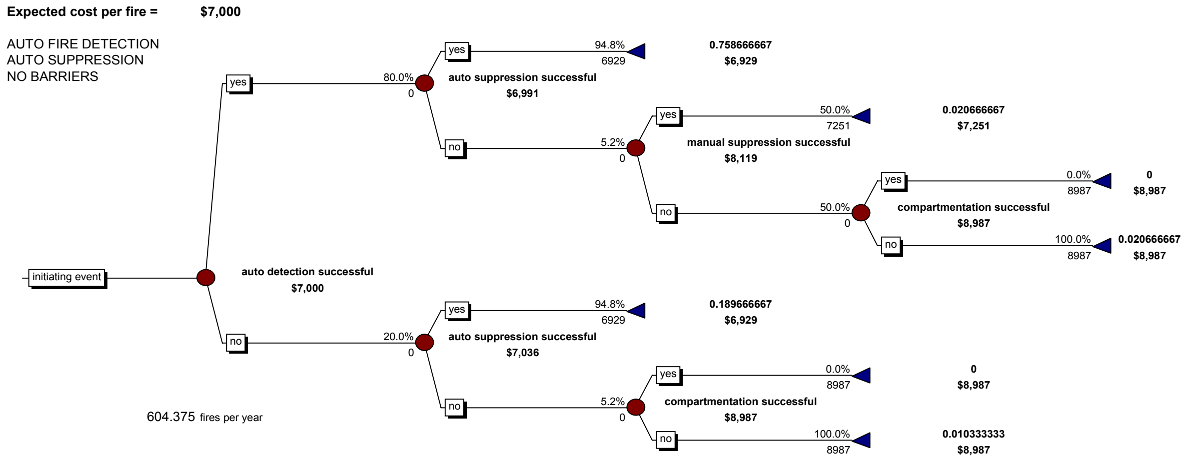
Event Tree 2. No detection, no suppression, barriers



Event Tree 3. No detection, auto suppression, no barriers



Event Tree 4. Auto detection, no suppression, no barriers



Event Tree 5. Auto detection, auto suppression, no barriers