Sprinklers for property protection – decision based on quantitative cost-benefit risk assessment *

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SUMMARY: *This paper presents a simple risk model for assessing whether sprinklers should be incorporated in buildings from the point of view of asset protection and/or business continuity. The basis of the assessment is the comparison of the difference between the costs and benefits, expressed in monetary value, over the life of the buildings. Life safety considerations are not addressed.*

This assessment provides a rational basis such that in cases where the costs outweigh the benefits, the installation of sprinklers is not justified. The converse is also true. It also provides a systematic approach whereby the relative risks of various fire scenarios can be highlighted and specific actions can be taken to minimise the risks.

NOTATION

D_i = the cost of damage associated with fire scenario i

d_k = potential damage associated with aspect k

M = the cost of maintenance (or increase in cost of maintenance for provision of additional sprinklers)

m = number of events

n = number of fire scenarios

p_i = the probability of a fire scenario i

p_j = the probability of event j that leads to the occurrence of fire scenario i (fire start is taken as event $j = 0$)

p_k = the probability of potential damage associated with aspect k

S = the capital cost of installing sprinklers (or increase in cost of installation for provision of additional sprinklers)

κ = number of aspects of damage considered

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1 INTRODUCTION

The issue of property protection is a complicated one that affects the building owner, the owner's insurer, the building occupant and the occupant's insurer. In addition, various flow-on effects can be experienced to other connected parties and industries.

This paper presents a simple risk model and an example where the model is used to assess whether sprinklers should be incorporated in a particular building situation in order to provide appropriate property protection. In this example, it is assumed that the owner and occupier are one and the building and its activities are "self-insured" by the owner. The paper does not address Building Code of Australia[6] *fire-safety* issues and the results are only applicable to the situation considered.

It is recognised that in many situations the owner, occupier and insurer are separate organisations. Even if that were the case for this particular example, the outcomes can be used to indicate the insurer's risk exposure with and without sprinklers. In a rational insurance industry this type of information could be used to set the excess and premium charges to give a sufficient likely return for the insurer.

2 BASIS OF ASSESSMENT

The basis of the assessment is the comparison of the difference between the *costs* and *benefits* of installing sprinklers (expressed in monetary value) over the life of the building or the period of occupation:

$$Costs = S + M$$

$$Benefits = \sum_i^n (p_i \times D_i)_{without\ sprinklers} - \sum_i^n (p_i \times D_i)_{with\ sprinklers}$$

where:

S = the capital cost of installing sprinklers (or increase in cost of installation for provision of additional sprinklers)

M = the cost of maintenance (or increase in cost of maintenance for provision of additional sprinklers)

p_i = the probability of a fire scenario i

D_i = the cost of damage associated with fire scenario i

n = number of fire scenarios

and

$$p_i = \prod_j^m p_j$$

p_j = the probability of event j that leads to the occurrence of fire scenario i (fire start is taken as event $j = 0$)

m = number of events

$$D_i = \sum_k^{\kappa} \left(p_k \times d_k\right)$$

d_k = potential damage associated with aspect k

p_k = the probability of potential damage associated with aspect k

κ = number of aspects of damage considered

The term "damage" refers not only to costs associated directly with damage to the building and its contents, but also to the costs of relocation and any loss of business resulting from a fire incident.

All monetary values are expressed in terms of their present value.

Both *costs* and *benefits* are dependent on the building characteristics and the usage of the building. In cases where the *costs* outweigh the *benefits*, the installation of sprinklers is not justified. The converse is also true. Some analysis of the sensitivity of the outcome to variation of the inputs is recommended.

The benefit associated with a sprinkler system is that it mostly prevents the development of large fires. Since there is a correlation between the size of the fire and the extent of damage, the presence of sprinklers will reduce the level of damage. Even with a sprinklered fire there is likely to be significant smoke damage but the damage costs will be less than if the fire was allowed to grow in severity. A critical aspect in modelling the effect of sprinklers is the level of effectiveness that can be associated with sprinklers in the particular building. An effective sprinkler system can be considered to be one that prevents further fire growth and spread or extinguishes the fire. The effectiveness of the system is likely to be a function of numerous factors, including:

- the availability of water
- the availability of sufficient pressure
- the level of shielding associated with the burning fuel with respect to the water spray from the heads
- the capacity of the system compared with the nature of the fuel

In the case of sprinklers in carparks, the sprinkler system may not extinguish the fire within a car due to the shielding offered by the car body. However, it will limit the likelihood of spread to adjacent cars and if this is achieved, the system may be considered to be fully effective. Furthermore, it is known that sprinklers will significantly wash the smoke and absorb the heat being released from the burning vehicle.[1]

In the analysis presented in this paper, the calculations require an estimate of the probability that the sprinklers will be fully effective in terms of the above definition of effectiveness. The appropriate value for carparks is considered to be high and can be estimated for a particular situation using fault-tree analysis. The sensitivity of the cost-benefit analysis can be tested against various values of sprinkler effectiveness.

3 ASSESSMENT PROCEDURES

The procedures for carrying out the assessment are summarised below:

Calculate *Costs*

Step 1: Calculate cost of installing sprinklers $= S$

Step 2: Calculate cost of maintenance $= M$

Step 3: Calculate costs $= S + M$

Calculate *Benefits*

Step 1: Establish potential events (0 to m) and fire scenarios with and without sprinklers (this may be by means of event tree analysis)

Step 2: Calculate probability of fire events (including fire starts) $= p_j$

Step 3: Calculate probability of fire scenarios

$$p_i = \prod_j^m p_j$$

Step 4: Establish aspects of damage for each fire scenario (1 to κ)

Step 5: Establish damage costs for each fire scenario $= d_k$

Step 6: Establish probability of damage for each aspect of damage = p_k

Step 7: Calculate likely damage costs for each fire scenario = $D_i = \sum_{k}^{K} (p_k \times d_k)$

Step 8: Calculate total benefits =

$$\sum_{i}^{n} (p_i \times D_i)_{without\ sprinklers} - \sum_{i}^{n} (p_i \times D_i)_{with\ sprinklers}$$

Compare *Costs-Benefits*

- If *costs* > *benefits* – installation of sprinklers not justified
- If *costs* < *benefits* – installation of sprinklers justified.

4 CASE STUDY

The case study considered involves a building with 4 levels of office spaces and a well-ventilated undercroft containing carpark and loading dock areas (see Figure 1). The office levels are protected by sprinklers.

The situation corresponds to one where the owner-occupier of the building needs to determine whether the installation of sprinklers in the carpark and/or loading dock areas is justified from the point of view of business continuity and self-insurance over an occupancy period of 25 years.

Potential losses for the owner-occupier include:

- Smoke damage to building fabric and contents within the office levels
- Structural damage to the carpark or the loading dock
- Business disruption and relocation of staff from office levels

Damage to vehicles and goods in loading dock are not included as these are insured by other parties.

Information relevant to this risk assessment are summarised in Table 1.

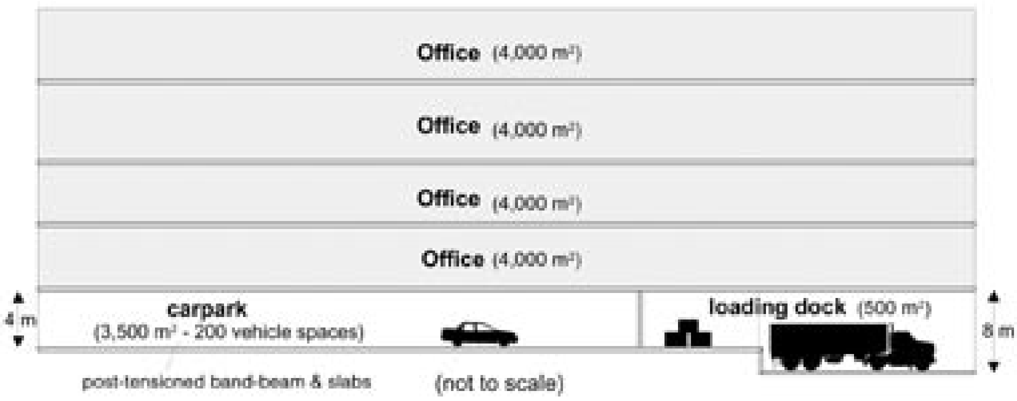


Figure 1: Case study.

Table 1
Relevant information for risk assessment.

Aspect	Relevant Information
Potential smoke flow paths from carpark to office levels	• Natural ventilation of carpark = significant openings in more than one wall. • Access between carpark level and office levels above = two fire-isolated stairs at opposite ends of building and a fire-resistant lift shaft incorporating a bank of lifts (a glazed lobby separates the lifts from the carpark).
Potential smoke flow paths from loading dock to office levels	• Natural ventilation of loading dock = substantial openings when the roller doors are open but will be largely closed when the doors are closed. Trucks and delivery vans will use this area but none will be parked overnight and the roller doors will be open when the trucks or vans are inside. This area will also house stored combustibles (largely paper).
Fire fighting equipment	• Fire hose reels, portable fire extinguishers, fire hydrant in carpark and loading dock areas.
Fire brigade access	• Excellent fire brigade access into the carpark and loading dock areas.

4.1 Calculate *Costs*

The costs associated with installation and maintenance of the sprinkler system are summarised in Table 2 below.

Table 2
Costs.

	Carpark	*Loading Dock*
S[a]	= 30 x 3500 = $105k	= 30 x 500 = $15k
M[b]	= 800 x 25 = $20k	= 800 x 25 = $20k
Costs	**= $125k**	**= $35k**

- Assumed cost of installation of additional sprinklers in the undercroft = $30/m^2.
- Assumed increase in maintenance costs for sprinklers installed in any part of the undercroft = $800 per year. Life of the occupation = 25 years.
- The maintenance costs will be only slightly greater if sprinklers are included in the carpark/loading dock areas since the upper office levels are sprinklered.

The calculation has not taken into account the investment opportunity associated with the *costs* associated with the sprinkler system. The impact of this omission on *costs* will be discussed later in this paper.

4.2 Calculate *Benefits*

The benefits are analysed using event tree analysis considering vehicle fires in the carpark, and vehicle and non-vehicle fires in the loading dock (see Appendix A for details). The benefits are summarised in Table 3.

The analysis in Appendix A includes the calculation of the probabilities of the fire scenarios and costs of damage associated with the fire scenarios. The damage includes:

- Smoke damage to building and contents
- Structural damage to building
- Business loss associated with relocation of staff

Business loss associated with loss of earnings is not included in the calculation of *benefits* in Appendix A. The impact of this omission on *benefits* will be discussed later in this paper.

4.3 Comparing *Costs* Against *Benefits*

A comparison of the *costs* and *benefits* for the carpark and loading dock areas (see Appendix A) is summarised below.

Carpark: *costs* (=$125k) > *benefits* (=$318)
sprinklers not justifiable

Loading dock: *costs* (=$35k) < *benefits* (=$68k)
sprinklers justifiable

The comparison shows that the *costs* of installing sprinklers in the carpark outweigh the associated *benefits* and hence the installation of sprinklers in carpark is not justifiable.

For the loading dock area, however, the *benefits* of installing sprinklers is greater than the associated *costs*. Therefore, the installation of sprinklers in loading dock area is justifiable.

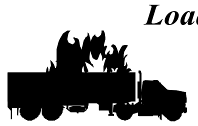
4.4 Discussion

The above analysis suggests that it would be difficult to justify the inclusion of sprinklers within the carpark part of this building. However, some further consideration with respect to the sensitivity of the assessment is warranted. This is discussed below.

a) Rate of fire starts

If the rate of fire starts was a factor of 5 greater (as suggested by MFESB general statistics on fires in carparks [2]) this would increase the *benefits* by a factor of 5 – but this gives a *benefit* that is still more than two orders of magnitude less than the *costs*.

Table 3
Benefits.

	Carpark	***Loading Dock***	
	 ***A. vehicle fires***	 ***B. vehicle fires***	 ***C. non-vehicle fires***
$\sum_i^n (p_i \times D_i)_{without\ sprinklers}$	=$441	=$204	=$111,937
$\sum_i^n (p_i \times D_i)_{with\ sprinklers}$	=$123	=$102	=$44,440
Benefits [a]	**=$318**	**=$102**	**=$67,497**

[a] Potential loss of earnings associated with fires not included in the calculation (see 4.4 Discussion).

b) Opportunity costs

The analysis has also not taken into account the investment opportunity associated with the costs associated with the sprinkler system, i.e money that could otherwise be invested.

It is interesting to note that if the cost associated with the sprinkler system of $120,000 was invested at 3% over 25 years, this will earn an additional $130,000.

The potential loss of earnings associated with fires within the carpark has not bee considered as this was not an issue in the particular case considered.

What level of loss of earnings would be required to justify the incorporation of sprinklers in the carpark. Assuming this event to coincide with a fire where spread to adjacent vehicles occurred the loss of earnings that would be required to match the *costs* would be around $15,000,000.

5 CONCLUSIONS

This paper has presented a general risk-based analysis for assessing the cost-benefit of installing sprinklers in buildings for the purpose of protecting against damage to buildings, contents and business interruption.

The findings presented in this case study are not necessarily applicable to other buildings and each case needs to be carefully considered. The findings for the carpark were not significantly altered by the application of an increased rate of fire starts.

This paper does not address the question of life safety but seeks to present a better rationale for evaluating the need or otherwise for sprinklers from a property protection perspective.

REFERENCES

1. Thomas, I. R., Bennetts, I. D., Lewins, R. R. and Proe, D. J., "Fire and Unprotected Steel in Closed Carparks", BHP Melbourne Research Laboratories Report No MRL/PS69/89/006, August 1989.

2. Metropolitan Fire and Emergency Services Board, Special Report of Fire Incidents in General Vehicle Parking Areas 1998 - 2000, Feb 2001.

3. Denda, D. F., "Parking Garage Fires", Parking Market Research Company, 1992.

4. Hall, J R. "Special Analysis: Patterns in 1981 - 1990 Reported US Structure Fires in Selected Office Properties and General Vehicles Parking Garages" NFPA, 1993.

5. Bennetts, I D, Poh, K W. and Thomas, I R., "A Framework for Fire-Engineering Design", Australian Journal of Structural Engineering, Vol SE3, Nos 1 & 2, 2000.

6. Building Code of Australia, Australian Building Codes Board, 2004.

APPENDIX A – CALCULATING *BENEFITS*

A separate event tree is used to calculate the *benefits* associated with:

A. Vehicle fires in the carpark
B. Vehicle fires in the loading dock
C. Non-vehicle fires in the loading dock

The event trees are similarly structured. The components of the event trees are illustrated in the Figure A1.

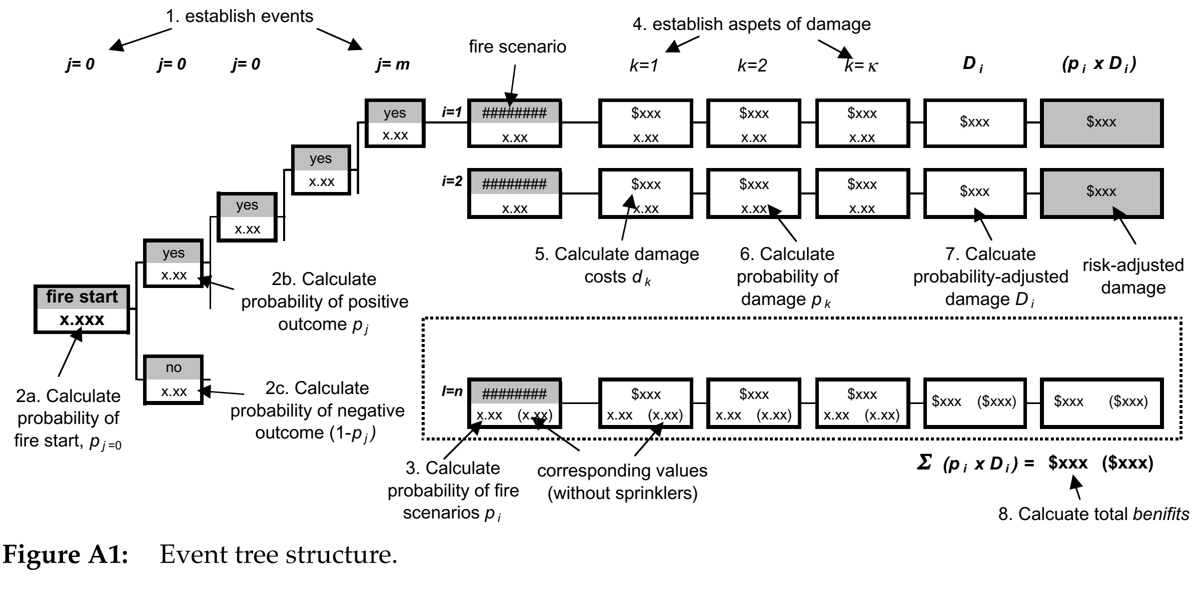


Figure A1: Event tree structure.

The assumptions made in the analysis are outlined below.

A.1 Potential events (j = 0 to m)

The following events are assumed.

j = 0 Fire start
j = 1 Fire occurs during occupied hours (day time)?
j = 2 Fire growth?
j = 3 Fire noticed by occupant at early stage?
j = 4 Fire extinguished by occupant?
j = 5 Fire extinguished by fire brigade?
j = 6 Sprinklers activate?
j = 7 Fire spread?

It is assumed that the fire brigade will eventually extinguish all fires in the carpark level. However, potential damage could result before this occurs. The analysis in this paper is therefore aimed at estimating the risk level associated with such damage.

A.3 Probabilities of fire scenarios – p_i

The probability of each fire scenario is calculated as the product of the conditional probability of the event times the probability of a fire start. For the cases with and without sprinklers, the events are identical except that without sprinklers, the probability of sprinkler activation is zero for event j=6.

A.4 Aspects of damage (k = 1 to κ)

The following aspects of damage are assumed:

k= 1 Smoke damage
k= 2 Structural damage
k= 3 Relocation costs

A.5 Potential damage – d_k

Potential damage associated with an uncontrolled fire involving a single car located near the lift lobby or stairway with door open are assumed to be as shown in Figure A.1.

A.2 Probabilities of fire events — p_j

Table A.1

Assumptions regarding probabilities of fire events.

	p_j	*Fire*	**Assumptions**[a]
$p_{j=0}$ [b]	= 200 x 25 x 1.6x10^{-5} = 0.08	*A*	• Spaces in carpark = 200 • Rate of fire start in carpark = 1.6x10^{-5} fires per car space per year [c]
	= 1x 25 x 1.6x10^{-5} x 0.5 = 0.0002	*B*	• One truck space within loading dock • Rate of fire start for truck same as that with cars = 1.6 x10^{-5} fires per vehicle space per year • Occupancy rate = 50%
	= 400 x 25 x 2 x 9x10^{-6} = 0.018	*C*	• Floor area of loading dock = 400 m^2 • Fire incident rate (on a m^2 basis) = twice that for office areas [4]. • Rate of fire start in office areas = 9x10^{-6}m^2/yr. [5]
$p_{j=1}$	= 1.0	*A,B*	• There are no vehicles in the carpark or loading dock during night time
	= 0.667	*C*	• There are twice as many fire starts during night time as there are during day time
$p_{j=2}$	= 0.05	*A,B,C*	• 5% of fire starts will self extinguish
$p_{j=3}$	= 0.9 = 0.6	*A,B,C* *C*	• During day time, 90% of the fires will be noticed by the occupants (including passers-by), given that the fires do not self extinguish • During night time, 60% of the fires will be noticed by the occupants (including passers-by), given that the fires do not self extinguish
$p_{j=4}$	= 0.15	*A,B,C*	• 15% of fires noticed by occupants will be extinguished by the occupants
$p_{j=5}$	= 0.75	*A,B,C*	• 75% of the fire attended by the fire brigade will be extinguished by the fire brigade
$p_{j=6}$	= 0.995 = 0.0	*A,B,C*	• Sprinklers (if present) have a probability of 99.5% to activate • In the absent of sprinklers, the probability of sprinkler activation is simply taken as 0.
$p_{j=7}$	= 0.5	*A,B,C*	• 50% of significant fires involving a car (fire that cannot be controlled by sprinklers or fire brigade) will spread to the adjacent cars.

a These assumptions are supported by statistical data.[2,3,4]

b Assumed 25 years of occupation.

c Relevant information on vehicle fires in carparks is obtained from.[3] There had been 105 reported fires in a survey of 771,000 car spaces in the US between Jan 1971 to May 1978 (8.5 years).

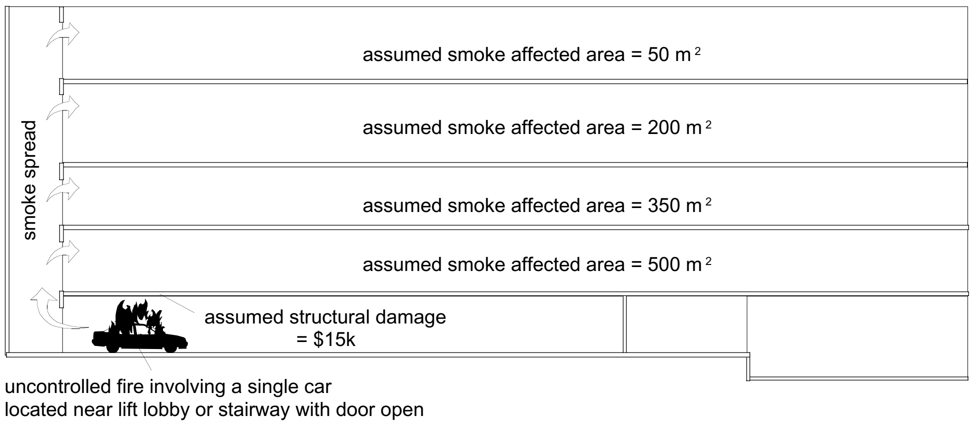


Figure A2: Assumed extend of smoke damage.

Table A2
Assumptions regarding potential damage.

	d_k	**Assumptions**
$d_{k=1}$	= 200 x 1100 = $220,000	• Replacement of floor coverings, ceilings and other furniture = $200 per m^2 (coverings and ceilings plus furniture).
$d_{k=2}$ [a]	= $15,000	• Damage only assumed to be associated with a three car fire
$d_{k=3}$	= $26,400	• Transferring staff and equipment from the smoke affected area in the office levels to another location and back again = $140 per person. • Each staff occupies 20 m^2 of office space in the building. • Alternative rental accommodation (assume a period of 6 weeks) = $150 per m^2/yr where it can be assumed that each person will occupy 10 m^2. • Smoke affected area due to a single car fire = 1100 m^2.

[a] Based on observation of damage associated with car fires the only form of damage that is likely is the cracking of furnishings such as partitions due to sagging of the floor. There are no known cases where the building has collapsed.

Further Assumptions:

- Damage is directly proportional to the number of cars involved in the fire.
- A fire involving a heavy vehicle is 10 times as severe as that of a fire involving a single car.
- During day time (roller door open), a non-vehicle fire in the loading dock is twice as severe as that involving a single car
- During night time, a non-vehicle fire in the loading dock is 10 times as severe as that involving a single car.
- If the fire is controlled by the fire brigade or by sprinklers, the damage is only 25% as extensive (this is due to the fact that the smoke will be less and "washed" to some extent).

A.6 Probability of Damage — p_k

- Given a vehicle fire in the carpark, smoke will get into the office levels in 3% of the fires. This figure was determined on the basis of the necessary location of car in relation to lobby for smoke to get into the lobby, likely wind direction and adjacent ventilation and lobby doors being sufficiently open.
- A fire involving a single car will not result in any significant damage to the building structure and is ignored.
- Given a multiple-car fire, it is estimated that there is a 20% chance that the fire will cause significant structural damage.
- Given the significant floor-to-floor height in the loading dock area, structural damage is very unlikely and ignored.
- No liquid fuel is involved in non-vehicle fire in the loading dock area. Structural damage is unlikely and is ignored.

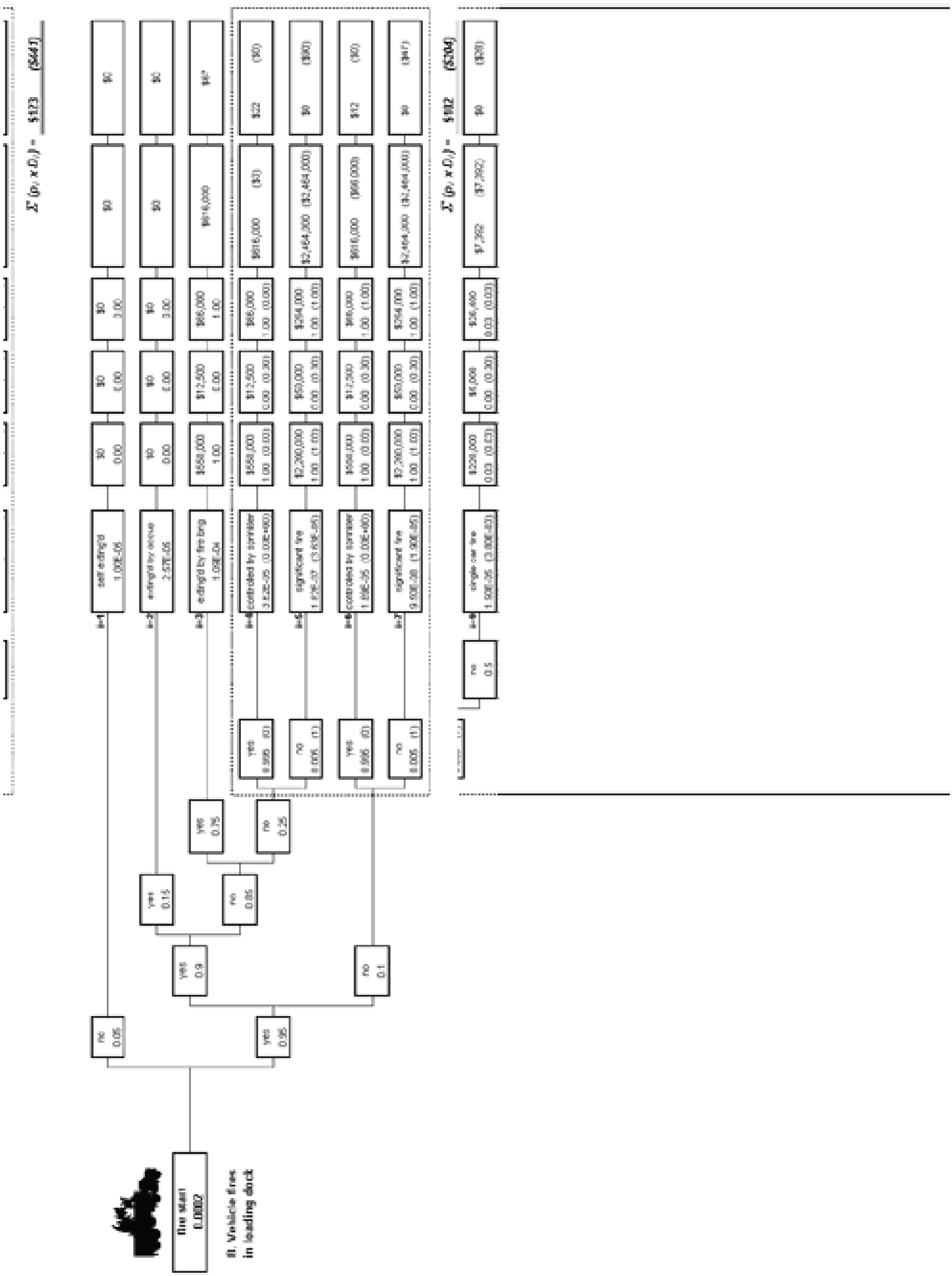


Figure A3: Event tree – vehicle fires.

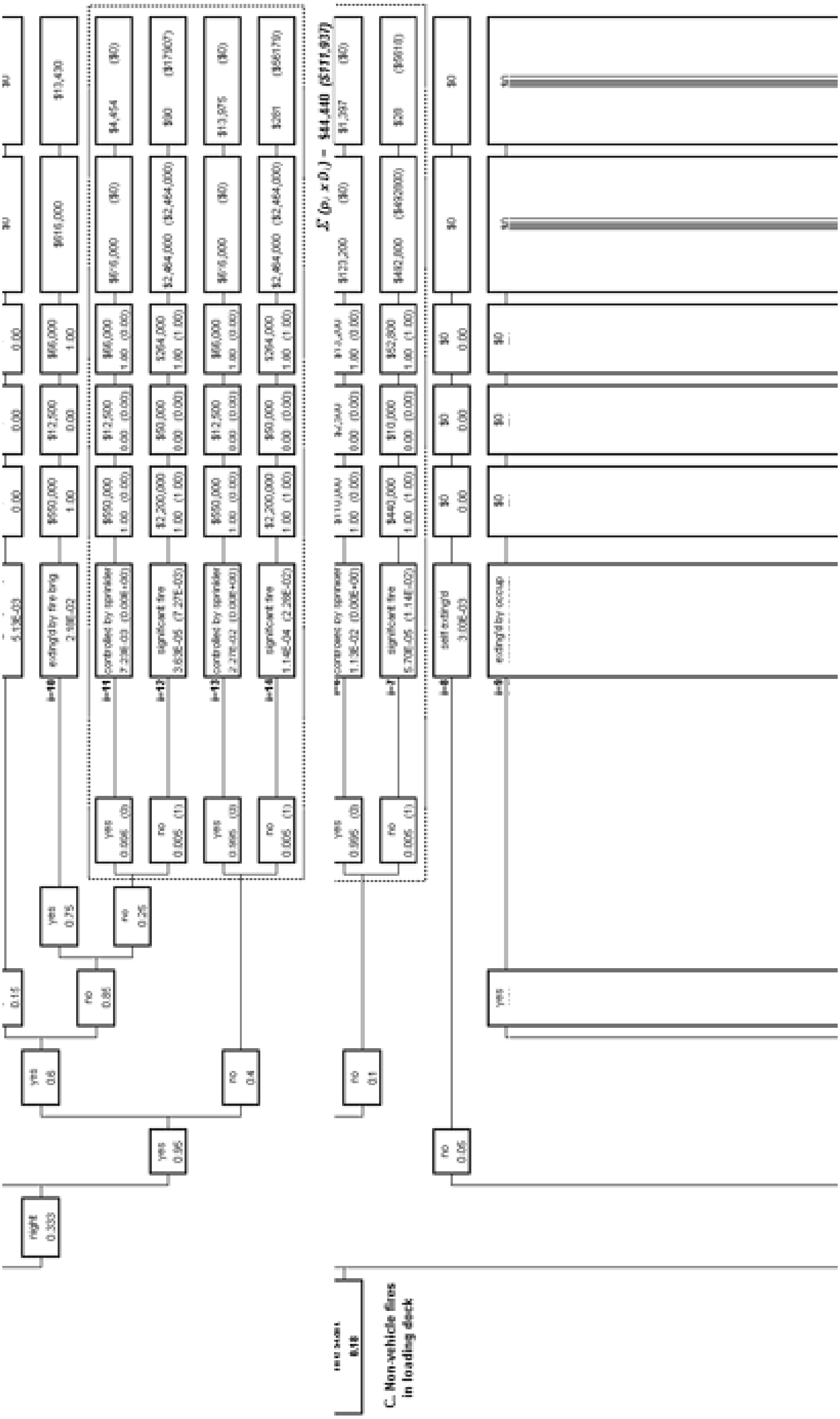


Figure A4: Event tree – non-vehicle fires.

WENG POH

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Weng obtained his Bachelor of Engineering (civil) from the University of Melbourne and the degrees of Master of Engineering Science and Doctor of Philosophy from Monash University.

Weng has a broad range of engineering experience. He has worked in various organisations as a site engineer, design engineer, research engineer, engineering risk-management consultant and fire safety engineer.

In the area of fire engineering Weng is an internationally recognised expert, particularly in the behaviour of building materials and structures in fire. He has been closely involved in the development of methodology for fire safety designs of buildings. Weng has published extensively in international journals and conference papers.

Recently, Weng, together with Dr Ian Thomas and Dr Ian Bennetts of Victoria University, have been awarded the IEAust's prestigious R.W. Chapman Medals for their paper entitled "A Framework for Fire Engineering Design".

Weng has been involved in numerous fire-engineering design projects. Some recent projects include the Toyota Head Office (Melbourne), Melbourne Sports and Aquatic Centre – Stage 2 Extension, Watergate Commercial Development (Dockland, Melbourne), GPO Melbourne Redevelopment, Chevron Redevelopment (Melbourne) and The John Curtin School of Medical Research Redevelopment (ACT).

Weng has also assisted a number of large organisations, including Telstra and Coles Myer Ltd, to develop national fire-safety policies and manuals for managing the fire safety of their facilities throughout Australia.

IAN BENNETTS

Ian Bennetts is a Research Fellow at the Centre for Environmental Safety and Risk Engineering at Victoria University of Technology where he undertakes research and teaching activities. He obtained his BE (Hons) from Monash University in 1971, M Eng Sc in 1973 and PhD in 1980 from the same institution. He joined BHP Research in 1980 after working for a major steel fabricator and as a Senior Tutor in structural engineering at Monash University. Since that time he has been involved with many research projects involving steel structures, steel connections, behaviour of steel, concrete and composite structures in fire, and fire-safety and risk assessment, and has supervised numerous research projects. He has also worked as a fire-safety consultant for various large mining and manufacturing companies and contributed directly to many of the large construction projects in Australia. He was the leader of Fire Code Reform Project 6 which was undertaken to study the fire safety of shopping centre buildings. His research interests include stair pressurization, fires in public transport vehicles, sprinkler reliability and effectiveness and various aspects relating to the behaviour of structures in fire.