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FIRE RISK ASSESSMENT USING THE BUILDING FIRE SAFETY ENGINEERING METHOD

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SUMMARY

This paper describes a method of fire risk assessment known as the Building Fire Safety Engineering Method (BFSEM).The method has mainly been developed at Worcester Polytechnic Institute in the USA and is designed for use by persons with knowledge and experience of fire behavior and building construction. The main components of the method include evaluation of the probability of the fire self-terminating, probability of automatic suppression, and probability of manual suppression by a fire service. Factors affecting each of these components are discussed. The probabilities are combined to form an L-Curve describing the probability of limiting the fire to defined areas of the building. Comparison of L-Curves for different fire protection options forms the basis of the risk assessment.

INTRODUCTION

New Zealand's performance-based building code[1] potentially provides the opportunity for the application of fire risk assessment methods as a way of evaluating alternative fire protection options in buildings. However, this type of risk assessment is generally not well understood either by the design engineers or the approving authorities. There are no particular methods which are currently generally accepted as being appropriate, and the methods which are in existence are not commonly used because: (1) they are still under development and are not yet readily usable by anyone other than the developers; (2) they are time-consuming and therefore very expensive to apply in an industry which is seeking to minimize costs; and (3) they are not widely understood or known.

Risk assessment has been available for many decades, and the scope and complexity of such methods varies greatly from simple checklists and points schemes,[2,3] to computer-based simulations of probability and consequence analysis.[4,5,6] Fire and smoke spread throughout buildings can be enormously complicated, and risk assessment methods which calculate scenario consequences using deterministic approaches must also by necessity make many simplifying assumptions. There are many exciting developments taking place where probabilistic and deterministic methods are brought together, but these methods are also very complex and their widespread use is still some years away. Therefore, it is clear that a range of different methods, of varying levels of complexity to suit the particular problem and application at hand, is likely to be required. This paper describes a fire risk assessment method developed in the United States and generally known as the Building Fire Safety Engineering Method (BFSEM).

BACKGROUND

Most of the development of the BFSEM has taken place at Worcester Polytechnic Institute, USA under the guidance of Professor Robert Fitzgerald over the last 20 years.[7] In principle, the BFSEM is based on an event tree analysis. However, the method relies quite heavily on the subjective judgment of the user who assesses the relative probability of many possible events based on knowledge of fire dynamics, building design, human behavior, and fire protection systems. This subjective judgment should in no way be interpreted as "guesswork," and therefore it is a requirement that a user of the method have experience and knowledge of fire and buildings. This being the case, conclusions drawn by different individuals based on the application of the method tend to be quite similar.

The BFSEM can be used to evaluate fire spread in terms of potential damage to the building, with most applications tending to concentrate on property protection issues. Consideration of life safety issues in terms of smoke spread is not yet adequately integrated into the method. Therefore, this discussion will focus on the use of the BFSEM to evaluate potential for fire spread and subsequent property loss.

BFSEM: A DESCRIPTION

The BFSEM revolves around the evaluation of a series of interconnected network diagrams or probability trees, with the first step being to identify fire scenarios and rooms of origin in the building which potentially form worst case scenarios. "Worst case" is not intended to include a nuclear event or other extraordinary occurrence, but rather "reasonable" fire scenarios having the most adverse effect on the building. In all cases, established burning is assumed to have occurred, so that this method does not consider probability of ignition, but rather the consequences given that fire has occurred and has reached the stage of established burning. Established burning is defined as the presence of a flame approximately knee-high (or about 5-10 kW in heat release terms).

Given established burning, the next step is to evaluate the likelihood that the fire will continue to grow (I-Curve), the likelihood that it will be controlled by an automatic suppression system (A-Curve) if one exists, and the likelihood that fire spread will be limited by manual suppression (M-Curve) through fire service intervention. These probabilities are then combined to calculate the probability of the fire being limited to a given area, room, or groups of rooms within the building (L-Curve). L-Curves for different fire protection strategies can be compared, and the design option with the higher probability of success in limiting the fire becomes the more effective or preferred fire protection strategy, given solutions of equal cost. Alternatively, given that an acceptable probability of success in limiting the fire has been agreed and achieved, different options can be then evaluated in terms of their cost.

To illustrate how the BFSEM may be used, an example will be presented in this paper. The analysis will be for a one-bedroom apartment on the 17th floor of an multistory apartment building, and the objective will be to limit fire spread to the apartment of fire origin. The apartment consists of a living room, bedroom, bathroom, and kitchen, with a total area of approximately 500 ft^2. The apartment is situated adjacent to a long corridor in the building, providing lengthy travel distances for occupants and for fire fighters. The apartment has a closely packed fire load, including easily ignited polyurethane foam padded seat cushions on a sofa and chair. The walls include combustible paneling, and the ceiling is of gypsum board construction. Some alternative fire protection strategies or options are as follows:

1. The apartment has sprinklers and easily ignited furniture
2. The apartment has no sprinklers and easily ignited furniture
3. The apartment has no sprinklers, but has room furniture and wall linings which are difficult to ignite
4. The apartment has both sprinklers and room furniture and wall linings which are difficult to ignite.

The I-Curve

The I-Curve is a representation of the measure of the probability (or degree of belief) of the fire self-terminating, given that established burning has occurred. An example of a network diagram used to determine the values required to construct an I-Curve is shown in Figure 1. The I-Curve is developed by considering the likelihood that the fire will self-terminate having already reached a certain size. Not unexpectedly, as the fire grows larger the probability that the fire self-terminates tends to reduce. Factors that must be considered include: the ignition and fire growth characteristics of the item first ignited; the proximity of other furniture/fuel to which the fire could spread (this might also include combustible wall lining material); and the size of the room (including the ceiling height). The network diagram is a form of probability tree. For example in Figure 1, the probability that self-termination does not occur is obtained by multiplying the values of the branches on the left side of the network diagram (0.82 x 0.90 x 0.95 x 0.95 = 0.666). The values on the right-hand side of the network diagram are determined by multiplying only the applicable branches and then summing the values.

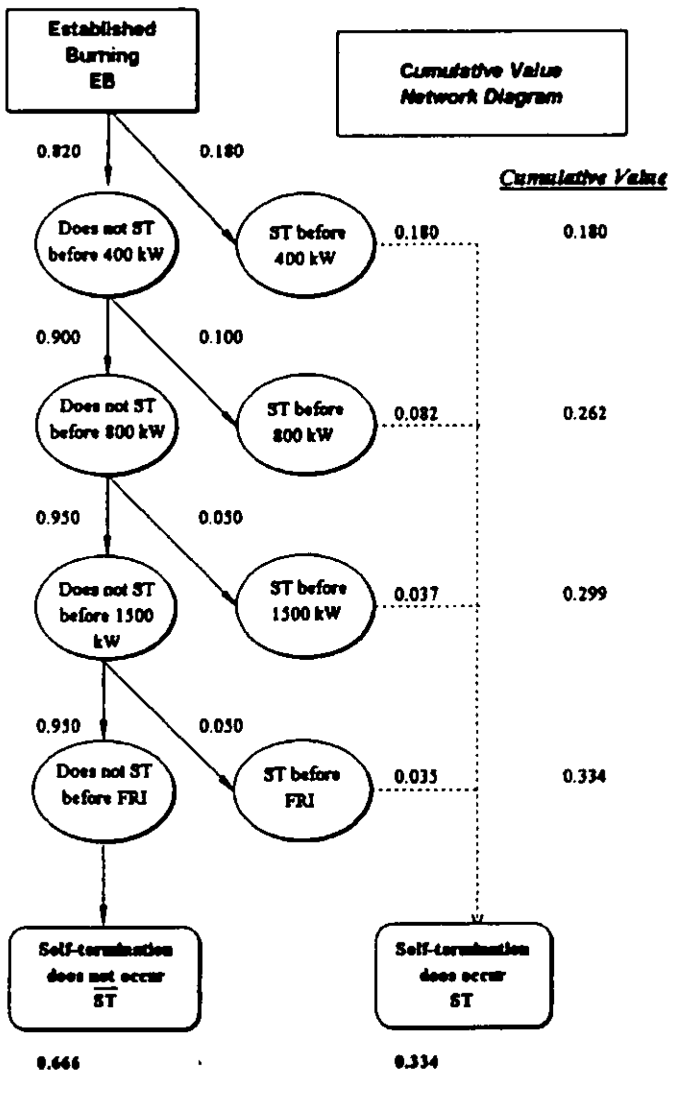

Figure 1. Network Diagram for the I-Curve (Option 1 and 2).

The A-Curve

The A-Curve is a representation of the measure of the effectiveness of an automatic suppression system in controlling the fire, given that established burning exists and the fire did not self-terminate. Figure 2 shows the single value networks for the probability that water can discharge from the sprinkler, and the probability that water does control the fire. The single value and cumulative value network diagrams used to determine the values for constructing the A-Curve are shown in Figure 3 and requires consideration of whether a sprinkler is present (AS), whether water is able to discharge from a sprinkler (AA), and also whether the water is able to control the fire (AC). A single value network considers the probability of each event based on the fire having already reached a specified size. The cumulative value network combines the single value network results into a cumulative estimate of the probability of the event.

In order for the overall reliability and effectiveness of an automatic sprinkler system to be evaluated, a number of individual factors need to be considered. These include:

- Is water available at the building site (baa)? Consider whether the water supply is adequate, whether the design of the distribution system is adequate, whether pipes are corroded, whether there are multiple or independent water supplies available, and whether the water pressure and flow rates available are adequate.

- Are the water supply valves open when the sprinkler heads fuse (vaa)? Consider whether the valves are monitored or supervised, and the frequency of inspection and maintenance.

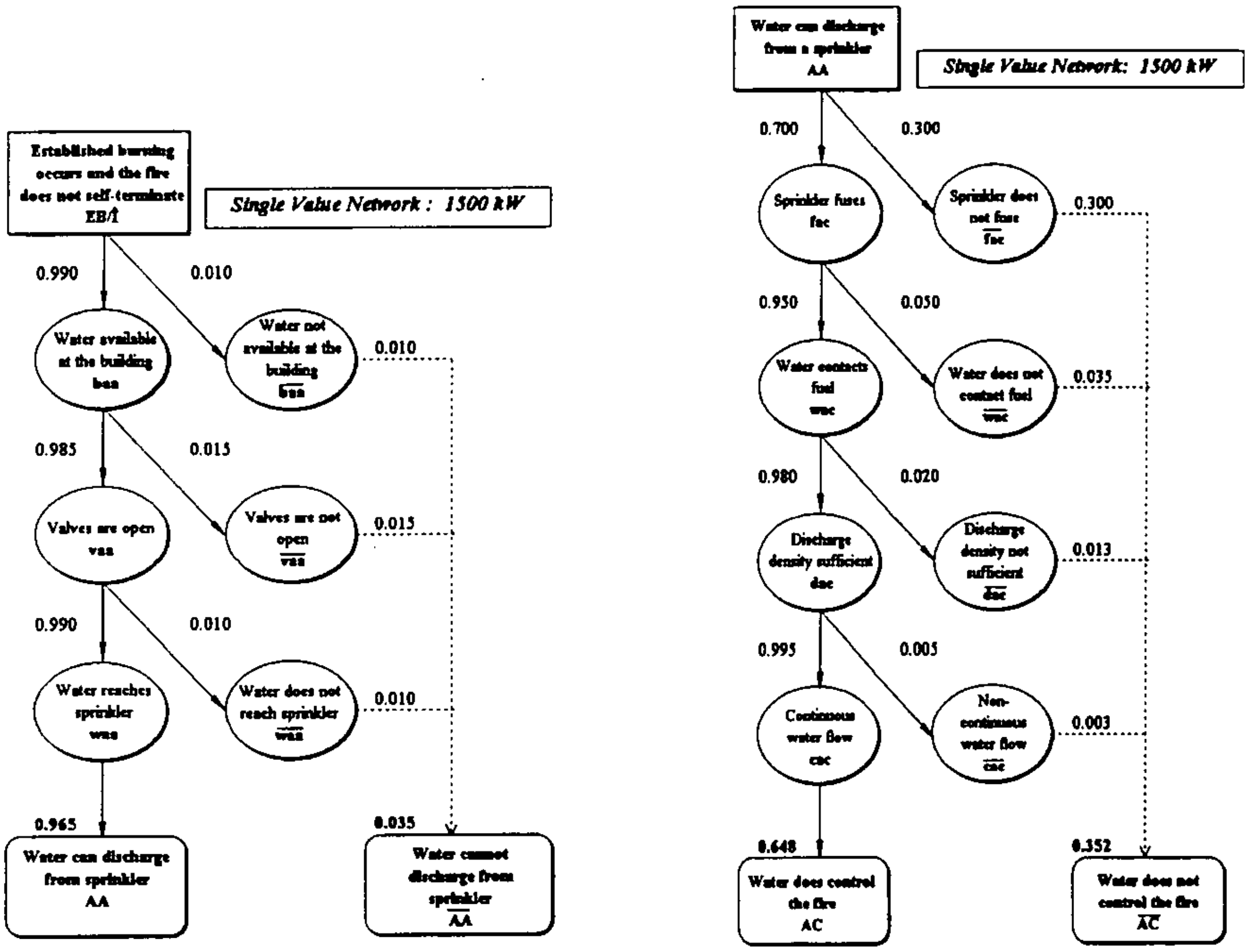

Figure 2. Network Diagrams for Sprinkler Effectiveness (Option 1 and 4).

- Is water able to reach the sprinkler head (waa)? Consider to what extent the pipes are affected by rust and scale deposits, and the frequency of pipe flushing. Is the sprinkler system wet or dry pipe?

- Does the sprinkler actuate before the fire extends beyond a critical size (fac)? Consider the nature of the fire and how quickly it is expected to grow. Is the temperature rating of the sprinkler bulb or link appropriate for the particular space, and are the sprinkler heads corroded or painted over?

- Is water from the sprinkler able to contact the fuel (wac)? Consider whether the fuel is protected with covers or shelves, or obstructed by new construction.

- Is the water discharge density sufficient to protect the hazard (dac)? Consider whether the water pressure is sufficient at the sprinkler head, whether the spray droplet sizes are sufficient with respect to the heat release rate of the fire, and the plume momentum.

- Will the water continue to flow for the required duration (cac)? Consider whether the water supply is adequate, whether changes have been made to the supply since the original design, and the reliability of fire pumps and power supplies.

Utilization of the BFSEM forces users to apply their own knowledge and experience, but they should also use deterministic approaches (such as simple engineering equations, experimental correlations, or computer models) to aid their judgment. An example of this would be in assessing the probability of a sprinkler link fusing (fac). An estimate of the likely fire size needed for sprinkler actuation is necessary. Fire protection engineers have available several computer models[8,9] for calculating an expected time of sprinkler actuation based on the room height, sprinkler tem-

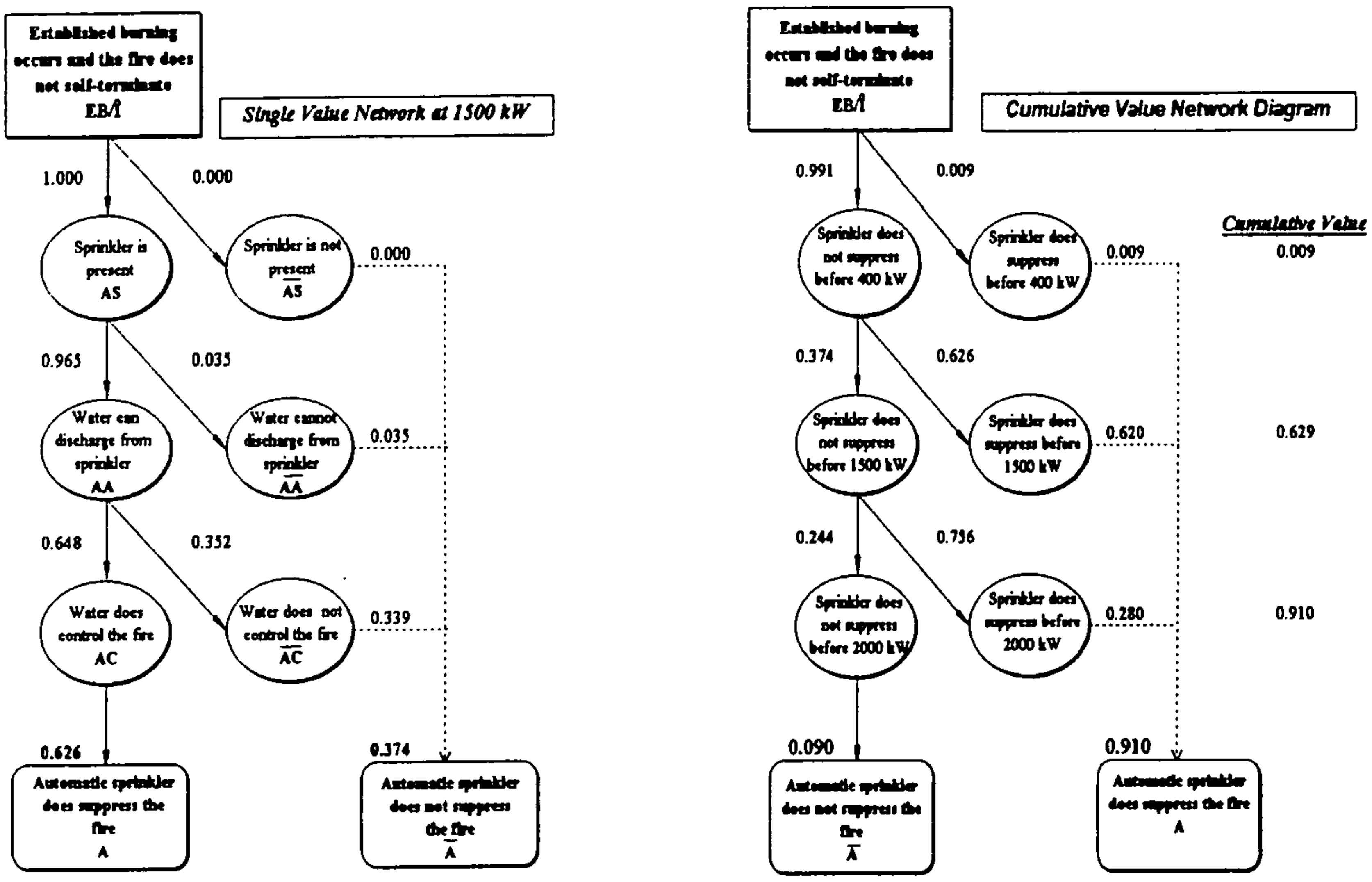

Figure 3. Network Diagrams for the A-Curve (Option 1 and 4).

perature rating and thermal lag characteristics of the sprinkler, and a heat release rate history for the fire. For example, if calculations show that a fire needs to reach 1000 kW before the sprinkler is expected to actuate, only a small probability of sprinkler actuation will be assigned if the current fire size is only 400 kW. And conversely, if the current fire size is 2000 kW, a high probability of sprinkler actuation will be assigned. An example of this single value network at a fire size of 400 kW is shown in Figure 4. This can be compared with the previous example at 1500 kW in Figure 2.

The M-Curve

The M-Curve is a representation of the measure of the effectiveness of manual suppression by fire service intervention in controlling the fire spread, given that established burning (EB) exists, the fire did not self-terminate, and automatic suppression was not effective. In order to evaluate the effectiveness of fire service intervention, timelines should be developed so that the growth of the fire can be compared against the likely response of the fire service. The timelines should indicate the likely time of fire detection, full room involvement (FRI), fire service notification, fire service arrival at the scene, and the time at which water is put on the fire. Calculations and other available data can be used to assist the user in estimating these times. For example, a certain fire growth rate could be assumed based on a t-squared fire. Correlations might then be used to predict the fire size (and therefore time) for a given room to reach full room involvement (or flashover).

An example timeline is shown in Figure 5. The timeline provides the user of the BFSEM with a better basis for evaluating the probabilities for the M-Curve. For example, if the timeline indicates that it would be very unlikely for the fire service to have water on the fire within 5 minutes of established burning, the probability of water discharge (by 5 minutes) would be correspondingly small.

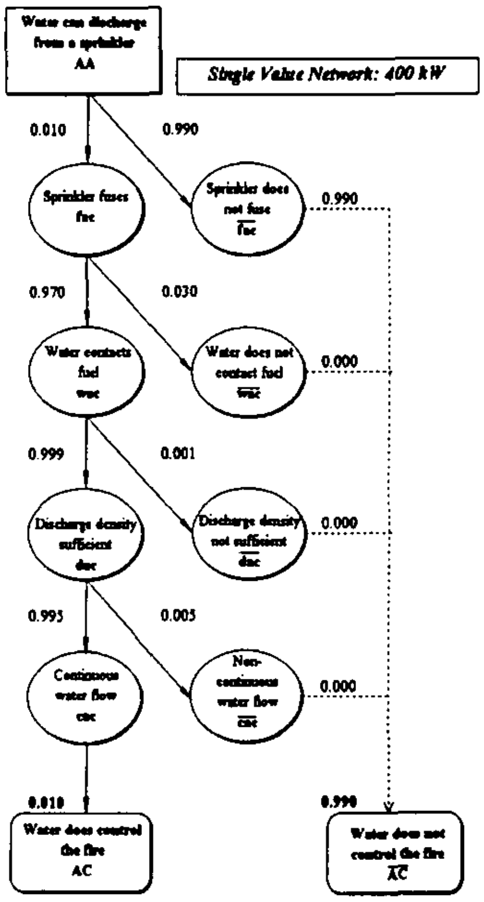

Figure 4. Single Value Network Diagrams for a Fire Size of 400 kW (Option 1 and 4).

The M-Curve encompasses three main components. The probability of fire service being notified (MN), the probability of a suppression agent (e.g., water) being applied (MA), and the probability of the fire being extinguished (ME). Each of these are evaluated at different times to form the network diagrams as shown in Figure 6 and used to construct the M-Curve. The input probabilities for Figure 6 come from Figures 7 and 8.

Similar to the development of the A-Curve, a number of different factors need to be considered before deciding on the effectiveness of manual suppression. They are:

- How is the fire detected (dmn)? Are there automatic detection systems, and how reliable are they? Where are the detectors located? What is the quality of the inspection and maintenance programs carried out? Is the building occupied? How many occupants (human detectors) are there? How big does the fire need to be before it is detected?
- Does someone decide to notify the fire service (pmn)? How big is the fire? Is it small enough that someone would choose to try to extinguish it, or would they make an emergency call instead? What is the mental state and capability of the occupants? Are they capable of raising an alarm?
- Is a message actually sent to the fire service (smn)? Is there a telephone available? How far away is it? How reliable are the transmission lines? Is there an automatic connection to the fire service?
- Is the message received by the fire service (rmn)? Can the caller be understood? Do the caller and answerer speak the same language?
- Will the fire service reach the site (rma)? How far do fire fighters have to travel? Is access to the fire scene easy? What are the expected weather and traffic conditions?
- Do the fire service get their hose nozzles to the area of fire origin (mna)? Is the seat of the fire easy to locate? How far do fire fighters need to carry hoses? Are there architectural obstructions that hinder hose-laying? What is the condition of hydrants and standpipes (dry-risers)? Are the resources of the fire service adequate?
- Does water flow from the hoses (sma)? Is water available, and do hydrants exist? If pumps are required, how reliable are they?
- Is the quantity of water available sufficient to extinguish the fire (qme)? Are there a sufficient number of hydrants, and are they conveniently located? Are standpipes available and are they adequately sized? Are there sufficient resources for fire fighting?

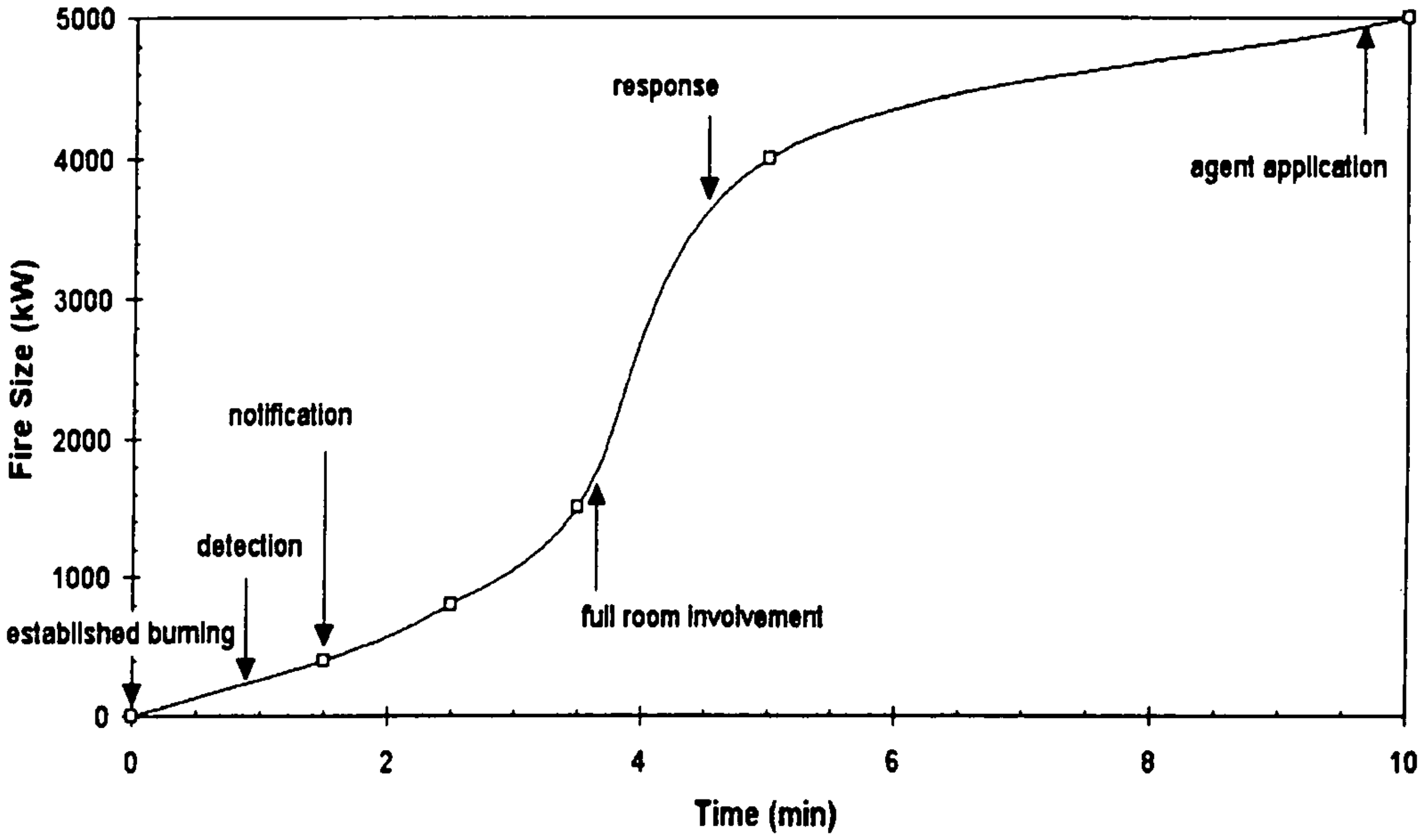

Figure 5. An Example Timeline for the Fire (Option 2).

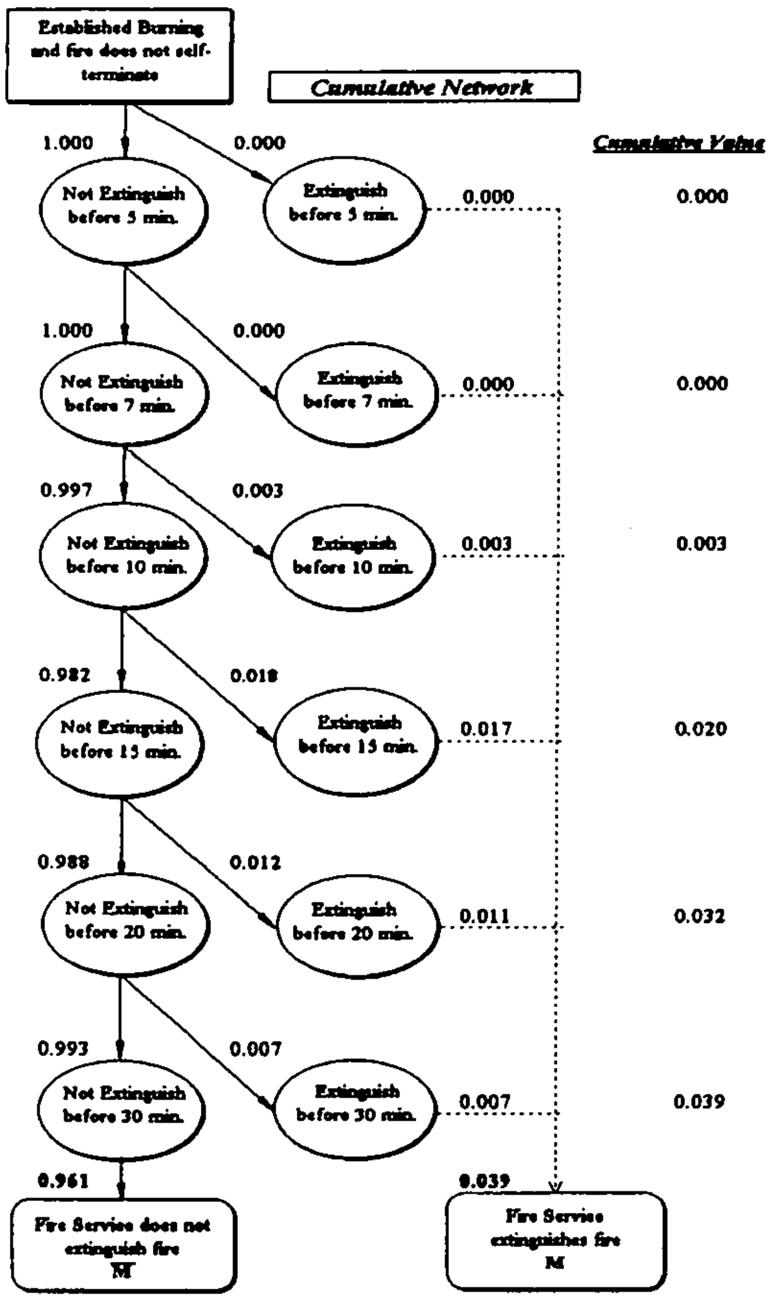

Figure 6. Network Diagram for the M-Curve (Option 1 and 2).

- Does extinguishment occur (bme)? Can the fire be vented? How big is the fire? What are smoke/heat conditions? How well-trained and experienced are the fire fighters?

The L-Curve

The L-Curve is the result of combining the I, A, and M curves and provides a representation of the measure of the overall probability of success in limiting the fire to a defined area. Single value network diagrams for a selected number of fire sizes (or times) are produced and these are then combined into a cumulative network diagram as shown in Figure 9.

Evaluating Alternative Protection Strategies

For Option 2, the I-Curve and M-Curve input values remain as given by Figures 1 and 6. However the L-Curve changes with the probability of automatic suppression becoming zero. The L-Curves for each of the four options are plotted on the fire safety evaluator shown in Figure 11.

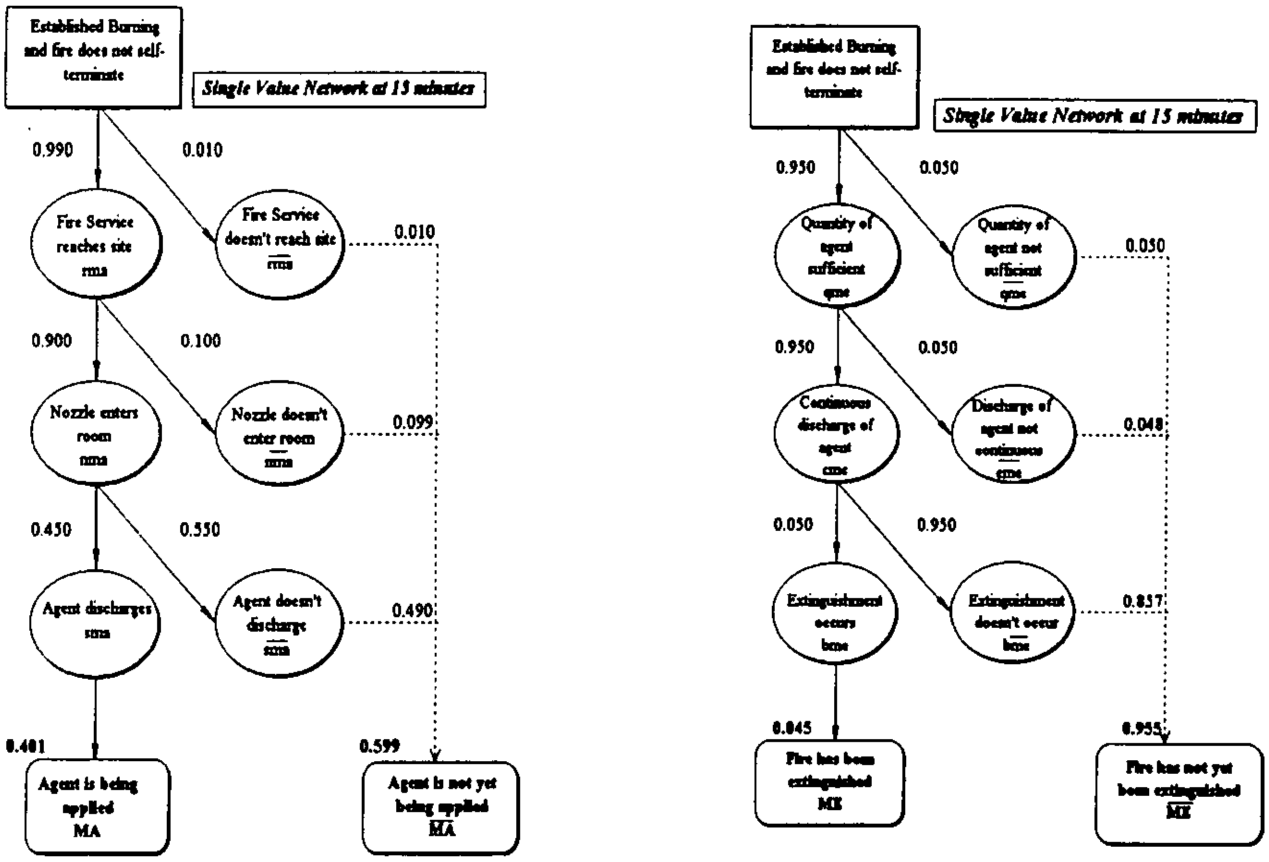

Figure 7. Single Value Networks for the M-Curve at 15 Minutes (Option 1 and 2).

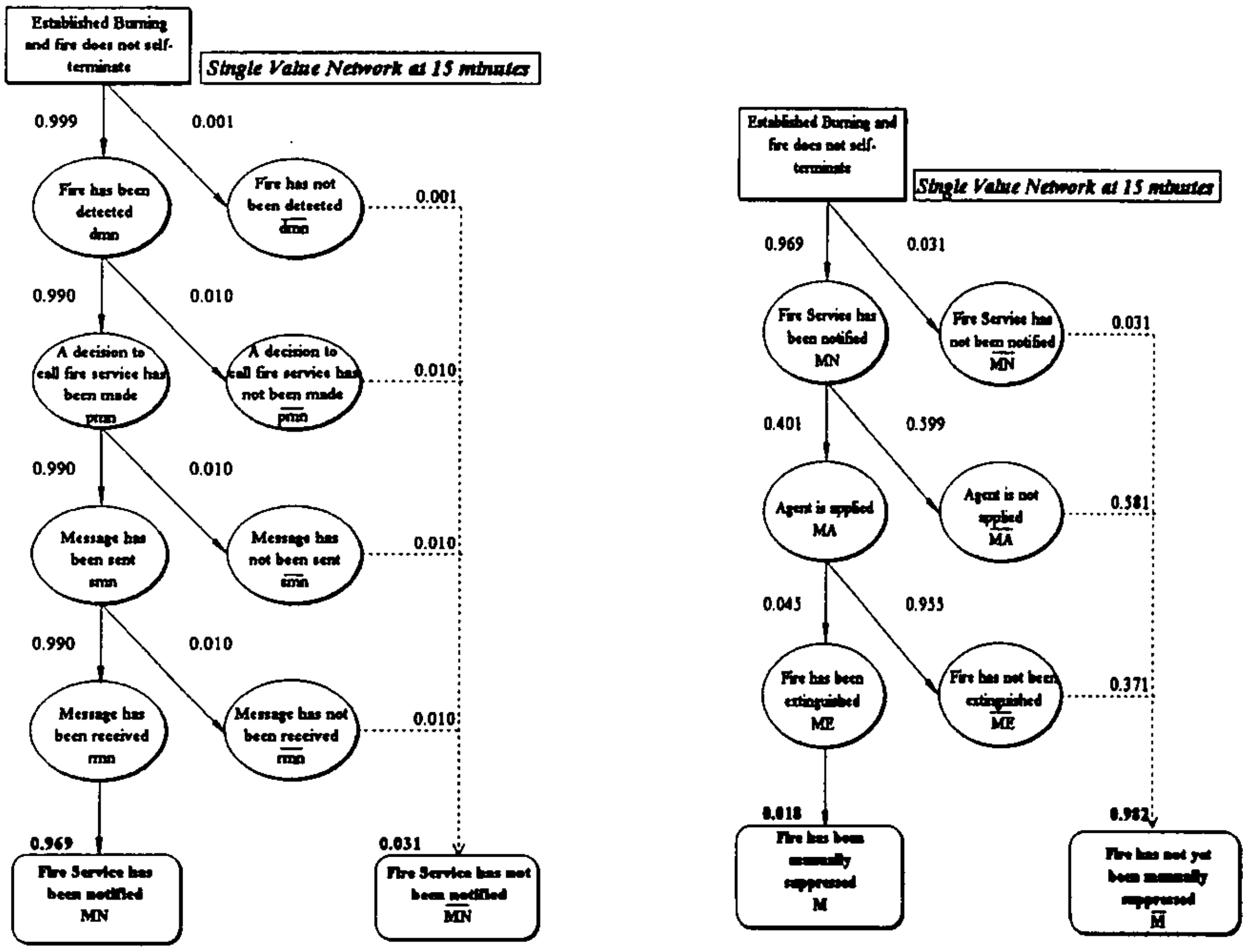

Figure 8. Single Value Networks for the M-Curve at 15 Minutes (Option 1 and 2).

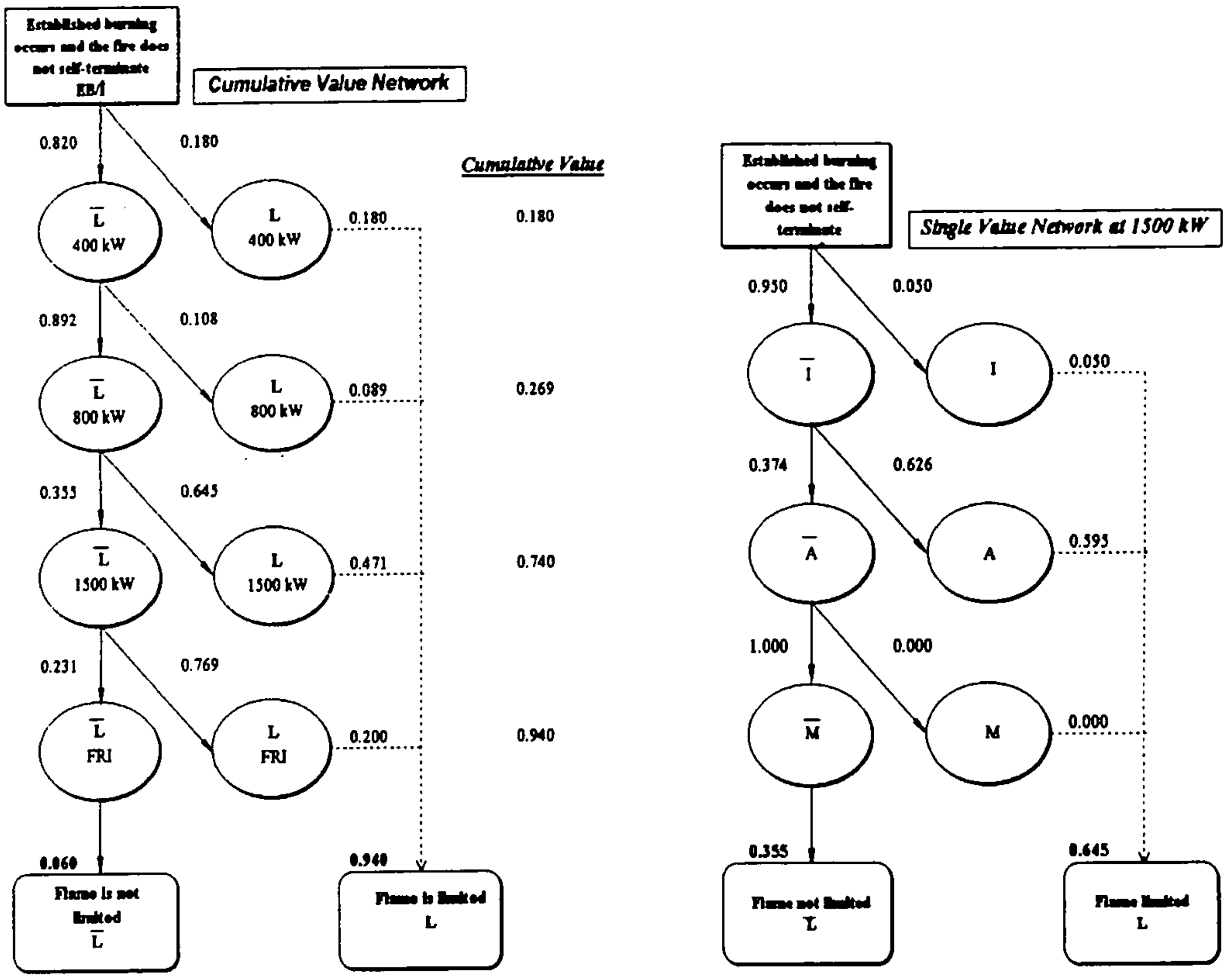

Figure 9. Network Diagram for the L-Curve (Option 1).

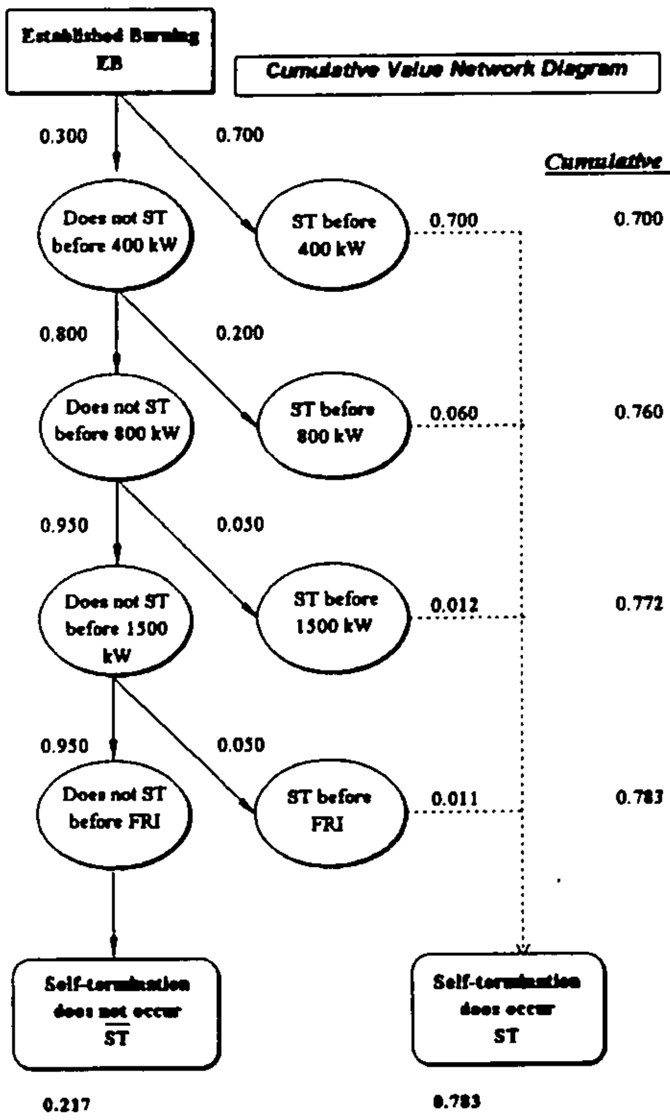

Figure 10. Network Diagram for the I-Curve (Option 3 and 4).

Option 3 is the same as Option 2 but the change in furniture flammability affects the I-Curve, and the resultant L-Curve as shown in Figures 10 and 11. Option 4 is the same as Option 1, but again the change in furniture flammability affects the I-Curve and the resultant L-Curve. It is assumed that, because of the location and height of the apartment in the building, the M-curve would be relatively unaffected by the change in the furniture characteristics.

Although this analysis has been relatively crude, it demonstrates the overall concept, and in this case purports to show that there are different means by which a certain level of safety or protection can be achieved, *i.e.*, by changing the flammability of the room contents and/or by using an automatic suppression system. In this example, the option with the greatest probability of success in limiting the fire to the apartment of origin is Option 4 (sprinklers and change in furniture). It is also noted that in this example the effect of fire service intervention in limiting the fire spread to

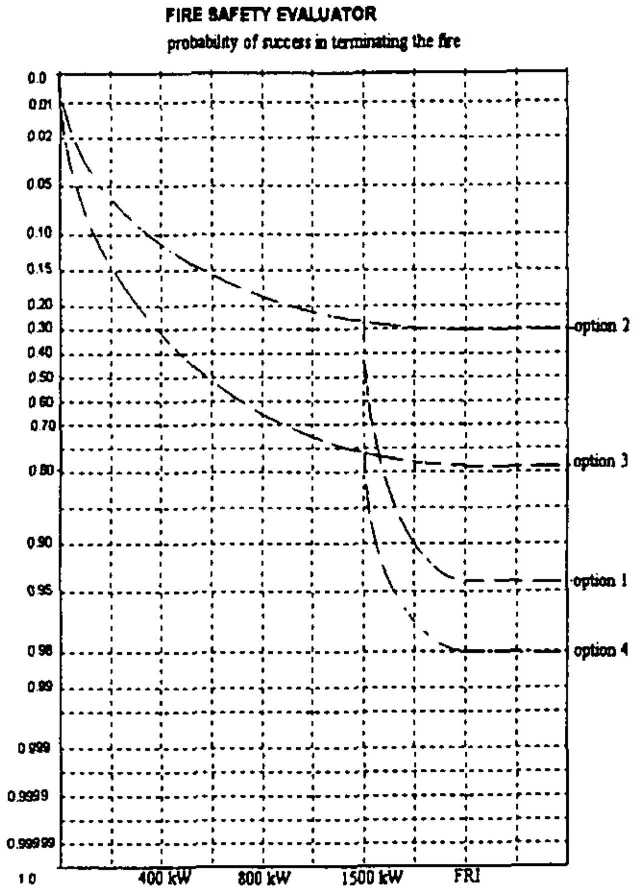

Figure 11. The Fire Safety Evaluator Showing Limit of Flame Spread for Options 1,2, 3, and 4.

the apartment of fire origin is negligible, since their response time is significantly longer than the time needed for the fire to totally involve the apartment of fire origin.

CONCLUSION

It can be seen that the BSFEM can quickly become quite complex and even unwieldy to use for anything but rather simple analyses. It is believed that this is one reason why the method has not been used as much as it might have been. It would certainly benefit from "computerization," and the authors believe that work is continuing toward this end at WPI. The main benefit from the method is that the analysis is very transparent, and it doesn't suffer from the "black box" syndrome that other methods (usually computer-based) have been criticized for. The use of subjective judgment is not necessarily detrimental, as there are so many areas and factors to consider, that suitable data may just not be available; then the knowledge, experience, and judgment of the user become invaluable.

This paper has described the BSFEM method of fire risk assessment, and has shown how it can be used in an analysis of a single apartment in a large apartment building. The probability of fire spread beyond the apartment of origin was compared for different fire protection options.

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NOTATION

A	probability of sprinkler suppressing the fire
AS	probability of sprinkler being present (0/1)
AA	probability of water discharge from sprinkler
AC	probability of water controlling the fire
EB	established burning
FRI	full room involvement
M	probability of manual suppression
MN	probability of fire service being notified
MA	probability of manual suppression agent being applied
ME	probability of fire being extinguished manually
ST	self-termination
L	probability of limiting the fire

aa	time of agent application
d	time of fire detection
n	time of fire service notification
r	time of fire service arrival at site
baa	probability of water being available at site
vaa	probability of water supply valves being open
waa	probability of water reaching the sprinkler head
fac	probability of sprinkler operating
wac	probability of water contacting the fuel
dac	probability of water discharge density being sufficient
cac	probability that water continues to flow
dmn	probability of fire being detected
pmn	probability of deciding to notify fire service
smn	probability of message being sent to fire service
rmn	probability of message being received by fire service
rma	probability of fire service reaching the site
nma	probability of hose nozzles reaching the area of fire origin
sma	probability of water flow from hoses
qme	probability of sufficient water available
bme	probability of extinguishing the fire

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