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Fire Propagation Tracing Model in the Explicit Treatment of Events of Fire PSA

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1. Introduction

The fire propagation model in a fire PSA has not been considered analytically [1, 2] instead a simplified analyst's intuition was used to consider the fire propagation path. A fire propagation equation is developed to trace all the propagation paths in the fire area in which a zone is defined to identify various fire ignition sources. An initiation of fire is assumed to take place in a zone. Then, the propagation is modeled with a Boolean equation. Since the explicit fire PSA modeling requires an exclusive event set to sum up the…, exclusive event sets are derived from the fire propagation equation. As an example, we show the exclusive set for a 2X3 rectangular fire zone. Also, the applicability the developed fire equation is discussed when the number of zone increases including the limitation of the explicit fire PSA modeling method.

2. Fire Propagation Equation

In this section fire propagation equation and exclusive event set are described.

2.1 Status Vector in a Fire Zone

In a usual fire risk assessment, fire area is divided into zones among which an initiating fire event in a single zone can be propagated depending on their propagation characteristics such as propagation probability. A fire event from a zone can have multiple fire propagation scenarios. In order to evaluate a risk of fire event in a fire area, the status of all fire zones should be known to assign a status which is used to indicate the operability of system/function located in this zone. Depending on the fire propagation route, the fire area would have numerous status of its zone. The status of zones in a fire area can be replaced with a status vector as follows:

$$\vec{S} = \left(s_1, \cdots s_i \cdots s_M\right) \quad (1)$$

Where s_i represent a stature of i'th zone. It can have values of 0 or 1. According to the Boolean notation convention, 1 means that a fire event occurs or is propagated to i'th zone. "0" means that there is no fire event or propagation in the i'th zone. The subscript, M in Eq. (1) denotes the total number of zones in a fire area. This status vector is an input to the conditioning of internal event fault tree (FT) to evaluate conditional core damage probability (CCDP). By mapping the status vector to the internal event FT, a CCDP of a single fire propagation scenario of a fire event can be obtained.

As an example, let's suppose a fire area with three fire zone as shown in Fig. 1. Assuming the initiating fire event taking place in zone 1, they can 4 exclusive status vectors as (1, 0, 0), (1, 1, 0), (1, 0, 1), and (1, 1, 1)

With an explicit approach of fire risk evaluation considering all possible fire propagation, all feasible fire propagation scenarios should be searched for a fire event. In other word, all possible status vectors should be known for a fire event. Then, a fire risk for a fire event can be evaluated by summing all CCDP of corresponding fire propagation scenarios because each fire propagation scenario is exclusive event each other.

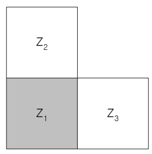

Figure 1 Fire Area segregated with three fire zone

2.1 Fire propagation equation

Let's denote F_i as an initiating fire event in i'th zones, and F_{ij} as a fire event which fire from i'th zone is propagated into j'th zone. They have the following relation using Boolean expression.

$$F_i = f_{ii} + \sum_{j \neq i}^{z_i} f_{ij} \qquad (2)$$

Where summation notation means an "OR" operation and the summation index, z_i represent the total number of zones neighboring i'th zone. The first term in the right-hand side means that the fire event from i'th zones was not propagated to any other adjacent zone. The repeated subscript hereafter is defined as a fire event was halted in the zone. The second term of right-hand side is sum of events which are propagated to adjacent zone. The two terms in the right-hand side is mutually exclusive because a fire event which is not propagated to other zone and a fire event which is propagated to other zone cannot happen simultaneously.

Eq. (2) can be further expanded considering fire propagation to next zone from j'th zone as follows:

$$F_i = f_{ii} + \sum_{j \neq i}^{z_i} \sum_{k}^{z_j} f_{ijk} \qquad (3)$$

The second term in the right-hand side can be separated two event group. One is for the events which fire propagation is stopped at the j'th zone and the other is for the events which are propagated to k'th zone. The separated equation is as follows:

$$F_i = f_{ii} + \sum_{j \neq i}^{z_i} f_{ijj} + \sum_{j \neq i}^{z_i} \sum_{k \neq i, j}^{z_j} f_{ijk} \qquad (4)$$

This process can be done until there is no zone to be propagated. The general form of fully expanded fire propagation equation can be written as:

$$F_i = f_{ii} + \sum_{j \neq i}^{z_i} f_{ijj} + \sum_{j \neq i}^{z_i} \sum_{k \neq i, j}^{z_j} f_{ijkk} + \cdots + \sum_{j \neq i}^{z_i} \cdots \sum_{k \neq i, j \cdots m}^{z_m} f_{ijk \cdots nn} \qquad (5)$$

3. Exclusive Event Set and an Example

To obtain a status vectors which are mutually exclusive, the events in Eq. (5) should be grouped. One can see from the Eq. (5) that events in the same propagation path are mutually exclusive. For the convenience of grouping, let's suppose a k'th path vector as follow:

$$P_k = (i, \quad j, \quad \cdots \quad n) \qquad (6)$$

All events occurring in the above path are mutually exclusive. For example, f_{ijj} and f_{ijkk} are mutually exclusive explained in the previous section. The path vectors can be obtained by inspecting the last terms of Eq. (5)

When a fire area has "m" numbers of path vector, the fire event can be written as follows:

$$F_i = \sum_{i=1}^{m} \Phi_i$$
$$= \sum_{i=1}^{m} \left(\Phi_i \cdot \prod_{\theta \neq i}^{m} \overline{\Phi_\theta} \right) + \sum_{i=1}^{m} \sum_{j=i+1}^{m} \left(\Phi_i \cdot \Phi_j \cdot \prod_{\theta \neq i, j}^{m} \overline{\Phi_\theta} \right)$$
$$\cdots + \prod_{\rho=1}^{m} \Phi_\rho \qquad (7)$$

where Φ_i represent the event group in the i'th path vector. In Eq. (7) all terms are mutually exclusive.

For an example, we show an exclusive event set in the fire area as shown in figure. 2.

1	2	3
4	5	6

Figure 2 A fire area with 6 zones

Table 1 shows the all possible propagation path vectors and event set in their paths. In this example, there are 5 propagation paths. Table 2 shows the exclusive event set under the truncation limit of 4 zone propagation.

Table 1 Path Vector and events for 2X3 fire area

Propagation Path	group	Events
P_1=(1,2,3,6,5,4)	Φ_1	f_{122}, f_{1233} f_{12366}, f_{123655}, $f_{1236544}$
P_2= (1,2,5,4)	Φ_2	f_{1255}, f_{12544}
P_3= (1,2,5,6,4)	Φ_3	f_{12566}, f_{125633}
P_4= (1,4,5,6,3,2)	Φ_4	f_{144}, f_{1455}, f_{14566}, f_{145633}, $f_{1456322}$,
P_5= (1,4,5,2,3,6)	Φ_5	f_{14522}, f_{145233}, $f_{1452366}$,

Table 2 Event set truncated by 4 zone limitation

Propagation type	Events
Single	f_{122}, $f_{1233,}$ f_{12366}, f_{1255}, $f_{12544,}$ $f_{12566,}$ f_{144}, f_{1455}, f_{14566}, f_{14522}
Double	f_{1233}X $f_{1255,}$ f_{122}X $f_{144,}$, f_{122}X $f_{1455,}$, f_{1233}X $f_{144,}$, f_{1255}X $f_{144,}$

4. Conclusions

Fire propagation equation was developed to trance possible propagation path and to identify the status of the fire zone. All propagation event was redistributed to obtain exclusive event set. As an example, a fire area with 6 fire zones was analyzed, in which fire propagation path and their feasible fire event was identified.

The developed model has some limitations in the implementation to real fire PSA model since the number of events will increase exponentially. Some approximation techniques will be needed to reduce the event set.

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