Benefits of Balancing Method for Component RAW Importance Measure

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1. Introduction

In the Risk Informed Regulation & Applications (RIR&A), the determination of risk significant Structure, System and Components (SSCs) plays an important role, and importance measures such as Fussell-Vesely (FV) and RAW (Risk Achievement Worth)[1,2] are widely used in the determination of risk significant SSCs. For example, in the Maintenance Rule[3], Graded Quality Assurance(GQA)[4] and Option 2[5], FV and RAW are used in the categorization of SSCs.

Especially, in the GQA and Option 2, the number of SSCs to be categorized is too many to handle, so the FVs and RAWs of the components are practically derived in a convenient way with those of the basic events which have already been acquired as PSA (Probabilistic Safety Assessment) results instead of by reevaluating the fault tree/event tree of the PSA model. That is, the group FVs and RAWs for the components are derived from the FVs and RAWs of the basic events which consist of the group. Here, the basic events include random failure, Common Cause Failure (CCF), test and maintenance, etc. which make the system unavailable. A method called "Balancing Method" which can practically and correctly derive the component RAW with the basic event FVs and RAWs even if CCFs exists as basic events was introduced in Ref.[6]. However, "Balancing Method" has other advantage, i.e., it can also fairly correctly derive component RAW using fault tree without using basic events FVs and RAWs.

2. Methods and Results

If R is defined as a risk such as a Core Damage Frequency(CDF), and if base risk is R_o , and R_i^+ is the increased risk due to unavailable component *i*, then RAW is defined as bellows;

$$RAW = R_i^+ / R_0 \quad \text{-------------------------------------- (1)}$$

Let's assume R is represented as the following simple logic model:

$$R = (C_1 + C_2)f_1 + Af_1 + Bf_2 + Af_3 \quad \text{------------------- (2)}$$

Here, let's assume A, B, C_1 , C_2 have all 0.1 unavailability, and f_1 , f_2 , f_3 are 0.1/yr, 3.4/yr, 0.23/yr, respectively. C_1 and C_2 are the component C's failure modes.

To derive the component RAW for C using the fault tree, the common mistakes is just using '1' or 'True' for C_1 or C_2 in Eq. (2). A detailed analysis of the mistakes is described in Ref. [7]. For example, if just using '1' for C_1 or C_2, Eq. (2) becomes ;

$$R = 2f_1 + Af_1 + Bf_2 + Af_3 \quad (\rightarrow \text{overestimate by } 2f_1)$$

Or, if just using 'True' for C_1 or C_2, Eq. (2) becomes ;

$$R = f_1 + Af_1 + Bf_2 + Af_3$$
$$= f_1 + Bf_2 + Af_3 \ (\rightarrow \text{underestimate by deleting } Af_1)$$

2.1 Traditional Method

Thus, usually a good algorithm to calculate component RAW is to handle cutset equation as suggested in Ref.[8]. The followings are the steps to derive RAW for component C (= RAW_c) using the algorithm.

Step 1: Rename C_1 and C_2 with C. Thus,

$$R = (C + C)f_1 + Af_1 + Bf_2 + Af_3$$

Step 2: Boolean Reduction. Thus,

$$R = C f_1 + Af_1 + Bf_2 + Af_3$$

Step 3: Derive R_c^+ by assigning C = 1. Thus,

$$R_c^+ = f_1 + Af_1 + Bf_2 + Af_3 = 0.463$$

Meanwhile,

$$R_0 = (C_1 + C_2)f_1 + Af_1 + Bf_2 + Af_3 = 0.393$$

Thus,

$$RAW(C) = 0.463 / 0.393 = 1.18 \quad \text{------------------- (3)}$$

The disadvantage of this method is that it is not suitable for the components which have CCF failure modes[6].

2.2 Balancing Method

Risk R can be expressed by minimal cutsets. Each cut indicates a basic event whose probability is usually an unavailability of a SSC. Then, R can be expressed by a linear function of the basic event probability P as below[9]:

R= aP+b -- (4)

where,

P = an event probability of a component,
aP = the sum of all the minimal cutsets containing P,
b = the sum of all the other minimal cutsets which do not have P.

Then, the following relationship can be derived[10]:

RAW= 1 + FV*(1-P)/P -------------------------------- (5)

In the Balancing Method, component RAW can be derived using Eq. (5). Thus, in the example of Eq. (2), in order to derive RAW of component C using Balancing Method, first of all, FV_c should be calculated.

$$FV_c = [(C_+ C)f_1] / R_0 = [(0.1 + 0.1)*0.1] / 0.393 = 0.05$$

In the fault tree, however, FV_c can be directly derived as the followings. If the value of decreased CDF derived by assigning 'False' to the component or system C is defined as CDF^-_c, then

$$FV_c = (CDF - CDF^-_c) / CDF$$

From Eq. (5),

$$RAW_c = 1 + FV_c*(1-P_c)/P_c = 1 + (0.05)*[1- 0.8]/0.8 = 1.2 \quad \text{-- (6)}$$

By comparing Eq. (3) with Eq. (6), we can find two results are similar. That is, Balancing Method is good one to derive component RAW using the fault tree without using basic events FVs and RAWs since usually FV and P are derived easily.

3. Conclusion

Balancing Method is simple method to derive component RAW using fault tree without falling into a mistakes by assigning '1' or 'True', and first of all, it fairly correctly estimates the component RAW for the components having CCF modes.

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