

FTREX Features for a Multi-unit PSA

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1. Introduction

South Korea has many multi-unit nuclear sites. It is well known that there are possible $2^N - 1$ combinations of single unit PSA models for a *site risk model* (one or more core-damaged nuclear units) if there are N nuclear units in a single nuclear site. Furthermore, $2^N - N - 1$ combinations of single unit PSA models should be generated for a *multi-unit risk model* (two or more core-damaged nuclear units).

If a nuclear site has 10 nuclear units, there are 1,023 combinations for a site risk model, and possible 1,013 combinations for a multi-unit risk model. It means that the size of a site or multi-unit risk model is one thousand times larger than the single unit PSA model.

There has been no published document that explains a practical method (1) to combine single unit PSA models for generating a single or multi-unit risk model, and (2) to generate MCSs of all the combinations without losing their property.

2. Site and Multi-unit Risks

N unit PSA models should be carefully combined for generating all possible combinations of single unit PSA models for a site or multi-unit risk model. Since each combination is a very complex model, a site risk model is a gigantic fault tree that has $2^N - 1$ combinations of single unit PSA models. Thus, it is not easy to manually compose a site or multi-unit risk model and solve this model due to its huge size.

Let us illustrate three single unit PSA models for a site or multi-unit risk model. As shown in Fig. 1, there are seven ($2^3 - 1$) combinations of single unit PSA models for a site risk model, and four ($2^3 - 3 - 1$) combinations for a multi-unit risk model.

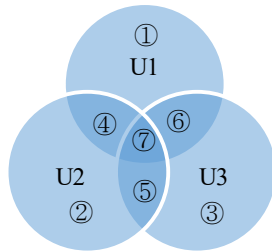


Fig. 1. Venn diagram for site or multi-unit risk

The seven combinations ① to ⑦ in Fig. 1 are listed in the form of a truth table in Table I. Here, Un and $/Un$ ($\#Un-X$ and $\#U1-0$) denote failed and successful states

(core damaged or not) of a single nuclear unit n , respectively.

Table I. Seven combinations for site risk

	System states	Flag combination
①	U1 /U2 /U3	#U1-X #U2-0 #U3-0
②	U2 /U1 /U3	#U2-X #U1-0 #U3-0
③	U3 /U1 /U2	#U3-X #U1-0 #U2-0
④	U1 U2 /U3	#U1-X #U2-X #U3-0
⑤	U2 U3 /U1	#U2-X #U3-X #U1-0
⑥	U1 U3 /U2	#U1-X #U3-X #U2-0
⑦	U1 U2 U3	#U1-X #U2-X #U3-X

By using the combinations in Table I, site and multi-unit risks can be formulated as

$$p(Risk_{Site}) = p(U1/U2/U3) + p(U2/U1/U3) + p(U3/U1/U2) + p(U1U2/U3) + p(U2U3/U1) + p(U1U3/U2) + p(U1U2U3) \quad (1)$$

$$p(Risk_{MUnit}) = p(U1U2/U3) + p(U2U3/U1) + p(U1U3/U2) + p(U1U2U3) \quad (2)$$

3. Two Methods for Site Risk Model

In this Section, truth-table and combination methods for composing site risk model are explained with three single unit PSA models. Logically, these two methods should generate identical minimal cut sets (MCSs) for a site risk model.

Truth table method generates all MCSs for a site risk in a single calculation. On the other hand, combination method can be employed at the initial stage of site risk model development and revision. These methods were implemented into fault tree solver FTREX (Fault Tree Reliability Evaluation eXpert)[1,2] for automatically generating a site risk model by reading N single unit PSA models. The fault tree solver FTREX is a popular fault tree solver for US EPRI members that is interfaced with US EPRI PSA tools such as CAFTA.

Let us illustrate very simple PSA models in Table II. The fault tree in MULTI.FTP has multiple top events of U1-CDF, U2-CDF, and U3-CDF. This fault tree shows that U1-CDF, U2-CDF, and U3-CDF have MCSs AB, CD, and EF, respectively. They have a common MCS XY.

Another fault tree in MULTIP.TOP has a single OR logic that has U1-CDF, U2-CDF, and U3-CDF that is used for informing FTREX of logical gates for single unit PSA models.

Table II. Multiple top event logics for three unit CDFs

MULTI.FTP
U1-CDF + U1-G1 U1-G2 U1-G1 * A B U1-G2 * X Y U2-CDF + U2-G1 U2-G2 U2-G1 * C D U2-G2 * X Y U3-CDF + U3-G1 U3-G2 U3-G1 * E F U3-G2 * X Y
MULTI.TOP
TOP + U1-CDF U2-CDF U3-CDF

FTREX command in Table III lets FTREX (1) generate a fault tree for a site risk model in Fig. 2 by combining U1-CDF, U2-CDF, and U3-CDF, and (2) convert this fault tree into MCSs in Table III. These MCSs are for the site risk in Eq. (1). MCSs that have at least two flag events among #U1-X, #U2-X, and #U3-X are chosen for the multi-unit risk in Eq. (2).

Table III. Site risk model by using truth table method

FTREX command
FTREX.exe MULTI.FTP MULTI.TXT /EMAP_MLT_TTBL=MULTI.TOP
Site risk model
TOP * U1 U2 U3 -TOP-MEX TOP-MEX * #U1-O #U2-O #U3-O U1 + U1-X U1-O U2 + U2-X U2-O U3 + U3-X U3-O U1-X * #U1-X U1-CDF U2-X * #U2-X U2-CDF U3-X * #U3-X U3-CDF U1-O * #U1-O -U1-CDF U2-O * #U2-O -U2-CDF U3-O * #U3-O -U3-CDF U1-CDF + U1-G1 U1-G2 U1-G1 * A B U1-G2 * X Y U2-CDF + U2-G1 U2-G2 U2-G1 * C D U2-G2 * X Y U3-CDF + U3-G1 U3-G2 U3-G1 * E F U3-G2 * X Y
Site risk MCSs in MULTI.TXT
#U1-X #U2-O #U3-O A B #U1-O #U2-X #U3-O C D #U1-O #U2-O #U3-X E F #U1-X #U2-X #U3-O A B C D #U1-O #U2-X #U3-X C D E F #U1-X #U2-O #U3-X A B E F #U1-X #U2-X #U3-XX Y #U1-X #U2-X #U3-X A B C D E F

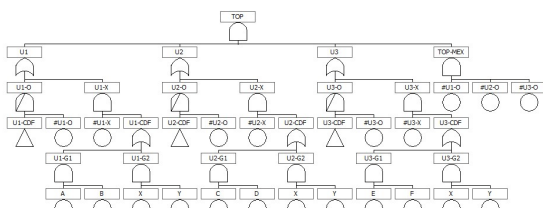


Fig. 2. Site risk model by using truth table method

The command in Table IV lets FTREX (1) generate a fault tree that has various combinations of U1-CDF, U2-

CDF, and U3-CDF, and (2) convert this fault tree into MCSs in Table IV. These MCSs should be manually or automatically processed for a site or multi-unit risk by delete-term approximation for reflecting the logics /Un in Table I.

Table IV. Site risk model by using combination method

FTREX command
FTREX.exe MULTI.FTP MULTI.TXT /EMAP_MLT_COMB=MULTI.TOP
Site risk model
TOP + TOP-G1 TOP-G2 TOP-G3 TOP-G1 * TOP-C1 #C1 TOP-G2 * TOP-C2 #C2 TOP-G3 * TOP-C3 #C3 TOP-C1 + U1-X U2-X U3-X TOP-C2 2 U1-X U2-X U3-X TOP-C3 * U1-X U2-X U3-X U1-X * #U1 U1-CDF U2-X * #U2 U2-CDF U3-X * #U3 U3-CDF U1-CDF + U1-G1 U1-G2 U1-G1 * A B U1-G2 * X Y U2-CDF + U2-G1 U2-G2 U2-G1 * C D U2-G2 * X Y U3-CDF + U3-G1 U3-G2 U3-G1 * E F U3-G2 * X Y
Site risk MCSs in MULTI.TXT (a)
#C1 #U1 A B #C1 #U2 C D #C1 #U3 E F #C1 #U1 X Y #C1 #U2 X Y #C1 #U3 X Y #C2 #U1 #U2 X Y #C2 #U1 #U3 X Y #C2 #U2 #U3 X Y #C2 #U1 #U2 A B C D #C2 #U1 #U3 A B E F #C2 #U2 #U3 C D E F #C3 #U1 #U2 #U3 X Y #C3 #U1 #U2 #U3 A B C D E F

(a) MCSs should be further processed for a site risk.

4. Conclusions

In this paper, truth-table and combination methods for composing a site or multi-unit risk model are explained and demonstrated with extremely simple PSA models. These two methods were implemented in FTREX. PSA analysts can take advantage of this FTREX feature instead of manual development of a site or multi-unit risk model. It is expected that this automation will drastically reduce the burden for multi-unit PSA.

REFERENCES

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- [2] W.S. Jung, "ZBDD algorithm features for an efficient Probabilistic Safety Assessment," Nuclear Engineering and Design, 239(10), pp. 2085-2092, 2009.