Application of fault tree analysis method to Force on Force (FOF) scenario development

Yun-Seon Chung , Jung-Soo Kim, Woo-Sik Jung*
Quantum and Nuclear Engineering, Sejong University, 209 Neungdong-ro, Gwanggin-gu, Seoul, Republic of Korea
Corresponding author: woosjung@sejong.ac.kr

1. Introduction

In 2015, the Act of Physical Protection and Radiological Emergency (APPRE) was revised, requiring licensees to submit their Force on Force (FOF) plan to the Nuclear Safety and Security Commission for approval, with evaluation conducted by the regulatory agency. The Korea Institute of Nuclear Nonproliferation and Control (KINAC) developed and evaluated a FOF evaluation system, and created FOF scenarios tailored to nuclear facilities and training types.

The existing method for generating FOF scenarios using Excel has several limitations. Firstly, combinations must be written manually, one by one. Secondly, errors in equations can be difficult to detect. Finally, once validation is completed, items that pass inspection must be separated and extracted.

However, generating scenario combinations using Fault Tree Analysis (FTA) has several advantages. It is easy to detect errors due to FTA's excellent visibility. It is possible to perform validation and exclusion of similar items simultaneously. Finally, FTA can quickly analyze more complex combinations.

2. Object and Contents

The purpose of this paper is to develop an efficient scenario generation method by comparing the existing scenario generation method using Excel with the scenario generation method using Fault Tree Analysis (FTA). Chapter 3.1 explains how to create scenarios using Excel, based on the final report on the development of physical protection training regulatory standards and evaluation technologies prepared by the Korea Institute of Nuclear Nonproliferation and Control (KINAC) [1]. Chapter 3.2 explains how to create scenarios using Fault Tree. Chapter 3.3 compares the scenario generation methods using Excel and Fault Tree. Chapter 4 presents the conclusions of this report.

3. Scenario generation method

3.1 Scenario generation method using Excel [1]

The scenario generation method step is shown in Fig.1. In the case of a general nuclear power plant, it is configured as shown in Fig.2. The routes of invasion of sabotage are as follows. Based on Fig.2, the table summarizing the intrusion routes is as follows.

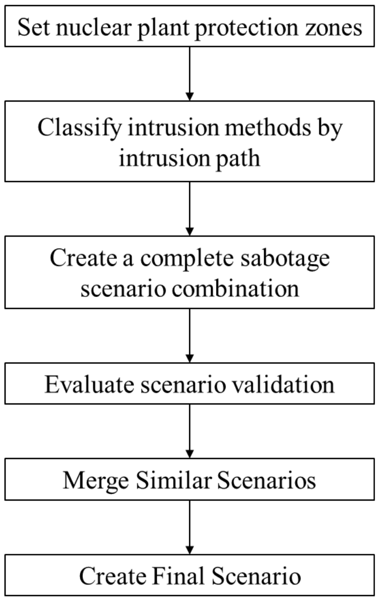

Fig. 2. Scenario generation method step

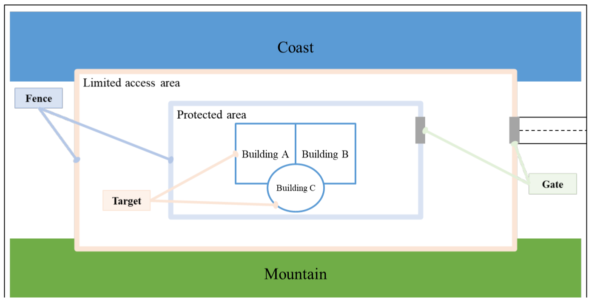

Fig. 1. Typical nuclear protected area conditions

Table I. Intrusion path classification

Purpose	Limited access area	Protected area	Target
Sabotage	Mountain	Fence	Building A
	Coast	Gate Periphery	Building B
	Airborne attack	Fake pass 2	Building C
	Main gate		
	Fake pass 3		

By combining the scenario components, complete scenarios with the main event can be generated. Table II below summarizes the constituent factors.

Table II. Intrusion method by intrusion path

Purpose	Intrusion method		Intrusion path		
	Weapon	Explosive	Limited access area	Protected area	Target
Sabotage	Homemade Gun	Vehicle Bomb	Mountain	Fence	Building A
	Pistol	Airborne Bomb	Coast	Gate Periphery	Building B
	Shotgun	Suicide vest	Airborne attack	Fake pass 2	Building C
	Rifle		Main gate		
	Machine gun		Fake pass 3		

The number of scenarios according to Table II is as follows.
Number of scenarios = 5 (Weapon) × 3 (Explosive) × 5 (Limited access area) × 3 (Protected area) × 3 (Target) = 675 (1)

Table III shows the overall sabotage scenario combination that combines the scenario constituent factors.

When a scenario combination is created, there are many scenarios that lack realism or logic. The procedure for excluding these illogical scenarios is called validation. Validation proceeds in the order of finding logically incorrect factor combinations and excluding scenarios that include those factor combinations among all scenarios. In the sabotage scenario, the following four combinations are logically incorrect.

- (Non-logical combination 1) Vehicles are difficult to come mountain, coast and airborne.
- (Non-logical combination 2) Suicide vests are difficult to pass through X-ray detectors or metal detectors.
- (Non-logical combination 3) If there is a forged access to the limited access area, the protected area can also be forged, so it is impractical to forcefully invade other areas.
- (Non-logical combination 4) After the main gate attack, it is common to break into the nearest fence quickly.

Using the Excel equation shown in Fig. 3 below, we found 675 scenarios that contained the four non-logical combinations described above. As a result of the validation test, 345 of the 675 sabotage scenarios passed.

Fig. 3. Example of scenario validation

After validation, the resulting scenarios can be used for physical protection training, but because there are so many scenarios, we should perform a procedure to merge similar ones for ease of use and management.

Scenarios with similar expected effects are extracted and the scenario with the greatest effect is selected. The merger of similar scenarios applies the following two points.

- Machine guns with the highest killing power were selected as the maximum effect scenario.
- Since the inside of the building is not included in the training range, the expected effect of each target building is similar, so A, which is closest to the fence among targets A, B, and C, was selected as the maximum effect scenario.

Table III. Intrusion method by intrusion path

No.	Weapon	Explosive	Limited access area	Protected area	Target
1	Homemade Gun	Vehicle Bomb	Mountain	Fence	Building A
2	Homemade Gun	Vehicle Bomb	Mountain	Fence	Building B
3	Homemade Gun	Vehicle Bomb	Mountain	Fence	Building C
4	Homemade Gun	Vehicle Bomb	Mountain	Gate Periphery	Building A
5	Homemade Gun	Vehicle Bomb	Mountain	Gate Periphery	Building B
6	Homemade Gun	Vehicle Bomb	Mountain	Gate Periphery	Building C
7	Homemade Gun	Vehicle Bomb	Mountain	Fake pass 2	Building A
:	:	:	:	:	:
672	Machine gun	Suicide vest	Fake pass 3	Gate Periphery	Building C
673	Machine gun	Suicide vest	Fake pass 3	Fake pass 2	Building A
674	Machine gun	Suicide vest	Fake pass 3	Fake pass 2	Building B
675	Machine gun	Suicide vest	Fake pass 3	Fake pass 2	Building C

After merging similar scenarios, we generated the final set of scenarios shown in Table IV below.

Table IV. Combination of final sabotage scenarios

No.	Weapon	Explosive	Limited access area	Protected area	Target
568	Machine gun	Vehicle Bomb	Main gate	Fence	Building A
577	Machine gun	Vehicle Bomb	Fake pass 3	Fence	Building A
580	Machine gun	Vehicle Bomb	Fake pass 3	Gate Periphery	Building A
583	Machine gun	Vehicle Bomb	Fake pass 3	Fake pass 2	Building A
586	Machine gun	Airborne Bomb	Mountain	Fence	Building A
589	Machine gun	Airborne Bomb	Mountain	Gate Periphery	Building A
595	Machine gun	Airborne Bomb	Coast	Fence	Building A
598	Machine gun	Airborne Bomb	Coast	Gate Periphery	Building A
604	Machine gun	Airborne Bomb	Airborne attack	Fence	Building A
607	Machine gun	Airborne Bomb	Airborne attack	Gate Periphery	Building A
613	Machine gun	Airborne Bomb	Main gate	Fence	Building A
622	Machine gun	Airborne Bomb	Fake pass 3	Fence	Building A
625	Machine gun	Airborne Bomb	Fake pass 3	Gate Periphery	Building A
628	Machine gun	Airborne Bomb	Fake pass 3	Fake pass 2	Building A
631	Machine gun	Suicide vest	Mountain	Fence	Building A
634	Machine gun	Suicide vest	Mountain	Gate Periphery	Building A
640	Machine gun	Suicide vest	Coast	Fence	Building A
643	Machine gun	Suicide vest	Coast	Gate Periphery	Building A
649	Machine gun	Suicide vest	Airborne attack	Fence	Building A
652	Machine gun	Suicide vest	Airborne attack	Gate Periphery	Building A

3.2 Scenario generation method using Fault Tree

This chapter details the process of generating scenarios using Fault Tree. The process is illustrated in Fig.4.

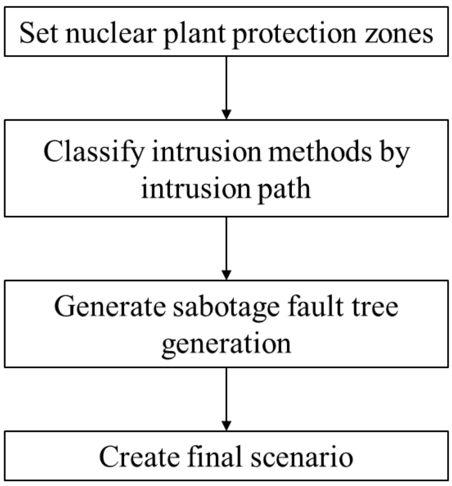

Fig. 4. Example of scenario validation

Sabotage was selected as the Top Event according to the intrusion method for each intrusion path (Table II). The words in parentheses in Table V are abbreviations used when creating fault tree.

Sabotage was selected as the top event according to the intrusion method for each intrusion path (Table V).

- Sabotage is successful only when both the characteristics of the threat and the route of intrusion are successful, so connect it to And gate.
- Since the nature of the threat is successful only when both Weapon/Explosive are successful, connect them to the And gate.
- Limited access area/Protected area/Target must all be successful in order for the intrusion path to succeed, so connect it to the And gate.
- The basic events of detailed Weapon/Explosive/ Limited access area/Protected area/Targets are all connected to Or gate.

The Fault Tree prepared according to the above situation are shown in Figure 5 below.

- In an illogical combination, both factor 1 and factor 2 must succeed to succeed, so connect to And gate.
- The basic events of factor 1 and factor 2 connect to the Or gate.
- Connect the four non-logical combinations of the fault trees in Figure 5 with Not gate.

Table V. Intrusion method by intrusion path

Purpose	Intrusion method		intrusion path		
	Weapon	Explosive	Limited access area	Protected area	Target
Sabotage	Homemade Gun (HOM)	Vehicle Bomb (VHB)	Mountain (MTN)	Fence (FEN)	Building A
	Pistol (PIS)	Airborne Bomb (ABB)	Coast (COA)	Gate Periphery (GPE)	Building B
	Shotgun (SHG)	Suicide vest (SVB)	Airborne attack (AIR)	Fake pass 2 (FPS2)	Building C
	Rifle (RFL)		Main gate (MGA)		
	Machine gun (MGN)		Fake pass 3 (FPS3)		

The fault trees prepared according to the described situation are shown in Figure 6. Similar scenarios are applied to the fault trees in Figure 6. The attack target set is calculated using FTREX (Fault Tree Reliability Expert) software for the completed sabotage fault tree in Figure 7. As a result, 23 scenarios were created using the same method as the existing scenario generation method.

Table 6 appears to be different from Table 5 as it is not sorted, but upon sorting through Excel, it can be seen that the two tables are identical. While the current version of FTREX lacks sorting capabilities, we plan to add sorting and grouping functions in the future.

4. Comparison of scenario generation methods

The two scenario generation methods share the same approach of setting the state of the nuclear protected area and classifying the intrusion method by intrusion path. Furthermore, both methods generate 23 scenarios, as evidenced by the final results.

The differences between the two methods lie in the way they handle non-logical factors and similar scenarios. The Excel-based scenario generation method extracts these factors and scenarios after creating the entire combination, whereas the fault tree-based method deals with them while simultaneously creating the fault tree.

Despite having different calculation processes, the two methods yield the same results. Hence, using the fault tree to write physical protection training scenarios can aid in developing more efficient scenarios and evaluating them.

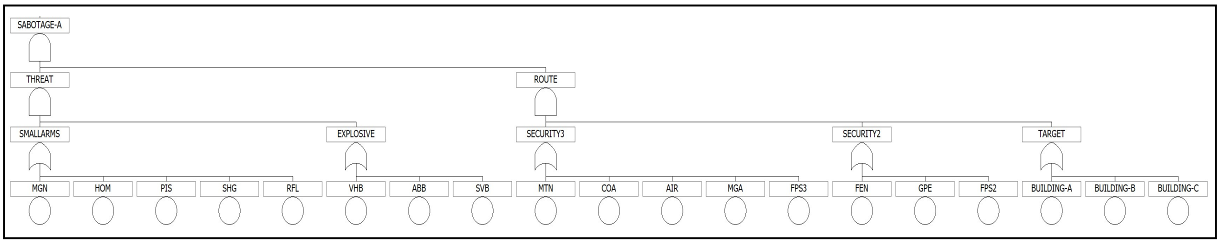

Fig. 5. Sabotage Fault Tree

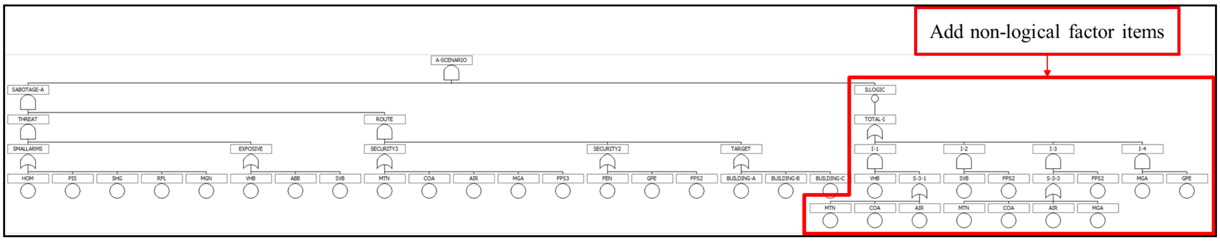

Fig. 6. Adding non-logical factor items to a sabotage fault tree

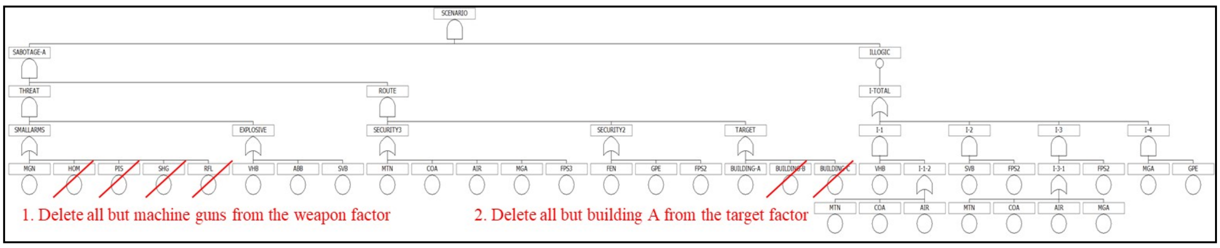

Fig. 7. Delete similar scenario entry on sabotage fault trees

Table VI . Combination of final sabotage scenarios

No.	Event1	Event2	Event3	Event4	Event5
1	BUILDING A	FPS3	GPE	MGN	VHB
2	ABB	BUILDING A	FEN	MGA	MGN
3	BUILDING A	FPS3	GPE	MGN	SVB
4	BUILDING A	FPS2	FPS3	MGN	VHB
5	ABB	BUILDING A	FPS3	GPE	MGN
6	BUILDING A	FEN	MGA	MGN	SVB
7	ABB	BUILDING A	GPE	MGN	MTN
8	BUILDING A	GPE	MGN	MTN	SVB
9	BUILDING A	FEN	MGN	MTN	SVB
10	BUILDING A	FEN	MGA	MGN	VHB
11	ABB	BUILDING A	FEN	MGN	MTN
12	ABB	BUILDING A	FPS2	FPS3	MGN
13	AIR	BUILDING A	GPE	MGN	SVB
14	ABB	BUILDING A	COA	FEN	MGN
15	ABB	AIR	BUILDING A	GPE	MGN
16	ABB	AIR	BUILDING A	FEN	MGN
17	AIR	BUILDING A	FEN	MGN	SVB
18	BUILDING A	COA	FEN	MGN	SVB
19	BUILDING A	FEN	FPS3	MGN	SVB
20	BUILDING A	FEN	FPS3	MGN	VHB
21	ABB	BUILDING A	FEN	FPS3	MGN
22	ABB	BUILDING A	COA	GPE	MGN
23	BUILDING A	COA	GPE	MGN	SVB

5. Conclusions

Conventional methods for calculating scenario combinations using Excel require manual creation of combinations one by one when extracting the entire scenario by combining scenario constituent factors such as intrusion purpose, portable weapon, intrusion path, etc. As a result, analysis may not be possible if it takes a long time or the combination becomes more complicated. Furthermore, after combining the scenario components, validation and exclusion of similar items should be performed using the Excel program formula, which is difficult to detect if there is an error in the formula, and it is a hassle to extract the items that passed the test separately after validation.

In contrast, the method of calculating scenario combinations using fault trees can efficiently handle relatively complex combinations and has the advantage of handling validation and similar scenario merging procedures at once during the process of generating fault trees. Currently, the scenarios derived are limited to outside the building in the training scope, but when calculated using fault trees, they can be linked to the physical protection training scenarios inside the building.

The existing methods of calculating scenario combinations using Excel and fault trees had different calculation processes, but they produced the same results. Therefore, it is believed that using fault trees to write physical protection training scenarios will help to develop more realistic and efficient scenarios and evaluate them..

Acknowledgments

This work was supported by the Korea Foundation Of Nuclear Safety (KOFONS) grant funded by the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 2106062-0323-SB110 and 2204017-0223-SB110).

REFERENCES

[1] KINAC, Development of regulation standards & evaluation technology on physical protection exercise, N-STAR, 2021.
[2] IAEA, Nuclear security recommendations on physical protection of nuclear material and nuclear facilities, book name, INFCIRC/225/Rev.5, 2011.