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Development of Dependency Analysis Rules for Multi-Unit HRA

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1. Introduction

Human reliability analysis (HRA) is often performed as part of the support structure for probabilistic safety assessment (PSA) in nuclear power plants (NPPs). Dependence is said to be involved when the occurrence of one event affects the possibility of another event occurring. According to NUREG-1792 [1], it is necessary to quantitatively account for dependencies among post-initiator human failure events (HFEs) in an accident sequence in the PSA model by virtue of the joint probability used for the human error probabilities (HEPs). The same would also apply to pre-initiator HFEs. To avoid dependency analysis of the human actions will be to inadvertently make the combined probabilities too optimistic. Therefore, there would be an inappropriate decrease in the risk significance of human actions and the related accident sequences and equipment failures.

Some of the current single unit HRA methodologies determine dependency levels based on a few dependency evaluation factors. However, these are for single unit HFE only. In fact, according to the Nordic PSA Group (NPSAG) report [2], HRA dependencies in multi-unit scenarios need to be developed.

This paper aims to describe new dependency assessment rules for assessing the dependency of multiple HFEs in the case of a multi-unit event scenario. The current dependency rules from different HRA methods are first described, followed by the new set of rules developed for dependency analysis for different HFEs in multiple units. An example is also used to describe the application of the rules.

2. Dependency rules for current single-unit HRA methods

In this section, some of the techniques used for dependency analysis by different methods for single unit HRA are briefly discussed.

2.1 The THERP/ASEP Method

The technique for human error rate prediction (THERP) method [3] is a generic HRA method which has a five-level dependency analysis model across human actions in a PRA sequence but requires significant analyst judgment. THERP method was the first to describe five dependency levels as; zero dependence, low dependence, moderate dependence, high dependence, and complete dependence. THERP also describes the fundamental equations governing the dependency levels of current and previous tasks based on success or failure paths. The Accident sequence evaluation program (ASEP) method [4] provides a simplified version of the THERP dependence model to include factors such as ‘Actions close in Time’, ‘Same Visual Frame of Reference’, ‘General Area only’, and ‘Writing Required’, but only three levels of dependence i.e. complete, high, and zero dependency.

2.2 The EPRI HRA Method

The ‘Electric Power Research Institute (EPRI) Method’ was a result of a project related to fire PRA. Although the NUREG 1921 [5] provided a method to assign levels of dependence while estimating HEPs for HFEs under fire conditions, it represents a state of practice for general HFEs in the NPP for EPRI and US NRC based methods. It includes nine factors to be considered and five dependency levels i.e. complete, high, medium, low, and zero dependencies.

2.3 The SPAR-H Method

The Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method [6] considers four factors for dependency evaluation. They include; crew (same or different), Time (close in time or not close in time), location (same or different), and cues (additional or no additional). This method also allocates five dependency level based on the THERP method.

2.4 The K-HRA Method

The standard Korean human reliability analysis (K-HRA) method [7] was developed at the Korean Atomic Energy Research Institute (KAERI) and it is currently being adopted at some NPPs in Korea. This method suggest a dependency analysis method which considers eight factors such as crew (same/different), cues (same/different), judgement rules of the cues (same/different), time difference between system time windows, time of cue occurrence, location, time interval between sequential cues, and stress level. However, it also reflects five dependency levels based on the THERP method.

3. Proposed dependency rules for multi-unit HRA

In this section, the rules developed to assess the dependency of multiple HFEs in a multi-unit event scenario are introduced. Thereafter, an example is used to describe the application of the rules.

3.1 Decision Tree for dependency Level Assessment

In determining the level of dependence, some factors from the SPAR-H method such as the Time (close in time / not close in time) and Crew (same/different) were adapted and modified, while adding new factors such as Action timing and Work device. It is considered that these factors generally reflect the unique case of multi-units. Figure 1 shows the suggested dependency analysis tree.

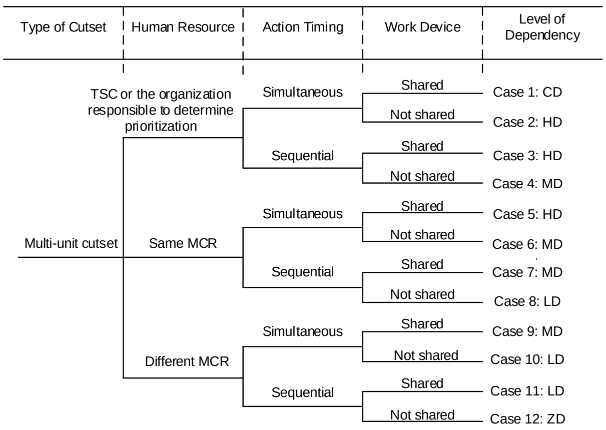

Fig. 1. Suggested dependency analysis tree for HFEs in multiple unit cutsets.

The 'Human Resource' (i.e. decision-making crew) is an important factor. The significant consideration for a multi-unit case is whether the decision-making is done by the technical support center (TSC), the same main control room (MCR) or a different MCR. The decision-making of the higher organization could greatly affect the next HFE. Representatively, the TSC's decision-making errors may affect both units at the same time or affect the decision of other units.

As for 'Action Timing', the term 'simultaneous' is used to denote actions performed at the same time or close in time (e.g. <5minutes) while 'sequential' is used to denote actions performed not close in time (e.g. >5minutes) respectively. Simultaneous actions performed are assigned higher dependency compared with those that are sequential. The assumption is that the simultaneous action cannot be corrected in a subsequent action. Whereas, there is some time between sequential actions, thereby allowing time to avoid repetition of the previous erroneous action. This should not be confused for recovery. For example, the TSC may make a decision and give directive on a wrong course of action but based on immediate feedback from the first MCR (from operators or system response), he/she may change his/her decision to another course of action.

The 'Work Device' factor refers to whether relevant equipment are shared by the affected units or not. The shared equipment includes mobile equipment or other shared devices. The non-shared equipment includes those that are dedicated to only one nuclear power plant (NPP) unit. An example is the MCR board. If there is no need to prioritize the use of shared equipment among units, then it could be selected as the non-shared type.

The dependency levels adopted are those of the SPAR-H method i.e. complete dependency (CD), high dependency (HD), moderate dependency (MD), low dependency (LD), and zero dependency (ZD). Noteworthy is that only the major factors that affect a multi-unit scenario are selected for the dependency analysis.

Where two HFEs are from the same NPP unit (decision-making is from the same MCR), the dependency levels are similar to those of existing methods. Only the HD, MD, and LD are assigned for those HFEs in the same MCR in a multi-unit cutset. This is especially because, in a multi-unit cutset, there will be one or more other HFEs from another unit.

3.2 Example of multi-unit HRA dependency Level Assessment

The example used here is based on a cutset/ sequence of events from a multi-unit PSA for pressurized water reactor (PWR) plants. The initiating event is a multi-unit loss of offsite power (LOOP). The Scenario is depicted by the multi-unit cutset shown in Table I. The basic events numbers 3 and 4 are the HFEs in the cutset.

Table I: Multi-unit cutset for a LOOP event

No.	**Basic event #1**	**Basic event #2**	**Basic event #3**	**Basic event #4**
#1	%IE-LOOP	ALL-EDBYK-HIJKLMNO	S1-SDOPHEARLY	S2-SDOPHEARLY

The HFEs are further described in Table II. These show the affected plants, the decision makers, and the working devices. Basic event #2 is the HFE which occurs in unit 1 and basic event #3 is the HFE that occurs in unit 2.

Table II: More description of HFEs and attributes

HFE ID	S1-SDOPHEARLY	S2-SDOPHEARLY
Description	Operator fails to perform SD Bleed (F&B)	
Affected Plants	Unit1	Unit2
Decision Makers	MCR	MCR
Work Devices	SDS, HPSI Manual Pump, SDS Shutoff Valve and Control Valve Open (unit1)	SDS, HPSI Manual Pump, SDS Shutoff Valve and Control Valve Open (unit2)

With knowledge of the plant and the scenario, including the above information, the dependency of the HFEs can be analyzed as follows;

Firstly, the type of cutset is multi-unit cutset and the HFEs occur in separate units. These are unit 1 and unit 2.

Secondly, the Human resource factor is analyzed as ‘Different MCR’ because the decision-making at this stage is still the responsibility of the various MCR operators. This is so because the safety depressurization (SD) bleed operation is expected to be performed in less than an hour after the initiating event occurs, meanwhile the TSC is normally not set-up until after an hour.

Thirdly, the action timing is analyzed as ‘simultaneous’. The assumptions here are (i) that the initiating event occurs at the same time in both units 1 and 2, (ii) that units 1 and 2 are alike in design, and (iii) that the MCR operators in both units respond using the same procedures. Hence it is most likely that the actions will be performed at the same time or very close in time.

Fourthly, all the safety depressurization systems in both units 1 and 2 are fully separated and independent of each other. Thus the work device factor is evaluated as ‘Not shared’.

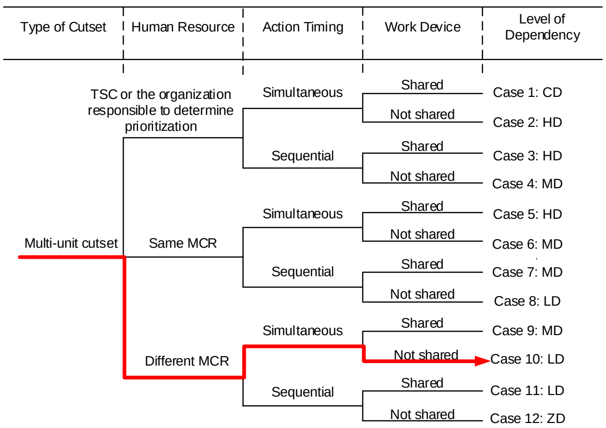

Fig. 2. Analysis path on the suggested dependency analysis tree for the example cutset.

Based on the foregoing, the dependency of the HFEs in the example cutset is analyzed as a low dependency. The dependency analysis path (in red lines) on the suggested dependency analysis tree is depicted in figure 2. The HEP of either HFEs in the cutset can thus be adjusted based on this result.

4. Conclusions

This paper has tried to show a way to consider and evaluate the dependency level between multiple HFEs based on a single multi-unit PSA cutset/ accident sequence in a simplified manner.

The joint HEPs due to multiple HFEs can therefore, be adjusted using the dependency analysis rules suggested. However, further research will go on to determine the appropriate limit for the joint HEP values for a multi-unit case.

Acknowledgments

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REFERENCES

[1] A. Kolaczkowski, J. Forester, E. Lois, and S. Cooper, Good Practices for Implementing Human Reliability Analysis, NUREG-1792, US-NRC, 2005.

[2] X. He, Dependencies in HRA, NPSAG Report, Report no: 21190_R001 Rev. 2, 12 January 2016.

[3] A.D. Swain and H.E. Guttmann. Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications. NUREG/CR-1278/SAND80-0200, Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, Washington, DC, August 1983.

[4] A.D. Swain, Accident Sequence Evaluation Program Human Reliability Analysis Procedure. NUREG/CR-4772/SAND86-1996, Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, Washington, DC, February 1987.

[5] NUREG-1921. EPRI/NRC-RES Fire Human Reliability Analysis Guidelines – Final Report. 2012.

[6] D.I. Gertman, H.S. Blackman, J. Byers, L. Haney, C. Smith, and J. Marble. The SPAR-H Method. NUREG/CR-6883, U.S. Nuclear Regulatory Commission, Washington, DC, August 2005.

[7] W. Jung, A standard HRA method for PSA in nuclear power plant; K-HRA method. KAERI/TR-2961/2005, 2005.