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Dependency Analysis of Human Failures in Multi-unit Scenarios: Types and Evaluation Method

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Contents

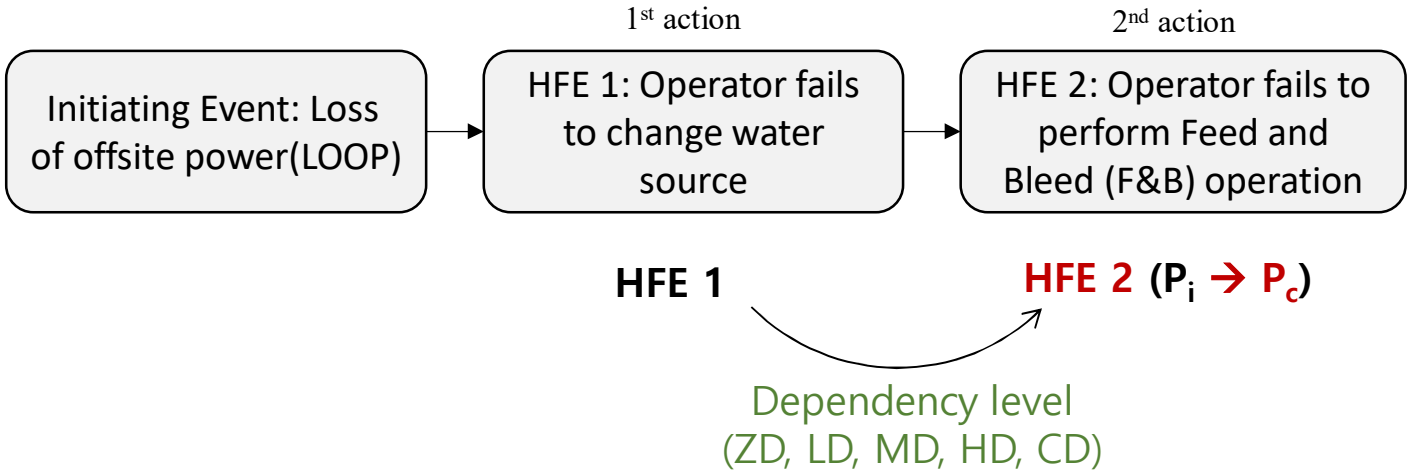
1. Introduction

1. Introduction

❖ What is the dependency in HRA?

- ◆ Dependence between human failure events (HFEs) refers to the situation in which the human error probability (HEP) on one HFE is influenced by other HFEs [1].

- ◆ Dependency analysis evaluates and quantifies the additional impacts of the failures/success of the preceding actions on the following actions that have not been accounted for explicitly in the individual HEP evaluation.



[1] A. D. Swain and H. E. Guttmann, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications - Final Report," NRC, 1983, U.S.Washington.

1. Introduction

❖ General Process of Dependency Analysis

◆ Step 1: Evaluation of dependency levels between HFEs

- The level of dependency is determined considering elements that may affect the interaction between HFEs.
  - Crew
  - Timeline
  - Similarity of cues and location
  - etc.

◆ Step 2: Quantification of interaction effects and calculation of joint human error probabilities

- Joint HEP = HEP of HFE 1 X HEP of HFE 2 (with consideration of dependency effect)
- Quantification of HFE 2 based on the THERP [1].
  - Zero dependence (ZD): $P_c = P_i$
  - Low dependence (LD): $P_c = (1 + 19 * P_i)/20$
  - Moderate dependence (MD): $P_c = (1 + 6 * P_i)/7$
  - High dependence (HD): $P_c = (1 + P_i)/2$
  - Complete dependence (CD): $P_c = 1.0$

[1] A. D. Swain and H. E. Guttmann, “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications - Final Report,” NRC, 1983, U.S.Washington.

1. Introduction

❖ Elements considered in the evaluation of dependency levels

<General HRA dependency elements in single-unit HRA methods>

	THERP [1]	ASEP [2]	SPAR-H [3]	K-HRA [4]	DEPEND-HRA [5]	EPRI HRA [6]
Similarity of crew		X	X	X	X	X
Timing of cue demand	X	X	X	X		X
Interval time of sequential action				X	X	X
Stress	X			X	X	X
The similarity of cue (for cognitive)			X	X	X	X
The similarity of decision-making rule or state (for cognitive)	X			X		
The similarity of location	X	X	X	X		X
Functional relatedness	X					
Preceding succeeded action	X					X
Adequate manpower						X
Complexity of execution					X	

[1] A. D. Swain and H. E. Guttmann, “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications - Final Report,” NRC, 1983, U.S.Washington.

[2] A. D. Swain, “Accident Sequence Evaluation Program Human Reliability Analysis Procedure,” NRC, 1987, California.

[3] D. Gertman, H. Blackman, J. Marble, J. Byers, and C. Smith, “The SPAR-H Human Reliability Analysis Method,” NRC, 2005, U.S.Washington.

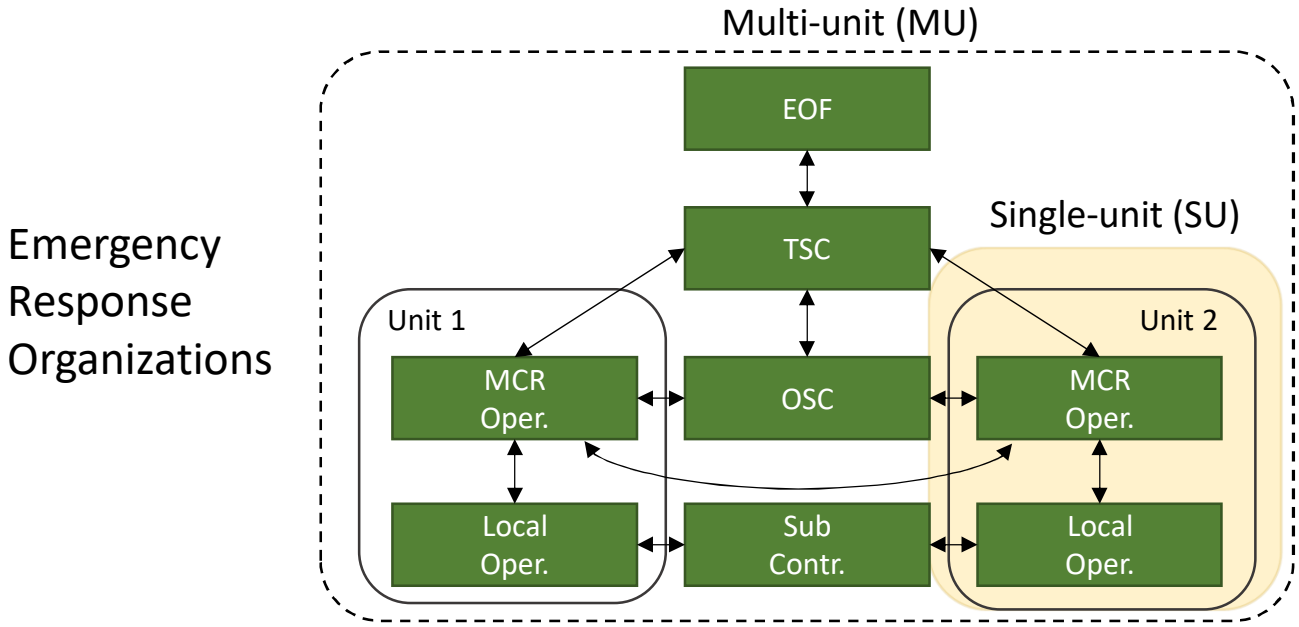
[4] J. Wondea, “Development of A Standard Method for Human Reliability Analysis (HRA) of Nuclear Power Plants,” KAERI, 2005, Daejeon (Korean).

[5] M. Čepin. “DEPEND-HRA-A method for consideration of dependency in human reliability analysis”, Reliability Engineering and System Safety, vol. 93, pp. 1452–1460, (2007).

[6] S. C. S. Lewis, “EPRI/NRC-RES Fire Human Reliability Analysis Guidelines,” NRC, 2012, California.

1. Introduction

- Limitations of dependency analysis methods for multi-unit scenarios [6]
  - Single-unit HRA methods are focused on the main control room (MCR) operation, i.e., the actions performed by MCR operators.
    - Emergency response organizations (EROs) needs to be considered.
  - Operational situations become more complicated due to the inter-unit interaction.
    - For instance, mobile equipment, shared equipment, shared personnel, and environmental factors such as radiation and external events.



[7] A. M. Arigi, G. Kim, J. Park, and J. Kim. "Human and organizational factors for multi-unit probabilistic safety assessment: Identification and characterization for the Korean case", Nuclear Engineering and Technology, vol. 51, pp. 104–115, (2019).

Abbreviations: ERO, Emergency response organization; EOF, Emergency operating facility; OSC, Operational support center; MCR, Main control room; TSC, Technical support center;

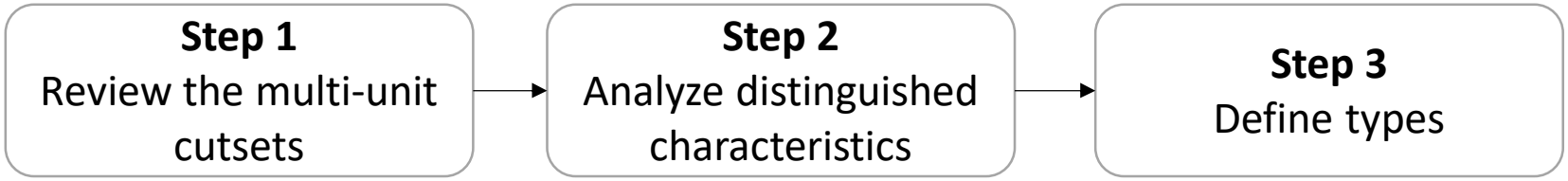
1. Introduction

❖ Purpose of this study

- ◆ To identify the characteristics of MU HRA dependency based on a practical experience of MU PSA and HRA

❖ Process

- ◆ Step 1: Review 818 cutsets from a multi-unit PSA model
- ◆ Step 2: Analyze the characteristics of multi-unit cutsets distinguished from single unit ones
- ◆ Step 3: Define the distinguished types

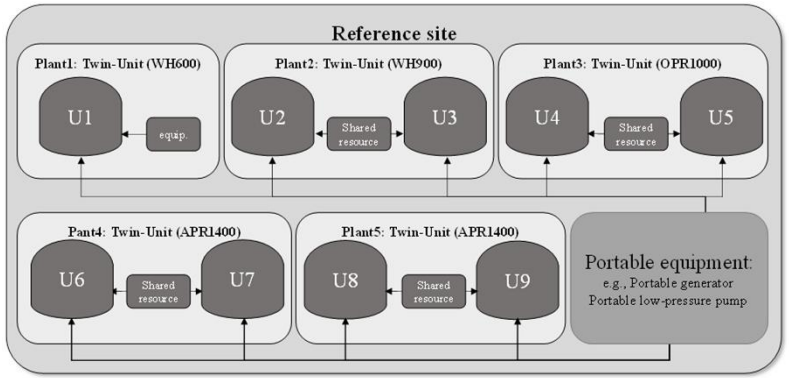


2. Method

2.1 Multi-unit PSA model

- **Multi-Unit Risk Research Group (MURRG) Project** [8,9]
  - Project Period: 2017~2021
  - Reference site (Kori site: 9 units)
    - Westinghouse 2-loop (WH600): 1 units
    - Westinghouse 3-loop (WH900): 2 units
    - Optimized power reactor (OPR1000): 2 units
    - Advanced power reactor (APR1400): 4 units
  - Operation mode
    - At-power / Low-power-shutdown (LPSD)
  - Internal / external events
  - Considering portable equipment

<Simple Diagram of Kori site in Korea>



<Organization of MURRG>

[8] K. Son et al. "Development of Level 1 Internal Event Single-unit PSA Models for Multi-unit Risk Profiles", 2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021), pp. 944–952, (2021).

[9] J. S. Kim et al. "Modeling portable equipment in probabilistic safety assessment of nuclear power plants", 2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021), pp. 592–600, (2021).

2.2 Multi-unit Cutset Review

❖ The number of multi-unit cutsets including 2 or more HFEs

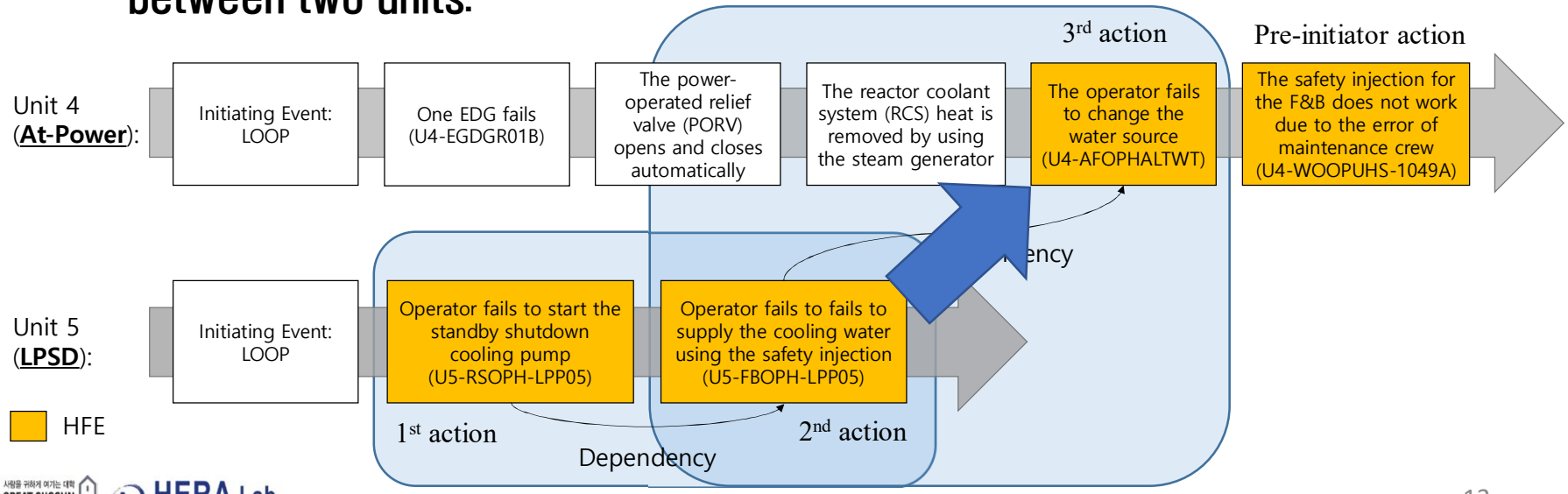
◆ Risk significant 818 cutsets were reviewed.

No.	HFE1	HFE2	HFE3	HFE4	HFE5	HFE6
1	S3-HR-RS-LPP05	S4-HR-RS-LPP05	S3-HR-FB-LPP05-C	S4-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	S4-HR-FS-LPP05-C
2	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	S4-MSOPH-MSADV	S3-HR-FS-LPP05-C	S4-AFOPH-AFWSC	S4-RCOPH-SDL-TR
3	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	S4-SCOPH-LTSDC-SCS	S3-HR-FS-LPP05-C	S4-AFOPH-AFWSC	S4-RCOPH-SDL-TR
4	S3-HR-RS-LPP05	K3-EKOPH-SWGR-RC	S3-HR-FB-LPP05-C	K3-HSOPH-FD1LXP5	S3-HR-FS-LPP05-C	
5	S3-HR-RS-LPP05	K3-EGOPH-AAC-P5	S3-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	K3-HSOPH-FD2LXP5	
6	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	S1-AFOPHALTWT	S1-SDOPHLATE	
7	S3-HR-RS-LPP05	S4-HR-RS-LPP05	S4-HR-FB-LPP05	S3-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	
8	S3-HR-RS-LPP05	K3-LSOPH-LP-P5	S3-HR-FB-LPP05-C	K3-HSOPH-FDLPP5	S3-HR-FS-LPP05-C	
9	K3-LSOPH-LP-P5	S3-MSOPH-MSADV	K3-HSOPH-FDLPP5	S3-AFOPH-AFWSC	S3-RCOPH-SDL-TR	
10	K3-LSOPH-LP-P5	K3-HSOPH-FDLPP5	S3-SCOPH-LTSDC-SCS	S3-AFOPH-AFWSC	S3-RCOPH-SDL-TR	
11	S3-HR-RS-LPP05	S4-HR-RS-LPP05	S3-HR-FS-LPP05	S4-HR-FB-LPP05-C	S4-HR-FS-LPP05-C	
12	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	S4-HR-FB-LXP05-02	S4-HR-FS-LXP05-02-C	
13	S3-HR-RS-LPP05	S3-HR-FS-LPP05	S4-MSOPH-MSADV	S4-AFOPH-AFWSC	S4-RCOPH-SDL-TR	
14	S3-HR-RS-LPP05	S3-HR-FS-LPP05	S4-SCOPH-LTSDC-SCS	S4-AFOPH-AFWSC	S4-RCOPH-SDL-TR	
15	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	S3-HR-FS-LPP05-C	K2-AFOPHL-AFWS		
16	S3-HR-RS-LPP05	S3-HR-FB-LPP05-C	K2-CSOPHM-CSR1	S3-HR-FS-LPP05-C		
			.			
			.			
			.			
809	K3-RCOPH-FDBD-SHORT	K2-HSOPHM-HPR1				
810	K3-HSOPH-HPCR	K4-HSOPH-HPCR				
811	K3-EKOPH-SWGR-RC	K4-HSOPH-PCRHS-SCSS				
812	K4-RCOPH-FDBD-SHORT	K3-HSOPH-HPCR				
813	K4-RCOPH-FDBD-SHORT	K3-LSOPH-PPSP				
814	K3-RCOPH-FDBD-SHORT	K4-RCOPH-FDBD-SHORT				
815	S1-EFOPVSIAS	S2-EFOPVSIAS				
816	S4-EDOPH-DCSHED	S3-AFOPH-AFWSC				
817	S3-EDOPH-DCSHED	S4-EDOPH-DCSHED				
818	S3-EDOPH-DCSHED	S5-AFOPH-AFWSC				

3. Characteristic Identification of Multi-unit HRA Dependency

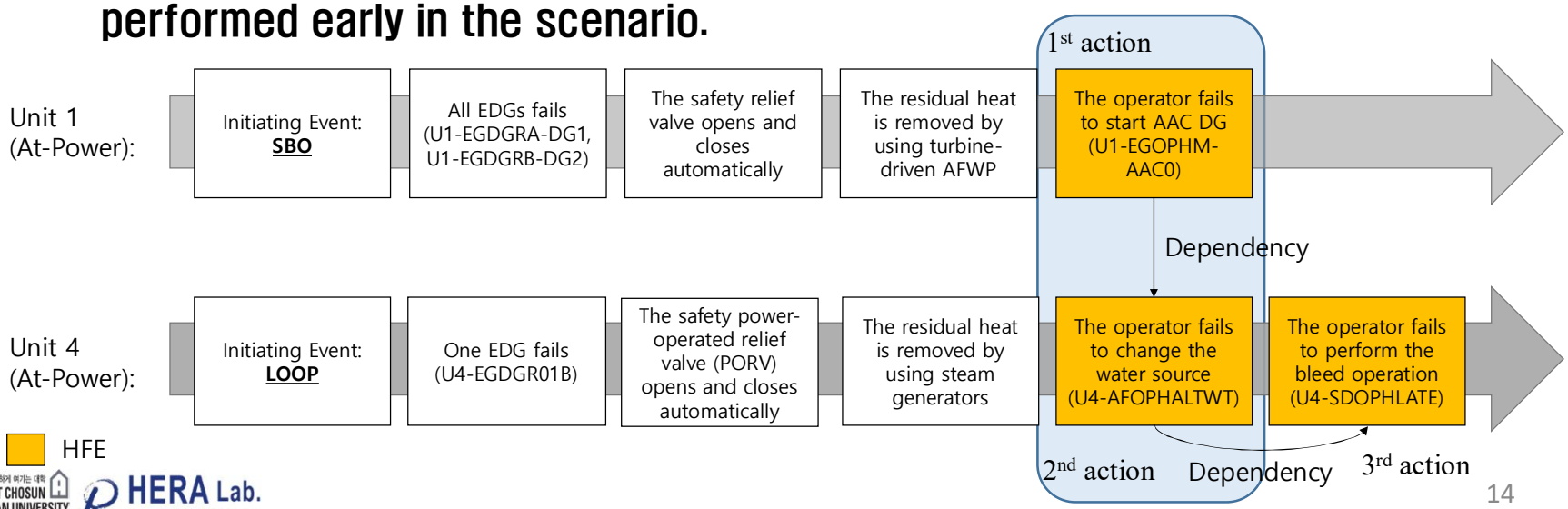
1) A cutset can contain HFEs in different operation modes.

- A MU PSA cutset can include HFEs under different operation modes, which is impossible in a single unit cutset.
  - This characteristic accounts for 337 cutsets among 818 ones.
- Example
  - U4 is under at-power mode while U5 is in the LPSD mode.
  - In this case, generally, the dependency between the actions in the same unit is considered.
  - In addition, to evaluate the interaction between units, the dependency between U5-FBOPH-LPP05 and U4-AFOPHALTWT was assessed because this interaction was evaluated as the strongest in all possible dependencies between two units.



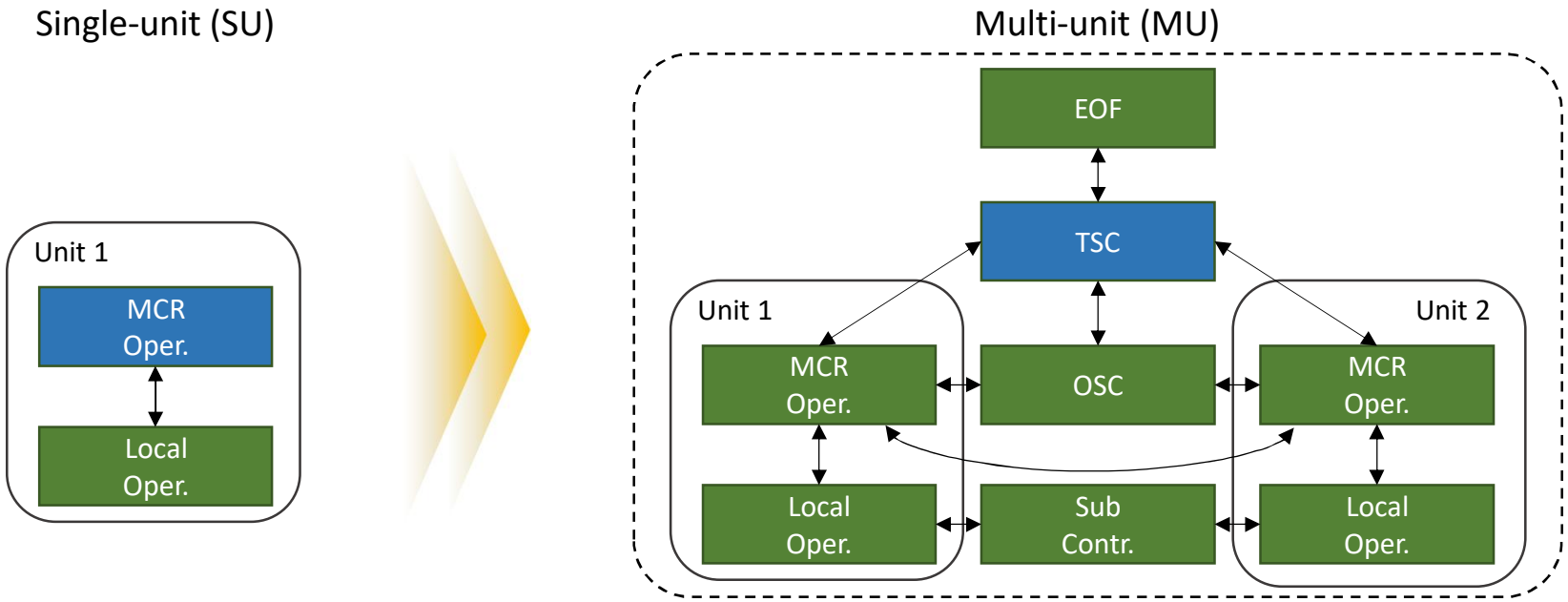
2) A cutset can include two or more initiating events.

- A MU PSA cutset can contain HFEs from two or more initiating events that are not possible in a SU cutset.
  - This characteristic accounts for 391 cutsets among 818 ones.
- Example
  - U1 is in station black out (SBO) event while U4 is in loss of off-site power (LOOP) event.
  - In this case, the interaction between the units is not so strong that the dependency between the actions in U4 is considered primarily.
  - Then, to evaluate the interaction between the units, the dependency between U1-EGOPHM-AAC0 and U4-AFOPHALTWT was assessed. In this dependency, U1-EGOPHM-AAC0 was regarded as the preceding action because it was performed early in the scenario.



3) The MU dependency analysis should consider the involvement of emergency response organizations.

- EROs such as TSC and EOF should be established in the event that has potential to release the radiation out of the NPP.
  - This characteristic accounts for 189 cutsets among 818 ones.

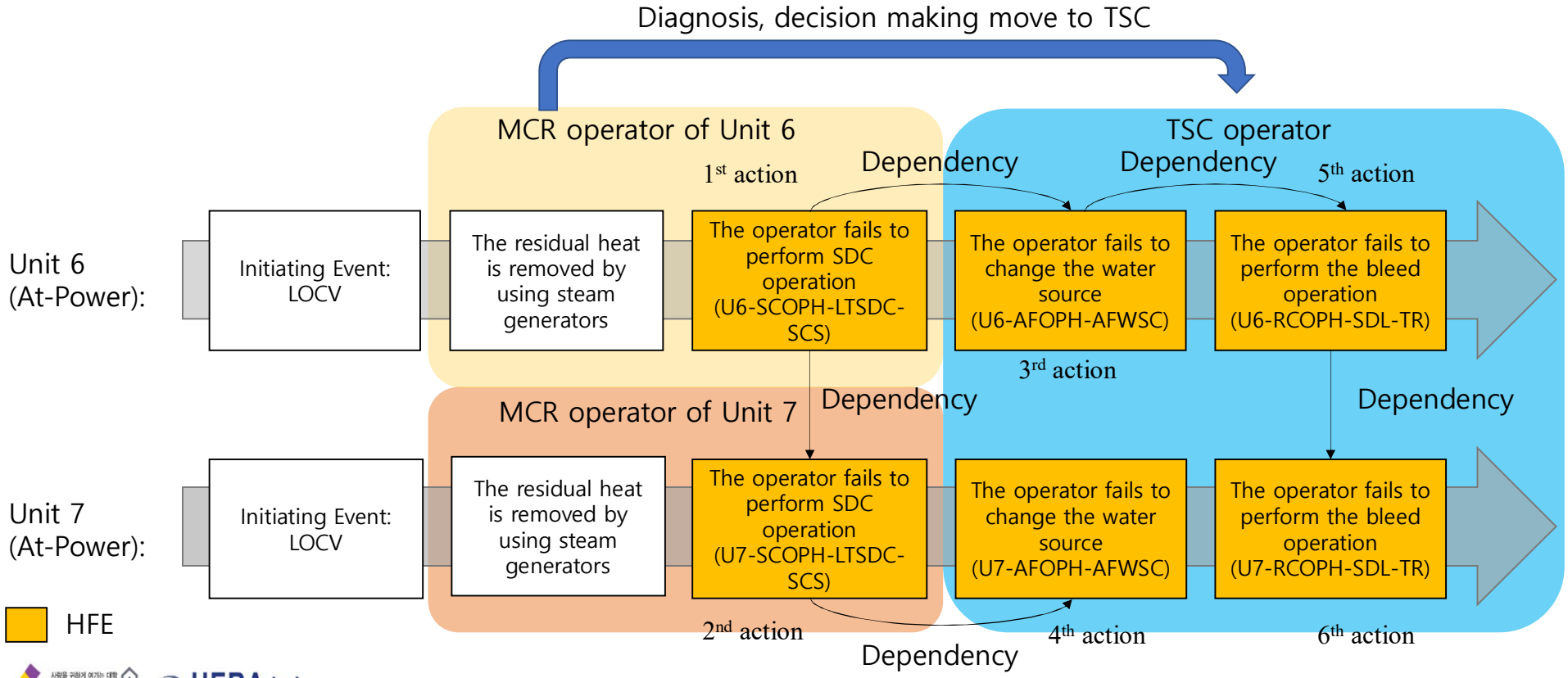


Abbreviations: ERO, Emergency response organization; EOF, Emergency operating facility; OSC, Operational support center; MCR, Main control room; TSC, Technical support center;

3) The MU dependency analysis should consider the involvement of emergency response organizations.

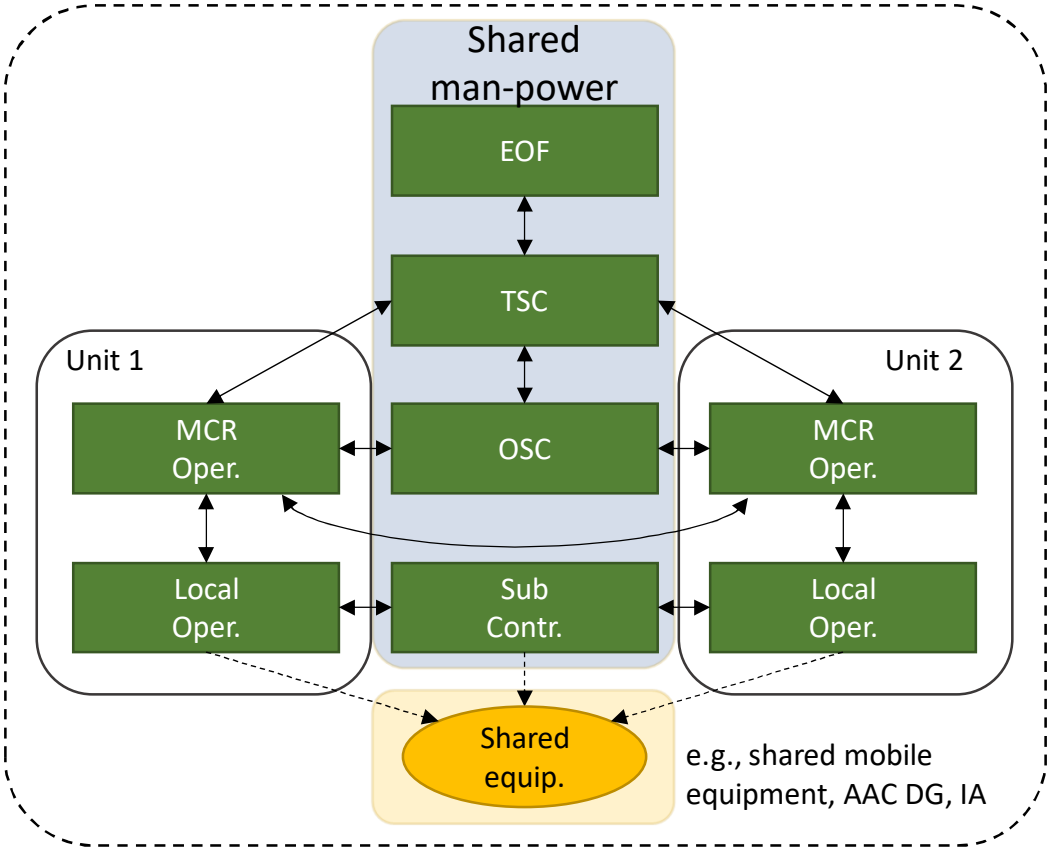
❖ Example

- ◆ The dependency between the first and second actions in the cutset of each unit.
- ◆ However, interestingly, the dependency between the bleed operations in U6 and U7 was considered because the actions were decided by the TSC and then the interaction was evaluated to be strong.



4) The dependency analysis should consider the limitation of shared resources.

- The resource can be systems such as shared mobile equipment and shared AAC DG, or man-power such as the personnel who transport and install the mobile equipment.
  - This characteristic accounts for 4 cutsets among 818 ones.

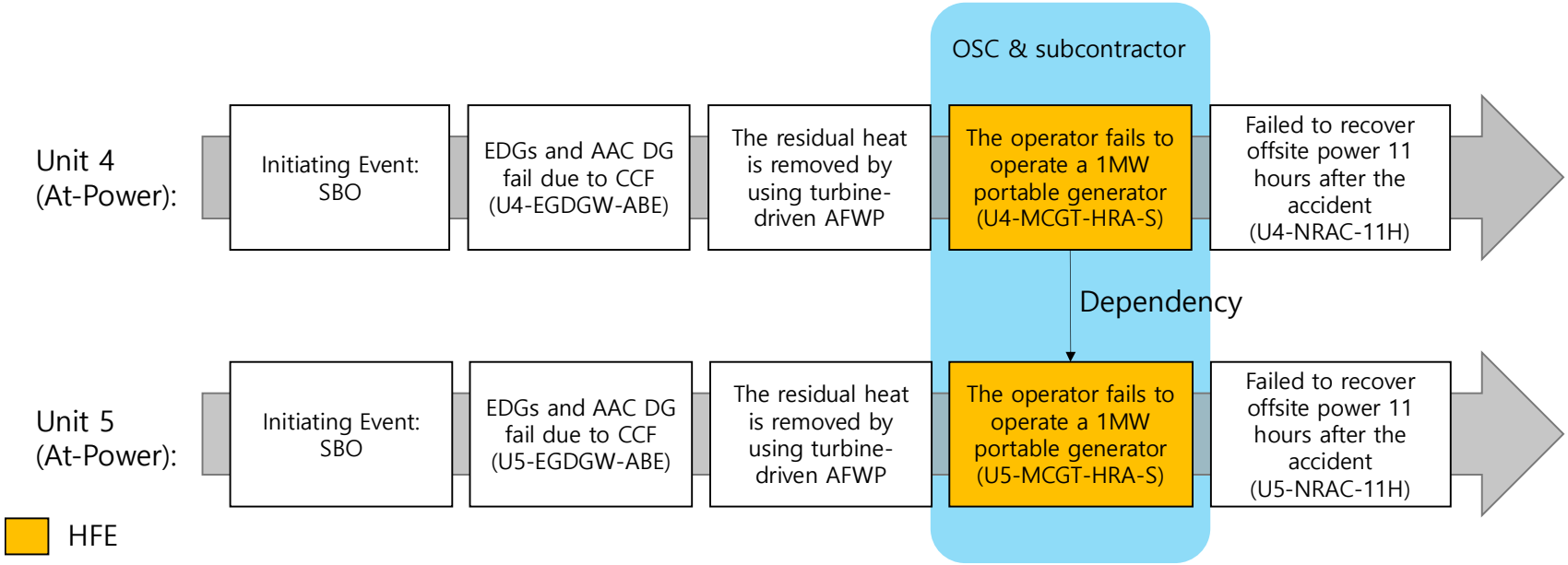


Abbreviations: ERO, Emergency response organization; EOF, Emergency operating facility; OSC, Operational support center; MCR, Main control room; TSC, Technical support center; AAC DG, Alternative alternating current diesel generators;

4) The dependency analysis should consider the limitation of shared resources.

❖ Example

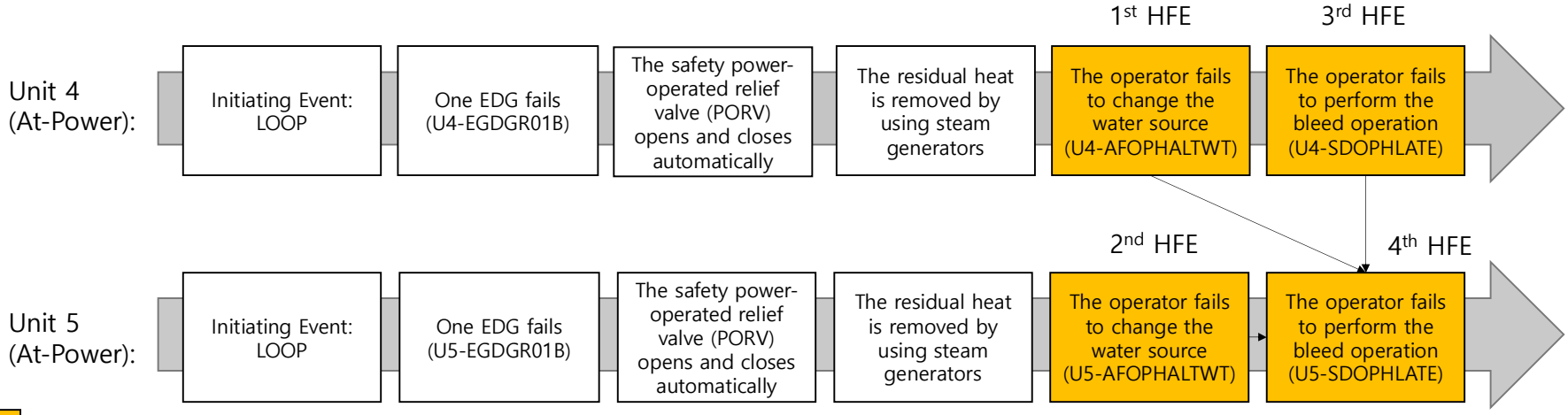
- ◆ The personnel applied the mobile diesel generator to a unit that had a higher priority. Therefore, the installation of equipment was performed sequentially on the second unit. The dependency analysis separated the timeline of actions and regarded those actions as sequential ones.



5) An HFE can be affected by multiple preceding actions.

- In the multi-unit cutset, an HFE can be affected by multiple preceding actions, even by actions from another unit.
  - This characteristic accounts for 493 cutsets among 818 ones.

- Example
  - U5-SDOPHLATE can be influenced by three actions.
  - First, it can be affected by U5-AFOPHALTWT because this is the preceding action in the same unit.
  - In addition, it can be also affected by the actions performed in U4 because the same TSC makes the decisions for the actions. In this case, we analyze all the three potential dependencies and applied the strongest dependency.



4. Discussion

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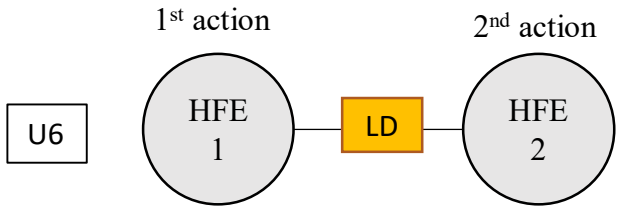
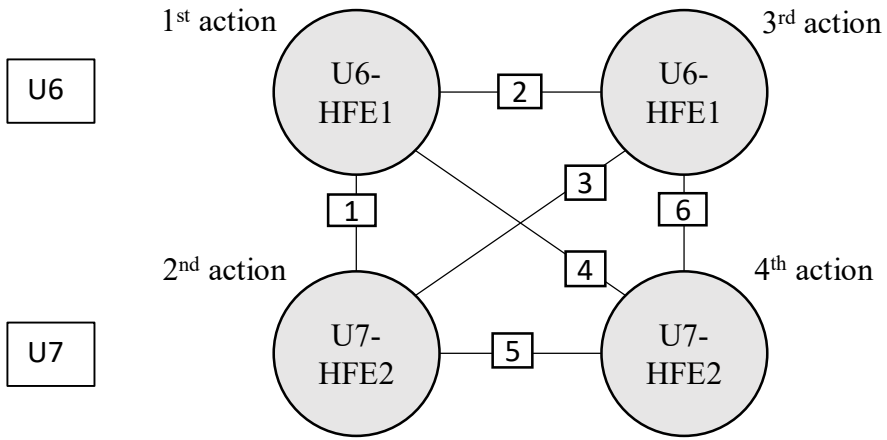
- The interactions are more complicated in the multi-unit model.
- And then more assessments, i.e., multi-dimensional analyses, are necessary.

Single Units:
1 interactions



Multi-Units:
6 interactions

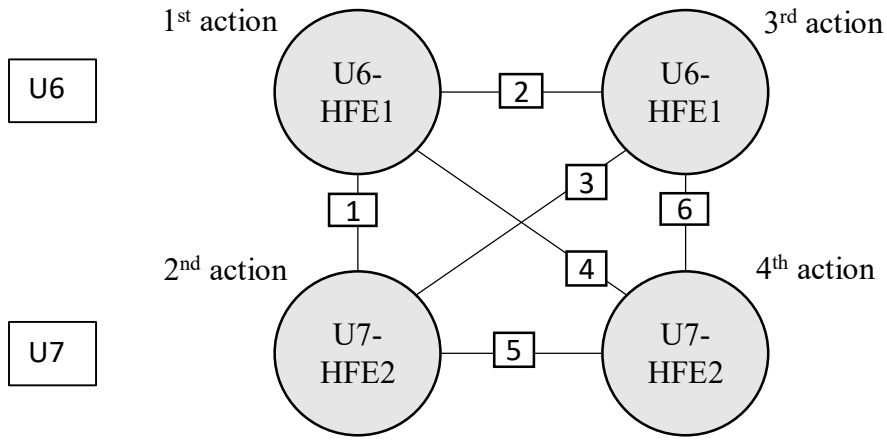


4. Discussion

❖ Dependency analysis of multi-unit cutset

Multi-unit cutset:

Initiating event	U6-HFE1	U6-HFE2	U7-HFE1	U7-HFE2
U6&U7: Loss of condenser vacuum	The operator fails to change the water source	The operator fails to change the water source	The operator fails to perform the bleed operation	The operator fails to perform the bleed operation



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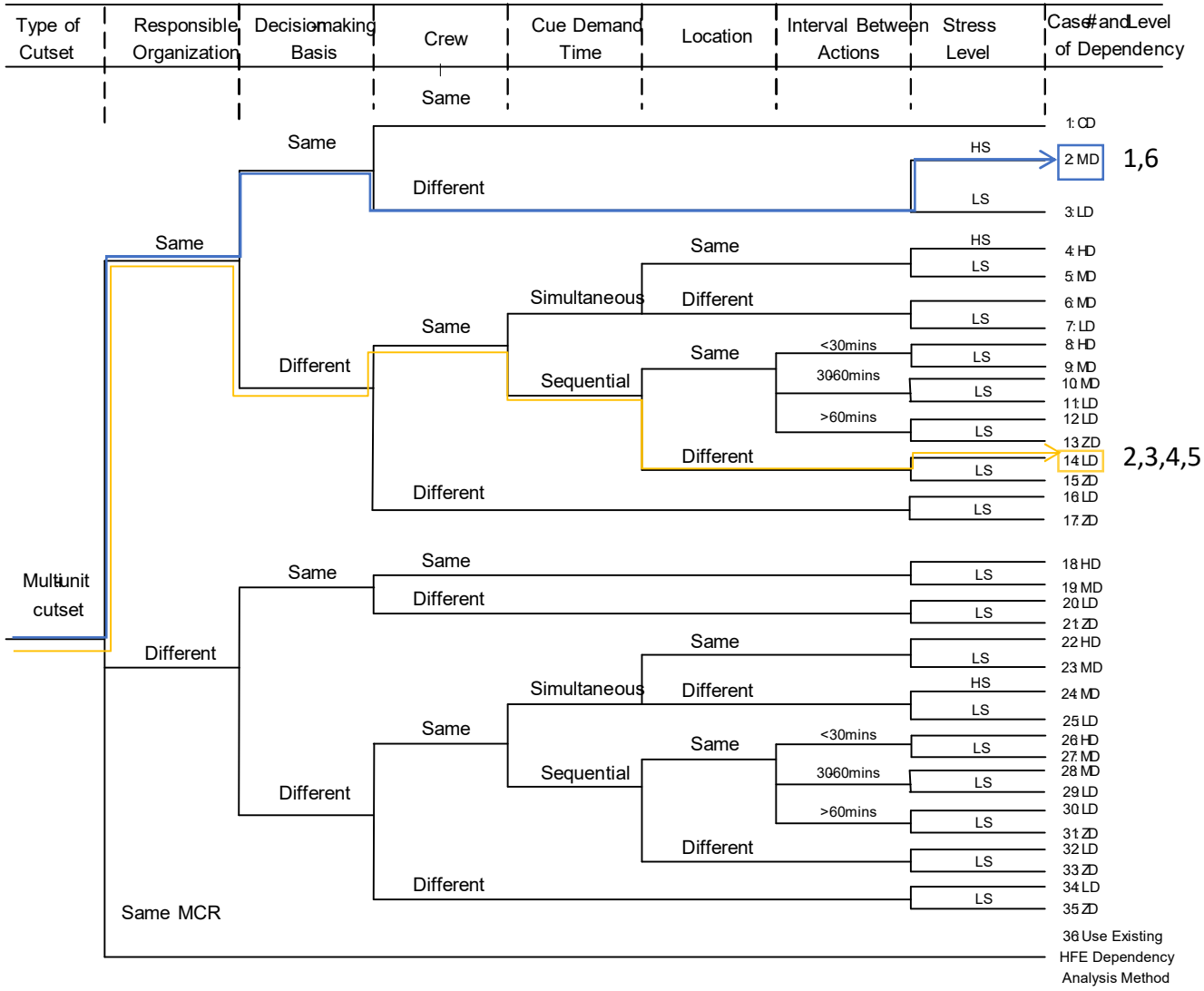
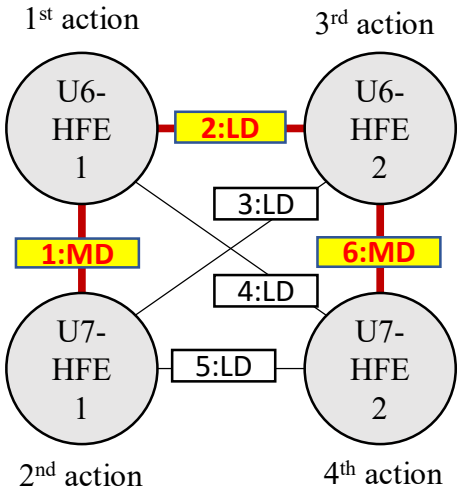
❖ Dependency analysis of multi-unit cutset



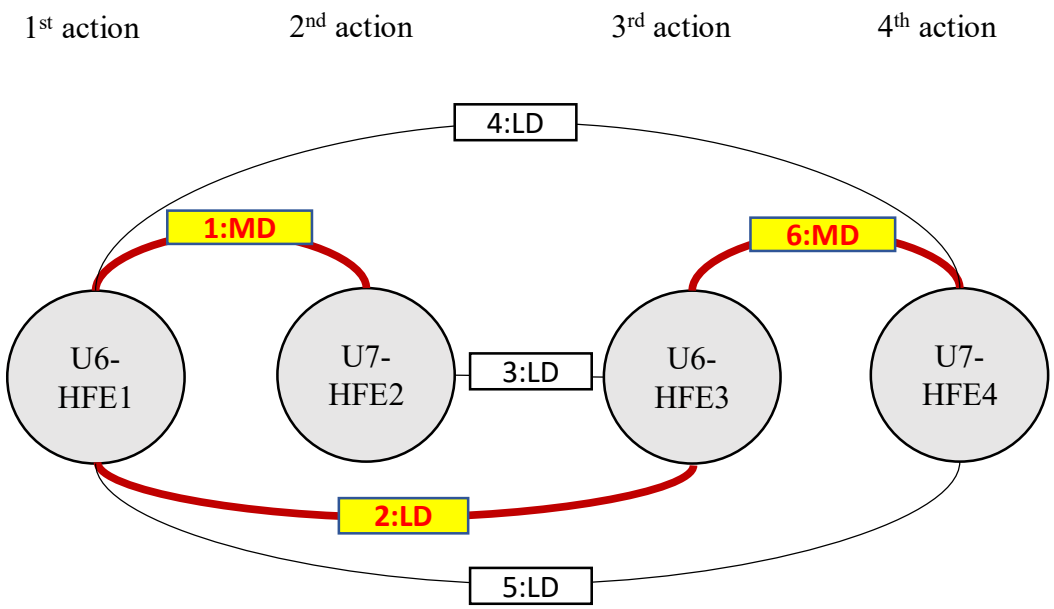


[10]A. M. Arigi, G. Park, and J. Kim. "Dependency analysis method for human failure events in multi-unit probabilistic safety assessments", Reliability Engineering and System Safety, vol. 203, (2020).

4. Discussion

❖ Dependency analysis of multi-unit cutset

◆ Analysis result



5. Conclusion

5. Conclusion

- This study introduced the characteristics of MU HRA dependency from the practical examples.
- This study reviewed more than 800 cutsets from the MURRG project in which the authors participated.
- Then, the characteristics distinguished from the single unit HRA were identified and discussed.
- The method to determine the dependency level and quantify the effect of dependency will be studied in the following study.

Thank you

Reference

[1] A. D. Swain and H. E. Guttmann, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications – Final Report," NRC, 1983, U.S.Washington.

[2] A. D. Swain, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure," NRC, 1987, California.

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