Proceedings of the Korean Nuclear Society Spring Meeting
Seoul, Korea, May 1998

Safety-Related Equipment Classification for Maintenance Purposes with Risk Measures

Byoung-Chul Park, Jong-Jooh Kwon and Sung-Hwan Cho

Korea Electric Power Research Institute
Nuclear Power Generation Laboratory
103-6 Munji-dong, Yusong-gu
Taejon, Korea 305-701

Abstract

Risk importance measures are widely used to rank risk contributors in risk-based applications. Typically, Fussell-Vesely (F-V) importance and risk achievement worth (RAW) are used in the component importance ranking for the reliability centered maintenance (RCM) analysis of safety systems in nuclear power plants (NPPs). This study was performed as part of feasibility study on RCM for domestic NPPs, which is focused on the component importance ranking approach for the maintenance recommendations. The approach of modulizing fault tree basic events was applied in the simplification process of the PSA model and the validity of the approach was evaluated. As a result of the case study, this paper included the importance and the maintenance recommendations for the safety-related equipments associated with safety injection and containment spray in large loss of coolant accident sequences.

I. Introduction

Risk importance measures are widely used to rank risk contributors in risk-based applications. Typically, F-V importance and RAW are used in the component importance ranking for RCM analysis of safety systems of NPPs. The ranking is to identify components important to risk and to develop an initial set of recommendations, which the expert panel working group consider for the maintenance strategy of components.

The most common selection of a model element for the ranking is the importance of basic events in the system fault trees, which are directly computed in the level 1 PSAs (called fault tree linking model). The importance is included in the sequence database, one of the final products of a PSA. Such basic event importance rankings might then be combined, often by simply algebraically summing the associated basic events, to determine the risk importance of plant equipments. However, it is not convenient to use the importance of the basic events, due to the following reason. There are many basic events in the sequence database that the analyst cannot easily combine the respective importances of the basic events correspond with failure of the component. Therefore, it is useful to simplify the PSA model for the convenience of the component importance ranking with fault tree linking model.

This study was performed as part of feasibility study on RCM for domestic NPPs, which is focused on the component importance ranking approach for the maintenance recommendations. In this study, the approach of modulizing the basic events in system fault trees was applied in the simplification of PSA model, which could decrease the number of basic events in the sequence database and easily rank the component importance. As a case study on the risk importance raking using the approach, we performed the safety-related equipment classification for the maintenance recommendation. In the ranking, the PSA model for large loss of coolant accident (LLOCA) of Ulchin units 3&4, of which the level 1 PSA was completed in 1998, was selected as a baseline model to evaluate the validity of the approach.

II. Importance Measures and Criteria

1. Basic Importance Measures

In this section, we describe the several risk importance measures which are widely used in analyzing risk-based component prioritization.

A component is often associated with several failure modes, each representing specific basic event. The risk importance of a given component depends on the risk importance of all of its basic events. Thus, F-V importance of a given component C can be as follows;

$$I_c = \sum_{i=1}^{m} I_i$$

where

m : number of failure modes of the component C

I_i : F-V importance associated with the failure mode i of the component

RAW of a given basic event measures the increase of the CDF associated with the occurrence of the basic event. In difference from F-V importance, the total increase of the CDF associated with several basic events occurring simultaneously can be explicitly larger than the sum of individual occurrences. Therefore, RAW importance of a given component C can be as follows;

$$A_c = 1 + \frac{1 - Q_c}{Q_c} I_c$$

where I_c is given by (1), and Q_c is the sum of unavailabilities associated with the failure modes of the component, i.e.,

$$Q_c = \sum_{i=1}^{m} Q_i$$

2. Classification Criteria

The criteria suggested by S. Martorell *et al*[1]., was adopted for the classification of components. The criteria was based on the fact that a given component C ranks high in RAW ranking if it satisfies;

$$\frac{A_C-1}{A_M-1} \geq 0.01$$

where
A_c : RAW for the component C,
A_M : RAW of the component ranked first in RAW

otherwise, it ranks low. In the same way, it ranks high in the F-V importance if it satisfies;

$$\frac{I_C}{I_M} \geq 0.01$$

where
I_c : F-V importances for the component C,
I_M : F-V importance of the component ranked first in F-V importance

otherwise, it ranks low.

Table 1 shows the ranking matrix of component classification and maintenance recommendation considering both F-V importance and RAW.

Table 1. Component classification and maintenance recommendations

Component classification (Maintenance recommendation)		Fussell-Vesely ranking(I)	
		High	Low
Risk Achievement Worth Ranking(A)	High	#1 Critical (Dependent on unavailability)	#2 Critical (Surveillance and preventative action)
	Low	#3 Critical (Overhaul and corrective actions)	#4 Non critical (Remove)

Ⅲ. Approach for Component Importance Ranking

1. Simplification of the PSA model for LLOCA

The PSA model for LLOCA of Ulchin units 3&4 was selected to evaluate the validity of component importance ranking for RCM analysis using the modulization of fault tree basic events.

In this study, the importance rankings and the classifications were, therefore, limited on only equipments associated with the actuation of safety functions to prevent or mitigate the accident consequence.

The event tree for LLOCA sequence includes six headings of the top event associated with fault trees of safety systems. To mitigate LLOCA consequence, several safety systems are involved, including safety injection tank, high pressure safety injection system, low pressure injection system, containment spray system and their supporting systems.

As stated previously, one should simplify the PSA model for the importance ranking of equipments included those systems. Therefore, we were simplifying the system faults trees using the following procedure. Firstly, we identified the fault trees associated with the headings and removed the basic events associated with the operator errors and the unavailably of test and maintenance from system fault trees. Secondly, the basic events associated with failure modes of a component was modulized into one basic event. Thus, the simplified fault trees involve fewer basic events than the original and come to decrease the number of basic events in the sequence database. It is noted that the basic events associated with common cause failures (CCFs) of the component were not modulized together into one basic event for the sensitivity analysis and the avoidance of double counting in Boolean reduction process.

2. Quantification and Ranking

The core damage frequency (CDF) of LLOCA sequence was quantified with truncation limit of 1×10^{-11} using kcut 4.7c version in KIRAP code. The importance database of the component, not of basic events associated with failure modes of the component was included in the sequence database of the result of the quantification. It gives convenience to the analyst in ranking and interpreting the component importance.

CCFs are modeled in PSAs to account for dependent failures of redundant components within a system. Dependencies among similar components performing redundant functions in two different systems are generally not modeled in PSAs. Therefore, a given component may be ranked as non critical component because it has negligible or no contribution to CCFs[4]. The sensitivity analysis in which the basic events associated with CCFs of a component set to zero, was performed to consider the impact of CCFs on the importance ranking.

The sequence database were used to assign the ranks of the component importance with the adopted criteria and according to the ranking, maintenance recommendations was located to the component.

However, most importance rankings of components were assigned with the criteria, with identifying components that shift to a higher class in the sensitivity analysis, these components were treated as higher class.

III. Results and Maintenance Recommendations

Table 2 shows the impotance and the maintenance recommendation of components. According to the criteria for the determination of risk critical component, most of the components associated with LLOCA sequence are considered to be risk critical. This result arises from the fact that the components of interest is directly associated with safety functions during LLOCA sequences. Containment spray actuation signal generation device was ranked first in F-V importance and refueling water storage tank in RAW. As a result of the result of the sensitivity analysis for CCFs, Two manual valves(VV-435, 477), feed breakers, and heat exchangers of containment spray system treated as higher class(#4 → #2).

In terms of maintenance for valves and pumps of safety system, ten valves come into group #4, and those valves could be removed from a risk perspective. A total of 32 risk critical components come into group #1, and the maintenance of those component depends on the unavailability. Only two of them have the unavailability above 0.01, which are the most important contributor to the limited CDF. A total of 48 risk critical components come into group #2. Actual or alternative surveillance and preventive maintenance tasks are considered to be important to control component failures which have a relatively large impact to risk. No component is come into group #3, and it is not needed to introduce new overhaul or corrective actions to reduce their unavailability.

Ⅳ. Conclusion

As part of feasibility study on reliability centered maintenance for domestic NPPs, we performed the component importance ranking using the approach of modulizing fault tree basic events in simplifying PSA model. The approach is demonstrated to be very effective in component prioritization, because the analyst can easily rank the component importance. Also, this study shows the applicability of the level 1 PSA model for Ulchin units 3&4 in reliability centered maintenance analysis.

There are many issues related to regulatory acceptance of ranking using importance measures in general. These issues include the use of truncation limits during sequence quantification, multiple component, depense-in-depth, allowable plant configurations, binning criteria, uncertainty evaluation, and the sensitivity analyses for a component group and recovery actions. In the further study, these issues must be considered in component importance ranking.

Reference

1. Martorell, S., Serradell, V., & Verdu G., Safety-related equipment prioritization for reliability centered maintenance purposes based on a plant specific level 1 PSA. Reliability Engineering and System Safety, 52 (1996) 35-44.
2. Vesely, W. E., Belhadj, M., & Rezos, J. T., PRA impotance measures for maintenance prioritization applications. Reliability Engineering and System Safety, 43 (1994) 307-308.
3. KEPCO, Final Probabilic Safety Assessment Report for Ulchin units 3&4, 1998.
4. USNRC, Use of PRA in Risk-Informed Applications, Draft NUREG/CR-1602, June 1997.

Table 2. Maintenance recommendation for safety equipments associated with LLOCA

#	component	ID	U[1]	F-V[2]	A-W[3]	C[4]
1	Check Valve	SI-113 123 133 143	1.870E-6	1.000E-4	54.476	#1
		SI-114 124 134 144	2.019E-4	3.000E-4	2.486	#2
		SI-200 201	2.021E-4	3.000E-4	2.484	#2
		SI-205 206	2.021E-4	9.000E-4	5.453	#1
		SI-215 225 235 245	2.022E-4	2.000E-4	1.989	#2
		CH-305 306	2.021E-4	3.000E-4	2.484	#2
		SI-404 405	2021E-4	5.000E-4	3.474	#2
		SI-434 446 448 451	2.021E-4	3.000E-4	2.484	#2
		SI-522 532	2.021E-4	5.000E-4	3.474	#2
		SI-523 533	2.021E-4	5.000E-4	3.474	#2
		SI-540 541 542 543	2.019E-4	3.000E-4	2.486	#2
		CS-1003 1004	2.021E-4	5.000E-4	3.474	#2
		CS-1007 1008	2.021E-4	5.000E-4	3.474	#2
		CS-1011 1012	2.021E-4	5.000E-4	3.474	#2
2	Motor Operated Valve	SI-321 331	2.900E-2	2.920E-2	7.771	#1
		CH-530 531	1.546E-4	2.000E-4	2.293	#2
		SI-603 604	2.900E-2	2.920E-2	7.771	#1
		SI-614 624 634 644	9.198E-4	2.000E-4	1.217	#4
		SI-615 625 635 645	4.285E-3	2.420E-2	6.623	#1
		SI-616 626 636 646	2.620E-4	1.830E-2	70.829	#1
		SI-617 627 637 647	2.620E-4	1.830E-2	70.829	#1

#	component	ID	U	F-V	A-W	C
2	Motor Operated Valve	SI-675 676	4.294E-3	3.650E-2	9.464	#1
		SI-691 692	1.546E-4	2.000E-4	2.293	#2
		SI-698 699	4.449E-3	2.940E-2	7.579	#1
		CS-035 036	4.294E-3	2.910E-2	7.748	#4
		CC-141 142	4.294E-3	2.910E-2	7.748	#1
3	Manual Valve	VV-435 477	3.320E-5	0	1.0	#2
		VV-470 476	3.312E-5	1.000E-4	9.464	#2
		VV-402 478	3.312E-5	1.000E-4	2.293	#2
		VV-957 958	1.971E-4	4.000E-4	7.579	#1
		VV-1001 1002 1013 1014 1039 1040	2.021E-4	5.000E-4	7.748	#4
4	Pump	LPSI -PP01A -PP01B	2.695E-3	1.430E-2	6.291	#1
		HPSI -PP02A -PP02B	2.374E-3	1.692E-2	8.101	#1
		CS -PP01A -PP01B	6.769E-3	5.300E-2	8.777	#1
5	ESFAS	SIAS	1.203E-3	8.190E-2	70.918	#1
		CSAS	2.240E-3	1.568E-1	70.843	#1
		RAS	1.150E-3	8.050E-2	67.847	#1
6	EPS	TR	1.680E-5	1.000E-4	6.952	#2
		TR-BK	1.200E-5	0	1.000	#2
		LC-BK	1.440E-5	0	1.000	#2
		DG	4.800E-3	1.000E-4	1.021	#4
7	HVAC	-Cubicle cooler	9.240E-4	7.700E-3	9.326	#1
		-Actuation circuit	1.123E-2	9.213E-2	9.231	#1
		-Valves	1.116E-5	0	1.000	#4
		-CCW P/P cubicle cooler	2.640E-4	2.800E-3	11.982	#1
8	etc.	-RWT	2.400E-6	2.000E-4	84.333	#1
		-CS Hx	2.400E-5	0	1.000	#2
		-CTMT sump	5.000E-5	3.500-3	70.997	#1

[1]Unavailability [2]Fussell-Vesely importance [3]Risk Achievement Worth
[4]Conclusion(see Table 1),