

Maintenance Strategy: Burden to Importance Approaches

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In order to enhance maintenance effectiveness by using risk information, Burden to Importance Ratio (BIR) is used in this study. The BIR is a measure representing the extent of maintenance burden (resources or activities) imposed on a System, Structure, or Component (SSC) in comparison with the importance value of the SSC. Therefore maintenance burden imposed on the SSC having high BIR can be reduced to the extent of its importance. The evaluation of BIR were applied to 22 valves selected among 516 Motor Operated Valves (MOVs) tested in In-Service Test program of Ulchin unit 3 in South-Korea. Among them, 13 MOVs were evaluated to be reducible from the existing maintenance burden. In addition, a qualitative approach called “active searching for contradictory evidence” is utilized to complement limitations associated with the BIR. A case study regarding the active searching for contradictory evidence shows that challenges not considered in the BIR assessment can be identified and evaluated. Consequently, we conclude that burden to importance approaches incorporating the quantitative measure, BIR, and the qualitative evaluation based on active searching by experts can be a successful strategy for enhancing maintenance effectiveness.

Keywords: Maintenance Effectiveness, Burden to Importance Ratio, Active Searching for contradictory evidence, PSAs, Importance Measure

1. Introduction

The aim of maintenance in Nuclear Power Plants (NPPs) is to guarantee the safe, reliable and cost-effective production of electricity. In recent years, there is a growing concern on the subject of higher maintenance cost and maintenance productivity. According to some company, maintenance is the largest single manageable expenditure in the plant: in many companies, surpass their annual net profit. Therefore, it is very important for companies to maximize their maintenance effectiveness.

In this work, risk information from probabilistic safety assessments (PSAs) of NPPs is utilized as a source for enhancing the maintenance effectiveness. The underlying principle is that System, Structure, or Component (SSC) of NPPs should be treated according to their significance or importance from the view point of safety or risk [1].

In order to enhance the maintenance effectiveness by using the risk information, a resource-effectiveness measure, Burden to Importance Ratio (BIR) [2], is used in this study. The BIR is a measure representing the extent of burden (resources, requirements, or activities) imposed on a SSC in comparison with the importance value of the SSC. Therefore maintenance activities imposed on SSCs having high BIR can be reduced to the extent of their importance, if unnecessary burden was given to the SSCs in comparison with their importance value.

The BIR is dependent of the importance measures of PSAs

which have limitations associated with the structure of the PSA model, their assumptions, and the input data. Hence a qualitative approach called “active searching for contradictory evidence” is utilized to complement the quantitative measure: BIR. The BIR is explained in section 2 and the active searching for contradictory evidence is described in section 3. Applications including calculation of BIR and a case study on active searching for contradictory evidence and the results are covered in section 4. Some considerations are discussed in section 5. Finally, conclusion will be made in section 6.

2. Burden to Importance Ratio

To reduce burdens while maintaining or reducing risks, what is needed is to apply cost-benefit principles, which then become resource-importance principles [2]. In this work, BIR as a quantitative measure of resource-effectiveness of maintenance activities is utilized as follows:

$$\text{Burden to Importance Ratio (BIR)} \uparrow \frac{\text{Relative Burden}}{\text{Relative Importance}} \quad (1)$$

where relative burden refers to relative resources spent on an activity such as the number of tests conducted per year, the cost consumed per year, or man-power consumed for the relevant maintenance activities per year and relative importance refers to the relative importance measure in PSAs such as Fussell-Vesely (FV) importance or Risk Achievement Worth (RAW) [3]. If BIR of a SSC is high, which means the maintenance burden imposed on the SSC is too sufficient (or unnecessary) in comparison with the importance value of the SSC, the maintenance burden can be reduced to the extent of the relevant importance value.

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To get maximum resource-effectiveness, resource-effectiveness principle theoretically recommends that relative burden be reassigned such that the relevant BIR approaches to unity [2], in other words, the relative burden should be equal to the relative importance.

3. Active Searching for contradictory evidence

Active searching by expert for contradictory evidence against the expert's initial opinion has been suggested to reduce overconfidence of expert estimate [4]. This technique is, however, adapted to examining the challenges not considered in the BIR assessment. Experts are encouraged to actively search the contradictory evidences against the evaluation results of BIRs that the maintenance burden imposed on the SSC can be reduced to some extent. In other words, experts should actively find out the evidences that the maintenance burden must not be reduced. The active searching technique adapted in this work is a very rigorous way to find out the challenges compared with the conventional evaluation approaches based on expert discussion. Hence experts are to utilize as detailed, or sometimes trifle, expertise as possible to find out the challenges. If there are identified contradictory evidences, each of the contradictory evidences should be reviewed by all the experts to incorporate opinions of the experts. The following examples can be contradictory evidences:

- Failure of SSC will significantly increase the frequency of an initiating event.
- Failure of SSC will fail a safety function.
- SSC is necessary for safety significant operator actions credited in the PSA.
- Failure of SSC will result in failure of safety significant SSCs in a manner which poses a risk impact (through spatial interactions).
- Relaxing the burden will have considerable (or potential) impact on the failure rate increase.
- Historical data show that some failure modes of SSC occur occasionally and/or such failure modes can not be detected in a timely fashion.
- And so on.

Each of the experts is encouraged to find and add contradictory evidences on the basis of his or her expertise.

4. Applications and Results

In this section, calculated are BIRs of 22 valves selected among 516 Motor Operated Valves (MOVs) tested in In-Service Test program of Ulchin unit 3 in South-Korea. In addition, a case study regarding active searching for contradictory evidence is introduced.

4.1 Calculation of BIR

Relative burden and relative importance measure of SSCs

are required to calculate BIR. Hence, first appropriate population (reference SSCs) should be selected to compare BIRs of reference SSCs with one another, because the BIR is a relative measure. From the view point of importance measure, the distribution of the reference SSCs should not be concentrated into high safety significant SSCs (Hi), potentially safety significant SSCs (Po), or low safety significant SSCs (Lo) (or two out of the three), that is, the reference SSCs should be impartially distributed. In this work, total number of tests conducted per year is considered as a maintenance burden and FV importance and RAW are considered as the importance measures. Decision criteria of the importance measure for the selection of reference components were 0.001 and 0.005 for the FV importance and 2 and 10 for the RAW [5]. The 22 valves were selected in consideration of whether they are modeled in PSAs (the importance measures of the reference components can be obtained in case where they are modeled in PSAs), redundancy (one or two representative valves was selected out of 2, 3, or 4 redundant trains), and distribution of the reference valves with respect to the importance measures, as shown in Table 1.

Table 1. Selection of population (reference MOVs)

Number	System	Valve Number	Valve Name	Safety Class
1	CC	73	SCS Hx A Inlet Vv	3
2	CV	530	RWT To SIPP Iso Vv	2
3	SI	644	SIT 01D Out Vv	1
4	CC	105	D/G CCW Inlet Vv	3
5	CC	141	CV Spray Hx-A Inlet Vv	3
6	CS	35	CNMT Spray Hx-1A Out Vv	2
7	SI	321	HPSIPP-2A To HL Loop 1 Vv	2
8	SI	603	HPSIPP-2A To HL Loop 1 Vv	2
9	SI	651	RCS To LPSIPP-1A Suct Vv	1
10	SI	652	RCS To LPSIPP-1B Suct Vv	1
11	SI	655	RCS To LPSIPP-1A Suct Vv	2
12	SI	656	RCS To LPSIPP-1B Suct Vv	2
13	SI	657	SCS Hx-1A Out Vv	2
14	SI	658	SCS Hx-1B Out Vv	2
15	SI	675	CV Recir Sump A Out Vv	2
16	SI	676	CV Recir Sump B Out Vv	2
17	SI	689	LPSIPP-1A To Loop 1 Iso Vv	2
18	SI	690	LPSIPP-1A To Loop 2 Iso Vv	2
19	SI	695	SCS Hx-1A Out Vv	2
20	SI	696	SCS Hx-1B Out Vv	2
21	SI	698	HPSIPP-2B Disch Vv	2
22	SI	699	HPSIPP-2A Disch Vv	2

As can be seen in Figure 1, the importance analyses for selecting the reference valves include basic analysis, common cause analysis, basic analysis without human recovery action, and common cause analysis without human recovery action for each of them with respect to core damage frequency (CDF); and basic analysis, common cause analysis with respect to large early release frequency (LERF) [6]. 104 cases out of the 132 cases resulted from 22 MOVs multiplied by 6 importance analyses could be analyzed for examining the distribution,

because 28 cases were not applicable to the importance analyses. Among the 104 cases, the cases categorized into Hi were 29 cases, the cases categorized into Po were 38 cases, and the cases categorized into Lo were 37 cases. Consequently, the reference components are considered to be impartially selected. With regard to the relative maintenance burden, total number of tests conducted per year is considered in this work. Tests include full stroke test (F), location indicating test (Z), and leakage test (L) and tests periods were once per 3 months (3) and once per overhaul (R). BIRs of the reference MOVs were calculated with the relative number of tests conducted per year and the relative importance measures based on basic analysis with respect to CDF and LERF, as shown in Table 2.

Table 2. Calculating BIRs of reference MOVs

#	Valve #	Rb C-FV	Rb C-RAW	Test item	Test interval	No. of test	BIR (C-FV)	BIR (C-RAW)	BIR (L-FV)	BIR (L-RAW)
1	73	0.0105	0.0261	F/Z	3/R	0.043	4.067	1.650		
2	530	0.0159	0.1105	F/Z	3/R	0.043	2.711	0.389	0.084	0.060
3	644	0.0125	0.0251	F/Z	3/R	0.043	162.683	1.712		
4	105	0.0335	0.0242	F/Z	3/R	0.043	16.268	1.780		
5	141	0.0185	0.028	F/Z	3/R	0.043	2.324	1.537		
6	35	0.0185	0.038	L/F/Z	R/3/R	0.061	2.734	1.808		
7	321	0.0182	0.0276	F/Z	3/R	0.043	0.232	1.55		
8	603	0.0185	0.0276	F/Z	3/R	0.043	2.32	1.55		
9	651	0.0365	0.0392	L/F/Z	R/3/R	0.061	1.914	1.679	1.975	0.971
10	652	0.023	0.0335	L/F/Z	R/3/R	0.061	1.196	1.511	1.975	0.952
11	655	0.0105	0.0261	L/F/Z	R/3/R	0.061	4.785	1.941		
12	656	0.0132	0.0268	L/F/Z	R/3/R	0.061	3.828	1.889		
13	657	0.0105	0.0261	F/Z	3/R	0.043	4.067	1.650		
14	658	0.0132	0.0268	F/Z	3/R	0.043	3.254	1.605		
15	675	0.2328	0.0185	F/Z	3/R	0.043	0.185	0.562	0.210	0.670
16	676	0.2568	0.0189	F/Z	3/R	0.043	0.168	0.526	0.210	0.701
17	689	0.0105	0.0261	L/F/Z	R/3/R	0.061	4.785	1.941		
18	690	0.0132	0.0268	L/F/Z	R/3/R	0.061	3.828	1.889		
19	695	0.0105	0.0261	F/Z	3/R	0.043	4.067	1.650		
20	696	0.0335	0.0335	F/Z	3/R	0.043	1.627	1.284	1.679	0.809
21	698	0.0317	0.024	F/Z	3/R	0.043	1.356	0.325		
22	699	0.0317	0.1297	F/Z	3/R	0.043	1.356	0.338		
Total		1	1			1				

The 3rd and the 4th columns represent relative FV importance and relative RAW with respect to CDF respectively and the 7th column represents relative number of test conducted per year. Hence, the relative values in each of the 3rd, the 4th, and the 7th columns were normalized to be summed to unity. The 8th column represents the BIRs (C-FV) calculated with FV importance to CDF. The 9th column represents the BIRs (C-RAW) calculated with RAW to CDF. The 10th column represents the BIRs (L-FV) calculated with FV importance to LERF. Finally, the 11th column represents the BIRs (L-RAW) calculated with RAW to LERF. Only 6 MOVs were applicable to the evaluation of the BIRs (L-FV and L-RAW). The distribution of the BIRs calculated is depicted in the Figure 1. The abscissa represents the BIRs calculated with the FV importance and the ordinate represents the BIRs calculated with the RAW.

Among the reference MOVs, total number of tests per year of the 13 components can be reduced from the view point of resource-importance principles, as shown in Table 3. The 6th column in Table 3 represents the minimum values among BIRs of a MOV which are summarized in the 2nd, the 3rd, the 4th, and the 5th columns, respectively. Considering the uncertainty of the BIR measures, the

minimum value is selected for reducing total number of tests per year.

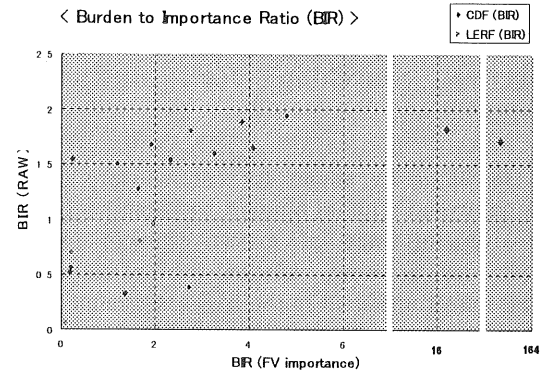


Figure 1. Distribution of BIRs calculated

Table 3. Results of BIR applications

Valve #	BIR (C-FV)	BIR (C-RAW)	BIR (L-FV)	BIR (L-RAW)	Min. BIR	Burden change (BIR→1)
73	4.067	1.650			1.65	↓
530	2.711	0.389	0.084	0.060	0.06	**↑
644	162.683	1.712			1.71	↓
105	16.268	1.780			1.78	↓
141	2.324	1.537			1.54	↓
35	2.734	1.808			1.8	↓
321	0.232	1.55			0.23	↑
603	2.32	1.55			2.23	↓
651	1.914	1.679	1.975	0.971	0.97	***N/C
652	1.196	1.511	1.975	0.952	0.95	N/C
655	4.785	1.941			1.94	↓
656	3.828	1.889			1.89	↓
657	4.067	1.650			1.65	↓
658	3.254	1.605			1.61	↓
675	0.185	0.562	0.210	0.670	0.19	↑
676	0.168	0.526	0.210	0.701	0.17	↑
689	4.785	1.941			1.94	↓
690	3.828	1.889			1.89	↓
695	4.067	1.650			1.65	↓
696	1.627	1.284	1.679	0.809	0.81	↑
698	1.356	0.325			0.33	↑
699	1.356	0.338			0.34	↑

↓: reduce, **↑: enhance, and ***N/C: Not Change

4.2 A Case Study: An Active Searching for Contradictory Evidence

Among the reference MOVs, SI-V644 has extremely high BIR (C-FV). Hence the maintenance burden imposed on the SI-V644 is thought to be reducible from the view point of the resource-importance principle. SI-V644, however, has design basis function such as supplying safety injection flow (safety function), connecting safety injection tank (SIT) to reactor coolant system (RCS) in normal operation condition, and disconnecting SIT from RCS in normal operation condition. The FV importance and the RAW of SI-V644 were evaluated as very low

values and sufficient redundancy was provided (four redundant trains). A PSA expert who was engaged in the author's previous study [5], however, issued that the safety function of SI-V644 is very critical and hence more consideration should be taken to the component. As a result, failure modes relevant to the safety function were evaluated. The failure mode relevant to the safety function was stuck-out failure to maintaining open status which was also maintained during normal operating condition. SI-V644 is not required to provide a certain activity: it is required to just maintain the open status. The failure rate of stuck-out failure was 10^{-9} /year, which could be thought to hardly occur even if test interval was somewhat increased. Finally the challenge due to increasing test interval was thought not to be significant. But if the component had different failure modes significantly affected by changes in treatment such as increasing the test interval, this could be potential challenge to safety due to the changes.

5. Discussions

Focus for enhancing maintenance effectiveness is concentrated on reducing unnecessary or sometime too sufficient maintenance burden on the basis of the recommendation of the resource-effectiveness principle in this work. As a result, total number of tests per year of the 13 MOVs can be reduced as shown in Table 3 but on the other hand, the total number of tests per year of other 7 MOVs can be enhanced from the evaluation results of the applications. So eventual concern lie in how to treat those SSCs. Regardless of how to treat those SSCs such as reducing or enhancing the maintenance burden, it must be assured that there will be no significant risk (CDF or LERF) change due to changing the burden. Hence a trade-off blending appropriate reduction of the maintenance burden for high BIR SSCs and enhancement of that for low BIR SSCs may be needed for enhancing the maintenance effectiveness, while maintaining the overall risk level.

6. Conclusions

In this work, Burden to Importance Ratio (BIR), as a quantitative measure of resource-effectiveness of maintenance activities, is used in order to enhance the maintenance effectiveness by using the risk information. The BIR has limitations associated with PSAs. Hence a qualitative approach called "active searching for contradictory evidence" is utilized to complement the BIR. The application results demonstrate that the use of BIR can be used to enhance the maintenance effectiveness by reducing the unnecessary maintenance burden. In addition, a case study regarding the active searching for contradictory evidence also shows that the challenges not considered in the BIR assessment can be identified and evaluated rigorously. Consequently, we conclude that

burden to importance approaches incorporating the quantitative measure, BIR, and the qualitative evaluation based on active searching by experts can be a successful strategy for enhancing maintenance effectiveness.

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