Estimation of computer-based display complexity in digitalized MCR of NPPs

Inseok Jang [a*], Chang Hwoi Kim [a], Wondea Jung [b], Hyoung Ju Kim [c]
[a] *I&C and Human Factors Division, Korea Atomic Energy Research Institute, 111, Daedeok-Daero 989Beon-Gil, Yuseong-gu, Daejeon, Republic of Korea*
[b] *Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 111, Daedeok-Daero 989Beon-Gil, Yuseong-gu, Daejeon, Republic of Korea*
[c] *Core Engineering Department, Korea Electric Power Corporation Nuclear Fuel Company, Daejeon, Republic of Korea*
[*]Corresponding author: isjang@kaeri.re.kr

1. Introduction

By adopting new human system interface (HSI) that are based on computer-based technologies, the operation environment of main control rooms (MCRs) in nuclear power plants (NPPs) has considerably changed. In this operation environment, computer-based information displays support operators' information searching behavior and situation awareness. On the other hand, it also causes the unexpected human factor issues such as problem due to high level of information density in limited display area, operators' situation awareness problem due to complexity of HSI and others [1]. In this light, it is necessary to develop a quantitative method to evaluate display complexity and resolve corresponding human factor issues. Accordingly, the objectives of this study are to develop a quantitative measure to estimate the complexity of computer-based display and to validate the proposed measure by comparing the estimated complexity with the subjects' performance time in the corresponding displays.

2. Methods

In order to develop the quantitative measure to estimate display complexity, the decomposition method proposed by Simon Li, et al (2011) [2] is used. This method basically uses design attributes/properties and component to describe a design feature. The design attribute characterize the properties of the design and the design components capture and convey the physical constituents of design. By using the design attribute and design component, a display is decomposed and represented as a property-component incident matrix. Then, similarity between properties/component can be calculated and the original indent matrix is transferred as diagonal matrix, and block angular matrix by cluster analysis, and partition point analysis. Finally, the display complexity is measured based on the information theoretic definition of complexity, with block angular matrix.

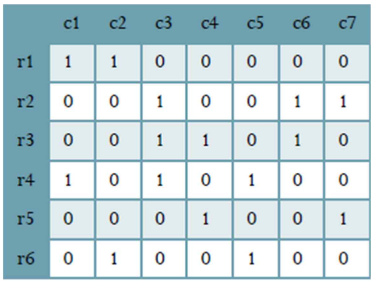
2.1 Property-component incident matrix

Consider a computer-based display involving *n* components and *m* attributes/properties. Then, the incident matrix can be expressed by

$$\mathrm{M} = [m_{ij}], (i = 1,2,\dots,m, \;\; j = 1,2,\dots n) \qquad (1)$$

$$m_{ij} = 1,$$
$$where, the\ component\ c_j\ contains\ the\ property\ r_i$$
$$m_{ij} = 0,$$
$$where, the\ component\ c_j\ does\ not\ contain\ the\ property\ r_i$$

An example of incident matrix is shown in Fig. 1.



	c1	c2	c3	c4	c5	c6	c7
r1	1	1	0	0	0	0	0
r2	0	0	1	0	0	1	1
r3	0	0	1	1	0	1	0
r4	1	0	1	0	1	0	0
r5	0	0	0	1	0	0	1
r6	0	1	0	0	1	0	0

Fig. 1. An example of incident matrix

The incident matrix in Fig.1 can be explained that component c1 has the properties 'r1' and 'r2' and components 'c1' and 'c2 have the same property 'r1'.

2.2 Similarity analysis

The similarities between columns and between rows are calculated using the Jaccard similarity coefficient 'r'.

Jaccard similarity coefficient [3] is defined as

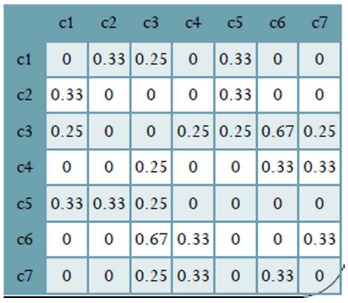
$$r_{col\_ij} = \frac{\sum_{k=1}^{m}\min(m_{ki},m_{kj})}{\sum_{k=1}^{m}\max(m_{ki},m_{kj})} \qquad (2)$$

$$r_{row\_ij} = \frac{\sum_{k=1}^{m}\min(m_{ik},m_{jk})}{\sum_{k=1}^{m}\max(m_{ik},m_{jk})} \qquad (3)$$

$where, r_{col_{ij}}$ $is\ the\ Jaccard\ similarity\ coefficient$ $for\ measuring\ the\ similarity\ between\ the\ i_{th}\ column$ $and\ j_{th}\ column$

$where, r_{row_{ij}}$ $is\ the\ Jaccard\ similarity\ coefficient$ $for\ measuring\ the\ similarity\ between\ the\ i_{th}\ row$ $and\ j_{th}\ row$

The result of similarity calculation between columns in Fig. 1 can be expressed as Fig. 2



	c1	c2	c3	c4	c5	c6	c7
c1	0	0.33	0.25	0	0.33	0	0
c2	0.33	0	0	0	0.33	0	0
c3	0.25	0	0	0.25	0.25	0.67	0.25
c4	0	0	0.25	0	0	0.33	0.33
c5	0.33	0.33	0.25	0	0	0	0
c6	0	0	0.67	0.33	0	0	0.33
c7	0	0	0.25	0.33	0	0.33	0

Fig. 2. Matrix by similarity analysis using Jaccard similarity coefficient

2.3 Cluster analysis

Cluster analysis is a process to reorganize the incident matrix as a diagonal matrix based on the results of the similarity analysis. The similar attributes and the similar components are brought close to each other. The higher number resulted from the similarity analysis means stronger relation between columns/rows. Two cluster trees from each cluster analysis of row and column are generated with partition lines. Fig. 3 shows the column cluster analysis.

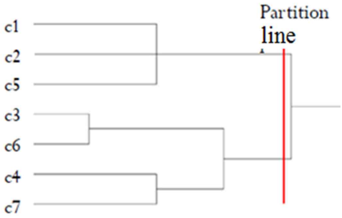


Fig. 3. Cluster Analysis

2.4 Partition point analysis

The partition point is generated by the intersection of two partition lines from row and column cluster analysis. The diagonal matrix is transformed into a block angular matrix including interaction part and independent block parts by partition point as shown in Fig. 4

Fig. 4. Diagonal matrix to Block angular matrix

2.5 Complexity measurement

Decision on each design component is binary, thus the decision space is *2^n*

$$COM_0 = m ln2^n$$

Complexity, COM_0 denotes the complexity for the original incident matrix [4, 5].

Complexity of block angular matrix is then expressed as

$$COM = \sum_{i=1}^{n_b} m_i ln2^{n_{ci}} + m_a ln2^{n_a} \qquad (4)$$

where ,

n_b: the number of blocks
m_i: the number of design properties
n_{ci}: the number of design components
m_a: the number of interaction rows
n_a: the number of interaction columns.

3. Application

The complexity measure for the computer-based display is applied to the displays of Compact Nuclear Simulator (CNS). Four displays such as feedwater system, reactor coolant system, chemical and volume control system, and residual heat removal system display are selected. The display of each system are shown in Fig. 5

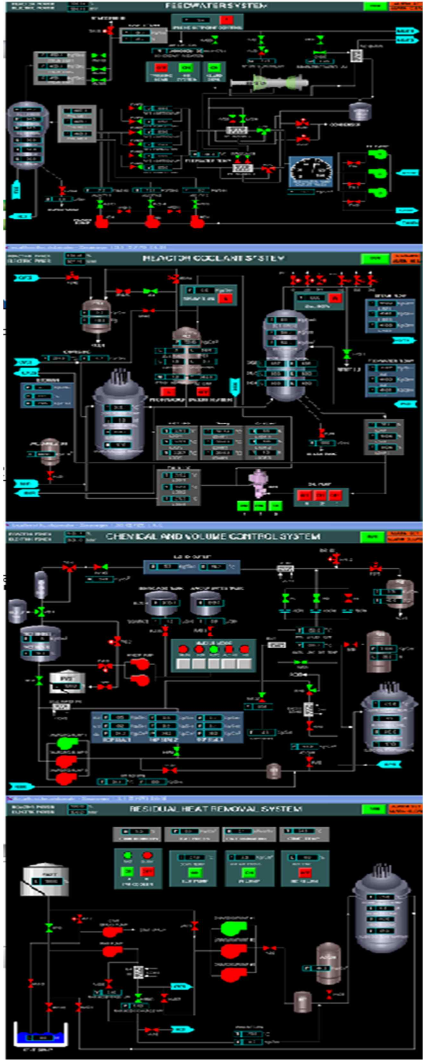


Fig. 5. Four CNS system displays

For each system display, the number of components and properties are determined. In particular, in this study, the properties are limited to the color, label, and the shape of valve, pump, and controller. Incident matrix considering the component and properties of the reactor coolant system is shown in Fig. 6

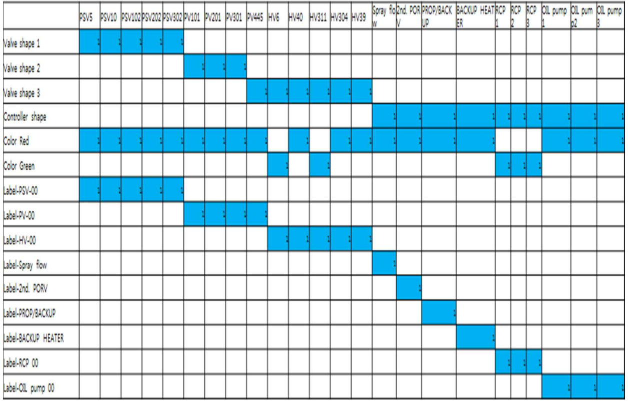


Fig. 6. Incident matrix for the display of reactor coolant system

As the number of components and properties are increased, the hand calculation for similarity analysis, cluster analysis, and partition point analysis will not be applicable. To overcome this problem, MATLAB is used from similarity analysis to generation of the block angular matrix.

Fig. 7 shows the block angular matrix of feedwater system display using MATLAB.

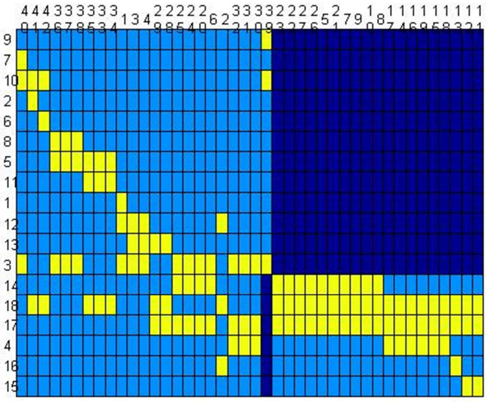


Fig. 7. Block angular matrix of feedwater system display

Then, computer-based display complexities of each system are calculated by equation (4).

$$COM_{RCS} = 7 \times ln2^{1} + 8 \times ln2^{2} + 15 \times ln2^{22} = 244.681$$
$$COM_{FWS} = 12 \times ln2^{1} + 6 \times ln2^{19} + 18 \times ln2^{22} = 361.823$$
$$COM_{CVCS} = 6 \times ln2^{1} + 9 \times ln2^{8} + 15 \times ln2^{19} = 251.612$$
$$COM_{RHR} = 6 \times ln2^{1} + 10 \times ln2^{14} + 16 \times ln2^{7} = 178.832$$

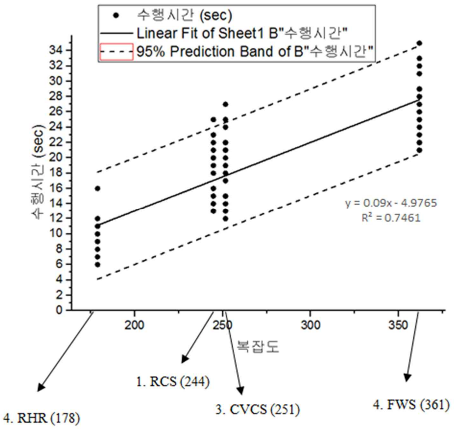
4. Validation

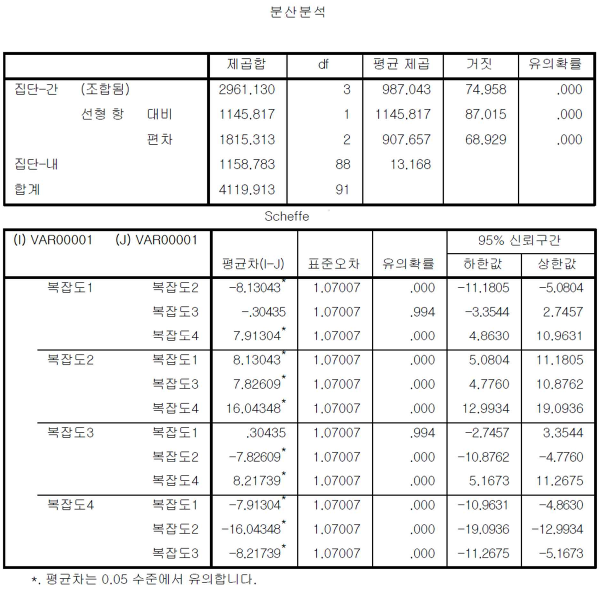
In order to validate the proposed computer-based display complexity measure, experiments with 23 subjects were conducted. The subjects were asked to perform the tasks in each display. And, time required recognizing the target component was measured. Table I shows the subjects' response time and display complexity of each system.

Table I: Subjects' response time and display complexity of each system

System display	1. RCS	2. FWS	3. CVCS	4. RHR
	Complexity			
	244.681	361.8228	251.6124	178.832
Subjects	Response time (sec)			
S_1	15	25	15	7
S_2	18	28	19	8
S_3	19	19	17	21
S_4	18	24	15	9
S_5	13	21	14	6
S_6	19	25	17	12
S_7	20	26	24	9
S_8	13	28	20	9
S_9	15	32	18	11
S_{10}	16	26	22	10
S_{11}	18	25	17	16
S_{12}	23	24	21	9
S_{13}	18	33	13	9
S_{14}	21	23	20	9
S_{15}	20	35	25	12
S_{16}	16	23	27	16
S_{17}	18	28	18	8
S_{18}	20	22	21	9
S_{19}	20	31	13	7
S_{20}	25	24	19	6
S_{21}	22	29	19	11
S_{22}	19	27	21	12
S_{23}	14	29	12	12

Using the data of Table I, calculated computer-based display complexity are compared with subjects' response time, and Fig. 8 shows the regression analysis and analysis of variance (ANOVA) results using them.





분산분석

			제곱합	df	평균 제곱	거짓	유의확률
집단-간	(조합됨)		2961.130	3	987.043	74.958	.000
	선형 항	대비	1145.817	1	1145.817	87.015	.000
		편차	1815.313	2	907.657	68.929	.000
집단-내			1158.783	88	13.168		
합계			4119.913	91			

Scheffe

(I) VAR00001	(J) VAR00001				95% 신뢰구간	
		평균차(I-J)	표준오차	유의확률	하한값	상한값
복잡도1	복잡도2	-8.13043*	1.07007	.000	-11.1805	-5.0804
	복잡도3	-.30435	1.07007	.994	-3.3544	2.7457
	복잡도4	7.91304*	1.07007	.000	4.8630	10.9631
복잡도2	복잡도1	8.13043*	1.07007	.000	5.0804	11.1805
	복잡도3	7.82609*	1.07007	.000	4.7760	10.8762
	복잡도4	16.04348*	1.07007	.000	12.9934	19.0936
복잡도3	복잡도1	.30435	1.07007	.994	-2.7457	3.3544
	복잡도2	-7.82609*	1.07007	.000	-10.8762	-4.7760
	복잡도4	8.21739*	1.07007	.000	5.1673	11.2675
복잡도4	복잡도1	-7.91304*	1.07007	.000	-10.9631	-4.8630
	복잡도2	-16.04348*	1.07007	.000	-19.0936	-12.9934
	복잡도3	-8.21739*	1.07007	.000	-11.2675	-5.1673

*. 평균차는 0.05 수준에서 유의합니다.

Fig. 8. Regression analysis and analysis of variance (ANOVA) results

As shown in Fig. 8, subjects' response time is strongly proportional to calculated computer-based display complexity ($R^2 = 0.7461$). In addition, from the ANOVA analysis, it is clear that calculated computer-based display complexity and subjects' response time have a statistical meaningful correlation ($p<0.05$).

5. Conclusions

In this study, a quantitative measure to estimate the complexity of computer-based display was proposed. In addition, the proposed measure was validated by comparing the estimated complexity with the subjects' performance time in the corresponding displays. With adaptation of the results of this study, it is expected that the proposed method will be helpful for HSI design (in particular, screen/display design) and quantification of performance shaping factor related to HSI/display complexity. However, further researches such as optimizing display design and determining display properties will be needed to enhance the proposed method.

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