A Study on Improving the Efficiency of Nuclear Security System Design Using Analytic Hierarchy Process

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ABSTRACT

As terrorism is increasing internationally, interest in the security of nuclear facilities is also increasing. Accordingly, the IAEA has published various Nuclear Security Series, which are security requirements documents, and presents various security measures. As a result of these IAEA efforts, the effectiveness of nuclear security is increasing internationally. However, it is not easy to find guidelines on nuclear security design considering efficiency. In general, effectiveness should indeed have a high priority in nuclear security. However, efficiency should be considered when considering the economic sustainability of nuclear energy and establishing balanced nuclear security systems.

In order to consider efficiency, it is necessary to be able to compare input and output. In this study, after presenting a methodology for quantifying effort(input) and effectiveness(output) and obtaining efficiency with the ratio, a pilot application of response measures against insider threats was applied to the design. Expert judgment was used in quantifying qualitative effort and effectiveness, and the Analytic Hierarchy Process technique was used for reasonable statistical processing of this expert judgment. As a result of the pilot application, this study is expected to reasonably set the application priority among numerous protection measures as it can evaluate the effectiveness of each protective measure considering the characteristics of the national security environment and technology.

I. INTRODUCTION

Since the September 11, 2001, terrorist attacks, security for nuclear facilities has been continuously strengthened. The IAEA also presents many requirements that member states fulfill for nuclear security, such as publishing 32 new Nuclear Security Series over the past ten years. Applying all the security requirements would be encouraged, but it is practically impossible because the state's financial resources are limited. Therefore, a method for efficiently establishing a physical protection system using limited resources is required.

In addition to the strengthening and diversifying security requirements, various protective measures for each requirement are also presented. The IAEA document for physical protection design suggests twenty-one types of sensors for intrusion detection, five methods for access control, and nine types of barriers for the delay. [1] The IAEA document for insider threat suggests eleven preventive measures and fifteen protective measures. [2] Taking all protective measures for each requirements would be desirable, but it is impossible with limited resources. Although the pros and cons of each protective measure have been analyzed, it needs to suggest how to select and apply which protective measure. Therefore, a procedure is needed to select and apply the most appropriate protective measures for the country for nuclear facilities.

Considering the impact of a nuclear security event, such as the unauthorized removal of nuclear material or the occurrence of sabotage, nuclear security should remain a high priority in the operation of nuclear facilities. Therefore, nuclear security effectiveness is very important. After that, it is essential to consider efficiency for the overall performance of nuclear security and the economic sustainability of nuclear energy. Nuclear security effectiveness and efficiency are different. So far, many efforts have been made to increase the effectiveness of nuclear security, and it is now time to consider the efficiency of nuclear security.

This paper presents a methodology for designing a nuclear security system in consideration of efficiency, and a pilot application is intended for response of insider threat. Expert opinions were used to quantify the efficiency, and the Analytic Hierarchy Process technique was used for reasonable quantification.

II. Design Methodology

A. Methods for Evaluating the Efficiency

Efficiency is usually expressed as output versus input. A lot of effort is needed to improve nuclear security, and many effects are obtained through this effort. Therefore, the efficiency of nuclear security is intended to be expressed as the ratio of effort to effectiveness.

$$\text{efficiency} = \frac{output}{input} = \frac{effectiveness}{effort}$$

B. Quantifying Effort and Effectiveness

Multiple Criteria Decision Making (MCDM) is a methodology for making complex decisions based on multiple criteria. It has been actively studied since the 1970s and used in various policy decision-making processes. MCDM has several techniques, such as the Scoring Method, Goal Achievement Method, Multi-Attribute Utility Theory, Outranking Method, and Analytic Hierarchy Process(AHP), each with strengths and weaknesses.

Between 2000 and 2014, 393 papers were published using the MCDM method. Of these, 128 papers (32.56%) used the AHP technique. The AHP technique is widely used in various fields. After all, explaining the evaluation process, understanding the rationale, and applying it is easy because it analyzes by classifying layers. In nuclear power, since the method of deriving results must be transparent and easily understood by many stakeholders, the AHP technique will be used among several MCDM techniques. [3]

The AHP technique is a method of determining the weight of each factor after quantifying the relative importance of the factors constituting the evaluation criteria with scores. After deriving the factors constituting effort and the factors constituting effectiveness through the opinions of security experts, the importance and weight of factors can be obtained through the AHP pairwise comparison of each factor. [4]

For example, applying physical protection measures requires effort such as cost, technology development, and inconvenience. In that case, the factors constituting the effort are 1) cost, 2) technology development, and 3) inconvenience, and each weight can be calculated as shown in Table 1 according to the AHP technique.

Table 1. Weight calculation method through AHP technique

Effort	Cost	Technology development	Inconve-nience
Cost	1	i	j
Technology development	1/i	1	k
Inconve-nience	1/j	1/k	1
Sum	$1+\frac{1}{i}+\frac{1}{k}$	$i+1+\frac{1}{k}$	$j+k+1$

→ Normalize

Effort	Cost	Technology development	Inconve-nience	Weight
Cost	$\frac{1}{1+\frac{1}{i}+\frac{1}{k}} = c_{11}$	$\frac{i}{i+1+\frac{1}{k}} = c_{12}$	$\frac{j}{j+k+1} = c_{13}$	$c_{11}+c_{12}+c_{13} = w_1$
Technical development	$\frac{1/i}{1+\frac{1}{i}+\frac{1}{k}} = c_{21}$	$\frac{1}{i+1+\frac{1}{k}} = c_{22}$	$\frac{k}{j+k+1} = c_{23}$	$c_{21}+c_{22}+c_{23} = w_2$
Inconve-nience	$\frac{1/j}{1+\frac{1}{i}+\frac{1}{k}} = c_{31}$	$\frac{1/k}{i+1+\frac{1}{k}} = c_{32}$	$\frac{1}{j+k+1} = c_{33}$	$c_{31}+c_{32}+c_{33} = w_3$

C. Evaluation of Protective Measures

Through the opinions of security experts, the effort score and effectiveness score of each physical protection measure is evaluated. After evaluation, each physical protection measure's final effort score and effectiveness score can be derived, as shown in Table 2, by reflecting the previously derived weight.

Table 2. Effort and effectiveness score evaluation for each protective measure

Technologies	Raw score from an expert				Weighted reflection				Effort or effectiveness of the technology
	Cost	Technology development	Inconve-nience		Cost	Technology development	Inconve-nience		
Measure.1	a_1	b_1	c_1	→ Normalize	$a_1 \times w_1$	$b_1 \times w_2$	$c_1 \times w_3$	→ Sum	$a_1 \times w_1 + b_1 \times w_2 + c_1 \times w_3$ $= effort_1$ or $effec_1$
…	…	…	…		…	…	…		…
Measure.n	a_n	b_n	c_n		$a_n \times w_1$	$b_n \times w_2$	$c_n \times w_3$		$a_n \times w_1 + b_n \times w_2 + c_n \times w_3$ $= effort_n$ or $effec_n$

D. Derivation of Efficiency of Protective Measures

Since efficiency was previously defined as the ratio of effectiveness to effort, the efficiency of each protective measure can be quantitatively derived, as shown in Table 3, by calculating the ratio.

Table 3. Calculation of efficiency of protective measure

Technologies	Effort (x)	Effectiveness (y)	Efficiency (x/y)
Measure.1	$effort_1$	$effec_1$	$effic_1 = \frac{effec_1}{effort_1}$
…	…	…	…
Measure.n	$effort_n$	$effec_n$	$effic_n = \frac{effec_n}{effort_n}$

Protective measures with high efficiency means that high effectiveness appears despite low effort. By plotting effort on the x-axis and effectiveness on the y-axis, the efficiency of each protective measure can be visualized, as shown in Figure 1. It can be analyzed that the closer the measure is to Area 1, the higher the efficiency and preferred protective measures, and the closer to Area 2, the less preferred protective measures.

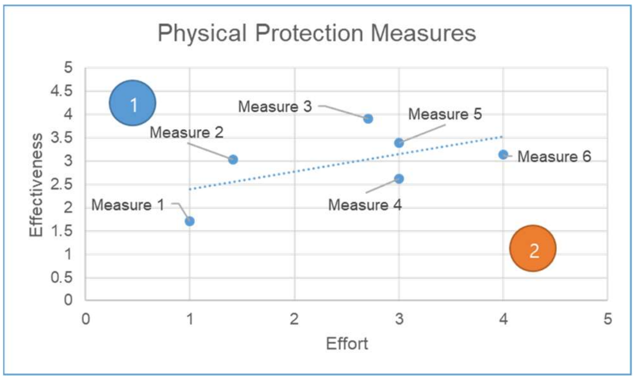


Fig 1. Graphs for analysis

III. Methodology Application

In order to verify the usability of the methodology and derive improvements, the methodology was pilot-applied to some nuclear security field. Among various nuclear security fields, responding to insider threats has recently been emphasized, and various preventive and protective measures have been suggested. However, a plan to design which measures to introduce first and which measures to take is more appropriate has yet to be suggested. Therefore, this methodology was pilot-applied to designing an insider threat response system.

A. Derivation of Factors for Effort and Effectiveness

The effort factor and effectiveness factor of insider threat should be derived.

Introducing insider threat response measures may require cost and technology development. In addition, there may be inconveniences caused to employees by introducing such measures. Therefore, the effort factors comprised cost, technical development, and inconvenience.

The effectiveness can vary by factor depending on the criterion. There may be effectiveness by access type (employees, contractors, and visitors), by area, and by time. This survey will classify the effectiveness factor into areas such as Limited Access Area(LAA), Protected Area(PA), and Vital Area(VA), which are the same standards internationally, and the effectiveness will be evaluated.

B. Weighted Evaluation of Effort and Effectiveness

A survey was conducted targeting thirteen security experts from two countries to enable comparison between countries. It would have been nice if the number of experts was the same, but it took work to cooperate smoothly because this survey was on security.

The results were derived from eleven security experts from country A and two security experts from country B. The average value of each country in the survey was calculated with the AHP technique presented in Chapter 2 to obtain weights, and the results were derived as shown in Table 4.

Table 4. Weight of insider threat response design factors in Countries A and B

		Country A	Country B
Effort (100%)	Cost	48%	21%
	Technical Development	31%	67%
	Inconvenience	21%	12%
Effectiveness (100%)	LAA	55%	20%
	PA	31%	8%
	VA	14%	73%

Analyzing Table 4, in the case of country A, in establishing an insider threat response system, the cost has the most significant influence (48%) on designing a system, and insider detection in LAA is the most important (55%). In the case of country B, technical development has the most significant influence (67%) on the design of the insider threat response system, and it is the most important thing (73%) to detect insiders in VA.

C. Evaluation of Insider Threat Response Measures

Similar to the survey for the weight of factors, a survey was conducted targeting eleven security experts in country A and two security experts in country B. Six representative insider threat response measures presented by the IAEA were evaluated. The range of scores was zero to five points. Table 5 shows the average score of eleven experts in country A and the average score of two experts in country B.

Table 5. Effort and effectiveness evaluation score

Country A		Background check	Access control	Behavior monitoring	Two-person rule	Bio-signal assessment	CCTV monitoring
Effort (0~5)	Cost	1.55	2.55	2.36	2.82	3.45	2.82
	Technical Development	1.36	2.36	1.91	1.00	3.91	2.09
	Inconvenience	2.64	3.00	3.09	3.91	3.27	2.18
Effective ness (0~5)	LAA	2.45	2.27	2.45	2.00	2.09	2.45
	PA	3.27	3.18	3.18	3.45	2.82	3.18
	VA	3.00	3.55	3.82	4.18	3.55	3.82
Country B		**Background check**	**Access control**	**Behavior monitoring**	**Two-person rule**	**Bio-signal assessment**	**CCTV monitoring**
Effort (0~5)	Cost	2.00	2.00	2.00	1.50	3.50	2.00
	Technical Development	3.00	2.50	4.00	1.50	3.50	2.50
	Inconvenience	2.50	1.50	2.50	2.00	2.50	1.00
Effective ness (0~5)	LAA	4.00	3.00	4.00	3.50	4.00	4.50
	PA	4.50	4.50	5.00	4.50	4.50	4.50
	VA	5.00	5.00	5.00	5.00	5.00	5.00

The results of reflecting the weights obtained in Table 4 to the results of Table 5 are shown in Table 6.

Table 6. Effort and effectiveness evaluation score

Country A		Background check	Access control	Behavior monitoring	Two-person rule	Bio-signal assessment	CCTV monitoring
Effort (0~5)	Cost	0.74	1.22	1.13	1.35	1.66	1.35
	Technical Development	0.43	0.74	0.60	0.31	1.23	0.66
	Inconvenience	0.54	0.62	0.64	0.81	0.67	0.45
Total		1.71	2.58	2.37	2.47	3.56	2.46
Rank		1	5	2	4	6	3
Effectiveness (0~5)	LAA	1.35	1.25	1.35	1.10	1.15	1.35
	PA	1.02	0.99	0.99	1.08	0.88	0.99
	VA	0.42	0.49	0.53	0.58	0.49	0.53
Total		2.79	2.73	2.87	2.76	2.52	2.87
Rank		3	5	1	4	6	1
Country B		Background check	Access control	Behavior monitoring	Two-person rule	Bio-signal assessment	CCTV monitoring
Effort (0~5)	Cost	0.43	0.43	0.43	0.32	0.75	0.43
	Technical Development	2.00	1.66	2.66	1.00	2.33	1.66
	Inconvenience	0.30	0.18	0.30	0.24	0.30	0.12
Total		2.73	2.27	3.39	1.56	3.38	2.21
Rank		4	3	6	1	5	2
Effectiveness (0~5)	LAA	0.78	0.59	0.78	0.68	0.78	0.88
	PA	0.35	0.35	0.39	0.35	0.35	0.35
	VA	3.64	3.64	3.64	3.64	3.64	3.64
Total		4.77	4.57	4.80	4.67	4.77	4.86
Rank		3	6	2	5	3	1

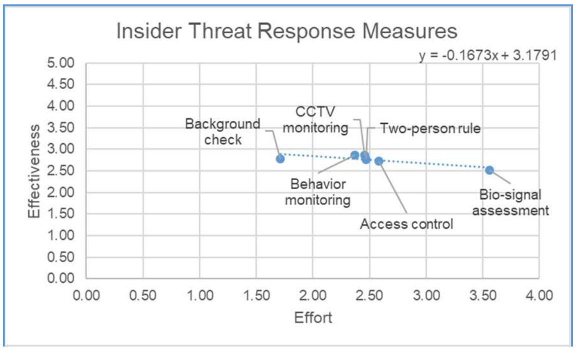
D. Analysis and visualization of evaluation results

In evaluating the weight of effort and effectiveness factors, country A was the most critical effort factor for cost, and country B was the most crucial effort factor for technology development. In addition, country A evaluated detecting insiders in LAA as the most critical effectiveness and country B evaluated detecting insiders in VA as the essential effectiveness. It is judged that the weight evaluation of the factor may vary depending on each country's level of threat, sociocultural environment, and technological development.

In evaluating the effort of measures, country A was evaluated as the most readily applicable measure for background checks, and country B was evaluated as the most readily adopted measure for the two-person rule. The difference in the effort score between the measures evaluated in each country was significant, 1.71 for the lowest value and 3.56 for the highest value for country A, 1.56 for the lowest value, and 3.39 for the highest value for country B and the deviation was significant.

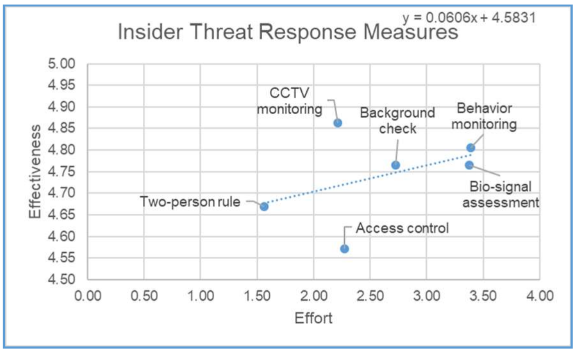
In evaluating the effectiveness score of measures, behavior monitoring and CCTV monitoring were jointly evaluated as the most effective measures in country A. CCTV monitoring was evaluated as the most effective measure in country B, resulting in similar results. However, the difference between the effectiveness of each measure was not significant.

Since effectiveness was assessed similarly, efficiency tends to be determined according to the effort. In country A, the background check was evaluated as the most efficient measure, and in country B, the two-person rule was evaluated as the most efficient technology. Figure 2, 3 shows the efficiency results graphically.



Country A	Efficiency	Rank
Background check	1.63	1
Access control	1.06	5
Behavior monitoring	1.21	2
Two-person rule	1.12	4
Bio-signal assessment	0.71	6
CCTV monitoring	1.17	3

Fig 2. Results of efficiency evaluation of insider threat response measures in Country A



Country B	Efficiency	Rank
Background check	1.75	4
Access control	2.01	3
Behavior monitoring	1.42	5
Two-person rule	2.99	1
Bio-signal assessment	1.41	6
CCTV monitoring	2.20	2

Fig 3. Results of efficiency evaluation of insider threat response measures in Country B

IV. CONCLUSION

For quite a long time, the international community has prepared new nuclear security requirements and protective measures and has increased the effectiveness of nuclear security. In strengthening nuclear security, effectiveness is one of the most important virtues, but it is necessary to consider efficiency for balanced performance and economic sustainability of nuclear energy. Therefore, this study developed a methodology for designing an efficient physical protection system.

There were two primary considerations for improving this methodology. The first is a method for evaluating factors and measures, and the second is quantifying the results. To this end, the evaluation targeted security experts, and the MCDM method called the AHP technique was used for reasonable quantification.

As a result of the pilot application of this methodology to two different countries, each country has its security environment. Even if it is the same measure, the effort to apply the measure and the effectiveness obtained from the measure is different. This methodology could derive the efficiency of measures reflecting the characteristics of the country concerned. Designing an efficient physical protection system, such as applying a graded approach according to the results and rankings derived, would be possible.

However, there were some points for improvement in the future. First, it is necessary to be able to select reliable experts, as quantification is made through expert opinions. The IAEA proposes a pool of experts to participate in threat assessment. The same expert can be used when applying the methodology of this study. Second, in the case of MCDM, research is being actively conducted to the extent that there is a separate society for this methodology. If a quantitative evaluation methodology for more rational decision-making is developed, it will be necessary to introduce it.

This study evaluated and quantified the results of the design of an efficient nuclear security system. This methodology can reflect a country or facility’s characteristics and quantitatively evaluate efficiency, so it can be used to prioritize introduction or apply a graded approach. Through this, it is expected to increase the effectiveness in one field, improve the overall level of nuclear security and performance, and help maintain economic sustainability.

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