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Research Article

A Study on the Design Risk Reduction Using QFD Technique that Incorporates Joint Reliability Importance

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Abstract: As the system developed recently becomes larger, it's increasingly difficult to design the system. Particularly, such a large complex system contains many problems at development stage that is directly related to safety issue. Railroad car today has been developed as much as to run automatically without driver. Viewing such development, LRT requires more design reliability than anything else. This study is intended to refine the requirements using QFD that was improved based on requirements at design stage as well as incorporate the importance into the design. QFD has been mainly used in product development from design standpoint. Thus this study, to make sure the safety in system design, proposes QFD methodology improved through implementing operational concept and hierarchical approach-based system engineering. Furthermore, joint reliability importance is introduced to consider the safety at design stage so as to lay the foundation to ensure the safety will be maintained at design stage using QFD. As keyword and inter-working component to design requirements for safety are distinguishable in this study, they would be used as core data in integrating the design of LRT system.

Keywords: Complexity, joint reliability importance, light rail transit, QFD, system design, safety, requirements priority

INTRODUCTION

Recently, it has been difficult to develop systems due to the trend toward large scale, complication and advanced technology (Creveling *et al*., 2003; INCOSE, 2007; Sheard and Mostashari, 2009; Pahl and Beitz, 1996). The system including high speed train, nuclear power plant and weapon system that may cause a huge personnel and material loss when accident occurred is defined as Safety Critical System (El-Haik and Yang, 1999; Peliti and Vulpiani, 1987). Lately, the study to incorporate the safety at design stage to secure the safety for such a large system has been on the rise (Domerçant and Mavris, 2011; Sheard and Mostashari, 2009).

As part of such efforts, many studies on design implementation and improvement using Quality Function Deployment (QFD) that incorporates the requirements of interested parties through system engineering approach that materializes and hierarchizes the abstract requirements (Kinsner, 2008; Blanchard and Fabrycky, 2006; Valerdi, 2006; Calvano and John, 2004; Senge, 1990). However, the problems still remain because should design be implemented based on existing QFD, it would rather consider design and production only and safety could hardly be incorporated into the design.

From this aspect, the studies include risk-reducing model QFD to incorporate the safety into QFD through combination of the product from existing QFD and safety activities (Agrawalla, 2011) modification of HOQ form which is the key activity for implementing QFD (Kim, 1999) and presentation of integrated frame model between QFD and other solutions to accomplish the research goal (Ameri *et al*., 2008).

In this study, incorporation of importance evaluation of technical elements with regard to HOQ form used generally for key activity of QFD and proposal of HOQ (House of Quality) improved to incorporate the safety are made as Fig. 1 and based on this, the procedure for QFD implementation is proposed. Furthermore, the study is also intended to analyze and identify the requirements which are considered important in designing through the interworking analysis based on importance index between client's requirements and technical requirements (Summers and Shah, 2003).

However with such approach, activity in analyzing and identifying the requirements in systematic way is limited. Hence, should the approach be based on such system engineering approach (Suh, 1990) as operation concept and scenario with regard to design and safety elements and as proposed in Fig. 2, repeated implementation of QFD depending on system

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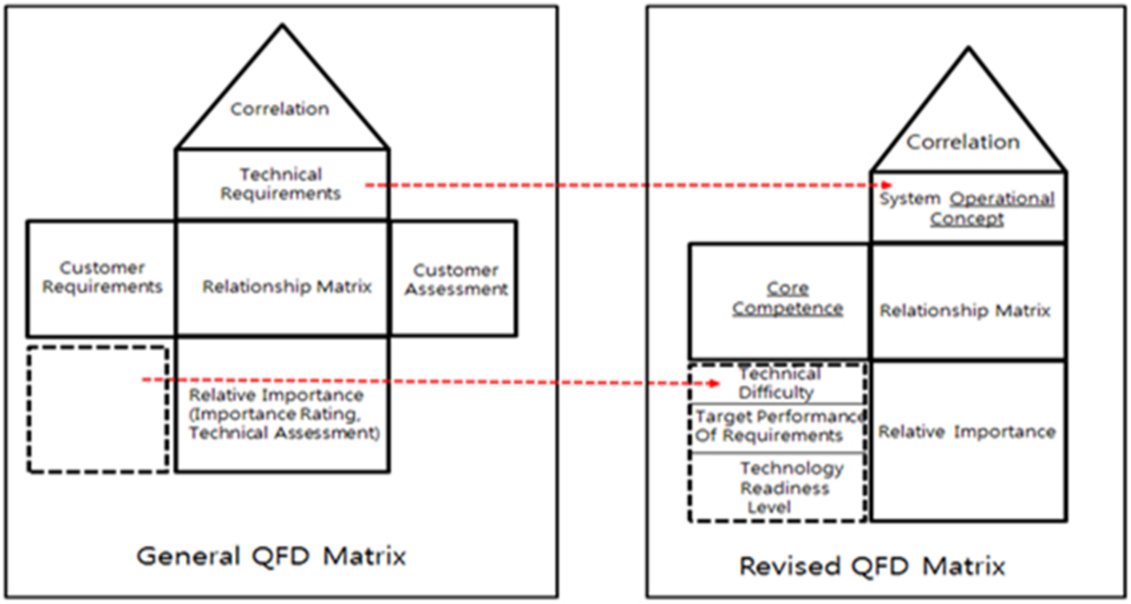

Fig. 1: Ordinary QFD and improved HOQ of QFD

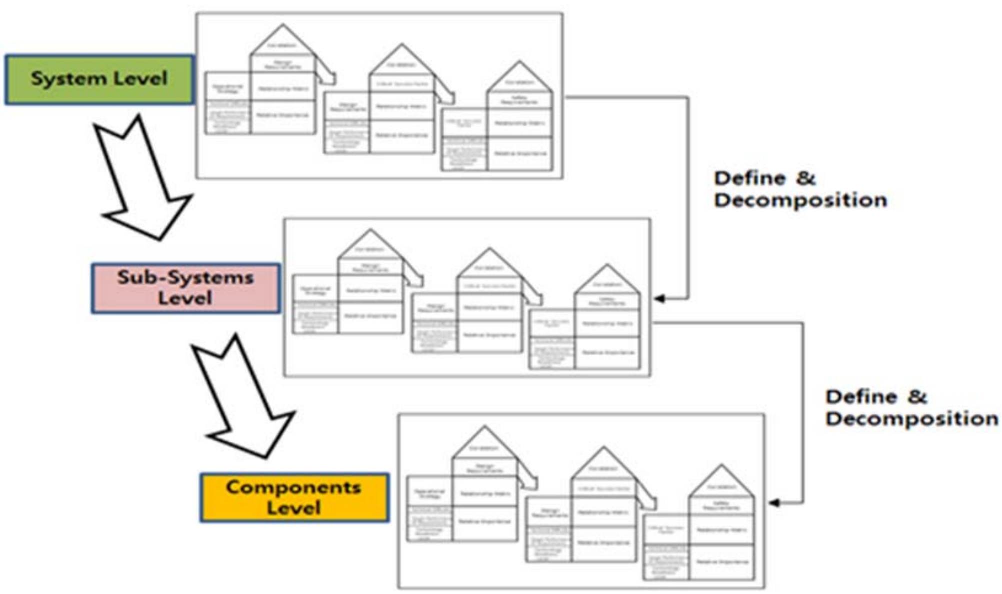

Fig. 2: Implementation of QFD depending on QFD system level

hierarchy, accuracy of the analysis and identification of early requirements would possibly be enhanced than existing implementation method using technical requirements directly. Thus, the approach developed and proposed in such study is expected to achieve the improvement in systemization and reliability of the data which was obtained by repeating the process in existing QFD method from system engineering viewpoint.

DEFINITION OF PROBLEMS

Analysis of preceding research: Viewing preceding studies, the studies implemented through QFD were classified into three categories as shown in Table 1. With regard to the elements defined among the results of preceding studies, error or pending issues are described in Table 1. Basedon this, the study to deal with the problems defined is conducted.

Need for Implementing Operation Concept-based QFD Procedure: According to design approach used by current QFD, requirements are analyzed and identified through document-based analysis of mutual importance linkage of core competence and related technical requirements (Braha and Maimon, 1998) which makes difficult the analysis and identification of

Table 1: Analysis of preceding researches

Risk-reducing model through interworking between QFDand other methods (safety)	Agrawalla (2011)	At Ph-1 of QFD, the product is generated at technical importance rating and implementation level for individual design requirements and at Ph-2, importance is rated to score and the importance is mentioned for implementation role at first two phases if total four phases if QFD. Thus, the measure is provided for link in designing FMEA (Failure mode and Effect analysis) to evaluate Potential failure and effect for risk analysis based on design requirements from Ph-1 of QFD process.	Implementation for FMEA based on developed design requirements. FMEA is not implemented in systematic approach to hierarchic level for individual design requirements
HOQ modification of QFD	Kim (1999)	Ergonomics activity to be incorporated for developing HOQ to incorporate Ergonomics and elements are analyzed and identified for incorporation into HOQ (House of quality)	The author pointed the difficulty and the problem with efficiency while supporting continuous update of HOQ matrix for needs. The author conducted the study focusing on STEP_1and STEP_2 linked directly to system design, instead of balanced viewpoint to entire step
Integration of QFD with other solutions	Ameri *et al*. (2008)	To support and accomplish the goal through the study, a model integrating ECQFD, TRIZ and AHP was proposed.	Given the overlapped commitment among the approaches proposed, interrelations among the approaches needs to be defined

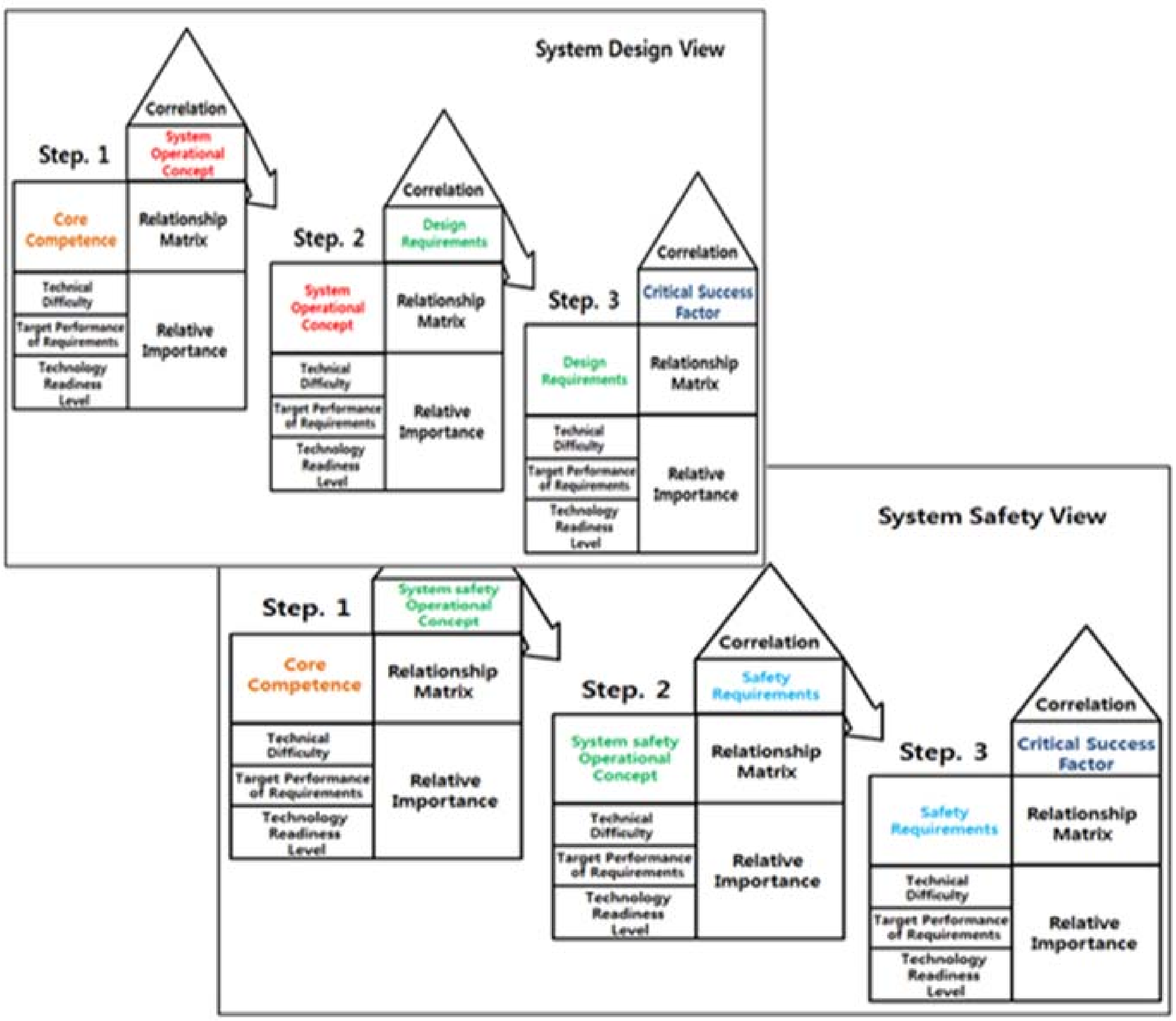

Fig. 3: Operation concept-based system design and safety requirements

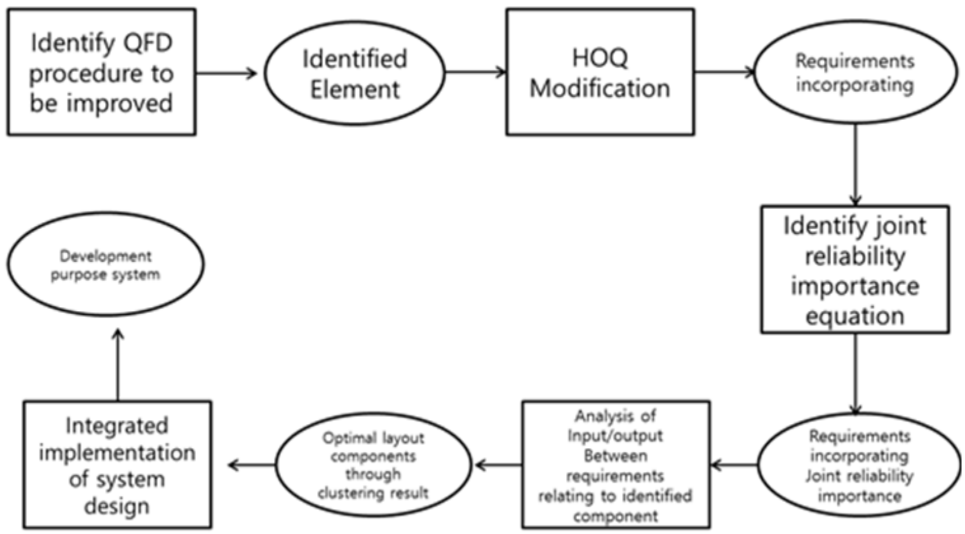

Fig. 4: Goal of study and concept

requirements depending on system hierarchy for individual requirements and failure of generating the data depending on system hierarchy in a systematic way also results in difficulties in interlinking based on such result from safety viewpoint. But in this study, analysis and identification of requirements were made at early upper level based on core competence and operation concept and scenario proposed in Fig. 3 which allows hierarchical approach. Thus, more useful approach than existing one is achievable.

Importance of requirement-based design that incorporates design-safety combined weight: A system is designed and developed based on relationships with numerous interested parties under multidisciplinary approaches because of system development environment that has to deal with a large system (Kolmogorov, 1983). Thus, system development of LRT system in unmanned operation now has become more difficult because of complex system configuration and diverse interested parties involved. For such reasons, system safety has been emerged as critical issue today. As part of the approaches to deal with such problems, design method incorporating importance evaluation and client's requirements using QFD is suggested but has yet to be incorporated from safety standpoint. Should system design be implemented based on requirements identified using combined weight that considers both design and safety at a time, safety which was not obtainable by QFD would possibly be secured, thereby enhancing safety and reliability of system design.

Goal and Scope of the Study: According to the analysis of preceding study, QFD shall be used based on repetitive approach depending on operation concept and system hierarchy level ay system design stage and to incorporate the safety factor into QFD used mostly for design, a measure incorporating the joint reliability importance in design and safety aspect to individual requirements is needed. To that end, a joint reliability importance equation that is able to evaluate the importance of both design and safety which are different each other is proposed in this study. In addition, a system design using requirement data calculated based on this is proposed. The scope of this study is limited to conceptual design stage which is the initial stage of system design. The process to accomplish the goal of the study is illustrated as Fig. 4.

DEVELOPMENT OF QFD IMPROVED BY INCORPORATING COMBINED IMPORTANCE

Existing QFD is the approach in system development aspect which is aimed at satisfying the initial requirements of the client on finished product, but failed to incorporate safety into the design. This study thus is intended to propose the combined measure, instead of implementing design and safety separately. So as part of the measures to secure the safety at early design stage, the method to identify and use the joint reliability importance in design and safety territory as a single approach is proposed in this study.

Concept of combined importance: A joint reliability importance, as suggested in Fig. 5, refers to the index of an integrated importance of design requirements and safety requirements. And joint reliability importance was implemented based on degree of risks of requirements calculated by multiplying requirements importance by degree of difficulty of Simon (1998) and Dixon *et al*. (1988), Where, DR refers to design requirements and SR refers to safety requirements and R attached to the end of each word refers to degree of

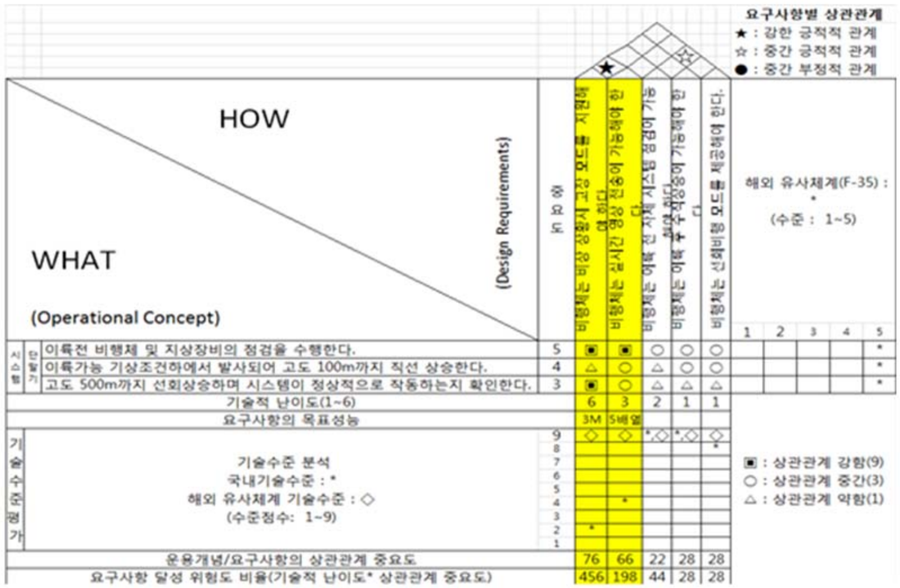

Fig. 5: Detail analysis of degree of risks of requirements

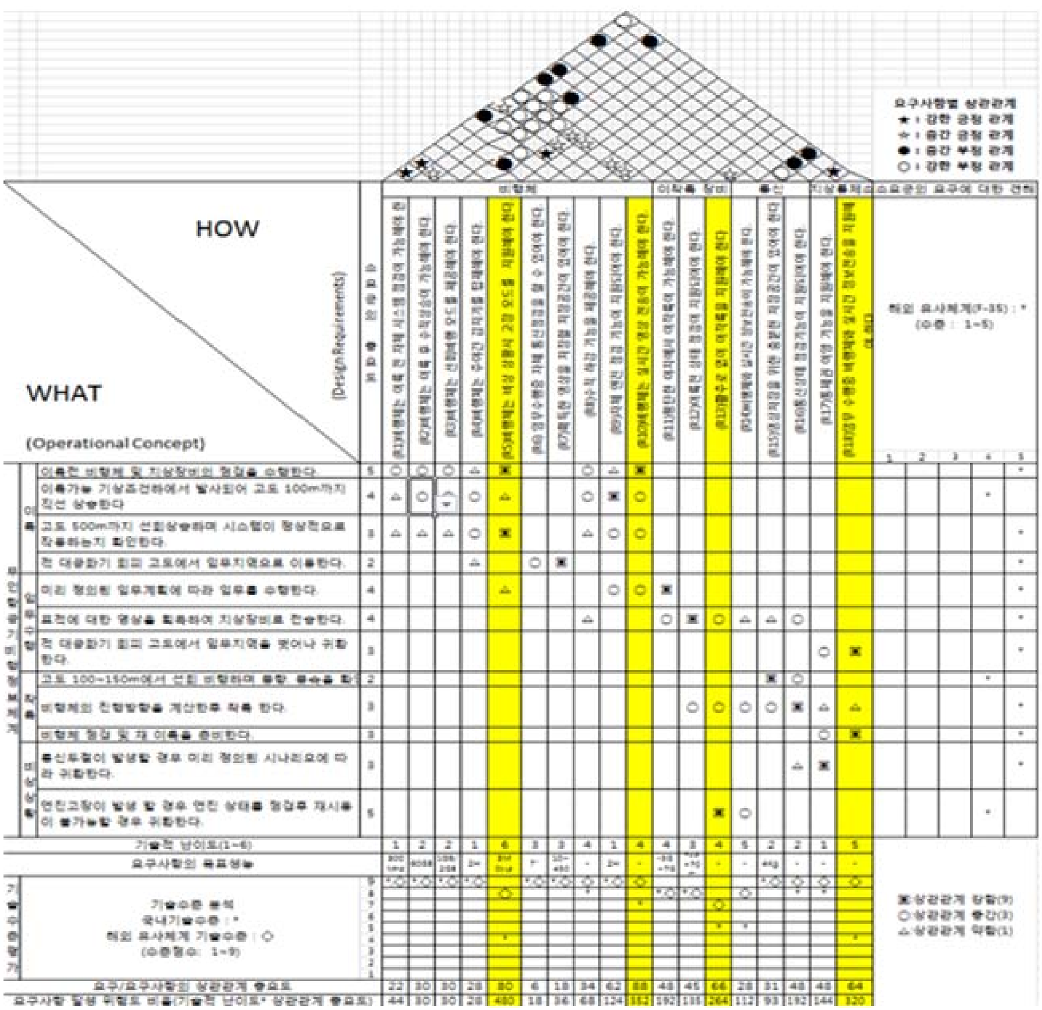

Fig. 6: (Step 2) Analysis of correlations between operation concept and design requirements

risks. Thus DRR refers to degree of risks of design requirements. As the study is implemented based in system design focusing on safety, 0.4 or less was applied to the value "a" in Eq. (1) Thus to give the weighted value to the safety in safety-focused system design, 0.4 or less was applied to "a" W(RR) indicates relative importance based on weighted value to safety in relation to design requirements:

$$W\,(RR) = a \cdot DRR + (1-a) \cdot SRR,\ 0 \le a \le 1 \qquad (1)$$

QFD incorporating joint reliability importance: To incorporate joint reliability importance into QFD, it's necessary to implement the analysis of relative importance of core competence, operation concept and related requirements which are third stage respectively from design and safety viewpoint proposed in Fig. 6. The requirements finally produced through such process would result in a single value in the wake of applying relative weight of safety requirement relating to design requirements based on joint reliability importance in Eq. (1). An integrated requirement importance index between system design requirements and safety requirements may be produced.

SYSTEM DESIGN USING IMPROVED QFD

Improved approach depending on operation concept and system hierarchy was proposed from existing document and design-centered QFD. And as part of the efforts to secure both design and safety aspects, the principle of joint reliability importance was introduced so as to pave the foundation to incorporate the safety using QFD as well. Thus, based on result from QFD considering joint reliability importance, the measure to use the following system design was proposed.

The procedure of applying improved QFD: A 9-stage procedure below is applied to use the data for design using improved QFD proposed in this study:

Step 1: Collect core competence of the system to be developed from interested parties
Step 2: Classify operation concept of the system
Step 3: Evaluate technology importance of core competence by expert group
Step 4: Identify operation concept-based requirements
Step 5: Evaluate relations between identified core competence and index and requirements.
Step 6: Evaluate the requirements incorporating joint reliability importance
Step 7: Identify design core design requirements incorporating safety
Step 8: Identify the components relating to identified requirements
Step 9: Identify optimal design allocation combination through matrix generation between core requirements and components. Step. 1~5 is implemented equally by differentiating the viewpoint between design and safety.

System design development through proposed QFD model: It's possible to identify the components of each system hierarchy depending on analysis of operation concept by system level proposed in this study as well as the requirements thereof. Accordingly, as system decomposition is achievable by such approach, identifying the components of the system for development would be possible when applying the approach proposed in Fig. 2 And the requirements relating to each component becomes identifiable, making it possible interface analysis by component.

Matrix structure in Fig. 7 is obtained based on core requirements identified by incorporating components identified at component level and joint reliability importance. Viewing Fig. 7, analysis of input/output relations by individual component identified from A to

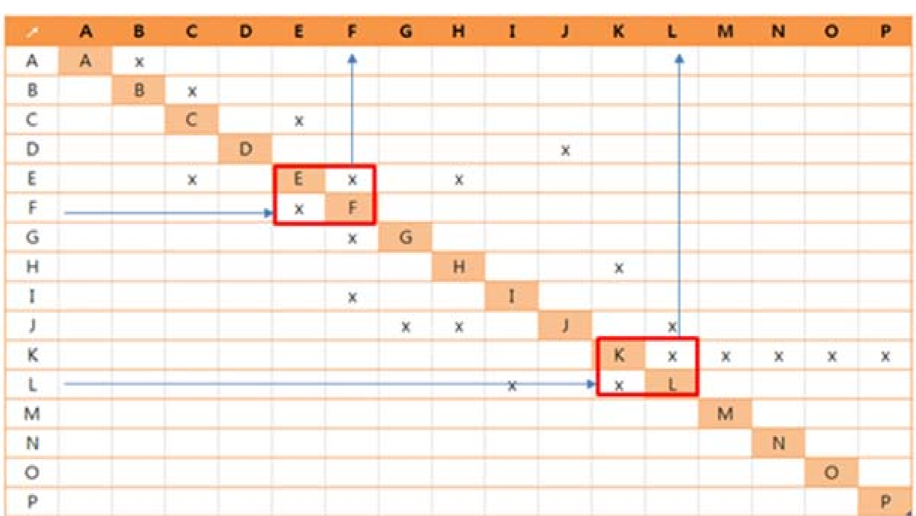

Fig. 7: Input/output analysis matrix by component identified

P was conducted. When it comes to component F, it works as input to E only and when it comes to E, it has input relations to C and F. Viewing such result, relationship between component E and F and component K and L were revealed. As such clustering structure has close relations, optimal allocation solution can be provided at a system design integration stage by arranging the allocation closely. Thus when system design is implemented based on such optimal allocation; reliability in safety as well as design would be achievable.

VALIDATION OF THE STUDY

Priority requirements for three cases emerged in this study. Three approaches in this study are 1. Design requirements, 2 Safety requirements by incorporating the importance to operation concept-based requirements and 3. Requirements by applying joint reliability importance which allows integrated implementation to different design and safety factor and validation was conducted with the result value based on degree of risks of the requirements. When the requirement has high degree of risks, countermeasure shall be developed in a way of changing the requirements at design stage. Analysis to determine whether the requirements which incorporates importance index proposed by QFD covers the result after incorporating joint reliability importance as well as the result was conducted. Where, P refers to importance of correlations, D refers to Degree of difficulty and RR refers to Degree of risks. For comparing the requirements using same standard, distribution of technology difficulty (D) and degree of Risks of Requirement (RR) was implemented. Based on

Design	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
P	22	30	30	28	80	6	18	24	62	88	32	45	66	28	31	48	48	57
D	1	2	2	1	6	3	3	4	1	4	4	3	4	5	2	2	1	5
RR	22	60	60	28	480	18	54	136	62	352	128	135	264	140	62	96	48	285
	0.04	**0.12**	**0.12**	**0.05**	**1.0**	**0.03**	**0.11**	**0.28**	**0.12**	**0.73**	**0.26**	**0.28**	**0.55**	**0.29**	**0.12**	**0.20**	**0.1**	**0.59**

Safety	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
P	18	26	20	32	85	6	18	20	67	78	48	45	48	20	31	35	56	63
D	1	2	2	1	6	3	3	4	1	4	4	3	4	5	2	2	1	5
RR	18	52	40	32	510	18	54	80	67	312	192	135	192	100	62	70	56	315
	0.03	**0.10**	**0.07**	**0.06**	**1.0**	**0.03**	**0.10**	**0.15**	**0.13**	**0.61**	**0.37**	**0.26**	**0.37**	**0.19**	**0.12**	**0.13**	**0.10**	**0.61**

Combine Importance	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18
DRR	0.016	0.048	0.048	0.02	0.4	0.012	0.044	0.112	0.048	0.292	0.104	0.112	0.22	0.116	0.048	0.08	0.04	0.236
SRR	0.018	0.06	0.042	0.036	0.6	0.018	0.06	0.09	0.078	0.366	0.222	0.156	0.222	0.114	0.072	0.078	0.06	0.366
W(RR)	**0.034**	**0.108**	**0.09**	**0.056**	**1.0**	**0.03**	**0.1**	**0.202**	**0.126**	**0.658**	**0.326**	**0.268**	**0.442**	**0.23**	**0.12**	**0.158**	**0.1**	**0.602**

Fig. 8: Comparison of degree of risks of requirements

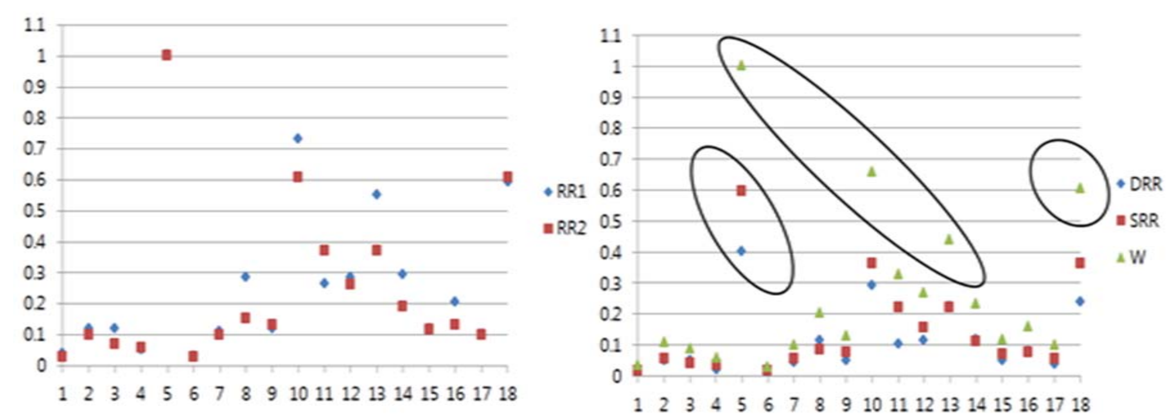

Fig. 9: Distribution of the risk of requirements

result in Fig. 8, maximum value among the values obtained by multiplying correlations by technology difficulties with regard to 18 safety requirements was set as 1 and the risk index of other requirements was calculated. The figures on the right of Fig. 9 are the results obtained by incorporating joint reliability importance.

The figure on left comparing individual implementation and the fire on right incorporating joint reliability importance in Fig. 9 are similar in pattern, indicating the possibility of replacement. In other territory, requirements to secure relative safety in designing the safety-focused system are identifiable.

CONCLUSION

A large complex system today offers the various benefits to our society but the large and complex system also brings about many problems. Thus, higher design reliability than current level is required at development stage of a large and complex safety-focusing system.

In this study, improved QFD model that secures the safety in developing a large and complex safety-focusing system is proposed. For systematic approach to existing design-centered QFD, deployment of QFD through system operation concept depending on system level, instead of existing technical requirement-based approach, was proposed.

To incorporate safety factor into design-centered QFD, HOQ which is the core activity in implementing QFD was developed by incorporating technical weighted values. Moreover, the measures to secure the safety at design stage which was not achievable by existing QFD were proposed. Based on such result, the measure applicable at design integration stage was also proposed. Should system design be implemented based on the result obtained in this study, the foundation to secure the safety of system design is expected to be paved.

REFERENCES

Agrawalla, R.K., 2011. Systems engineering to conquer complexity. Proceeding of the 3rd International Conference on Electronics Computer Technology (ICECT, 2011), pp: 154-159.

Ameri, F., J.D. Summers, G.M. Mocko and M. Porter, 2008. Engineering design complexity: an investigation of methods and measures. Res. Eng. Des., 19(2-3): 161-179.

Blanchard, B.S. and W.J. Fabrycky, 2006. Systems Engineering and Analysis. 4th Edn., Prentice Hall, Upper Saddle River, NJ.

Braha, D. and O. Maimon, 1998. The measurement of a design structural and functional complexity. IEEE T. Syst. Man Cy. A, 28(4): 527-535.

Calvano, C.N. and P. John, 2004. Systems engineering in an age of complexity. Syst. Eng., 7(1): 25-34.

Creveling, C.M., J.L. Slutsky and D. Antis, 2003. Design for Six Sigma in Technology and Product Development. 1st Edn., Prentice Hall PTR, New Jersey, pp: 123-125.

Dixon, J., M. Duffey, R. Irani, K. Meunier and M. Orelup, 1988. A proposed taxonomy of mechanical design problems. Proceeding of the ASME Computers in Engineering Conference. San Francisco, pp: 41-46.

Domerçant, J.C. and D.N. Mavris, 2011. Measuring the architectural complexity of military systems-of-systems. Proceeding of the IEEE Aerospace Conference. Big Sky, MT, pp: 1-16.

El-Haik, B. and K. Yang, 1999. The components of complexity in engineering design. IEEE Trans., 31(10): 925-934.

INCOSE, 2007. Systems Engineering Vision 2020. Retrieved from: oldsite.incose.org/ProductsPubs/.../SEVision2020_20071003_v2_03.pdf.

Kim, Y.S., 1999. A system complexity approach for the integration of product development and production system design. M.A. Thesis, Institute of Technology, Massachusetts, pp: 35-48.

Kinsner, W., 2008. Complexity and its measures in cognitive and other complex systems. Proceeding of the 7th IEEE International Conference on Cognitive Informatics, pp: 13-29.

Kolmogorov, A., 1983. Combinatorial foundations of information theory and the calculus of probabilities. Russ. Math. Surv+., 38(4): 29-40.

Pahl, G. and W. Beitz, 1996. Engineering Design: A Systematic Approach. Springer, New York, pp: 234-247.

Peliti, L. and A. Vulpiani, 1987. Measures of complexity. Proceeding of the Conference on Measures of Complexity. Springer-Verlag, Berlin, pp: 150.

Senge, P.M., 1990. The Fifth Discipline. Century Business, London.

Sheard, S.A. and A. Mostashari, 2009. Principles of complex systems for systems engineering. Syst. Eng., 12(4): 295-311.

Simon, H., 1998. The Sciences of the Artificial. MIT Press, Cambridge, pp: 183-215.

Suh, N.P., 1990. The Principles of Design. Oxford University Press, New York, pp: 147-171.

Summers, J.D. and J.J. Shah, 2003. Developing measures of complexity for engineering design. Proceeding of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. ASME, Chicago, DETC2003/DTM-48633, pp: 381-392.

Valerdi, R., 2006. Academic COSYSMO user manual. Proceeding of the MIT Lean Aerospace Initiative Consortium, pp: 4-8.