ISBN: 978-981-18-5852-9
WCSE 2022 Spring Event: 2022 9th International Conference on Industrial Engineering and Applications
doi: 10.18178/wcse.2022.04.026

Method to Manage Design Conflicts and Complexity in the Early Stage of Engineering Design

Pattarawit Srimuang[1+], Kusol Pimapunsri[2]

[1]Department of Industrial and Logistics Engineering Technology, Faculty of Engineering and Technology, King Mongkut's University Technology of North Bangkok, Thailand

[2]Department of Industrial Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok , Thailand

Abstract—At the early phase of the engineering design, numerous ideas were generated as many as possible to satisfy the customer needs. Those ideas finally were transformed into a set of design matrices. However, the result of idea generation usually gave abundant of possible design variants. To avoid design conflicts and to obtain potential design variants, the design team must find the possible design variants and evaluate them. This process is considered a time-consuming and iterative work. This paper presents a method to find the possible design variants and to evaluate it complexity. It focuses on the mapping process between the function domain and the design domain. The generated ideas were transformed into design matrices represent a set of functional requirements (FRs) and a set of design parameters (DPs). The possible design variants were stored in the design library. They were then evaluated its complexity with complexity index (Ci). This method supports the design team to avoid design conflicts and to select suitable design variants at the early design phase.

Keywords—Engineering Design, Design Evaluations, Design Selection, Complexity.

1. Introduction

In the engineering design, there was a collaborative environment when design teams created their design parameters (DPs) or parts to satisfy functional requirements (FRs). In the early design stage, designers create and generate ideas to satisfy customer requirements. As a result, many ideas andDPsare represented. Then, the design team must find the possible design variants by selecting compatible sets ofDPsand evaluating their complexity to find the most potential design variants. This iterative process is time-consuming. Thisproblem challenges the design team tomanagethe iterations in the design process. This study proposes a method to detect and manage the design conflict then reducethe design complexity during the engineering design stage.

2. Literature Review

2.1 Design Conflict

Collaborative design is the designer's interaction with teams, which deals with sharing various interests and resources among various actors with the aim of purpose[1]. The design processusually changes products or processes to satisfy customer needs. When designers propose parts or DPs to satisfy FRs, conflicts can emerge from disagreements between designers about proposed designs[2]. Design conflict management is focused on conflict detection, negotiations, and solution generation[3]. The phase of conflicts management in collaborative design can beillustratedin Fig.1.

Fig. 1: Conflicts Management in Collaborative Design. [3]

+ Corresponding author.
E-mail address: Pattarawit.srimuang@gmail.com.

Group decisions at the early stagecan reduce the design conflicts and generate design solutions. Disagreements however could occur at any time when design solutions or DPs are generated. At this step, the design tools e.g., tree diagram, design matrix, can supports the design team to analyze the proposed design solutions.

2.2 Design Complexity.

Complexity is the nature of a problem in the negotiation phase of engineering design. It is defined as many components involved, and through links of different strengths, these components influence each other [4]. It reflects the demands for innovation, function, cost, and quality. A system would be complex when more parts or components exist and with more connections in between them. Suh [5]defined complexity in engineering design context as: "Complexity is a measure of uncertainty in understanding what it is we want to know or in achieving a functional requirement (FR)."He proposed Axiomatic Design theoryto analyze a system by using design matrices. The zigzagging method is a tool of Axiomatic Design to decompose between the domains called the "mapping process" creatingadesign matrix between two domains as shown in Fig.2.

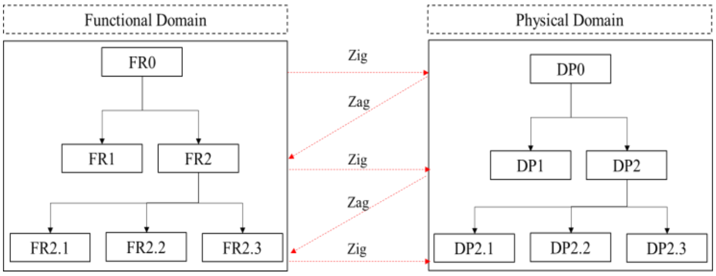


Fig.2: Zigzagging method [6].

Adesign matrix represents a set of FRs and a set of DPs, and relationships between them. The complexity of the design is determined by the design matrix. It is divided into three types of design concepts: uncoupled design, decoupled design, and coupled design. The relationship between these two vectors can be written as shown in (1) and Table 1.

$$[FR]=[A][DP] \tag{1}$$

Table 1: Type of relation in design matrix [7].

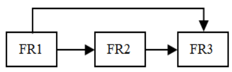
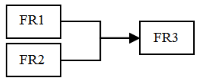
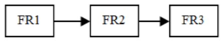
Type of design	Design equation	Design process
Uncoupled design	$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$	$FR_1=A_{11}\times DP_1$ $FR_2=A_{22}\times DP_2$ $FR_3=A_{33}\times DP_3$
Decoupled design	$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$	$FR_1=A_{11}\times DP_1$ $FR_2=A_{21}\times DP_1+A_{22}\times DP_2$ $FR_3=A_{31}\times DP_1+A_{32}\times DP_2+A_{33}\times DP_3$
Coupled design	$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$	$FR_1=A_{11}\times DP_1+A_{12}\times DP_2+A_{13}\times DP_3$ $FR_2=A_{21}\times DP_1+A_{22}\times DP_2+A_{23}\times DP_3$ $FR_3=A_{31}\times DP_1+A_{32}\times DP_2+A_{33}\times DP_3$

An off-diagonal elements of the design matrix relates to design complexity. When the relations aredecoupled or coupled, complexity emerges. there are several ways to reduce the design complexity. If the design is coupled, the designer should eliminate bias and variance of the design to satisfy the independence axiom. It can be solved by removing the off-diagonal elements, or coupling terms, in the design matrix. If the design is decoupled, the designer should write down and rearrange the design equationto eliminate the imaginary complexity.The design complexity index can be calculated by the equation(2) below.

$$C_i= -log_2\left(\frac{Z}{n!}\right) \tag{2}$$

Whenz is the number of acceptable sequences that satisfy FRs, and n! is the total number of sequences for the design matrix. [8] noticed that the non-zero off-diagonal elements decrease, Ci decreases while z increases, as shown in Table 2.

Table 2: The imaginary complexity [9].

Design Equation	Flow Diagram	$n!$	z	C_i
$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix}$		6	1	2.58
$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ X & X & X \end{bmatrix} \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix}$		6	2	1.58
$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ 0 & X & X \end{bmatrix} \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix}$		6	1	2.58

Many researchers proposed the method to solve design conflicts and complexity. A strategy for solving complexity and eliminating coupling terms from a design matrix is presented in [8], [9] focused on solving complexity with the heuristic method. [10] proposed the approach to selection and evaluation methods, [11] created an integrated design environment to manage the design conflicts. [12]focused on detecting design conflicts and propose a method to negotiate between designers with a knowledgeable. Many researchers offer a technique to solve design conflicts and propose design solutions that consumed time and resources.

This study proposes a method to manage design compatibilities in the DPsselection process and reduce complexity. It supports the designer to detect design conflicts, where created DPsestablish design solutions.

3. Methodology

This sectionpresentsa method to manage design conflict by creatingcorrelation of design variants. This method can help engineering design teams to select DPs at the early stage of design. The proposed method can be shown in Fig. 3and described below.

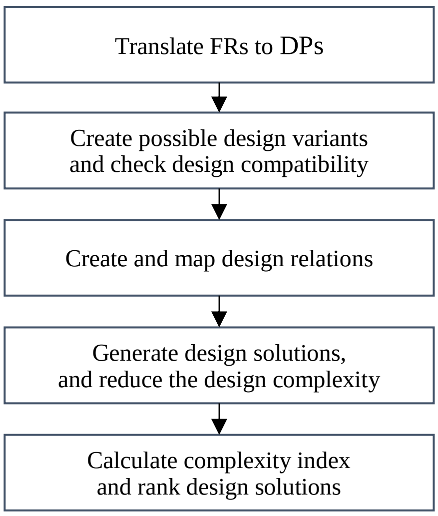


Fig.3:Research methodology.

3.1 Translate FRs to DPs.

Customer needs are reflex to complex products with multi-disciplinary development teams. Engineering design methods such as QFD, where good translate customer needs to FRs, and Axiomatics Design have a zigzagging to translate FRs to DPs.

3.2 CreatePossible Design Variants and Manage Design Conflicts.

When the FRs represents, we need to select the solution or DP to satisfy them. Then, the design team must find the design solutions by selecting compatible DPs. The morphological chart is used to create lists of the functions and solutions. The first column represents functions or FRswhile the top row representsthe index of solutions proposed or DPs,and the proposed alternatives of the DPs, as shown in Fig.4.

	Solution A (DP)	Solution B (DP)
Function 1	(DP1A)	(DP1B)
Function 2	(DP2A)	(DP2B)
Function 3	(DP3A)	(DP3B)
Function 4	(DP4A)	(DP4B)

Fig.4: Morphological Chart[13].

The design team searches for the solutions by selecting potential design variants. We propose a selection method to manage design conflicts between DPs by the correlation matrix to choose the possible sets of DPs.The total number of possible sequences can be written by counting rule when each event has a different number of possibilities as shown in (3).Assume that each DP has two alternatives, the correlation matrix can be written as shown in Fig. 5.

$$n = k_1 * k_2 * k_3 * ....k_n \quad (3)$$

	DP1A	DP1B	DP2A	DP2B	DP3A	DP3B	DP4A	DP4B
DP1A								
DP1B								
DP2A								
DP2B								
DP3A								
DP3B								
DP4A								
DP4B								

Fig.5:Correlation matrix of the proposed DPs.

Possible design variants can be shown by compatibility matrix (DPs vs. DPs) or tree diagram as Fig.6. As a result, it illustrates all sequences of the design generated by the proposed DPs. However, only the compatible sequences of DPs are determined for the next step.

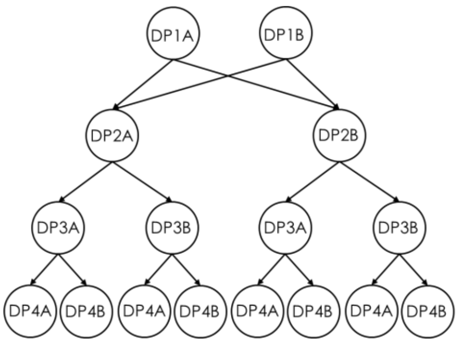


Fig.6: Tree diagram of all sequences of the proposed DPs.

3.3 Create and Mapping Design Relations.

Regarding Fig. 6, the compatible sequences of DPs are transformed into a design matrix and are stored in the design variant library. Then the mapping process between FRs and DPs are performed for each design matrix to identified the relations between them.

3.4 Generate Design Solutions and Reduce Design Complexity.

From the design variant library, the complexity of design depends on the form of the design matrix. When the number of off-diagonal elements in the design matrix increases, the design is more complex. The complexity of a decoupled design due to "imaginary complexity." It occurs because the off-diagonal elements are not fixed regarding the design decision made in an improper order design matrix.

However, real complexity may be reduced when the design is either uncoupled or decoupled. At this stage, such coupling term(s) must be eliminated to obtain a decoupled or uncoupled design. To reduce the complexity since the early stage of the design process are reorganize a design matrix.

3.5 Calculate Complexity index and Ranking Design Solutions.

Regarding the Axiomatic Design theory, The imaginary complexity (Ci) can be quantified by the probability of finding the right sequence given by (2).

4. Case Study

This section presents a case study of a 4x4 design matrix as shown in Fig. 7.

4.1 Translate FRs to DPs.

According to Axiomatics Design theory, the zigzagging method was used to translate FRs to DPs. The design matrix is shows relations between FRs and DPswith the design matrix. As shown in Fig. 7.

	DP1	***DP2***	***DP3***	***DP4***
FR1				
FR2				
FR3				
FR4				

Fig.7:Original matrix.

4.2 Create Potential Design Variants and Check Design Compatibility.

In the early phase of the design stage, FRs are translated into terms of DPsby designers. Variants of DPswere created, then we check design compatibility with "binary" when "0" DPs are not compatible and "1" DPsare compatible as shown in Fig.8.

	DP1A	***DP1B***	***DP2A***	***DP2B***	***DP3A***	***DP3B***	***DP4A***	***DP4B***
DP1A			0	1	1	1	0	0
DP1B			1	0	1	0	0	1
DP2A					0	1	1	1
DP2B					1	0	1	0
DP3A							1	1
DP3B							0	1
DP4A								
DP4B								

Fig.8:Correlation matrix.

Regarding the correlation matrix in Fig. 8, three possible design variant libraries can be represented as a tree diagram as shown in Fig. 9.

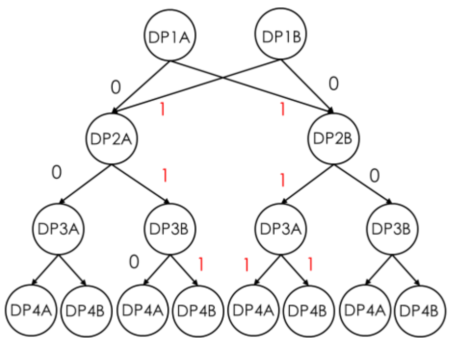


Fig.9:Tree diagram of possible design variant libraries.

From Fig. 9, We create a design variant library from the design compatibility. The design variant library can be represented as a design matrix, as shown in Fig. 10.

	DP1A	***DP2B***	***DP3A***	***DP4A***
FR1	*X*			
FR2		*X*		
FR3			*X*	
FR4				*X*

	DP1A	***DP2B***	***DP3A***	***DP4B***
FR1	*X*			
FR2		*X*		
FR3			*X*	
FR4				*X*

	DP1B	***DP2A***	***DP3B***	***DP4B***
FR1	*X*			
FR2		*X*		
FR3			*X*	
FR4				*X*

Fig. 10: Design variant libraries

4.3. Create and Map Design Relations.

From the design variant library, we map relations of the design matrix in terms FRs and DPs by the designer group decision, As shown in Fig. 11.

	DP1A	***DP2B***	***DP3A***	***DP4A***
FR1	*X*			
FR2		*X*	*X*	
FR3	*X*		*X*	
FR4		*X*		*X*

	DP1A	***DP2B***	***DP3A***	***DP4B***
FR1	*X*			
FR2		*X*	*X*	*X*
FR3	*X*		*X*	
FR4		*X*		*X*

	DP1B	***DP2A***	***DP3B***	***DP4B***
FR1	*X*	*X*		
FR2		*X*		
FR3			*X*	
FR4	*X*	*X*		*X*

Fig.11: The Design Parameter Libraryshows relationships of FRs and DPs.

At this stage, we can map the relationships of FRs and DPs from the selection of compatible DPs to create the Design Parameter Library (DPL), when the number of off-diagonal elements in the design matrix increases, the design is more complicated.

4.4 Generate Design Solutions,and Reduce Design Complexity.

Regarding the Design Parameter library in Fig. 11, when the design is decoupled [8] proposed the heuristic method to sort and rearrange the off-diagonal elements in the design matrix. The objective is to find the off-diagonal elements in the design matrix, as shown in Fig.12.

DPL1	***DP1A***	***DP3A***	***DP2B***	***DP4A***
FR1	*X*			
FR3	*X*	*X*		
FR2		*X*	*X*	
FR4			*X*	*X*

DPL2	***DP1A***	***DP3A***	***DP4B***	***DP2B***
FR1	*X*			
FR3	*X*	*X*		
FR4			*X*	*X*
FR2		*X*	*X*	*X*

DPL3	***DP3B***	***DP2A***	***DP1B***	***DP4B***
FR3	*X*			
FR2		*X*		
FR1		*X*	*X*	
FR4		*X*	*X*	*X*

Fig.12: Rearreanged design Parameter library.

From Design Parameter Library 1, FR2, FR3, and FR4 are rows with one non-zero element. As a result, DP1A is the precedence constraint ofDP3A. DP3Ais the precedence constraint ofDP2B. DP2B is the precedence constraint of DP4A. We can summarize the relationships between FRs and DPs as precedence constraints as shown in Table 3.

Table 3: Precedence constrains of the design matrix.

Task	Constraints	Precedence constraint(s)
DP1A	-	-
DP3A	*must follow*	DP1A
DP2B	*must follow*	DP3A
DP4A	*must follow*	DP2B

According to Table III, DP1A is the first tier of all sequences. There is one possiblesequence that can be represented as a tree diagram as shown in Fig. 13, and the number of acceptable sequences (z) of this design = 1, n! =4! =24,Ci = $-\log_2(1/24)$ = 4.5849.

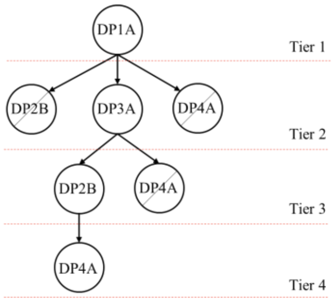


Fig. 13: possible sequences of design parameter library 1.

From Design Parameter Library 2, FR2 and FR4 are rows with one non-zero element. As a result, DP2B is couple with DP4B. We can modify DP2B to DP2B* to reduce the complexity of DPL2, So the new DPL2* can be shown as Fig. 14.

*DPL2**	*DP1A*	*DP3A*	*DP4B*	*DP2B**
FR1	*X*			
FR3	*X*	*X*		
FR4			*X*	
FR2		*X*	*X*	*X*

Fig. 14: Modified design parameter library 2.

We can find the number of acceptable sequences (z) of DPL2*;z = 6, n! =4! =24,Ci = $-\log_2(6/24)$ = 2.0000.From Design Parameter Library 3, We can find the number of acceptable sequences (z)= 4, n! =4! =24,Ci = $-\log_2(4/24)$ = 2.5849.

4.5 Calculate Complexity index and Rank Design Solutions.

The imaginary complexity of the design parameter library can be quantified by the probability of finding the right sequencegiven by (2) as shown in Table 4.

Table 4: Ranking complexity from the design matrix solution.

Design Parameter Library	z	n	$Ci = -\log_2(z/n!)$
DPL2*	6	4!	2.0000
DPL3	4	4!	2.5849
DPL1	1	4!	4.5849

Table 4 represents the Ci value from the design Parameter Library. The least value of imaginary complexity is chosen.

5. Discussion and conclusion

The paper proposes a method to manage design conflict and reduce design complexity in an early stage of engineering design. The method applies the correlation matrix of DPsto support the design team to manage design conflicts when designers choose DPsto propose the possible design solutions. The other stage show method to reduce the imaginary complexity and compute a complexity index. However, this method is challenging to implement more design variants with decimal or non-binary relationships of DPsin the future.

6. References

[1] L. Gzara Yesilbas, M. Lombard, “Towards a knowledge repository for collaborative design process: focus on conflict management” Computers in Industry, vol. 55, pp. 335-350, 2004.

[2] M.Z. Ouertani,“Supporting conflict management in collaborative design: An approach to assess engineering change impacts” Computers in Industry,vol 59, pp 882-893, 2008.

[3] Grebici, Khadidja & Ouertani, Mohamed & Eric, Blanco & Gzara, Lilia & Rieu, Dominique. (2006). "Conflict Management in Design Process: Focus on Changes Impact."13th ISPE International Conference on concurrent engineering: research and applications, pp. 161-168.

[4] G. Pahl, W. Beitz, J. Feldhusen, and K. H. Grote, Engineering design: a systematic approach, Springer-Verlag, London, 2007.

[5] N. P. Suh, Complexity: Theory and applications, Oxford University Press, 2005.

[6] Kreß, Antonio & Metternich, Joachim, "System development for the configuration of learning factories". Procedia Manufacturing. vol 45,pp. 146-151. 2020.

[7] G. J. Park, Analytic methods for design practice, Springer, 2007.

[8] K. Pimapunsri and P. Srimuang, "Method to Decrease Complexity in Engineering Design and Technical Systems," 2019 Research, Invention, and Innovation Congress (RI2C), pp. 1-5, 2019

[9] T. Lee, "Optimal strategy for eliminating coupling term from design matrix," Journal of Integrated Design and Process Technology. vol. 10, pp. 45-55, 2006.

[10] S. Tichkiewitch,"Specification on integrated design methodology using a multi - view product model."CIRP annual, vol. 46,pp.101-108, 1996.

[11] L. Roucoules,S. Tichkiewitch,"CoDE: a cooperative design environment—a new generation of CAD systems.", Concurrent engineering, vol. 8, pp. 263-280,2000.

[12] K. Pimapunsri and S. Tichkiewitch, "Integrated design for solving imaginary complexity in design," CIRP Design Seminar, Daejon, South Korea, pp. 24-31, 2011.

[13] V. Kumar, 101 Design Methods: A Structured Approach for Driving Innovation in Your Organization, John Wiley & Sons, 2012.