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Design Parameter Decision Making Methodology for Commonization Considering its Impact on Manufacturing Systems

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Design Parameter Decision Making Methodology for Commonization Considering its Impact on Manufacturing Systems

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Abstract

Design Parameter Decision Making Methodology for Commonization Considering its Impact on Manufacturing Systems

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The product development process is generally a series of processes starting from product planning to product concept development, system-level design, detailed design, testing and refinement, and production. During this process, inevitable iterations of modifying the design occur due to various feedbacks in order to reflect the problems that occur in the latter stages of the process. The larger the cycle of the iterative process, the more time and expense it takes to develop the product. Numerous concurrent engineering approaches are proposed to minimize the time and cost of inevitable repetition. However, the conceptually presented methodologies are far from being applicable to the enterprise in practice.

Platform-based product family design is an effective means for mass customization. Using common component is one of the key strategies in developing product platforms. Generally, companies produce common components from various factories, but most factory environments are different. Thus, in order to prevent the unexpected iterative process occurring in the manufacturing stage, it is essential to reflect various manufacturing environments at the stage of designing common components. However, there are few studies that have simultaneously considered the influence of various factory environments for the specification of common components.

This thesis proposes a design parameter decision making methodology for common components considering its impact on diverse manufacturing environments. The proposed framework classifies manufacturing constraints into three categories which occur in various manufacturing environments. The methodology is proposed to reflect manufacturing constraints to the design of common components. The analysis based on the methodology reveals design parameter decision considering manufacturing environments. As the result of analysis, DP-PV Information Matrix is presented for the designers to simultaneously reflect problems occurring in diverse manufacturing environments. The results of case study on automobile alternators advocate the validity of proposed methodology.

Keywords: Platform Design, Design Parameter, Common Component, Manufacturing Constraint, Concurrent Engineering, Design for Manufacturing

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Chapter 1. Introduction

The purpose of this study is to propose design parameter decision methodology for common components considering its impact on diverse manufacturing environments. This chapter presents backgrounds of research and specific research questions. Section 1.1 provides the component commonization strategy. In Section 1.2, The challenges of sequential decision making when implementing component commonization strategy are introduced. Section 1.3 states the research goal of the thesis and the last Section 1.4 provides a brief overview of the subsequent chapters.

1.1. Component Commonization Strategy

Increasing number of customers demanding differentiated products has shifted the paradigm of mass production to mass customization. Mass customization has led to an increasing fragmentation of the automotive market: the number of automotive models in the U.S. increased each year from 33 in 1947 to 198 in 1990 (Simmons, 2005). Manufacturing firms had to increase the variety to products they offer in order to maintain their market share. In order to occupy target markets while reducing cost, firms have decided to implement strategies such as product family, platform, component sharing, etc. Although different strategies stated above differ in their purpose and mechanism, the ultimate goal of the firm is common: maximizing costs while delivering products that satisfy customers.

There are many definitions to the term platform. Robertson (1998) defines platform as the collection of assets that are shared by a set of products. Ulrich (2003) defines platform as a collection of assets, including component designs, shared by multiple products. Platform decision occupies domain-crossing complexity since the decision has to be made with the basic and overall understanding of the interplay between product architecture, manufacturing cost, engineering performance, value, demand, the role of competition, etc. (de Weck, 2006). There is a view that such a collection of shared components is generally not considered a product platform. However, following the definition of platform (Robertson, 1998) and regarding components that make up the product as the collection of assets, this research considers component commonization strategy as an implementation of platform strategy.

The main issue when it comes to platform decision is balancing the trade-off between 'component commonality' and 'product distinctiveness'. Component commonality denotes that one or more components are commonly used across a family of products as shown in Figure 1-1. Product distinctiveness is a necessity to consider in order to closely meet individual customer's needs. Customers care whether the firm offers a product that closely meets their needs; they are not particularly concerned about how many parts a collection of products has in common (Robertson and Ulrich, 1998). Since customers perceive a product as a combination of specifications (Krishnan and Ulrich, 2001), the term attribute was used to denote a characteristic that customers deem important in distinguishing a product from others. Trade-off between 'component commonality' and 'product distinctiveness' occurs when sharing components among a family of products influences the distinctiveness of a product among other products in the family. When the common component affects the product, there are two cases: 'what component is shared among products' and 'how to set the design parameters of the common component'. Consider a case where a firm sells two products: vehicle 1 (SUV) and vehicle 2 (sedan). Assuming that stability and acceleration are two among many attributes that consumers deem important, we can designate the ideal attribute location of vehicle 1 and vehicle 2 in two dimensional space as in Figure 1-2. Company wishes to share component for two products in order to minimize cost. For instance, consider a case where SUV and sedan share the same subframe, which is a structural component of a vehicle that uses a discrete and separate structure within a larger body-on-frame or unit body to carry certain components, such as the engine, drivetrain, or suspension. When a component is shared among products, engineering constraints occur: e.g. since the thickness of the subframe correlates with the size of the vehicle, the subframe of sedan might be inappropriate to be used in SUV. Due to component sharing, the attribute space of sedan might shift unintentionally: the use of thick subframe in sedan increases the stability but it decreases the acceleration. Attribute breakaway of a product, as in Figure 1-2, leads to market loss due to the performance deviation of a product. Thus, which component to share among products and how to set the design parameter of the common component is a critical issue in component sharing.

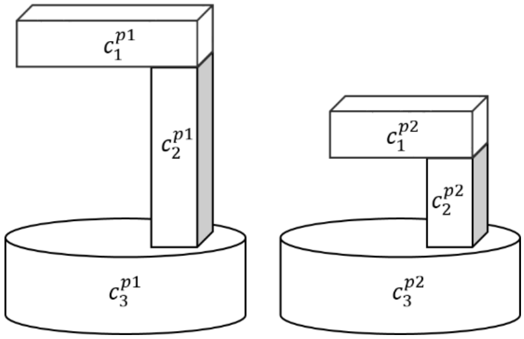


Figure 1-1. Component sharing (c_3^{p1}) within a family of products

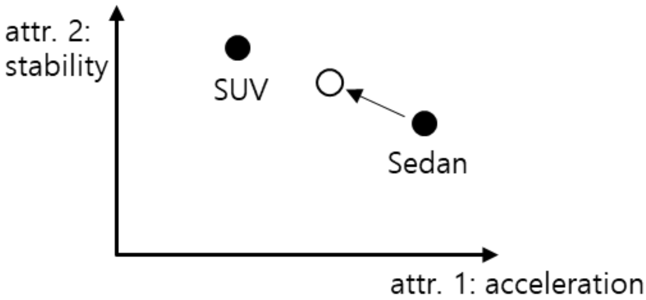


Figure 1-2. Attribute space shift due to component sharing

1.2. The Challenges of Component Commonization Strategy

The product development process is generally a series of processes starting from product planning to product concept development, system design, detailed design, testing, and supplementation to production. Although the product development process is generally processed sequentially, inevitable iterations occur that constantly throws back various feedbacks from the latter parts of the process. The larger the cycle of the iterative process, the more time and expense it takes to fix the problem.

Therefore, many researches regarding concurrent engineering have been conducted.

Although the manufacturing process is at the very end of the product development process, it is the costliest and most time-consuming process. Moreover, since most companies occupy a variety of manufacturing facilities, it is rare for a company to produce diverse products only at one factory. It is also important to note that most factories have different manufacturing environments (facilities, tools, workers, etc.) and processes. Since it is costly to change or upgrade existing manufacturing facilities, it is important to take consideration of various occupying assets. Figure 1-3 below shows the unwanted diversification of common components due to different manufacturing environments.

Due to the problems presented above, even if the component commonization strategy is planned and the design parameters of the common component are set at the beginning of the product development process, the design parameters of common component often change unexpectedly during the manufacturing process. To minimize the time and cost that may occur unexpectedly at the latter stage of product development process, a framework that considers diverse manufacturing domain from the early stage of design domain is needed.

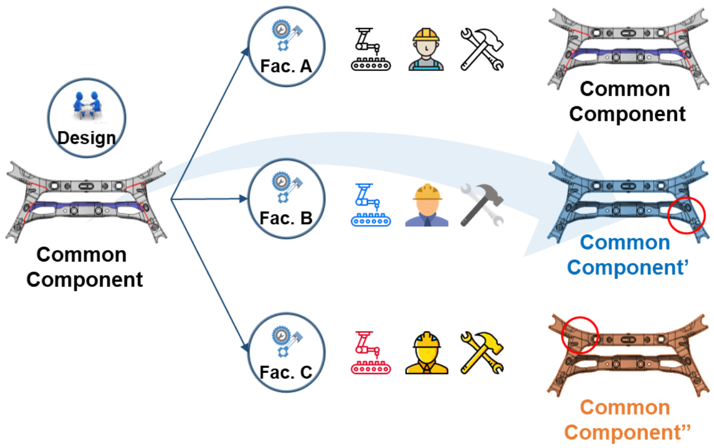


Figure 1-3. Diversification of common components due to different manufacturing environments

1.3. Research Goal

While there are many concurrent engineering researches conducted, most researches lack in the managerial implications that firms can practically implement. Moreover, although there are many researches of designing products in such a way that they are easy to manufacture and assemble, few researches consider various environments simultaneously.

To systematically establish the design decision considering its impact on diverse manufacturing environments, it is imperative to definitely understand and configure the design issues of common components occurring in the manufacturing process. On the foundation of the investigation, this paper proposes a design parameter decision making methodology.

1.4. Structure of Thesis

A brief description of subsequent chapters is presented in this section. Chapter 2 provides review on previous literature related to platform and component commonization strategies. Since there exists not much literature on common component design strategies incorporating diverse manufacturing environments, literatures on Concurrent Engineering and Design for Manufacturability are reviewed as a supplement of lacking literature. Chapter 3 proposes a methodology through a case of a vehicle rear axle assembly in order to determine design specifications of common components reflecting manufacturing constraints. The suggested methodology reflects three categorization of manufacturing constraints. To prove the validity of the suggested methodology, Chapter 4 presents a case-study of applying the methodology to the assembly of automobile alternators. In Chapter 5, conclusions of this research are presented, and contributions are summarized. Implications of presented methodologies and more complicated issues that this research lacks will stimulate further research.

Chapter 2. Literature Review

2.1. Platform and Component Commonization Strategies

Platform-based product development is commonly used in many industries for implementing mass customization, while preserving mass-production-like efficiency in developing and manufacturing customized products (Simpson, 2004). Platform decision occupies domain-crossing complexity since the decision has to be made with the basic and overall understanding of the interplay between product architecture, manufacturing cost, engineering performance, value, demand, the role of competition, etc. (de Weck, 2006). There are many definitions to the term platform. Ulrich (2003) defines platform as a collection of assets, including component designs, shared by multiple products. Robertson and Ulrich (1998) encourages to use platform strategy early in the product development process and stated that it must include consideration of marketing, design, and manufacturing issues. Robertson and Ulrich (1998) categorizes assets into four categories: component, processes, knowledge, people and relationships. It is noted that parts-standardization efforts across products may lead to the component sharing. However, such a collection of shared components is generally not considered a product platform.

On the other hand, Farrell and Simpson (2003) defines product platform as the set of common parameters, features, or components that remain constant from product to product within a given product family. It is referred to as a basis for the products in the family, which are derived through the addition, substitution, or exclusion of one or more modules from the platform or by scaling the platform in one or more dimensions. Two basic approaches to product family design suggested by Simpson et al. (2001) is Top-down approach and Bottom-up approach. Bottom-up approach is wherein a company redesigns or consolidates a group of distinct products to standardize component to improve economies of scale. Pessina and Renner (1998) shows an instance of redesigning the product line so that 100+ individual lighting control products can be configured from 15-20 standard components. The thesis, by means of Bottom-up approach of product family design, classify component sharing strategy as an implementation of platform strategy.

Among many components that comprises a product, what should be taken as common component has been studied by many researchers. Agard and Bassetto (2013) solves a problem of selecting which modules to use in a set of products by considering cost and product performance. The degree of commonness among product family has been widely studied as well. Simpson (2001) proposed the 'Product Variety Tradeoff Evaluation Method' in order to assess alternative product platform concepts with varying levels of commonality. Thonemann and Brandeau (2000) presents an approach for determining the optimal level of commonality in a sub-product that does not differentiate models form the customer's point of view. Emphasizing on component sharing, Ramdas et al. (2003) presents a methodology for determining which version of a set of related components should be offered to optimally support a defined finished product portfolio. Unlike the viewpoint of previous researches, the thesis will present a methodology of setting the configuration of common components considering the existing manufacturing environments.

2.2. Concurrent Engineering

Yassine and Braha (2003) defines Concurrent Engineering (CE) as an engineering management philosophy and a set of operating principles that guide a product development process through an accelerated successful completion. Love and Gunasekaran (97) refers CE as an application that improved performance and application of manufacturing industry. At the design stage of product development process, it is not easy to consider every aspect of problems that might occur in the later stages of the product development process. The application of CE prevents the unwanted iteration that occurs in the outdated 'throw the design over the wall' methodology.

Skander et al. (2007) defines design for manufacturing (DFM) as a product design approach that takes into account design goals and manufacturing information as soon as possible in product definition. Many studies suggested presentation and methodologies of DFM concepts. Boothroyd (1994) developed a methodology for selection and design of components that are easy to assemble. He developed criteria for flagging the theoretically unnecessary parts with a metric called assembly efficiency. Nevin and Whitney (1989) addressed the interactions between product design and production processes. De Fazio and Whitney (1987) modelled the space of possible assembly sequences for a product. Today, the information of manufacturing domain must link design process data and product data. (Nowak et al., 2004)

CE principles have matured over time. However, many companies still face challenges when implementing CE practices. This is due to the lack to methodologies and tools that incorporates the downstream concerns into the upstream phases of a development process. While there are many concurrent engineering researches conducted, most researches lack in the managerial implications that firms can practically implement.

Chapter 3. Research Framework

This chapter introduces a framework for design parameter decision making methodology considering its impact on manufacturing systems. The suggested framework is presented in Section 3.1 and the categorization of three manufacturing constraints is presented in Section 3.2. The detailed methodology procedures are explained in Section 3.3. The proposed framework is applied to setting the design parameters of a vehicle rear axle assembly. Section 3.4 presents DP-PV information matrix as the outcome of the methodology.

3.1. Design and Manufacturing Domains

The presented framework creates mapping between design domain and manufacturing domain in order to reflect the manufacturing constraints in the early stage when deciding the design parameter of common components. Mapping between domains is formed in parameter units. The overall structure of research framework is represented in Figure 3-1. Prior to mapping the design domain and the manufacturing domain, the constituent units of each domain must be defined.

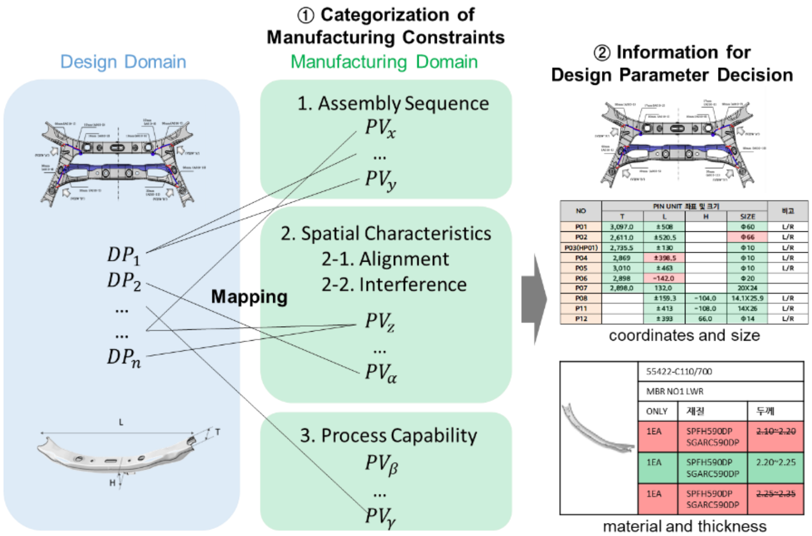
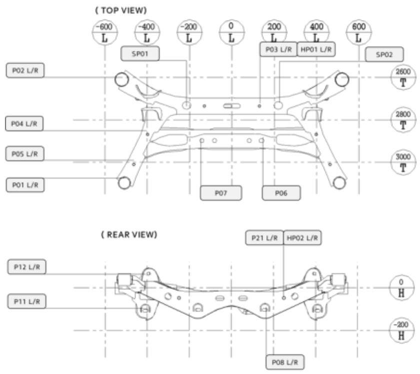


Figure 3-1. Research framework

Design parameter (DP) is defined as the parametric decision unit of components. DPs are the units that characterize the component in the design domain. DPs are qualitative and quantitative aspects of physical and functional characteristics of a component that are input to its design process. DPs determine cost, design, and other factors of a component or a product. As an example, DPs of a vehicle rear-subframe is shown in Figure 3-2 (JF denotes a vehicle model of a company).

Manufacturing domain is composed of manufacturing processes. Manufacturing process is composed of lines which are organized by task-by-task basis. Resources, such as facilities, machines, workers, and tools etc., are the subjects of task execution. The capability of a resource performing a determines the possibility of performing the task. An illustrative figure of manufacturing process is described in Figure 3-3. By defining the manufacturing process as such, it becomes possible to categorize the manufacturing constraints which will be introduced in the next section.

A few more terms need to be defined for better understanding of remaining thesis. Manufacturing constraint is defined as element, process, or subsystem in the process domain that limits the intended design. Process variables (PVs) are the units that characterize the processes in the manufacturing domain. PV is defined as the key variable in the process domain that characterize the given manufacturing constraints. The suggested methodology starts by mapping the units of design domains and manufacturing domain: design parameter in design domain and process variable in manufacturing domain.



JF RR Subframe

NO	PIN UNIT 좌표 및 크기				비고
	T	L	H	SIZE	
P01	3,097.0	±508		Φ60	L/R
P02	2,611.0	±520.5		Φ66	L/R
P03(HP01)	2,735.5	±130		Φ10	L/R
P04	2,869	±398.5		Φ10	L/R
P05	3,010	±463		Φ10	L/R
P06	2,898	-142.0		Φ20	
P07	2,898.0	132.0		20X24	
P08		±159.3	-104.0	14.1X25.9	L/R
P11		±413	-108.0	14X26	L/R
P12		±393	66.0	Φ14	L/R
P21(HP02)		±249.4	-48.0	Φ12/16	L/R
SP01	2,735.5	-214.0		35X42	
SP02	2,735.5	219.0		35X42	

coordinates and size

Figure 3-2. Design Parameter of JF RR subframe

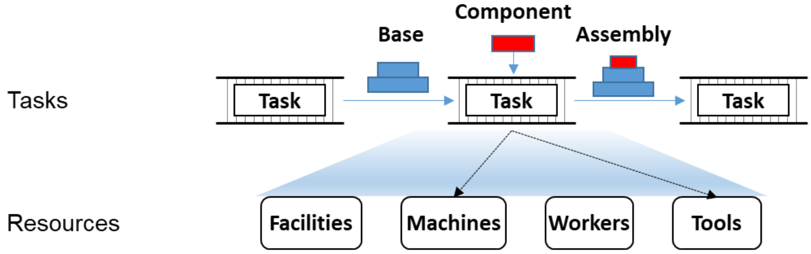


Figure 3-3. Manufacturing process

3.2. Categorization of Manufacturing Constraints

Manufacturing constraint is an element, process, or subsystem in the process domain that limits the intended design. Due to different manufacturing environments of factories, various problems arise. Since diverse manufacturing problems occur due to various reasons, it is imperative to categorize problems into several simpler subproblems. In order to analyze the problem more systematically, manufacturing constraints are divided into three categories: assembly sequence, spatial characteristics, and process capability. Assembly sequence is caused by the difference in task sequence performed by each factory. Spatial characteristics considers the direct and indirect impacts among components in the process of assembling or manufacturing the task. Lastly, process capability considers the capability of a resource to perform certain task. The schematic of the categorization of manufacturing constraints is shown in Figure 3-4.

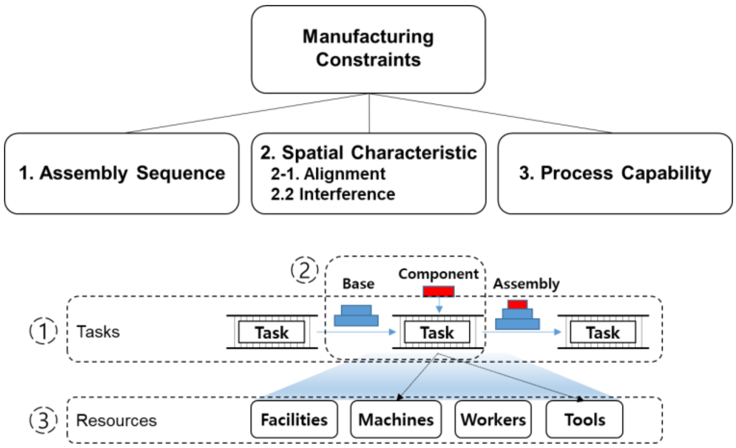


Figure 3-4. Categorization of manufacturing constraints

3.2.1. Assembly Sequence

Assembly sequence shows how the manufacturing environments differ from one factory to another. Figure 3-5 shows the difference of assembly sequence of common component from one factory to another. Component C in a black circle denotes the common component.

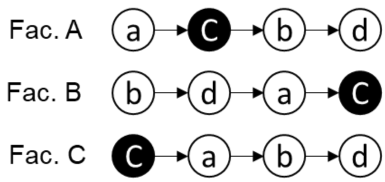


Figure 3-5. Different assembly sequences

Different assembly sequence leads to difference in tasks to make a certain set of subassemblies. Figure 3-6 illustrates an example of diversification of common components due to different assembly sequences. It is an example of assembling booster and pedal. For factory A in Figure 3-6, pedal is assembled to the booster which is fixated by jig. However, in factory B, booster is assembled to the pedal which causes the pedal to push back. Due to the difference in assembly sequence, the design parameter of the pedal need to reflect the alignment pin so that it will not wobble during assembly. Thus, the design parameter of common component can reflect both manufacturing environment.

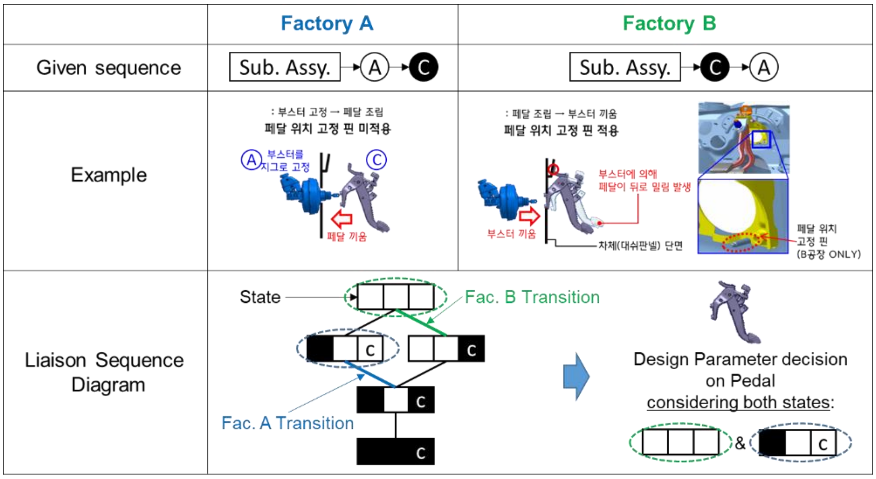


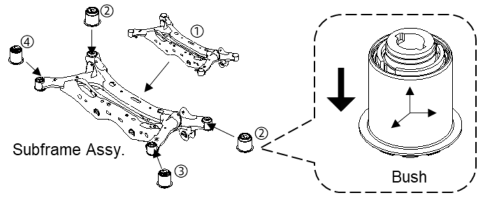
Figure 3-6. Diversification of common components (ⓒ in the Figure) due to different assembly sequences

3.2.2. Spatial Characteristics

Spatial Characteristics are the topological, geometric, or geographic properties of components that are important for manufacturing purposes. Although the spatial characteristics are fixed at the design stage, these features are made during manufacturing process, so they are, or correspond to, manufacturing features. Two categories of spatial characteristics are considered: alignment, which shows the direct mating features between two components, and interference, which shows indirect intervention to reveal which feasible transitions are required to make a certain set of feasible subassemblies.

3.2.2.1. Alignment – Spatial Characteristics

Alignment shows the information where the component is and the direction from which a compatible mating component would approach. An illustration of alignment features of bush in subframe assembly is shown in Figure 3-7. Each feature is accompanied by information showing where it is and the direction from which a compatible mating component would approach.



Location	X, Y, Z
Orientation	α, β, χ
Diameter	Number
Depth	Number of NIL
Chamfer Angle	Number of NIL
Chamfer Depth	Number of NIL
Assembly Direction	$-Z$

Features

Figure 3-7. Alignment features of bush in subframe assembly

3.2.2.2. Interference – Spatial Characteristics

Interference reveals which feasible transitions are required to make a certain set of feasible subassemblies. To check the interference among components, not only the mating component, but also a selected group of components must be considered.

Figure 3-8 is a simple example showing the interference during the process of assembling common component. It illustrates an example of interference due to component B during the process of assembling component C on component A.

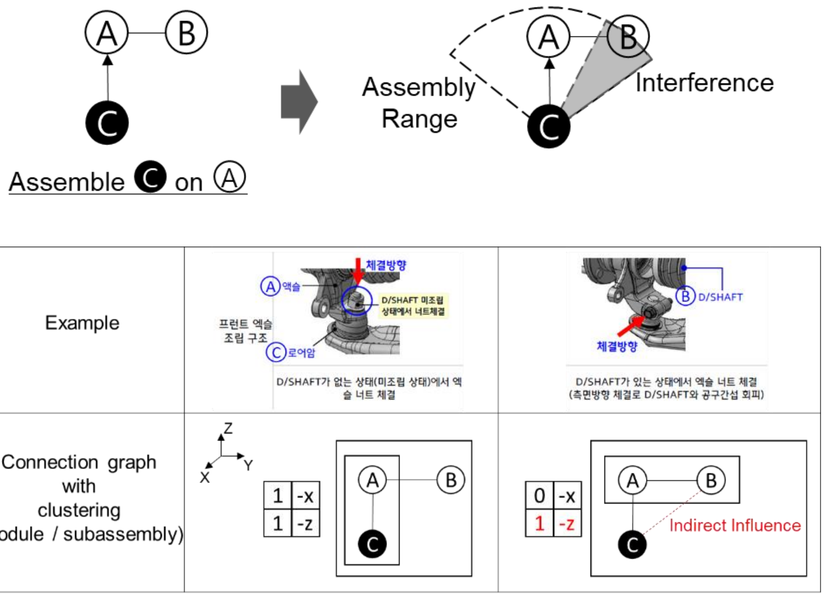


Figure 3-8. Interference due to B occurring during the process of assembly of C on A

3.2.3. Process Capability

Process capability shows the capability of a resource performing a specific task where resources are the subjects of task execution. The present research defines resource as the subject of task execution in the manufacturing domain. Suh (1998) defined system as an assemblage and people designed to satisfy specified requirements. Following such definition, the capability of resources in the manufacturing domain is regarded as the system range. There are various methods, such as dimensional analysis and information theory, to check the already existing system. Figure

3-9 illustrates an example of comparing two system ranges with the target design range.

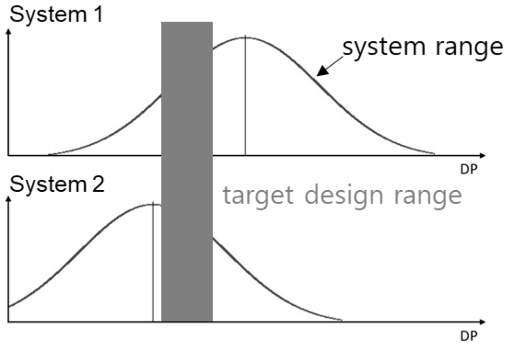


Figure 3-9. Comparison of system ranges and the target design range

3.3. Design Parameter Decision Making Methodology

This section presents Design Parameter Decision Making Methodology in order to reflect categorized manufacturing constraints into setting the design parameters of the common components. The method, outlined in Figure 3-10, breaks a complex decision problem into simpler subproblems. Liaison diagram and precedence relations will be used to systematically explore the product architecture in the design perspective. Through liaison sequence diagram, Design Structure Matrix, and capability analysis, conflicting design issues are identified for the subproblems of three manufacturing constraints.

This section will follow the procedure of the suggested methodology and will describe each of the steps in detail. Although the methodology is presented in a linear sequence, reflection of manufacturing constraints is almost always iterative. Like other development methods, these steps are intended to be a baseline from which design teams can develop and refine their component designs.

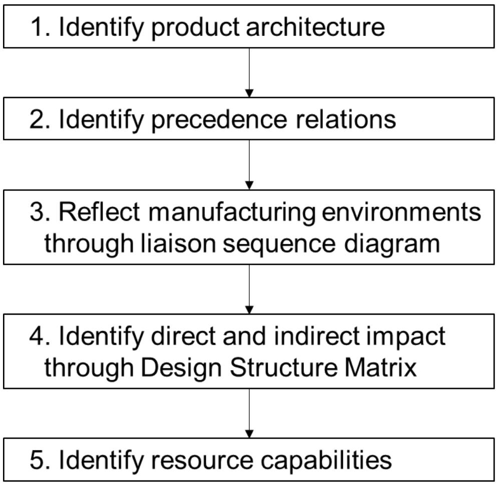
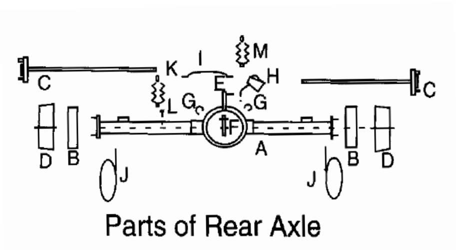


Figure 3-10. Design Parameter Decision Making Methodology

Also note that while the example involves an assembly of relatively technical product, the same basic approach can be applied to nearly any product and manufacturing environments.

This section presents vehicle rear axle assembly in different manufacturing environments as an example in order to help explain the methodology procedure. Figure 3-11 is a diagram of this assembly and its part list and let us consider the shaft, component C, as the common component.



Parts

A = Carrier Assy
B = Backing Plate
C = Shaft
D = Brake Drum and Nut
E = Pinion Shaft & Bolt Withdrawn
F = Pinion Shaft & Bold Re-inserted
G = Push In Shaft & Insert C-Washer & Push Shaft Out
H = Oil
I = Cover
J = Brake Cable, Coiled
K = Final Press Test
L = Air Testing Plug
M = First Pressure Test

Figure 3-11. Diagram and part list for the rear axle

3.3.1. Step 1: Identify Product Architecture

Liaison diagram is a simple graph that uses nodes to represent parts and lines between nodes to represent liaisons or connections between parts. In a liaison diagram, each part is a node and each link is a liaison. Liaisons indicate the fact that two parts join. The liaison diagram in this stage does not take account of many details of the joint. For example, an assembly may consist of different features, such as pocket screws and biscuits, but the liaison diagram represents this as a single line. Figure 3-12 shows a simple liaison diagram. This liaison diagram contains four parts. Part A connects to parts B, C, and D. Other connections may be read analogously (Whitney, 2004).

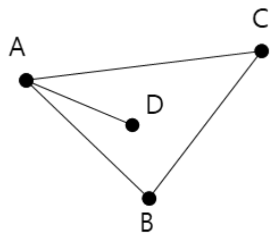
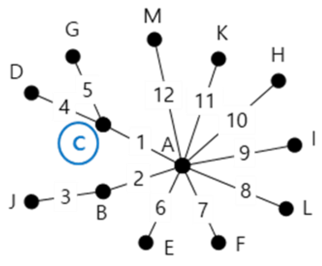


Figure 3-12. A liaison diagram

The main purpose of representing product architecture with liaison diagram is to acknowledge the product structure as a whole, the required functionality of design target component, and its relationships to other components. As the first step of the methodology, the architecture of rear axle assembly was expressed as liaison diagram in Figure 3-13.



Liaison Diagram

Liaisons	
1 = C to A	7 = F to A
2 = B to A	8 = L to A
3 = J to B	9 = I to A
4 = D to C	10 = H to A
5 = G to C	11 = K to A
6 = E to A	12 = M to A

Figure 3-13. A liaison diagram for the rear axle

3.3.2. Step 2: Identify Precedence Relations

Precedence relations is aimed at finding the precedence constraints regarding assembly in designers' perspective. While liaison diagram only shows the presence or the absence of relationship among components, Precedence Relations show the order the such relations.

Figure 3-14 shows the precedence relation of components. The first precedence states '2 > 1'. Liaison 1 is 'C to A', meaning 'assemble the axle shaft into the carrier assembly'. Liaison 2 is 'B to A', meaning 'install the backing plate to the carrier'. The precedence relation says that the backing plate must be installed before the axle shaft can be put in. If the shaft is put in first, then the large hub on the end of the axle will make it impossible to put the backing plate on the carrier and tighten the fasteners (Whitney, 2004).

Precedence Relations	
2 > 1	12 > 10
3 > 1 & 4 & 5	12 > 11
1 & 2 & 6 > 5	3 > 1 & 4 & 5
5 > 7	7 > 10
11 > 8	9 > 11
10 > 9	

Figure 3-14. Precedence relations for the rear axle

3.3.3. Step 3: Reflect Manufacturing Environments through Liaison Sequence Diagram

The liaison sequence diagram shows the different assembly sequences among different manufacturing environments. Figure 3-15 shows the liaison sequence diagram for the example of rear axle assembly. There are two different manufacturing factories that assemble the rear axle assembly. Both involve assembling component C, the common component. However, the assembly sequence for factory A and factory B are different. The difference is that, in factory B, component J has to be assembled before assembling component C, the common component. The diagram on the left of figure 3-15 shows the assembly sequence of parts expressed in part figures while the diagram on the right of figure 3-15 shows the liaison sequence diagram.

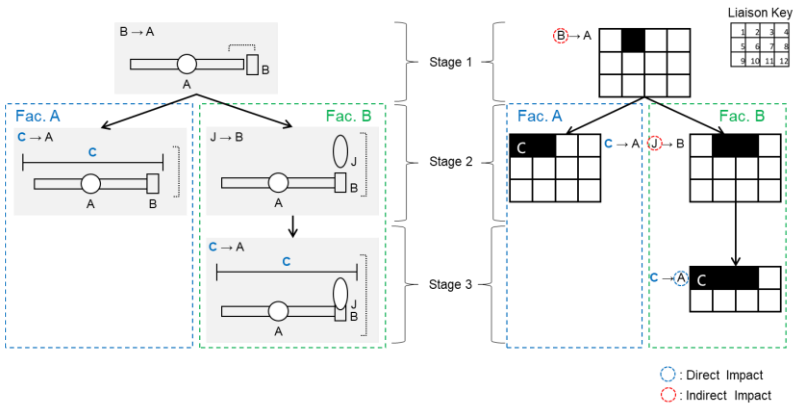


Figure 3-15. Liaison sequence diagram for the rear axle

Liaison 1 is denoted with the letter C in Figure 3-15 because it is the assembly action regarding the common component. Through the liaison sequence diagram, we can see that liaison 2 is conducted first in stage 1. However, there are difference in tasks executed in stage 2. Liaison 1 is conducted in factory A and liaison 3 is conducted in factory B. For factory B, liaison 1 is conducted in stage 3. Thus, the difference in the assembly sequence between factories shows what other components, that was assembled beforehand, to consider when designing the common component C.

Considering both factories, the design parameters of common component C should be set considering both subassembly of A and B in factory A and the subassembly of A, B, and J in factory B. Not only the stage where the common component is assembled but also the previous stages should also be reflected in designing the common components.

3.3.4. Step 4: Identify Direct and Indirect Impact through Design Structure Matrix

The Design Structure Matrix (DSM) is a useful tool for representing and analyzing dependencies among components. This representation was originally developed by Steward (1981) for the analysis of design descriptions.

Figure 3-16 shows a DSM model of part lists in rear axle assembly. Reading across a row reveals all of the components whose design parameters are required to set the design parameters corresponding to the row. Reading down a column reveals which components receive information from the component corresponding to the column. Thus, in Figure 3-16, component A provides information to component C and component C depends on information from components A, B, D, G and J.

From 'Step 3: Liaison Sequence Diagram', it was noted that consideration is needed not only the components where common components are assembled, but also the components in the previous stages. The components that are directly assembled to the common component is regarded as the direct influence, while the components in the previous stages are regarded as the indirect influence. For example, in Figure 3-17, components A, D, and G have direct impact on common component C. Although it is not obvious by the liaison diagram, since component B and J are assembled before assembling component C, component B and J have indirect influence on common component C. The DSM shows these direct influence with bold 'X' and indirect influence with narrow 'X' as in Figure 3-16. By doing so, the design parameters of the common component can be set by reflecting the indirect influences as well as mainly reflecting the direct influences.

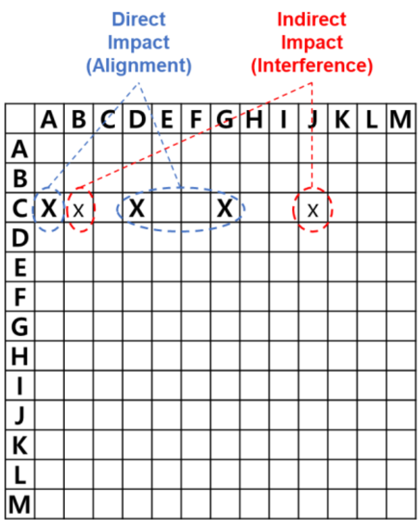


Figure 3-16. DSM for the rear axle

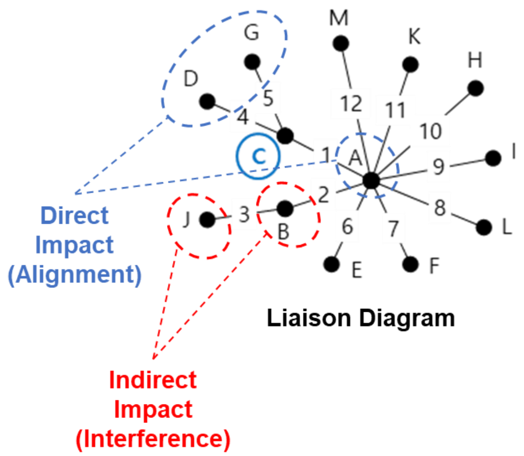


Figure 3-17. Direct and indirect impact of components

3.3.5. Step 5: Identify Resource Capability

Capability analysis is a set of calculations used to assess whether a system is statistically able to meet a set of specifications or requirements. Specifications or requirements of a system are the numerical values within which the system is expected to operate, that is, the minimum and maximum acceptable values. Capability analysis is an excellent tool to demonstrate the extent of the process of satisfying given design parameters.

In any design situation, the probability of success is given by what designer wishes to achieve in terms of tolerance (i.e. design range), and what the system is capable of delivering (i.e. system range). As shown in Figure 3-18, the overlap between the designer-specified ‘Design range’ and the system capability range ‘System range’ is the region where the acceptable solution exits (Babic, 1999). Thus, in case of uniform probability distribution function, the probability of successfully achieving the design parameters of the common components can be written as (Kim and Suh, 1991):

$$I = \log_2\left(\frac{System\ range}{Common\ range}\right)$$

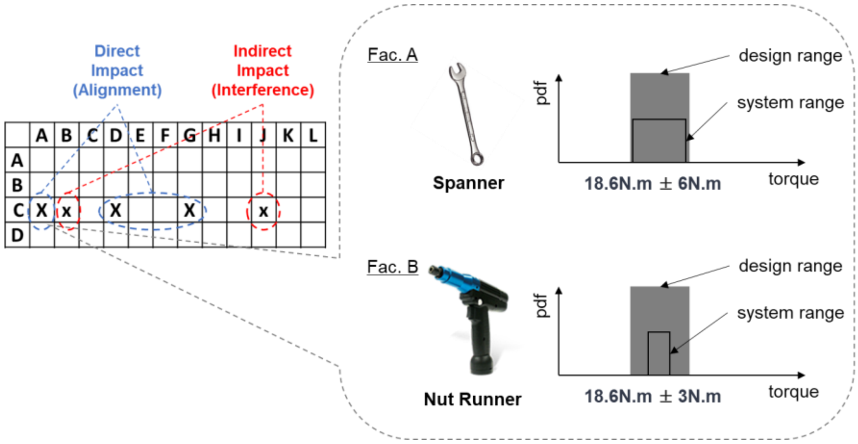


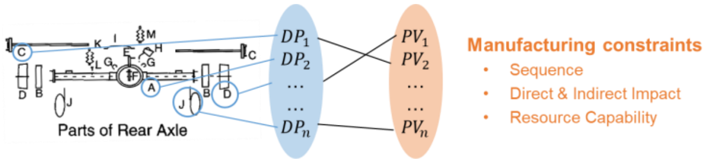
Figure 3-18. Probability distribution of a system parameter

Although information content is a way to calculate the capability of resources, other methods can and should be used according to the characteristics of occupying resources.

3.4. DP-PV Information Matrix

The DP-PV Information Matrix is the output of the suggested methodology which shows the impact of design parameter decision on occupying manufacturing environments. The strength of DP-PV Information Matrix is that it enables the consideration of different manufacturing environments simultaneously.

Through the DP-PV Information Matrix, designers can reflect diverse manufacturing environments at a glance and grasp the impact of the design parameter settings on occupying manufacturing environments. The row represents the design parameter values of common components and the column represents the process variable values of manufacturing processes in diverse manufacturing environments. Figure 3-19 is an example of DP-PV Information Matrix. Torque as an example of design parameter is illustrated in the Figure 3-19. Torque of 18.6 ± 3N.m is set as one of the design parameters of common component. The systems ranges of 18.6 ± 3N.m and 18.6 ± 6N.m shows that the design parameter setting is not an acceptable solution in factory B.



DP-PV Information Matrix		Factory A			Factory B		
		PV_{11}	PV_{12}	PV_{13}	PV_{21}	torque	PV_{23}
Commonized Component	DP_1						
	DP_2		"DP Value" / "PV range"				
	…						
	torque	18.6N.m ± 3N.m		18.6N.m ± 3N.m	18.6N.m ± 3N.m		18.6N.m ± 6N.m
	DP_m						

Figure 3-19. DP-PV Information Matrix

Chapter 4. Case Study

The demonstration case study is illustrated with design of automobile alternator. The case study is from a pioneering robot assembly system of Charles Stark Draper Laboratory, Inc. built in 1977-1978 (Nevin and Whitney, 1978). An automobile alternator is composed of multiple physical components that interact each other as illustrated in Figure 4-1. The purpose is to find what components influence the current manufacturing environments and how to set the design parameters of such components so as to manufacturing the automobile alternators in occupying manufacturing environments. The application of suggested methodology to the automobile alternators verifies the validity of the methodology.

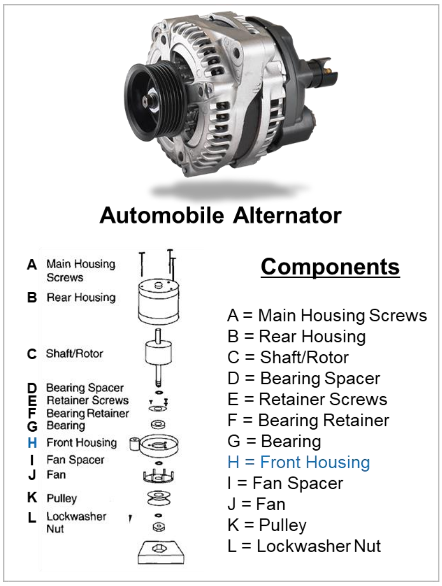


Figure 4-1. Automobile alternator and its components

4.1. Application of Methodology

Figure 4-2 shows different manufacturing processes for the alternator due to different manufacturing environments. Sequence difference among factories will be explained beforehand for better understanding of the methodology application.

Sequence 1 is conducted in one unbroken sequence from a single direction and no orientation is needed. Sequence 2 starts the assembly sequence by placing the rear housing in a fixture and adding parts to it. The front housing is built as a subassembly which permits the use of a fixture that can grasp the retainer from below while the screws are inserted. Sequence 3 differs from sequence 1 in that the front housing is built on a separate fixture as a subassembly just like sequence 2. Sequence 4 also assembles front housing as a separate subassembly but it is clear that the manufacturing constraint restricts the assembly direction to +z orientation.

Let us consider the front housing, component H, as the target component that needed design parameter fixation in order to be assembled in all factories. Following the suggested methodology, from the part list of the automobile alternator in Figure 4-1, liaison diagram for automobile alternator is presented in Figure 4-3. Due to the given manufacturing environments of factory A~D, precedence relations are given as constraints in Table 4-1.

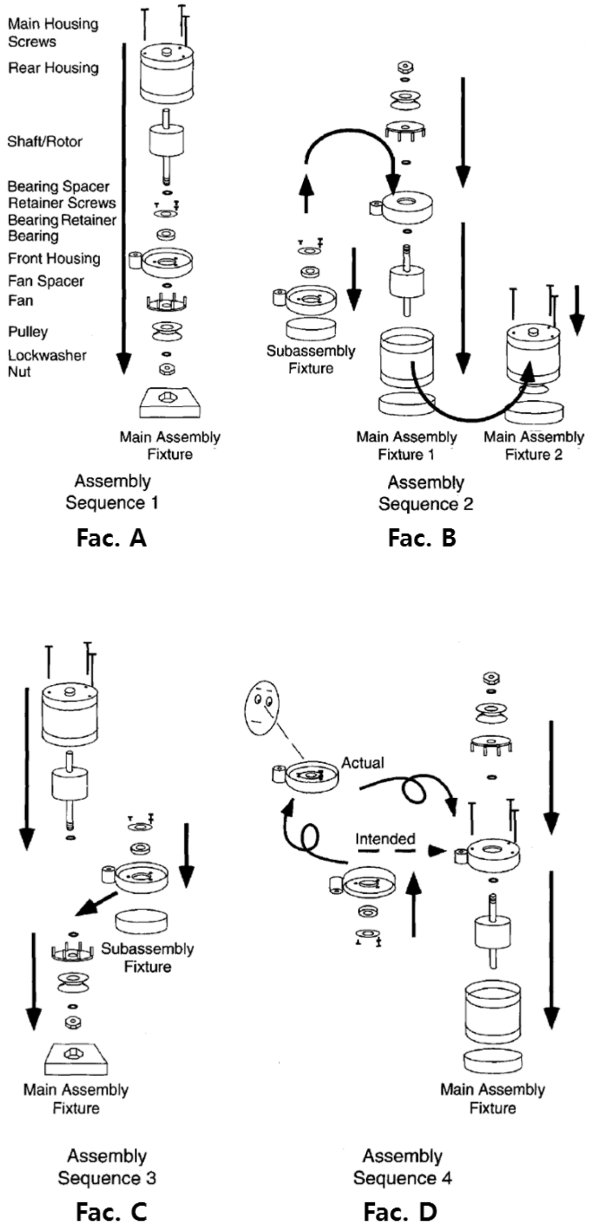
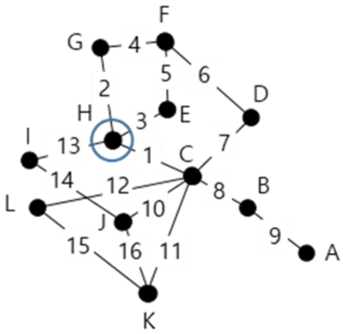


Figure 4-2. Four feasible assembly sequences for an automobile alternator



Liaison Diagram

Liaisons	
1 = C to H	9 = B to A
2 = G to H	10 = C to J
3 = H to E	11 = C to K
4 = G to F	12 = C to L
5 = F to E	13 = I to H
6 = F to D	14 = I to J
7 = C to D	15 = L to K
8 = C to B	16 = K to J

Figure 4-3. Liaison diagram for automobile alternator

Table 4-1. Precedence relations for automobile alternator

Precedence Relations		
4 > 3	14 > 13	2, 4, 5 > 7

Different manufacturing environments of factory A and D result in different assembly sequence as in Figure 4-4. The difference in assembly sequence results in different liaison sequence diagram as in Figure 4-5.

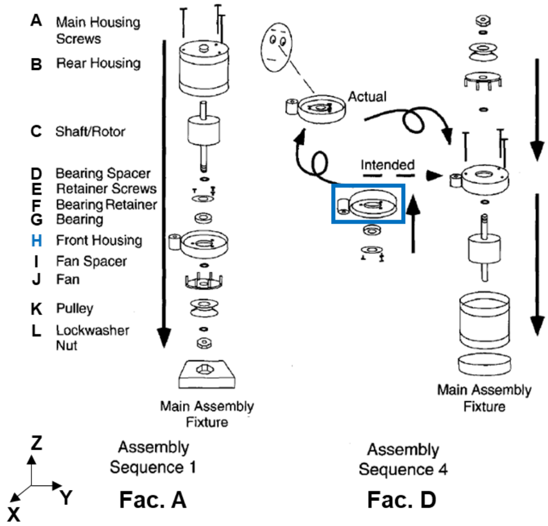


Figure 4-4. Assembly sequence difference in factory A and D

In factory A, the first task related to the common component H, assembly of H on I, is conducted at stage 4. Otherwise, the first task related to component H, assembly of G on H, is conducted at stage 3 in factory B. Although their tasks are different, H on I in factory A and G on H in factory B, there is no doubt that all those tasks must be taken into account for the setting of design parameter decision of common component H. Regarding component I and G respectively in factory A and B respectively, as the directly influencing components to component H, other components in the previous stages are regarded as indirectly influencing components. Direct and indirectly influencing components can be expressed by the DSM as in Figure 4-6. The direct influencing components are represented in bold x and the indirect influencing components are represented in narrow x. From DSM, it can be informed that not only shaft/rotor, bearing, and fan spacer but also rear housing, fan, pulley, and lockwasher nut must be taken into account when setting the desing parameter of front housing.

This result concord with the problem occurred at each factory. In factory A, fan was assembled before the front housing. The difficulty with this sequence is that it is hard to access the front housing in the presence of the fan in such a way that the bearing retainer can be kept stationary while its screws are being driven (Whitney, 2004). Thus, it is imperative to reflect the characteristic of fan when designing the front housing.

In factory D, the manufacturing constraint restricts the assembly direction to +z orientation. Thus, the subassembly was built in the orientation shown, with the bearing, retainer, and screws somewhat precariously installed upside down from below (Whitney, 2004). The precariously assembled front housing needed extra work of a person picking up each housing and inspecting it to be sure that all the parts were present.

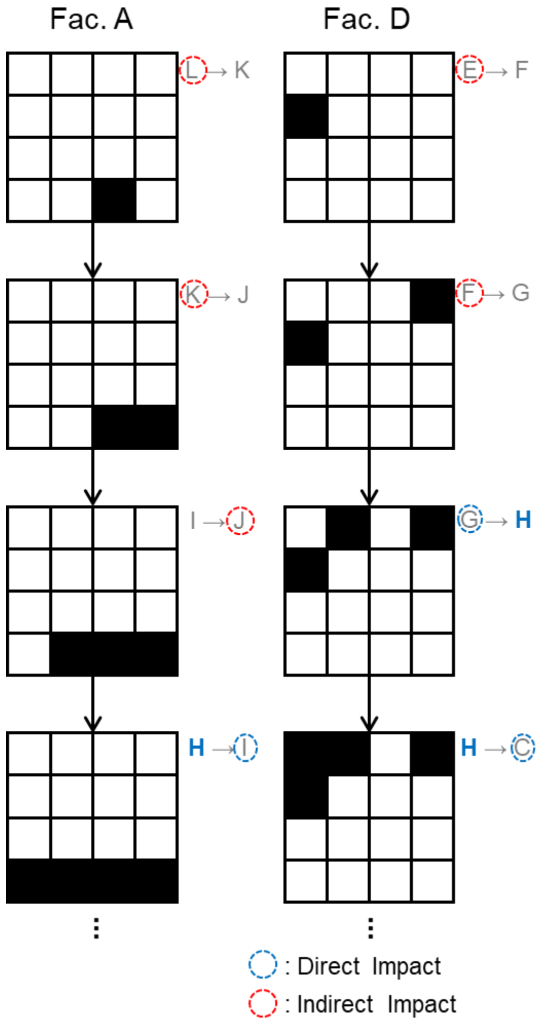


Figure 4-5. Liaison sequence diagram of factory A and D

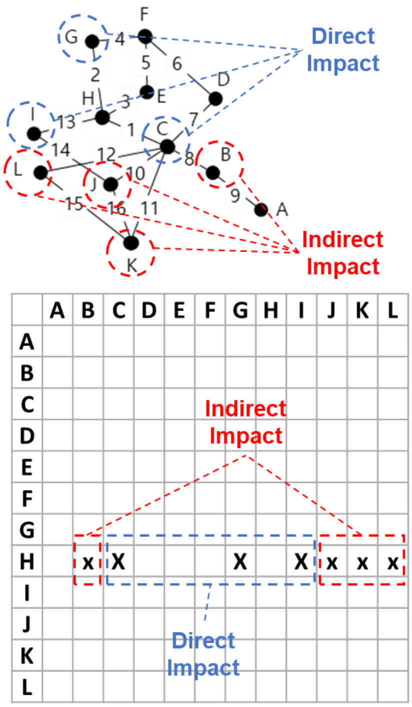


Figure 4-6. Design Structure Matrix representing direct and indirect influencing components on common component (H)

4.2. DP-PV Information Matrix

The case study shows that the same product assembled in different manufacturing environment faces different problems. Due to manufacturing constraints, assembly problem occurs in factory A and factory D. As the outcome of the methodology, DP-PV Information Matrix is presented as in Figure 4-7.

In factory A, fixture stability issue is occurred since the bearing retainer cannot be kept stationary while its screws are being driven since the fan wings cannot stabilize the front housing. There are two possible options. One is to change the design parameters of the fan wing in a way so that it can stabilize the front housing while the bearing retainer is assembled. Changing the composing material of fan tip in order to stabilize the fixture could be an example. Another option is to add another assembly fixtureto the assembly to fixate front housing.

In factory D, front housing is assembled only in +z direction due to the limitation of resource capability. This constraint is categorized as process capability. In order to reflect the constraint to the design, the screw assembly orientation of the front housing should be changed so that the retainer screws can be assembled in –z direction. Another option is to change the design range of torque so that it meets the system range.

From this case study, assembly sequence, alignment (spatial characteristics), and process capability were revealed as manufacturing constraints among the three categories suggested in the thesis.

Due to the limited information of automobile alternator the capability analysis is not conducted in the case study. However, an illustrative example is presented in Section 4.3 conducting capability analysis is excerpted from Gonçalves-Coelho (2007) using information content.

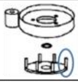
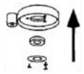
DP-PV Information Matrix		Fac. A	Fac. D	
		Fixation (Stability)	Orientation	Torque
Front Housing	Material of Fan wing	 α β γ	-	-
	Additional assembly fixture	+ assembly fixture	-	-
	Screw assembly orientation	-	 $+Z$ $-Z$	-
	Torque	-	-	18.6N.m ± 6N.m / 18.6N.m ± 3N.m

Figure 4-7. DP-PV Information Matrix for automobile alternator

4.3. Illustrative Example of Capability Analysis

Illustrative example from Gonçalves-Coelho (2007) is excerpted to present a simple method, among many, to calculate the system range using information content. The data and the system analysis methodology presented in Table 4-2 (Gonçalves-Coelho, 07) is related to the total unit cost of specific steel parts that can be manufactured in different quantities either by machining or by forging.

Many different technologies are available to manufacture the same component. The capabilities of two different manufacturing process are regarded as their system ranges. The system range for the surface roughness is $0.8\mu m \sim 25\mu m$ for machining and $1.6\mu m \sim 25\mu m$ for forging. As in Figure 4-8, uniform probability density functions were used for surface roughness because it is assumed that each technology can produce any design specification that is in their system range with the same degree of easiness. Likewise, uniform probability density functions were used for unit cost, because production volumes are equally probable in the range.

Table 4-2. The capability of two different manufacturing processes

	Factory A **Machining**	Factory B **Forging**
① Cost **System Range** $(C_{min} \sim C_{max})$	$C = \frac{1170}{n} + 5.12$ $\$5.41 \sim \$8.04$	$C = \frac{3848}{n} + 3.27$ $\$4.23 \sim \$12.89$
② Roughness **System Range** $(R_{min} \sim R_{max})$	$0.8\mu m \sim 25\mu m$	$1.6\mu m \sim 25\mu m$

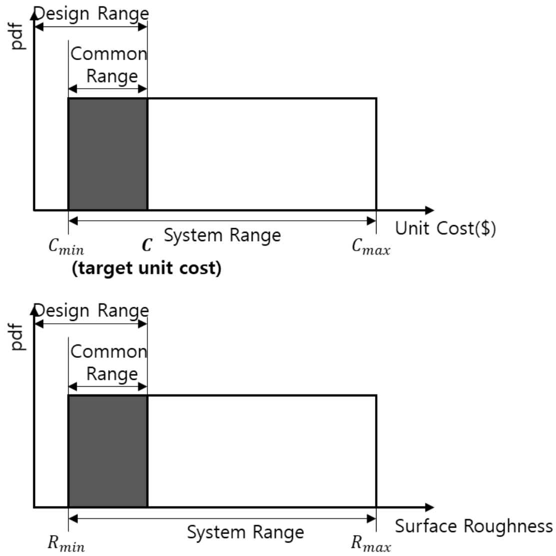


Figure 4-8. The design and system ranges for unit cost and surface roughness

Thus, probability density functions for machining and for forging, pdf(C), are

pdf(C) = P_0, $C_{min} < C < C_{max}$

pdf(C) = 0, otherwise

$$\int_{-\infty}^{+\infty} pdf(C)dC = \int_{C_{min}}^{C_{max}} P_0 dC = (C_{max} - C_{min})P_0 = 1$$

Since the information content of a design solution is the probability of fulfilling a given design, the information content, *I(C)*, for a given cost, *C*, is computed:

$$\mathrm{I}(C) = \log_2 \frac{1}{P} = \log_2 \frac{C_{max} - C_{min}}{(C - C_{min})}$$

Adding the contribution of the surface roughness for the total information content:

$$\mathrm{I}(C,\ R) = \log_2 \frac{C_{max} - C_{min}}{(C - C_{min})} + \log_2 \frac{R_{max} - R_{min}}{(R - R_{min})}$$

The result of total information content for both machining and forging, for different product volumes and for the surface roughness is in Figure 4-9 (Gonçalves-Coelho and Mourao, 2007). By comparing the capability of resources in different manufacturing environments, designers could see beforehand whether the occupying resources could manufacture their design configurations.

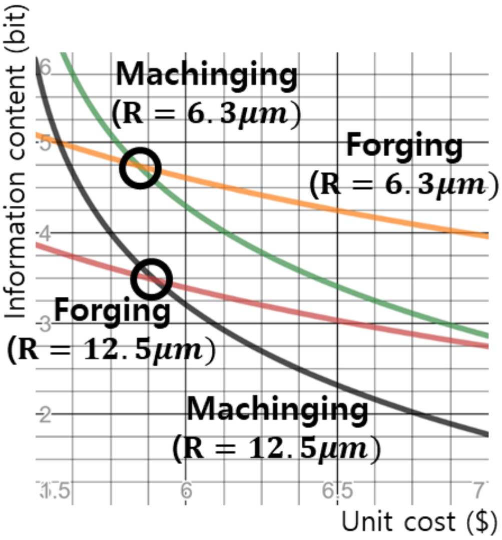


Figure 4-9. Machining and forging: information content vs. unit cost

Chapter 5. Conclusions and Future Works

The thesis proposed design parameter decision making methodology considering its impact on diverse manufacturing environments.

Contributions of this study are stated as follows, First, the suggested framework reflects diverse manufacturing environments simultaneously to the design of common components in the early stage of product development process. Second, the categorization of manufacturing constraints reflects many problems that may arise in the manufacturing domain. Third, the suggested Design Parameter Decision Making Methodology reflects categorized manufacturing constraints into setting the design parameters of the common components.

The limitation of suggested methodology is that it is demanding to collect all the information regarding diverse manufacturing environments that is needed for the analysis. Thus, a future work is to development a data management frame that could collect and manage such diverse manufacturing constraints.

Extension of this study would be possible by applying the framework specifically to an industry since the methodology could vary depending on industry domains. If a more sophisticated analysis is developed for a certain industry, it would be possible to establish a domain-specific methodology.

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국문 초록

제품개발과정은 일반적으로 제품계획에서 시작하여 제품 컨셉 개발, 시스템 설계, 상세 설계, 테스트 및 보완을 거쳐서 생산까지 이루어지는 일련의 과정이다. 제품개발과정은 일반적으로 순차적으로 진행되지만 제품계획에서 시작하여 생산까지의 과정에서 지속적인 피드백으로 인해 설계가 변경되는 반복(iteration)이 불가피하게 발생한다. 반복 과정의 주기가 길수록 제품개발과정에서 더 많은 시간과 비용이 발생하게 된다. 불가피한 반복의 과정에서 오는 시간과 비용을 최소화하고자 수많은 연구에서 동시공학적인 접근법을 제시했다. 하지만 기존 연구들은 주로 개념적으로 동시공학적인 접근 방법을 제시하여 현실적으로 기업에서 적용하기에 동떨어져 있거나 방법론적으로 취약한 부분이 많다.

대량맞춤 생산을 위하여 기업은 플랫폼 전략을 활용한 제품군 설계(Product family design)를 한다. 부품공용화 전략은 플랫폼 전략의 대표적인 방법이다. 글로벌 대기업과 같은 경우에는 출시하는 제품을 하나의 공장에서만 생산하는 경우는 드물다. 공장마다 생산과정과 환경이 다르기 때문에 하나의 제품을 계획하더라도 생산과정에서 제품이 예기치 않게 변경되는 경우가 많다. 이러한 예기치 않는 변경사항이 제품개발과정 중 후반부에 발생하게 되면 갑작스럽게 제품의 설계를 변경해야 하거나 혹은 공장의 환경을 변경해야 하는 등의 많은 시간과 비용이 발생하게 된다. 이렇게 발생할 수 있는 시간과 비용을 최소화시키기 위해서는 제품개발과정 초기에서부터 생산의 환경을 고려하는 프레임워크가 필요하다. 하지만, 기존 연구에서는 공용부품의 스펙을 결정함에 있어서 다양한 생산환경을 동시에 고려하는 관점이 부족했다.

본 연구는 다양한 생산환경에 미치는 영향력을 고려한 공용부품 설계인자(Design Parameter) 설정 방법론을 제시한다. 제시한 프레임

워크는 다양한 생산환경에서 나타날 수 있는 생산제약조건을 세 가지 카테고리로 분류한다. 제시한 방법론을 활용한 분석을 통해 다양한 생산환경에서 발생하는 문제를 공용부품의 설계인자 의사결정에 반영할 수 있다. 분석의 결과로써 설계자는 DP-PV 정보행렬(DP-PV Information Matrix)을 통해 다양한 생산환경을 설계에 반영할 수 있다. 제안하는 방법론은 자동차 교류발전기(automobile alternator)에 적용되었다.

핵심어: 플랫폼 디자인, 디자인 파라미터, 부품 공용화, 생산제약조건, 동시공학, 제조고려설계
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