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PRODUCT DESIGN, A METHODOLOGY BASED ON AXIOMATIC AND STRATEGIC APPROACH

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ABSTRACT

Product Design and Development, PDD is a set of processes to physically convert a new idea or concept to a new or pre-developed product which can be offered to the customer. These processes are mostly based on the creativity and experience and then are very difficult to manage or transfer. There are several methods to organize and document the design and development processes, many of which neglect to consider the strategies and conflicting goals of the stakeholders such as those stages in the supply chain involved with the design. This paper introduces the axiomatic design, a recently developed method of design, combined with the conventional methods and with a strategic approach that result in a new methodology for product design and development.

Keywords: Product Design and Development; Axiomatic Design; Strategy in Design

1 INTRODUCTION

1.1 Design Process, an overview

Simultaneous use of "design" and "development" is usually the process of the new idea creation that idea influences the product appearance and performance. The key position of the product design and development in product supply chain is shown in figure 1.

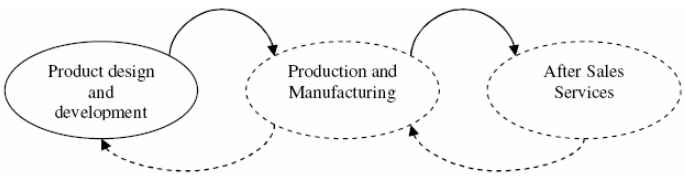

Figure 1 – A general product supply chain

The importance of this process is originated from the impacts of mistakes and faults in design which are thereafter apparent in the successive processes such as production and maintenance, these impacts is easily understandable by the rule of base ten. [1] Reducing the backwards in the product supply chain that means cost of changes, is appreciated by the management. Considering the characteristics and nature of traditional product development method, it may said that it's dependent on human's creativity and so no definite framework or algorithm has covered its concepts. Science is to justify and interpret the natural phenomena and to organize its processes. Design is not yet a perfect science according to mentioned definition. [2]
The process of Product Design and Development, PDD, should be well documented and procedural to be transferable. (Figure 2)

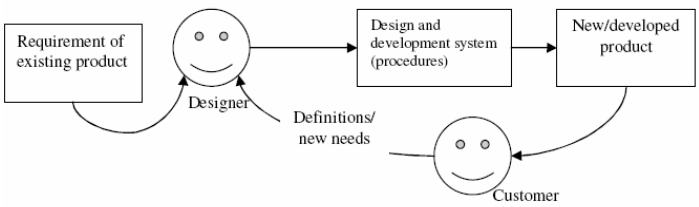

Figure 2 – information cycle of product design and development

Figure 2 – information cycle of product design and development

TRIZ technique is fairly successful to reach this goal. It tries to define two matrixes of requirements and specifications to organize the creativity of design. [2]
In QFD, the voice of customer results in some specific technical specification by application of the houses of quality. The other recently introduced methodology of Axiomatic Design, developed by Suh, the axioms of independence and information ends to a product or system design. [3]
Ulrich and Eppinger have also developed a 14-step approach to make the process of PDD, systematic.
Their method is shown in figure 3 and is typically for an industrial physical product. [4]

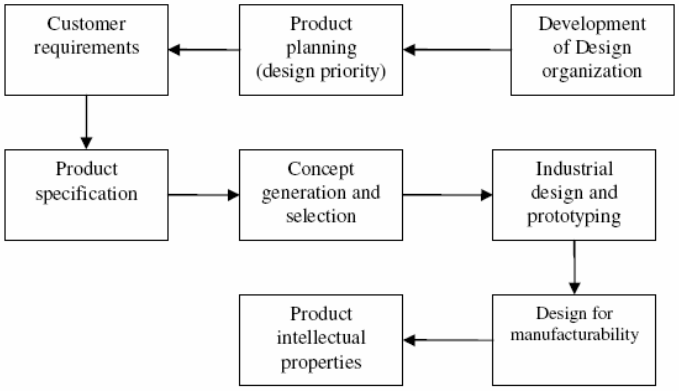

Figure 3 – Ulrich and Eppinger's methodology

1.2 Axiomatic Design

Axiomatic design was introduced by Suh in the late of 1900. It's a methodology to design products, processes, and organizations. In Axiomatic Design, two axioms are introduced to obtain an acceptable design. The main feature of axiomatic design methodology is interaction of functional requirements and design parameters. Functional requirements, FR, must be determined and then a physical tool must be prepared to satisfy these FR's. Such a physical tool is considered by Design Parameters, DP. [5]
As shown in figure 4, the FR domain is related to DP domain by the design. In addition customer needs, CN, should be predefined to specify FR's. Process variables, PV's, describe the applicability of the extracted design.

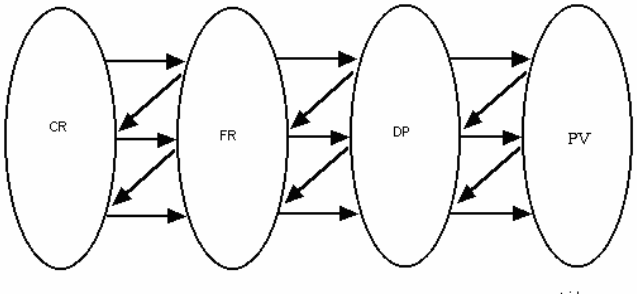

Figure 4 – four domains of design process in Axiomatic Design

Axiomatic design theory tries to make a scientific base in design branch on which the products, processes, systems and even organizations to be assigned properly. This method is no longer dependent on only experience and creativity. By definition, axioms are fundamental truths that are always observed to be valid and for which there are no counterexamples or exceptions. In axiomatic design theory there are two axioms: the independence axiom and information axiom. There is also a design matrix to express the relationship between FR and DP might be described by the design matrix, A as shown in figure 4.
In this matrix, A_{ij} is the effect of design parameter j to satisfy functional requirement i so we have:

$$FR_i = \sum_j A_{ij} DP_j$$

For instance, a design including two FR's and DP's has a matrix like this, when FR's
changes the change in DP's will be obtained by the depicted equations. (Figure 5)

$$\begin{Bmatrix} \Delta FR_1 \\ \Delta FR_2 \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{Bmatrix} \Delta DP_1 \\ \Delta DP_2 \end{Bmatrix}$$

$$\Delta FR_1 = \frac{\partial FR_1}{\partial DP_1}\Delta DP_1 + \frac{\partial FR_1}{\partial DP_2}\Delta DP_2$$

$$\Delta FR_2 = \frac{\partial FR_2}{\partial DP_1}\Delta DP_1 + \frac{\partial FR_2}{\partial DP_2}\Delta DP_2$$

Figure 5 – relationship between FR and DP in Design Matrix

The structure of axiomatic design starts from the design goal and continue by the sequence of FR, DP and PV. The relationship between each two levels should be independent. [6]

2 PROBLEM DEFINITION

Most of the systematic approaches, often neglect the long term and strategic goals of organizations. In fact, design is performed regardless of strategic plans and organization vision; therefore it may result in excessive costs in the next stages. Another notable point is that functional requirement should be evaluated regarding the needs of different and often conflicting customers. The final design should consider the benefits of separate stages in the supply chain. The problem becomes more complicated when we find out that the goals and intentions of these stages or echelons are conflicting to each other. Suppose a part manufacturer is interested in an economic and unique design and on the other hand, the assembly company needs diversity in the designs and high quality that may dictate excessive costs to its supplier, manufacturer. In this paper, product design and development process is investigated based on these two points of view. To clarify the aim and apply the proposed approach, we delineate an example and follow the designing process. The product is the seat for off-road buses which is often criticized by the travelers. There are two main points as described before: first, who is responsible for the seat design and what are the objectives in this process and the secondary, how strategic plans may influence the design.
We assume the seat manufacturer as the main designer and it's the company who is responsible to prepare the design documents. Look at figure 6 and see how different players deal with such a design regarding their needs and usages. Considering the needs and application, many parties in supply chain are dealt with such a design.

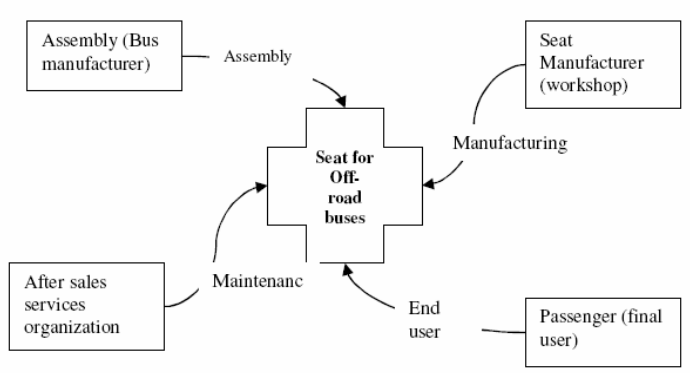

Figure 6 – How the different players are involved with the seat design

Customers' needs should be exactly extracted from the needs of these four parties (shown in figure 6) layers and the final design should encompass their requirements. Each player has a set of goals and logically look for maximize its beneficence from the new design. Figure 7 simply classifies these sets of players and their benefits (requirements).

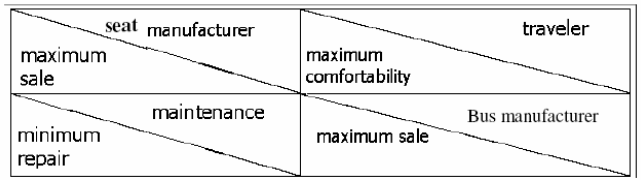

Figure 7 – different goals of different players

To apply axiomatic design, one goal should be defined and neglecting a player's consideration may make the design and eventually the manufactured product inappropriate. Figure 8 depicts the strong relationship among the different players in this case.

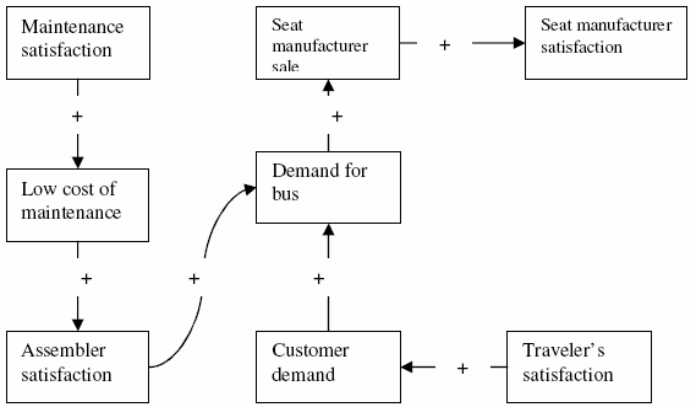

Figure 8 – Impact of suppliers and users goals on each other

3 STRATEGIC AXIOMATIC DESIGN

Following approach is suggested to be followed to clarify the design process:
The proposed approach by this paper regarding the systematic existing methods for our product and generally every physical and industrial product will be as following:

1. Explicating the strategies of designer company clearly so that every design follows them. Generic strategy may be in three forms:

> Cost leadership, in which the product compete with the rival's product by its lower finished price.
>
> Differentiation, in which the company is differentiated from the others by a special feature in the products or services. Using a type of very light material in a mobile cell phone to make it more easily portable is an instance.
> Focus or concentrating on a specific demand by targeting a demographical market, selling only in the south of the country for example. [7]

They are generic strategies and usually prescribed and applied from the top level of the organization; see the pyramid in figure 9. Design, often is prepared in the functional level of this pyramid and is based on functional strategies.

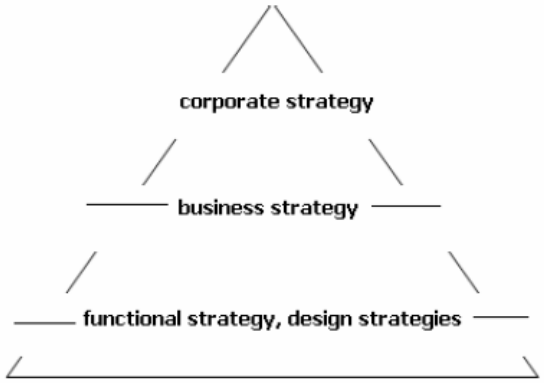

Figure 9 – Organizational strategic levels

2. Design and development goals should be defined from the functional strategies, consider the cost leadership as a corporate strategy, a functional strategy might be "design for cost" for all involved in the team consist of at least one member of each parties (organizations) involved in this design..
3. Team or organization, depending on the size of the project, should be formed. This group contains an internal and external people. The internal team has members from design, manufacturing and marketing departments and external usually from sale, finance, suppliers and other support departments. [4]
4. In this stage, data collection and interpretation through interview and historical information of the product help to reach the right functional requirements FR's. Ulrich and Eppinger indicate how to extract these requirements from the needs of customers. [4]
5. PV's are in fact, the standards and necessities that specify whether a design is feasible or not.

4 CASE STUDY

It's highly recommended to provide the product identification before start the new design. This sheet includes the designer company, the successive customer of the product, the strategy of the designer company, the goal of this design, design organization, applied methodology for design.

(All the operations of design have been performed by Accelaro, the accredited software released in 2000 by MIT to facilitate axiomatic design process)[8]

1. Customer needs are defined. Needs of the assembler as the successive customer is stated. To uniform the expressions, all the sentences has the same pattern, "the product" should satisfy "a need". Figure 10 shows the CN's description.

Customer Needs
Description
The seat should be cost effective
The seat should be easily installed
The seat should be comfortable for the final passenger

Figure 10 – Customer Needs definition

2. FR's, in the exact number of CN's , are described by the manufacturer (designer in this case also) directly from the CN's which previously defined by the customer. In FR definition, manufacturing, sale and marketing considerations will be noted. The following figure shows the tree of FR's breakdown.

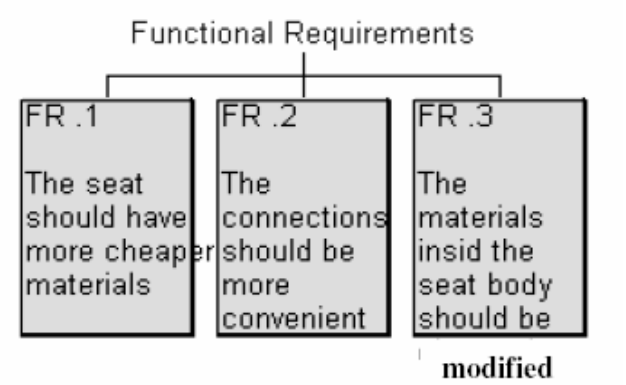

Figure 11 – FR tree

3. Mapping, to satisfy the independency of FR and CN, the matrix of their coincidence is created, for uncoupled design, CN should be satisfied by only one FR and this is the first axiom.
It's noticeable that the seat manufacturer previously designed the seat with washable and changabe cover but here it's apparent that this FR is not related to any CN and should be eliminated.

	FR.1: The seat should have more cheaper mateials	FR.2: The connections should be more convenient	FR.3: The materials inside the body should be changed
CN1: The seat should be cost effective	x	O	O
CN2: The seat should be easily installed	O	x	O
CN3: The seat should be comfortable for the final passenger	O	O	X

Figure 12 –FR, CN Matrix

To make the process clearer, FR's are decomposed into lower categories. For instance, to meet the FR of "easy installation", these new FR's are defined:

- The installation should be easier
- The assembly time should be shorter
The next FR is also divided to the following FR's:
- The raw material should be cheaper
For each FR a DP is assigned and here also the condition of independency should be considered carefully. Each DP connects to its corresponding FR as shown in figure 13

Functional Requirements	Design Parameters
The seat should have more cheaper materials	
The raw material should be cheaper	A design without plastic plate in behind
The manufacturing process should be cost effective	A design without traditional connections

Figure 13 – relationship between FR and DP in Design Matrix

modified

To make the connections more comfortable for the assembler, two different designs are offered: A design with the joint base parts for double seat and a design without thread and have fast fasteners.
The first suggestion is because the seats are often installed in pairs.
The later design makes the assembly operation simpler.

Functional Requirements	Design Parameters
The connections should be more convenient	
The assembly time should be shorter	A design with a joint base parts for double seat
The installation should be easier	A design without thread and have fast fastener

Figure 14 – Design Parameters definition

The uncoupled design, like in figure 15, matrix shows that this axiom has been regarded.

	DP#.1	DP#.2
FR#.1	X	O
FR#.2	O	X

Figure 15– Design Matrix

The last FR is "The material inside the body should be changed " and its DP is to replace the fume with polyurethane a more comfortable material.

4. Design Selection

Selection of the best design in axiomatic design is performed by the information axiom. This axiom says that the design of the minimum amount of information should be selected. This information is quantified as the following equation: (figure 16)

$$I=\log (\Delta L_x/\Delta L_0)$$

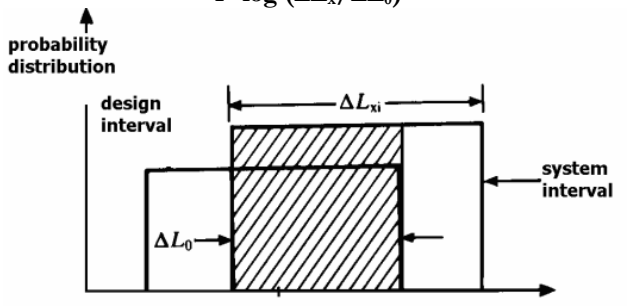

Figure 16– system and design intervals

The intervals of system and design may be defined for many attributes of the product. For example one may be interested in selecting the design in which the life of fasteners is longer than that of other designs or mechanical strength of connections may be considered.
This paper introduces a strategic approach in which the attribute of interest should be a strategy parameter. Consider the functional strategy in design department is generating the design as cheap as possible so that the corporate strategy is met. Therefore, cost as the main factor is to be considered to evaluate the designs and all the intervals mentioned in figure 16 should be expressed as a saving occurred in the new designs.

Example:

Design A: the seat without the plastic board and with the fasteners and joint to the seat beside. (pair assembly) the material inside the body is from polyurethane.

Figure 17–a schematic of design A

Design B:
The seat with the screw and not connection and with the material of fume dm120 instead of old materials. The cover is made up of new cloth so there is a saving.
These two designs (or every other) is quantified as their cost savings in the product:
Diagram of information axiom for design A is shown in figure 18.

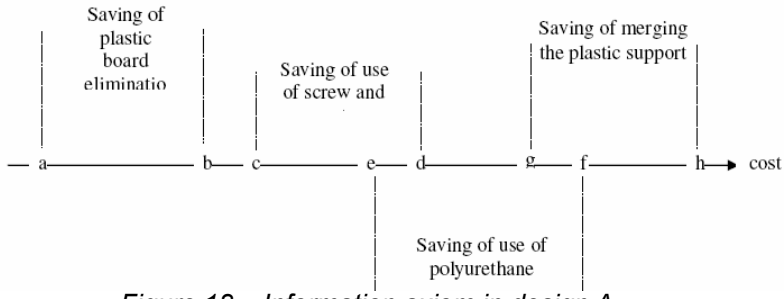

Figure 18 – Information axiom in design A

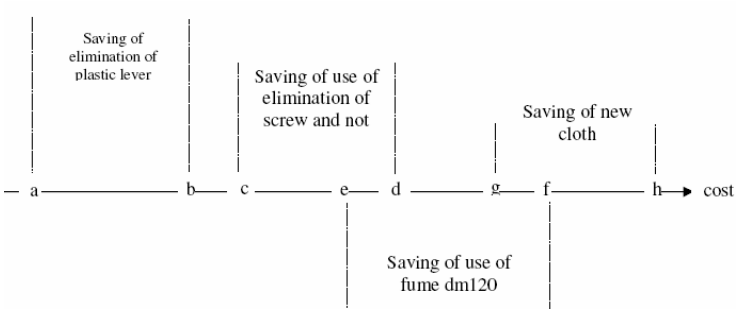

Figure 19 – Information axiom in design A

The design with the minimum amount of information will be selected and this information is quantified for both designs as following:

$$I=\log_2\left[\frac{t}{(b-a)+(c-d)+(f-e)+(h-g)}\right]$$

Where t is the total expected cost saving from the new design that should be reached by even A or B design. Actually the functional strategy for product design or development is to obtain a cost saving by "t" unit currency.

5 A QUANTITATIVE EXAMPLE

The management decides to reduce the cost of each product in 50$ and two following designs are available and possible:
Suppose for the product which is built based on design A, we have:
5$ when eliminating the plastic board
2$ when using screw and not
9$ when using the new cloth
3.5$ when using fume dm10
The information value of this design is calculated by:

$$I=\log_2\left[\frac{500}{(50)+(20)+(90)+(35)}\right]=1.36 \text{ bit}$$

This calculation is also accomplished for design B and the design with lower amount of information is the final design. The point is that if some DP has no cost saving, e.g. in design B that the use of fast fastener may result in more price for the materials, another attribute, often a qualified one, is replaced.

In this case, using this type of fastener prompt the assembly operation to be done more quickly and this will end to a cost saving that should be entered to this equation as a cost saving item.

6 CONCLUSION

By applying a new sequence in product design process, we can be sure that all the aspects are considered. Old methods often neglect the goals of design and their conflicting nature. The functional requirements in Axiomatic Design were well extracted regarding the goals of different player who benefit the design of the product. The DP's, designs, with the minimum information are selected as the second axiom recommends. In this paper, the criteria to quantify the amount of information is a strategic parameter. In a company who follows cost leadership in market cost saving is the most significant factor of all activities and design and development processes are not exceptional.

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