**MASTER OF SCIENCE IN MECHANICAL ENGINEERING**

# Study of Product Design Perspectives for Manufacturing Refrigerators in Bangladesh using Analytic Hierarchy Process (AHP)

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**DEPARTMENT OF MECHANICAL AND CHEMICAL ENGINEERING**
**ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)**
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**SEPTEMBER, 2014**

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Thesis Submitted in Partial Fulfillment of the Requirements of the Degree of
**Master of Science in Mechanical Engineering**

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SEPTEMBER, 2014

# DECLARATION

This is to certify that the work presented in this thesis is the outcome of the investigation carried out by **Farhad Ahmed** under the supervision of **Asst Prof. Dr. Abu Raihan Md. Harunur Rashid**, Department of Mechanical and Chemical Engineering, Islamic University of Technology (IUT), The Organization of the Islamic Cooperation (OIC), Dhaka, Bangladesh. It is hereby declared that this thesis which is submitted to the University for the degree of Master of Science in Mechanical Engineering, has not or never been submitted by me for a degree at any other university or educational establishment.

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Student No: 101604
Academic Year: 2011-2013

## DEDICATION

**DEDICATED TO MY BELOVED FAMILY MEMBERS**
**MAY ALLAH BLESS YOU ALL**

# ACKNOWLEDGEMENT

First and foremost, I thank Allah for giving me wisdom, health and passion to complete all courses as well as thesis of M.Sc. Engineering successfully.

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**Farhad Ahmed**

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# ABSTRACT

Product design is a new engineering practice in Bangladesh. Now-a-days different companies are showing willingness on manufacturing engineering products in Bangladesh, where product designing is playing very important role. Product design in R&D level can play vital role in a country on creativity, renovation &/or innovation in engineering field. Because, engineering field cannot flourish without product designing practice.

However, engineers or designers may design products from different views along with their individual style spontaneously in their fields. But, a systematic approach is always prolific.

There is a scope of studying & classifying product designing methodologies. Besides, there is also scope for systematic analysis on different product designing methodologies. A systematic approach on product designing methodology selection could be an effective strategy to provide business success.

Different product designing methodologies could aim on specific goals for improving or aligning with productivity, manufacturability, aesthetics etc. depending on market situation, durability, cost etc. Analytical Hierarchy Process (AHP) is a multi-criteria decision making process, which could be very effective tool on these analysis.

# Chapter 01: Introduction

## 1.1 Background of Study

*Engineering Design* is a key engineering practice which defines &/or contributes to a country's technical strength as well as development. Obviously the concept and applications of *Engineering Design* are far distinct comparing to normal *Design* which is still very much unclear to the majority of the developing countries where literacy rate is poor. Besides, it is also a matter of practice which makes people familiar with technical concepts/tools.

Industrialization and manufacturing ability defines a countries economic and technical strength, where *Product Design* is a very handy and powerful tool. This *discipline* of *Engineering Design* is newly introduced to our country. And there is much scope of finding &/or accumulating *Engineering Design Disciplines* as well as studying different *Product Design Methodologies*.

There are many new industries in our country who have taken lead in manufacturing engineering products like refrigerator, air-conditioner, television, motor-cycle, ship, mold, transformer etc. and they are using different *Product Designing & Simulation Software* like *AUTOCAD, SOLIDWORKS, ANSYS, MATLAB* etc. Though the resources are very limited in our developing country, they have been showing very vigilant and visible leadership in terms of acquiring knowledge and absorbing new technology in their fields. But still, there is scope remaining for finding the *best product designing methodology* in each of their field according to the circumstances of our country using *multi criteria decision making (MCDM)* process.

There are several techniques now available in the literature to deal with *multi criteria decision-making* problem (Goodwin and Wright, 1998; Saaty, 1980; Keeney and Raiffa, 1976; Van Laarhoven and Pedrycz, 1983). Some of the well known techniques are *Multi Attribute Utility (MAU)* model, *Simple Multi Attribute Rating Technique (SMART), Analytic Hierarchy Process (AHP)* and *Fuzzy Hierarchical Decision Making (FHDM)* method. Among these AHP is possibly the most familiar and extensively used *MCDM* method. It is simple and easily comprehensible. In spite of some criticisms leveled against it (Belton and Gear, 1983; Belton and

Gear, 1985; Harker and Vargas, 1987), this method has been widely applied in many *MCDM* problems, e.g. technology selection, vendor selection, project management, plant layout, maintenance strategy selection, transportation fuels and policy etc. [1]

## 1.2 Statement of the problem:

In this thesis we would like to study different *product design methodologies* and find out the *best product design methodology* using *Analytical Hierarchy Process (AHP)* for manufacturing refrigerator in the present circumstances of our country/developing countries.

## 1.3 Objectives of the study:

Objectives of our study/thesis are:

1. Studying different product design perspectives
2. Studying Analytical Hierarchy Process (AHP)
3. Collecting statistical data from product designers who have experience on refrigerators (specially on Research & Development level)
4. Finally, finding the prominent product design perspectives for manufacturing refrigerators in Bangladesh using AHP.

The finding from this study would be helpful for product designers to give emphasis on specific product design perspectives.

## 1.4 Significance of the study:

Product Design is not only an art but also a lengthy process which demands series of engagement/decisions, trial & error, simulation with not only size, shape and aesthetics but also other variables like productivity, manufacturability, environment, durability, market feedback and ergonomics. Emphasis on each variable defines the nature or methodology of the product design from the very beginning. Thus different product designing techniques or methodologies should be distinguished with well explanation.

Besides, emphasis on the above mentioned variables varies from designer to designer and product to product, which ultimately impacts on the product's sales/marketing, lifetime, pricing, cost saving etc. Thus, different product design methodologies have different impacts on the product's sales/marketing, lifetime, pricing, cost saving etc. So, these may be some criterion to judge a product design methodology which is to be clarified.

Therefore, a comparative study of different product design methodologies based on different criterion may improve product designing to next level. For example, a comparative study may be used as a tool for selecting the most appropriate methodology for designing a specific product. AHP could be a very useful tool for this purpose as it can express qualitative judgments into quantitative judgments. Thus, product designing strategies may be reviewed.

## 1.5 Assumptions:

The researcher also assumes that, a scope of study is remaining for finding out the best suited product designing methodology for manufacturing refrigerator in the present circumstances of our country. And in this study AHP could be a perfect Multi-Criteria Decision Making tool.

### 1.6 Limitation of the study:

There are many organizations in Bangladesh who are involved in refrigerator business. But Walton Hi-Tech Industries Ltd. is the only known industry where engineers are working on refrigerator at R&D level. Only 12 engineers are working there in product designing. And approximately 6 other engineers who previously worked in product designing are transferred or promoted to other functions or joined with some other organizations. Besides, Walton is a new industry with technical limitations. So, the decision making data collection will have limitations as well.

# Chapter 02: Literature Review

## 2.1 Design

Design is the creation of a plan or convention for the construction of an object or a system (as in architectural blueprints, engineering drawing, business process, circuit diagrams and sewing patterns).[2] Design has different connotations in different fields (see design disciplines below). In some cases the direct construction of an object (as in pottery, engineering, management, cowboy coding and graphic design) is also considered as design.[3]

More formally design has been defined as follows:

*(noun) a specification of an* object*, manifested by an* agent*, intended to accomplish* goals*, in a particular* environment*, using a set of primitive components, satisfying a set of* requirements*, subject to constraints;(verb, transitive) to create a design, in an* environment *(where the designer operates)* [4]

Another definition for design is *a roadmap or a strategic approach for someone to achieve a unique expectation. It defines the specifications, plans, parameters, costs, activities, processes and how and what to do within legal, political, social, environmental, safety and economic constraints in achieving that objective.* [5]

Here, a "specification" can be manifested as either a plan or a finished product, and "primitives" are the elements from which the design object is composed. [3]

With such a broad denotation, there is no universal language or unifying institution for designers of all disciplines. This allows for many differing philosophies and approaches toward the subject (see Philosophies and studies of design, below). [3]

The person designing is called a designer, which is also a term used for people who work professionally in one of the various design areas, usually also specifying which area is being dealt with (such as a *fashion designer*, *concept designer* or *web designer*). A designer's sequence of activities is called a design process. The scientific study of design is called design science. [6] [7] [8] [9]

Designing often necessitates considering the aesthetic, functional, economic and sociopolitical dimensions of both the design object and design process. It may involve considerable research, thought, modeling, interactive adjustment, and re-design. [10] Meanwhile, diverse kinds of objects may be designed, including clothing, graphical user interfaces, skyscrapers, corporate identities, business processes and even methods of designing. [11]

Thus the word "design" is applied differently in varying contexts. Different meanings of design in the fields i.e.; arts, engineering, process etc. are discussed in following sections.

### 2.1.1 Design and art

Today the term design is widely associated with the Applied arts as initiated by Raymond Loewy and teachings at the Bauhaus and Ulm School of Design (HfG Ulm) in Germany during the 20th Century.[3]

The boundaries between art and design are blurred, largely due to a range of applications both for the term 'art' and the term 'design'. Applied Arts has been used as an umbrella term to define fields of industrial design, graphic design, fashion design, etc. The term 'decorative arts' is a traditional term used in historical discourses to describe craft objects, and also sits within the umbrella of Applied arts. In graphic arts (2D image making that ranges from photography to illustration) the distinction is often made between fine art and commercial art, based on the context within which the work is produced and how it is traded. [3]

To a degree, some methods for creating work, such as employing intuition, are shared across the disciplines within the Applied arts and Fine art. Mark Getlein suggests the principles of design are "almost instinctive", "built-in", "natural", and part of "our sense of 'rightness'." [12] However, the intended application and context of the resulting works will vary greatly. [3]

### 2.1.2 Design and Engineering

In engineering, design is a component of the engineering process. Many overlapping methods and processes can be seen when comparing Product design, Industrial design and Engineering. The American Heritage Dictionary defines design as: *"To conceive or fashion in the mind; invent,"* and *"To formulate a plan"*, and defines engineering as: *"The application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems."*. [13] Both are forms of problem-solving with a defined distinction being the application of "scientific and mathematical principles". The increasingly scientific focus of engineering in practice, however, has raised the importance of new more "human-centered" fields of design. [14] How much science is applied in a design is a question of what is considered "science". Along with the question of what is considered science, there is social science versus natural science. Scientists at Xerox PARC made the distinction of design versus engineering at "moving minds" versus "moving atoms". [3]

## 2.2 Design Disciplines

Nowadays different design disciplines are in practice worldwide. Most common design disciplines are mentioned here:

- Applied arts
- Architecture
- Fashion Design
- Game Design
- Instructional Design
- Interaction Design

- Interior Design
- Engineering Design
    - Industrial Design Engineering
        - Process Design
    - Electrical & Electronics Engineering Design
        - Circuit Design
    - Mechanical Engineering Design
        - Product Design
            - Plastic Product Design
            - Sheet Metal Product Design
        - Mold & Die Design
        - Machine Design
    - Computer Science Engineering Related Designs
        - Software Design
        - Web Design
        - Graphic Design
    - Civil Engineering Design
- Landscape Architecture
- Military Design Methodology
- Service Design

## 2.3 Engineering Design

Engineering Design may be defined as the design discipline where design is done using engineering concepts, drawing, calculations, engineering designing &/or simulation software, programming languages etc. for various purposes like product design, mold & die design, machine design, process design, automation, software designing, web-page designing, graphic designing, circuit design etc.

Most engineering designs can be classified as inventions-devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems. Inventions, or designs, do not suddenly appear from nowhere. They are the result of bringing together technologies to meet human needs or to solve problems. [15]

Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step-by-step methodology. [15]

We described engineers primarily as problem solvers. What distinguishes design from other types of problem solving is the nature of both the problem and the solution. Design problems are open ended in nature, which means they have more than one correct solution. The result or solution to a design problem is a system that possesses specified properties. [15]

Design problems are usually more vaguely defined than analysis problems. Suppose that you are asked to determine the maximum height of a snowball given an initial velocity and release height. This is an analysis problem because it has only one answer. If you change the problem statement to read, "Design a device to launch a 1-pound snowball to a height of at least 160 feet," this analysis problem becomes a design problem. The solution to the design problem is a system having specified properties (able to launch a snowball 160 feet), whereas the solution to the analysis problem consisted of the properties of a given system (the height of the snowball). The solution to a design problem is therefore open ended, since there are many possible devices that can launch a snowball to a given height. The original problem had a single solution: the maximum height of the snowball, determined from the specified initial conditions. [15]

Solving design problems is often an iterative process: As the solution to a design problem evolves, you find yourself continually refining the design. While implementing the solution to a design problem, you may discover that the solution you've developed is unsafe, too expensive, or will not work. You then "go back to the drawing board" and modify the solution until it meets your requirements. For example, the Wright brothers' airplane did not fly perfectly the first time. They began a program for building an airplane by first conducting tests with kites and then gliders. Before attempting powered flight, they solved the essential problems of controlling a plane's motion in rising, descending, and turning. They didn't construct a powered plane until after making more than 700 successful glider flights. Design activity is therefore cyclic or iterative in nature, whereas analysis problem solving is primarily sequential.[15]

The solution to a design problem does not suddenly appear in a vacuum. A good solution requires a methodology or process. There are probably as many processes of design as there are engineers. Therefore, this lesson does not present a rigid "cookbook" approach to design but presents a general application of the five-step problem-solving methodology associated with the design process. The process described here is general, and you can adapt it to the particular problem you are trying to solve.[15]

## 2.4 Product design

Product design is the process of creating a new product to be sold by a business to its customers.[16] It is the efficient and effective generation and development of ideas through a process that leads to new products.[17]

In a systematic approach, product designers conceptualize and evaluate ideas, turning them into tangible inventions and products. The product designer's role is to combine art, science, and technology to create new products that other people can use. Their evolving role has been facilitated by digital tools that now allow designers to communicate, visualize, analyze and actually produce tangible ideas in a way that would have taken greater manpower in the past.[3]

Product design is sometimes confused with industrial design, and has recently become a broad term inclusive of service, software, and physical product design. Industrial design is concerned with bringing artistic form and usability, usually associated with craft design and ergonomics, together to mass produce goods. [17]

### 2.5 Product design process

There are various product design processes and they are all focused on different aspects. The process shown below is "The Seven Universal Stages of Creative Problem-Solving," outlined by Don Koberg and Jim Bagnell. It helps designers formulate their product from ideas. This process is usually completed by a group of people, designers or field experts in the product they are creating, or specialists for a specific component of the product, such as engineers. The process focuses on figuring out what is required, brainstorming possible ideas, creating mock prototypes, and then generating the product. However, that is not the end of the process. At this point, product designers would still need to execute the idea, making it into an actual product and then evaluate its success by seeing if any improvements are necessary. [3]

The product design process has experienced huge leaps in evolution over the last few years with the rise and adoption of 3D printing. New consumer-friendly 3D printers can product dimensional objects and print upwards with a plastic like substance opposed to traditional printers that spread ink across a page.[3]

The design process follows a guideline involving three main sections: [18]

- Analysis
- Concept
- Synthesis

The latter two sections are often revisited, depending on how often the design needs touch-ups, to improve or to better fit the criteria. This is a continuous loop, where feedback is the main component.[18] To break it down even more, the seven stages specify how the process works. Analysis consists of two stages, concept is only one stage, and synthesis encompasses the other four. [3]

### 2.5.1 Analysis

- **Accept Situation:** Here, the designers decide on committing to the project and finding a solution to the problem. They pool their resources into figuring out how to solve the task most efficiently. [18]
- **Analyze:"** In this stage, everyone in the team begins research. They gather general and specific materials which will help to figure out how their problem might be solved. This can range from statistics, questionnaires, and articles, among many other sources. [18]

### 2.5.2 Concept

- **Define:** This is where the key issue of the matter is defined. The conditions of the problem become objectives, and restraints on the situation become the parameters within which the new design must be constructed. [18]

### 2.5.3 Synthesis

- **Ideate:** The designers here brainstorm different ideas, solutions for their design problem. The ideal brainstorming session does not involve any bias or judgment, but instead builds on original ideas. [18]
- **Select:** By now, the designers have narrowed down their ideas to a select few, which can be guaranteed successes and from there they can outline their plan to make the product. [18]

- **Implement:** This is where the prototypes are built, the plan outlined in the previous step is realized and the product starts to become an actual object. [18]
- **Evaluate:** In the last stage, the product is tested, and from there, improvements are made. Although this is the last stage, it does not mean that the process is over. The finished prototype may not work as well as hoped so new ideas need to be brainstormed. [18]

## 2.6 Demand-pull innovation and invention-push innovation

Most product designs fall under one of two categories: demand-pull innovation or invention-push innovation. [19]

Demand-pull happens when there is an opportunity in the market to be explored by the design of a product. This product design attempts to solve a design problem. The design solution may be the development of a new product or developing a product that's already on the market, such as developing an existing invention for another purpose. [19]

Invention-push innovation happens when there is advancement in intelligence. This can occur through research or it can occur when the product designer comes up with a new product design idea. [19]

## 2.7 Product design expression

Design expression comes from the combined effect of all elements in a product. Colour tone, shape and size should direct a person's thoughts towards buying the product. Therefore it is in the product designer's best interest to consider the audiences who are most likely to be the product's end consumers. Keeping in mind how consumers will perceive the product during the design process will direct towards the product’s success in the market. However, even within a specific audience, it is challenging to cater to each possible personality within that group. [20]

The solution to that is to create a product that, in its designed appearance and function, expresses a personality or tells a story. Products that carry such attributes are more likely to give off a stronger expression that will attract more consumers. On that note it is important to keep in mind that design expression does not only concern the appearance of a product, but also its function. For example, as humans our appearances as well as our actions are subject to people's judgment when they are making a first impression of us. People usually do not appreciate a rude person even if they are good looking. Similarly, a product can have an attractive appearance but if its function does not follow through it will most likely drop in regards to consumer interest. In this sense, designers are like communicators, they use the language of different elements in the product to express something. [20]

## 2.8 Product design considerations

Product design is not an easy task. The stakeholders involved all demand something different from the product designer and from the design process. [21]

- The manufacturer is concerned with production cost; in the end, the manufacturer wants an economically produced product. [21]
- The purchaser looks at price, appearance, and prestige value. [21]
- The end user is concerned with usability and functionality of the final product. [21]
- The maintenance and repair department focuses on how well the final product can be maintained: is the product easily reassembled, disassembled, diagnosed, and serviced? [21]

Stakeholders' needs vary from one another and it is the product designer's job to incorporate those needs into their design.

## 2.9 Trends in product design

Product designers need to consider all of the details: the ways people use and abuse objects, faulty products, errors made in the design process, and the desirable ways in which people wish they could use objects. [21] Many new designs will fail and many won't even make it to market. Some designs eventually become obsolete. [21] The design process itself can be quite frustrating usually taking 5 or 6 tries to get the product design right.[21] A product that fails in the marketplace the first time may be re-introduced to the market 2 more times. If it continues to fail, the product is then considered to be dead because the market believes it to be a failure.[21] Most new products fail, even if it's a great idea. All types of product design are clearly linked to the economic health of manufacturing sectors. Innovation provides much of the competitive impetus for the development of new products, with new technology often requiring a new design interpretation.[21] It only takes one manufacturer to create a new product paradigm to force the rest of the industry to catch up - fueling further innovation.[22] Products designed to benefit people of all ages and abilities—without penalty to any group—accommodate our swelling aging population by extending independence and supporting the changing physical and sensory needs we all encounter as we grow older.[23]

## 2.10 Product Design Disciplines:

According to focused concern of the designer, product designing methodologies can be separated and studied by following areas:

1. Design for Production
2. Design for Manufacturability
3. Design for Aesthetics
4. Design for Environment
5. Design for Ergonomics

Product designers follow different design disciplines according to availability of resources whether they are aware of which design discipline they are following or not. Different design disciplines are discussed here.

### 2.10.1 Design for Production:

Design for Production might be defined as the general engineering art of designing products where main concern of a designer is to increase production. In this discipline designer tries to reduce the processes. He/she also might tend to reduce parts of the final product so that assembly processes might be reduced. Designer may tend to reduce complicacy of decorative parts to reduce the production time. Designer may also compromise aesthetics of product to reduce fabrication/molding time. Most of the companies of developing countries emphasize much on production rate, thus it is much popular in developing countries.

For example, one single sheet metal of right-side picture can replace four sheet metals of the assembly of left picture, which improves productivity by decreasing production time in assembly line.

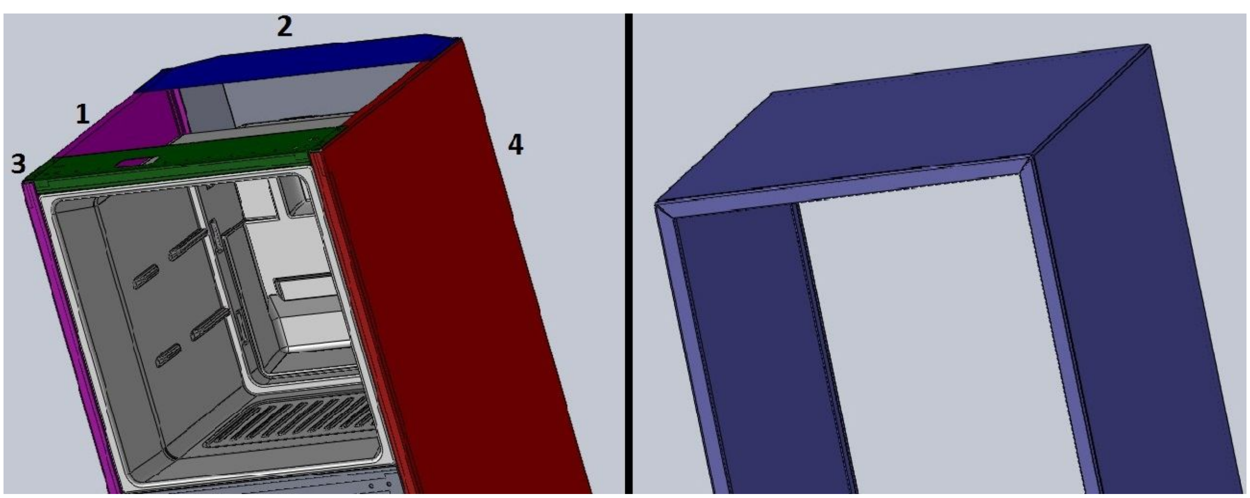


Figure 2.1: Design for Production

The relationship between design and production is one of planning and executing. In theory, the plan should anticipate and compensate for potential problems in the execution process. Design involves problem-solving and creativity. In contrast, production involves a routine or pre-planned process. A design may also be a mere plan that does not include a production or engineering process, although a working knowledge of such processes is usually expected of designers. In some cases, it may be unnecessary and/or impractical to expect a designer with a broad multidisciplinary knowledge required for such designs to also have a detailed specialized knowledge of how to produce the product. [3]

Design and production are intertwined in many creative professional careers, meaning problem-solving is part of execution and the reverse. As the cost of rearrangement increases, the need for separating design from production increases as well. For example, a high-budget project, such as a skyscraper, requires separating (design) architecture from (production) construction. A Low-budget project, such as a locally printed office party invitation flyer, can be rearranged and printed dozens of times at the low cost of a few sheets of paper, a few drops of ink, and less than one hour's pay of a desktop publisher.[3]

This is not to say that production never involves problem-solving or creativity, nor that design always involves creativity. Designs are rarely perfect and are sometimes repetitive. The imperfection of a design may task a production position (e.g. production artist, construction worker) with utilizing creativity or problem-solving skills to compensate for what was overlooked in the design process. Likewise, a design may be a simple repetition (copy) of a known preexisting solution, requiring minimal, if any, creativity or problem-solving skills from the designer. [3]

Traditional CAD systems are based on the serial approach of the product development cycle: the design process is not integrated with other activities and thus it cannot provide information for subsequent phases of product development. Product Development Cycle is the period of time needed to complete the set of events that develops an idea into a quality product.

### 2.10.2 Design for Manufacturability:

Design for manufacturability (also sometimes known as design for manufacturing) - (DFM) is the general engineering art of designing products in such a way that they are easy to manufacture. The basic idea exists in almost all engineering disciplines, but of course the details differ widely depending on the manufacturing technology. This design practice not only focuses on the design aspect of a part but also on the producibility in available technology. In simple language it means relative ease to manufacture a product, part or assembly.[3]

For example, if any new sheet-metal product is designed according to any other existing sheet metal product, then the old product can be absorbed in a new model. Thus existing technological support can boost up new product launching by multi-use.

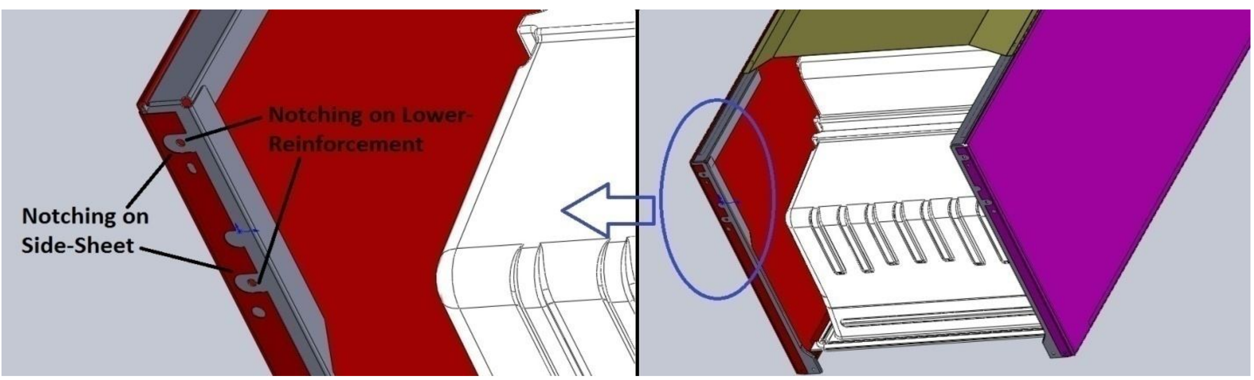


Figure 2.2: Design for Manufacturing

The design stage is very important in product design. Most of the product lifecycle costs are committed at design stage. The product design is not just based on good design but it should be possible to produce by manufacturing as well. Often an otherwise good design is difficult or impossible to produce. Typically a design engineer will create a model or design and send it to manufacturing for review and invite feedback. This process is called a design review. If this process is not followed diligently, the product may fail at the manufacturing stage.[3]

If these DFM guidelines are not followed, it will result in iterative design, loss of manufacturing time and overall resulting in longer time to market. Hence many organizations have adopted concept of Design for Manufacturing.[3]

Depending on various types of manufacturing processes there are set guidelines for DFM practices. These DFM guidelines help to precisely define various tolerances, rules and common manufacturing checks related to DFM. [3]

While DFM is applicable to the design process, a similar concept called DFSS (Design for Six Sigma) is also practiced in many organizations. [3]

### 2.10.3 Design for Aesthetics:

Aesthetics is the human perception of beauty, including sight, sound, smell, touch, taste, and movement – not just visual appeal. Occasionally the complex contents of a product have their own aesthetic appeal to (perhaps more technical) users and this can sometimes be exploited. [24] But in general, the designer's main attention is on the visual appeal of the product.

As we see in the figure, there might be different types of ice-trays. But, each of them has different decorative value in a refrigerator.

Figure 2.3: Design for Aesthetics [28] [29] [30]

Aesthetics is the aspect of design and technology which most closely relates to art and design, and issues of colour, shape, texture, contrast, form, balance, cultural references and emotional response are common to both areas. Like the artist, the design and technologist makes use of creativity and imagination, divergent thinking, personal interests, inspiration from design movements and from nature. And like the artist, the design and technologist will usually make use of sketches in the early stages of developing a design. [24]

Where design and technology diverges from art and design is that its aim is to produce a product which is both useful and attractive. And so design and technology involves the challenge of holding together the values of practical utility and aesthetic appeal. [24]

People like to own products that they perceive as being attractive. At its worst this can lead to 'designer' products where the 'attraction' is a large designer label backed by trendy advertising of the brand. But at its best good industrial design leads to products that are genuinely appealing and involve an authentic synthesis of function and form.

### 2.10.4 Design for Environment

In recent years the increased awareness of environmental issues has led to the development of new approaches to product design, known as Design for Environment where main consideration of a designer lies in the environmental impact of the products.

In the year 1992 a United States Environmental Protection Agency (USEPA) program was created named as Design for the Environment Program (DfE) which works to prevent pollution, and the risk pollution presents to humans and the environment. The EPA DfE program provides information regarding safer electronics, safer flame retardants, safer chemical formulations, as well as best environmental practices. DfE employs a variety of design approaches that attempt to reduce the overall human health and environmental impact of a product, process or service, where impacts are considered across its life cycle. Different software tools have been developed to assist designers in finding optimized products (or processes/services). [3]

The DfE program has three priorities: [26]

a. **Energy efficiency** – Reduction of the energy needed to manufacture and use our products [26]

b. **Materials innovation** – Reduction of the amount of materials used in our products and develop materials those have less environmental impact and more value at end-of-life[26]

c. **Design for recyclability** - Designing equipment that is easier to upgrade and/or recycle[26]

Besides, there is another very much relevant term with Design for environment, which is Life Cycle Assessment (LCA).  Life cycle assessment (LCA) is employed to forecast the impacts of different (production) alternatives of the product in question, thus being able to choose the most environmentally friendly. A life cycle analysis can serve as a tool when determining the environmental impact of a product or process. Proper LCAs can help a designer compare several different products according to several categories, such as energy use, toxicity, acidification, $CO_2$ emissions, ozone depletion, resource depletion and many others. By comparing different products, designers can make decisions about which environmental hazard to focus on in order to make the product more environmentally friendly. [3]

### 2.10.5 Design for Ergonomics

Ergonomics is the human factor in engineering. It is the study of how people interact with machines. Most products have to work with people in some manner. In recent years, ergonomics (physical comfort) for both user/consumer and production line workers has come to attention of the designers.[26]

For example, the position, length, width, curve &/or grip of a door handle of refrigerator may define the comfort of opening the refrigerator door.

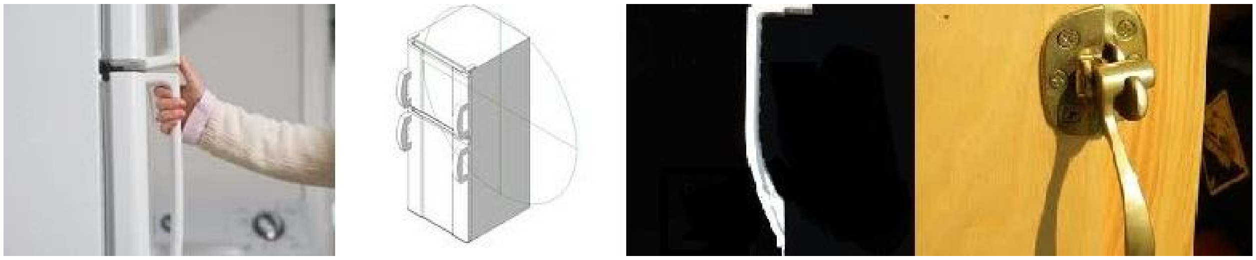

Figure 2.4: Design for Ergonomics [31] [32] [33] [34]

People occupy a space in or around the design, and they may provide a source of power or control or act as a sensor for the design. For example, people sense if an automobile air-conditioning system is maintaining a comfortable temperature inside the car. These factors form the basis for human factors, or ergonomics, of a design. A design solution can be considered successful if the design fits the people using it. The handle of a power tool must fit the hand of everybody using it. The tool must not be too heavy or cumbersome to be manipulated by all sizes of people using the tool. The geometric properties of people-their weight, height, reach, circumference, and so on-are called anthropometric data. The difficulty in designing for ergonomics is the abundance of anthropometric data. The military has collected and evaluated the distribution of human beings and published this information in military standard tables. A successful design needs to be evaluated and analyzed against the distribution of geometry of the people using it. The following Figure shows the geometry of typical adult males and females for the general population in millimeters. Since people come in different sizes and shapes, such data are used by design engineers to assure that their design fits the user. A good design will be adjustable enough to fit 95 percent of the people who will use it. [26]

### 2.11 Decision Criteria

The choice of most appropriate method for a particular product in a particular market/country may depend on following criterions or variables:

a) **Sales Quantity:** Market demand &/or sales is the first priority for any business. Thus, product designing must suit with sales and marketing.

b) **Product Durability:** Product lifetime has a direct or potential effect on market feedback, which must be taken care of at design level.

c) **Cost Saving:** Costing for a product directly influences the price & profit as well as it also affects the lifetime, ergonomics, and environmental outcome of the product.

d) **Easy to Produce:** Product design must be user friendly as well as easy to produce which affects the productivity and manufacturability of the product.

And this method selection is a qualitative decision, which may be converted to quantitative values by the help of Analytical Hierarchy Process (AHP).

### 2.12 Analytical Hierarchy Process

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. [3]

It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education. [3]

Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. [3]

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood—anything at all that applies to the decision at hand. [3]

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. [27]

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques. [3]

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action. [3]

Basically, AHP has got following steps:

a) **Model the problem as a hierarchy:** The first step in the analytic hierarchy process is to model the problem as a *hierarchy*. In doing this, participants explore the aspects of the problem at levels from general to detailed, then express it in the multileveled way that the AHP requires. As they work to build the hierarchy, they increase their understanding of the problem, of its context, and of each other's thoughts and feelings about both. [27]

b) **Evaluate the hierarchy:** Once the hierarchy has been constructed, the participants analyze it through a series of *pair-wise comparisons* that derive numerical scales of measurement for the nodes. The criteria are pair-wise compared against the goal for importance. The alternatives are pair-wise compared against each of the criteria for preference. The comparisons are processed mathematically, and *priorities* are derived for each node. [3]

c) **Establish priorities:** At last, priorities are established by the calculating the values of each node, which will see in our next chapter. [3]

# Chapter 03: Research Methodology

## 3.1 Techniques of Data Analysis

As discussed before, product designing may have different methodologies. Perception on most appropriate product designing methodology for refrigerator is a qualitative decision which may vary designer to designer. AHP is used to convert qualitative decisions into quantitative decision. Thus various quantities from various designers may lead to a conclusion on most appropriate product design methodology of product designing for refrigerator on the current perspectives of Bangladesh. Similar works has been done before on Renewable Energy (ISAHP 2003, Bali, Indonesia, August 7-9, 2003).

In this research we are also going to use following steps of AHP (developed by Saaty) to find out the most appropriate product design methodology: [1]

I. Define the decision problem and determine its object. [1]

II. Define the decision criteria in the form of a hierarchy of objectives. This hierarchical structure consists of different levels. The top level is the objective to be achieved. This top level consists of intermediate levels of criteria and sub-criteria, which depend on subsequent levels. The lowest level consists of list of the alternatives. [1]

III. For making pair-wise comparisons, structure a matrix of size (n x n). The number of judgments required to develop the set of matrix is given by n (n – 1) / 2. [1]

IV. Obtain the importance of the criteria and sub-criteria from experts' judgment by making pair wise comparison. This comparison is made for all levels. Verbal judgments of preferences are shown in Table 1. [1]

V. Determine the weight of each criterion. By hierarchical synthesis, the priority vectors are calculated. These values are the normalized eigenvectors of the matrix. [1]

VI. The consistency is determined by using the eigen value, $\lambda max$. For finding the consistency index, CI, the formula used is; CI = ($\lambda max$ – n) / (n – 1), where n is the size of the matrix. The consistency ratio (CR) is simply the ratio of CI to average random consistency (RI). The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent; then the matrix has to be reviewed to obtain a consistent matrix. These are calculated for all the matrices structured from the hierarchy. Some computer packages are available nowadays to implement this calculation procedure. [1]

**Table 3.1: Pair-wise Comparison Scale for AHP Preferences [1]**

| Numerical Rating | Verbal Judgments of Preferences |
|---|---|
| 9 | Extremely Preferred / Important |
| 8 | Very Strongly to Extremely |
| 7 | Very Strongly Preferred / Important |
| 6 | Strongly to Very Strongly |
| 5 | Strongly Preferred / Important |
| 4 | Moderately to Strongly |
| 3 | Moderately Preferred / Important |
| 2 | Equally to Moderately |
| 1 | Equally Preferred / Important |

**Table 3.2: Average Random Consistency** [1]

| Size of Matrix | 01 | 02 | 03 | 04 | 05 | 06 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random Consistency | 0.00 | 0.00 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

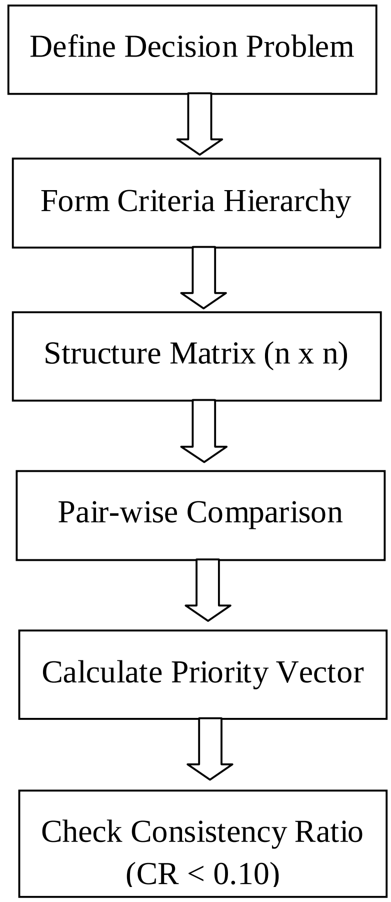


**Chart 3.1: Flow of Steps for AHP Analysis**

## 3.2 Questionnaires

Analytical Hierarchy Process (AHP) is designed for situations in which ideas, feelings, and emotions affecting decision process are quantified to provide a numeric scale for prioritizing the alternatives. And this scale might be best captured by a questionnaire which fulfills following two objectives:

i. To maximize the proportion of subjects answering our questionnaire—that is, the response rate.

ii. To obtain accurate relevant information for our study & analysis.

A questionnaire with above two objectives was prepared for data collection. It consists of several tables which were designed according to AHP. It started with few sentences explaining the purpose of the questionnaire, and what the data will be used for. Much effort was given to provide a clear structure to the questionnaire and much concentration was also given to make the questionnaire simple and easy. (Actual Questionnaire is presented with details in Appendix A)

### 3.3 Validation

The validity of the questionnaire was established as follows:

i. It was scrutinized by experienced product designers. Details biography of the designers is given in Appendix B.

ii. The supervisor of the study provided advice on items to be reshaped, deleted or added questions.

### 3.4 Population

The population consisted of 15 engineers (up to 2013) who are experienced in product designing for refrigerator. 11 of them are still working with product designing in R&D (Refrigerator), Walton Hi-Tech Industries Ltd (up to 2013). And rest is promoted to other functions. However, 14 of them were contacted by the researcher for data collection and response was received from 7 engineers. It should be kept in mind that, many other product designers are working on different products other than refrigerator in Bangladesh. Thus there was no scope of sampling due to small expertise availability in Bangladesh.

### 3.5 Restrictions

There is minimum 400 km distance between the dwelling location of researcher and participants. As both researcher and participants are job holders, it was very difficult for them to consult face to face. Thus, the questionnaire and feedback were communicated by mail as well as telephonic discussion. Besides, answering the questionnaire was a voluntary one. Thus, all of the 14 product designers did not provide feedback, though all of them were knocked. And their feedback also did not result in CR less than 0.1 always. The participants were communicated again to review the answers in such cases. And participants are used to design products aimed for economically low or mid level customers irrespective of capacity or size.

### 3.6 Data Collection Procedure

The questionnaire was mailed to researcher's fellow designers, with whom he worked with before. It was also explained to the participants over prolonged telephonic discussions. As it was a voluntary work and somewhat lengthy/critical, many of the designers did not respond promptly. In those cases, the participants were given follow-up. Getting the full data in hand, many of them were also followed up again to keep the CR < 0.1. And all data transfer in-between took place by mail.

# Chapter 04: Computation

### 4.1 Preface of Calculation

This chapter presents method used in finding out the most appropriate product designing methodology for refrigerator in current aspects of Bangladesh by using AHP. The data from the questionnaire were tabulated within a scale of 0 to 5. Separate tables were used to compare different methodologies based on different criterions. Prior to these methodology comparisons, those criterions were also compared among themselves in tabulated format.

PDM (Product Designing Methodology) Assessment Criteria Hierarchy is as followed:

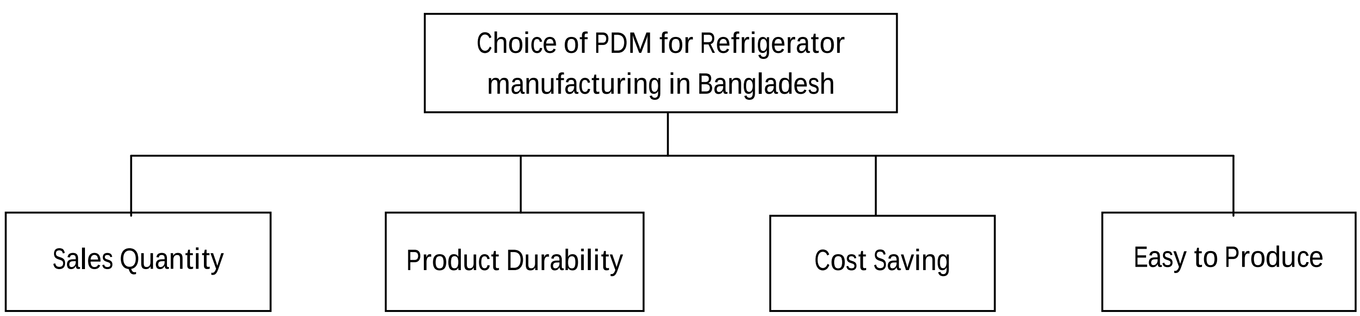


Fig 4.1: Hierarchy for Choice of PDM

### 4.2 Data Analysis

Following the standard AHP methodology, the PDMs have been compared with each other in turn for each criterion and their preferential weights have been determined. The result of the analysis according to the participants is presented in Tables 4.A.1 – 4.G.6 in detail prior to the details calculation of Table 4.A.1 & 4.A.6 showed.

In Table 4.A.1 Pair-wise Comparison Matrix for Criteria by Participant A and corresponding Priority Vectors are shown in together. By the calculation shown in Table 4.1 & 4.2, Priority Vectors are found.

**Table 4.1: Pair-wise Comparison Matrix for Criteria (by Participant A):**

Find Column Summation (n = 4)

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce |
|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.25 | 1.25 | 0.83 |
| Product Durability | 0.80 | 1.00 | 0.83 | 0.56 |
| Cost Saving | 0.80 | 1.20 | 1.00 | 0.67 |
| Easy to Produce | 1.20 | 1.80 | 1.50 | 1.00 |
| Column Sum | 3.8 | 5.25 | 4.583 | 3.0556 |

**Table 4.2: Priority Vector Calculation from Table 4.1:**

(¡) Divide each cell item by corresponding column summation

(¡¡) Find average of row values, which is weight or Priority Vector

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Avg. of Row |
|---|---|---|---|---|---|
| Sales Quantity | 0.26316 | 0.23810 | 0.27273 | 0.27273 | 0.26 |
| Product Durability | 0.21053 | 0.19048 | 0.18182 | 0.18182 | 0.19 |
| Cost Saving | 0.21053 | 0.22857 | 0.21818 | 0.21818 | 0.22 |
| Easy to Produce | 0.31579 | 0.34286 | 0.32727 | 0.32727 | 0.33 |

So, the comparison matrix,

$$A = \begin{pmatrix} 1.00 & 1.25 & 1.25 & 0.83 \\ 0.80 & 1.00 & 0.83 & 0.56 \\ 0.80 & 1.20 & 1.00 & 0.67 \\ 1.20 & 1.80 & 1.50 & 1.00 \end{pmatrix}$$

And the Weight Matrix, W $= \begin{pmatrix} 0.26 \\ 0.19 \\ 0.22 \\ 0.33 \end{pmatrix}$

$$\lambda max = \begin{pmatrix} 1.00 & 1.25 & 1.25 & 0.83 \\ 0.80 & 1.00 & 0.83 & 0.56 \\ 0.80 & 1.20 & 1.00 & 0.67 \\ 1.20 & 1.80 & 1.50 & 1.00 \end{pmatrix} \begin{pmatrix} 0.26 \\ 0.19 \\ 0.22 \\ 0.33 \end{pmatrix} = 4.0029$$

CI = (λmax – n) / (n – 1) = 0.00096

RI = 1.98(n – 2) / n = 0.99

Consistency Ratio, CR = CI / RI = 0.001

Now, Priority Vectors & CR values are found from Table 4.A.2, 4.A.3, 4.A.4, 4.A.5 & 4.A.6 according to the calculation shown for Table 4.A.1. And from the Priority Vectors of Table 4.A.2, 4.A.3, 4.A.4 & 4.A.5 Priority Matrix or Table 4.A.6 is formed.

**Participant-A**

**Table 4.A.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.25 | 1.25 | 0.83 | 0.26 |
| Product Durability | 0.80 | 1.00 | 0.83 | 0.56 | 0.19 |
| Cost Saving | 0.80 | 1.20 | 1.00 | 0.67 | 0.22 |
| Easy to Produce | 1.20 | 1.80 | 1.50 | 1.00 | **0.33** |
| CR = 0.001 | | | | | $\sum = 1.00$ |

**Table 4.A.2: Pair-wise Comparison Matrix for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.67 | 0.33 | 0.67 | 0.50 | 0.11 |
| Design for Manufacturability | 1.50 | 1.00 | 0.33 | 1.25 | 0.50 | 0.16 |
| Design for Aesthetics | 3.00 | 3.00 | 1.00 | 0.50 | 1.25 | 0.27 |
| Design for Environment | 1.50 | 0.80 | 2.00 | 1.00 | 1.00 | 0.24 |
| Design for Ergonomics | 2.00 | 2.00 | 0.80 | 1.00 | 1.00 | 0.23 |
| CR = 0.001 | | | | | | $\sum = 1.00$ |

**Table 4.A.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.33 | 1.43 | 2.00 | 1.11 | 0.20 |
| Design for Manufacturability | 3.00 | 1.00 | 1.67 | 2.50 | 1.25 | 0.33 |
| Design for Aesthetics | 0.70 | 0.60 | 1.00 | 1.00 | 0.83 | 0.15 |
| Design for Environment | 0.50 | 0.40 | 1.00 | 1.00 | 0.91 | 0.14 |
| Design for Ergonomics | 0.90 | 0.80 | 1.20 | 1.10 | 1.00 | 0.19 |
| CR = 0.03 | | | | | | ∑ = 1.00 |

**Table 4.A.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.50 | 2.00 | 5.00 | 1.25 | 0.28 |
| Design for Manufacturability | 2.00 | 1.00 | 2.50 | 1.25 | 1.11 | 0.28 |
| Design for Aesthetics | 0.50 | 0.40 | 1.00 | 1.00 | 0.67 | 0.12 |
| Design for Environment | 0.20 | 0.80 | 1.00 | 1.00 | 0.67 | 0.13 |
| Design for Ergonomics | 0.80 | 0.90 | 1.50 | 1.50 | 1.00 | 0.20 |
| CR = 0.07 | | | | | | ∑ = 1.00 |

**Table 4.A.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 1.00 | 5.00 | 3.33 | 1.25 | 0.34 |
| Design for Manufacturability | 1.00 | 1.00 | 1.67 | 2.00 | 1.43 | 0.25 |
| Design for Aesthetics | 0.20 | 0.60 | 1.00 | 1.00 | 1.00 | 0.12 |
| Design for Environment | 0.30 | 0.50 | 1.00 | 1.00 | 0.83 | 0.12 |
| Design for Ergonomics | 0.80 | 0.70 | 1.00 | 1.20 | 1.00 | 0.17 |
| CR = 0.04 | | | | | | $\sum = 1.00$ |

**Table 4.A.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.11 | 0.20 | 0.28 | 0.34 | 0.24 |
| Design for Manufacturability | 0.16 | 0.33 | 0.28 | 0.25 | **0.25** |
| Design for Aesthetics | 0.27 | 0.15 | 0.12 | 0.12 | 0.17 |
| Design for Environment | 0.24 | 0.14 | 0.13 | 0.12 | 0.15 |
| Design for Ergonomics | 0.23 | 0.19 | 0.20 | 0.17 | 0.19 |
| | | | | | $\sum = 1.00$ |

## Participant-B

**Table 4.B.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.25 | 1.00 | 0.50 | 0.21 |
| Product Durability | 0.80 | 1.00 | 0.67 | 0.50 | 0.17 |
| Cost Saving | 1.00 | 1.50 | 1.00 | 0.67 | 0.24 |
| Easy to Produce | 2.00 | 2.00 | 1.50 | 1.00 | **0.37** |
| CR = 0.004 | | | | | ∑ = 1.00 |

**Table 4.B.2: Pair-wise Comparison Matrix for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.50 | 0.29 | 0.40 | 0.33 | 0.08 |
| Design for Manufacturability | 2.00 | 1.00 | 0.33 | 0.40 | 0.33 | 0.11 |
| Design for Aesthetics | 3.50 | 3.00 | 1.00 | 2.00 | 1.00 | 0.32 |
| Design for Environment | 2.50 | 2.50 | 0.50 | 1.00 | 0.67 | 0.20 |
| Design for Ergonomics | 3.00 | 3.00 | 1.00 | 1.50 | 1.00 | 0.29 |
| CR = 0.01 | | | | | | ∑ = 1.00 |

**Table 4.B.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 1.00 | 2.00 | 3.33 | 1.25 | 0.28 |
| Design for Manufacturability | 1.00 | 1.00 | 1.25 | 3.33 | 1.25 | 0.26 |
| Design for Aesthetics | 0.50 | 0.80 | 1.00 | 1.25 | 0.50 | 0.14 |
| Design for Environment | 0.30 | 0.30 | 0.80 | 1.00 | 0.50 | 0.10 |
| Design for Ergonomics | 0.80 | 0.80 | 2.00 | 2.00 | 1.00 | 0.22 |
| CR = 0.01 | | | | | | ∑ = 1.00 |

**Table 4.B.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.25 | 1.25 | 1.67 | 1.11 | 0.45 |
| Design for Manufacturability | 4.00 | 1.00 | 2.00 | 5.00 | 3.33 | 0.14 |
| Design for Aesthetics | 0.80 | 0.50 | 1.00 | 1.11 | 0.83 | 0.10 |
| Design for Environment | 0.60 | 0.20 | 0.90 | 1.00 | 0.67 | 0.15 |
| Design for Ergonomics | 0.90 | 0.30 | 1.20 | 1.50 | 1.00 | 0.15 |
| CR = 0.02 | | | | | | ∑ = 1.00 |

**Table 4.B.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.67 | 1.25 | 2.00 | 3.33 | 0.24 |
| Design for Manufacturability | 1.50 | 1.00 | 1.11 | 2.00 | 5.00 | 0.31 |
| Design for Aesthetics | 0.80 | 0.90 | 1.00 | 5.00 | 2.00 | 0.26 |
| Design for Environment | 0.50 | 0.50 | 0.20 | 1.00 | 0.50 | 0.09 |
| Design for Ergonomics | 0.30 | 0.20 | 0.50 | 2.00 | 1.00 | 0.10 |
| CR = 0.06 | | | | | | $\sum = 1.00$ |

**Table 4.B.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.08 | 0.28 | 0.45 | 0.24 | **0.26** |
| Design for Manufacturability | 0.11 | 0.26 | 0.14 | 0.31 | 0.22 |
| Design for Aesthetics | 0.32 | 0.14 | 0.10 | 0.26 | 0.21 |
| Design for Environment | 0.20 | 0.10 | 0.15 | 0.09 | 0.13 |
| Design for Ergonomics | 0.29 | 0.22 | 0.15 | 0.10 | 0.17 |
| | | | | | $\sum = 1.00$ |

**Participant-C**

**Table 4.C.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.00 | 0.50 | 0.50 | 0.18 |
| Product Durability | 1.00 | 1.00 | 1.00 | 1.00 | 0.25 |
| Cost Saving | 2.00 | 1.00 | 1.00 | 1.00 | **0.29** |
| Easy to Produce | 2.00 | 1.00 | 1.00 | 1.00 | **0.29** |
| CR = 0.02 | | | | | ∑ = 1.00 |

**Table 4.C.2: Pair-wise Comparison Matrix for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.25 | 0.50 | 1.00 | 1.00 | 0.11 |
| Design for Manufacturability | 4.00 | 1.00 | 2.00 | 4.00 | 2.00 | 0.38 |
| Design for Aesthetics | 2.00 | 0.50 | 1.00 | 3.00 | 0.33 | 0.19 |
| Design for Environment | 1.00 | 0.25 | 0.30 | 1.00 | 1.00 | 0.11 |
| Design for Ergonomics | 1.00 | 0.50 | 3.00 | 1.00 | 1.00 | 0.21 |
| CR = 0.09 | | | | | | ∑ = 1.00 |

**Table 4.C.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.33 | 1.00 | 1.00 | 0.33 | 0.12 |
| Design for Manufacturability | 3.00 | 1.00 | 2.00 | 2.00 | 2.00 | 0.34 |
| Design for Aesthetics | 1.00 | 0.50 | 1.00 | 0.50 | 0.50 | 0.12 |
| Design for Environment | 1.00 | 0.50 | 2.00 | 1.00 | 1.00 | 0.19 |
| Design for Ergonomics | 3.00 | 0.50 | 2.00 | 1.00 | 1.00 | 0.23 |
| CR = 0.03 | | | | | | $\sum = 1.00$ |

**Table 4.C.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 0.22 |
| Design for Manufacturability | 1.00 | 1.00 | 1.00 | 2.00 | 1.00 | 0.17 |
| Design for Aesthetics | 1.00 | 1.00 | 1.00 | 1.00 | 0.50 | 0.13 |
| Design for Environment | 0.50 | 0.50 | 1.00 | 1.00 | 0.50 | 0.23 |
| Design for Ergonomics | 0.50 | 1.00 | 2.00 | 2.00 | 1.00 | 0.23 |
| CR = 0.03 | | | | | | $\sum = 1.00$ |

**Table 4.C.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.25 | 2.00 | 1.43 | 1.00 | 0.18 |
| Design for Manufacturability | 4.00 | 1.00 | 4.00 | 1.00 | 1.00 | 0.32 |
| Design for Aesthetics | 0.50 | 0.25 | 1.00 | 1.00 | 0.33 | 0.10 |
| Design for Environment | 0.70 | 1.00 | 1.00 | 1.00 | 1.00 | 0.18 |
| Design for Ergonomics | 1.00 | 1.00 | 3.00 | 1.00 | 1.00 | 0.22 |
| CR = 0.08 | | | | | | ∑ = 1.00 |

**Table 4.C.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.11 | 0.12 | 0.22 | 0.18 | 0.16 |
| Design for Manufacturability | 0.38 | 0.34 | 0.17 | 0.32 | **0.30** |
| Design for Aesthetics | 0.19 | 0.12 | 0.13 | 0.10 | 0.13 |
| Design for Environment | 0.11 | 0.19 | 0.23 | 0.18 | 0.18 |
| Design for Ergonomics | 0.21 | 0.23 | 0.23 | 0.22 | 0.22 |
| | | | | | ∑ = 1.00 |

## Participant-D

**Table 4.D.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 0.20 | 0.33 | 0.50 | 0.08 |
| Product Durability | 5.00 | 1.00 | 4.00 | 4.00 | **0.56** |
| Cost Saving | 3.00 | 0.25 | 1.00 | 0.40 | 0.15 |
| Easy to Produce | 2.00 | 0.25 | 2.50 | 1.00 | 0.20 |
| CR = 0.09 | | | | | ∑ = 1.00 |

**Table 4.D.2: Pair-wise Comparison Matrix for Design for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.20 | 0.25 | 0.25 | 0.33 | 0.05 |
| Design for Manufacturability | 5.00 | 1.00 | 2.00 | 5.00 | 5.00 | 0.44 |
| Design for Aesthetics | 4.00 | 0.50 | 1.00 | 4.00 | 4.00 | 0.29 |
| Design for Environment | 4.00 | 0.20 | 0.25 | 1.00 | 1.00 | 0.11 |
| Design for Ergonomics | 3.00 | 0.20 | 0.25 | 1.00 | 1.00 | 0.10 |
| CR = 0.08 | | | | | | ∑ = 1.00 |

**Table 4.D.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.20 | 4.00 | 0.20 | 0.33 | 0.10 |
| Design for Manufacturability | 5.00 | 1.00 | 5.00 | 1.00 | 4.00 | 0.37 |
| Design for Aesthetics | 0.25 | 0.20 | 1.00 | 0.20 | 0.33 | 0.05 |
| Design for Environment | 5.00 | 1.00 | 5.00 | 1.00 | 3.00 | 0.34 |
| Design for Ergonomics | 3.00 | 0.25 | 3.00 | 0.33 | 1.00 | 0.14 |
| CR = 0.09 | | | | | | ∑ = 1.00 |

**Table 4.D.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 1.00 | 4.00 | 3.00 | 2.50 | 0.10 |
| Design for Manufacturability | 1.00 | 1.00 | 5.00 | 5.00 | 5.00 | 0.37 |
| Design for Aesthetics | 0.25 | 0.20 | 1.00 | 0.33 | 0.33 | 0.05 |
| Design for Environment | 0.33 | 0.20 | 3.00 | 1.00 | 3.00 | 0.34 |
| Design for Ergonomics | 0.40 | 0.20 | 3.00 | 0.33 | 1.00 | 0.14 |
| CR = 0.09 | | | | | | ∑ = 1.00 |

**Table 4.D.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 1.00 | 4.00 | 1.33 | 0.50 | 0.22 |
| Design for Manufacturability | 1.00 | 1.00 | 4.00 | 4.00 | 4.00 | 0.39 |
| Design for Aesthetics | 0.25 | 0.25 | 1.00 | 0.33 | 0.33 | 0.06 |
| Design for Environment | 0.75 | 0.25 | 3.00 | 1.00 | 1.00 | 0.14 |
| Design for Ergonomics | 2.00 | 0.25 | 3.00 | 1.00 | 1.00 | 0.19 |
| CR = 0.09 | | | | | | $\sum$ = 1.00 |

**Table 4.D.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.05 | 0.10 | 0.10 | 0.22 | 0.16 |
| Design for Manufacturability | 0.44 | 0.37 | 0.37 | 0.39 | **0.38** |
| Design for Aesthetics | 0.29 | 0.05 | 0.05 | 0.06 | 0.07 |
| Design for Environment | 0.11 | 0.34 | 0.34 | 0.14 | 0.25 |
| Design for Ergonomics | 0.10 | 0.14 | 0.14 | 0.19 | 0.14 |
| | | | | | $\sum$ = 1.00 |

## Participant-E

**Table 4.E.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.67 | 1.67 | 0.67 | 0.28 |
| Product Durability | 0.60 | 1.00 | 0.67 | 0.67 | 0.17 |
| Cost Saving | 0.60 | 1.50 | 1.00 | 0.50 | 0.20 |
| Easy to Produce | 1.50 | 1.50 | 2.00 | 1.00 | **0.35** |
| CR = 0.02 | | | | | ∑ = 1.00 |

**Table 4.E.2: Pair-wise Comparison Matrix for Design for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.67 | 0.50 | 0.50 | 1.00 | 0.14 |
| Design for Manufacturability | 1.50 | 1.00 | 2.00 | 1.25 | 1.25 | 0.25 |
| Design for Aesthetics | 2.00 | 0.50 | 1.00 | 0.50 | 0.50 | 0.15 |
| Design for Environment | 2.00 | 0.80 | 2.00 | 1.00 | 0.33 | 0.20 |
| Design for Ergonomics | 1.00 | 0.80 | 2.00 | 3.00 | 1.00 | 0.27 |
| CR = 0.08 | | | | | | ∑ = 1.00 |

**Table 4.E.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.33 | 0.50 | 0.25 | 0.33 | 0.07 |
| Design for Manufacturability | 3.00 | 1.00 | 0.40 | 0.25 | 0.33 | 0.11 |
| Design for Aesthetics | 2.00 | 2.50 | 1.00 | 0.29 | 0.40 | 0.15 |
| Design for Environment | 4.00 | 4.00 | 3.50 | 1.00 | 0.50 | 0.32 |
| Design for Ergonomics | 3.00 | 3.00 | 2.50 | 2.00 | 1.00 | 0.35 |
| CR = 0.09 | | | | | | ∑ = 1.00 |

**Table 4.E.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.25 | 0.33 | 0.40 | 0.40 | 0.15 |
| Design for Manufacturability | 4.00 | 1.00 | 0.33 | 0.40 | 0.50 | 0.15 |
| Design for Aesthetics | 3.00 | 3.00 | 1.00 | 0.50 | 0.67 | 0.22 |
| Design for Environment | 2.50 | 2.50 | 2.00 | 1.00 | 0.67 | 0.27 |
| Design for Ergonomics | 2.50 | 2.00 | 1.50 | 1.50 | 1.00 | 0.28 |
| CR = 0.08 | | | | | | ∑ = 1.00 |

**Table 4.E.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.25 | 0.33 | 0.40 | 0.40 | 0.08 |
| Design for Manufacturability | 4.00 | 1.00 | 0.33 | 0.40 | 0.50 | 0.15 |
| Design for Aesthetics | 3.00 | 3.00 | 1.00 | 0.50 | 0.67 | 0.22 |
| Design for Environment | 2.50 | 2.50 | 2.00 | 1.00 | 0.67 | 0.27 |
| Design for Ergonomics | 2.50 | 2.00 | 1.50 | 1.50 | 1.00 | 0.28 |
| CR = 0.08 | | | | | | $\sum = 1.00$ |

**Table 4.E.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.14 | 0.07 | 0.15 | 0.08 | 0.11 |
| Design for Manufacturability | 0.25 | 0.11 | 0.15 | 0.15 | 0.17 |
| Design for Aesthetics | 0.15 | 0.15 | 0.22 | 0.22 | 0.19 |
| Design for Environment | 0.20 | 0.32 | 0.27 | 0.27 | 0.26 |
| Design for Ergonomics | 0.27 | 0.35 | 0.28 | 0.28 | **0.29** |
| | | | | | $\sum = 1.00$ |

## Participant-F

**Table 4.F.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 0.25 | 0.33 | 0.33 | 0.09 |
| Product Durability | 4.00 | 1.00 | 5.00 | 3.00 | **0.54** |
| Cost Saving | 3.00 | 0.20 | 1.00 | 0.50 | 0.15 |
| Easy to Produce | 3.00 | 0.33 | 2.00 | 1.00 | 0.23 |
| CR = 0.08 | | | | | ∑ = 1.00 |

**Table 4.F.2: Pair-wise Comparison Matrix for Design for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.50 | 0.25 | 0.29 | 0.33 | 0.07 |
| Design for Manufacturability | 2.00 | 1.00 | 0.33 | 0.50 | 0.40 | 0.11 |
| Design for Aesthetics | 4.00 | 3.00 | 1.00 | 3.00 | 2.00 | 0.40 |
| Design for Environment | 3.50 | 2.00 | 0.33 | 1.00 | 1.00 | 0.20 |
| Design for Ergonomics | 3.00 | 2.50 | 0.50 | 1.00 | 1.00 | 0.22 |
| CR = 0.02 | | | | | | ∑ = 1.00 |

**Table 4.F.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.50 | 3.00 | 3.00 | 2.00 | 0.27 |
| Design for Manufacturability | 2.00 | 1.00 | 4.00 | 3.00 | 2.00 | 0.37 |
| Design for Aesthetics | 0.33 | 0.25 | 1.00 | 0.33 | 0.50 | 0.07 |
| Design for Environment | 0.33 | 0.33 | 3.00 | 1.00 | 1.00 | 0.14 |
| Design for Ergonomics | 0.50 | 0.50 | 2.00 | 1.00 | 1.00 | 0.15 |
| CR = 0.03 | | | | | | ∑ = 1.00 |

**Table 4.F.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 2.00 | 3.00 | 2.00 | 2.00 | 0.28 |
| Design for Manufacturability | 0.50 | 1.00 | 2.00 | 3.00 | 3.00 | 0.28 |
| Design for Aesthetics | 0.33 | 0.50 | 1.00 | 0.40 | 0.50 | 0.09 |
| Design for Environment | 0.50 | 0.33 | 2.50 | 1.00 | 0.67 | 0.14 |
| Design for Ergonomics | 0.50 | 0.33 | 2.00 | 1.50 | 1.00 | 0.16 |
| CR = 0.06 | | | | | | ∑ = 1.00 |

**Table 4.F.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.33 | 3.00 | 2.00 | 2.50 | 0.23 |
| Design for Manufacturability | 3.00 | 1.00 | 4.00 | 3.00 | 3.00 | 0.42 |
| Design for Aesthetics | 0.33 | 0.25 | 1.00 | 0.67 | 0.67 | 0.09 |
| Design for Environment | 0.50 | 0.33 | 1.50 | 1.00 | 0.50 | 0.11 |
| Design for Ergonomics | 0.40 | 0.33 | 1.50 | 2.00 | 1.00 | 0.14 |
| CR = 0.04 | | | | | | ∑ = 1.00 |

**Table 4.F.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.07 | 0.27 | 0.28 | 0.23 | 0.24 |
| Design for Manufacturability | 0.11 | 0.37 | 0.28 | 0.42 | **0.35** |
| Design for Aesthetics | 0.40 | 0.07 | 0.09 | 0.09 | 0.11 |
| Design for Environment | 0.20 | 0.14 | 0.14 | 0.11 | 0.14 |
| Design for Ergonomics | 0.22 | 0.15 | 0.16 | 0.14 | 0.15 |
| | | | | | ∑ = 1.00 |

## Participant-G

**Table 4.G.1: Pair-wise Comparison Matrix for Criteria**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Priority Vector |
|---|---|---|---|---|---|
| Sales Quantity | 1.00 | 1.25 | 1.25 | 0.50 | 0.23 |
| Product Durability | 0.80 | 1.00 | 1.00 | 0.50 | 0.19 |
| Cost Saving | 0.80 | 1.00 | 1.00 | 0.67 | 0.21 |
| Easy to Produce | 2.00 | 2.00 | 1.50 | 1.00 | **0.38** |
| CR = 0.009 | | | | | ∑ = 1.00 |

**Table 4.G.2: Pair-wise Comparison Matrix for Design for *Sales Quantity***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.45 | 0.26 | 0.29 | 0.33 | 0.07 |
| Design for Manufacturability | 2.20 | 1.00 | 0.29 | 0.40 | 0.50 | 0.11 |
| Design for Aesthetics | 3.80 | 3.50 | 1.00 | 3.00 | 1.33 | 0.38 |
| Design for Environment | 3.40 | 2.50 | 0.33 | 1.00 | 1.00 | 0.21 |
| Design for Ergonomics | 3.00 | 2.00 | 0.75 | 1.00 | 1.00 | 0.23 |
| CR = 0.03 | | | | | | ∑ = 1.00 |

**Table 4.G.3: Pair-wise Comparison Matrix for Design for *Product Durability***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.31 | 0.67 | 1.25 | 0.36 | 0.12 |
| Design for Manufacturability | 3.20 | 1.00 | 1.33 | 2.00 | 1.33 | 0.30 |
| Design for Aesthetics | 1.50 | 0.75 | 1.00 | 0.40 | 0.50 | 0.38 |
| Design for Environment | 0.80 | 0.50 | 2.50 | 1.00 | 1.00 | 0.21 |
| Design for Ergonomics | 2.80 | 0.75 | 2.00 | 1.00 | 1.00 | 0.23 |
| CR = 0.06 | | | | | | ∑ = 1.00 |

**Table 4.G.4: Pair-wise Comparison Matrix for Design for *Cost Saving***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.67 | 3.33 | 5.00 | 5.00 | 0.35 |
| Design for Manufacturability | 1.50 | 1.00 | 2.00 | 5.00 | 3.33 | 0.35 |
| Design for Aesthetics | 0.30 | 0.50 | 1.00 | 1.25 | 0.83 | 0.11 |
| Design for Environment | 0.20 | 0.20 | 0.80 | 1.00 | 0.67 | 0.07 |
| Design for Ergonomics | 0.20 | 0.30 | 1.20 | 1.50 | 1.00 | 0.10 |
| CR = 0.03 | | | | | | ∑ = 1.00 |

**Table 4.G.5: Pair-wise Comparison Matrix for Design for *Easy to Produce***

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics | Priority Vector |
|---|---|---|---|---|---|---|
| Design for Production | 1.00 | 0.20 | 1.25 | 1.67 | 0.50 | 0.14 |
| Design for Manufacturability | 5.00 | 1.00 | 3.33 | 1.00 | 1.00 | 0.32 |
| Design for Aesthetics | 0.80 | 0.30 | 1.00 | 1.00 | 0.33 | 0.11 |
| Design for Environment | 0.60 | 1.00 | 1.00 | 1.00 | 1.00 | 0.18 |
| Design for Ergonomics | 2.00 | 1.00 | 3.00 | 1.00 | 1.00 | 0.25 |
| CR = 0.09 | | | | | | $\sum = 1.00$ |

**Table 4.G.6: Priority Matrix for Choice of Appropriate PDM (Final Result)**

| | Sales Quantity | Product Durability | Cost Saving | Easy to Produce | Overall Priority Vector |
|---|---|---|---|---|---|
| Design for Production | 0.07 | 0.12 | 0.35 | 0.14 | 0.17 |
| Design for Manufacturability | 0.11 | 0.30 | 0.35 | 0.32 | **0.28** |
| Design for Aesthetics | 0.38 | 0.38 | 0.11 | 0.11 | 0.22 |
| Design for Environment | 0.21 | 0.21 | 0.07 | 0.18 | 0.17 |
| Design for Ergonomics | 0.23 | 0.23 | 0.10 | 0.25 | 0.21 |
| | | | | | $\sum = 1.00$ |

### 4.3 Summary of Result

Data analysis in table - 1.6, 2.6, 3.6, 4.6, 5.6, 6.6 & 7.6 show the final results for each participant. The overall priority vector shows the preferential ranking of all PDM. It appears that Design for Manufacturability is the most preferred option to 5 designers (participant - A, C, D, F & G). Besides, one designer (participant - B) prefers Design for Production and one designer prefers (participant - E) prefers Design for Ergonomics. So, analysis from most of the participant's data (5 out of 7) shows that Design for Manufacturability is the most preferred option for manufacturing refrigerator in the context of Bangladesh.

### 4.4 Summarized Biography of Respondents

Seven participants experienced in designing from R&D (Refrigerator), Walton Hi-Tech Industries Ltd. responded to the questionnaires administered. The biographical details of the designers have been tabulated (refer Appendix B). The designers who responded to the questionnaires were Bangladeshi male. Their age group ranged above the 27 plus category and all of them are engineers. Their experience as product designer ranged between 2 to 10 years. Each product designer has intensive experience on the field with full ability to answer the questionnaire. And they have provided effective information in order to complete the questionnaire according to their experiences. (Details biography is presented in Appendix C)

### 4.5 Discussion

According to the researcher's knowledge there were around 15 product designers in the country in Refrigerator (up to 2013). 14 of them were knocked during the survey. And 7 of them replied. So, the data analysis compiles data from 47% product designer of the country. Besides, CR value is less than 0.1 in each case. Thus, the result may be approved for current situation of Bangladesh.

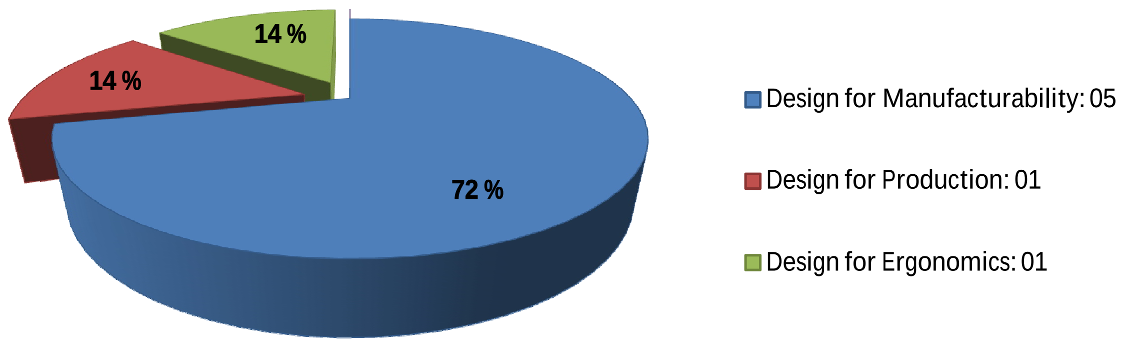


**Chart 4.1: Design Methodology Preference Ratio**

Here most of the product designers preferred Design for Manufacturability over other PDMs. A comparative study is shown in Chart 4.1. However, if we analysis the main criteria matrix from table 4.A.1, 4.B.1, 4.C.1, 4.D.1, 4.E.1, 4.F.1 & 4.G.1; we see that the most important factor for prioritizing PDMs was taken '*Easy to Produce*' by most of the designers (Chart 4.2). And importance of the factors behind prioritizing PDMs is very much influenced by the working environment & resource availability of the organization.

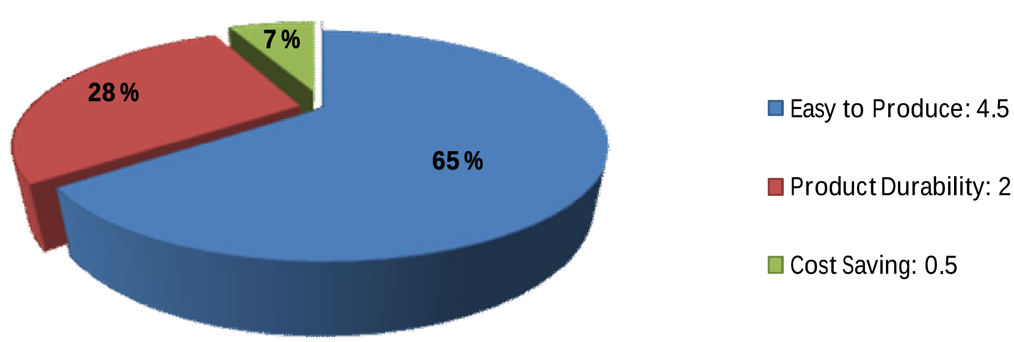


**Chart 4.2: Criteria Preference Ratio**

# Chapter 05: Conclusions

## 5.1 Conclusions

From this study the following conclusions may be drawn:

1. *Design for Manufacturability* is the most appropriate PDM according to the choices provided by Designers. Thus, adaptation to available/existing technology is getting priority for PDM, where a single manufacturing process producing different types or models of refrigerator is the most preferred.

2. Bangladesh is a developing country and it is lagging behind in technology. Perhaps, this has been highlighted in the result of data analysis. PDM classification for refrigerator manufacturing in Bangladesh was not done before this thesis.

3. Selection of most appropriate PDM for manufacturing refrigerator in Bangladesh was not done before either. It is true that, more samples from expertise would have been better for the study, but expertise in this field is not available in Bangladesh. Thus, the AHP was done by these limited samples.

## 5.2 Further Recommendation

Similar study and analysis might be performed for:

i. Any other specific market Segment: Similar study and analysis might be performed for any other specific market segment like air-conditioner, fan, motor-cycle etc. Thus, Product Design Methodologies for other products would be established.

ii. Any specific customer segment: Similar study and analysis might be performed for any other specific customer segment like economically low, mid or high level customers. Thus, Product Design Methodologies for any product would be enhanced.

iii. Other Countries: Similar study and analysis might be performed for other developing as well as developed countries. Thus, Product Design Methodologies for any product would be enhanced.

iv. Specific parts of an assembled product: Similar study and analysis might be performed for any specific parts of an assembled product like side cabinet or liner of a refrigerator etc. Thus, vital decisions could be taken at root level of designing any product.

v. Using other criterions/variables: Similar study and analysis might be performed using other criterions/variables like product material, aesthetics, environment etc. Thus, Product Design Methodologies for any product would be enhanced.

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# Appendix A

There are different product designing methodologies. A brief of them are:

**Design for Production:** Design for Production might be defined as the general engineering art of designing products where main concern of a designer is to increase productivity. In this discipline designer tries to reduce the processes or number of parts.

**Design for manufacturability:** The general engineering art of designing products in such a way that they are easy to manufacture. Parts or processes might be improvised according to available technology.

**Design for Aesthetics:** Occasionally the complex contents of a product have their own aesthetic appeal to (perhaps more technical) users and this can sometimes be exploited. But in general, the designer's main attention is on the visual appeal of the product.

**Design for Environment:** In recent years the increased awareness of environmental issues has led to the development of new approaches to product design, known as Design for Environment where main consideration of a designer lies in the environmental impact of the products.

**Design for Ergonomics:** In recent years, ergonomics (physical comfort) for both user/consumer and production line workers has come to attention of the designers.

These methodologies may be judged by following criterion:

**Sales Quantity:** Market demand &/or sales is the first priority for any business. Thus, product designing must suit with sales and marketing.

**Product Durability:** Product lifetime has a direct or potential effect on market feedback, which must be taken care of at design level.

**Cost Saving:** Costing for a product directly influences the price & profit as well as it also affects the lifetime, ergonomics, and environmental outcome of the product.

**Easy to Produce:** Product design must be user friendly as well as easy to produce which affects the productivity and manufacturability of the product.

Please fill out the following table with a scale of 0 to 5. Read from left of a row with respect to column. If the topic of row and topic of column seems equal important to you, just put 1. If row item is 2 times more important than column topic, write 2. If column item is 2 times important than the row item please put 1/2 and so on.

| | Sales Quantity | Product durability | Cost Saving | Easy to produce |
|---|---|---|---|---|
| Sales Quantity | 1 | | | |
| Product durability | | 1 | | |
| Cost Saving | | | 1 | |
| Easy to produce | | | | 1 |

Please fill out the following table in the same manner (at a scale 0 to 5) considering **Sales Quantity:**

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics |
|---|---|---|---|---|---|
| Design for Production | 1.00 | | | | |
| Design for Manufacturability | | 1.00 | | | |
| Design for Aesthetics | | | 1.00 | | |
| Design for Environment | | | | 1.00 | |
| Design for Ergonomics | | | | | 1.00 |

Please fill out the following table in the same manner (at a scale 0 to 5) considering **Product Durability:**

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics |
|---|---|---|---|---|---|
| Design for Production | 1.00 | | | | |
| Design for Manufacturability | | 1.00 | | | |
| Design for Aesthetics | | | 1.00 | | |
| Design for Environment | | | | 1.00 | |
| Design for Ergonomics | | | | | 1.00 |

Please fill out the following table in the same manner (at a scale 0 to 5) considering **Cost Saving:**

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics |
|---|---|---|---|---|---|
| Design for Production | 1.00 | | | | |
| Design for Manufacturability | | 1.00 | | | |
| Design for Aesthetics | | | 1.00 | | |
| Design for Environment | | | | 1.00 | |
| Design for Ergonomics | | | | | 1.00 |

Please fill out the following table in the same manner (at a scale 0 to 5) considering **Easy to Produce:**

| | Design for Production | Design for Manufacturability | Design for Aesthetics | Design for Environment | Design for Ergonomics |
|---|---|---|---|---|---|
| Design for Production | 1.00 | | | | |
| Design for Manufacturability | | 1.00 | | | |
| Design for Aesthetics | | | 1.00 | | |
| Design for Environment | | | | 1.00 | |
| Design for Ergonomics | | | | | 1.00 |

# Appendix B

## Table: Biographic Details of Respondents (up to June, 2014)

| Sl. | Name | Qualification | Approximate Engineering Experience (Years) | Approximate Product Designing Experience (Years) |
|---|---|---|---|---|
| 1 | Md Masudul Haque | B.Sc. in ME | 7.5 | 7 |
| 2 | Tapash Kumar Majumder | B.Sc. in IPE | 9.5 | 7.5 |
| 3 | Tawfik Ul Kader | B.Sc. in ME | 5.5 | 4.5 |
| 4 | Tofail Ahmed | B.Sc. in ME | 4.5 | 4.5 |
| 5 | Md Ibrahim Khalilullah | B.Sc. in ME | 4.5 | 3.5 |
| 6 | Farhad Ahmed | B.Sc. in ME | 3.5 | 2 |
| 7 | Md Reza | B.Sc. in ME | 2.5 | 2.5 |