Military Institute of Science and Technology

IPE 304
Product Design Sessional

A Report on
CNC PCB Plotter

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FORWARDING LETTER

May 28, 2018

Brig Gen Mustafa Kamal

Head of The Department

Department of Industrial and Production Engineering

Subject: A report on ‘CNC PCB Plotter’

With due respect, we would like to submit you a report on ‘CNC PCB Plotter’.

PCBs are needed in any product which use electricity. The size and shape of the PCB used in the product however vary with the product under consideration. Getting a customized PCB for a product is very hard as it has to be outsourced. And designers end up changing their designs for the lack of a PCB made for their prototype. We designed our product to eliminate this hassle and impediment to the design process. The CNC PCB Plotter is a device which is able to create a specially designed PCB for a product at a very low cost and time.

We would like to thank you for helping us with suggestions and advices for completing this product. We would like to apologize for any mistakes in our part and hope that you would be kind enough to oblige thereby.

Sincerely yours,

Humayra Zerin Chowdhury – 201636006
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PREFACE

Product design is the design of products for desired physical and/or chemical transformation of materials. Process design is central to industrial engineering, and it can be considered to be the summit of that field, bringing together all of the field's components.

In our Product Design-I sessional, we learnt how to design a new product or to improve the design of an existing product. In Product Design-II sessional course (which will be covered in the next semester), we will manufacture it. So, every step of a product development process will be performed.

After consulting with our course teachers, ‘PCB CNC Plotter’ was selected as our sessional course project. The PCB CNC Plotter is a machine which creates customized PCBs for designers who work on electronic devices. This device removes the need for outsourcing PCBs for prototypes and also makes the design process more true to the designer’s imagination as an outsourced PCB imposes design restrictions on the product.

The main objective of this project was to apply different class concepts that we learnt in our Product Design theory course. For completing the project work, we had to handle various phases of a product development process. This will surely help us in designing and developing more complex products in the future. This project was undoubtedly very important. Engineering is not all about reading books and learning techniques. It is valueless if we do not implement it in our practical life. This project is an outcome of practical implementation of Product Design Techniques that we learnt in the theory and sessional courses.

SUMMARY

The ‘CNC PCB Plotter’ – is proposed as a handy tool to make a single PCB with in very short time and cost. This can save one from the hassle from handling many wires and extensions. In the sophisticated art of product design, the creativity of the visionary designers and the needs of the customer should be the only constraints. With this in mind we decided to make our product to remove one of the vital design obstacles for products which incorporate the use of electronic components and thus PCBs.

ACKNOWLEDGEMENT

This section is dedicated to express our heartfelt gratitude to the personnel who helped us to complete the challenging task of completing this report.

We would like to thank Lec. Nadia Tanzeem, Lec. Ashfaqur Arefin and Lec. Nighat Ma'am for teaching us the very basics of the different segments which make up the total report. This report would have never been complete without their guidance. We would also like to thank them for having the patience in answering our relentless questions at every step of the entire process.

We would also like to thank the creator of Alibaba and all the different sellers who put details of the machines and materials in their website. Our speculations on the machine, material and process selections would not be possible without them.

We would also like to thank our teachers in the previous semesters. Their insightful knowledge on the basics of manufacturing and designing helped us in designing our product from scratch.

At the very end we would like to thank Brig Gen Mustafa Kamal for his strong support behind our every endeavor.

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Chapter-1

Introduction

1.1 Product Design

Product design is the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

1.2 Our Product

After consulting with our honorable teachers and considering all possible options ‘CNC PCB Plotter’ was assigned as our product to design.

1.3 CNC PCB Plotter

A Printed Circuit Board (PCB) mechanically supports and electrically connects electronic components or electrical components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate.

PCBs are not so economical to produce in small quantities due to its manufacturing process. So sometimes for testing or prototyping small quantity of PCB is required. Our CNC PCB Plotter will overcome the problem above and will help in those situation. This will be helpful for lots of projects and research work.

1.4 Planned Features

Our CNC PCB Plotter will include,

- Customized PCB making abilities.
- Cheaper single unit cost.
- Easy maintenance and low running costs.
- Freedom of designing.
- Smaller size for integration into a lab of any size.
- Simple operation and repairing methods.

Chapter-2

Understanding Customer Needs, Gathering and Prioritizing Needs

2.1 Introduction

Quality can be defined as the characteristics of a product or service to constantly meet or exceed customer expectations. Customers are interested in various aspects of quality depending upon requirements which may vary widely from case to case. Customers may not have a complete idea about quality, but it should be our focus to provide them with service (engineering specifications) corresponding to their perceived idea about quality. There are many techniques used to define engineering specifications. To determine the demands and specifications of customers, we must first ascertain our customers. Once the customers have been identified, the next goal is to determine what is to be designed. That is, what is it that the customers want. This is the information collecting step. We completed this step by using a survey.

2.2 Target Customers for Survey

We have gone through some R&D labs, Design labs, Robotics club, personnel involved in various project and prototype work and people from school and colleges with similar interest. The survey was concluded among 43 people The survey results are shown in percentage in pie chart.

2.3 Survey Results

1. How often do you need a PCB?
   i) Frequently
   ii) Intermittently
   iii) Not sure

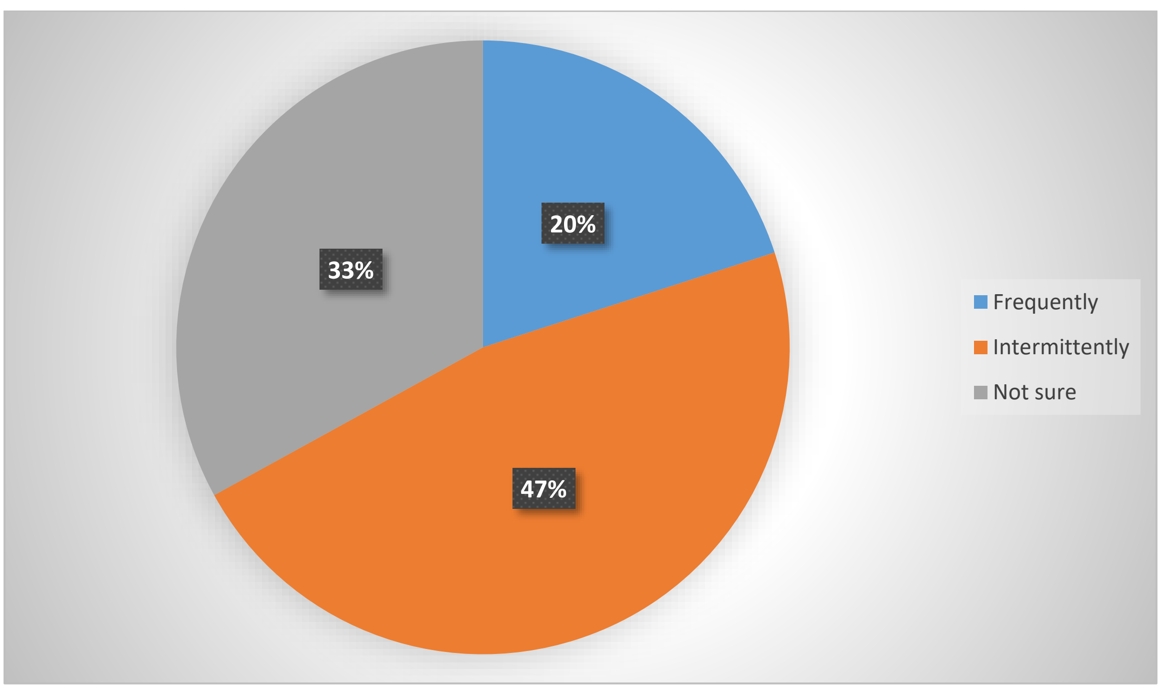


Figure 1: Pie chart for question no 1

2. How often do you need a PCB readily available in the market?
    i) Frequently
    ii) Intermittently
    iii) Not sure

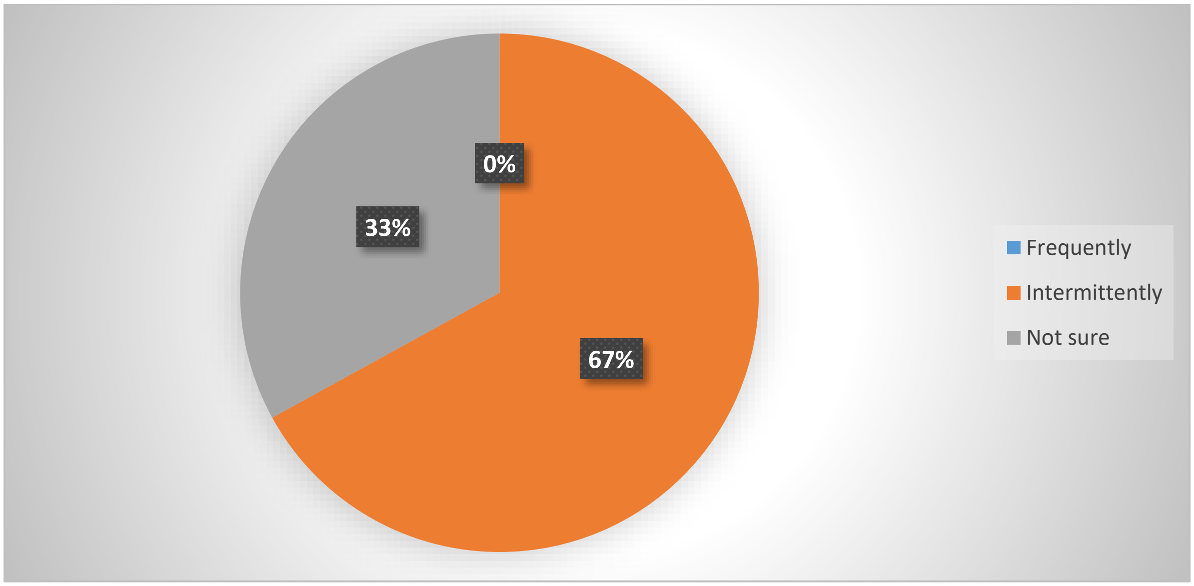


Figure 2: Pie chart for question no 2

3. How often do you need a customized PCB?
    i) Frequently
    ii) Intermittently
    iii) Not sure

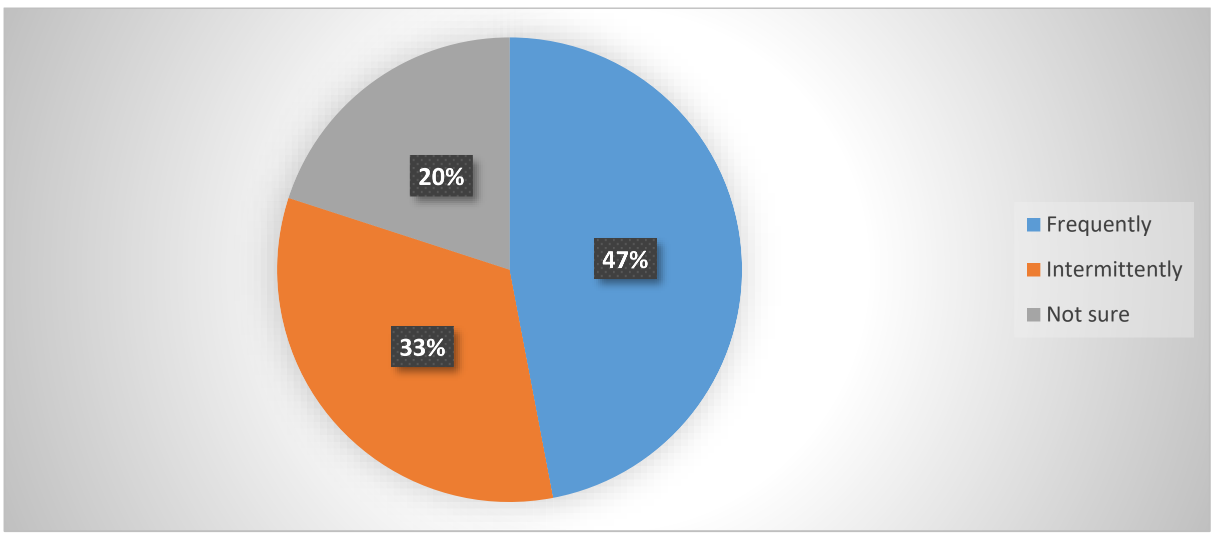


Figure 3: Pie chart for question no 3

4. Is it feasible to get a single prototype PCB made for a single project?
   i) Yes
   ii) No
   iii) Not sure

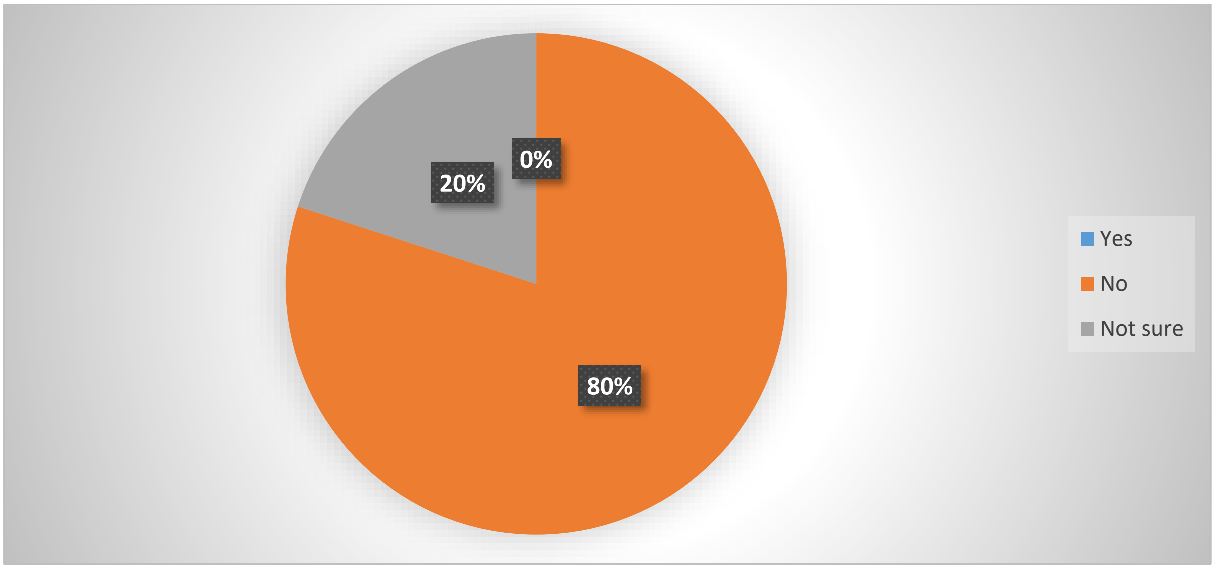


Figure 4: Pie chart for question no 4

5. How often do you need to change your design because the PCB available does not conform to your design?
   i) Frequently
   ii) Intermittently
   iii) Not sure

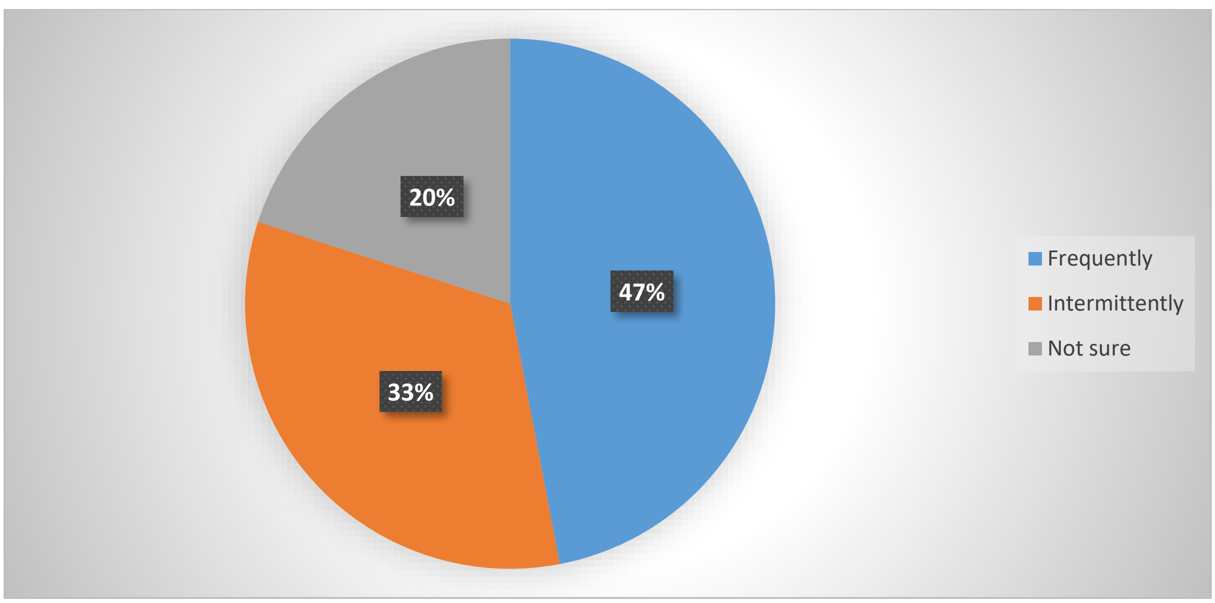


Figure 5: Pie chart for question no 5

6. How expensive is it to get one PCB made which might not even be in the final project?
    i) Quite a lot
    ii) Considerable
    iii) Not sure

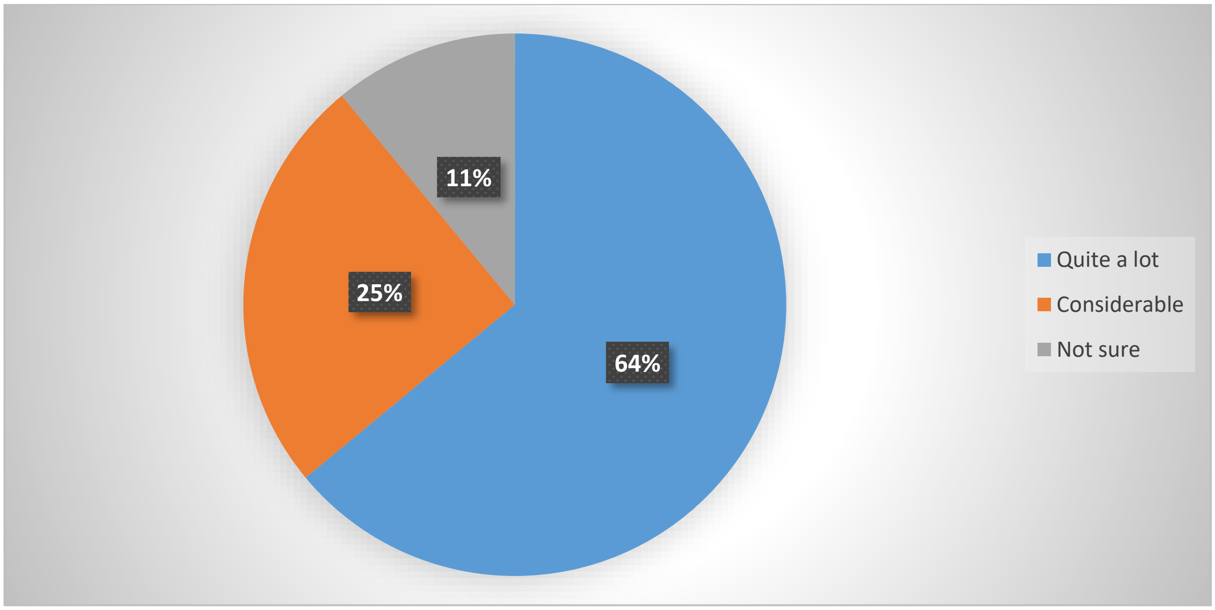


Figure 6: Pie chart for question no 6

7. How much time do you need to get your prototype PCBs made from the PCB makers?
    i) 1 Day
    ii) 1 Week
    iii) Not sure

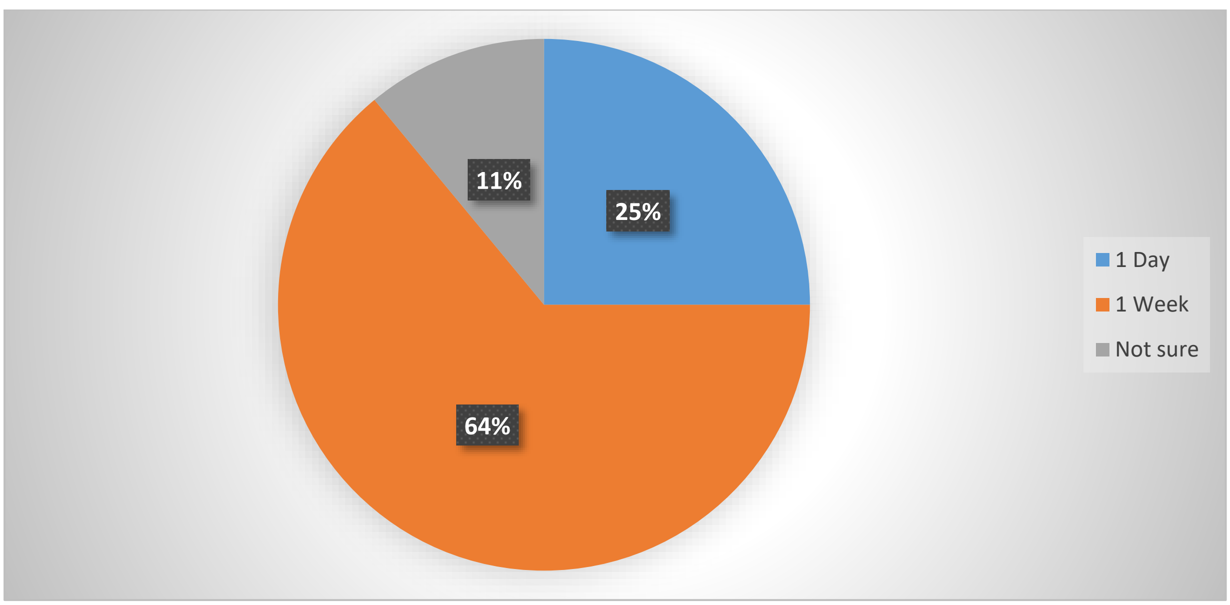


Figure 7: Pie chart for question no 7

8. How many times did your project didn't look up to the mark because it had wires instead of PCB?
    i) Frequently
    ii) Intermittently
    iii) Not sure

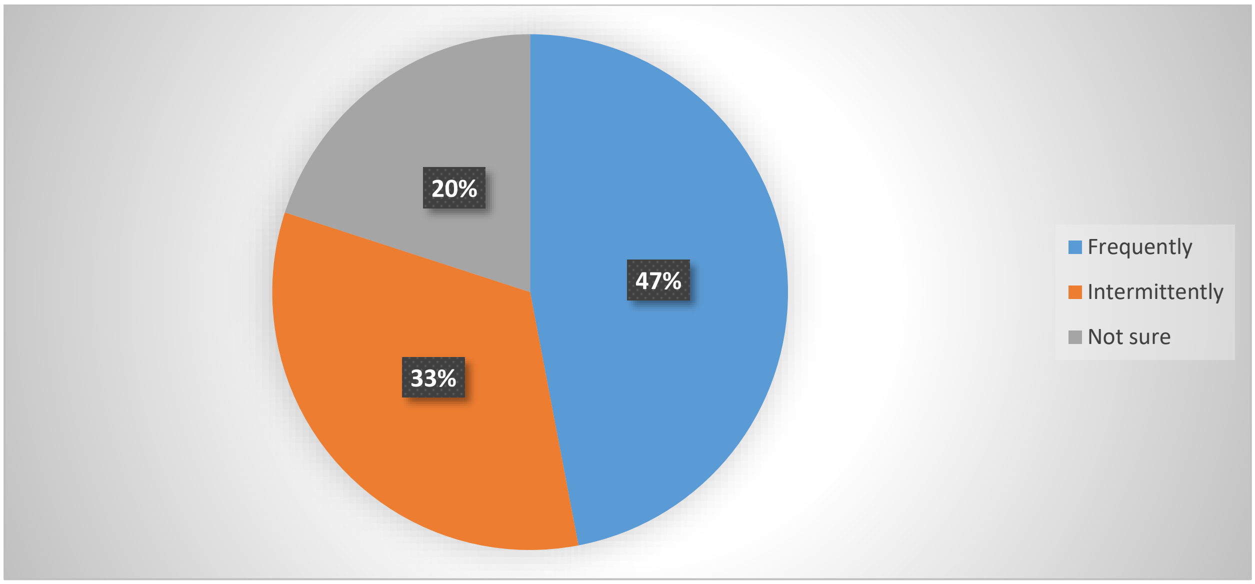


Figure 8: Pie chart for question no 8

9. Do you think your project would be better if you had the chance to make your own PCB?
    i) Yes
    ii) No
    iii) Not sure

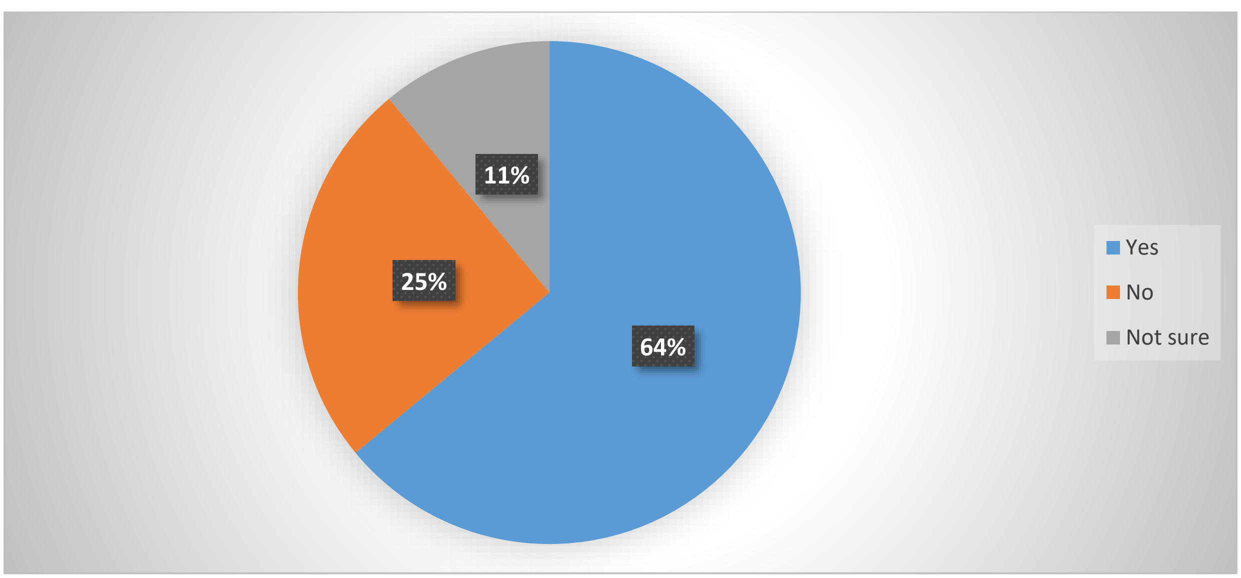


Figure 9: Pie chart for question no 9

10. What is stopping you from getting a PCB for your prototype?
    i) PCB making is expensive
    ii) PCB making is time consuming
    iii) Both above
    iv) Not sure

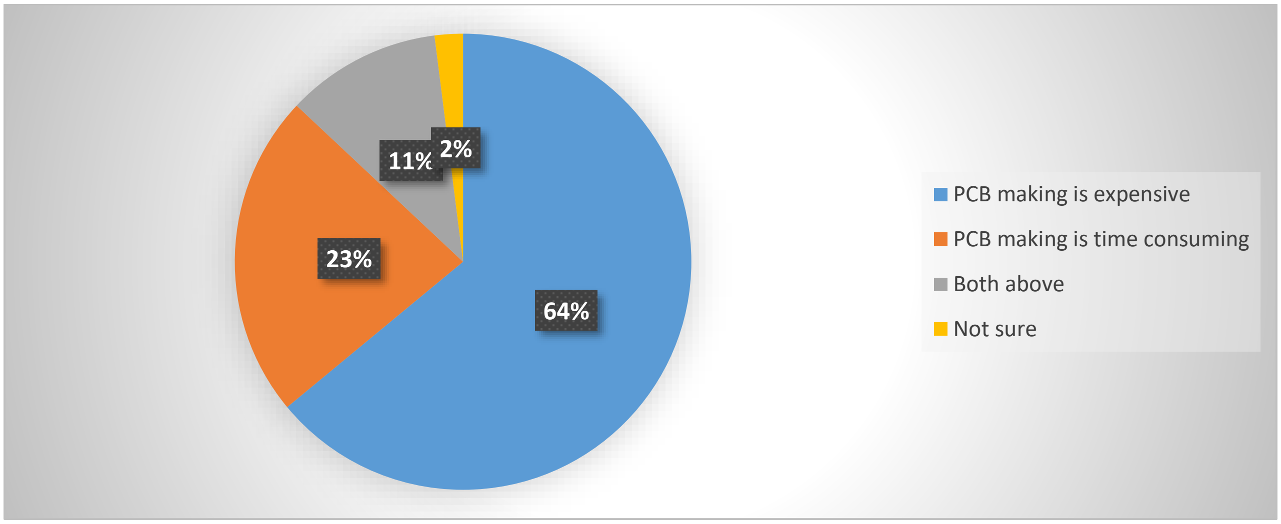


Figure 10: Pie chart for question no 10

11. Do you think that a CNC PCB maker would make your design phases and prototyping more efficient?
    i) Yes
    ii) No
    iii) Not sure

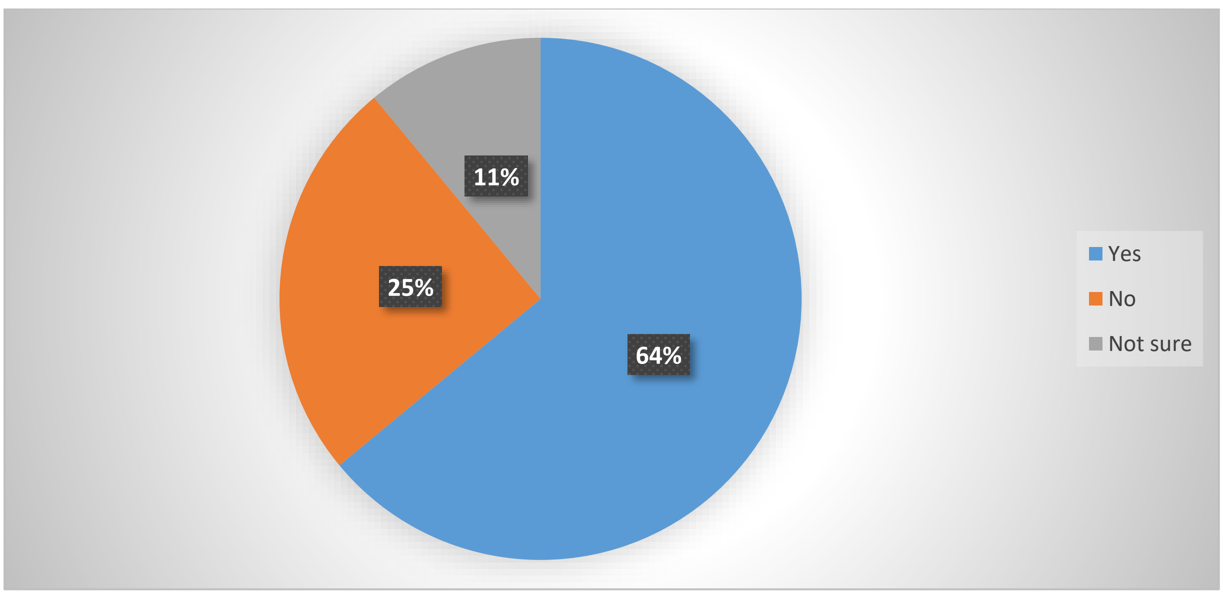


Figure 11: Pie chart for question no 11

2.4 Customer Requirements

Based on the results of the survey we intend to include the following features in our product

1. Ease of use
2. Operating speed
3. modularity
4. Reliability
5. Durability
6. Adoptability
7. Low cost

2.5 Conclusion

Surveys are generally used to gather specific information or ask people's opinions about a well-defined subject. Surveys use questionnaires that are carefully crafted and applied either through mail, over telephone or in face-to-face interviews. Surveys are well suited for collecting requirements on products to be redesigned or on new. For determining customer requirements questionnaires were quite a good choice for conducting the survey. After being finished with surveying, we now can move to the next step for developing QFD.

Chapter 3

Incorporating the Voice of Customer in Product Design with Quality Function Deployment (QFD)

3.1 Introduction

Quality function deployment is a systematic way of acknowledging customer needs or requirements and thus using them to create various aspects of the product development and production process. This ensures that the process is productive as it is tailored to the customer's demands.

The first step of QFD is to extract the customer's desires. This includes both the stated and the implied demands of the customers. This is termed as the voice of the customer (VOC). The data is extracted from the customers using various techniques such as interviews or surveys using various questionnaires.

In the previous segment of the report, we conducted a survey on the feasibility of our product based on the needs of the customers. The main objective of this section is to translate the data extracted from the VOC into engineering specifications which will be used to design and thus manufacture the final product.

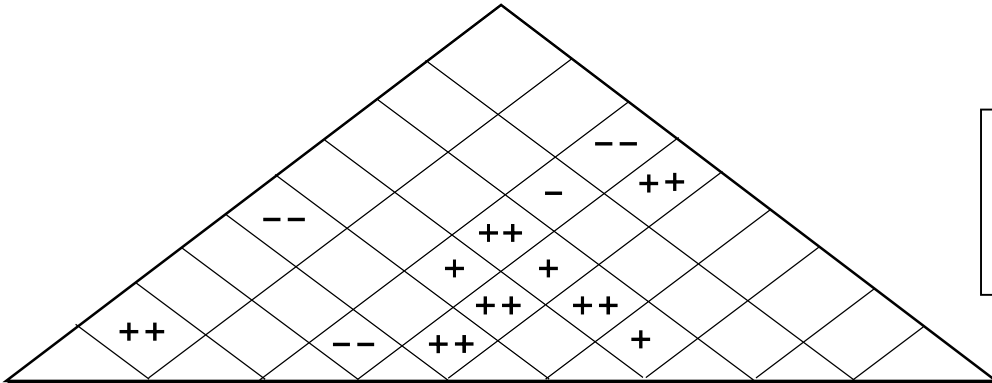
The information regarding engineering specifications are structurally represented in the 'House of Quality'. HOQ is a product planning matrix. These matrices are a good communicating tool and they act as the means. They act as reliable source of information during decision making and communicating.

3.2 Quality Function deployment's House of Quality

House of Quality is a diagram, resembling a house, used for defining the relationship between customer desires and the firm/product capabilities.

The "House of Quality", the basic design tool of the management approach known as quality function deployment (QFD), originated in 1972 at Mitsubishi's Kobe shipyard site. Toyota and its suppliers then developed it in numerous ways. The house of quality has been used successfully by Japanese manufacturers of consumer electronics, home appliances, clothing, integrated circuits, synthetic rubber, construction equipment, and agricultural engines.

Quality Function Deployment's House of quality for our CNC PCB Plotter is shown below:



++	**Very Strong Relation**
+	**Strong Relation**
-	**Weak Relation**
- -	**Very Weak Relation**

Symbol **Score**

● – Strong Relationship (9)
○ – Moderate Relationship (3)
□ – Weak Relationship (1)
Blank – No Relationship

		Software Specification		Electrical Design		Mechanical Design		Hardware Configuration		Physical Aspects				
		Software Architecture	Operating System	Wiring	Motor Design	Cutting Speed	Warranty, Maintenance	Hardware Configuration	Hardware Platform	Shape & weight	Importance (10)	Sales Point	Scores	Percentage Scores
Functionality	Precision				●	□		●			10	1.5	15	21
Usability	Ease of Use	●	●					●		□	7	1.3	9	13
	Operating Speed	○			●	●		○			8	1.1	9	12
	Modularity			○	○			○	●		5	1.0	5	7
Reliability	Reliability			□		□	●				8	1.2	10	13
	Durability			○	○		□	○			7	1.4	10	14
Portability	Adaptability			□					○	●	4	1.0	4	6
Price	Low Cost			□	□		○	●			8	1.3	10	14
Score (Sum ∑ = 1734)		153	117	96	374	142	173	531	81	67	Sum = 72			
Percent Score (100)		9	7	5	21	8	10	31	5	4				

Figure 12: Product planning diagram for CNC PCB Plotter

3.3 Relationship Between Customer Requirements and Technical Requirements

Table 1 : Table explaining relationship between customer and technical requirements

Customer Requirement	Engineering Requirement	Relationship	Explanation
Precision	Motor Design	Strong	Good motor setup will provide high precision
	Cutting Speed	Weak	Cutting speed may effect on precision
	Hardware Configuration	Strong	Accurate hardware configuration will assure good finishing
Ease of Use	Software Architecture	Strong	Simple user interfaced software will make the process easier
	Operating System	Strong	Popular operating system support will lessen user hassle
	Hardware Configuration	Strong	Easeful hardware configuration will be efficient
	Shape & Weight	Weak	Simple shape always preferable
Operating Speed	Software Architecture	Moderate	Total process flow time is moderately dependent on software architecture
	Motor Design	Strong	Optimally configured motor design will ensure greater operating speed
	Cutting Speed	Strong	Cutting speed is proportional to operating speed
	Hardware Configuration	Moderate	Hardware configuration might affect the operating speed
Modularity	Wiring	Moderate	Systematically wired machine may offer modularity

Customer Requirement	Engineering Requirement	Relationship	Explanation
Modularity	Motor Design	Moderate	Systematically designed motor will also offer modularity
	Hardware Configuration	Moderate	Easy to assemble hardware parts will provide modularity
	Hardware Platform	Strong	Professionally designed hardware platform will ensure easier modularity
Reliability	Wiring	Weak	Better grade wire may be a key factor for reliability
	Cutting Speed	Weak	Adaptable speed may insure reliability
	Warranty, Maintenance	Strong	After sale services will reliable the customers
Durability	Wiring	Moderate	Quality grade wire will increase the product’s durability
	Motor Design	Moderate	Long lasting motor will serve for longer period
	Warranty, Maintenance	Weak	Unwanted failure may be minimized through warranty and maintenance
	Hardware Configuration	Moderate	The materials used in hardware needs to be standard for long life of the product
Adaptability	Wiring	Weak	Wiring is a factor for adaptability
	Hardware Platform	Moderate	Easy to carry platform ensure adaptability
	Shape & Weight	Strong	The physical aspects are the key factors to adaptation at any situation
Low Cost	Wiring	Weak	Standard wires are available in the market at cheap rate

Customer Requirement	Engineering Requirement	Relationship	Explanation
Low Cost	Motor Design	Weak	Powerful motor costs more
	Warranty, Maintenance	Moderate	Warranty may increase the price
	Hardware Configuration	Strong	Better hardware configuration will cost more

3.4 Importance Rating

Table 2 : Importance rating

Observation Number	Engineering Requirement	Importance Rating	Percentage Rating (%)
1	Software Architecture	153	9
2	Operating System	117	7
3	Wiring	96	5
4	Motor Design	374	21
5	Cutting Speed	142	8
6	Warranty, Maintenance	173	10
7	Hardware Configuration	531	31
8	Hardware Platform	81	5
9	Shape & Weight	67	4

3.5 Conclusion

House of Quality is a technique to estimate technical specification to design a product on the basis of customer voice. From the above QFD table we obtain that precision and durability of the product should be focused on the marketing purpose.

For technical specification hardware configuration (31%) and motor design (21%) are prioritized. On the other hand, hardware platform (5%) and shape & weight (4%) are least important.

Chapter 4

Functional Decomposition

4.1 Introduction

Every automated process around us is composed of a number of different smaller machines or devices. These devices are the components which work together or in a chronological order to make the entire process successful. In order to understand how one of these systems consisting of different components work and what contributions the component elements have on the total process, we need to perform a functional decomposition.

A functional decomposition is therefore what the name suggests, a decomposition of the functional process under consideration. The decomposition however has to be done in a manner which permits the formation of the original process when the smaller components found after decomposition are put together. Functional decomposition of a product allows engineers to understand the exact purpose of each component in the product and at the same time it allows them to create a better design by removing or replacing parts which are out of place or are not contributing to the products true purpose.

Another advantage of doing a functional decomposition is that is allows us to work on each component one at a time this simplifies even the most complex of machines. The downside is however being that it is time consuming and it might get a bit over whelming for really complex projects.

In order to perform the functional decomposition, we need to go through the following steps.

1. **Finding the main objective or propose**
   This step is a summary of the entire product under consideration. The task here is to find out what the product does i.e. its true purpose. This can be one very specific task or it can be a collection of different actions the product can perform. After the function has been found, it is put into a black box to create a pictorial representation of the entire project.
2. **Finding sub functions which help accomplish the main objective**
   After the prime function of the product has been identified, it is necessary to find the smaller functions which make the main objective of the machine possible. There are usually a lot of these and they vary as per the complexity of the process. The sub functions are found by decomposing the product by its functions.
3. **Ordering the sub functions**
   In this step the sub functions found in the previous step are ordered in the way they occur in the process. If any of the components require any sort of redesign, it is done on the previous step when the sun functions are identified.

4. **Refining sub functions**
   In this step the ordered sub functions are put under further scrutiny and they are further decomposed to find more sub functions. The decomposition process is carried on until there is nothing left to decompose and we are left with the most basic of functions. This step paints a very clear picture of the product that we are reviewing and it allows for replacement of the components as well removing them to create a design which is optimized.

4.2 Black Box Model for CNC PCB Plotter

In engineering, a black box is a device, system or object which can be viewed in terms of its inputs and outputs (or transfer characteristics), without any knowledge of its internal workings. A Black Box Model consists of the overall function of the product, the flows into the product and the flows out of the product.

The Black Box Model for CNC PCB Plotter is shown below:

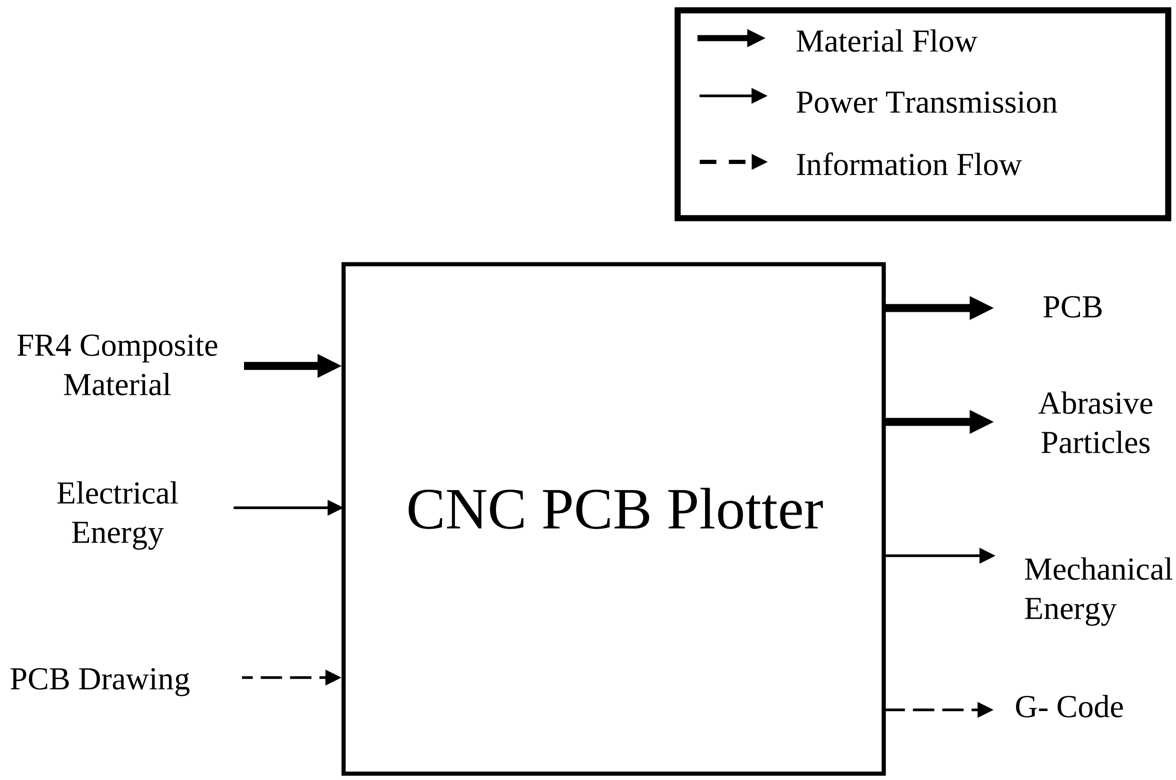


Figure 13: Black box of CNC PCB Plotter

There are generally three types of flows that are shown in the Black Box Model. These are

1. **Energy flow**
   Our product will take electrical energy in form of manual input.
2. **Material flow**
   Our product will take FR4 Composite Material as input and give PCB and Abrasive particles as output.

3. **Information flow**
   The desired PCB drawing will be drawn in Estlecam. Universal G-Code sender will send the G-Code to Arduino.

4.3 Component Hierarchy

A component hierarchy is an arrangement of components in which the items are represented as being "above," "below," or "at the same level as" one another.

We analyze how a product's design hierarchy shapes the evolution of the underlying body of technological knowledge, building on the literature on technological evolution in complex products. This literature suggests that the design hierarchy of a product can have an ordering effect on the evolution of commercialized artifacts, in particular when product design decisions on high levels of the design hierarchy set the agenda for subsequent variation and experimentation on lower levels.

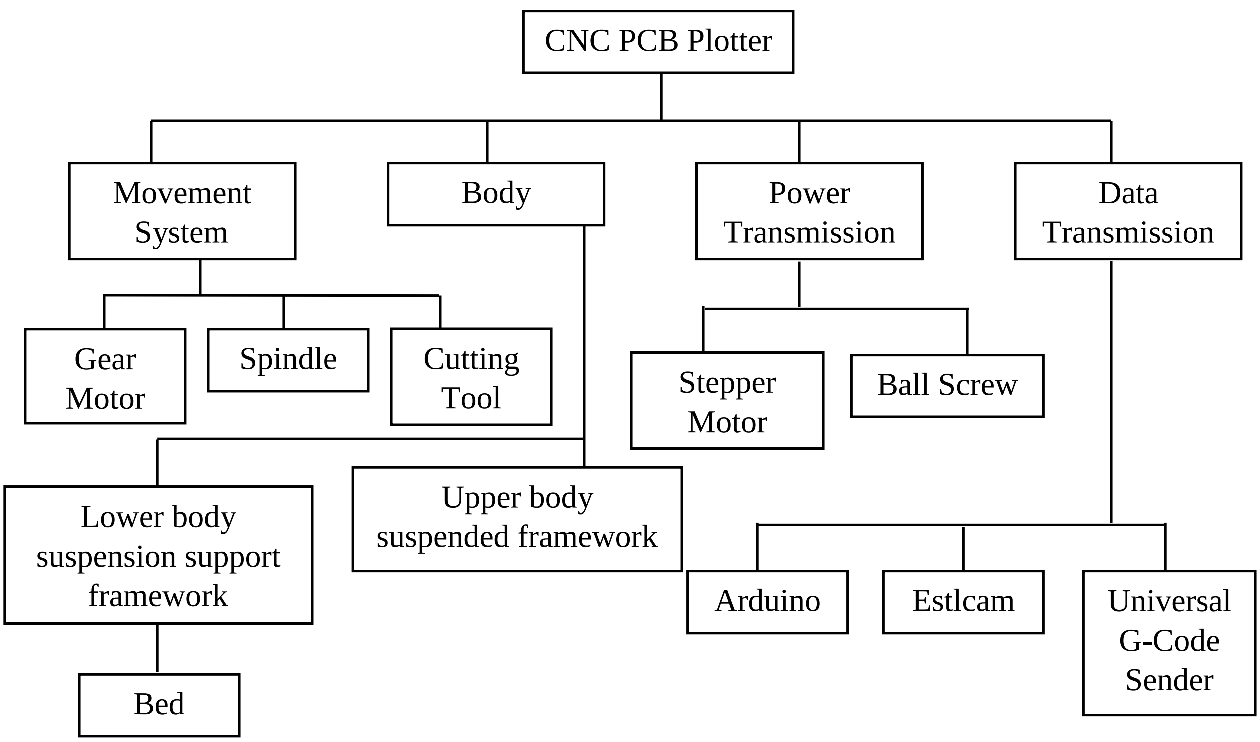


Figure 14: Component Hierarchy

4.4 Cluster Function Structure for CNC PCB Plotter

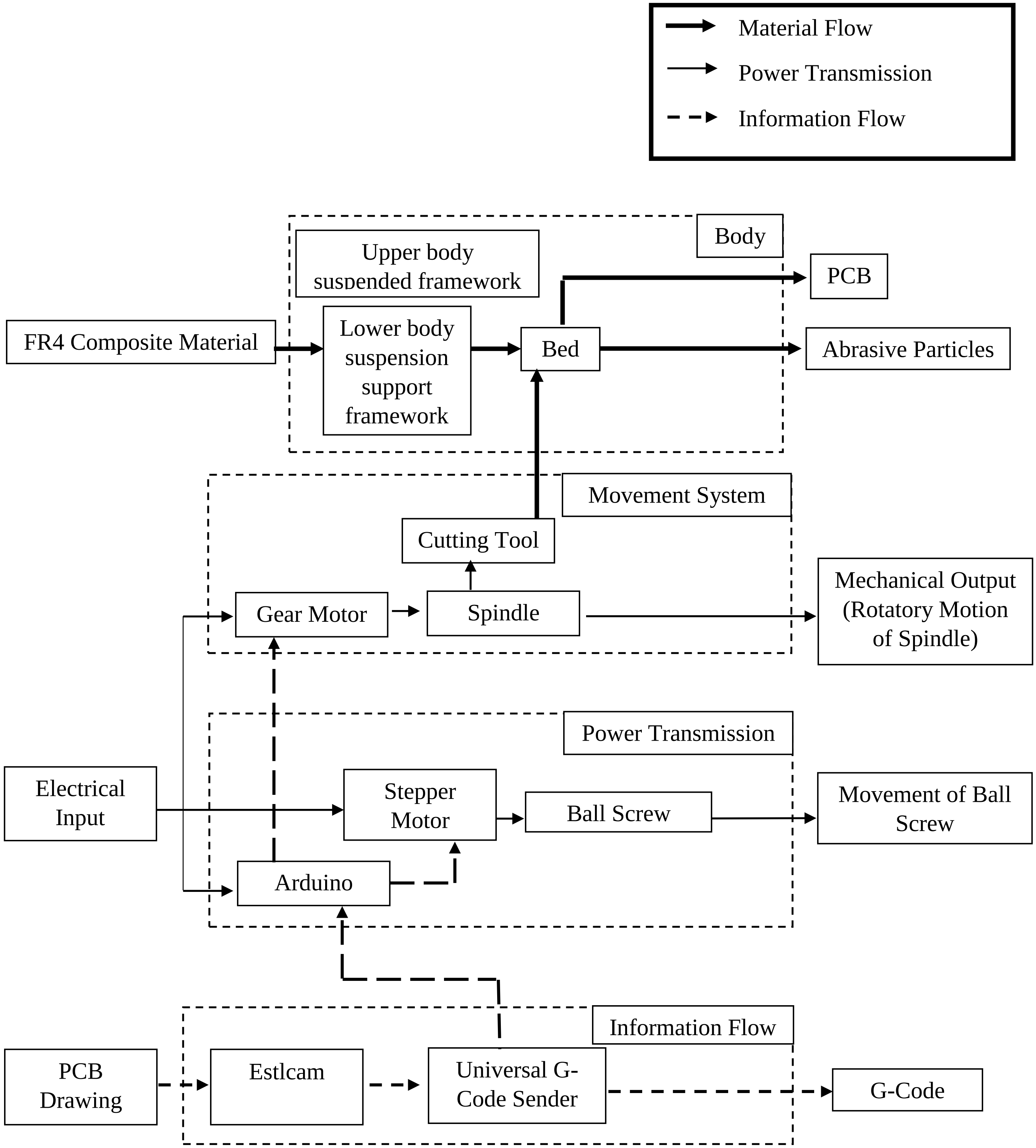


Figure 15: Cluster Function Structure for CNC PCB Plotter

4.5 Conclusion

In conclusion we see that functional decomposition reveals the innards of the entire project. It exposes the barebones of the product which facilitates in analyzing the faults and adding value and precision to the design by eliminating the components which do not add value. This procedure also streamlines the products flow of work which makes the product more efficient. It also lets us replace components with better alternatives which further develops the product into its best form.

Chapter 5

Design Analysis

5.1 Introduction

This study represents an approach for establishing an intelligent support system in order to design a product through managing variety. The interpretive tool is applied to visualize the hierarchy of component interactions within a product. This approach represents the design priority and related design dimensions for helping designers to create variant design solutions in a product for different market requests. The designer must define specific motions of each part and the sequence in which components are added to the base, they are more likely to understand how parts fit together as well as realize the purpose of the assembly.

5.2 Parts of CNC PCB Plotter

1. Angle bracket for framework

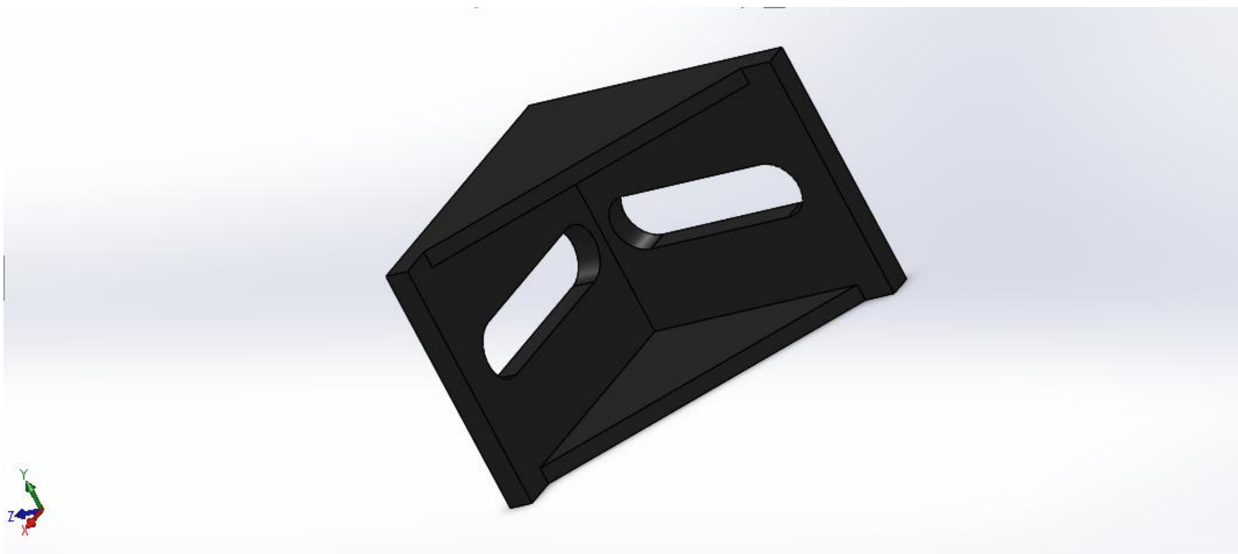


Figure 16: Angle bracket for framework

2. Ball screw shaft holder

Figure 17: Ball screw shaft holder

3.Bed segment with T-slots

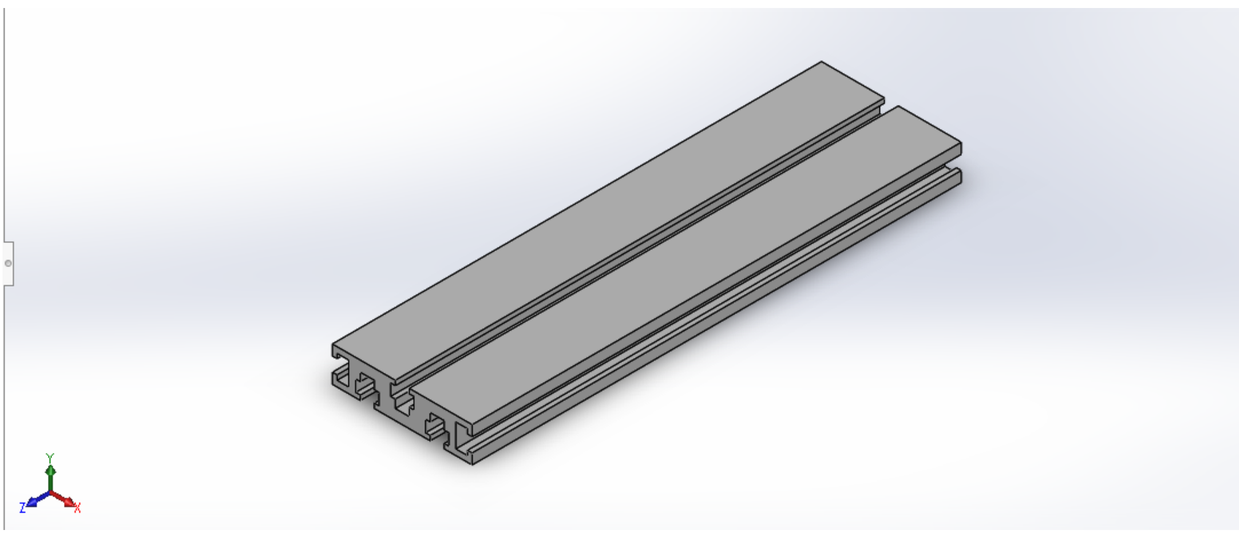


Figure 18: Bed segment with T-slots

4. Framework for the base

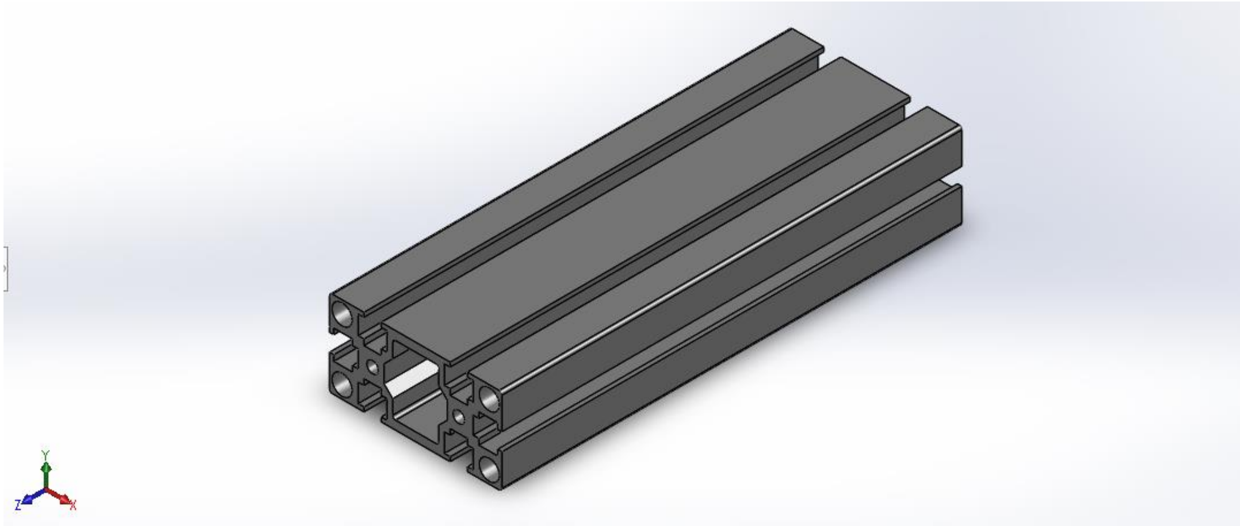


Figure 19: Framework for the base

5.Joining fixture for shaft

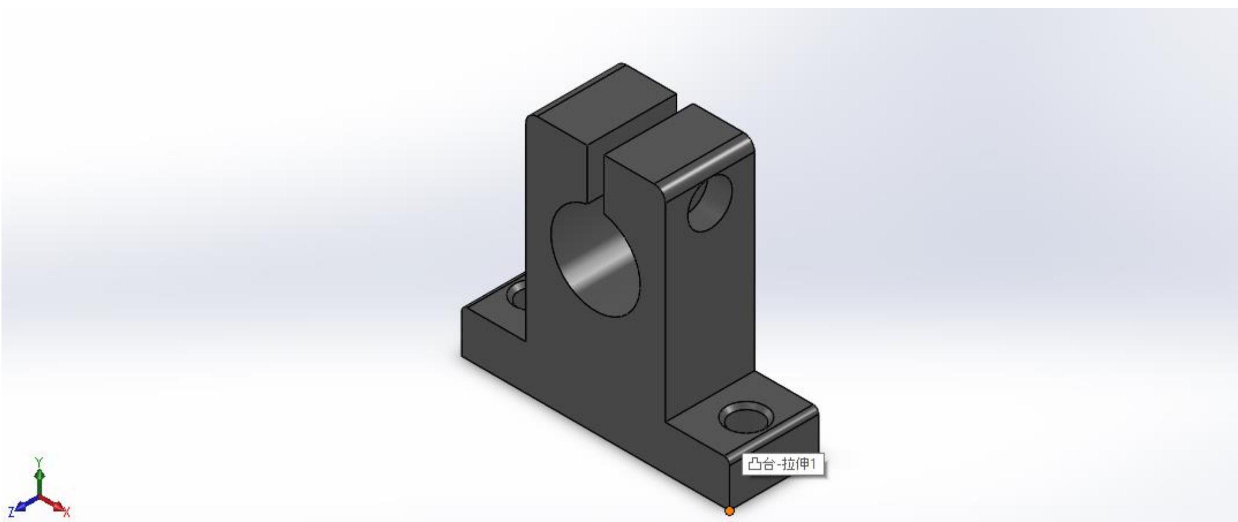


Figure 20: Joining fixture for shaft

6. Joining fixture for stepper motor

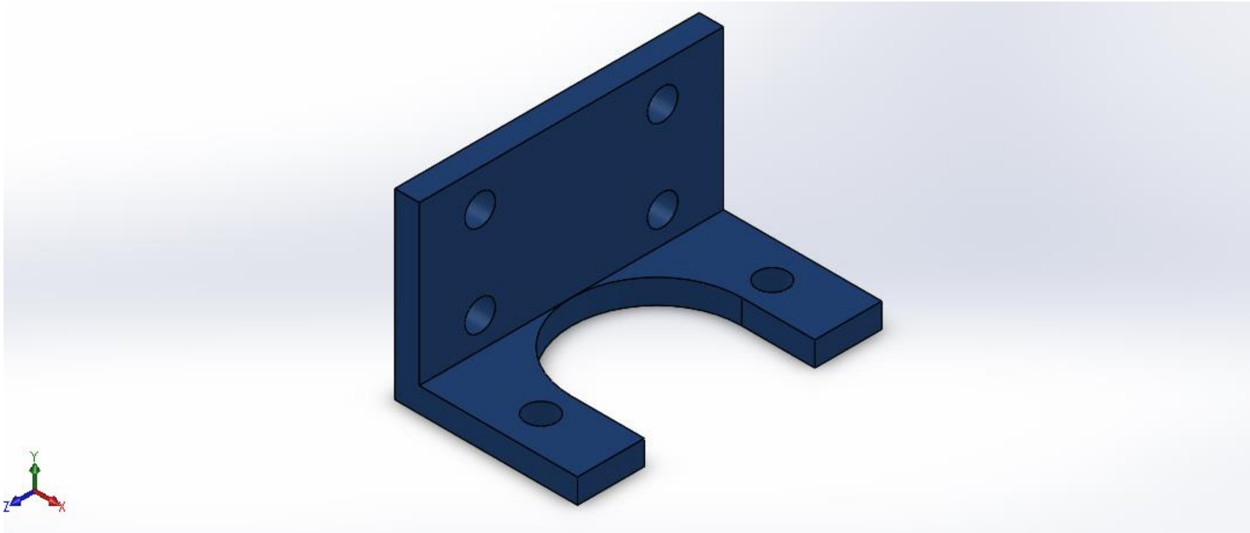


Figure 21: Joining fixture for stepper motor

7. Lead screw

Figure 22: Lead screw

8. Motor mount

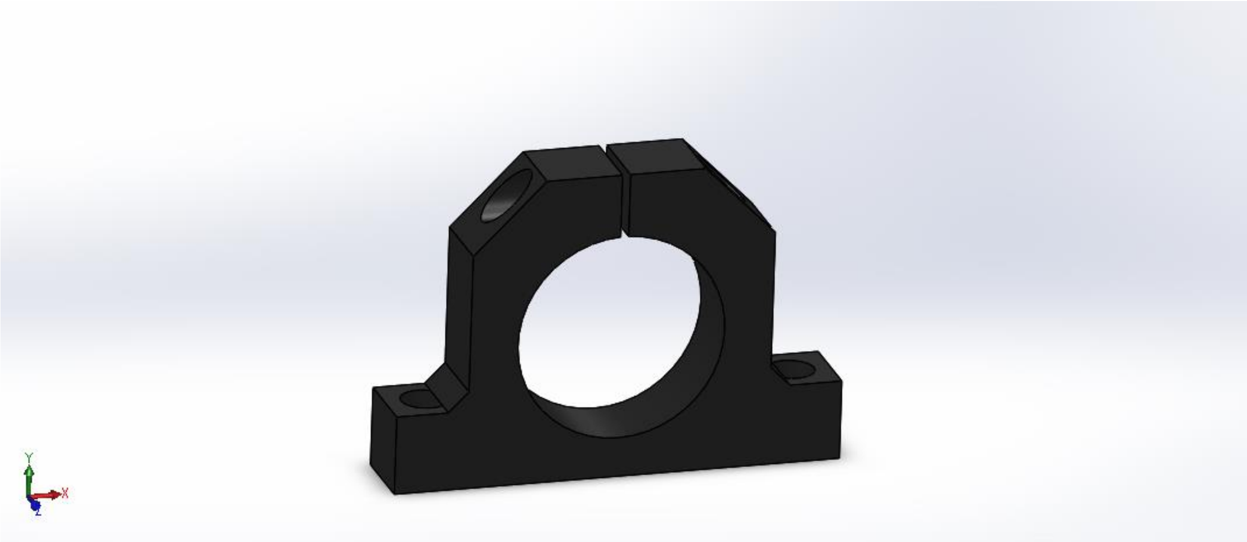


Figure 23: Motor mount

9. Plate for attaching suspended drilling machine

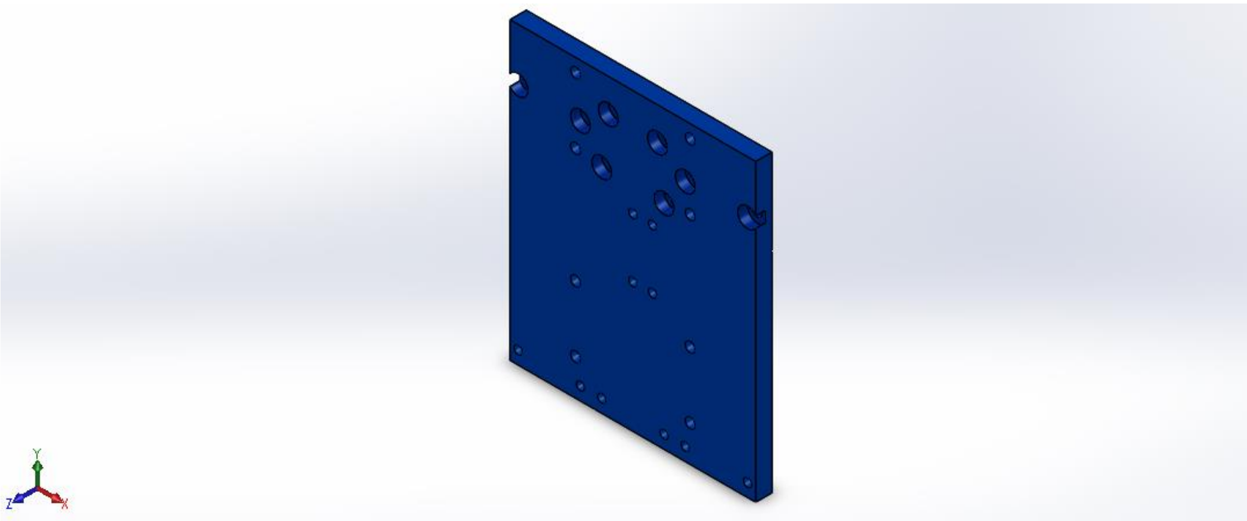


Figure 24: Plate for attaching suspended drilling machine

10. Shaft for the screw mechanism for bed

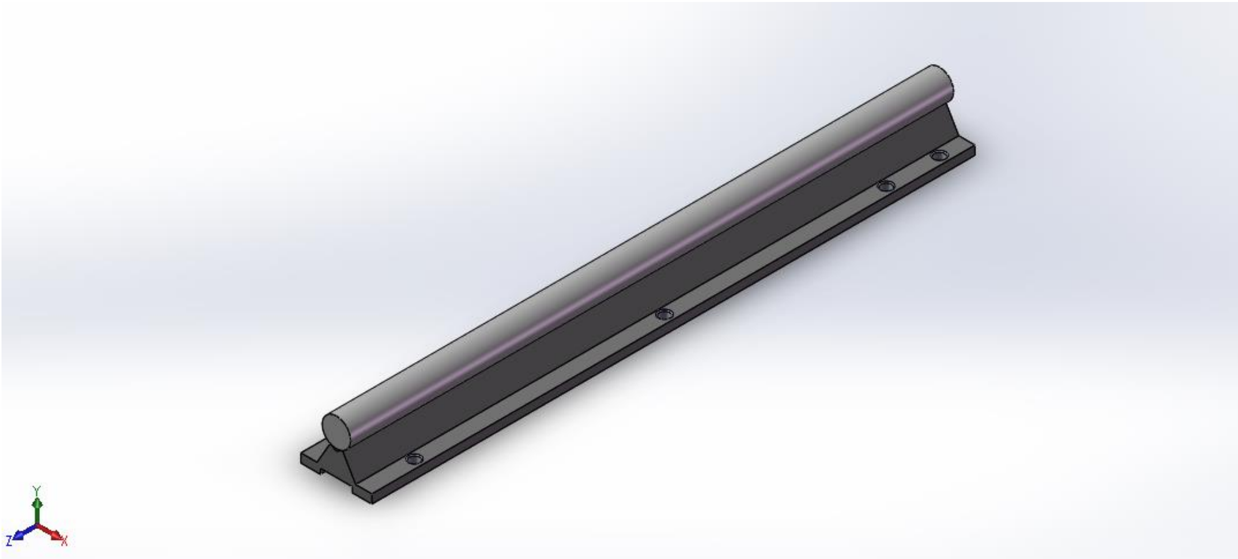


Figure 25: Shaft for the screw mechanism for bed

11. Shaft guide for bed

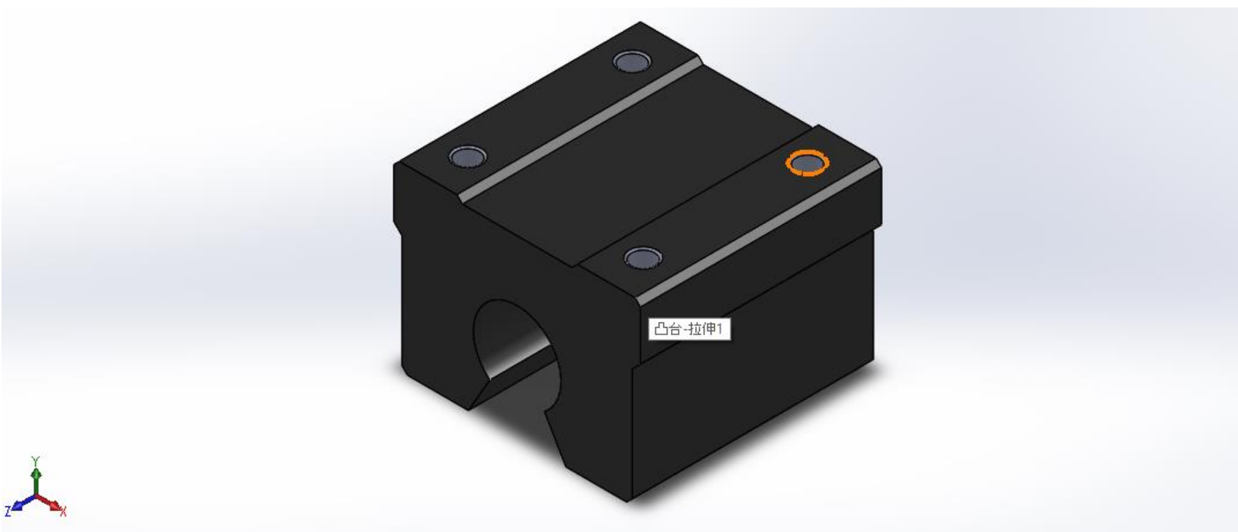


Figure 26: Shaft guide for bed

12. Stepper motor

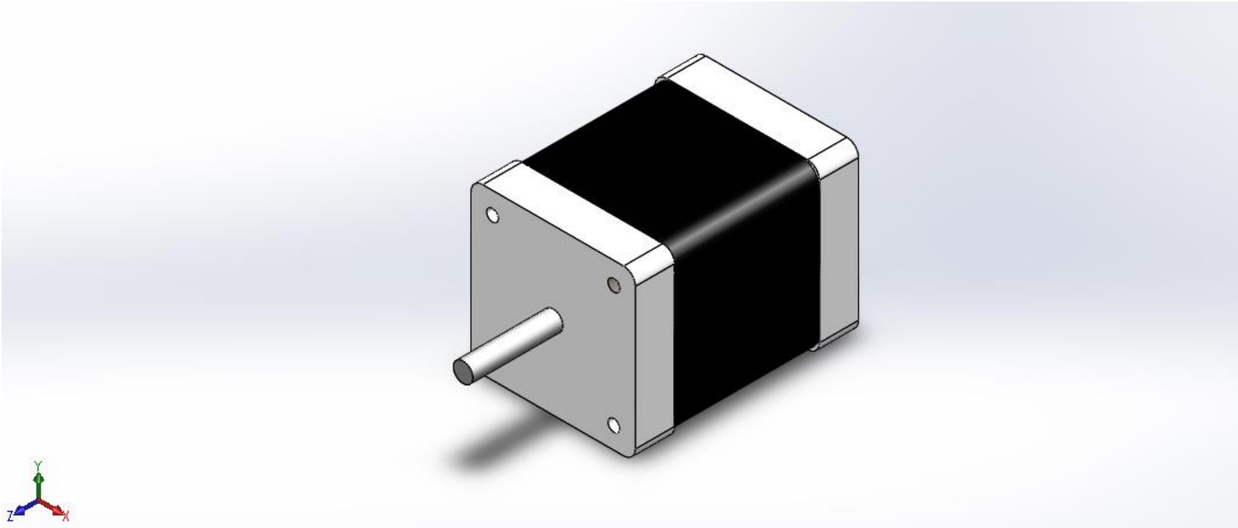


Figure 27: Stepper motor

13. Vertical framework for suspension

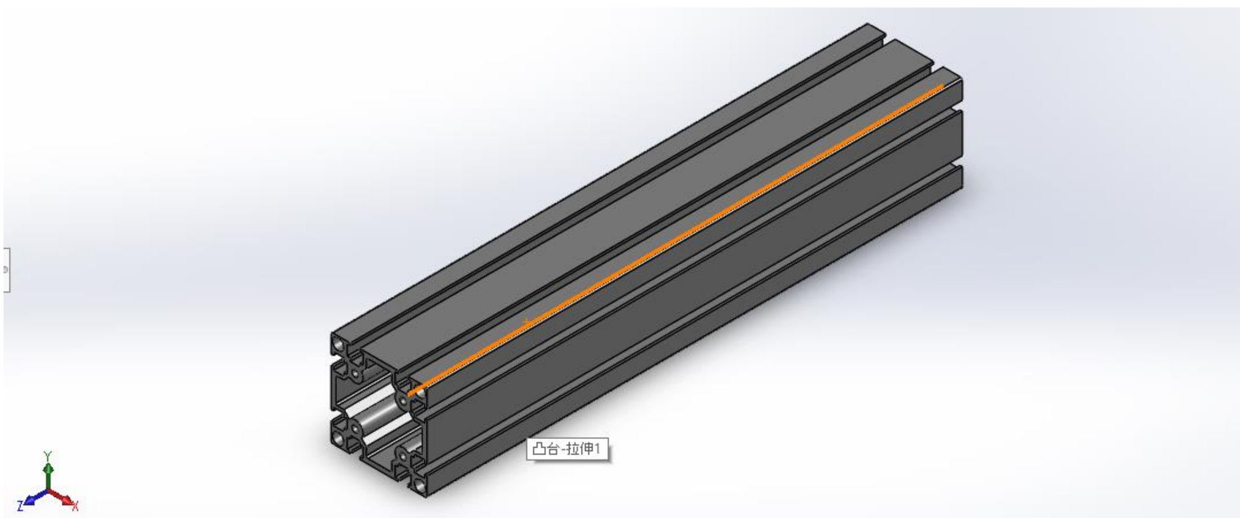


Figure 28: Vertical framework for suspension

14. Base and suspension framework

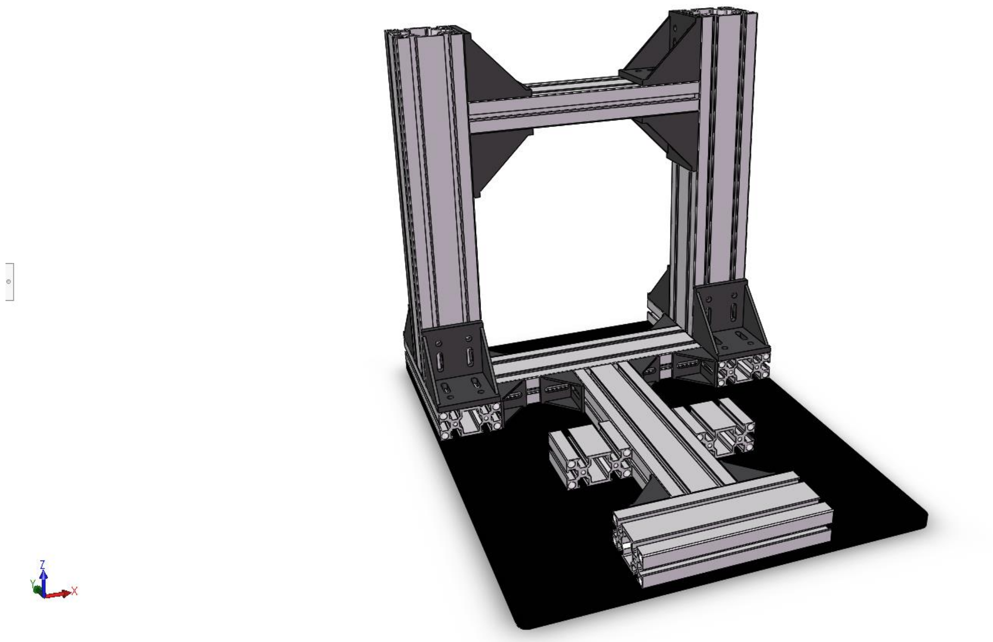


Figure 29: Base and suspension framework

15. Bed

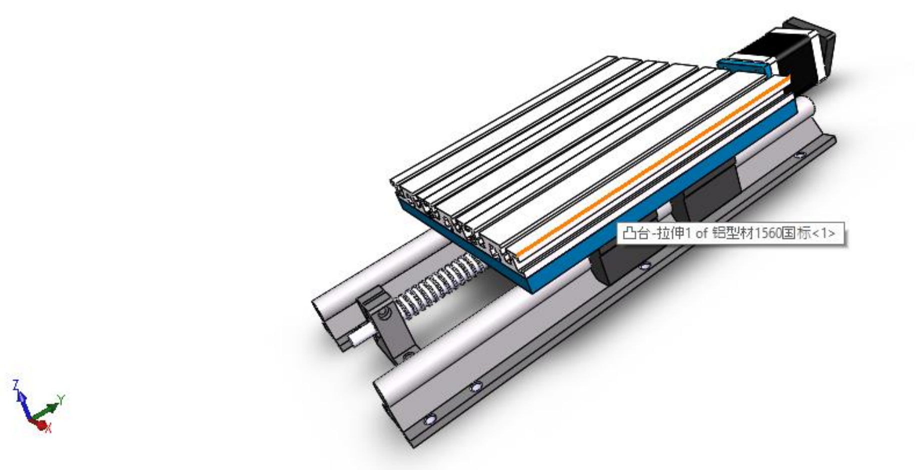


Figure 30: Bed

16. Ball screw mechanism

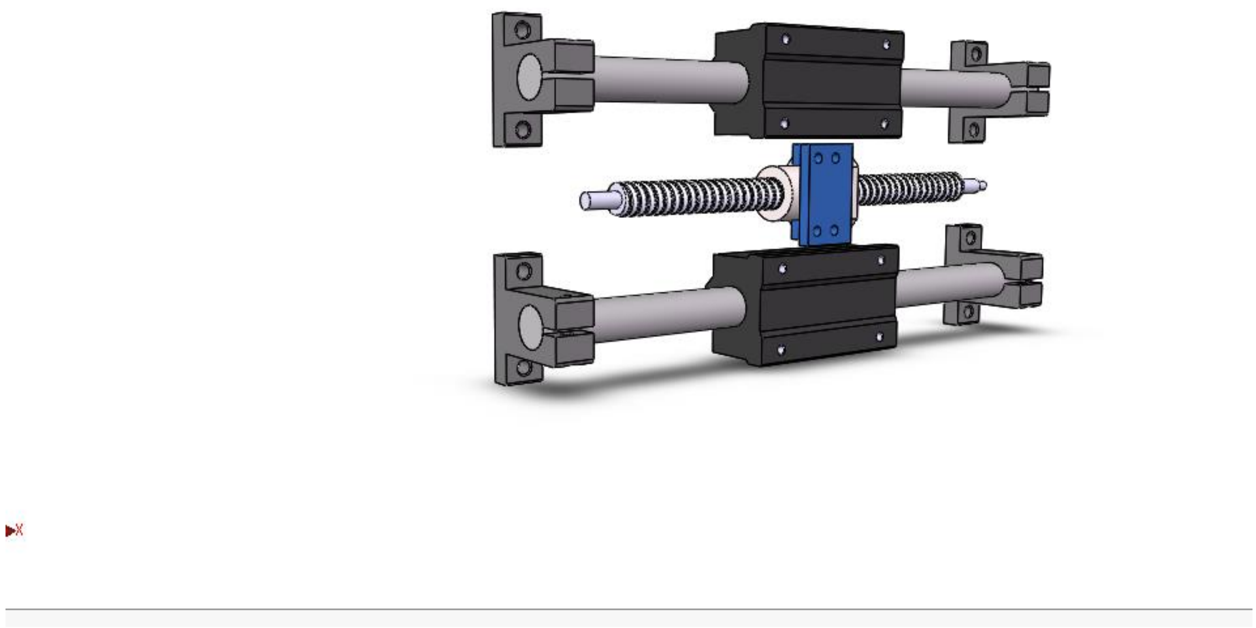


Figure 31: Ball screw mechanism

17. Suspended framework

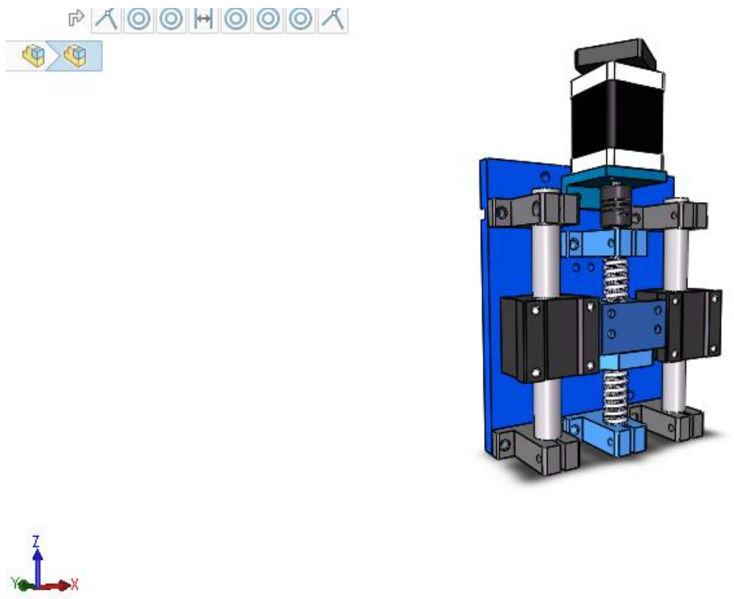


Figure 32: Suspended framework

18. Motor Bracket

Figure 33: Motor Bracket

19. CNC PCB Plotter

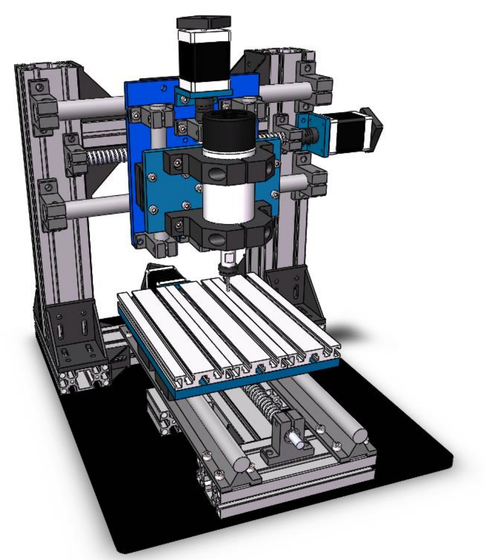


Figure 34: CNC PCB Plotter

5.3 Conclusion

Design analysis for our CNC PCB Plotter was done using Solidworks 2018. With detailed part drawing and assemble of those parts gave us a clear concept of the product. This also helped us in doing material selection and selection of manufacturing process. Basic information of parts for cost analysis was also available here.

Chapter 6

Material Selection using Weighted Average Method

6.1 Introduction

As it stands for any product the selection of the proper materials is very important. This avoids failure of the parts during operation and also reduces cost as well as helps the production process. The wrong material can be the only cause for an otherwise perfect design to fail. It will not only fail to meet expectations but it might also be the root of disastrous failures which may lead to injuries if the machine is powered and has cutting instruments attached. It is a huge waste of resources and renders the entire process as a fail.

For designing our product, we divided the entire thing into three different parts for consideration. Then we analyzed and assessed the different types of forces these members might face during the operation. We considered cases of both static and dynamic loads as well as the different stresses (tensile, shear) that might work on the material.

The analysis inferred that using different materials in different parts of the machine would prove to be effective the lower part of the machine can be made from steels as it requires structural rigidity and the suspended part has to be made from lightweight aluminum as that would prevent any deformation due to the tensile loads that might develop due to its weight. we also opted for harder and more rigid materials for the power transmission assembly to avoid any deformation due to the torque.

Our ethos for the entire material selection was to avoid any kind of deformation due to yielding caused by any force as the machine has to be precise in its operation and any deformation in any on the axis would result in disastrous failures.

6.2 Structural Parts for CNC PCB Plotter

1. Lower Body Suspension Support Framework (bed and suspension support framework)
2. Upper Body Suspended Framework (gear motor case, and movement rails)
3. Power Transmission Assembly (ball screws, stepper motor cases)

6.3 Material Selection: Lower Body Suspension Support Framework (base and suspension support framework)

6.3.1 Determination of Relative Importance of Goals using Digital Logic Method

Table 3: Chart for determining Relative Importance of goals using Digital Logic Method

Selection Criteria	**Number of Positive Decisions, N= n(n-1)/2= 7*6/2= 21**																					**Positive Decision**	**Relative emphasis co-efficient, α**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
Material Cost	1	0	0	0	0	1																2	.095
Availability	0						0	1	0	0	1											2	.095
Young's Modulus		1					1					1	1	0	1							5	.238
Ultimate Tensile Strength			1					0				0				0	0	0				1	.048
Yield Strength				1					1				0			1			1	1		5	.238
Shear Modulus					1					1				1			1		0		1	5	.238
Machinability						0					0				0			1		0	0	1	.048
Total Number of Positive Decisions																						21	∑α=1.00

6.3.2 Calculation of the Performance Index of Lower Body Suspension Support Framework

The digital logic table is constructed for various properties. Almost all of these properties have units which mean they can be compared based on numeric values. But there also quantities which do not have units and thus cannot be assigned any numerical value. These are compared based on their preferences. While we are making the performance index, these properties are assigned values based on their relative scored on the mentioned property. For example, ordinarily mild steel is easily available but aluminum 5052 is not. So in case of availability mild steel will score a 5 but aluminum 5052 will score a 1.

Table 4: Property table

Property	**Grade 304 SS**	**AISI 1018 MS**	**AISI 1020 MS**	**Aluminum 5052**
Material Cost(Tk/kg)	175	72	72	375
Young's Modulus(GPa)	193	205	205	69.3
Ultimate Tensile Strength(MPa)	505	440	420	262
Yield Strength(MPa)	215	370	350	214
Shear modulus(GPa)	86	80	80	25.9

6.3.3 Numerical Rating for Availability and Machinability

Table 5: Chart for relative evaluation values

Proficiency	**Numerical Value**
High	5
Medium	3
Low	1

Table 6: Chart for evaluation of Specifications

Criteria	**Grade 304 SS**	**AISI 1018 MS**	**AISI 1020 MS**	**Aluminum 5052**
Availability	5	5	5	1
Machinability	3	5	3	3

6.3.4 Formula Used

1. For goals: Young's Modulus, Ultimate Tensile Strength, Yield Strength, Shear Modulus, Machinability, Availability-

$$Scaled\ Property, \beta\ = \frac{Numerical\ value\ of\ property}{Maximum\ value\ in\ list} \times 100$$

2. For goals: Material Cost-

$$Scaled\ Property, \beta\ = \frac{Minimum\ value\ in\ list}{Numerical\ value\ of\ property} \times 100$$

6.3.5 Material Selection by Weighted average method for Lower Body Suspension Support Framework

Table 7: Material Selection by Weighted average method for Lower Body Suspension Support Framework

Selection Criteria	**Weight (α)**	**Grade 304 SS**		**AISI 1018 MS**		**AISI 1020 MS**		**Aluminum 5052**	
		β	αβ	β	αβ	β	αβ	β	αβ
Material Cost	.095	41.14	3.91	100	9.5	100	9.5	20.28	1.93
Availability	.095	100	9.5	100	9.5	100	9.5	20	1.9
Young's Modulus	.238	94.15	22.40	100	23.8	100	23.8	33.80	8.04
Ultimate Tensile Strength	.048	100	4.8	87.13	4.18	83.16	3.99	51.88	2.49
Yield Strength	.238	58.11	13.83	100	23.8	94.6	22.51	57.84	13.77
Shear Modulus	.238	100	23.8	93.02	22.14	93.02	22.14	30.12	7.17
Machinability	.048	60	2.88	100	4.8	60	2.88	60	2.88
			81.12		**97.72**		94.32		38.18

6.3.6 Result

Material Performance Index is greatest (97.72) for **AISI 1080 MS**.

So, we selected AISI 1080 MS for Lower Body Suspension Support Framework

6.4 Material Selection: Upper Body Suspended Framework (gear motor case, and movement rails)

6.4.1 Determination of Relative Importance of Goals using Digital Logic Method

Table 8: Chart for determining Relative Importance of goals using Digital Logic Method

Selection Criteria	**Number of Positive Decisions, N= n(n-1)/2= 7*6/2= 21**																					**Positive Decision**	**Relative emphasis co-efficient, α**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
Material Cost	0	0	1	1	0	0																2	.095
Availability	1						0	1	0	0	0											2	.095
Young's Modulus		1					1					1	1	0	0							4	.190
Ultimate Tensile Strength			0					0				0				1	0	0				1	.048
Shear Modulus				0					1				0			0			0	0		1	.048
Weight /Density					1					1				1			1		1		0	5	.238
Yield Strength						1					1				1			1		1	1	6	.286
Total Number of Positive Decisions																						21	∑α=1.00

6.4.2 Calculation of the Performance Index of Upper Body Suspended Framework

The digital logic table is constructed for various properties. Almost all of these properties have units which mean they can be compared based on numeric values. But there also quantities which do not have units and thus cannot be assigned any numerical value. These are compared based on their preferences. While we are making the performance index, these properties are assigned values based on their relative scored on the mentioned property. For example, ordinarily mild steel is easily available but aluminum 5052 is not. So in case of availability mild steel will score a 5 but aluminum 5052 will score a 1.

Table 9: Property table

Property	Grade 304 SS	Aluminum 5052	Aluminum 6061
Material Cost(Tk/Kg)	175	375	375
Young's Modulus(GPa)	193	69.3	68.9
Ultimate Tensile Strength (MPa)	505	262	310
Shear Modulus(GPa)	86	25.9	26
Density(Kg/m^3)	8000	2680	2700
Yield Strength(MPa)	215	214	276

6.4.3 Numerical Rating for Availability

Table 10:Chart for relative evaluation values

Proficiency	Numerical Value
High	5
Medium	3
Low	1

Table 11: Chart for evaluation of Specifications

Criteria	Grade 304 SS	Aluminum 5052	Aluminum 6061
Availability	5	1	3

6.4.4 Formula Used

1. For goals: Young's Modulus, Ultimate Yield Strength, Shear Modulus-

$$Scaled\ Property, \beta\ = \frac{Numerical\ value\ of\ property}{Maximum\ value\ in\ list} \times 100$$

2. For goals: Material Cost, Density-

$$Scaled\ Property, \beta\ = \frac{Minimum\ value\ in\ list}{Numerical\ value\ of\ property} \times 100$$

6.4.5 Material Selection by Weighted average method for Upper Body Suspended Framework

Table 12: Chart for Material Selection by Weighted average method for Upper Body Suspended Framework

Selection Criteria	Weight (α)	Grade 304 SS		Aluminum 5052		Aluminum 6061	
		β	αβ	β	αβ	β	αβ
Material Cost	.095	100	9.5	46.67	4.43	46.67	4.43
Availability	.095	100	9.5	20	1.9	60	5.7
Young's Modulus	.190	100	19	35.90	6.82	35.70	6.78
Ultimate Tensile Strength	.048	100	4.8	51.88	2.49	61.39	2.95
Shear Modulus	.048	100	4.8	30.12	1.44	30.23	1.45
Density	.238	33.50	7.97	100	23.8	99.26	23.62
Yield Strength	.286	77.89	22.28	77.53	22.17	100	28.6
			77.85		63.05		73.53

6.4.6 Result

Material Performance Index is greatest (77.85) for **Grade 304 SS**.

So, we should select **Grade 304 SS** for Upper Body Suspended Framework.

6.5 Material Selection: Power Transmission Assembly (ball screws, stepper motor cases)

6.5.1 Determination of Relative Importance of Goals using Digital Logic Method

Table 13: Table 1- Chart for determining Relative Importance of goals using Digital Logic Method

Selection Criteria	**Number of Positive Decisions, N= n(n-1)/2= 6*5/2= 15**															**Positive Decision**	**Relative emphasis co-efficient, α**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Material Cost	0	0	1	1	0											2	.133
Availability	1					0	0	0	0							1	.067
Yield Strength		1				1				1	1	0				4	.267
Young's Modulus			0				1			0			1	0		2	.133
Endurance Limit				0				1			0		0		0	1	.067
Shear Modulus					1				1			1		1	1	5	.333
Total Number of Positive Decisions																15	∑α=1.00

6.5.2 Calculation of the Performance Index of Power Transmission Assembly

The digital logic table is constructed for various properties. Almost all of these properties have units which mean they can be compared based on numeric values. But there also quantities which do not have units and thus cannot be assigned any numerical value. These are compared based on their preferences. While we are making the performance index, these properties are assigned values based on their relative scored on the mentioned property. For example, ordinarily mild steel is easily available but aluminum 5052 is not. So in case of availability mild steel will score a 5 but aluminum 5052 will score a 1.

Table 14: Property Table

Property	Grade 304 SS	AISI 1018 MS	AISI 1020 MS
Material Cost(Tk/kg)	175	72	72
Yield Strength(MPa)	215	370	350
Young's Modulus(GPa)	193	205	205
Endurance Limit(MPa)	240	320	320
Shear Modulus(GPa)	86	80	80

6.5.3 Numerical Rating for Availability

Table 15: Chart for relative evaluation values

Proficiency	Numerical Value
High	5
Medium	3
Low	1

Table 16: Chart for evaluation of Specifications

Criteria	Grade 304 SS	AISI 1018 MS	AISI 1020 MS
Availability	5	5	3

6.5.4 Formula Used

1. For goals: Young's Modulus, Endurance Limit, Yield Strength, Shear Modulus-

$$Scaled\ Property, \beta\ = \frac{Numerical\ value\ of\ property}{Maximum\ value\ in\ list} \times 100$$

2. For goals: Material Cost-

$$Scaled\ Property, \beta\ = \frac{Minimum\ value\ in\ list}{Numerical\ value\ of\ property} \times 100$$

6.5.5 Material Selection by Weighted average method for Power Transmission Assembly

Table 17: Chart for Material Selection by Weighted average method for Power Transmission Assembly

Selection Criteria	Weight (α)	Grade 304 SS		AISI 1018 MS		AISI 1020 MS	
		β	αβ	β	αβ	β	αβ
Material Cost	.133	41.14	5.47	100	13.3	100	13.3
Availability	.067	100	6.7	100	6.7	60	4.02
Yield Strength	.267	58.11	15.51	100	26.7	94.59	25.25
Young's Modulus	.133	94.15	12.52	100	13.3	100	13.3
Endurance Limit	.067	75	5.025	100	6.7	100	6.7
Shear Modulus	.333	100	33.3	93.02	30.98	93.02	30.98
			75.525		**97.68**		93.58

6.5.6 Result

Material Performance Index is greatest (97.68) **AISI 1018 MS**.

So, we should select **AISI 1018 MS** for Power Transmission Assembly.

Conclusion

Among a number of close alternatives, we have selected the most suitable material for different components of our product “CNC PCB Plotter” by using the Weighted Average Method as described. We have selected **AISI 1018 MS** for Lower Body Framework, **Grade 304 SS** for Suspended Framework and **AISI 1018 MS** for Power Transmission Assembly. Now we can move to the next stage of product design which is to select appropriate manufacturing criterion for different parts and processes.

Chapter 7

Manufacturing Process Selection by Weighted Average Method

7.1 Introduction

Manufacturing is the process of converting raw materials into finished goods. This might sound simple at first but choosing the right method for manufacturing is one of the most important stages in developing a product. The cost of the product, the way it is going to perform, the value it provides, in short everything depends on choosing the proper process of manufacturing. In this section we use the weighted average method and the digital logic method to determine the proper method for our product.

The manufacturing processes under consideration are forming, bending, extrusion for the basic forming operations. Whereas for the processes selected for material removal are mostly drilling. As we intend to keep the maintenance of our product rather simple in case of any failure, we are excluding welding as a process of joining altogether. In its place we are going to use nuts and bolts as the fasteners to hold the pieces together.

The preferable process depends on the desired properties of the finished product. The surface finish of the product, its dimensional accuracy, the necessary strength of the joint that is needed, all of it is kept under consideration while we choose the manufacturing process for the different parts. In the previous material selection chapter, the divided ours into three broad categories based on their position in the product as well the type of load they were going to face. In this chapter we are going to conduct the process selection in the same groups or clusters as before. The processes are going to be decided upon so that it can fulfill the desired qualities of the product in the final stage, and at the same time to provide minimum labor costs and durability.

7.2 Structural Parts for CNC PCB Plotter

1. Lower Body Suspension Support Framework (bed and suspension support framework)
2. Upper Body Suspended Framework (gear motor case and movement rails)
3. Power Transmission Assembly (ball screws and stepper motor cases)

7.3 Process Selection: Forming lower and upper body framework from mild steel

This process includes both the suspension support and the suspended framework.

7.3.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 18: Chart for Determining Relative Importance of Goals using Digital Logic Method

Selection criteria	Number of positive decisions, N=n(n-1)/2=5(5-1)/2=10										Positive decisions	Relative emphasis Coefficient, α
	1	2	3	4	5	6	7	8	9	10		
Cost	0	1	1	0							2	0.2
Dimensional accuracy	1				1	1	1				4	0.4
Power Requirement		0			0			1	1		2	0.2
Surface Finish			0			0		0		1	1	0.1
Availability				1			0		0	0	1	0.1
	Total Number of Positive Decisions										10	Σα =1.00

7.3.2 Calculation of the Performance Index of Forming lower and upper body framework from mild steel

The selection criteria of the Digital Logic Table are actually critical properties of the materials and processes that are to be considered for the main process. Most of the properties have exact values with units. But there were some abstract properties which have no exact units or values. These properties were defined in terms of their proficiency with which each process qualify regarding the mentioned property.

7.3.3 Numerical Rating

For cost, dimensional accuracy, power requirement, surface finish and availability.

Table 19: Chart containing relative evaluations for Specification

Proficiency	Numerical Value
Very High	5
High	4
Medium	3
Low	2
Very Low	1

Table 20: Chart containing assigned values for Specifications

	Casting	**Extrusion**
Cost	5	3
Power requirement	3	2
Surface finish	4	4
Availability	3	5
Dimensional accuracy	5	3

7.3.4 Formula Used

1. For goals: Dimensional accuracy, surface finish and availability.

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2. For goals: Cost and power requirement.

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.3.5 Calculation of Performance Index

Table 21: Chart for Calculating Performance Index

Selection Criteria	Weighting Factor α	Casting		Extrusion	
		Scaled Property β	Weighted Score αβ	Scaled Property β	Weighted Score αβ
Cost	.2	50	10	100	20
Dimensional Accuracy	.4	75	30	100	40
Power Requirement	.2	100	20	100	20
Surface Finish	.1	100	10	50	5
Availability	.1	100	10	100	10
Process Performance Index γ			80		**95**

7.3.6 Result

Process Performance Index is Greatest (95.00) for **Extrusion**. So, we should select Extrusion for forming lower and upper body framework from mild steel.

7.4 Process Selection: Cutting the framework made from mild steel

7.4.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 22: Chart for Determining Relative Importance of Goals using Digital Logic Method

Selection criteria	Number of positive decisions, N=n(n-1)/2=5(5-1)/2=10										Positive decisions	Relative emphasis Coefficient , α
	1	2	3	4	5	6	7	8	9	10		
Cost	0	1	1	0							2	0.2
Dimensional accuracy	1				1	1	1				4	0.4
Power Requirement		0			0			1	1		2	0.2
Surface Finish			0			0		0		1	1	0.1
Availability				1			0		0	0	1	0.1
	Total Number of Positive Decisions										10	Σα =1.00

7.4.2 Calculation of the Performance Index of Forming lower and upper body framework from mild steel

The selection criteria of the Digital Logic Table are actually critical properties of the materials and processes that are to be considered for the main process. Most of the properties have exact values with units. But there were some abstract properties which have no exact units or values. These properties were defined in terms of their proficiency with which each process qualify regarding the mentioned property.

7.4.3 Numerical Rating

For cost, dimensional accuracy, power requirement, surface finish and availability.

Table 23: Chart containing relative evaluations for Specification

Proficiency	Numerical Value
Very High	5
High	4
Medium	3
Low	2
Very low	1

Table 24: Chart containing assigned values for Specifications

	Leaser Cutting	Gas Cutting
Cost	5	3
Power Requirement	3	2
Surface Finish	4	4
Availability	3	5
Dimensional Accuracy	5	3

7.4.4 Formula Used

1. For goals: Dimensional accuracy, surface finish and availability.

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2. For goals: Cost and power requirement.

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.4.5 Calculation of Performance Index

Selection Criteria	Weighting Factor α	Laser Cutting		Gas Cutting	
		Scaled Property β	Weighted Score αβ	Scaled Property β	Weighted Score αβ
Cost	0.2	50	10	100	20
Dimensional Accuracy	0.4	75	30	100	40
Power Requirement	0.2	100	20	100	20
Surface Finish	0.1	100	10	50	5
Availability	0.1	100	10	100	10
Process Performance Index γ			80		**95**

7.4.6 Result

Process Performance Index is Greatest (95.00) for **Gas cutting**. So, we should select gas cutting for cutting the framework made from mild steel.

7.5 Process Selection: Forming of shafts using mild steel

7.5.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 25: Chart for Determining Relative Importance of Goals using Digital Logic Method

Selection Criteria	Number of Positive Decisions, N=n(n-1)/2=5(5-1)/2=10										Positive Decisions	Relative Emphasis Factor
	1	2	3	4	5	6	7	8	9	10		
Cost	1	0	1	0							2	0.2
Power Requirement	0				0	1	0				1	0.1
Dimensional Accuracy		1			1			1	1		4	0.4
Availability			0			0		0		0	0	0
Defects				1			1		0	1	3	0.3
Total Number of Positive Decisions											10	Σα =1.00

7.5.2 Numerical Rating

For cost, power requirement, dimensional accuracy, availability and surface defects.

Table 26: Chart containing relative evaluations for Specifications

Proficiency	**Numerical Value**
Very High	5
High	4
Medium	3
Low	2
Very low	1

Table 27: Chart containing assigned values for Specifications

	Turning	**Extrusion**
Cost	3	4
Power Requirements	3	3
Dimensional accuracy	3	4
Availability	5	3
Surface Defects	2	4

7.5.3 Formula Used

1. For goals: Dimensional accuracy, surface finish and availability.

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2. For goals: Cost and power requirement.

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.5.4 Calculation of the Performance Index for Forming of Shafts

Selection Criteria	Weighting Factor α	Turning		Extrusion	
		Scaled Property β	Weighted Score αβ	Scaled Property β	Weighted Score αβ
Cost	0.2	100	20	75	15
Power Requirement	0.1	100	10	100	10
Dimensional Accuracy	0.4	75	30	100	40
Availability	0	100	00	60	0
defects	0.3	100	30	50	15
Process Performance Index γ			**90**		80

7.5.5 Result

Process Performance Index is Greatest (90.00) for **Turning**. So, we should select Turning for forming of solid shafts from Mild Steel.

7.6 Permanent Joining Process for Different parts

7.6.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 28: Chart for Determining Relative Importance of Goals using Digital Logic Method

Selection Criteria	Number of positive decisions, N=n(n-1)/2=6(6-1)/2=15															Positive Decisions	Relative Emphasis coefficient α
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Cost	0	0	0	0	1											1	0.07
Metallurgical Changes	1					0	0	0	1							2	0.13
Defects		1				1				0	0	1				3	0.20
Residual Stress			1				1			1			1	1		5	0.33
Strength				1				1			1		0		1	4	0.27
Power Requirement					0				0			0		0	0	0	00
Total Number of Positive Decisions																15	Σα =1.00

7.6.2 Numerical Rating

For cost, metallurgical change, defects, residual stress, strength and power requirement.

Table 29: Chart containing relative evaluations for Specifications

Proficiency	Numerical Value
Very High	5
High	4
Medium	3
Low	2
Very low	1

Table 30: Chart containing assigned values for Specifications

	Spot Welding	Resistance Welding
Cost	3	4
Metallurgical Change	3	2
Defects	3	3
Residual Stress	4	3
Strength	4	2
Power Requirements	4	4

7.6.3 Formula Used

1.For goals: Strength

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2.For goals: Cost, metallurgical change, power requirements, defects and residual stress

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.6.4 Calculation of the Performance Index

Table 31: Chart for Determining Performance Index

Selection Criteria	Weighting Factor α	Turning		Extrusion	
		Scaled Property β	Weighted Score αβ	Scaled Property β	Weighted Score αβ
Cost	0.07	100	7	75	5.25
Metallurgical Changes	0.13	66.67	8.67	100	13
Defects	0.20	100	20	100	20
Residual Stress	0.33	75	24.75	100	33
Strength	0.27	100	27	50	13.5
Power Requirement	0.0	100	00	100	0
Process Performance Index γ			**87.42**		84.75

7.6.5 Result

Process Performance Index is Greatest (87.42) for **Spot Welding**. So, we should select Spot Welding for permanent joining.

7.7 Temporary Joining Process for Different parts

7.7.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 32: Chart for determining Relative Importance of Goals using Digital Logic Method

Selection Criteria	Number of Positive Decisions, N=n(n-1)/2=4(4-1)/2=6						Positive Decisions	Relative Emphasis coefficient α
	1	2	3	4	5	6		
Cost	0	0	0				0	0.00
Strength	1			1	1		3	0.50
Reliability		1		0		1	2	0.33
Design Flexibility			1		0	0	1	0.17
Total Number of Positive Decisions							6	Σα =1.00

7.7.2 Numerical Rating

For cost, strength, reliability, design flexibility.

Table 33: Chart containing relative evaluations for Specifications

Proficiency	**Numerical Value**
Very High	5
High	4
Medium	3
Low	2
Very low	1

Table 34: Chart containing assigned values for Specifications

	Nut-Bolt	**Riveting**
Cost	3	3
Strength	4	5
Reliability	4	3
Design Flexibility	3	1

7.7.3 Formula Used

1.For goals: Strength, reliability and design flexibility

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2.For goals: Cost

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.7.4 Calculation of the Performance Index

Table 35: Chart for Determining Performance Index for Temporary Joining

Selection Criteria	**Weighting Factor α**	**Turning**		**Extrusion**	
		Scaled Property β	**Weighted Score αβ**	**Scaled Property β**	**Weighted Score αβ**
Cost	0.00	100	0	100	0
Strength	0.50	80	40	100	50
Reliability	0.33	100	33	75	24.75
Design Flexibility	0.17	100	17	20	3.40
Process Performance Index γ			**<u>90</u>**		78.15

7.7.5 Result

Process Performance Index is Greatest (90.00) for **<u>Nut-bolt</u>**. So, we should select Nut-bolt for temporary joining.

7.8 Finishing Process

7.8.1 Determination of Relative Importance of Goals Using Digital Logic Method

Table 36: Chart for determining Relative importance of Goals using Digital Logic Method

Selection Criteria	**Number of Positive Decisions, N=n(n-1)/2=4(4-1)/2=6**						**Positive Decisions**	**Relative Emphasis coefficient α**
	1	2	3	4	5	6		
Cost	0	0	1				1	0.17
Smoothness	1			0	1		2	0.33
Material Wastage		1		1		1	3	0.50
Availability			0		0	0	0	0.00
Total Number of Positive Decisions							6	Σα =1.00

7.8.2 Numerical Rating

For cost, smoothness, material, wastage and availability.

Table 37: Chart containing relative evaluations for Specifications

Proficiency	**Numerical Value**
Very High	5
High	4
Medium	3
Low	2
Very low	1

Table 38: Chart containing assigned values for Specifications

	Precision Finishing	**Non- Precision Finishing**
Cost	5	3
Smoothness	5	3
Material Availability	4	3
Availability	4	3

7.8.3 Formula Used

1.For goals: Smoothness and availability.

$$\text{Scaled Property, } \beta = \frac{\text{Numerical value of property}}{\text{Maximum value in list}} \times 100$$

2.For goals: Cost and material wastage

$$\text{Scaled Property, } \beta = \frac{\text{Minimum value in list}}{\text{Numerical value of property}} \times 100$$

7.8.4 Calculation of the Performance Index

Table 39: Chart for Determining the Performance Index for Finishing process

Table 40: Chart for Determining the Performance Index for Finishing process

Selection Criteria	**Weighting Factor α**	**Turning**		**Extrusion**	
		Scaled Property β	**Weighted Score αβ**	**Scaled Property β**	**Weighted Score αβ**
Cost	0.17	60	10.2	100	17
Smoothness	0.33	100	33	60	19.8
Material Wastage	0.50	75	37.5	100	50
Availability	0.00	75	00	100	00
Process Performance Index γ			80.7		**86.8**

7.8.5 Result

Process Performance Index is Greatest (86.8) for **Non-Precision Finishing** (Grinding). So, we should select Non-Precision Finishing (Grinding) for finishing process.

Conclusion

We conclude that we have selected multiple manufacturing process for our 'PCB CNC plotter' from a variety of alternatives by means of systematic procedure of Weighted Average and Digital Logic Method.

Chapter 8

Cost Analysis

8.1 Introduction

Cost analysis is the process of breaking down and calculating the cost for every element in the product. This process is very important in every product now a day because the market for almost every product is competitive, even if the product is original. And in order to make a product profitable it is essential to make sure that it does not incur any unnecessary cost. In order to do this, we have to obtain a clear picture of all the different costs which add up for the product, and a cost analysis enables us to make this exact diagram which in turn helps us to replace or eliminate a cost which does not contribute to the product. A cost analysis also shows us how profitable a product will be in the long run.

Product cost is composed of the costs incurred in making the product available to the market. That is, it includes direct labor, direct material and manufacturing overhead costs and nothing else. A very confusing and misunderstood aspect of a cost analysis is that the cost incurred in developing a prototype is not to be included in the product costs. Which means costs incurred for design analysis, engineering analysis and such other cases are to be excluded from the calculations. These processes although very expensive are to be kept separate from the calculations as the product costs are to include the actual manufacturing costs which are directly associated with the product only.

A competitive product must address factors such as cost, performance, aesthetics, schedule or time to-market, and quality. The importance of these factors will vary from product to product and market to market.

Cost is an important factor in the acquisition of a product in the following two situations.

(i) As the technology and aesthetics of a product stabilizes, competition tends to become increasingly based on cost.

(ii) A customer's financial limitations may shift the acquisition decision toward affordability as a more dominant factor.

In either case, a successful product supplier must focus more attention on managing product cost. The management of product cost begins with the conception of a new product. Typically, sixty to seventy percent of a product's cost or life cycle costs are committed based on decisions made during concept or architecture development. Eighty-five to ninety percent of a product's cost or life cycle cost is committed by the time that the product has been designed and its manufacturing process has been developed. Design to cost is a management strategy and supporting methodologies to achieve an affordable product by treating target cost as an independent design parameter that needs to be achieved during the development of a product.

The cost analysis approach consists of the following elements:

- An understanding of the product's cost drivers and consideration of cost drivers in establishing product specifications and in focusing attention on cost reduction
- Establishment and allocation of target costs down to a level of the hardware where costs can be effectively managed
- Balancing customer requirements with affordability
- Exploration of concept and design alternatives for the purpose of developing lower cost design approaches
- Active consideration of costs during development as an important design parameter appropriately weighted with other decision parameters
- Access to cost data to support this process and empower development team members
- Consistency of accounting methods between cost systems and product cost models as well as periodic validation of product cost models
- Continuous improvement through value engineering to improve product value over the longer term.

Product development personnel must understand competitive pricing or customer affordable requirements. Target cost must be established at the start and used to guide decision-making.

We have performed the required cost analysis from the viewpoint of a mass production system. A break-even analysis is also given.

8.2 Cost Analysis

8.2.1 Machine and Associated cost

1. **Industrial Manual Turret Lathe** (Brand name: DATAN, China, Model-CDE)
   Buying cost: 5,60,000 Tk.
   Life: 25 yrs.
   Quantity: 1
   Salvage Value: 25,000 Tk.

2. **Spot Welding Machine** (Brand name: Zhouxiang, China (mainland), Model-HZJ1500)
   Buying cost: 18,00,000
   Life: 30 yrs.
   Quantity: 1
   Salvage Value: 30,000 Tk.

3. **600-ton Extrusion Hydraulic Press forging Machine** (Brand name: YIHUI, Guangong, China (mainland), Model-YHAI)
   Buying cost = 40,00,000 Tk.
   Life = 30 Yrs.
   Quantity = 1
   Salvage Value: 50,000 Tk.

4. **Portable Gas Cutting Torch** (Brand name: UWELD, China, Model-IC005_0012)
   Buying cost: 1125 Tk.
   Life = 25 Yrs.
   Quantity = 2
   Salvage Value: 300 Tk.

5. **Non Precision Grinding Machine** (Brand name: Sunlike machineries, Taiwan, model no. Sk-65080)
   Buying cost: 1,29,000 Tk.
   Life = 25 Yrs.
   Quantity = 1
   Salvage Value: 10,000 Tk.

6. **Drilling machine** (Brand name: Bosch GWS Professionals, China, Model-6-100)
   Buying cost = 2,00,000 Tk.
   Life = 5 Yrs.
   Quantity = 1
   Salvage Value: 15,000 Tk.

Total Machine cost = 66,91,250 Tk.

8.2.2 Cost of furniture, computer and other accessories

Total Furniture & accessories cost for office: 2,75,000 Tk.

Life: 10 Yrs.

Computer cost: 2,50,000 Tk.

Life: 10 Yrs.

8.2.3 Cost of raw materials (per unit of production)

1. **AISI 1018 MS**
   Raw material required = 10 Kg
   Market Price of raw material = 72 Tk. Per Kg
   Total cost = 720 Tk.
2. **Grade 304 SS**
   Raw material required = 5 kg
   Market price of raw material = 175 Tk. Per Kg
   Total cost = 875 Tk.

Total raw material cost per unit production = 1595 Tk.

Total raw material cost per year = (1595*3000) = 47,85,000 Tk.

8.2.4 Manufacturing costs of different operations (per month)

- **Extrusion**
  Labor Cost
  No of workers = 4
  Wage/labor = 12,000 Tk.
  Total Labor cost = 48,000 Tk.

- **Cutting**
  Labor Cost
  No of workers = 2
  Wage/labor = 10,000 Tk.
  Total Labor cost = 20,000 Tk.

- **Drilling**
  Labor cost
  No of workers = 1
  Wage/labor = 12,000 Tk.
  Total Labor cost = 12,000 Tk.

- **Assembly and Joining**
  Labor cost
  No of workers = 2
  Wage/labor = 13,000 Tk.
  Total Labor cost = 26,000 Tk.

- **Quality Control**
  Labor cost
  No of workers = 2
  Wage/labor = 14,000 Tk.
  Total Labor cost = 28,000 Tk.

- **Finishing Operations**
  Labor cost
  No of workers = 2
  Wage/labor = 10,000 Tk.
  Total Labor cost = 20,000 Tk.

- **Packaging Operations**
  Labor cost
  No of workers = 2
  Wage/labor = 8,000 Tk.
  Total Labor cost = 16,000 Tk.

Total labor cost per month = 1,70,000 Tk.

Total labor cost per year = 20,40,000 Tk.

8.2.5 Purchasing Cost

Below is a list of parts which we are going to purchase.

Table 41: Chart of cost of parts needed to purchase

Serial No.	**Name of Components**	**Quantity**	**Price in Tk.**
01.	NEMA 17	3	500*3=1500
02.	Spindle Motor	1	4000*1=4000
03.	Drill Bit Set	1	150*1=150
04.	Ball screw	2	1350*2=2700
05.	Arduino	1	2300*1=2300
06.	Nuts and Bolts	-	25
07.	Spindle Fixture	1	500*1=500
08.	Wire and Connectors	-	100
		Total	11,275 Tk.

Purchasing cost per year (11,275*3000) = 3,38,25,000 Tk.

8.2.6 Manufacturing Cost

- **Direct material cost**
  Raw material cost = 47,85,000 Tk.
  Purchasing cost = 3,38,25,000 Tk.
  Total direct material cost per year = 3,86,10,000 Tk.
- **Direct labor cost**
  Labor cost per year = 20,40,000 Tk.
- **Manufacturing overhead**

Table 42: Chart of manufacturing overhead

Cost Item	**Number of Posts**	**Salary per Person (Tk.)**	**Total (Tk.)**
Production Manager	1	40,000	40,000
Manufacturing Engineer	1	35,000	35,000
Design Engineer	1	30,000	30,000
Assemble Manager	1	25,000	25,000
Quality Control Manager	1	30,000	30,000
Supply Chain Manager	1	35,000	35,000
Power Consumption	N/A		40,000
Factory Rent	N/A		60,000
		Total	2,60,000

Total manufacturing overhead par month = 2,60,000 Tk.
Total manufacturing overhead par year = (2,60,000*12) = 31,20,000 Tk.

Total manufacturing cost per year = **4,37,70,000 Tk.**

8.2.7 Selling and Administrative Expenses

- Administrative Cost

Table 43: Chart for administrative cost

Post	Number of Posts	Salary per Person (Tk.)	Total (Tk.)
CEO	1	1,00,000	1,00,000
HR Manager	1	60,000	60,000
Accountant	1	40,000	40,000
Secretary	2	20,000	40,000
Clerk	6	10,000	60,000
Guard	4	8,000	32,000
Office Rent	N/A	N/A	50,000
Power Bill	N/A	N/A	6,000
Water Bill	N/A	N/A	1,000
Internet Bill	N/A	N/A	5,000
		Total	3,94,000

Administrative Cost per month = 3,94,000 Tk.

Administrative Cost per year = (3,94,000*12) = 47,28,000 Tk.

- Selling Expenses

Table 44: Chart for selling expenses

Cost Item	Number of Post	Salary per Person (Tk.)	Total (Tk.)
Marketing Executive Manager	1	30,000	30,000
Sales Representative	4	15,000	60,000
		Total	90,000

Selling expenses per month = 90,000 Tk.
Selling expenses per year = (90,000*12) = 10,80,000 Tk.

Total administrative and selling cost = **58,08,000 Tk.**

8.3 Break-Even Analysis

Fixed cost

- Machine cost = 66,91,250 Tk.
- Furniture cost = 2,75,000 Tk.
- Computer Cost = 2,50,000 Tk.
- Fixed manufacturing overhead = 4,37,70,000 Tk.
- Fixed selling and administrative cost = 58,08,000

Total fixed cost = **5,67,94,250 Tk.**

Variable Cost (for 3000 units)

- Raw material cost = 47,85,000 Tk.
- Purchasing cost = 3,38,25,000 Tk.
- Labor cost = 20,40,000 Tk.

Total variable cost per year = 4,06,50,000 Tk.

Total variable cost per unit production = 13,550 Tk.

Selling price per unit = **20,000 Tk**.

The equation for break-even analysis:

At break-even point

Selling price × break-even unit = Fixed cost + Variable cost

So the equation stands as:

$20{,}000 \times x = 5{,}67{,}94{,}250 + 13{,}550x$

$X = 8806$

Break even quantity = 8806 units

Payback period is almost 3 years.

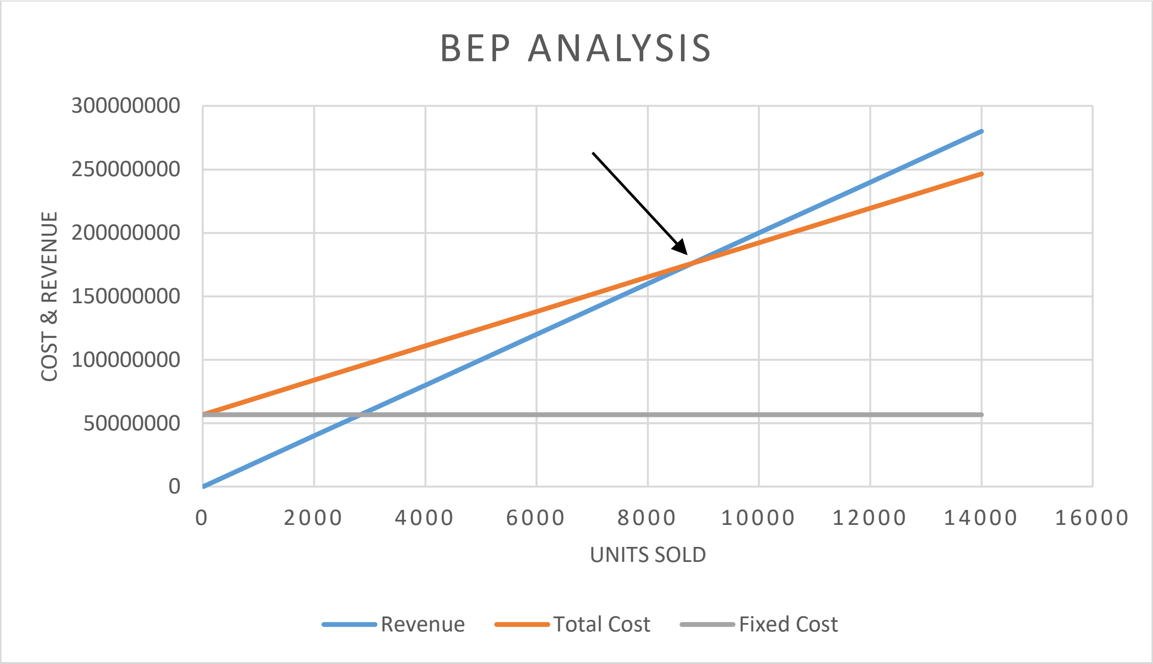


Figure 35: Break-Even analysis

8.4 Explanation on Break-even Analysis

After the analysis, we can see that break-even quantity for our product is approximately 1162 units. The interpretation of that figure is, if sales amount is exactly 8806 units, total revenue will be equal to total cost. When sales amount exceeds 8806 units, we will begin to earn profit. As our production goal is to manufacture 3000 units per year, the break-even period is roughly 3 years.

8.5 Conclusion

Product cost is a vital part of a company's cost base. During a product development process early stage there is often a lack of established methods and processes for calculation of the product cost. Especially it is difficult to estimate product cost in early stages of the product development process when the uncertainty around the construction of the product is big. That might lead to lack of knowledge around material cost and need of investments occur. Consequently, some of the costs used during cost analysis were estimates of actual value since we were not certain about their cost. But the estimates are reasonable and we have tried our best to show different types of costs related to the mass production of our product as extensively as possible. In this cost analysis - we have hold the assumption that variable cost per unit is the same regardless of the volume produced, fixed costs do not change with volume changes and the unit price is constant regardless of the market demand. But any of these factors might change in the actual market environment. Despite of this fact, cost analysis has given us the primary idea and rough estimate about the products price and approximate time to achieve the return on investments made.

Chapter 9

Conclusion

In the process of designing any product which makes use of electricity, a PCB is a must. This vital component however changes form with the product under consideration. Since the conventional process of getting a PCB made for a certain product is rather lengthy and is not very convenient, we came up with our product, a CNC PCB router which will make customized PCBs for any design project. Using our product would give the designers freedom and it would make the entire designing process more fluid, which would make the entire production process faster. Our machine brings down the cost of single unit production, is easy to operate and also is very easy to maintain with minimum running costs. Its compact size allows us to integrate it into any design lab. Adopting this product will not only ensure the best use of a designer's visions, it would also make the designing process more efficient.

Product Design-I course has helped us gain the basic idea of the product development phase- from developing the idea to finally implementing it to a 3D design software. We have learnt that a mere idea can open tremendous opportunities and if we can manipulate it systematically it can provide benefits to both the business organizations and the consumers. Developing idea is an art and Product Design is the science that converts the idea into reality.

Appendices

Appendix A: Questionnaire for the survey

Name:
Gender:
Age:
Address:
Date:

Survey Questions:

1. How often do you need a PCB?
   i) Frequently
   ii) Intermittently
   iii) Not sure
2. How often do you need a PCB readily available in the market?
   i) Frequently
   ii) Intermittently
   iii) Not sure
3. How often do you need a customized PCB?
   i) Frequently
   ii) Intermittently
   iii) Not sure
4. Is it feasible to get a single prototype PCB made for a single project?
   i) Yes
   ii) No
   iii) Not sure
5. How often do you need to change your design because the PCB available does not conform to your design?
   i) Frequently
   ii) Intermittently
   iii) Not sure
6. How expensive is it to get one PCB made which might not even be in the final project?
   i) Quite a lot
   ii) Considerable
   iii) Not sure
7. How much time do you need to get your prototype PCBs made from the PCB makers?
   i) 1 Day
   ii) 1 Week
   iii) Not sure

8. How many times did your project didn’t look up to the mark because it had wires instead of PCB?
    i) Frequently
    ii) Intermittently
    iii) Not sure
9. Do you think your project would be better if you had the chance to make your own PCB?
    i) Yes
    ii) No
    iii) Not sure
10. What is stopping you from getting a PCB for your prototype?
    i) PCB making is expensive
    ii) PCB making is time consuming
    iii) Both above
    iv) Not sure
11. Do you think that a CNC PCB maker would make your design phases and prototyping more efficient?
    i) Yes
    ii) No
    iii) Not sure

If you have and comment or suggestions regarding our product, please write down below:

Appendix B: Properties of different metals

The following tables were used for material selection:

Table 45: Chart of metal and alloy properties

Metal	Alloy and Temper	Hardness Rockwell B-Scale	Yield Strength Ksi	Yield Strength MPa	Ductility 1-very ductile 5-stiff
Aluminum	A93003-H14	20-25	21	145	1
Aluminum	A93004-H34	35-40	29	200	1
Aluminum	A95005-H34	20-25	20	138	1
Aluminum	A96061-T6	60	40	275	4
Copper	1/8 hard (cold roll)	10	28	193	1
Gilding Metal	¼ hard	32	32	221	1
Commercial Bronze	¼ hard	42	35	241	2
Jewelry Bronze	¼ hard	47	37	255	2
Red Brass	¼ hard	65	49	338	2
Cartridge Brass	¼ hard	55	40	276	1
Yellow Brass	¼ hard	55	40	276	2
Muntz Metal	1/8 hard	55	35	241	3
Architectural Bronze	As extruded	65	20	138	4
Phosphor Bronze	½ hard	78	55	379	3
Silicon Bronze	¼ hard	75	35	241	3
Aluminum Bronze	As cast	77	27	186	5
Nickel Silver	1/8 hard	60	35	214	3
Steel-low carbon	Cold rolled	60	25	170	2
Cast Iron	As cast	86	50	344	5
Stainless Steel-304	Temper pass	88	30	207	2
Lead	Sheet lead	5	0.81	5	1
Monel	Temper pass	60	27	186	3
Zinc-Cu, Tn Alloy	Rolled	40	14	97	1
Titanium	Annealed	80	37	255	3

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