Bangladesh University of Engineering and Technology

A Report On

Super Handy Lawn Mower

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Super Handy Lawn Mower

Course No: IPE 318
Course Title: Product Design-II Sessional

Date of Submission: 28-08-2022

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28 August 2022

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Bangladesh University of Engineering and Technology

Subject: Report Submission on “Super Handy Lawn Mower”

Dear Teachers,

It is our great pleasure to present the report entitled “Super Handy Lawn Mower” to you. We are very thankful to you for your kind help to accomplish this product design project.

Lawn mowers are necessary tools for trimming grass. Cutting grass is an arduous task, having to collect grass clippings separately makes the whole process tedious. Hence, we tried to develop a cycle operated lawn mower where all the works can be done together with minimum effort to reduce labour and save time. Moreover, there is a detachable mechanism to create versatility in the mower so that it can be used as a push mower as well. The bicycle can also be used separately again after detachment from the lawnmower. In this report we showed the functions, working processes, manufacturing processes and overall costing of the Super Handy Lawn Mower.

We would like to thank you for your cooperation in completing this project. We solemnly apologize for the involuntary mistakes, if there are any.

Sincerely,

Avijit Saha Asru (Student ID: 1708009)

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Acknowledgement

This project would not be completed without the help and participation of many people. Firstly, we would like to thank our course teachers for their valuable advice, support, guideline and useful suggestions on product design. Their guidance showed us the path to make this report perfect.

We are thankful to Mr. Babu, owner of Suman Engineering Workshop for his cordial help. We are also thankful to the gardeners of Ahsanullah Hall of BUET for their valuable inputs.

Finally, we thank all the people who participated in the surveying of our product.

Abstract

In Bangladesh, a push lawnmower is usually used to trim the grass on fields. However, this process becomes very strenuous and time-consuming. The operator also has to do the additional work of moving around the entire field again to collect the grass clippings. In order to overcome this problem, we have designed a pedal-powered lawnmower which is a combination of a bicycle and a lawnmower with a bucket attached behind the helix blade to collect the grass clippings as they are trimmed off. The lawnmower is connected to the bicycle via a detachability mechanism so that it can be used as a push lawnmower in tight spaces. After detaching the lawnmower from the bicycle, the bicycle can be used on its own again. In this report, we have carried out various analyses on our designed product "Super Handy Lawnmower".

Based on the market survey results, we determined the customer requirements and technical requirements and their relationships and correlations and hence, we created the House of Quality. From the House of Quality, we figured out the importance ratings of the technical requirements. Then we conducted qualitative analysis of material, manufacturing process and joining process selections. Then we conducted their quantitative analyses by calculating relative emphasis coefficients using Digital Logic Method and performance indices. Then we carried out equivalent (von Mises) stress, total deformation, fatigue life and fatigue safety factor analyses using Ansys. Finally, we performed cost, breakeven and sensitivity analyses of our product.

Hopefully, this report will encourage students to design and analyse their own products.

Table of Contents

List of Figures

List of Tables

Chapter-01

Introduction

1.1 Product Design

Product Design is a process of generating a new object or service through a set of strategic and tactical activities, from idea generation to commercialization, manufacturing and implementation of that product or services. Design is a plan or specification for the construction of an object or system or the implementation of an activity or process, or the result of the plan or specification in the form of a prototype, product, or process. It is an innovative & highly iterative process. It is also a decision-making process. Product Designers conceptualize and evaluate ideas, making them tangible products in a more systematic approach. The design usually has to satisfy certain goals and constraints, may take into account aesthetic, functional, economic, or socio-political considerations and is expected to interact with a certain environment.

Developing a design concept is the initial phase of design engineering. Designing a new product goes through an analytical process and relies on a problem-solving approach to improve the quality of life of the end-user and his or her interaction with the environment. It is about problem-solving, visualizing the needs of the user, and bringing a solution. Moreover, an engineer puts his or her innovativeness into that design which can balance all the different factors that influence a product.

1.2 Proposed Product Ideas

In the beginning, we have selected these three designs which included:

1. Super Handy Lawn Mower
2. Multipurpose Cleaner
3. CPL (Centre Point Locator) Multipurpose Punching Machine

1.3 Selected Proposal

After proposing three different product ideas for Product Design Sessional-I, the ‘Super Handy Lawn Mower’ was selected as our project after analyzing its feasibility, innovative design, user-friendly features brought into the product.

1.3.1 Super Handy Lawn Mower:

Lawn mowers have been around since the early 19th century. The traditional push lawn mower requires the operator to push it from behind which rotates its wheels to achieve the cutting action. Its size is limited by the fact that it has to be pushed by a human so it can trim small areas of grass at a time. After trimming, the grass clippings are needed to be collected manually. So the operator has to move around the entire field again. This makes mowing large fields with a push lawn mower a time-consuming and labour-intensive process.

To overcome the problems of the traditional push lawn mower, a pedal-powered lawn mower is to be designed. This is essentially a combination of a lawn mower in the front and a cycle at the back. Thus it can trim large areas of grass at a time. A bucket is attached just behind the cutting blades to collect the grass clippings as they are trimmed. Hence, lawn mowing becomes much more efficient. A mechanism is provided to detach the cycle from the lawn mower so that it can be used as an ordinary push lawn mower if desired. This ensures that the lawn mower can be moved around places where it is difficult to cycle, allowing the operator an extra degree of convenience. Not only this, the bicycle also remains operational after detaching it from the lawnmower.

Features-

1. Uses a detachable mechanism that enables it to be used as a push lawn mower and a pedal-powered lawn mower
2. Attached bucket for collecting grass clippings
3. It can cover ground 4 to 5 times faster than an average push lawn mower
4. Can be motorized for easy operation
5. After detachment from lawnmower, bicycle can be used on its own

1.3.2 Background that leads us to design an efficient grass cutting mechanism:

In Bangladesh, generally, people use the Push Lawn Mower to trim grass. But it's not feasible for trimming grasses on a big field. It is a highly strenuous, time-consuming and labour-intensive process. Although Modern Lawn Mowers are very effective for large areas, they are too expensive for mass use. Therefore, there is the need to develop a cost-effective lawn mower that can take care of this operation easily. So, our objective is to design and develop a locally fabricated pedal-powered spiral blade lawn mower that is affordable by general people. Moreover, it can also be used as a push lawn mower when operating in a squeezed area and a bicycle after the bicycle is detached from the lawn mower which increases its usefulness.

Chapter-02

Understanding Customer Needs Through Survey

2.1 Introduction

A typical lawn mower is not too easy to operate and it has many limitations. For those reasons, a more efficient lawn mower is necessary. A lawn mower with a cycle mechanism will be revolutionary as it will be easy to operate and more efficient.

As a primary research, we identified our main customers are:

- Institutions
- Parks
- Fields
- Home with a Garden

We carried out a survey for developing customer requirements for our Super Handy Lawn Mower among some of the above customers in a very short period of time.

2.2 Areas and Locations of Survey

- Bangladesh University of Engineering and Technology
- Rajshahi University of Engineering and Technology
- Shahjalal University of Science and Technology

2.3 Survey Result:

The survey was done among 55 people. The results of the survey are shown in the following pages with the help of pie charts along with percentage:

1. Do you cut grass regularly in your garden or lawn?
    a. Yes
    b. No
    c. Sometimes

Table 2.1: Regularity of grass cutting

Options	Response Count	Response Percentage (%)
Yes	30	54%
No	12	22%
Sometimes	13	24%

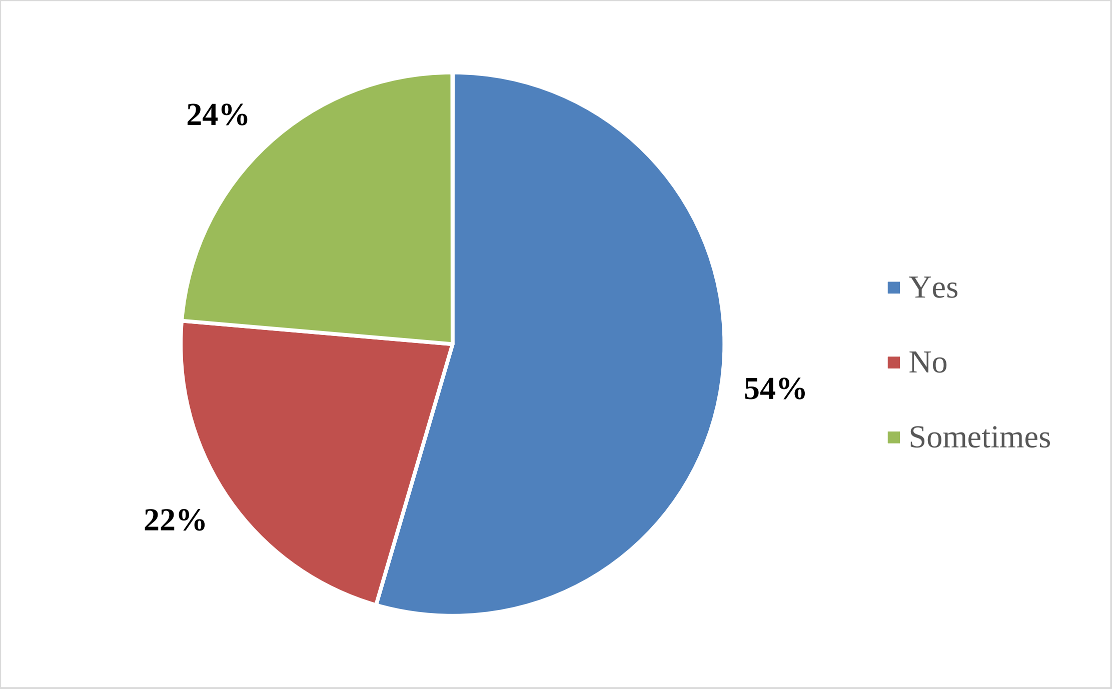


Figure 2.1: Regularity of grass cutting

2. How much time do you need to clean the grasses of a large area (average football field)?
    a. Few hours
    b. One day
    c. More than day

Table 2.2: Time needed for cutting

Options	Response Count	Response Percentage (%)
Few Hours	06	11%
One day	21	38%
More than a day	28	51%

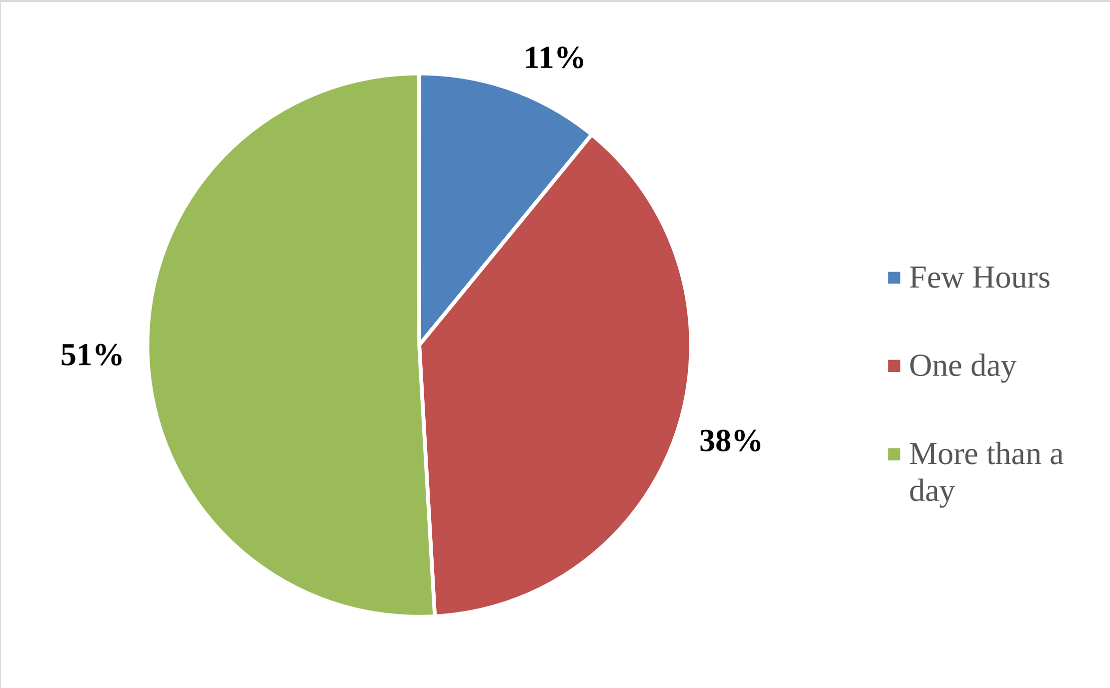


Figure 2.2: Time needed for cutting

3. Do you have a grass collector attached to your mower?
    a. Yes
    b. No

Table 2.3: Attached Grass Collector

Options	**Response Count**	**Response Percentage (%)**
Yes	09	30%
No	46	70%

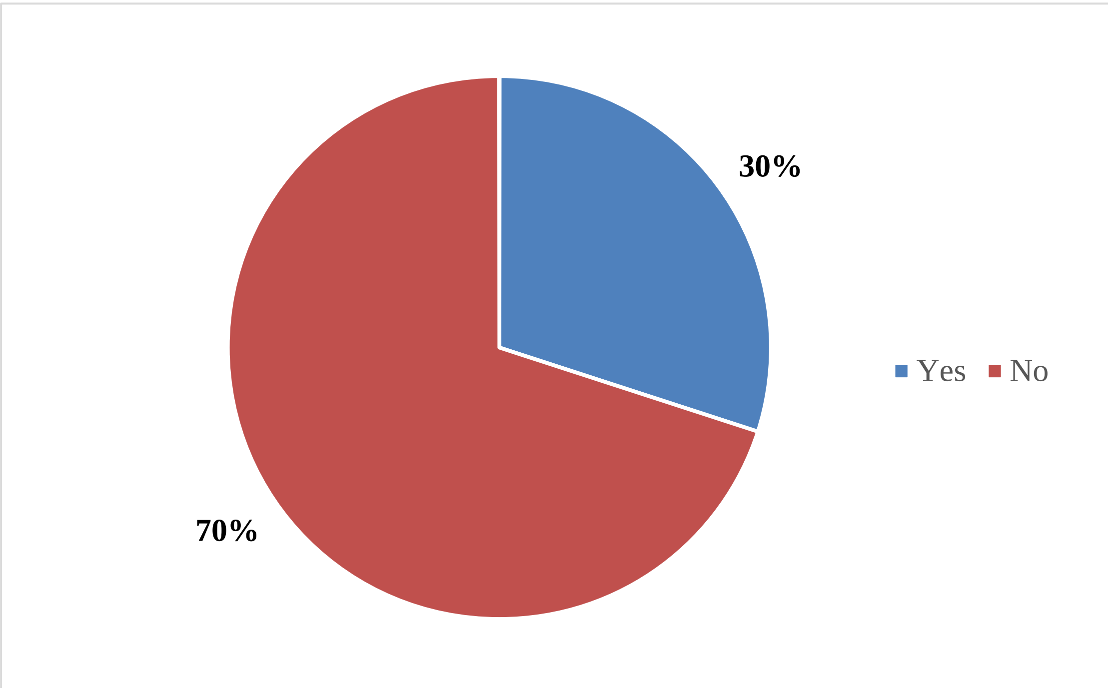


Figure 2.3: Attached Grass Collector

4. Select the difficulties you face the most while trimming the lawn?
    a. Time consuming
    b. No grass collecting mechanism
    c. Heavy equipment
    d. Energy

Table 2.4: Difficulties

Options	Response Count	Response Percentage (%)
Time consuming	19	35%
No grass collecting mechanism	21	38%
Heavy equipment	7	13%
Energy	8	14%

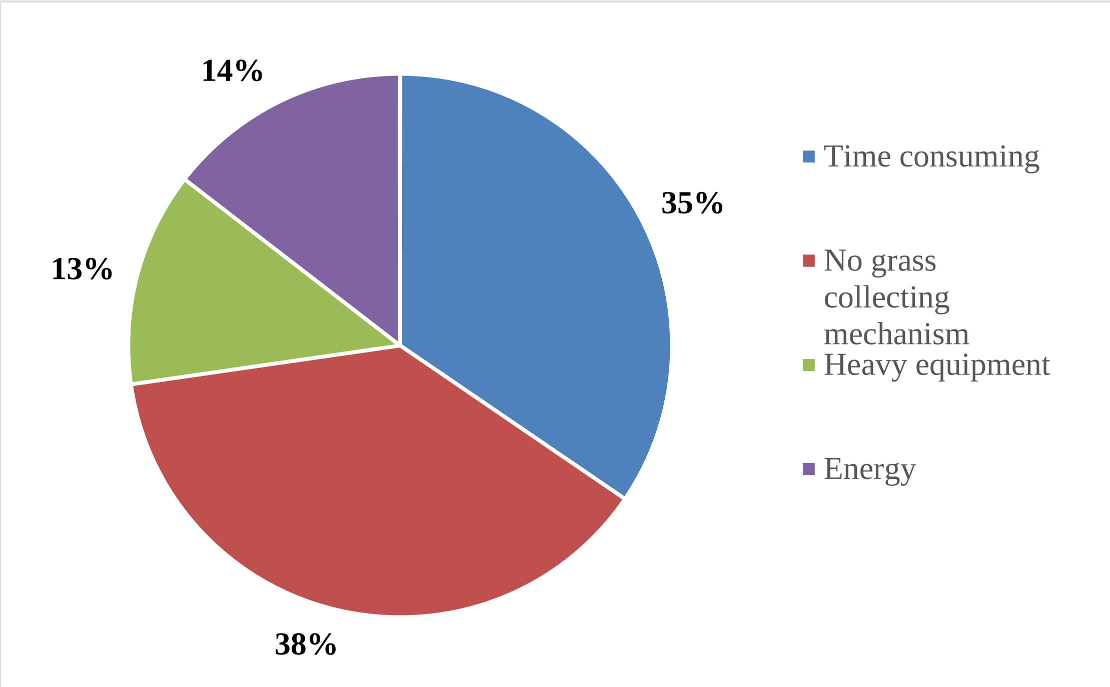


Figure 2.4: Difficulties

5. If you can clean your lawn more quickly with a new tool, would you buy that?
    a. Yes
    b. No
    c. Maybe

Table 2.5: Tendency to buy new tool

Options	Response Count	Response Percentage (%)
Yes	30	55%
No	11	20%
Maybe	14	25%

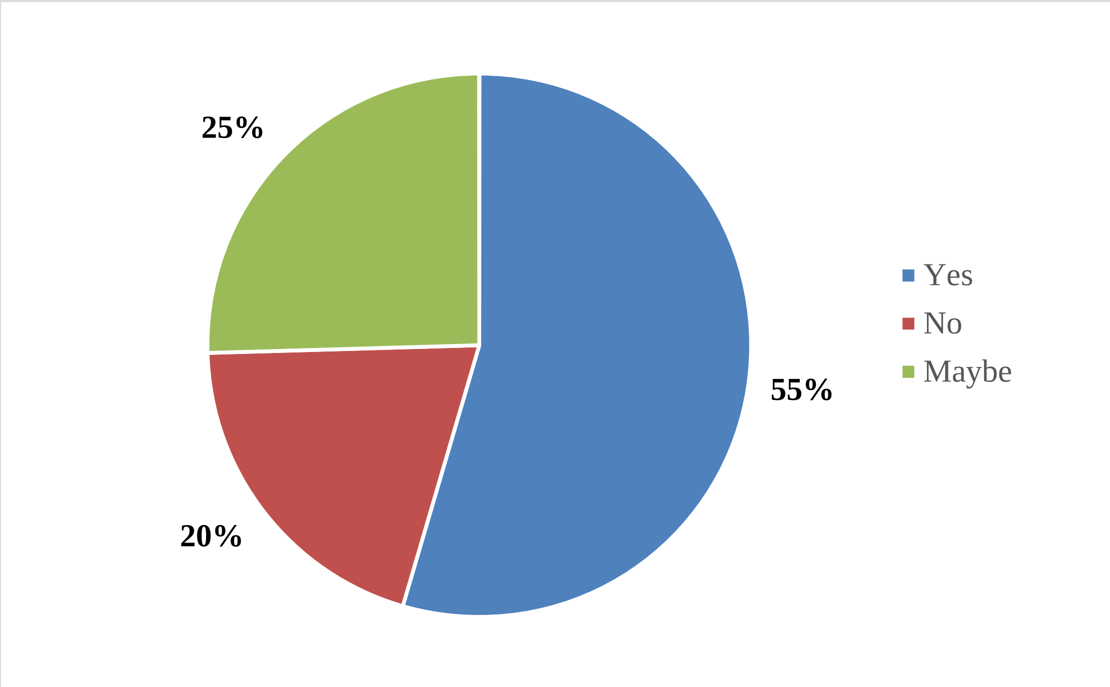


Figure 2.5: Tendency to buy new tool

6. Do you think that the combination of a Mower and a Cycle will make tasks easier or user friendly?
    a. Yes
    b. No

Table 2.6: User friendly or not

Options	Response Count	Response Percentage (%)
Yes	47	85%
No	8	15%

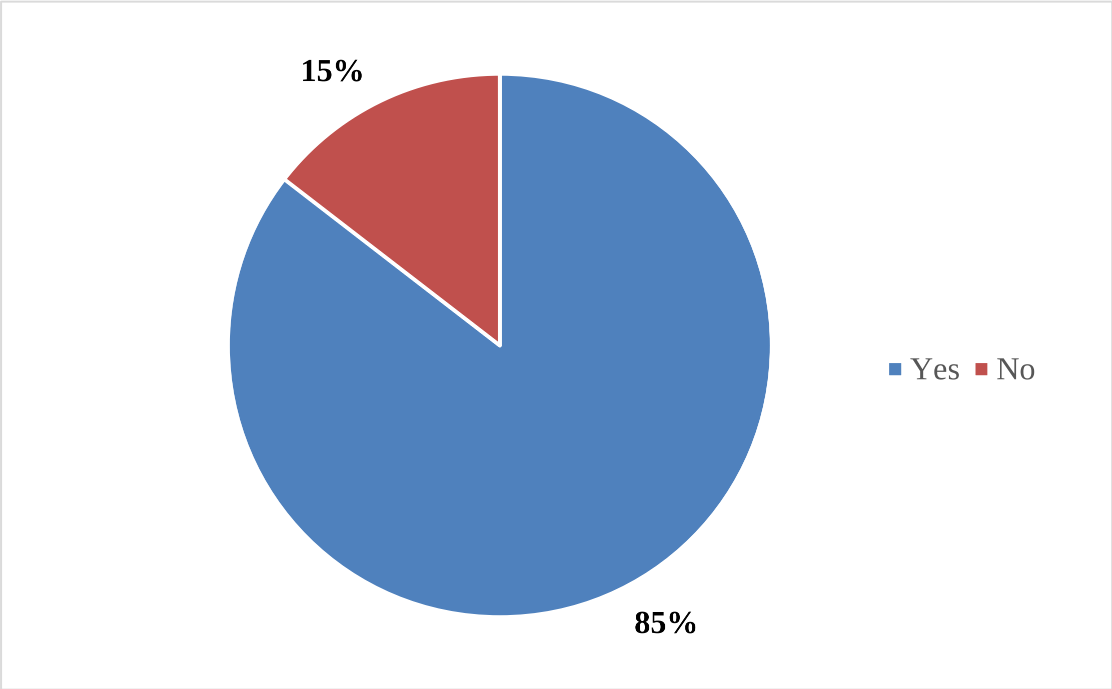


Figure 2.6: User friendly or not

7. What type of Cycle would you prefer to use in the Super Handy Lawn Mower?
    a. Paddle Powered
    b. Electric
    c. User can select

Table 2.7: Type of the cycle

Options	Response Count	Response Percentage (%)
Paddle Powered	12	22%
Electric	09	16%
User can select	34	62%

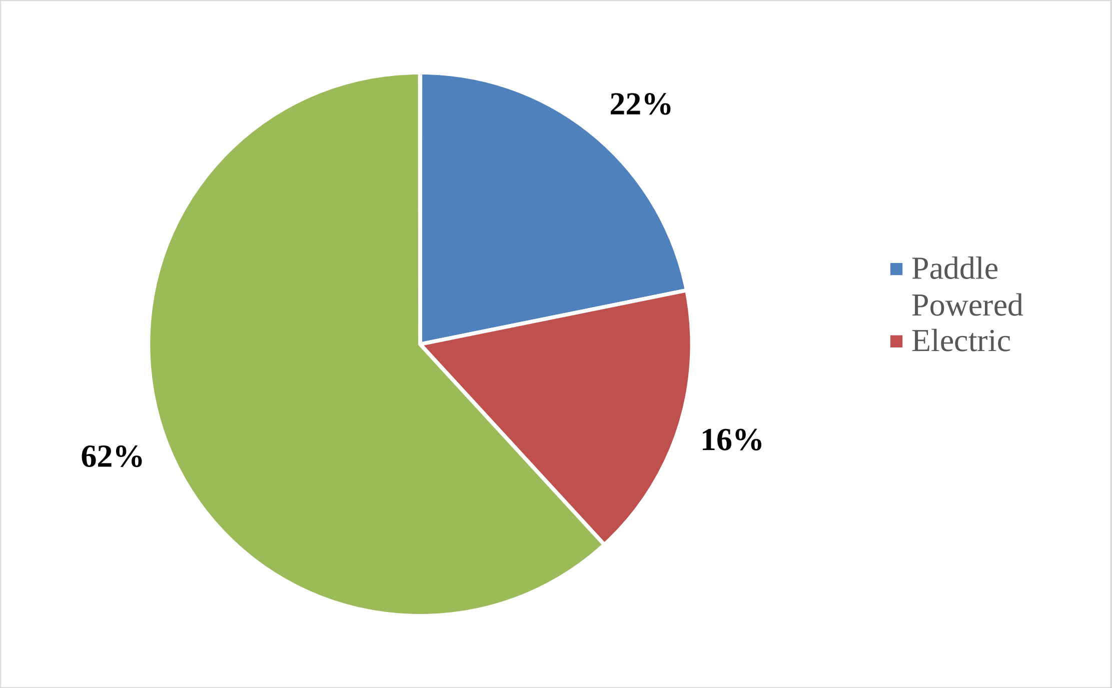


Figure 2.7: Type of the cycle

8. If there is a detachable mechanism in your newly improved lawn mower, how much will you be benefitted on a scale of 10?

1 2 3 4 5 6 7 8 9 10

Table 2.8: Detachable mechanism

Options	Response Count	Response Percentage (%)
5	10	18%
7	12	22%
8	09	16%
9	24	44%

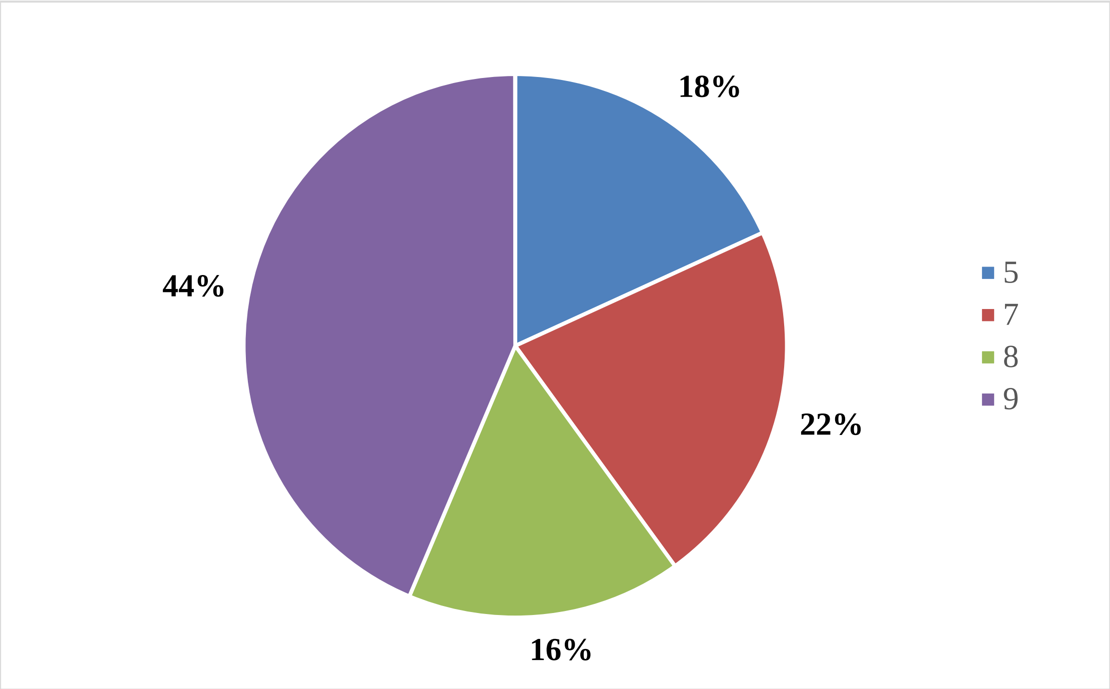


Figure 2.8: Detachable mechanism

9. How comfortable will you be in switching between cycle and push lawn mower?
    a. Very much comfortable
    b. Somewhat Comfortable
    c. Neutral
    d. Uncomfortable

Table 2.9: Comfort

Options	Response Count	Response Percentage (%)
Very much comfortable	23	35%
Somewhat comfortable	17	38%
Neutral	7	13%
Uncomfortable	8	14%

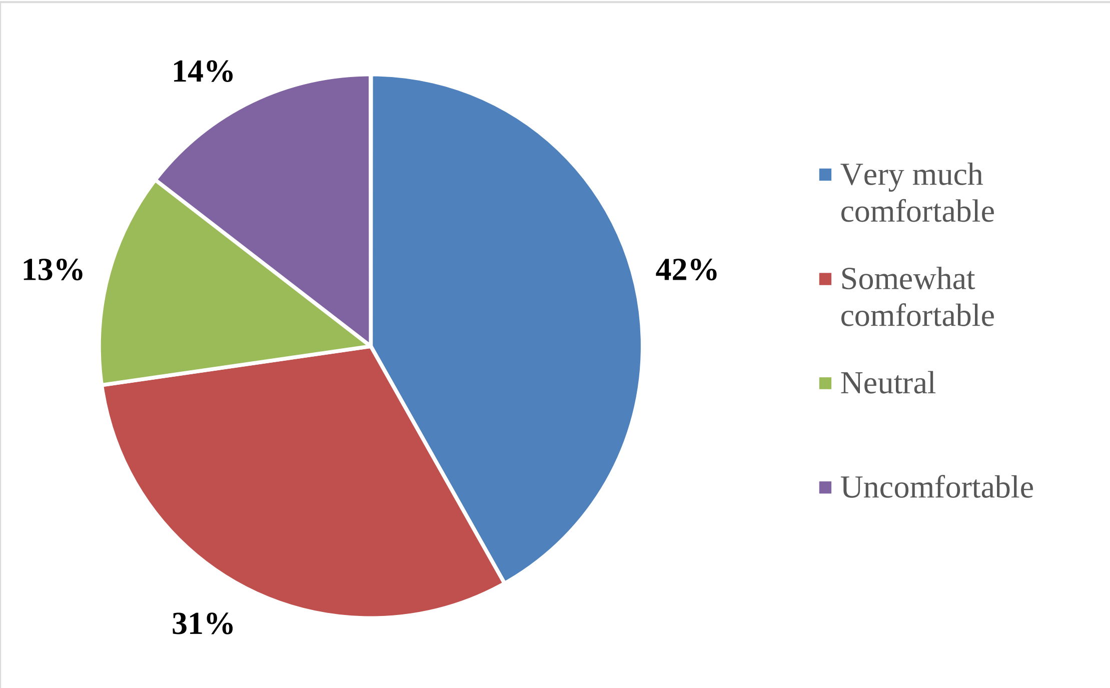


Figure 2.9: Comfort

10. How much are you willing to pay for the super handy lawn mower?

a. Less than 10k
b. 10-20k
c. More than 20k

Table 2.10: Price of the machine

Options	Response Count	Response Percentage (%)
Less than 10k	02	04%
10-20k	19	34%
More than 20k	34	62%

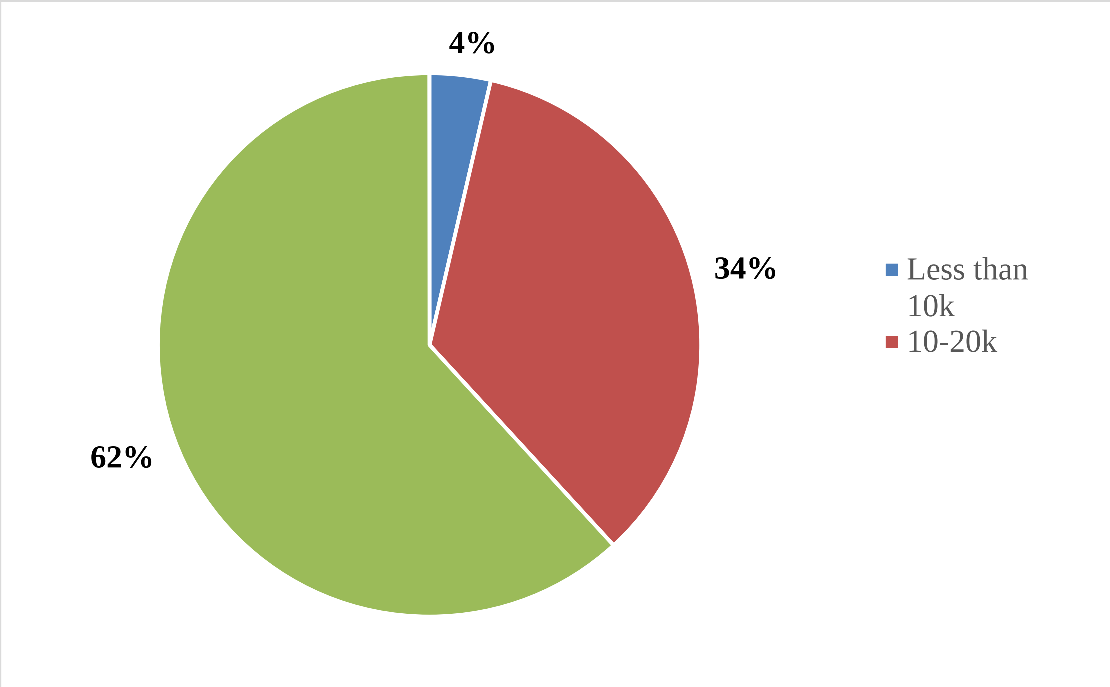


Figure 2.10: Price of the machine

Thus we carried out our survey and used the results to understand customer requirements

2.4 Customer Requirement Evaluation:

Customer requirements were categorized in nine groups and each were evaluated on a scale of 10. The results are shown below:

Table 2.11: Relative importance of customer requirements

Customer Requirement	**Relative Importance (Scale of 10)**
Easy to move	9
Good Stability	8
Easy conversion	7
Comfortable	7
Low cost	8
Easy to maintain	7
Reliability	9
Operating speed	7

After collecting all the necessary data, we moved on to construct our House of Quality diagram, which is show in the following chapter.

Chapter-03

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

3.1 Introduction:

The “voice of the customer” is a process used to capture the requirements/feedback from the customer (internal or external) to provide the customers with the best in class service/product quality. This process is all about being proactive and constantly innovative to capture the changing requirements of the customers with time. The “voice of the customer” is the term used to describe the stated and unstated needs or requirements of the customer. The voice of the customer can be captured in a variety of ways: Direct discussion or interviews, Surveys, Focus groups, Customer specifications, Observation, Warranty date, Field reports, Complaint logs, etc.

The house of quality is a voice of customer analysis tool and a key component of the quality function deployment technique. It starts with the voice of the customer. It is a tool to translate what the customer wants into products or services that meet the customer wants in terms of engineering design values by way of creating a relationship matrix.

House of Quality is a part of a larger process called QFD, which stands for Quality Function Deployment. QFD is a planning process with a quality approach to new product design, development, and implementation driven by customer needs and values.

Since we have already collected customer needs by conducting a survey, the next step in the QFD technique is to evaluate the importance of each of the customers’ requirements (out of 10 scales). This is accomplished by generating a weighting factor.

3.2 Customer Requirements and Engineering Requirements Relationship:

From the house of quality, we can explain the relationship between customer requirements and engineering requirements.

Table 3.1: Relationship Explanation

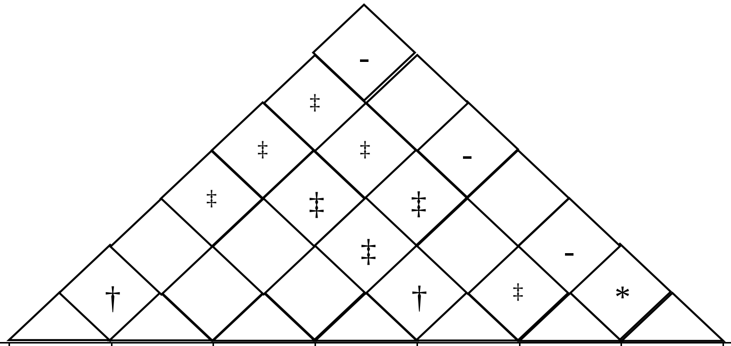
Customer Requirement	Engineering Requirement	Relationship	Explanation
Detachability	Strength of main body	Weak	Detachable mechanism depends on the strength of the main body.
	Detachable frame	Strong	Detachable frame is the medium of detaching the mower from the bicycle.
	Material	Moderate	Proper material selection ensures good linkage of the detachable frame to the main frame.
	Manufacturing cost	Strong	Detachable mechanism increases the manufacturing cost.
Stability	Strength of main body	Strong	Stability increases with the strength of the main body.
	Detachable frame	Strong	The better the detachable mechanism, the greater is the stability.
	Cutter	Moderate	The better the design of the cutter, the greater is the stability.
	Back wheel	Strong	Stability increases with the strength of the back wheel.

Customer Requirement	Engineering Requirement	Relationship	Explanation
Stability	Material	Moderate	The better the material quality, the greater is the stability.
	Manufacturing cost	Moderate	Greater stability means higher manufacturing cost.
Long service life	Strength of main body	Moderate	Stronger main body means longer service life
	Cutter	Strong	The greater the cutter strength, the longer is the service life.
	Material	Strong	Proper material selection ensures long service life.
	Manufacturing cost	Moderate	Longer service life requires greater manufacturing cost.
Fast cutting operation	Detachable frame	Weak	Easily detachable frame ensures fast cutting operation.
	Cutter	Strong	Better cutter design means faster cutting operation.
	Back wheel	Moderate	Optimum weight of the back wheel ensures greater speed and hence, faster cutting operation.
	Operational cost	Moderate	Faster cutting operation means lower operational cost.
Simple design	Detachable frame	Moderate	Detachable frame increases the complexity of the design.
	Manufacturing cost	Strong	Simpler design means lower manufacturing cost.
Aesthetics	Detachable frame	Moderate	Detachable frame has an impact on aesthetics.

Customer Requirement	**Engineering Requirement**	**Relationship**	**Explanation**
Aesthetics	Cutter	Weak	Cutter of good design improves aesthetics.
Repairable	Strength of main body	Weak	Stronger main body is more repairable.
	Detachable frame	Strong	Better detachable frame is more repairable.
	Cutter	Moderate	Cutter made of higher quality material is more repairable.
	Back wheel	Moderate	If back wheel is damaged, it can be easily repaired.
	Material	Weak	Material has an impact on repairability
	Operational cost	Moderate	Less repairable means greater operational cost.
Easy to operate	Cutter	Strong	Sharper cutter blades mean easier operation.
Safety	Strength of main body	Strong	Fracture of the main body could lead to a severe accident.
	Detachable frame	Moderate	A severe accident could occur if the detachable mechanism fails.
	Back wheel	Strong	The operator could be injured if the back wheel breaks.
	Material	Strong	Any crack in the material could lead to fracture in the main body.
	Manufacturing cost	Moderate	Lower manufacturing cost means safety is compromised.

Customer Requirement	**Engineering Requirement**	**Relationship**	**Explanation**
Low price	Detachable frame	Moderate	Installation of the detachable mechanism increases cost.
	Material	Moderate	Higher quality material means greater cost.
	Manufacturing cost	Strong	Proper selection of manufacturing process could reduce cost.
Low maintenance cost	Strength of main body	Weak	Main body frame requires proper maintenance to have e good service life.
	Detachable frame	Moderate	It requires a modified mechanism to be detachable.
	Back Wheel	Weak	The cost of replacing the back wheel tyre is a maintenance cost.
	Material	Weak	Specific kinds of materials need proper maintenance to be resist wear.
	Operational cost	Weak	Higher operational cost increases maintenance cost.

3.3 House of Quality



	Customer Requirements \ Functional Requirements	Customer Rating	Strength of Main Body	Detachable Frame	Cutter	Back Wheel	Material	Manufacturing Cost	Operational Cost	Sakura Power Ltd.	J.S. Lawnmower House
Functionality	Detachability	9	•	^			Δ	^		0	0
	Stability	8	^	^	Δ	^	Δ	Δ		7	8
	Long Service Life	7	Δ		^		^	Δ		8	8
	Fast Cutting Operation	8		•	^	Δ			Δ	9	8
Appearances	Simple Design	6		Δ				^		6	7
	Aesthetics	5		Δ	•					7	7
Physical	Repairable	7	•	^	Δ	Δ	•		Δ	8	8
	Easy to Operate	8			^					7	8
Safety	Safety	10	^	Δ		^	^	Δ		9	8
Price	Low Price	9		Δ			Δ	^		6	6
	Low Maintenance Cost	8	•	Δ		•	•		•	7	6
	Importance Rating		207	338	257	215	246	291	53		
	Percent Score		12.9	21.0	16.0	13.4	15.3	18.1	3.3		

Relationships		
^	Strong	9
Δ	Moderate	3
•	Weak	1
	No Relationship	0

Correlations	
‡	Strong Positive
†	Weak Positive
	No Correlation
-	Weak Negative
*	Strong Negative

Figure 3.1: House of Quality

3.4 Importance Rating Table:

From the house of quality, we arranged the technical requirements by their importance.

Table 3.2: Importance Rating

Observation Number	Engineering Requirement	Importance Rating (%)
1	Strength of the main body	12.9
2	Detachable frame	21
3	Cutter	16
4	Back wheel	13.4
5	Material	15.3
6	Manufacturing cost	18.1
7	Operational cost	3.3

QFD reduces the likelihood of late design changes by focusing on product features and improvements based on customer requirements. Effective QFD methodology prevents valuable project time and resources from being wasted on the development of non-value-added features or functions.

Chapter- 04

Functional Decomposition

4.1 Introduction

Functional decomposition is a method that decomposes a system into smaller subsystems and removes the complexity of the system. By decomposing, it fosters a better understanding of the overall system. Functional decomposition takes something complicated and simplifies it. A good functional decomposition is very useful for complex systems. A functional decomposition diagram contains the overall function or task as well as the necessary sub-functions or tasks needed to achieve the overall object.

There are four basic steps in applying the techniques and several guidelines for a good functional decomposition. These are given below:

Step 1: Find the Overall Function That Needs to Be Accomplished

All design problems have one or two major functions. These are reduced to a simple clause and put in a black box. The inputs to this box are all energy, material, and information that flow into the boundary of the system. The outputs are what flow out of the system.

Step 2: Create Sub-function Descriptions:

This step focuses on identifying the sub-functions that will be needed.

Step 3: Order the Sub-functions

The goal is to add order to the function generated in the previous step. The goal here is to order the functions found in step 2 to accomplish the overall function in step 1.

Step 4: Refine Sub-functions

The goal is to decompose the sub-function structure as finely as possible. Here we examine each sub-function if it can be further divided into more sub-functions.

4.2 Black Box Model of Functional Decomposition

The black box model is an abstraction representing a class of concrete open system which can be viewed solely in terms of its stimuli inputs and output reactions without any knowledge of its internal working. Its implementation is "opaque". The flow of inputs (material, energy, and information) to outputs is sufficient to describe a technical system or product.

The Black Box Model for Super Handy Lawn Mower is given below:

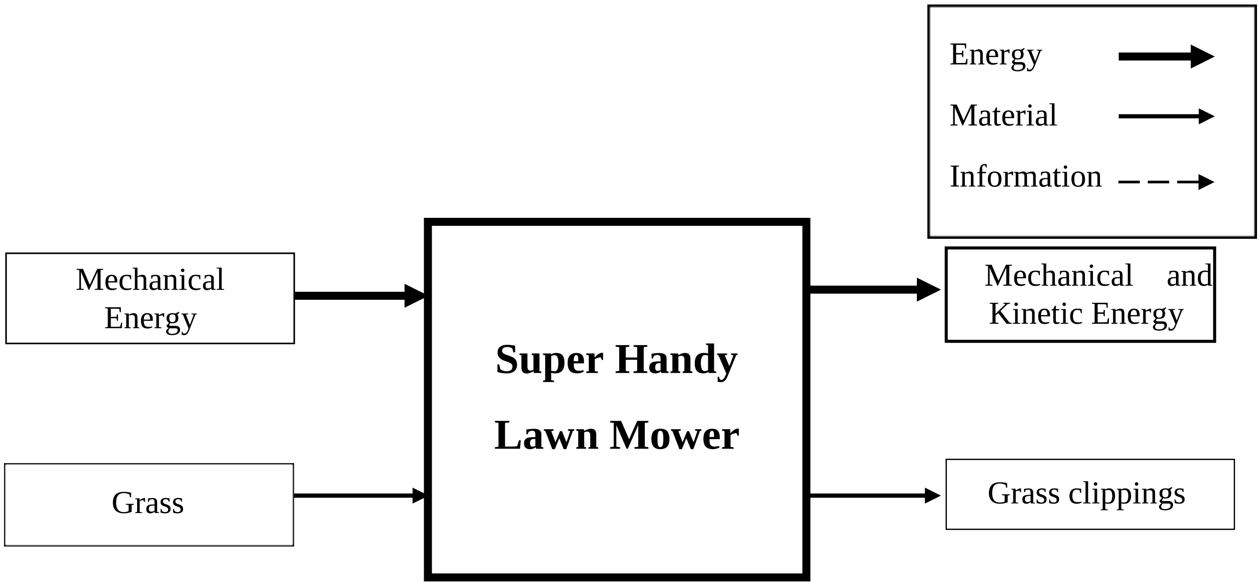


Figure 4.1: Black Box Model of the Super Handy Lawn Mower

There are generally three types of flows that are shown in the black-box model. These are:

- Energy flow
- Material flow
- Information flow

Our product has no Information flow. The other two types of flow are discussed below:

1. **Energy flow**: Our product will receive maneuvering from the operator and the received mechanical energy will be used to move the bicycle.
2. **Material flow**: A set of helical blades are mounted on the front of the super handy lawn mower. As bicycle moves forward, grass comes in contact with the blades. The fast-spinning reel of blades force the grass past the cutting bar and produces grass clippings.

4.3 Component Hierarchy

Component hierarchy is a very effective method of listing the components required to design a product. The component hierarchy methodology simply distinguishes between the core portions of the product and then lists the components for those portions. The portions are simply termed as sub-assembly. When the function of all sub-assemblies are satisfied, the prime function (compacting the trash in our case) is satisfied. This can be repeated iteratively down several levels developing a function tree. Function trees are fast and easy to construct, but this ease of construction comes at the expense of understanding interactions between sub- assemblies.

The component hierarchy of the Super Handy Lawn Mower is shown on the following page:

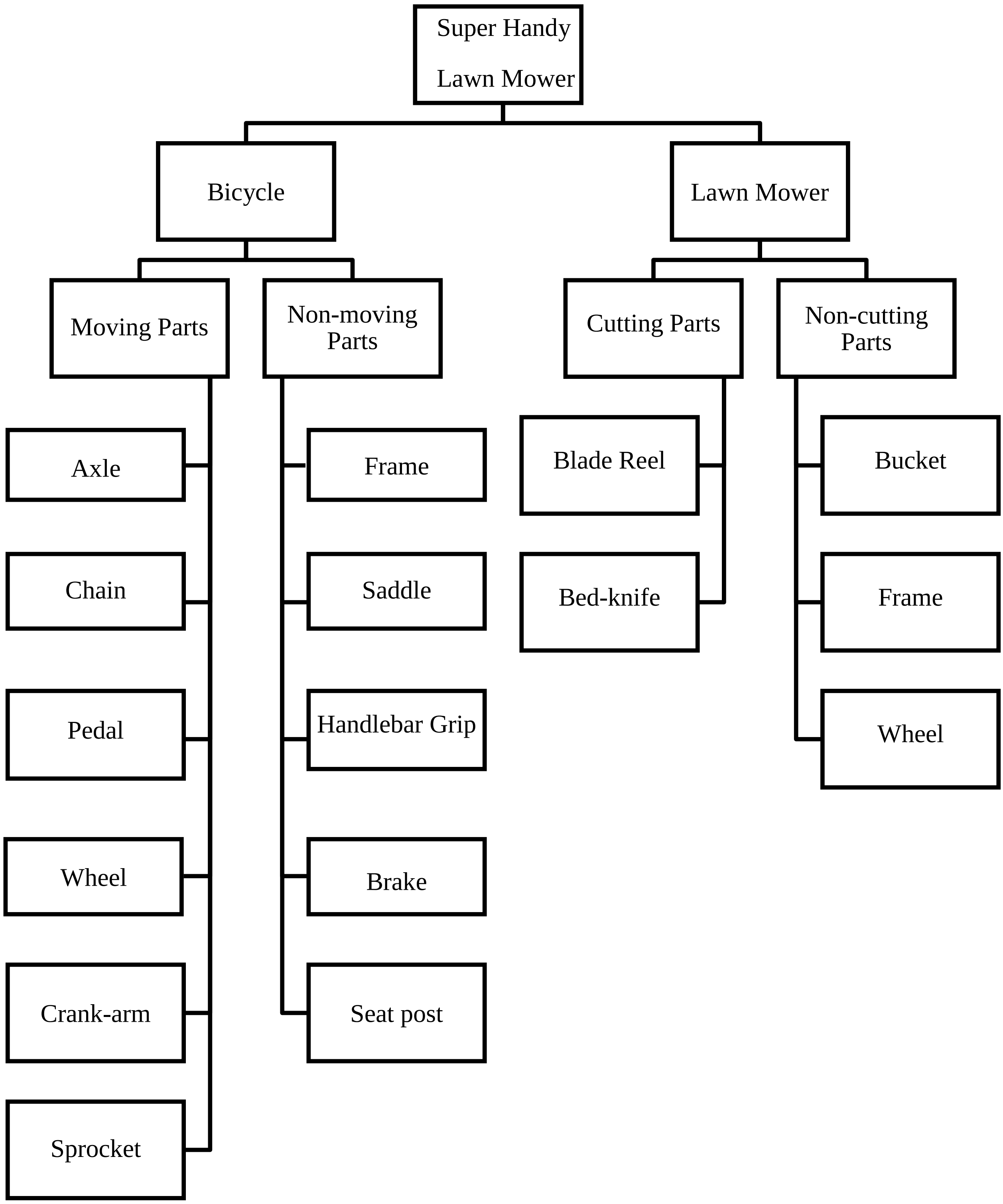


Figure 4.2: Component Hierarchy of Super Handy Lawn Mower

4.4 Cluster Function Structure of Super Handy Lawn Mower

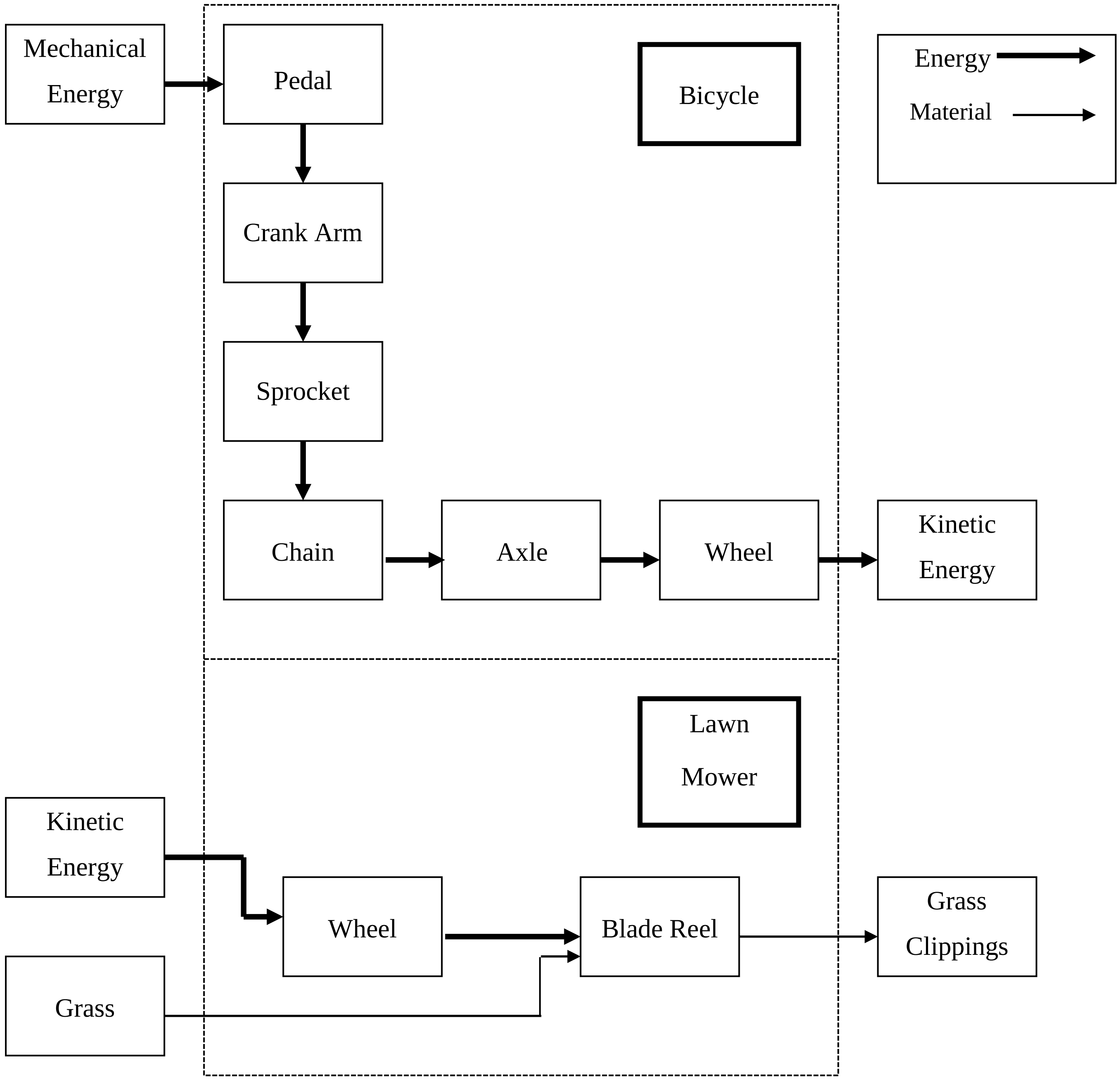


Figure 4.3: Cluster Function of Super Handy Lawn Mower

4.5 Functional Analysis System Technique (FAST) Diagram

Functional Analysis System Technique (FAST) is a technique to develop a graphical representation showing the logical relationships between the functions of a project, product, process or service based on the questions "How" and "Why." The FAST diagram of Super Handy Lawn Mower is shown below:

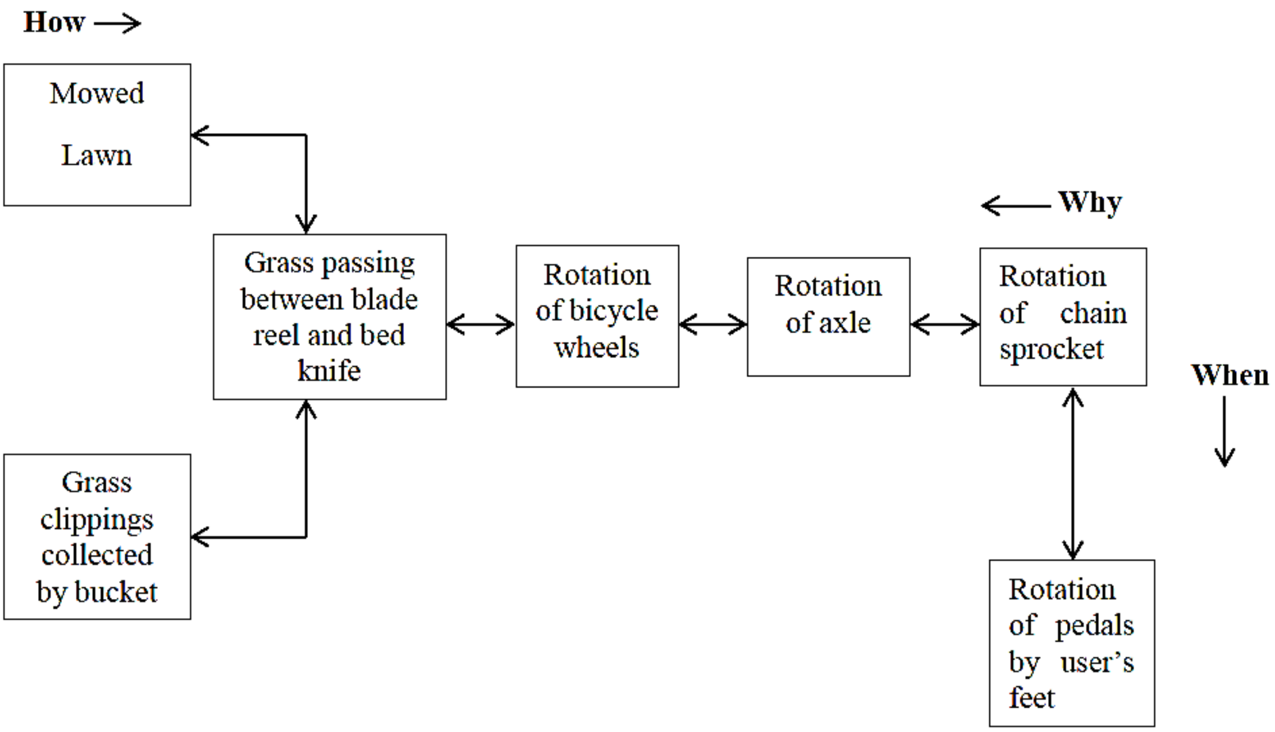


Figure 4.4: FAST diagram of Super Handy Lawn Mower

These four methods are very useful for the functional decomposition of a product. The Black Box model provides an idea about three types of inputs and outputs but without the knowledge of internal workings. The component hierarchy and cluster functions show detailed processes within the system with the material, energy, and information flow. FAST diagram helps to define, simplify and clarify the problem as well as identify missing functions.

Chapter- 05

Qualitative Analysis of Material, Manufacturing Process & Joining Process Selection

As the conceptual development and design are finalized for the Super Handy Lawn Mower, now it is important to assign specific materials and their manufacturing process for every part of the product. A qualitative analysis of the material, manufacturing process, and joining method selection is performed with the basic knowledge of material properties, manufacturing process, and their availability among the possible alternatives.

5.1 Selection of Materials for Different Sections

5.1.1 Cycle Body:

The qualitative analysis of material selection for the parts of cycle body is shown on the following page:

Table 5.1: Qualitative analysis of material selection for the parts of cycle body

Section	Parts	Types Selected	Options for other Types	Reasons Behind Selection
Cycle Body	Body Frame	Stainless Steel	Aluminum, Carbon Fiber	Durability, Long Lasting, Inexpensive
	Saddle	Fiber Reinforced Polymer	Leather, Polyurethane	Less Expensive, Light Weight
	Pedal	Plastic	Mild Steel	Light Weight, Less Expensive
	Back wheel	Natural and synthetic rubber	Nylon	Less Expensive, Long Lasting
	Battery	Li-ion	-	-
	Motor	DC	-	-

5.1.2 Detachability System:

The qualitative analysis of material selection for the parts of detachability system is given below:

Table 5.2: Qualitative analysis of material selection for the parts of detachability system

Section	**Parts**	**Types Selected**	**Options for other Types**	**Reasons Behind Selection**
Detachability System	Upper Clamp	Mild Steel	Aluminum, Stainless Steel	Low weight, Available, Strength to weight ratio is very good
	Lower Clamp	Mild Steel	Aluminum, Stainless Steel	Cost-effective
	Side Plate	Mild Steel	Aluminum, Stainless Steel	Lighter, Ideal ergonomic fit
	Grass Collector Holder	Mild Steel	Aluminum, Stainless Steel	Good impact resistance and Strength
	Joining Screws	Stainless Steel	Mild Steel, Aluminum	Good impact resistance and Strength

5.1.3 Mower Body:

The qualitative analysis of material selection for the parts of mower body is given below:

Table 5.3: Qualitative analysis of material selection for the parts of mower body

Section	**Parts**	**Types Selected**	**Options for other Types**	**Reasons Behind Selection**
Mower Body	Helix Blade	Stainless Steel	Aluminum, Carbon Steel	Corrosion resistance, Durable, Impact resistance and High strength
	Front Wheel	Stainless Steel	Aluminum, Mild Steel	Durable, High strength, Good impact resistance
	Bed Knife	Stainless Steel	Aluminum, Carbon Steel	Corrosion resistance, Durable, Good impact resistance and High strength
	Grass Collector	Nylon	HDPE, PVC	Easy to handle, Light weight

We prioritized the materials based on their availability, cost and certain properties that are required for our product.

5.2 Selection of Manufacturing Processes for Different Sections

5.2.1 Cycle Body & Detachability System:

The qualitative analysis of the manufacturing process selected for the cycle body and the parts of the detachability system are given below:

Table 5.4: Qualitative analysis of the manufacturing process selected for the cycle body and the parts of the detachability system

Part	Make or Buy Decision	Possible Alternatives	Reason Behind Selection
Cycle Body	Outsourced	-	Cost-effective to buy it than to make it
Joining Screws	Outsourced	Upsetting & Threading	Cost-effective to buy it than to make it
Li-ion Battery	Outsourced	-	Cost-effective to buy it than to make it
Upper Clamp	Cutting	Die Casting	Cheaper, Less Complexity
Lower Clamp	Cutting	Die Casting	Cheaper, Less Complexity
Side Plate	Cutting	Die Casting	Cheaper, Less Complexity
Grass Catcher Holder	Cutting	Die Casting	Cheaper, Less Complexity

5.2.2 Mower Body:

The qualitative analysis of the manufacturing process selected for the parts of the mower body are given below:

Table 5.5: Qualitative analysis of the manufacturing process selected for the parts of the mower body

Parts	Types Selected	Options for other Types	Reasons Behind Selection
Helix Blade	Outsourced	Forging	Cost-effective to buy it than to make it
Front Wheel	Outsourced	Injection Molding	Cost-effective to buy it than to make it
Bed Knife	Outsourced	Die Casting, Forging	Cost-effective to buy it than to make it
Grass Collector	Outsourced	Injection Molding, Rotational Molding	Cost-effective to buy it than to make it

We decided to outsource the cycle body as a single product (including all the parts shown in table 5.1). According to our analysis, it would be more convenient to outsource majority of the parts instead of making them.

5.3 Selection of Joining Process

5.3.1 Detachability System:

The qualitative analysis of joining process selection for the parts of detachability system is given below:

Table 5.6: Qualitative analysis of joining process selection for the parts of detachability system

Joining Part(s)	Type of Joint	Joining Process	Alternative Process	Reasons Behind Selection
Lower Clamp & Upper Clamp	Permanent	MIG Welding	Arc Welding, TIG Welding	Good strength
Upper Clamp & Grass Collector Holder	Permanent	MIG Welding	Arc Welding, TIG Welding	Good strength
Upper Clamp & Cycle Frame	Temporary	Nut-Bolt	Rivet	Easy removal, Firm joint
Lower Clamp & Side Plate	Temporary	Nut-Bolt	Rivet	Easy removal, Firm joint
Side Plate & Mower Body	Temporary	Nut-Bolt	Rivet	Easy removal, Firm joint

Since cycle body would be outsourced as a single product, no joining process is involved there. The other joining processes are selected as per the reasons described in the tables 5.6.

Chapter- 06

Material, Manufacturing Process and Joining Process Selection Using Weighted Average method

6.1 Introduction

Material selection is an important part of the product design process. The design of engineering components is limited by the available materials and selection of the wrong material can lead to catastrophic failures. In the previous chapter, a qualitative analysis of material, manufacturing process, and joining method selection has been carried out. But qualitative analysis is nothing but applying intuitive knowledge. Therefore, quantitative analysis for selection criteria is imperative to manufacture a good product.

There are several methods for quantifying the properties of a material or manufacturing process. Here, in this chapter, we are using the "Digital Logic Method" for selecting material based on their performance indices.

6.2 List of Parts for Each Sub-assembly

6.2.1 Cycle Body:

- Body Frame
- Saddle
- Pedal
- Back Wheel

6.2.2 Detachability System:

- Upper Clamp
- Lower Clamp
- Side Plate
- Grass Collector Holder

6.2.3 Mower Body:

- Helix Blade
- Front Wheel
- Bed Knife
- Grass Collector

6.3 Equations:

a. Relative Emphasis Coefficient, $\alpha = \frac{No.\ of\ positive\ decisions\ acquired\ by\ a\ criteria}{Total\ no.of\ positivge\ decisions}$

b. For properties to be maximized,
Scaled Property, $\beta = \frac{Numerical\ value\ of\ the\ property}{Maximum\ value\ in\ the\ list}\ x\ 100$

c. For properties to be minimized,
Scaled Property, $\beta = \frac{Minimum\ value\ in\ the\ list}{Numerical\ value\ of\ the\ property}\ x\ 100$

d. Weighted Score = Relative Emphasis Coefficient (α) × Scaled Property (β)

e. Performance Index, γ = $\Sigma Weighted\ Score\ (\alpha\beta)$

6.4 Likert Scale

Likert scale is a psychometric scale commonly involved in research that employs questionnaires. This scale is used for rating different categories according to their significance or intensity. When responding to a Likert item, respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. Thus the range captures the intensity of their feelings for the given item.

In this chapter, we are going to use the Likert scale for those criteria that can't be assigned with numerical values. The scale is given below:

Table 6.1: Likert Scale

Very Good	5
Good	4
Moderate	3
Poor	2
Very poor	1

6.5 Quantitative Analysis of Material Selection of Super Handy Lawn Mower

6.5.1 Material selection for frame and axle:

Table 6.2: List of selection criteria with numerical values or values from Likert Scale for Frame:

Selection Criteria	Stainless Steel	Aluminum	Carbon Fiber
Fatigue Strength (MPa)	350	103	200
Cost/kg (BDT)	220	180	1750
Corrosion Resistance (Likert Scale)	5	4	3
Weldability (Likert Scale)	5	4	2
Vibration Resistance	4	2	4
Availability	5	4	2

From these selection criteria, we want to maximize Fatigue Strength, Corrosion Resistance, Weldability and Vibration Resistance; and to minimize Cost.

Table 6.3: Determination of relative importance of material selection criteria for Frame 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		
Fatigue Strength	1	1	1	1	1											5	0.333
Cost	0					1	0	1	1							3	0.200
Corrosion Resistance		0				0				0	1	0				1	0.067
Weldability			0				1			1			1	1		4	0.267
Vibration Resistance				0				0			0		0		1	1	0.067
Availability					0				0			1		0	0	1	0.067
Total Number of Positive Decisions																15	$\Sigma\alpha=1$

Table 6.3 shows the digital logic method for different components of the Frame and Axle. Of these criteria, cost has the highest number of positive decisions i.e. highest relative co-efficient.

Table 6.4: Calculation of the performance index for material selection of Frame:

Selection Criteria	Relative Emphasis Coefficient, α	Stainless Steel		Aluminum		Carbon Fiber	
		Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ
Fatigue Strength	0.333	100	33.3	29.43	9.8	57.14	19.03
Cost	0.200	81.81	16.36	100	20.	10.29	2.06
Corrosion Resistance	0.067	100	6.7	100	6.7	75	5.03
Weldability	0.267	100	26.7	80	21.36	40	10.68
Vibration Resistance	0.067	100	6.7	50	3.35	100	6.70
Availability	0.067	100	6.7	100	6.7	50	3.35
Material Performance Index			**96.46**		67.91		46.84

Table 6.4 shows the weighted score for different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, AISI 4130 Steel has the maximum performance index. Therefore, for Frame Stainless Steel should be selected as material which we also selected in the previous chapter.

6.5.2 Material selection for Saddle:

Table 6.5: List of selection criteria with numerical values or values from Likert Scale for Saddle:

Selection Criteria	**Fiber Reinforced Polymer**	**Leather**	**Polyurethane**
Cost/meter (BDT)	22	155	345
Tensile Strength (MPa)	1720	25	96
Density (kg/m^3)	1500	860	80
Elastic Modulas (GPa)	53	0.172	0.151
Durability (Likert Scale)	4	2	3

From these selection criteria, we want to maximize Tensile Strength, Elastic Modulus and Durability; and to minimize Cost and Density (for lightweight).

Table 6.6: Determination of relative importance of material selection criteria for Saddle 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	1	1	1	1							4	0.4
Tensile Strength	0				1	1	0				2	0.2
Density		0		0	0			1	0		1	0.1
Elastic Modulus			0			0		0		1	1	0.1
Durability				0			1		1	0	2	0.2
Total Number of Positive Decisions											10	$\Sigma\alpha=1$

Table 6.6 shows the digital logic method for different components of the saddle. Of these criteria, cost has the highest number of positive decisions i.e. highest relative co-efficient.

Table 6.7: Calculation of the performance index for material selection of Saddle:

Selection Criteria	Relative Emphasis Coefficient, α	Fiber Reinforced Polymer		Leather		Polyurethane	
		Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ
Cost	0.4	100	40	14.19	5.68	6.38	2.55
Tensile Strength	0.2	100	20	1.45	0.29	5.58	1.12
Density	0.1	5.3	0.53	9.3	0.93	100	10.00
Elastic Modulus	0.1	100	10	9.12	0.91	8.00	0.80
Durability	0.2	100	20	50	10	75	15.00
Material Performance Index			**90.53**		17.81		29.47

Table 6.7 shows the weighted score for different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, Fiber Reinforced Polymer has the maximum performance index. Therefore, for Saddle, Fiber Reinforced Polymer should be selected as material which we also selected in the previous chapter.

6.5.3 Material selection for Pedal:

Table 6.8: List of selection criteria with numerical values or values from Likert Scale for Pedal:

Selection Criteria	Plastic	Mild Steel
Cost/pair (BDT)	90	300
Density (kg/m^3)	1350	7870
Tensile Strength (Mpa)	62	420
Comfortability (Likert Scale)	5	3

From these selection criteria, we want to maximize Tensile Strength and Comfortability; and to minimize Cost and Density (for lightweight).

Table 6.9: Determination of relative importance of material selection criteria for Pedal 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	1	1	1				3	0.5
Density	0			1	0		1	0.167
Tensile Strength		0		0		1	1	0.167
Comfortability			0		1	0	1	0.166
Total Number of Positive Decisions							6	$\Sigma\alpha=1$

Table 6.9 shows the digital logic method for different components of the Pedal. Of these criteria, cost has the highest number of positive decisions i.e. highest relative co-efficient.

Table 6.10: Calculation of the performance index for material selection of Pedal:

Selection Criteria	Relative Emphasis Coefficient, α	Plastic		Mild Steel	
		Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ
Cost	0.5	100	50.00	30	15.00
Density	0.167	100	16.70	17.15	2.86
Tensile Strength	0.167	14.76	2.46	100	16.70
Comfortability	0.166	100	16.60	60	9.96
Material Performance Index			**85.76**		44.52

Table 6.10 shows the weighted score for different selection criteria for two different materials and the performance index for each of the materials. Among the two materials, Plastic has the maximum performance index. Therefore, for Pedal, Plastic should be selected as material which we also selected in the previous chapter.

6.5.4 Material selection for Back Wheel:

Table 6.11: List of selection criteria with numerical values or values from Likert Scale for Back Wheel:

Selection Criteria	Natural and Synthetic Rubber	Nylon
Dynamic Friction Coefficient	0.7	2
Abrasion Resistance (Likert Scale)	5	3
Impact Resistance (Likert Scale)	5	4
Heat Resistance (Likert Scale)	4	3
Cost/kg (BDT)	80	40
Tensile Strength (MPa)	31.6	50

From these selection criteria, we want to maximize Abrasion Resistance, Impact Resistance, Heat Resistance and Tensile Strength; and to minimize Dynamic Friction Coefficient and Cost.

Table 6.12: Determination of relative importance of material selection criteria for Back Wheel 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		
Dynamic Friction Coefficient	0	1	0	1	1											3	0.2
Abrasion Resistance	1					1	1	1	1							5	0.333
Impact Resistance		0				0				1	0	1				2	0.133
Heat Resistance			1				0			0			0	0		1	.067
Cost				0				0			1		1		1	3	0.2
Tensile Strength					0				0			0		1	0	1	.067
Total Number of Positive Decisions																15	$\Sigma\alpha=1$

Table 6.12 shows the digital logic method for different components of the Back Wheel. Of these criteria, abrasion resistance has the highest number of positive decisions i.e. highest relative co-efficient

Table 6.13: Calculation of the performance index for material selection of Back Wheel:

Selection Criteria	Relative Emphasis Coefficient, α	Natural and Synthetic Rubber		Nylon	
		Scaled Property,β	Weighted Score,αβ	Scaled Property,β	Weighted Score,αβ
Dynamic Friction Coefficient	0.2	100	20.00	35	7.00
Abrasion Resistance	0.333	100	33.30	60	19.98
Impact Resistance	0.133	100	13.30	80	10.64
Heat Resistance	.067	100	6.70	75	5.03
Cost	0.2	50	10.00	100	20.00
Tensile Strength	.067	63.2	4.23	100	6.70
Material Performance Index			**87.53**		69.35

Table 6.13 shows the weighted score for different selection criteria for two different materials and the performance index for each of the materials. Among the two materials, Natural and Synthetic Rubber has the maximum performance index. Therefore, for Back Wheel, Natural and Synthetic Rubber should be selected as material which we also selected in the previous chapter.

6.5.5 Material Selection for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder:

Table 6.14: List of selection criteria with numerical values or values from Likert Scale for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder:

Selection Criteria	Mild Steel	Stainless Steel	Aluminum
Tensile Strength (MPa)	420	696	240
Compressive Strength (MPa)	250	365	400
Density (kg/m3)	7870	7860	2690
Cost (BDT/kg)	85	145	180
Availability (Likert Scale)	5	3	4

From these selection criteria, we want to maximize Tensile Strength, Compressive Strength and Availability and minimize Density and Cost.

Table 6.15: Determination of relative importance of material selection criteria for for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder 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		
Tensile Strength	1	1	0	1							3	0.3
Compressive Strength	0				1	0	1				2	0.2
Density		0			0			1	0		1	0.1
Cost			1			1		0		1	3	0.3
Availability				0			0		1	0	1	0.1
Total Number of Positive Decisions											10	$\sum \alpha = 1$

Table 6.15 shows the Digital Logic Method for Clamp and Clamp Holder. Among these criteria, Tensile Strength has the highest number of positive decisions i.e. highest relative emphasis coefficient.

Table 6.16: Calculation of performance index for material selection of for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder Wheel:

Selection Criteria	**Relative Emphasis Coefficient, α**	**Aluminium**		**Stainless Steel**		**Mild Steel**	
		Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ
Tensile Strength	0.3	34.48	10.34	100	30	60.34	18.1
Compressive Strength	0.2	100	20	91.25	18.25	63	12.6
Density	0.1	100	10	34.22	3.42	34.18	3.42
Cost	0.3	36.11	10.83	44.83	13.45	100	30
Corrosion Resistance	0.1	80	8	60	6	100	10
Material Performance Index			59.17		71.12		**74.12**

Table 6.16 shows the weighted score of different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, Stainless Steel has the highest performance index. Therefore, it is mathematically justified that Stainless Steel should be selected for for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder.

6.5.6 Material Selection for Joining Screw:

Table 6.17: List of selection criteria with numerical values or values from Likert Scale for Joining Screw:

Selection Criteria	Stainless Steel	Mild Steel	Aluminium
Tensile Strength (MPa)	696	420	240
Compressive Strength (MPa)	365	250	400
Cost (BDT/kg)	145	65	180
Corrosion Resistance (Likert Scale)	5	4	4
Shear Strength (MPa)	335	250	207

From these selection criteria, we want to maximize Tensile Strength, Compressive Strength, Corrosion Resistance and Shear Strength and minimize Cost.

Table 6.18: Determination of relative importance of material selection criteria for Joining Screw 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		
Tensile Strength	1	1	1	0							3	0.3
Compressive Strength	0				0	1	0				1	0.1
Cost		0			1			0	0		1	0.1
Corrosion Resistance			0			0		1		0	1	0.1
Shear Strength				1			1		1	1	4	0.4
Total Number of Positive Decisions											10	∑α = 1

Table 6.18 shows the Digital Logic Method for Joining Screw. Among these criteria, Shear Strength has the highest number of positive decisions i.e. highest relative emphasis coefficient.

Table 6.19: Calculation of performance index for material selection of Joining Screw:

Selection Criteria	Relative Emphasis Coefficient, α	Stainless Steel		Mild Steel		Aluminium	
		Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ
Tensile Strength	0.3	100	30	60.34	18.10	34.48	10.34
Compressive Strength	0.1	91.25	9.13	62.5	6.25	100	10
Cost	0.1	44.83	4.48	100	10	36.11	3.61
Corrosion Resistance	0.1	100	10	80	8	80	8
Shear Strength	0.4	100	40	74.63	29.85	61.79	24.72
Material Performance Index			**93.61**		72.20		56.67

Table 6.19 shows the weighted score of different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, Stainless Steel has the highest performance index. Therefore, it is mathematically justified that Stainless Steel should be selected for Joining Screw.

6.5.7 Material Selection for Grass Collector:

Table 6.20: List of selection criteria with numerical values or values from Likert Scale for Grass Collector:

Selection Criteria	Nylon	HDPE	PVC
Density (kg/m3)	1140	958	1300
Cost (BDT/kg)	40	100	140
Corrosion Resistance (Likert Scale)	4	5	5
Tensile Strength (MPa)	85	40	60

From these selection criteria, we want to maximize Corrosion Resistance and Tensile Strength and minimize Density and Cost.

Table 6.21: Determination of relative importance of material selection criteria for Grass Collector 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		
Density	1	1	1				3	0.5
Cost	0			0	1		1	0.17
Corrosion Resistance		0		1		0	1	0.17
Tensile Strength			0		0	1	1	0.17
Total Number of Positive Decisions							6	$\sum \alpha = 1$

Table 6.21 shows the Digital Logic Method for Grass Collector. Among these criteria, Density has the highest number of positive decisions i.e. highest relative emphasis coefficient.

Table 6.22: Calculation of performance index for material selection of Grass Collector:

Selection Criteria	**Relative Emphasis Coefficient, α**	**Nylon**		**HDPE**		**PVC**	
		Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ
Density	0.5	84.04	42.02	100	50	73.69	36.85
Cost	0.17	100	16.67	40	6.67	28.57	4.76
Corrosion Resistance	0.17	80	13.33	100	16.67	100	16.67
Tensile Strength	0.17	100	16.67	47.06	7.84	70.59	11.76
Material Performance Index			**88.68**		81.18		70.04

Table 6.22 shows the weighted score of different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, Nylon has the highest performance index. Therefore, it is mathematically justified that Nylon should be selected for Grass Collector.

6.5.8 Material Selection for Helix Blade and Bedknife:

Table 6.23: List of selection criteria with numerical values or values from Likert Scale for Helix Blade and Bedknife:

Selection Criteria	Stainless Steel	Mild Steel	Carbon Steel
Brinell Hardness	138	120	380
Heat Resistance (Likert Scale)	5	4	3
Density (kg/m3)	7860	7870	7540
Cost (BDT/kg)	145	65	45
Corrosion Resistance (Likert Scale)	5	4	3

From these selection criteria, we want to maximize Heat Resistance and Corrosion Resistance and minimize Brinell Hardness, Density and Cost.

Table 6.24: Determination of relative importance of material selection criteria for Helix Blade and Bedknife 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		
Brinell Hardness	1	0	1	0							2	0.2
Heat Resistance	0				1	1	0				2	0.2
Density		1			0			0	0		1	0.1
Cost			0			0		1		0	1	0.1
Corrosion Resistance				1			1		1	1	4	0.4
Total Number of Positive Decisions											10	∑α = 1

Table 6.24 shows the Digital Logic Method for Helix Blade and Bedknife. Among these criteria, Corrosion Resistance has the highest number of positive decisions i.e. highest relative emphasis coefficient.

Table 6.25: Calculation of performance index for material selection of Helix Blade and Bedknife:

Selection Criteria	**Relative Emphasis Coefficient, α**	**Stainless Steel**		**Mild Steel**		**Carbon Steel**	
		Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ
Brinell Hardness	0.2	86.96	17.39	100	20	31.58	6.32
Heat Resistance	0.2	100	20	80	16	60	12
Density	0.1	95.93	9.59	95.81	9.58	100	10
Cost	0.1	31.03	3.10	69.23	6.92	100	10
Corrosion Resistance	0.4	100	40	80	32	60	24
Material Performance Index			**90.09**		84.50		62.32

Table 6.25 shows the weighted score of different selection criteria for three different materials and the performance index for each of the materials. Among the three materials, Stainless Steel has the highest performance index. Therefore, it is mathematically justified that Stainless Steel should be selected for Helix Blade and Bedknife.

6.6 List of Manufacturing Processes and Joining Processes

6.6.1 Manufacturing Processes:

1. Cutting of Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder

6.6.2 Joining Processes:

1. Permanent Joint
2. Temporary Joint

6.7 Quantitative Analysis of Manufacturing Process Selection

6.7.1 Manufacturing Process Selection for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder:

Table 6.26: List of selection criteria with numerical values or values from Likert Scale for manufacturing the Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder:

Selection Criteria	Die Casting	Cutting
Cost	5	3
Strength	4	4
Defect rate	4	3
Dimensional Accuracy	4	3
Operational complexity	5	3

From these criteria, we want to maximize strength and dimensional accuracy; and minimize cost, operational complexity and defect rate.

Table 6.27: Determination of relative importance for manufacturing process selection for Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder 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	1							3	0.3
Strength	1				1	1	1				4	0.4
Defect rate		0			0			1	0		1	0.1
Dimensional Accuracy			0			0		0		1	1	0.1
Operational Complexity				0			0		1	0	1	0.1
Total Number of Positive Decisions											10	$\sum$**α**= 1

Table 6.27 shows the digital logic method for manufacturing processes of Clamp and Clamp Holder. Of these criteria, Strength has the highest relative emphasis coefficient.

Table 6.28: Calculation of performance index for manufacturing process selection of Upper Clamp, Lower Clamp, Side Plate and Grass Collector Holder:

Selection Criteria	**Relative Emphasis Coefficient α**	**Die Casting**		**Cutting**	
		Scaled Property, β	Weighted Property, αβ	Scaled Property, β	Weighted Property, αβ
Cost	0.3	60	18	100	30
Strength	0.4	100	40	100	40
Defect rate	0.1	75	7.5	100	10
Dimensional Accuracy	0.1	100	10	75	7.5
Operational Complexity	0.1	60	6	100	10
Process Performance Index			81.5		**97.5**

Table 6.28 shows the weighted score for Die Casting and Forging. Since the performance index of Die Casting is higher, it should be selected as the manufacturing process for Clamp and Clamp Holder.

6.8 Quantitative Analysis of Permanent Joining Process Selection

6.8.1 Joining Process of Lower Clamp & Upper Clamp, Upper Clamp & Grass Collector Holder:

Table 6.29: List of selection criteria with numerical values or values from Likert Scale for Permanent Joints

Selection Criteria	MIG Welding	Arc Welding	TIG Welding
Cost (BDT/product)	20	15	35
Surface Finish	5	3	5
Strength	5	4	5
Operation Time (s)	20	30	40
Defect Rate (%)	1	3	1

From these criteria, we want to maximize strength and surface finish; and minimize cost, operation time and defect rate.

Table 6.30: Calculation of the relative emphasis coefficient for joining process selection of Clamp & Upper Clamp, Upper Clamp & Grass Collector Holder 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	1	0	1	1							3	0.3
Surface Finish	0				0	1	0				1	0.1
Strength		1			1			1	1		4	0.4
Operation Time			0			0		0		1	1	0.1
Defect Rate				0			1		0	0	1	0.1
Total Number of Positive Decisions											10	∑**α**= 1

Table 6.30 shows the digital logic method for joining process selection of Frame and Clamp Holder with Handlebar, Clamp and Bed Knife Holder. Among these criteria, strength has the highest relative emphasis coefficient.

Table 6.31: Calculation of performance index for joining process selection of Clamp & Upper Clamp, Upper Clamp & Grass Collector Holder:

Selection Criteria	**Relative Emphasis Coefficient α**	**MIG**		**Arc Welding**		**TIG welding**	
		Scaled Property, β	Weighted Property, αβ	Scaled Property, β	Weighted Property, αβ	Scaled Property, β	Weighted Property, αβ
Cost	0.3	75	22.5	100	30	42.86	12.86
Surface Finish	0.1	100	10	60	6	100	10
Strength	0.4	100	40	80	32	100	40
Operation Time	0.1	100	10	83.33	6.67	50	5
Defect rate	0.1	100	10	33.33	3.33	100	10
Process Performance Index			**92.5**		78		77.86

Since the performance index for MIG welding is highest among all so, MIG welding will be selected as our joining process of Clamp & Upper Clamp, Upper Clamp & Grass Collector Holder.

6.9 Joining Process Selection for Temporary Joints:

6.9.1 Joining Process of Upper Clamp & Cycle Frame, Lower Clamp & Side Plate, Side Plate & Mower Body:

Table 6.32: List of selection criteria with numerical values or values from Likert Scale for Temporary Joints:

Selection Criteria	Nut-Bolt	Rivet
Cost	5	5
Strength	5	4
Availability	5	4
Surface Finish	4	5
Design Flexibility	5	4

From these criteria, we want to maximize strength, surface finish, weldability and design flexibility and minimize cost.

Table 6.33: Calculation of the relative emphasis coefficient for joining process selection of Clamp and Clamp Holder 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	0	1	1							2	0.2
Strength	1				0	1	1				3	0.3
Availability		1			1			1	0		3	0.3
Surface Finish			0			0		0		1	1	0.1
Design Flexibility				0			0		1	0	1	0.1
Total Number of Positive Decisions											10	∑ **α**= 1

Table 6.33 shows the digital logic method for joining process selection of Clamp and Clamp Holder. Among these criteria, strength and availability have the highest relative emphasis coefficient.

Table 6.34: Calculation of performance index for joining process selection of Clamp and Clamp Holder:

Selection Criteria	**Relative Emphasis Coefficient α**	**Nut-Bolt**		**Rivet**	
		Scaled Property, β	Weighted Property, αβ	Scaled Property, β	Weighted Property, αβ
Cost	0.2	100	20	100	20
Strength	0.3	100	30	80	24
Availability	0.3	100	30	80	24
Surface Finish	0.1	80	8	100	10
Design Flexibility	0.1	100	10	80	8
Process Performance Index			**98**		86

Since the performance index for Nut-bolt is larger than Riveting, so Nut-bolt will be used for the temporary joint between Upper Clamp & Cycle Frame, Lower Clamp & Side Plate, Side Plate & Mower Body.

Chapter 07

Design Analysis

7.1 Introduction

The goal of this chapter is to establish an intelligent support system to design a product through managing variety. The Interpretive Structural Model (ISM) technique is applied to visualize the hierarchy of component interactions within a product. To fulfill different market requests this approach renders the design priority and related design dimensions for helping designers to create variant design solutions in a product like Super Handy Lawn Mower.

The designer must define the specific motion 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.

7.2 Parts of Super Handy Lawn Mower

1. Body Frame:

Figure 7.1: Body Frame

2. Pedal:

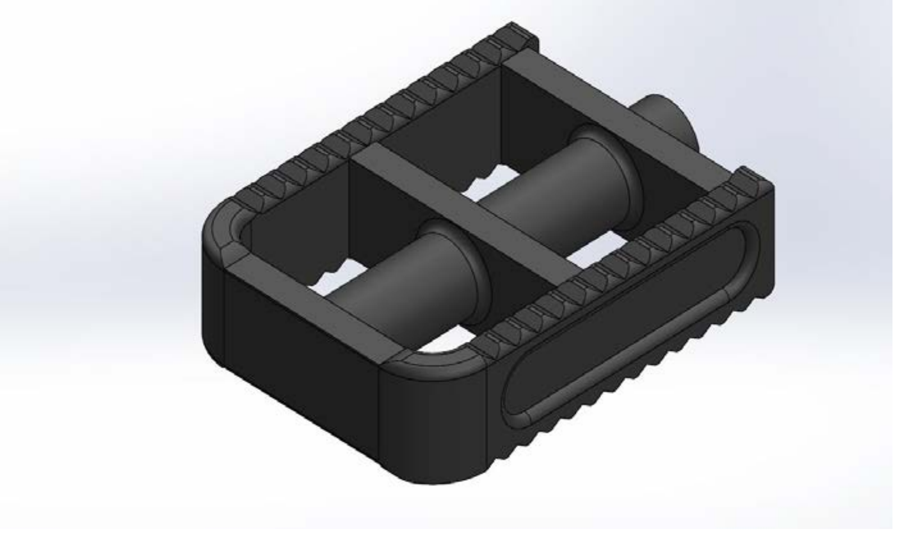


Figure 7.2: Pedal

3. Saddle:

Figure 7.3: Saddle

4. Detached Helix Blade with Clamp:

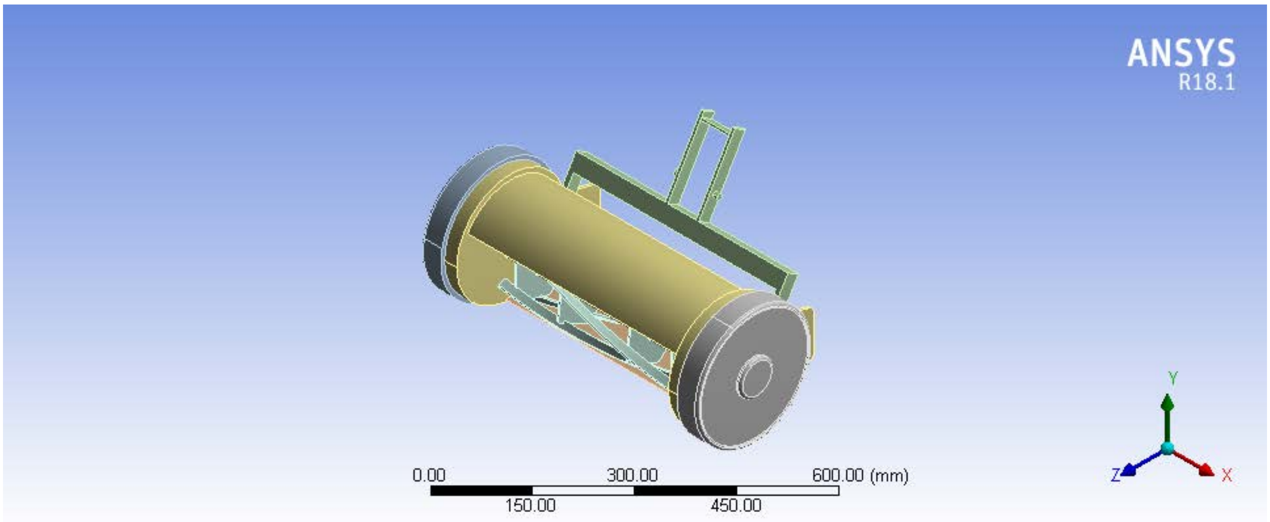


Figure 7.4: Detached Helix Blade with Clamp

7.3.1 Static Structural Analysis (ANSYS)

7.3.1 Static Structural Analysis of Body Frame:

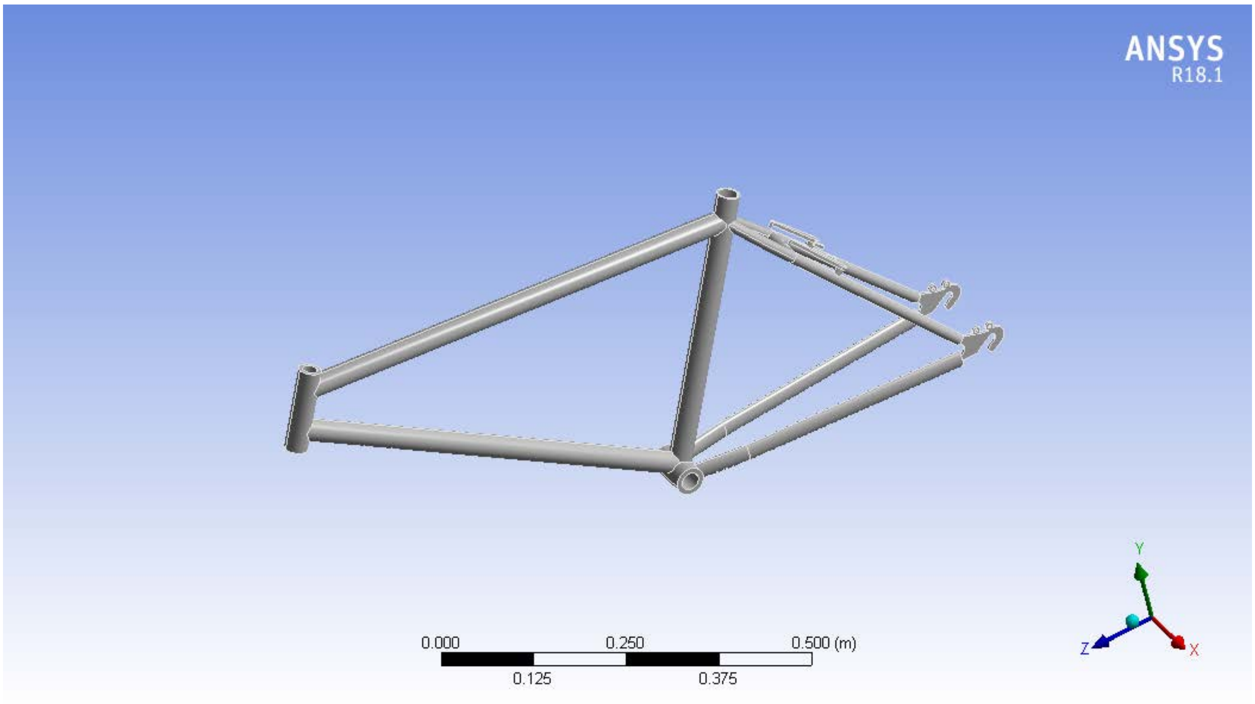


Figure 7.5: Body Frame

Load:

Types	Force
X-Component	0 N
Y-Component	-1096.3 N (ramped)
Z-Component	488.08(ramped)

1. Total deformation:

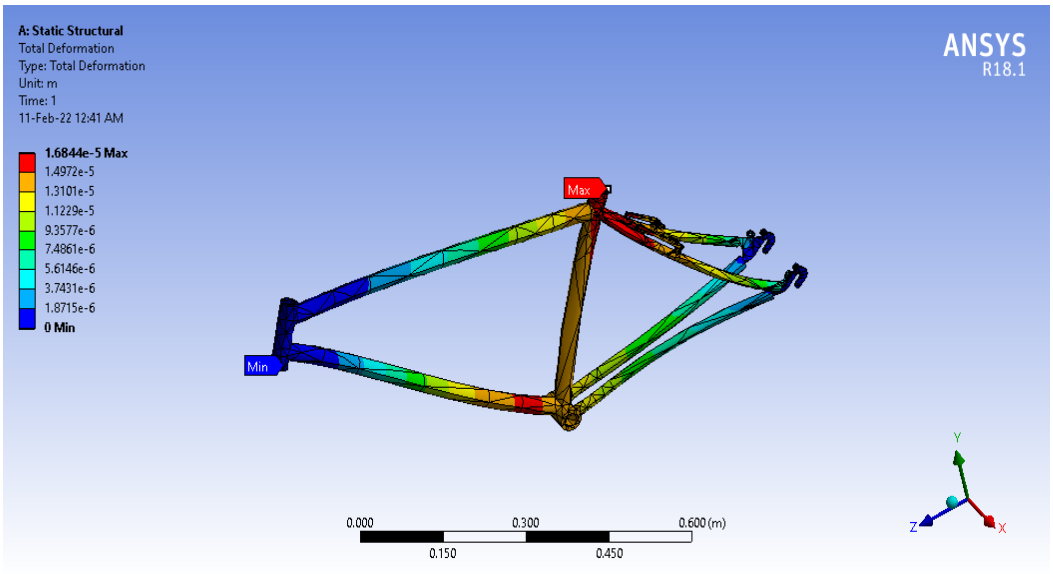


Figure 7.6: Total Deformation

Result:

Range	**Total Deformation**
Minimum	0 m
Maximum	1.6844e-5 m

2. Equivalent Stress:

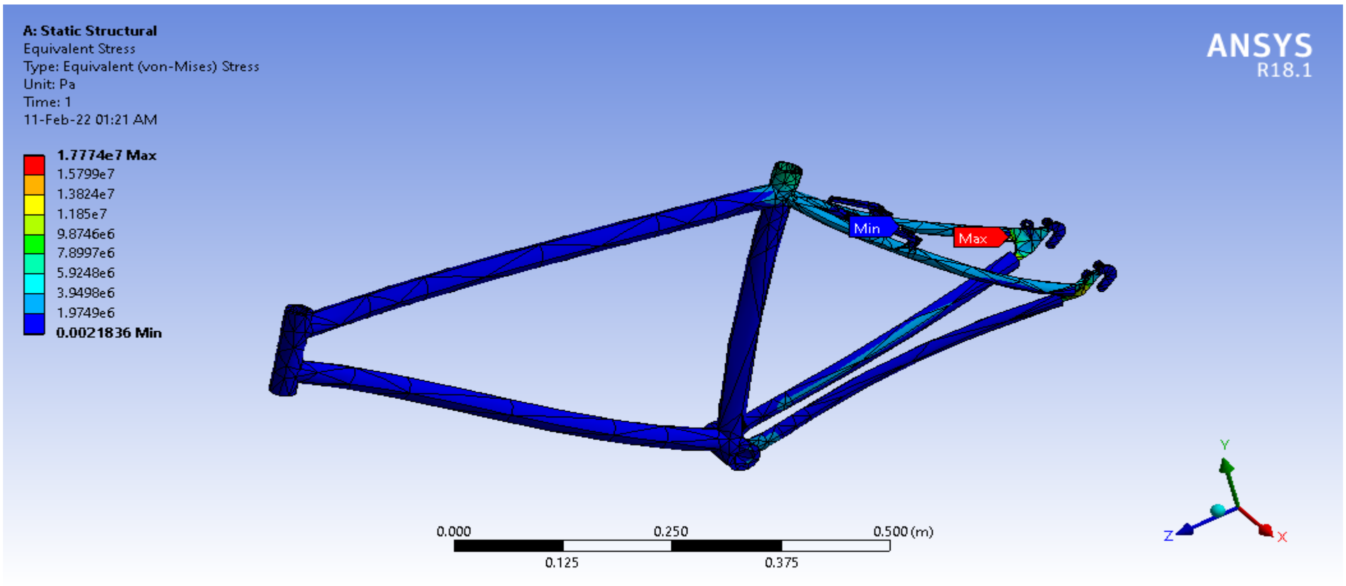


Figure 7.7: Equivalent Stress

Result:

Range	Equivalent (von-Mises) Stress
Minimum	0.0021836 Pa
Maximum	1.7774e7 Pa

3. Safety Factor:

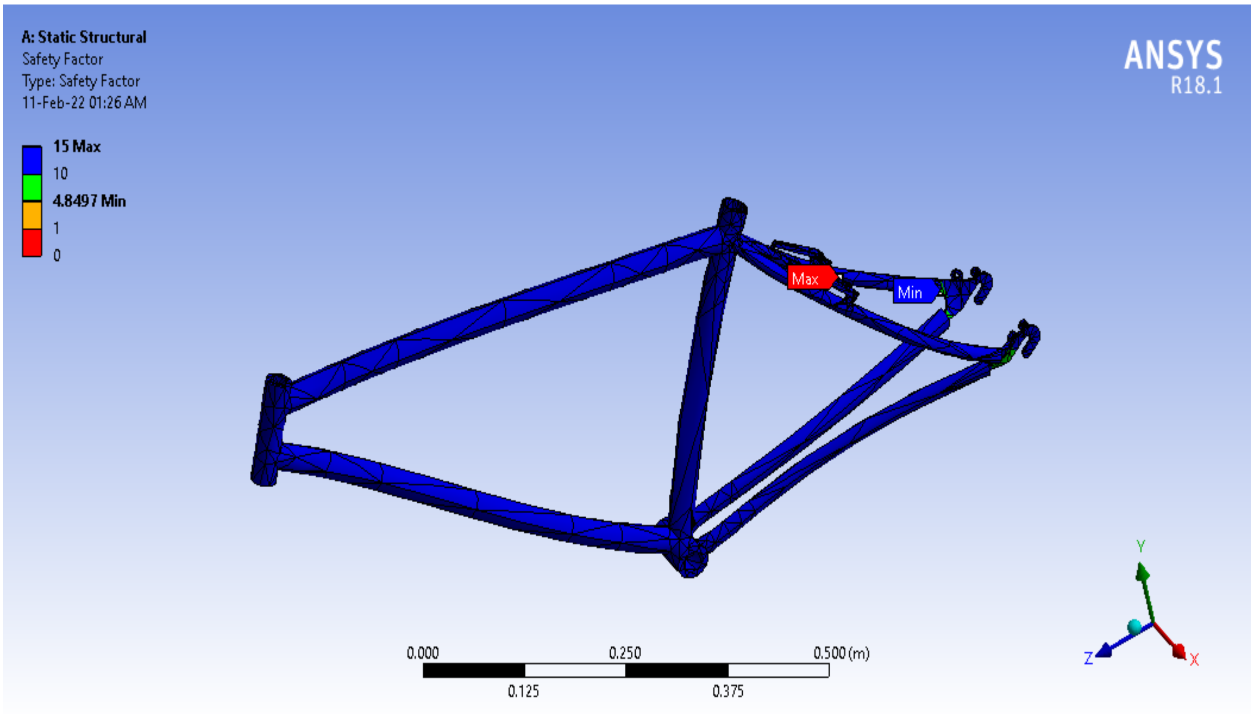


Figure 7.8: Safety Factor

Result:

Range	Safety Factor
Minimum	4.8497
Maximum	15

4. Fatigue Life:

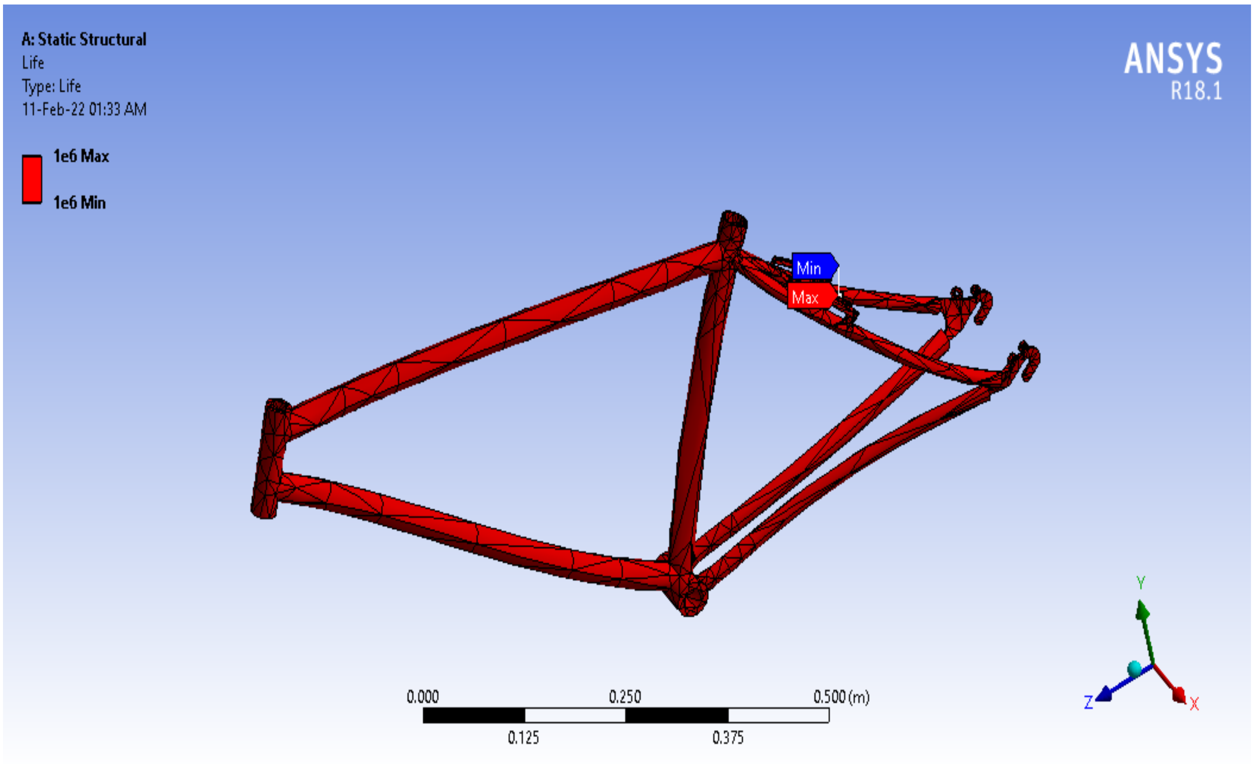


Figure 7.9: Fatigue Life

Result:

Range	Life (cycles)
Minimum	1e6
Maximum	1e6

7.3.2 Static Structural Analysis of Pedal:

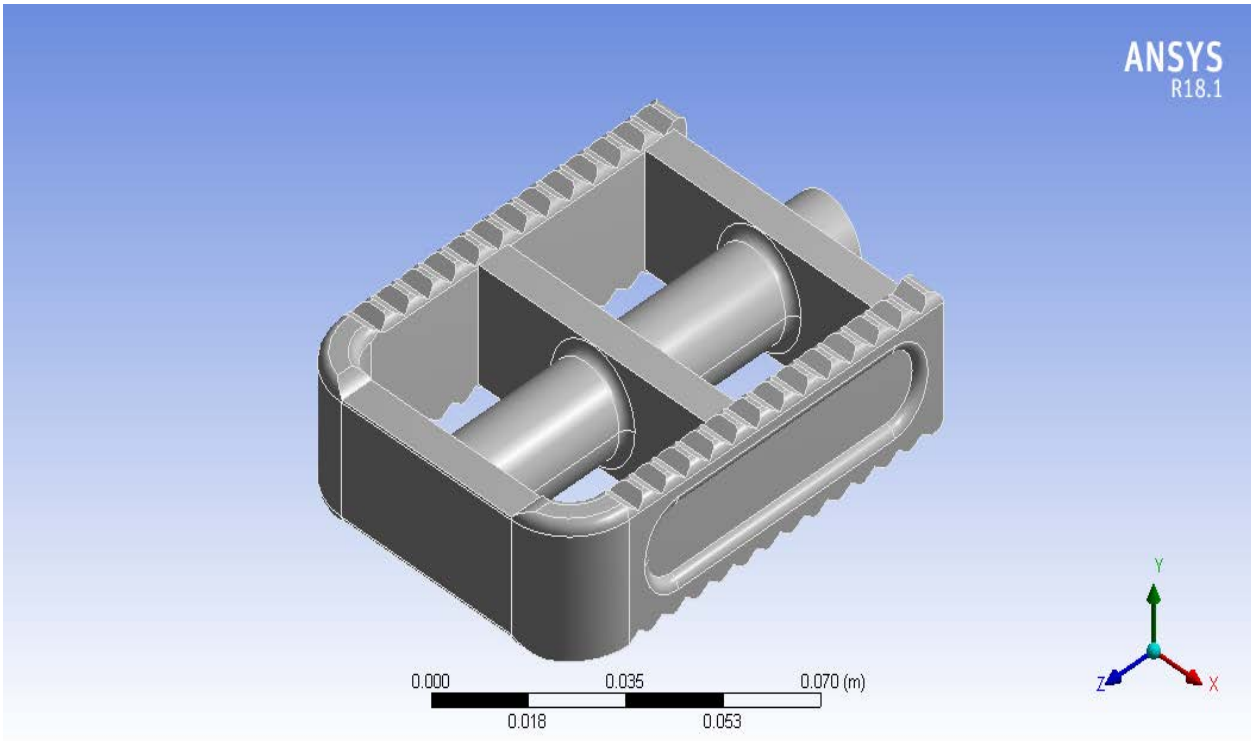


Figure 7.10: Pedal

Load:

Types	Force
X-Component	0 N (ramped)
Y-Component	-600 N(ramped)
Z-Component	0 N (ramped)

1. Total Deformation:

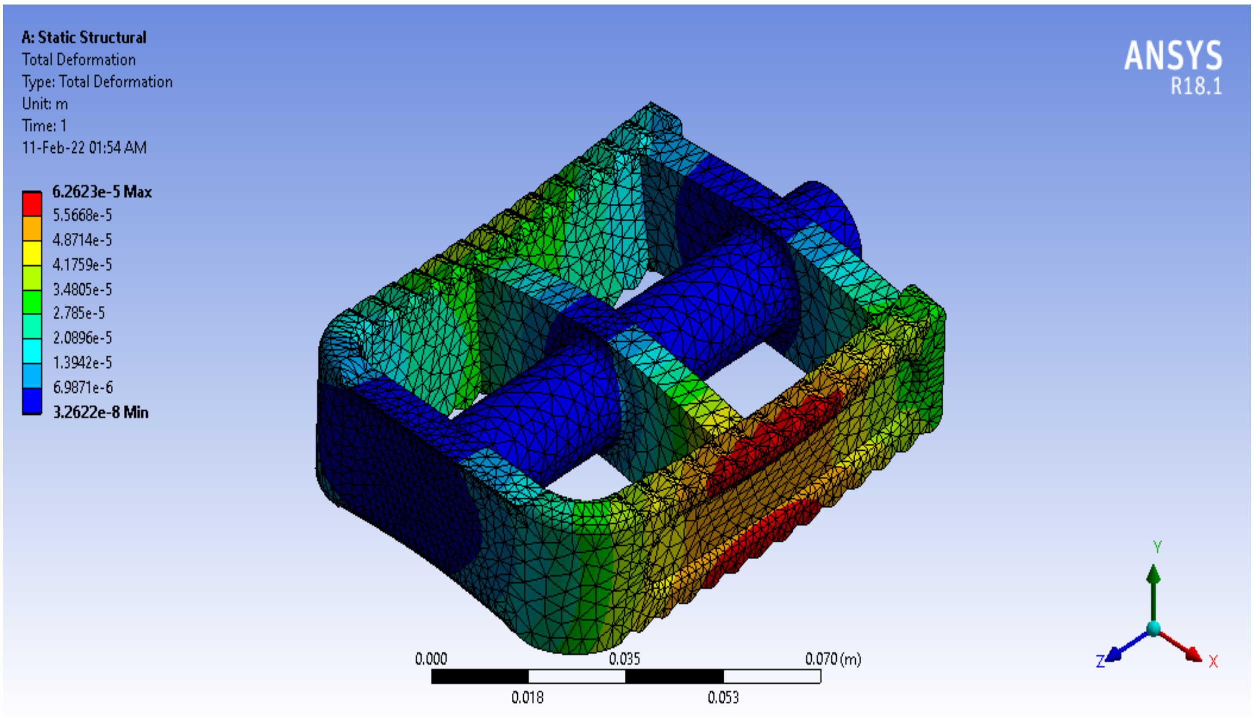


Figure 7.11: Total Deformation

Result:

Range	Total Deformation
Minimum	3.2622e-8 (m)
Maximum	6.2623e-5 (m)

2. Equivalent Stress:

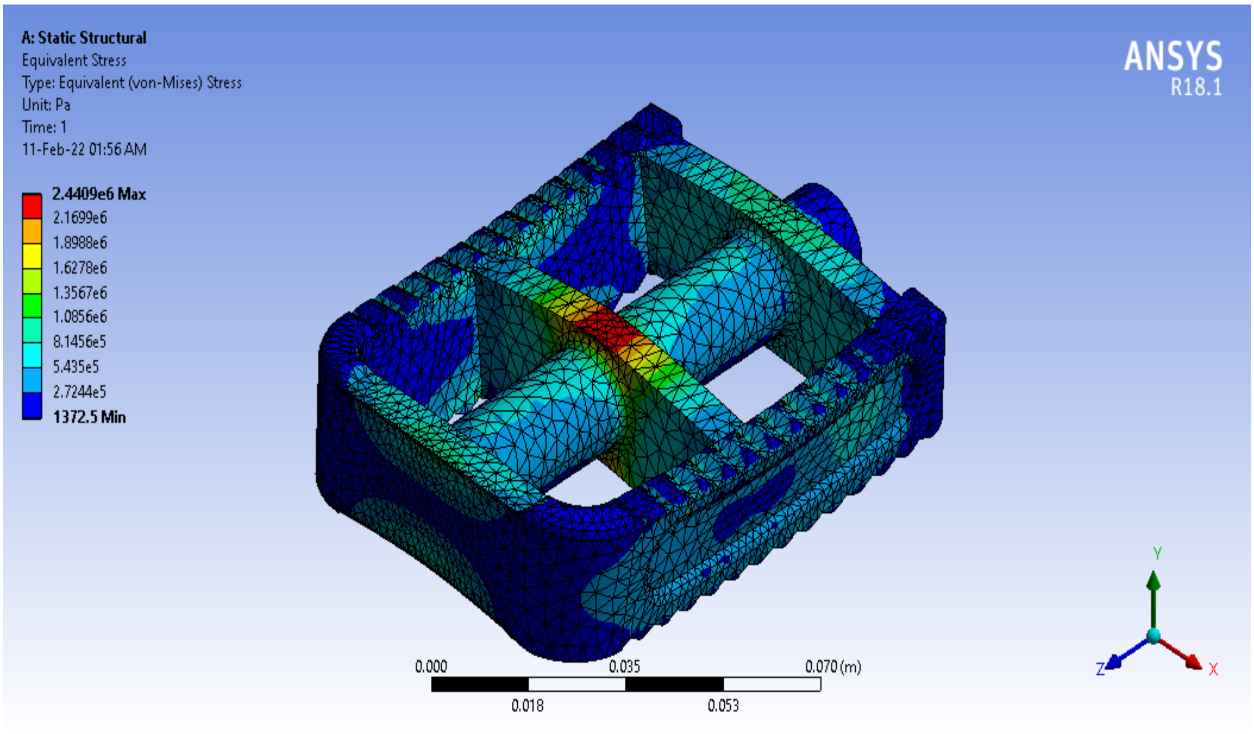


Figure 7.12: Equivalent Stress

Result:

Range	Equivalent Stress
Minimum	1372.5 Pa
Maximum	2.4409e6 Pa

3. Safety Factor:

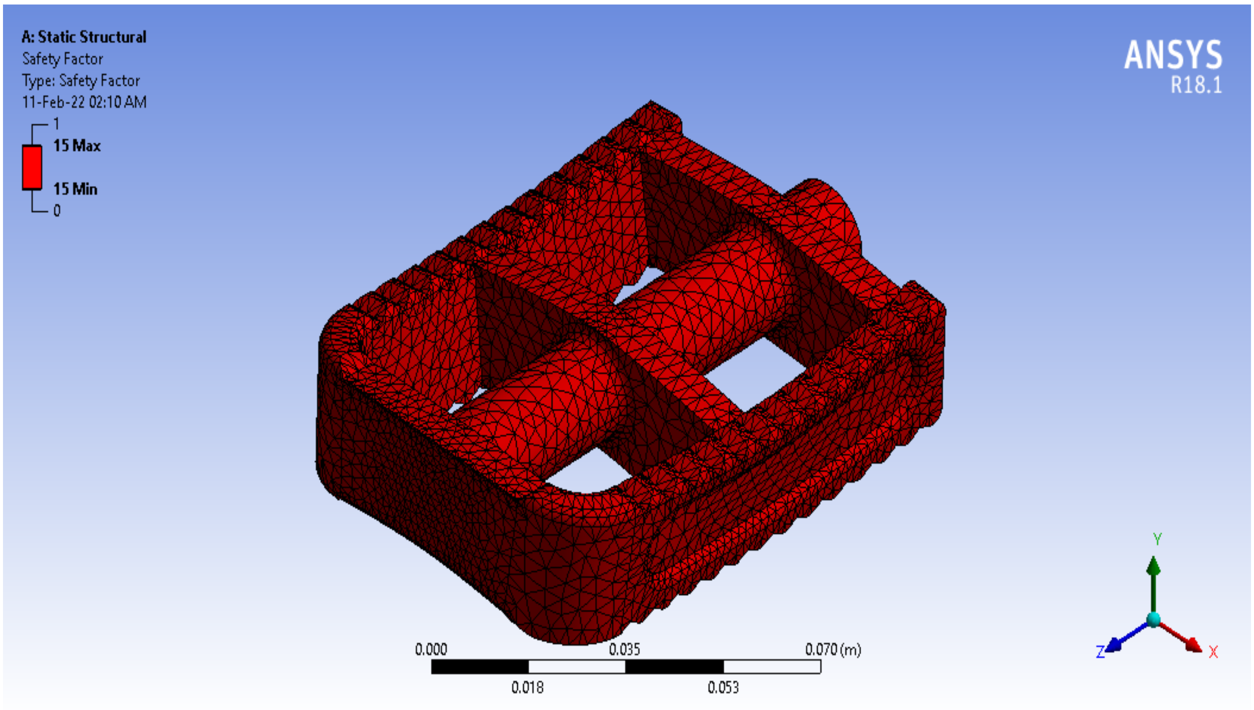


Figure 7.13: Safety Factor

Result:

Range	Safety Factor
Minimum	15
Maximum	15

4. Fatigue Life:

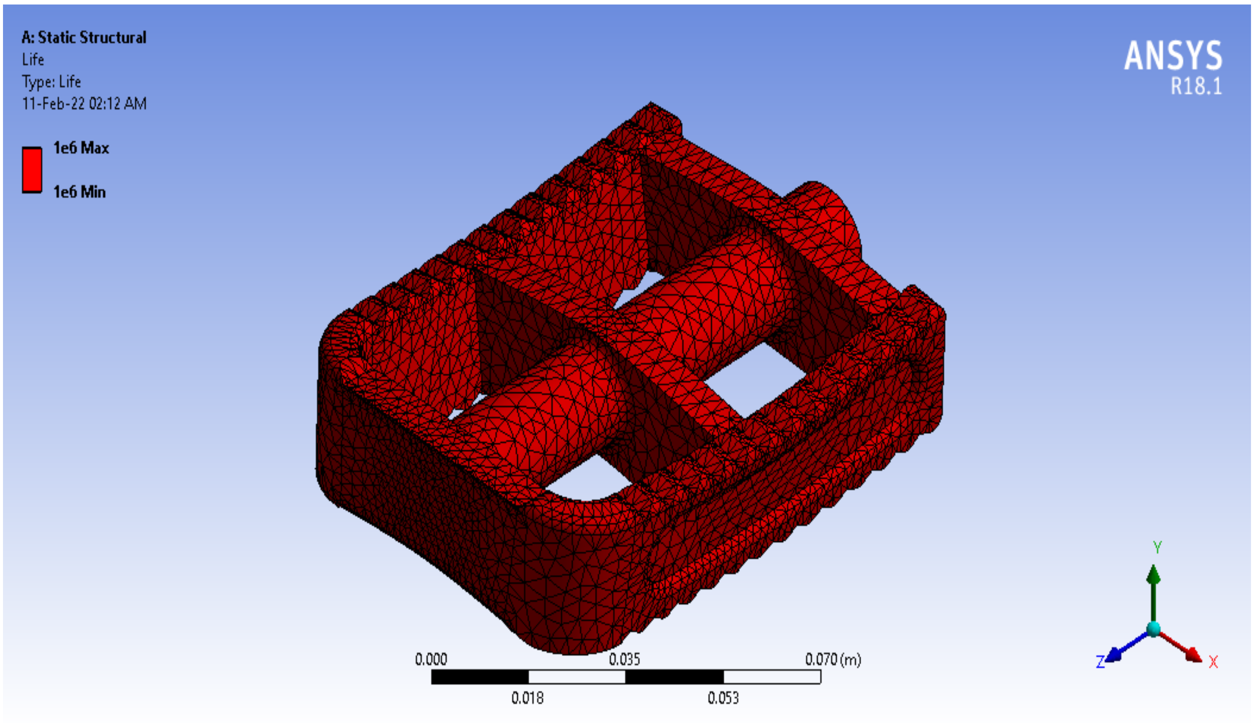


Figure 7.14: Fatigue Life

Result:

Range	Life (cycles)
Minimum	1e6
Maximum	1e6

7.3.3 Static Structural Analysis of Saddle:

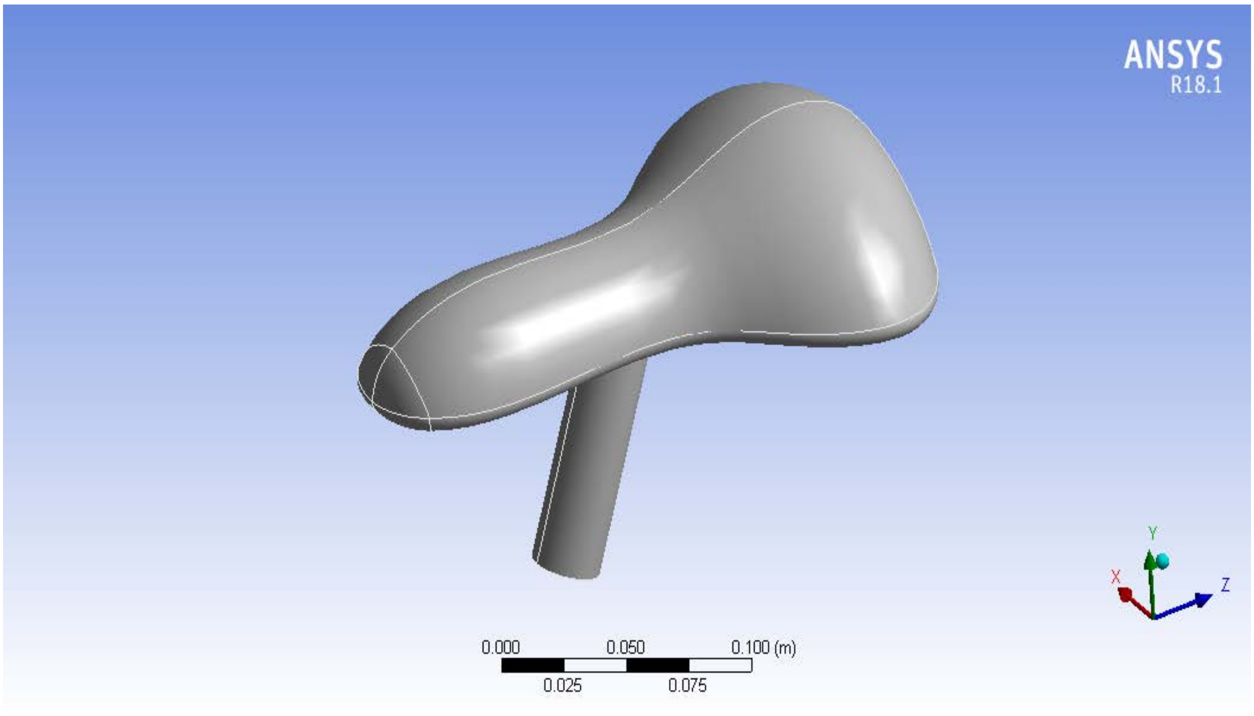


Figure 7.15: Saddle

Load:

Types	Force
X-Component	0 N (ramped)
Y-Component	-1200 N(ramped)
Z-Component	0 N (ramped)

1. Total Deformation:

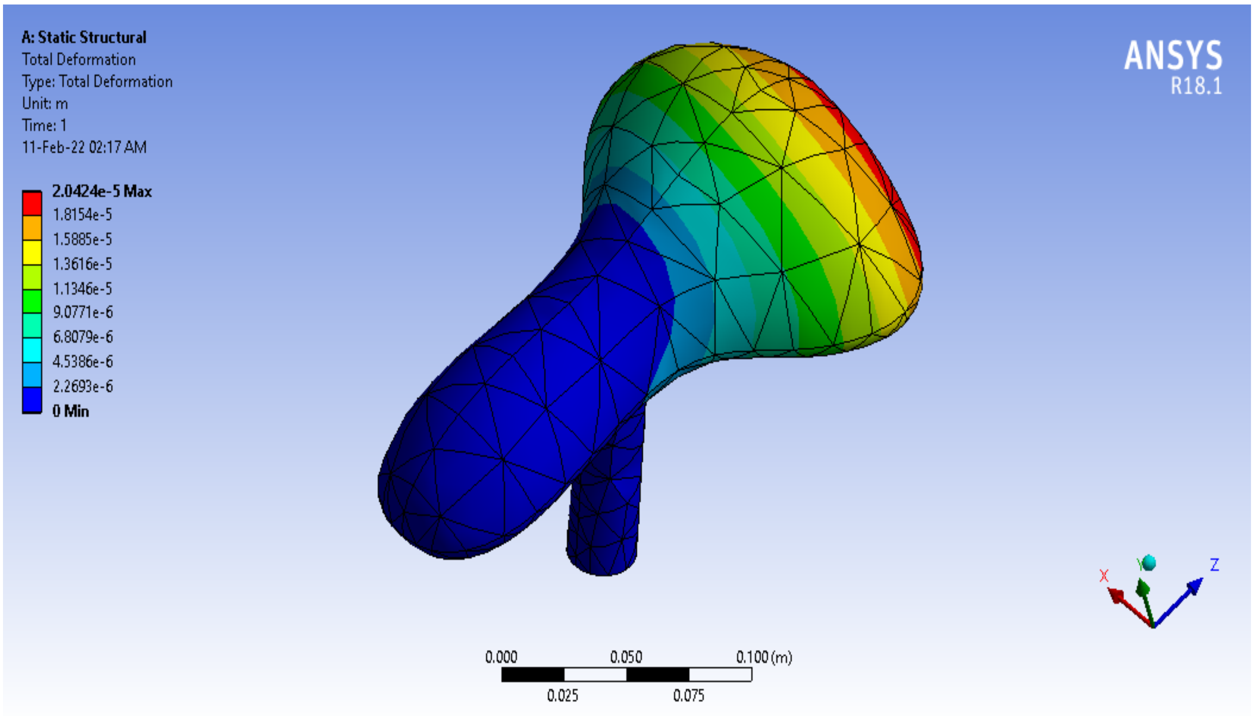


Figure 7.16: Total Deformation

Result:

Range	Total Deformation
Minimum	0 (m)
Maximum	2.0424e-5 (m)

2. Equivalent Stress:

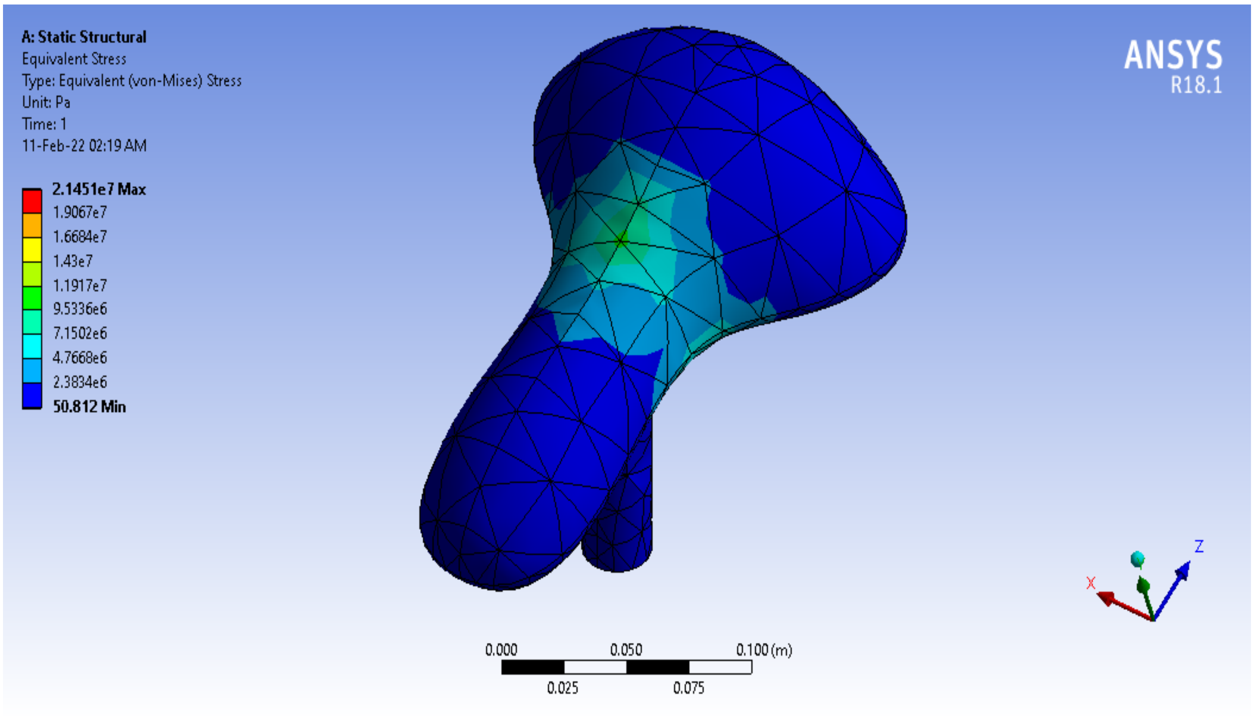


Figure 7.17: Equivalent Stress

Result:

Range	Equivalent Stress
Minimum	50.812 Pa
Maximum	2.1451e7 Pa

3. Safety Factor:

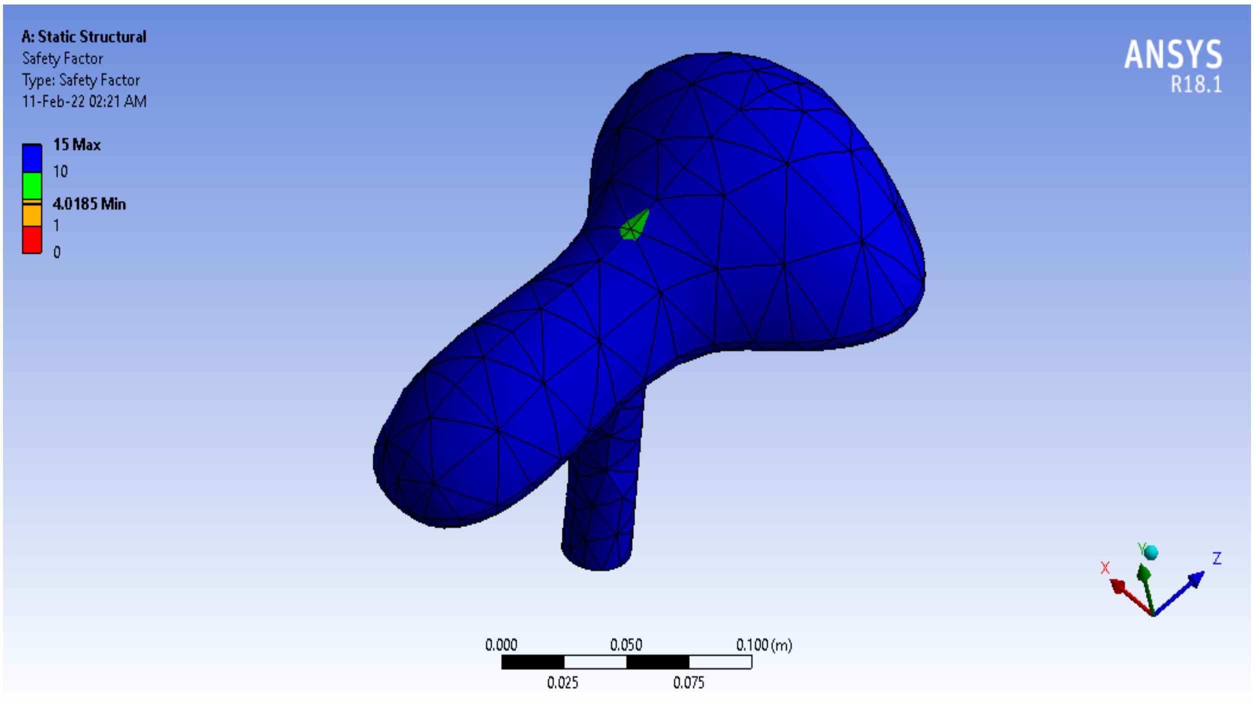


Figure 7.18: Safety Factor

Result:

Range	Safety Factor
Minimum	4.0185
Maximum	15

4. Fatigue Life:

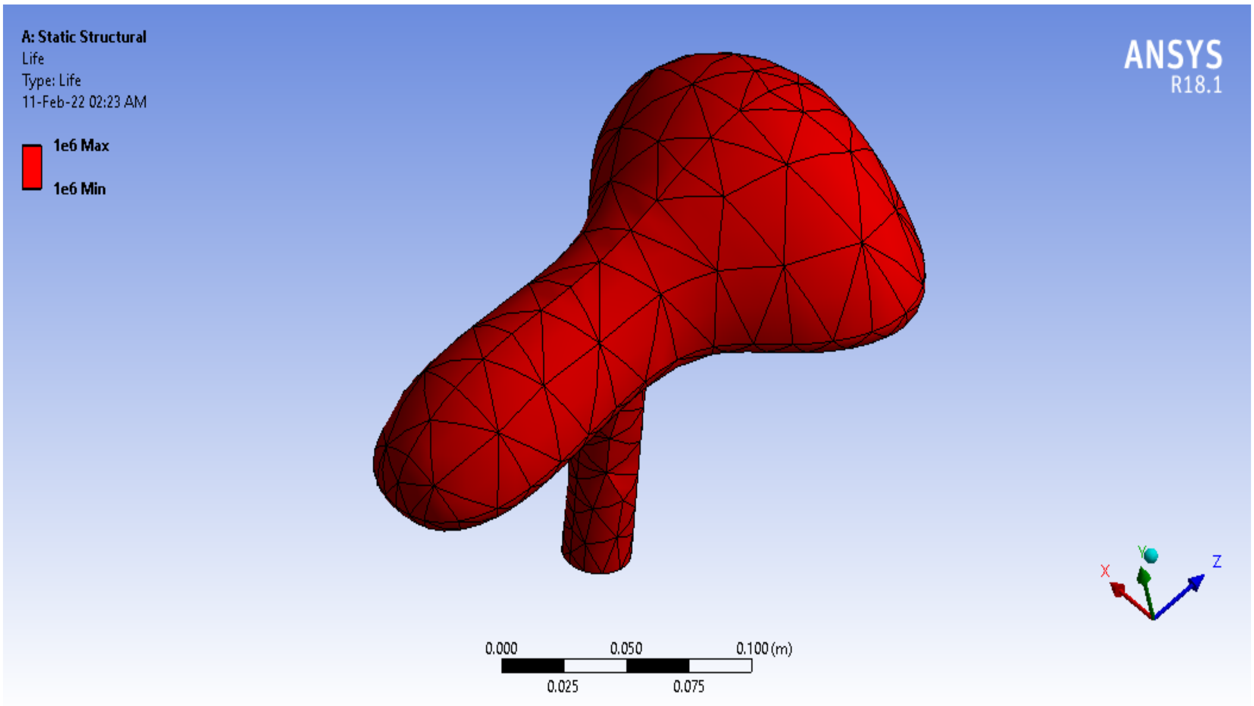


Figure 7. 19: Fatigue Life

Result:

Range	Life (cycles)
Minimum	1e6
Maximum	1e6

7.3.4 Static Structural analysis for Detached Helix Blade with Clamp:

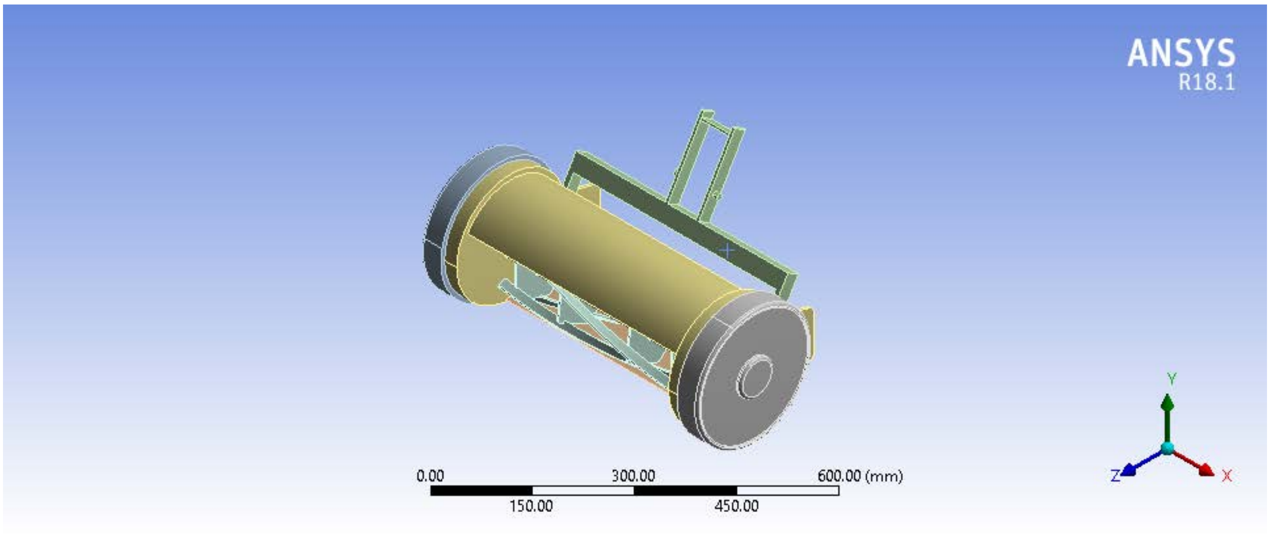


Figure 7. 20: Detached Helix Blade with Clamp

Load:

Types	Force
X-Component	0 N (ramped)
Y-Component	40 N(ramped)
Z-Component	0 N (ramped)

1. Total Deformation:

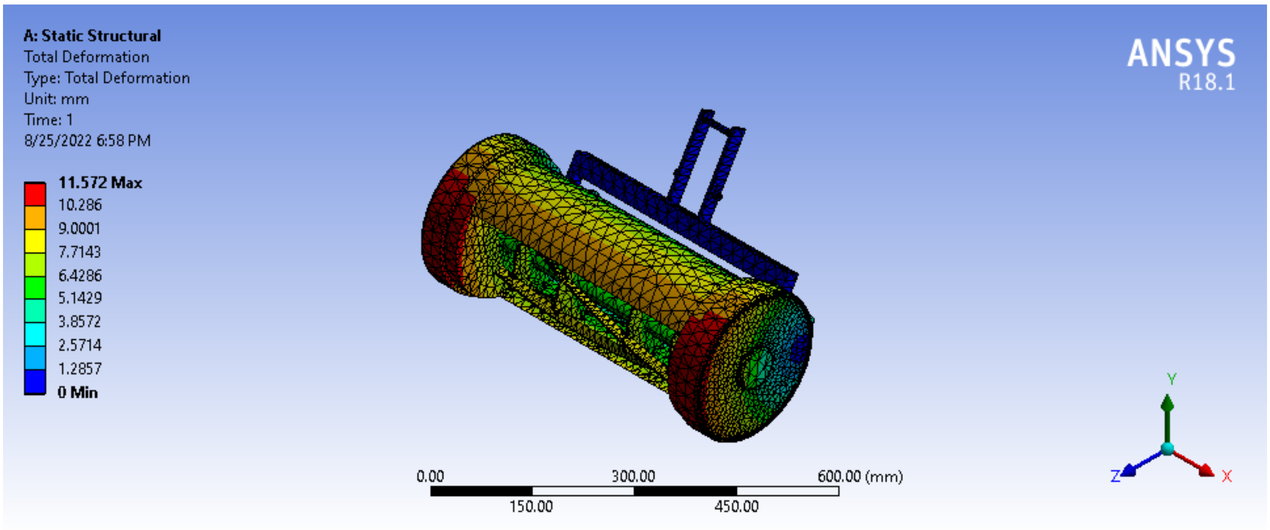


Figure 7.21: Total Deformation

Result:

Range	Total Deformation
Minimum	0 (m)
Maximum	11.572e-3 (m)

2. Equivalent Stress:

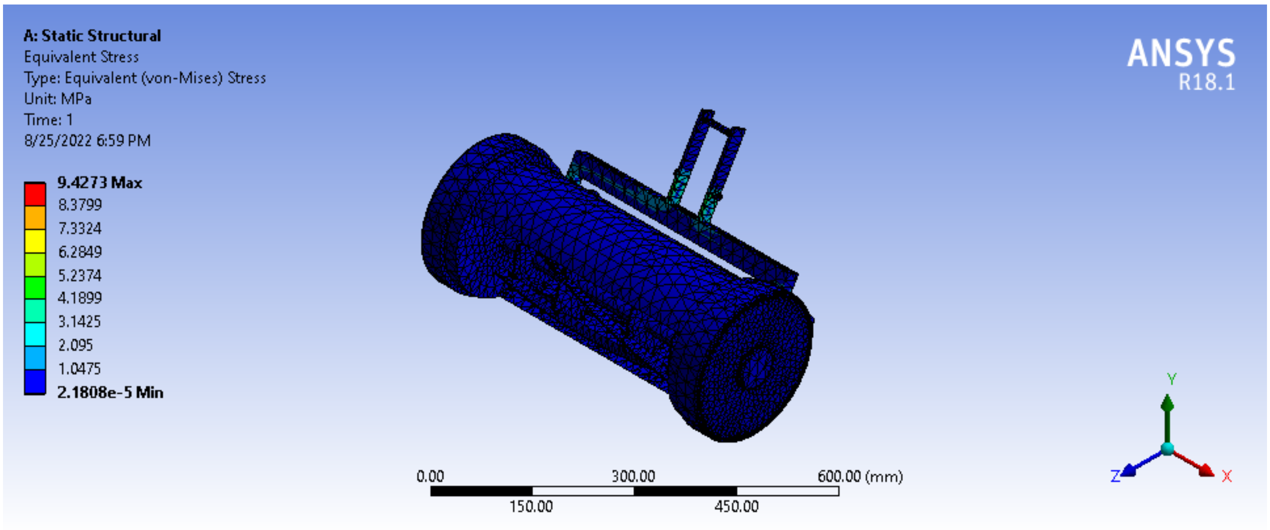


Figure 7.22: Equivalent Stress

Result:

Range	Total Deformation
Minimum	2.1808e1 Pa
Maximum	9.4273e6 Pa

3. Safety Factor:

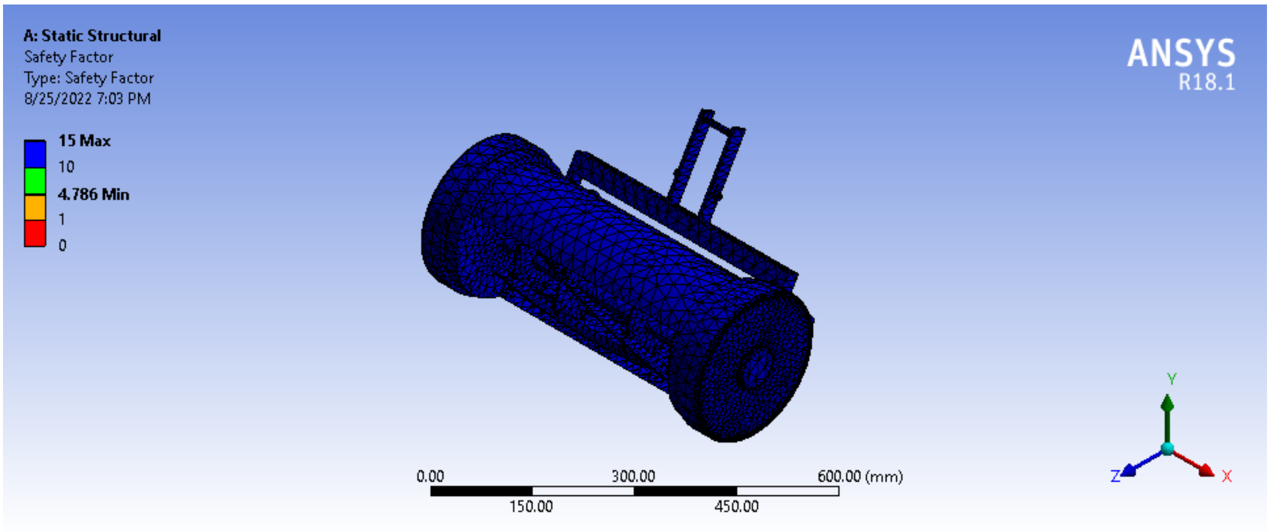


Figure 7.23: Safety Factor

Result:

Range	Safety Factor
Minimum	4.786
Maximum	15

4. Fatigue Life:

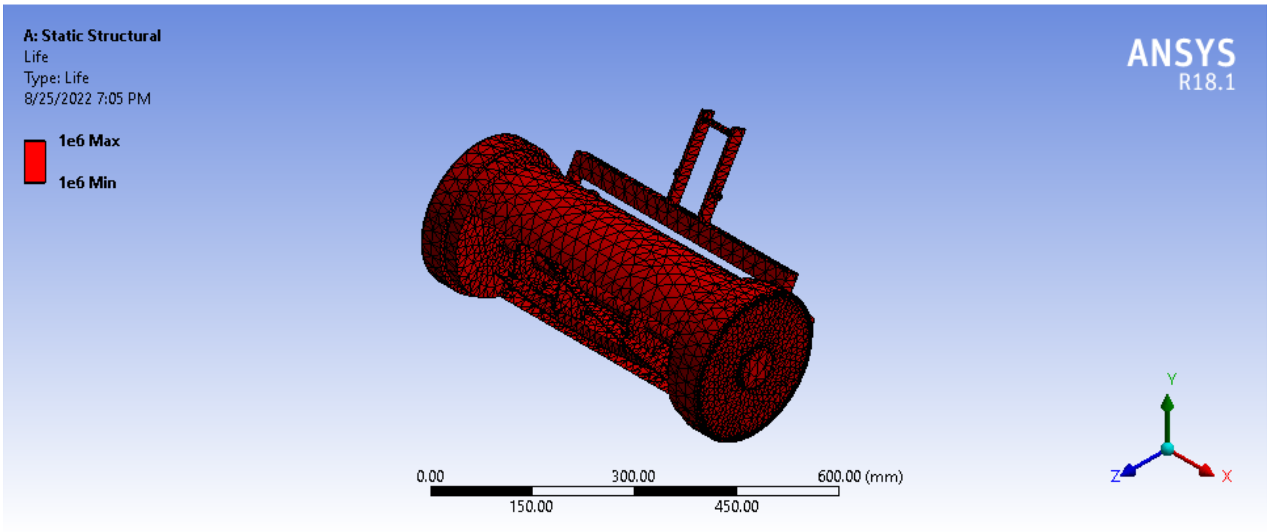


Figure 7.24: Fatigue Life

Result:

Range	Life (cycles)
Minimum	1e6
Maximum	1e6

The ANSYS analysis showed insignificant deformation, thus supporting our choice of materials.

We have installed a motor powered by an electric battery in the bicycle portion of our product. This motor has made the whole work easier and smoother for the operator. The motor we used here is a geared motor having power capacity of 250W (1/3 horsepower). Its no-load velocity is 3400 rpm at 24 volts. It Can be used with voltages ranging from 12V to 36V (DC). In short it is actually a ‘pancake’ motor having housing diameter of almost 4 inches with 11-tooth sprocket for 25 chain. The battery we used here is a 24V-12A Li-ion battery. It takes almost 5 hours for a full charging session. This battery can give power to the motor for almost 7-8 hours if this is used as bicycle (without attaching the lawn mower). A normal bicycle can travel almost 50-60 km depending on such power source. But this distance got reduced after attaching the mower by using a steel clamp in the front section of the bicycle. Increased weight of the whole product can be the reason behind it. Again, the overall capacity of the motor along with the battery was examined from the perspective of an almost flat surface where grass length is negligible. These values can alter for various lengths of the grass of a particular lawn. After doing several on-field experiments, we have calculated the battery lives and mower blade speeds depending on various grass lengths:

Table 7. 1: Relation between battery life and grass length

Grass Lengths (inch)	**Mower Blade Speed (rpm)**	**Battery Life (Hours)**
1-2	550	6
2-3	470	5
3-5	380	3

It can be seen that battery life reduces faster while operating on longer grass field. This is because friction increases with increasing grass length.

Chapter-8

Cost Analysis

8.1 Introduction

Cost is directly related to a product's design because cost largely varies with the decisions related to its design. Cost being an important factor has the vital role in the acquisition of a product for the following cases:

- Apart from the technology and aesthetics, cost becomes the main driving agent in this era of competition.
- A customer has also some financial limitations that may shift the acquisition decision toward affordability as an important factor.

In both cases, a successful product supplier must give more attention on the product cost. Design to cost is a vital strategy of management. An approach to make the product affordable for the customers is to set target cost as an independent design parameter which must be ensured during the product development phases.

The cost analysis method consists of the following elements:

- Identification of the product's cost drivers and consideration of cost drivers in detailing product specifications and emphasizing on cost reduction;
- Balancing customer requirements with affordability;
- Establishment and allocation of target costs down to a level of the components where cost scan be effectively managed;
- 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; and

- Continuous improvement through process value engineering to improve product value in the long run

In designing our “Super Handy Lawn Mower”, we have performed the required cost analysis from the viewpoint of a mass production system. A break-even analysis & sensitivity analysis is also done.

8.2 Demand Forecast

Forecasted Number of Products Per Year: 2,000 Pcs.

8.3 Manufacturing Costs

Manufacturing cost is the cost of production that is directly incurred during the production process. It includes direct labour, direct material and manufacturing overhead costs.

8.3.1 Cost of Machineries:

1. MIG welding setup (Brand Name: ESAB, United Kingdom)

Buying cost: 5, 00,000 Tk.

Effective working life: 20 years

Salvage value: 35,000 Tk.

Quantity: 2

2. Bosch GCO 14-24 J Metal Cutter

Buying Cost: BDT 40,000 Tk.

Effective working life: 5 years

Salvage value: BDT 5,000

Quantity: 3

Total Cost of Machineries: 11, 20,000 Tk.

8.3.2 Cost of Raw Materials (per unit of product):

1. Mild Steel Rod

Required Quantity: 2 kg

Market price: 85 Tk/ kg

Total Cost Per Product: 170 Tk.

2. Stainless Steel Rod

Required Quantity: 0.2 kg

Market price: 220 Tk/ kg

Total Cost Per Product: 44 Tk.

3. Epoxy Adhesive

Market price: 800 Tk/ container

Total Cost Per Product: 15 Tk.

4. Colour

Required Quantity: 100 gm

Market price: 250 Tk/ kg

Total Cost Per Product: 25 Tk.

5. Lubricating Oil

Required Quantity: 10 ml

Market price: 200 Tk/ litre

Total Cost Per Product: 2 Tk

Total Cost of Raw Materials Per Product: 256 Tk.

Total Cost of Raw Materials Per Year: 5, 12, 000 Tk.

8.3.3 Cost of Labour:

1. MIG welding operator

Number of workers: 2

Wage rate: 10000 Tk.

Total labour cost: 20000 Tk.

2. Cutting tool operator

Number of workers: 3

Wage rate: 10000 Tk.

Total labour cost: 30000 Tk.

3. Colouring

Number of workers: 1

Wage rate: 8000 Tk.

Total labour cost: 8000 Tk.

Total Cost of Labour Per Month: 58,000 Tk.

Total Cost of Labour Per Year: 6, 96,000 Tk.

8.3.4 Purchasing Cost per Unit of Product:

Table 8.1: Purchasing cost per unit

Parts	Price Per Unit (Tk.)	Quantity	Total Cost (Tk.)
Cycle Body	8300	1	8300
Li-ion Battery	4500	1	4500
DC Motor	4000	1	4000
Lawn Mower Body (Handle, Helix Blade, Bed-knife)	4500	1	4500
Grass Collector	200	1	200
Nut/Bolt	10	20	200
Total Purchasing Cost Per Unit (Tk.)			21700

Since we are going to buy these parts in bundle offer, we can get a handsome number of discounts. After analyzing the current market, we estimated that about 30% discount will be available.

So, total purchasing costs of outsourced parts (per unit product): BDT $21700 \times 0.7 \approx 15190$ BDT

Total purchasing costs of outsourced parts per year: BDT $15190 \times 2000 =$ BDT 3, 03, 80, 000 BDT

8.3.5 Manufacturing Overhead Cost (per month):

Table 8.2: Manufacturing Overhead Costs

Cost Item	No. of Post	Salary/person (BDT)	Total cost (BDT)
Production Manager	1	35,000	35,000
Manufacturing Engineer	1	30,000	30,000
Design Engineer	1	30,000	30,000
Supply Chain & Quality Control Manager	1	35,000	35,000
Power Consumption			10,000
Factory Rent			40,000
Total Manufacturing Overhead per month			1,80,000

Factory insurance: 20,000 Tk./ year

Material handling cost: 15,000 Tk./year

Yearly manufacturing overhead = BDT 21, 95,000

8.3.6 Total Manufacturing Cost:

Total Cost of Raw Materials Per Year: 5, 12,000 Tk.

Total Cost of Purchasing Per Year: 3, 03, 80, 000 Tk.

Total Cost of Labour Per Year: 6, 96,000 Tk.

Total Manufacturing Overhead Cost Per Year: 21, 95,000 Tk.

Total Manufacturing Cost Per Year: 3, 37, 83, 000 Tk.

8.4 Non-manufacturing Costs

Non-manufacturing costs are the costs that are not directly related to manufacturing, but these are needed to maintain the supply chain properly. Generally, these include selling and administrative cost. Non-manufacturing costs are generally incurred at the later portion of the supply chain.

8.4.1 Administrative Cost (per month):

Table 8.3: Administrative costs

Post	No. of post	Salary/person (BDT)	Total Cost (BDT)
Chief Executive Officer	1	80,000	80,000
HR Manager	1	50,000	50,000
Accountant	1	35,000	35,000
Secretary	1	20,000	20,000
Clerk	2	8000	16,000
Guard	1	7000	7,000
Office Rent			15,000
Power Consumption			5,000
Water Bill			2,000
Total			2,30,000

Yearly administrative cost: BDT 2, 30,000×12 = BDT 27, 60,000

8.4.2 Selling Expenses (per month):

Table 8.4: Selling Expenses

Cost Item	**No. of post**	**Salary/person (BDT)**	**Total Cost (BDT)**
Marketing Executive	2	30,000	60,000
Advertisement			40,000
Total			100,000

Yearly Selling Expenses: BDT 100,000×12 = BDT 12, 00,000

8.4.3 Total Non-manufacturing Cost:

Total Administrative Cost Per Year: 27, 60,000 Tk.

Total Selling Cost Per Year: 12, 00,000 Tk.

Total Selling and Administrative cost (or non-manufacturing cost): BDT 39, 60,000

8.5 Bank Loan & Interest

Total bank loan= 100, 00,000 Tk.

Interest rate, i= 18%

Repayment periods, n= 15 years.

Amount to be paid to the bank annually, A= P (A/P, 18, 15)

= 19, 65,000 Tk.

8.6 Total Cost

Total Manufacturing Cost Per Year: 3, 37, 83, 000 Tk.

Total Non-manufacturing Cost Per Year: 39, 60,000 Tk.

Total Bank Loan Repayment Per Year: 19, 65,000 Tk.

Total Cost Per Year: 3, 97, 08, 000 Tk.

8.6.1 Break Even Analysis:

For the first year,

Fixed Cost:

Bank payment: BDT 19, 65,000

Machine Cost: BDT 11, 20,000

Factory Insurance: BDT 20,000

Manufacturing Overhead: BDT 21, 95,000

Selling and Administrative Costs: BDT 39, 60,000

Total amount of fixed costs: BDT 92, 60,000

Variable Cost:

Total raw material cost: BDT 5, 12,000

Total purchase cost of outsourced parts: BDT 3, 03, 80,000

Total labour cost: BDT 6, 96,000

Total variable cost: BDT 3, 15, 88,000

Variable cost per unit: BDT 3, 15, 88,000 ÷ 2000 = BDT 15794

Selling Price: BDT 15794 + 25% of 15794 ≈ BDT 19740

At break even,

Selling price × break even unit (x) = Fixed cost + Variable cost

Or, $19740x = 9260000 + 15794x$

Or, $x \approx 2347$ units

So, the break-even quantity (Q_{BEP}) is 2347 units.

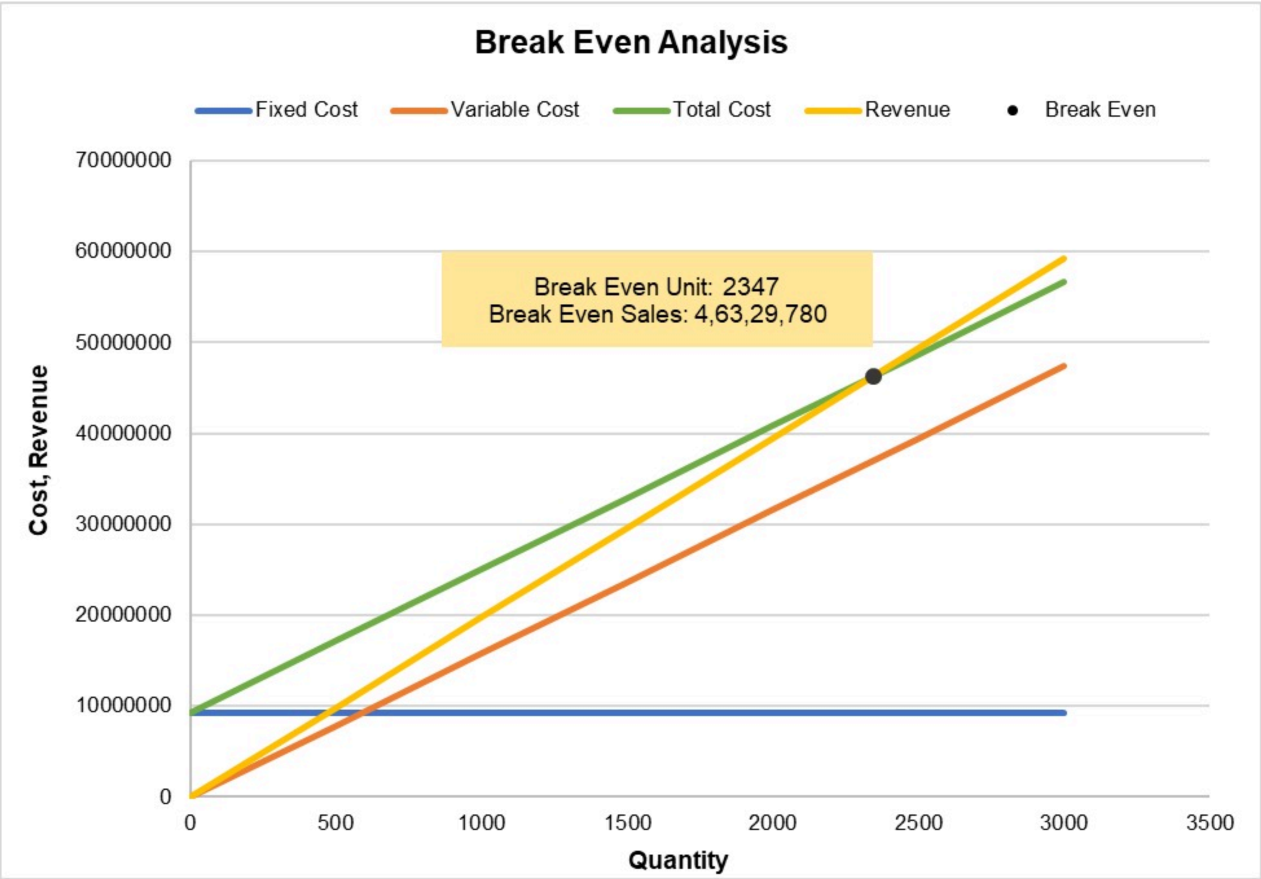


Figure 8.1: Break Even Analysis of Super Handy Lawn Mower

Here, we have only considered the first year where we had a major investment in machinery and other accessories. That's why the break-even is very large. But for the following years, there will be a very small amount of fixed cost (comprising of only factory insurance, manufacturing overhead, and non-manufacturing costs) compared to the first year. So, with the proper marketing strategy and quality products, our company can hope for crossing the break-even point and gain profit.

8.7 Sensitivity Analysis

Sensitivity analysis gives an insight about how sensitive the break-even point is with respect to a particular cost or revenue parameter. In this sensitivity analysis, a change of 8% is made for each cost parameter separately and then break-even point is computed. This analysis will provide the list of sensitive parameters.

8.7.1 Sensitivity of Demand:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost + (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} × 1.08 = 92, 60,000 + (15794 × Q_{BEP} × 1.08)

$\therefore$ Q_{BEP} = 2173

ΔQ_{BEP} = ((2347 -2173)/ 2347) ×100%

= 7.16%

So, Demand is very sensitive. The break-even point changes almost proportionally with change in demand. So, any change in demand will have a direct impact on the break-even quantity.

8.7.2 Sensitivity of Direct Material:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost+ (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} = 92, 60,000 + ((348+ ((3,08,92,000×1.08)/2,000)) × Q_{BEP})

$\therefore$ Q_{BEP} = 3417

ΔQ_{BEP} = ((3417 -2347)/ 2347) ×100%

= 45.6%

So, Direct Material is very sensitive. The cost of direct material can significantly dominate

on the break-even quantity.

8.7.3 Sensitivity of Direct Labour:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost+ (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} = 92, 60,000 + ((15446+ ((6, 96,000 × 1.08)/2,000)) × Q_{BEP})

∴ Q_{BEP} = 2364

ΔQ_{BEP} = ((2364 -2347)/ 2347) ×100%

= 0.72%

So, direct labour is not very sensitive. The break-even point changes about 0.72% with 8% change in direct labour. This indicates that if somehow cost of direct labour goes up and other cost parameters stay stable, then only 0.72% production is to be increased in order to attain break-even point.

8.7.4 Sensitivity of Manufacturing Overhead:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost+ (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} = ((70, 65,000+ (21, 95,000× 1.08)) + (15794 × Q_{BEP})

∴ Q_{BEP} =2392

ΔQ_{BEP} = ((2392-2347)/ 2347) ×100%

= 1.92%

So, manufacturing overhead is not very sensitive. The percentage change in break-even point is very low compared to percentage change of Manufacturing Overhead.

8.7.5 Sensitivity of Administrative Cost:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost+ (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} = ((65, 00,000+ (27, 60,000 × 1.08)) + (15794 × Q_{BEP})

$\therefore Q_{BEP} = 2403$

ΔQ_{BEP} = ((2403 -2347)/ 2347) ×100%

= 2.39%

So, administrative cost is slightly sensitive but it does not influence the break-even quantity.

The percentage change in break-even point is almost quarter of the percentage change of administrative cost.

8.7.6 Sensitivity of Selling Cost:

At Break Even Point,

Selling price × Q_{BEP} = Total Fixed cost+ (Variable cost × Q_{BEP})

Or, 19740 × Q_{BEP} = ((80, 60,000+ (12, 00,000 × 1.08)) + (15794 × Q_{BEP})

$\therefore Q_{BEP} = 2372$

ΔQ_{BEP} = ((2372 -2347)/ 2347) ×100%

= 1.1%

So, selling cost is not sensitive at all. The break-even point changes about 1.1% with 8% change in selling cost. This indicates that if somehow cost of selling goes up and other cost parameters stay stable, then only 1.1% production is to be increased in order to attain break-even point.

To summarize, we can see the sensitivity of-

Demand: 7.16%

Direct Material: 45.6%

Direct Labour: 0.72%

Manufacturing Overhead: 1.92%

Administrative Cost: 2.39%

Selling Cost: 1.1%

It can be seen direct material cost has the highest influence on sensitivity of Q_{BEP}. Since direct material contributes to the majority portion of the unit cost, a slight change in direct material cost fluctuates the Q_{BEP} a lot. So our target should be keeping the direct material cost as steady as possible.

Conclusion

Super Handy Lawn Mower is a great tool to reduce the labour and hassle involved in mowing lawns. It has the flexibility of operating as the both push and pedal powered mower. It is 4 to 5 times more efficient than the conventional one. Further mechanization of the product is possible by using motors. Currently, no local company manufactures such a product in our country.

It has been a privilege for us to be a part of the course where we have learned to connect dots between the customers and engineers. Also, this course taught us to utilize our theoretical knowledge in practical life, analyse a market situation, and put our potential together to bring out something useful for the welfare of humankind.

Appendix

1. Appendix A: Mechanical Properties of Some Heat-Treated Steels

1 AISI No.	2 Treatment	3 Temperature °C (°F)	4 Tensile Strength MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation, %	7 Reduction in Area, %	8 Brinell Hardness
1030	Q&T*	205 (400)	848 (123)	648 (94)	17	47	495
	Q&T*	315 (600)	800 (116)	621 (90)	19	53	401
	Q&T*	425 (800)	731 (106)	579 (84)	23	60	302
	Q&T*	540 (1000)	669 (97)	517 (75)	28	65	255
	Q&T*	650 (1200)	586 (85)	441 (64)	32	70	207
	Normalized	925 (1700)	521 (75)	345 (50)	32	61	149
	Annealed	870 (1600)	430 (62)	317 (46)	35	64	137
1040	Q&T	205 (400)	779 (113)	593 (86)	19	48	262
	Q&T	425 (800)	758 (110)	552 (80)	21	54	241
	Q&T	650 (1200)	634 (92)	434 (63)	29	65	192
	Normalized	900 (1650)	590 (86)	374 (54)	28	55	170
	Annealed	790 (1450)	519 (75)	353 (51)	30	57	149
1050	Q&T*	205 (400)	1120 (163)	807 (117)	9	27	514
	Q&T*	425 (800)	1090 (158)	793 (115)	13	36	444
	Q&T*	650 (1200)	717 (104)	538 (78)	28	65	235
	Normalized	900 (1650)	748 (108)	427 (62)	20	39	217
	Annealed	790 (1450)	636 (92)	365 (53)	24	40	187
1060	Q&T	425 (800)	1080 (156)	765 (111)	14	41	311
	Q&T	540 (1000)	965 (140)	669 (97)	17	45	277
	Q&T	650 (1200)	800 (116)	524 (76)	23	54	229
	Normalized	900 (1650)	776 (112)	421 (61)	18	37	229
	Annealed	790 (1450)	626 (91)	372 (54)	22	38	179
1095	Q&T	315 (600)	1260 (183)	813 (118)	10	30	375
	Q&T	425 (800)	1210 (176)	772 (112)	12	32	363
	Q&T	540 (1000)	1090 (158)	676 (98)	15	37	321
	Q&T	650 (1200)	896 (130)	552 (80)	21	47	269
	Normalized	900 (1650)	1010 (147)	500 (72)	9	13	293
	Annealed	790 (1450)	658 (95)	380 (55)	13	21	192
1141	Q&T	315 (600)	1460 (212)	1280 (186)	9	32	415
	Q&T	540 (1000)	896 (130)	765 (111)	18	57	262

(continued)

1 AISI No.	2 Treatment	3 Temperature °C (°F)	4 Tensile Strength MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation, %	7 Reduction in Area, %	8 Brinell Hardness
4130	Q&T*	205 (400)	1630 (236)	1460 (212)	10	41	467
	Q&T*	315 (600)	1500 (217)	1380 (200)	11	43	435
	Q&T*	425 (800)	1280 (186)	1190 (173)	13	49	380
	Q&T*	540 (1000)	1030 (150)	910 (132)	17	57	315
	Q&T*	650 (1200)	814 (118)	703 (102)	22	64	245
	Normalized	870 (1600)	670 (97)	436 (63)	25	59	197
	Annealed	865 (1585)	560 (81)	361 (52)	28	56	156
4140	Q&T	205 (400)	1770 (257)	1640 (238)	8	38	510
	Q&T	315 (600)	1550 (225)	1430 (208)	9	43	445
	Q&T	425 (800)	1250 (181)	1140 (165)	13	49	370
	Q&T	540 (1000)	951 (138)	834 (121)	18	58	285
	Q&T	650 (1200)	758 (110)	655 (95)	22	63	230
	Normalized	870 (1600)	1020 (148)	655 (95)	18	47	302
	Annealed	815 (1500)	655 (95)	417 (61)	26	57	197
4340	Q&T	315 (600)	1720 (250)	1590 (230)	10	40	486
	Q&T	425 (800)	1470 (213)	1360 (198)	10	44	430
	Q&T	540 (1000)	1170 (170)	1080 (156)	13	51	360
	Q&T	650 (1200)	965 (140)	855 (124)	19	60	280

*Water-quenched

2. Appendix B: Results of Tensile Tests of Some Metals

Number	Material	Condition	Strength (Tensile) Yield S_y, MPa (kpsi)	Ultimate S_u, MPa (kpsi)	Fracture, σ_f, MPa (kpsi)	Coefficient σ_0, MPa (kpsi)	Strain Strength, Exponent m	Fracture Strain ε_f
1018	Steel	Annealed	220 (32.0)	341 (49.5)	628 (91.1)†	620 (90.0)	0.25	1.05
1144	Steel	Annealed	358 (52.0)	646 (93.7)	898 (130)†	992 (144)	0.14	0.49
1212	Steel	HR	193 (28.0)	424 (61.5)	729 (106)†	758 (110)	0.24	0.85
1045	Steel	Q&T 600°F	1520 (220)	1580 (230)	2380 (345)	1880 (273)†	0.041	0.81
4142	Steel	Q&T 600°F	1720 (250)	1930 (210)	2340 (340)	1760 (255)†	0.048	0.43
303	Stainless steel	Annealed	241 (35.0)	601 (87.3)	1520 (221)†	1410 (205)	0.51	1.16
304	Stainless steel	Annealed	276 (40.0)	568 (82.4)	1600 (233)†	1270 (185)	0.45	1.67
2011	Aluminum alloy	T6	169 (24.5)	324 (47.0)	325 (47.2)†	620 (90)	0.28	0.10
2024	Aluminum alloy	T4	296 (43.0)	446 (64.8)	533 (77.3)†	689 (100)	0.15	0.18
7075	Aluminum alloy	T6	542 (78.6)	593 (86.0)	706 (102)†	882 (128)	0.13	0.18

3. Appendix C: Typical Properties of Gray Cast Iron

ASTM Number	Tensile Strength S_{ut}, kpsi	Compressive Strength S_{uc}, kpsi	Shear Modulus of Rupture S_{su}, kpsi	Modulus of Elasticity, Mpsi Tension†	Modulus of Elasticity, Mpsi Torsion	Endurance Limit* S_e, kpsi	Brinell Hardness H_B	Fatigue Stress-Concentration Factor K_f
20	22	83	26	9.6–14	3.9–5.6	10	156	1.00
25	26	97	32	11.5–14.8	4.6–6.0	11.5	174	1.05
30	31	109	40	13–16.4	5.2–6.6	14	201	1.10
35	36.5	124	48.5	14.5–17.2	5.8–6.9	16	212	1.15
40	42.5	140	57	16–20	6.4–7.8	18.5	235	1.25
50	52.5	164	73	18.8–22.8	7.2–8.0	21.5	262	1.35
60	62.5	187.5	88.5	20.4–23.5	7.8–8.5	24.5	302	1.50

*Polished or machined specimens.

†The modulus of elasticity of cast iron in compression corresponds closely to the upper value in the range given for tension and is a more constant value than that for tension.

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