PLANT LAYOUT ANALYSIS AND REDESIGN FOR IMPROVEMENT OF A TRICYCLE ASSEMBLING COMPANY IN GHANA: DESSERT LION COMPANY LTD

A Facilities Design Report Project

Presented to the:

Department of Mechanical Engineering

Faculty of Mechanical and Chemical Engineering

College of Engineering

Kwame Nkrumah University of Science and Technology

By:

CHARITY AFIA ANTWIWAA HLEEGOAH

ADRAKI ALBERT DANIEL

YASMINE ALI-OSMAN

ADAGLO FRANCIS SELORM

SARPONG EMMANUEL GERRALD

OWUSU-BANAHENE EXCEL

Submitted In Partial Fulfilment of the Requirements for The Degree of

BSc. Industrial Engineering

March 2024

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and rate it as satisfactory in terms of scope and quality.

……………………………….

PROF. SAMUEL MENSAH SACKEY

DECLARATION

We hereby declare that, with the exception of references, diagrams and secondary data used, the content of this report was based on our individual inputs and thorough research.

NAME	INDEX NUMBER	SIGNATURE
Charity AFIA ANTWIWAA HLEEGOAH	3108620	
ADRAKI ALBERT DANIEL	3100820	
YASMINE ALI-OSMAN	3101720	
ADAGLO FRANCIS SELORM	3100420	
SARPONG EMMANUEL GERRALD	3113320	
OWUSU-BANAHENE EXCEL	3112120	

DEDICATION

This project is dedicated to the almighty God who enabled us to successfully complete it.

We also dedicate this to our project supervisor, Prof. Samuel Mensah Sackey, the department of Mechanical Engineering and the College of Engineering. We appreciate the opportunity to work on this project and their immense support throughout this project.

We wholeheartedly dedicate this project to our beloved parents, who have been our source of inspiration and gave us strength when we thought of giving up, who continually provide their moral, spiritual, emotional and financial support.

We also dedicate this to everyone who helped made this successful in various ways.

ACKNOWLEDGEMENT

Firstly, we would like to thank God, for letting us through all the difficulties. We have experienced His protection and guidance day by day. You are the one who let us finish our degree.

We would like to acknowledge and give our warmest thanks to our supervisor Prof. Samuel Mensah Sackey from the Mechanical Engineering department, who made this work possible through his constant support, guidance and advice.

We would also like to give special thanks to our family and friends for their continuous support, understanding and prayers which has sustained us this far.

We also want to express our deepest gratitude to the CEO of Dessert Lion Company Ltd.

ABSTRACT

This thesis provides a thorough summary of our investigation into the cargo tricycle assembly facility layout currently being used and then redesign the said facility’s layout. Our study's goal is to analyze and remodel the Desert Lion International's cargo tricycle assembly facility layout structure to maximize output, efficiency, and productivity. Using process planning, facilities design and manufacturing relations techniques, advanced manufacturing technology and engineering work study, the project team was able to identify the shortcomings of the current layout and make recommendations on how to improve it.

The work includes a comprehensive literature review on cargo tricycles and their economic impact, facility layout design, plant layout analysis, lean manufacturing, etc. The thesis, under the topic PLANT LAYOUT ANALYSIS AND REDESIGN FOR IMPROVEMENT, also captures a proposed conceptual design of improved layouts and their evaluations.

The result is selection of a functionally improved concept that promises to increase overall productivity and efficiency.

Contents

TABLE OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

In Ghana, there are several means of transportation, such as cars, vans, buses, motorbikes, etc. Recently, the tricycle was introduced in many parts of the country and has caught up in many of the urban and rural areas. The use of tricycles has become popular in the Ho township, even though it has been used in Tamale, Wa, Bolgatanga, Accra, and Kumasi. Tricycles have different names in different localities in the country. They are mainly called "Aboboyaa" in Ghana. Tricycles as a means of road transport are vehicles similar to a motorbike, but having three wheels, two at the back and one at the front with a metallic cargo container used to carry goods. Tricycles have become more vital to the socio-economic development of individuals and society as it is mainly used in agriculture by farmers to transport harvested crops from farms to the market and also the transportation of other goods like fertilizers and other agricultural products. It also got adopted because of its affordability and tendency to provide jobs to several youths in the country.

Desert Lion International is in a unique collaboration with Kwame Nkrumah University of Science and Technology in Ghana, a leading science institution in the world, to assemble spraying machines, transfer technology and cargo tricycles to many young Ghanaians venturing into agriculture in general and cocoa industry in particular. The objective is to contribute to reducing rural poverty through maximizing the output of agriculture and also provide jobs for the youth to contribute to reducing unemployment. Recently they implemented an assembly process for motor tricycles, incorporating cutting-edge technology and modern techniques to enhance efficiency and quality. This recent upgrade underscores our commitment to innovation and reflects our ongoing efforts to stay at the forefront of the industry's technological advancements.

Desert Lion products are certified by the Cocoa Research Institute (CRIG) and the Environmental Protection Agency (EPA) and cover a wide range of products including the following;

- Insecticides
- Fungicides
- Herbicide
- Pruners (Motorized and Manual)
- Motorized and Manual Sprayers
- Cargo tricycles.
- Protective Clothing
- Solar products
- Accompanying parts for all our machines.

Dessert Lion has recently implemented an assembly process for motor tricycles. This recent upgrade underscores their commitment to innovation and reflects our ongoing efforts to stay at the forefront of the industry’s technological advancement.

1.2 PROBLEM STATEMENT AND OBJECTIVES

1.2.1 Summary

During the project team’s tour of Desert Lion's tricycle assembly plant, it was observed that most of the work there is done manually.

The main issue with the present facility's architectural layout was the poor use of space, which led to enclosed workstations and impeded manufacturing flow. This ultimately results in an unstable manufacturing system and a drop in product output. Achieving high levels of production, efficiency, and efficient scheduling is the manufacturing plant's main priority. There is a great deal of wasteful movement between tasks in the existing production process, both repeatedly and non-consecutively, leading to inefficiencies on the factory floor.

After further research, the configuration of the individual workstations and the plant floor as a whole were shown to be the primary causes of the issue. Moreover, the efficacy of the procedure is also being impacted by different worker productivity levels. Low worker productivity is caused by a number of factors including a disordered workstation layout that leads to unnecessary mobility and poor flow between tasks. Furthermore, a deficiency of defined activity approaches results in manufacturing process time wastage.

Additionally, unfinished work is left waiting for the flow process to go on to the next stage. The uneven flow of batches through the production process, which is also related to the existing workstation configuration, has resulted in a build-up of works-in-progress and bottlenecks in the process flow due to these non-standardized methods of production. Consequently, the plant cannot operate at maximum efficiency, resulting in inadequate flow, wasted energy, and lost time.

1.2.2 Problem statement

The problem statement outlines the significance of tricycles in Ghana's agricultural and transportation sectors, particularly focusing on Desert Lion's role in assembling tricycles. It highlights the challenges faced by Desert Lion due to a lack of standardized facility layout, resulting in lower production and higher operational costs. The thesis proposes the redesigning of Desert Lion's facility layout to address issues such as low production, high operational costs, and downtime. It suggests using a bottom-up innovation strategy to co-create a new facility layout with key stakeholders in the industry, aiming to improve production and meet market demands effectively.

1.2.3 Main Objective

The main objective of this project is to analyze and redesign the layout of Dessert Lion Company Ltd. to improve their tricycle assembling for effective production, efficiency and maximize productivity.

1.2.4 Specific objectives

The specific objectives include:

- Analyze the current facilities layout model for Cargo tricycle assembly at Desert Lion International.
- Develop concepts for redesign of the layout
- Compare and contrast concepts to select final redesigned layout
- Simulate current layout and final redesigned layout
- Examine the simulation outcomes to validate the final redesign of the facility.

1.2.5 Scope

The project's scope will cover the overall plan and objectives of the project. It includes all the key elements and considerations that need to be addressed to ensure a successful assembly line setup. The main objective is to ensure efficiency and increase productivity, starting from the arrival and storage of raw materials, material handling methods, processing and assembly sections, to the final product's storage on the factory floor. These activities are critical to the plant's layout and will be observed, analyzed, and studied to enhance the current production process and layout of the facility.

In addition to the points, the project team discussed earlier, the scope of designing the assembly line for manufacturing motor tricycles also involves finding and getting rid of any potential areas of inefficiency. This includes reducing idle time, minimizing unnecessary movements, and making sure resources are fully utilized. To achieve this, the project team will utilize industrial engineering techniques like work study to optimize the plant layout and enhance overall operating conditions in the facility.

1.2.6 Project Deliverables

The main outcome of this endeavor is to design a new facility layout for the assembly of motor tricycles at desert lion LTD. This will involve:

- Developing Process Plans
- Redesigning Workstations
- Establishing Worker Schedules

The proposed layout will undergo evaluation and refinement to optimize resource utilization, enhance productivity, improve plant efficiency, and minimize waste in the facility."

1.3 STRUCTURE OF REPORT

- **Chapter 1: Introduction**

This chapter covers the background, problem statement, scope, deliverables and report organization and outlines the aim and objectives of the project and sets the scene for the rest of the report.

- **Chapter 2: Literature Review**

This chapter involves an in-depth research and review of previous work done by other researchers.

- **Chapter 3: Methodology and Conceptual Design**

This chapter presents the methodology used to undertake the project. Concepts are developed for the redesign of the layout at Dessert Lion Company Ltd.

- **Chapter 4: Evaluation of Concepts, Final Redesign and Design Calculations**

This chapter presents the evaluation of concepts based on some criteria and the selection of the final redesign. It also involves design calculations such as space requirement of machines among others for the final redesign.

- **Chapter 5: Area Allocation Layout, Total Plant Layout and Simulation**

This chapter involves the area allocation diagram, Total Plant Layout Diagram and simulation of the current layout and final redesign for vital data analysis and comparison.

- **Chapter 6: Conclusion and Recommendation**

The final chapter of the report recaps the aim and objectives of the project and states to what degree they have been achieved. With the stated outcome of the research, suggestions for possible future work are given to the general reading.

2.0 LITERTURE REVIEW

2.1 TRICYCLE MANUFACTURING INDUSTRY

2.1.1 Introduction

An overview of recent studies in fields related to this topic is provided in this chapter. Throughout the composition of this literature review and the entire project, several works about the thesis topic were examined.

The procedures, output capacities, advantages, and present state of the tricycle (three-wheeled cargo vehicle) assembled at Dessert Lion Company Limited are all covered in this chapter. Additionally, it discusses facility layout design and how to use it to boost production and guarantee little to minimal downtime in tricycle assembling. Additionally, it assesses facility layout options for tricycle assembling that have already been studied.

A three-wheeled cargo vehicle(tricycle) is intended mostly for freight or product transportation. Although the size, shape, and function of these vehicles can vary greatly, they usually have a storage space or platform where items can be safely kept and carried.

In Africa, three-wheeled cargo trucks are frequently utilized for small-scale commercial operations, deliveries, and the movement of items within industrial facilities. When compared to bigger vehicles, they may be more maneuverable in confined locations and have reduced running expenses.

Figure 1: A completely assembled cargo tricycle

Figure 2: A completely assembled tricycle with a raised carriage

2.1.2 Applications of Tricycle.

Cargo tricycles, also known as cargo bikes, have gained significant attention in recent years due to their versatility and sustainability. Several studies have explored their applications across various domains, including urban logistics, product delivery, and personal transportation.

In urban logistics, cargo tricycles offer a promising solution to mitigate traffic congestion. *Research by Fishman et al. (2015)* demonstrated that replacing traditional delivery vehicles with cargo tricycles in urban areas can significantly decrease delivery time.

Moreover, cargo tricycles are particularly effective for product delivery, especially in dense urban environments where access by larger vehicles is limited. *Studies by de la Motte et al. (2017) and Lopes et al. (2019)* emphasized the cost-effectiveness and efficiency of cargo tricycles in delivering goods to customers' doorsteps.

Additionally, cargo tricycles have gained popularity for personal transportation purposes, especially among commuters seeking eco-friendly alternatives to cars and public transport. *Research by MacArthur et al. (2020)* highlighted the growing trend of individuals using cargo tricycles for transporting children, groceries, and other goods, thereby promoting active lifestyles.

2.1.3. Economic Importance of Motor Cargo Tricycles

- **Enhanced Productivity:**

Motor cargo tricycles contribute to enhanced productivity by facilitating the efficient movement of goods in urban and peri-urban areas. *Studies by Xie et al. (2019) and Li et al. (2020)* have demonstrated that the use of motor cargo tricycles significantly reduces delivery times and enhances supply chain efficiency, thereby enabling businesses to meet customer demands more promptly. Moreover, the maneuverability of motor cargo tricycles allows for access to narrow streets and congested areas, enabling last-mile deliveries that are often inaccessible to larger vehicles, thus further boosting productivity.

- **Cost Reduction:**

The potential for motor tricycles to lower transportation costs for both consumers and enterprises highlights their economic relevance. Research conducted by *Khan et al. (2018)* indicates that motor cargo tricycles offer a cost-effective alternative to traditional delivery methods, particularly in densely populated urban areas where congestion and parking limitations increase the operational expenses of larger vehicles. Additionally, the relatively lower acquisition and maintenance costs of motor cargo tricycles compared to trucks or vans make them an attractive option for small and medium-sized enterprises seeking to optimize their logistics operations within constrained budgets.

- **Socio-Economic Development:**

Motor tricycles are essential for advancing social and economic growth since they make it easier for less fortunate people to obtain products and services. *Studies by Yang et al. (2017) and Chen et al. (2021)* have highlighted the role of motor cargo tricycles in improving market access for rural producers and improving the standard of living for those in need by providing employment opportunities in the transportation sector. Furthermore, the deployment of motor cargo tricycles for goods delivery in urban slums and peri-urban areas has been shown to mitigate food insecurity and improve access to essential commodities, thereby fostering inclusive economic growth and poverty alleviation.

2.1.4. Sustainability

- **Environmental Sustainability:**

Motor cargo tricycles present both challenges and opportunities for environmental sustainability. On one hand, they contribute to air and noise pollution due to their reliance on fossil fuels and outdated engine technologies. On the other hand, the adoption of cleaner and more efficient propulsion systems, such as electric or hybrid engines, can significantly reduce emissions and mitigate environmental impact. *Studies by Khan et al. (2019) and Li et al. (2020)* emphasize the importance of transitioning towards electric auto-rickshaws to achieve sustainability goals related to air quality and climate change mitigation (SDG 7 - Affordable and Clean Energy, SDG 11 - Sustainable Cities and Communities

SDG 13 - Climate Action)

- **Social Sustainability:**

Social sustainability in motor three-wheel cargo tricycles encompasses various aspects, including drivers' livelihoods, safety, and accessibility. *Research by Ahmed et al. (2018)* highlights the socio-economic vulnerability of auto-rickshaw drivers, who often face exploitation, low wages, and inadequate working conditions. Addressing these challenges requires interventions aimed at improving drivers' income security, access to healthcare, and social protection mechanisms (SDG 1 - No Poverty, SDG 3 - Good Health and Well-being, and SDG 8 - Decent Work and Economic Growth). Furthermore, enhancing road safety measures, promoting gender inclusivity, and ensuring affordable transportation services contribute to social equity and accessibility (SDG 5 - Gender Equality and SDG 10 - Reduced Inequalities).

- **Economic Sustainability:**

Economic sustainability in the context of motor three-wheel cargo tricycles revolves around fostering entrepreneurship, supporting local economies, and promoting sustainable business models. *Research by Kumar et al. (2021)* emphasizes the role of microfinance initiatives and cooperative ownership structures in empowering auto-rickshaw drivers and enhancing their economic resilience (SDG 9 - Industry, Innovation, and Infrastructure and SDG 12 - Responsible Consumption and Production). Additionally, the integration of digital platforms for booking and payment systems not only improves operational efficiency but also enhances financial inclusion and transparency (SDG 16 - Peace, Justice, and Strong Institutions).

2.1.5 Benefits Cargo Tricycles

Environmental Sustainability: Cargo tricycles offer a sustainable alternative to traditional delivery vehicles, reducing carbon emissions and air pollution in urban areas.

Cost-Effectiveness: Compared to larger delivery vehicles, cargo tricycles have lower operating costs, including fuel, maintenance, and insurance, making them economically attractive for last-mile deliveries.

Traffic Congestion Reduction: Cargo tricycles can navigate through congested urban areas more easily than larger vehicles, reducing traffic congestion and improving overall traffic flow.

Flexibility and Accessibility: Cargo tricycles can access narrow streets and pedestrian zones, providing greater flexibility in delivery routes and accessibility to areas inaccessible to larger vehicles.

Community Integration: Cargo tricycles promote community engagement and positive interactions between delivery personnel and local residents, enhancing social cohesion and neighborhood relations.

Health Benefits: Utilizing cargo tricycles for deliveries encourages physical activity among delivery personnel, contributing to improved health and well-being.

Brand Image: Adopting cargo tricycles for deliveries aligns with sustainable and eco-friendly brand images, enhancing corporate social responsibility profiles and attracting environmentally conscious customers.

Regulatory Support: Many cities are introducing regulations and incentives to promote the use of cargo tricycles, such as designated lanes, subsidies, and tax breaks, further incentivizing their adoption.

By synthesizing existing literature, these benefits underscore the potential of cargo tricycles as an effective and sustainable solution for urban freight transportation.

2.2 FACILITIES DESIGN

2.2.1 Definitions

Manufacturing facilities design is the organization of a company's physical facilities to promote the efficient use of the company's resources such as people, equipment, material, and energy. Facilities design includes plant location and building design, plant layout, and material handling. Plant location decisions are made at the very top corporate level, and are to some extent influenced by such factors as proximity to the source of raw materials, markets, and transportation systems such as waterways, railroads, and highways. *[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]*

Material handling is defined simply as moving material. Physical drudgery can be eliminated from work by material handling equipment. The money to pay for material handling equipment must come from reduced labor, material, or overhead costs, and these expenses must be recovered in 2 years or less. Unit 4 will discuss material handling systems, procedures, and equipment. Material handling is so entwined with the physical layout of equipment that the two subjects, facilities planning and material handling, are usually treated as one subject in practice. As a result, material handling is part of nearly every step of a facility design process and material handling equipment choice will affect the layout. *[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]*

Layout is the physical arrangement of production machines and equipment, workstations, people, location of materials of all kinds and stages, and material handling equipment. The plant layout is the end result of a manufacturing facility design project and is the main focus of this course. In addition to the need for developing new manufacturing facilities, existing plants undergo some changes continually as a result of changes in product design, methods, materials, and process. *[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]*

Plant layout is a mechanism which involves knowledge of the space requirements for the facilities and also involves their proper arrangement so that continuous and steady movement of the production cycle takes place. *[Production Planning and Control: A Comprehensive Approach, 2019 by Kiran, D.R.]*

2.2.2 Goals of Manufacturing Facilities Design

A good set of goals ensures a successful facility design. Without goals facilities planners are without direction. *[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]*

A mission statement communicates the primary goals and the culture of the organization to the facilities planner. The statement should be short enough so that its essence is not lost. For the most part, the company's mission statement is a philosophical statement that sets the cultural tone of the organization. *[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]*

Production goals and objectives that are consistent with the mission of the corporation can then be derived from the mission statement. Sub-goals are added to help achieve specific goals.

Potential goals may include:

• Minimize unit and project costs.

• Optimize quality.

• Promote the effective use of;

(a) people

(b) equipment

(c) space

(d) energy.

• Provide for;

(a) employee convenience

(b) employee safety

(c) employee comfort

• Achieve the production start date.

• Build flexibility into the plan.

• Reduce or eliminate excessive inventory.

• Achieve miscellaneous goals such as restricting operator lifting to one part, and using plug-in-plug-out equipment to allow operators to move equipment easily.

The hazard assessment of a facilities layout is crucial to minimize the occurrence of hazardous events which in turn could result in a cascading effect of consequences of varying severity from minor to catastrophic.

2.2.3 Objectives of Plant Layout

Plant layout design has become a fundamental basis of today's industrial plants which can influence parts of work efficiency. It is needed to appropriately plan and position employees, materials, machines, equipment's, and other manufacturing supports and facilities to create the most effective plant layout.

An efficient layout may also contribute to the reduction in the production cycles, work-in-progress, idle times, number of bottlenecks or material handling times and to the increase in the production output, with obvious implications on productivity. It is a business strategy that focuses on improving customer requirement understanding, business system productivity and financial performance. Plant layout has set a new trend of excellence in the business environment and is enjoying great popularity.

The main goal of plant layout is to optimize productivity while minimizing expense. The layout should be created in a way that makes it adaptable to new production methods and procedures. All those involved in the production system, including employees, managers, and supervisors, should be able to have their demands met by the layout. To achieve the aforementioned aims, the plant layout should be planned with the following goals in mind:

• Minimizing handling of materials.

• Maintaining flexibility of operations.

• Ensuring optimum utilization of men, materials, equipment and available space.

• Achieving good work flow and avoiding accumulation of work.

• Minimizing delays and bottlenecks in the production system.

• Ensuring safety of workmen by minimizing and eliminating the chances of accidents.

• Providing for effective supervision and production control.

• Minimizing work-in-process inventory.

• Providing sufficient and conveniently located service centers.

• Flexibility in design to adapt to the changing future requirements.

[IE 451: Facilities Design KNUST]

2.2.4 Manufacturing Facilities Design Procedure

The quality of a manufacturing facility design (the plant layout blueprint) depends on how well the planner collects and analyzes the basic data. The blueprint is the final step of the design process and the step during which novice planners want to start. The designer must resist jumping into the layout phase before collecting and analyzing the basic data. The following is a systematic way of thinking about a project:

1. Determine what will be produced; for example, a toolbox or lawn mower.

2. Determine quantity to be made per unit time; for example, 1,500 per 8-hour shift.

3. Determine what parts will be made or purchased complete — some companies buyout all parts, and they are called assembly plants. Those parts the company makes itself require fabrication equipment and considerably more design work.

4. Determine how each part will be fabricated. This is called process planning and is usually done by a manufacturing engineer, but in many projects, the manufacturing facilities designer is also responsible for tool, equipment, and workstation design

5. Determine the sequence of assembly. This is called assembly line balancing, a topic covered in depth throughout this course.

6. Set time standards for each operation. It is extremely difficult to design a plant layout without time standards.

7. Determine the plant rate (takt time). This is how fast the facility needs to produce; for example, 1,500 units in 8 hours (480 minutes), resolving to one part every .32 minute (about three parts per minute).

8. Determine the number of machines needed from the plant rate and the time standard for each operation.

9. Balance assembly lines or work cells, i.e., divide work among assemblers or cell operators according to the line rate so that everyone gets as close to the same amount of work as possible.

10. Study the material flow patterns to establish the best (shortest distance through the facility) flow possible. Tools for this include:

a. string diagram

b. multiproduct process chart

c. from-to chart

d. process chart

e. flow process chart

f. flow diagram.

11. Determine activity relationships — how close do departments need to be to each other to minimize people and material movement?

12. Layout each workstation. These layouts will lead to department layouts, and then to a facility-wide layout.

13. Identify needs for personal and plant services, and provide the space needed.

14. Identify office needs and layout as necessary.

15. Develop total space requirements from the above information.

16. Select material handling equipment.

17. Allocate the area according to the space needed and the activity relationships established in item 11 above.

18. Develop a plot plan and the building shape.

19. Construct a master plan. This is the manufacturing facility design — the last page of the project and the result of all the data collected and decisions.

20. Seek input and adjust. Ask peer-level engineers and managers to review the plan before presenting it to management for approval.

21. Install the layout. This is the stage where the plan comes together.

22. Start production. Anticipate that many things will go wrong. There is always start-up problems with new facilities. Correct them as they come up.

23. Adjust as needed and finalize project report and budget performance.

[Garcia-Diaz, A. J., Smith, M. (2008), Facilities Planning and Design, Prentice Hall]

2.2.5 Sources of Information for Facilities Design

Information from Marketing

The marketing department provides a research function that analyzes what the world's consumers want and need. It searches out ways to fill these potential customers' demands. Some of the information that Marketing provides is:

• the selling product price,

• sales volume,

• seasonality, and

• replacement parts that an older product may require.

Information from Product Design

Blueprints, a bill of materials, assembly drawings, and model shop samples inform the facilities designer of the prime mission — a detailed description of what needs to be accomplished. The product design department is the source of this valuable information.

Information from Time Study

Time standards are among the most basic yet important pieces of information required by the facilities planner. For him, the standard time is the primary input for determining the required number of people and workstations needed to meet the production schedule, and for calculating the number of machines, work cells, assembly line balancing, and staffing. Ultimately, this information is used to calculate the space requirements for all work centers and the overall production facilities space requirements.

Information from management

Management refers to upper-level employees who are responsible for the financial performance of a company. Such information as:

• inventory policy and lean thinking,

• investment policy,

• startup schedules,

• make or buy decisions,

• organizational relationships, and

• feasibility studies,

will have an effect on the plant facility design. Facility designers must understand these policies up front, otherwise, they may waste a lot of time.

[IE 451: Facilities Design KNUST]

2.2.6 Types of Plant Layout

2.2.6.1 Product or Line Layout

Also referred to as line layouts, product layouts which has small cycle of manufacturing with reduced material handling is a type of plant layout where machines, equipment, and workers are organized in a line based on the operation's progression needed for a product. Here machines and equipment are grouped together, thereby enabling inventories to flow successively in a clear and easy to control manner from one machine to another as values are being added on them.

A good example of product layout is the vehicle assembly line which entails the movement of nearly all types of similar models in the same operation sequences. The decisions to be made before designing a product layout include the amount of the required cycle time, the number and the arrangement of the various manufacturing processes, how to tackle the time variations for the different processes, and the need to effectively balance the layout. *[Okpala, C.C. and Chukwumuanya, O., 2016. PLANT LAYOUTS'ANALYSIS AND DESIGN. Int J Adv Engg Tech/Vol. VII/Issue III/July-Sept, 201, p.206.]*

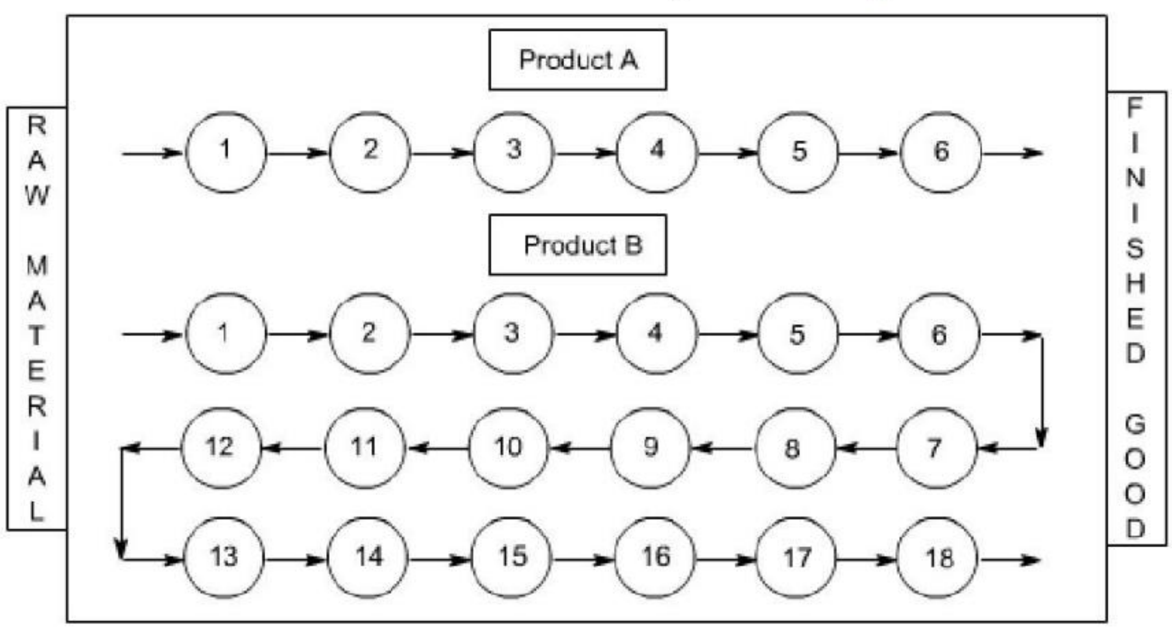


Figure 3: A pictorial presentation of line layout

Advantages of Product Layout:

- Reduced material handling cost, activities, and throughput time.
- Efficient floor space usage.
- Continuous and little amount of work in progress.
- Reduced manufacturing cost.

- Can be easily learnt and managed by unskilled operators.
- Simplified sequence of operations.

Limitations of Product Layout:

- Expensive investments in machines and equipment.
- Breakdown of any machine will lead to serious bottlenecks.
- Little or no flexibility in manufacturing processes.
- Expensive overhead cost.
- Monotonous and boring Operations.
- Changes in product design requires major layout alterations. *[Okpala, C.C. and Chukwumuanya, O., 2016. PLANT LAYOUTS'ANALYSIS AND DESIGN. Int J Adv Engg Tech/Vol. VII/Issue III/July-Sept, 201, p.206.]*

2.2.6.2 Process or Functional Layout

Also referred to as functional layout, process layouts are very suitable for applications where the products that are gotten from raw materials and work-in progress entails high variations while processing the individual operations. The layout which is designed to engender the processing of activities that need many value additions is widely adopted, if the operation's system requires large number of products in small volumes. It is very useful in situations where the production process is structured in batches as the different product are organized to move from an area to another, based on the succession of operations earlier established. Small Business (2013), explained that process layout "groups workstations together according to the activities being performed, regardless of which products each workstation is working on." Here the machines and workers needed to perform similar function are assigned in the same place, also the distance between sections should be very close reducing the waste of movements and materials handling.

The machine shop is a good example of a process layout, as it has different departments for boring, milling, pressing, and milling operations, which ensure that imbalances present in one section is not allowed to interfere in other sections, thereby achieving better utilization of the available machines and equipment. *[Okpala, C.C. and Chukwumuanya, O., 2016. PLANT LAYOUTS'ANALYSIS AND DESIGN. Int J Adv Engg Tech/Vol. VII/Issue III/July-Sept, 201, p.206.]*

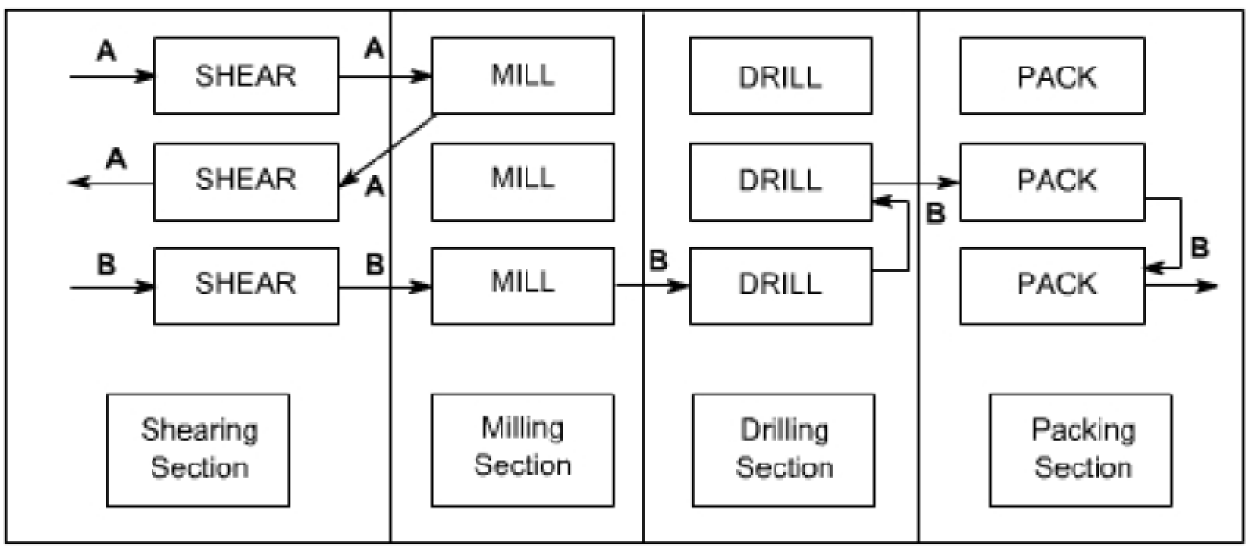


Figure 4: A pictorial presentation of process layout

Advantages Process or Functional Layout:

- Reduced overhead cost.
- Increased utilization of machine.
- Encourages efficient supervision.
- High products' variety.

- Enhanced flexibility.
- Reduced initial capital investment.

Disadvantages Process or Functional Layout:

- High work-in-progress inventory.
- Low operations and expensive material handling compared to the product layout.
- Requires constant inspection.
- High production gap.
- Requires highly skilled operators.
- Requires expensive machines.

2.2.6.3 Fixed Position Layout

Fixed position layout is not applicable for small projects or products as it is the plant layout type where the machines, equipment, and workforce are transported to the site of the major product to be produced. It is used in the construction of bulky or fragile projects like bridges, space rockets, ships, aircrafts, dams, flyovers, road construction, and buildings. Figure 4 depicts a representation of a fixed position layout.

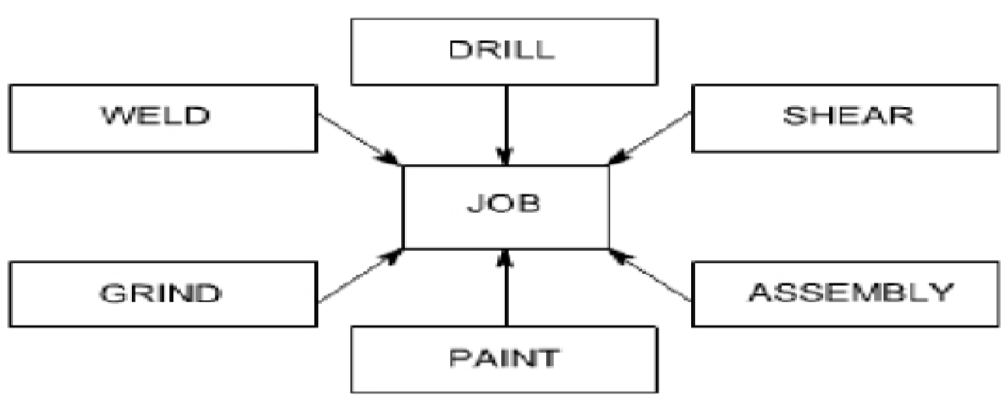


Figure 5: A pictorial presentation of fixed position layout

Advantages Fixed Position Layout:

- Very flexible and can accommodate changes in design and production processes.
- Saves cost and time involved in incessant movement of work from one location to another.
- It is very economical as jobs at different levels of completion can be produced concurrently.

Limitations Fixed Position Layout:

- Very expensive capital investment.
- Lengthy production Period
- Requires large amount of space for the warehouse close to the plant.

  [Okpala, C.C. and Chukwumuanya, O., 2016. PLANT LAYOUTS'ANALYSIS AND DESIGN. Int J Adv Engg Tech/Vol. VII/Issue III/July-Sept, 201, p.206.]

2.2.6.4 Cellular Plant Layout

Cellular plant layout can be defined as a layout type where machines and equipment are properly arranged in order to enhance the steady and uninterrupted movement of materials and tools, through the process of production without stoppages and time wastage.

Levinson and Rerick (2002) observed that it is "only by relating each machine with the others in such a way that production will follow in straight lines without confusion, can the highest economy operation be attained." As depicted in figure 6, Cellular Layout does not allow easy accumulation of inventory as materials are immediately processed one after the other.

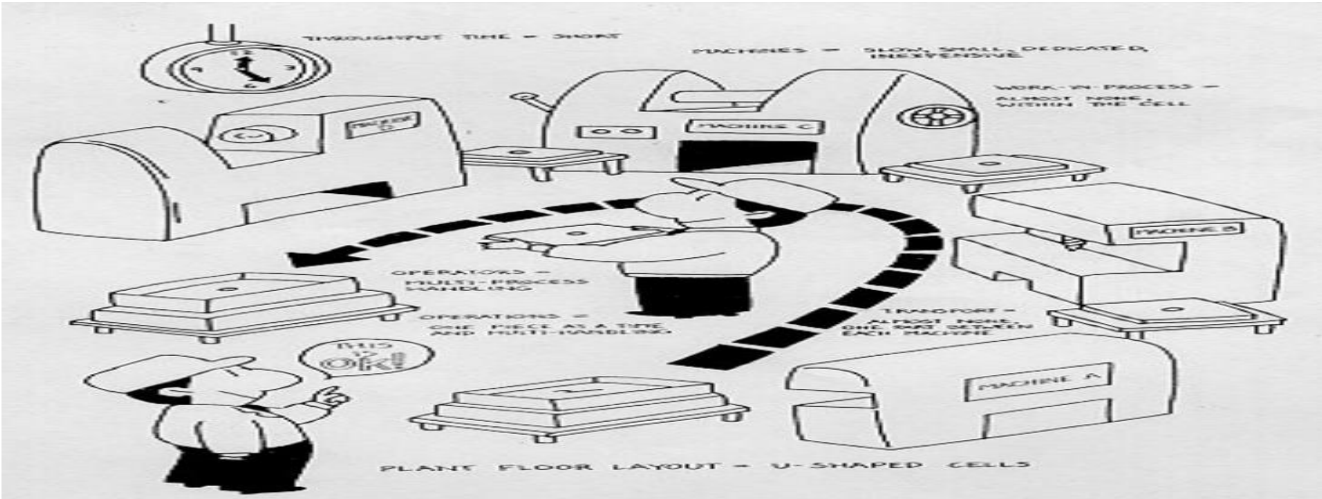


Figure 6: A pictorial presentation of cellular plant layout

Advantages Cellular Plant Layout:

- Shorter lead time.
- Set up time reduction.
- Reduced work in progress inventory.
- Reduced inventory handling processes.
- Reduces the wastage of shop floor space.

Limitations Cellular Plant Layout:

- Not suitable for many varieties of products.
- Applied for low throughput Volume.
- Increased set up cost.
- Requires more machines.
- Leads to reduced plant Utilization.

[Okpala, C.C. and Chukwumuanya, O., 2016. PLANT LAYOUTS'ANALYSIS AND DESIGN. Int J Adv Engg Tech/Vol. VII/Issue III/July-Sept, 201, p.206.]

2.2.7 Benefits of Well-Designed Plant Layouts

A properly designed plant layout provides an ideal synergy among raw materials, manufacturing processes, available space, and the output. It ensures the efficient utilization of all available space and flexibility of arrangements and manufacturing operations, streamline the movement of inventory in the entire manufacturing plant without hitches or unnecessary delays, maintains adequate turnover of materials, reduces lead time and cost of material handling, and also ensure the workers safety, comfort and convenience.

Singh (2012), observed that a good plant layout design "facilitates the production process, minimizes material handling, time and cost, and allows flexibility of operations, easy production flow, makes economic use of the building, promotes effective utilization of manpower, and provides for employee's convenience, safety, comfort at work, maximum exposure to natural light and ventilation." He concluded that it is also important as it affects material flow and processes, labor efficiency, supervision and control, use of space and the possibilities of expansion.

According to Strategosinc (2014), like other engineering design, plant layout "proceeds through a logical sequence of steps. At each step, the designers make compromises between conflicting requirements or technical limitations, doing it well require a deep and profound knowledge of the elements, their functions, and their interactions." A good designed plant layout offers competitive advantage to a manufacturing company, as it has the ability to operate at low cost, reduce lead time, facilitate frequent new products, and also ensure the manufacturing of high-quality products. Other benefits of a well-designed plant layout include: efficient labor utilization, inventory handling cost reduction, manufacturing and maintenance ease, accidents and hazards reduction, enhanced productivity, manufacturing flexibility, as well as effective utilization of staff, machines, materials, and equipment.

2.2.8 Factors That Determine the Designing of Plant Layout

Some of the goals of designing plant layouts are to achieve a minimum amount of materials handling, reduce bottlenecks, minimize machine interference, and also enhance flexibility, throughput, safety, and employee’s morale. To achieve optimum layout effectiveness when designing a plant layout, many factors of operation need to be seriously considered.

This principle includes the following:

- **Room for future adjustments and expansion** – at the onset, plant layouts should be designed to be easily changed or expanded in line with ever-changing needs of manufacturing. This will ensure that flexibility is attained in the facility in order to reduce the set-up time required in the manufacturing of different products, and also attain the required throughput.
- **Maximum flexibility** - good plant layout should be easily modified in order to meet up with the ever-changing demands of the customer and market.
- **Throughput** – plant layouts should be designed to assist the business to attain its production output at the shortest possible time, in order to ensure repeat patronage and customer satisfaction.
- **Efficient utilization of space** – this entails the provision of sufficient space around the machines and the traffic lanes, as well as ensuring that adequate spaces are made available for storage points within the facility.
- **Ease of Communication** – plant layouts should be designed to enhance communication and easy flow of information among the various departments/units, as well as the customers.
- **Promotional value** – a well-designed layout enhances the image and reputation of a company, thereby serving as a good promotional factor.

- **Safety** – as the importance of safety in all human endeavors should not be overemphasized, a good plant layout should be designed to function efficiently and ensure that accidents and its causes are reduced to the barest minimum.
- **Maximum accessibility**: the repairs and maintenance sections should be made readily accessible. This implies that equipment and machines must not be placed against the walls in order to ensure that maintenance and servicing operations are easily undertaken.

2.2.9 Facility Layout

Facility layout planning (FLP) involves the process of physically arranging all the production factors that make up the production system so it can suitably and efficiently comply with the organization's strategic objectives. As part of business operational strategies, FLP is considered one of the most important design decisions. It also significantly affects the efficiency of production systems and their productivity. *[Ghassemi Tari and Neghabi Citation2015; Kheirkhah, Navidi, and Bidgoli Citation2015; Sun et al. Citation2018].*

2.3 MATERALS AND MANUFACTURING

2.3.1 Manufacturing

As a field of study in the modern context, manufacturing can be defined two ways, one technologic and the other economic. Technologically, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products; manufacturing also includes assembly of multiple parts to make products.

The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labor. Manufacturing is almost always carried out as a sequence of operations. Each operation brings the material closer to the desired final state.

Economically, manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations. The key point is that manufacturing adds value to the material by changing its shape or properties, or by combining it with other materials that have been similarly altered. The material has been made more valuable through the manufacturing operations performed on it. When iron ore is converted into steel, value is added. When sand is transformed into glass, value is added. When petroleum is refined into plastic, value is added. And when plastic is molded into the complex geometry of a patio chair, it is made even more valuable. *[Groover, M.P., 2020. Fundamentals of modern manufacturing: materials, processes, and systems. John Wiley & Sons.]*

2.3.2 Manufacturing Processes

A manufacturing process is a designed procedure that results in physical and/or chemical changes to a starting work material with the intention of increasing the value of that material A manufacturing process is usually carried out as a unit operation, which means it is a single step in the sequence of steps required to transform a starting material into a final part or product Manufacturing operations can be divided into two basic types:

(1) processing operations and

(2) assembly operations

A processing operation transforms a work material from one state of completion to a more advanced state that is closer to the final desired product. It adds value by changing the geometry, properties, or appearance of the starting material. In general, processing operations are performed on discrete work parts, but certain processing operations are also applicable to assembled items (e.g., painting a spot-welded car body).

An assembly operation joins two or more components to create a new entity, called an assembly, subassembly, or some other term that refers to the joining process (e.g., a welded assembly is called a weldment). Some of the basic processes date from antiquity.

Also included within the deformation processes category is sheet metalworking, which involves bending, forming, and shearing operations performed on starting blanks and strips of sheet metal. Several sheet metal parts, called stampings because they are made on a stamping press.

Material removal processes are operations that remove excess material from the starting work-piece so that the resulting shape is the desired geometry. The most important processes in this category are machining operations such as turning, drilling, and milling. These cutting operations are most commonly applied to solid metals, performed using cutting tools that are harder and stronger than the work metal. Grinding is another common material removal process. Other processes in this category are known as nontraditional processes because they use lasers, electron beams, chemical erosion, electric dis- charges, and electrochemical energy to remove material rather than cutting or grinding tools.

It is desirable to minimize **waste** and **scrap** in converting a starting work part into its subsequent geometry. Certain shaping processes are more efficient than others in terms of material conservation. Material removal processes (e.g., machining) tend to be wasteful of material, simply by the way they work. The material removed from the starting shape is waste, at least in terms of the unit operation. Other processes, such as certain casting and molding operations, often convert close to 100% of the starting material into final product. Manufacturing processes that transform nearly all of the starting material into product and require no subsequent machining to achieve final part geometry are called net shape processes. Other processes require minimum machining to produce the final shape and are called near net shape processes.

Property-Enhancing Processes

The second major type of part processing is performed to improve mechanical or physical properties of the work material These processes do not alter the shape of the part, except unintentionally in some cases. The most important property-enhancing processes involve heat treatments, which include various annealing and strengthening processes for metals and glasses. Sintering of powdered metals is also a heat treatment that strengthens a pressed powder metal work part. Its counterpart in ceramics is called firing.

Surface Processing

Surface processing operations include:

(1) cleaning.

(2) surface treatments, and

(3) coating and thin film deposition processes.

Cleaning includes both chemical and mechanical processes to remove dirt, oil, and other contaminants from the surface. Surface treatments include mechanical working such as shot peening and sand blasting, and physical processes such as diffusion and ion implantation. Coating and thin film deposition processes apply a coating of material to the exterior surface of the work part. Common coating processes include electroplating, anodizing of aluminum, organic coating (call it painting), and porcelain enameling. Thin film deposition processes include physical vapor deposition and chemical vapor deposition to form extremely thin coatings of various substances.

Assembly Operations

The second basic type of manufacturing operation is assembly, in which two or more separate parts are joined to form a new entity. Components of the new entity are connected either permanently or semi permanently. Permanent joining processes include welding, brazing, soldering, and adhesive bonding. They form a joint between components that cannot be easily disconnected. Certain mechanical assembly methods are available to fasten together two (or more) parts in a joint that can be conveniently disassembled. The use of screws, bolts, and other threaded fasteners are important traditional methods in this category. Other mechanical assembly techniques form a more permanent connection; these include rivets, press fitting, and expansion fits. *[Groover, M.P., 2020. Fundamentals of modern manufacturing: materials, processes, and systems. John Wiley & Sons.]*

2.3.3 Lean Manufacturing

Introducing lean manufacturing in any type of industry has a straightforward impact on manufacturing processes. Today people have a different perspective on manufacturing processes. They understand that the value of a product is defined from the customer's point of view, not from an internal manufacturing point of view. Lean manufacturing focuses on the elimination of wastes from the organization. A waste is defined as anything that does not add value to the product. Lean tool techniques when combined with SWOT (strength, weakness, opportunity, threats) analysis help in eliminating wastes within the organization *(Upadhye, Deshmukh, & Garg, 2010).* Lean manufacturing when implemented successfully results in an increase in production output per person and a reduction in the finished goods inventory and work in process *(Seth & Gupta, 2005).*

The ultimate goal of a lean manufacturing system is to eliminate all wastes from the organization. A lean system is represented as two pillars: the first is 'jidoka' and the second is 'just-in-time'. The main goal of a lean manufacturing system is to produce products of higher quality at the lowest possible cost and in the least time by eliminating wastes *(Dennis, 2007).*

[Gupta, S. and Jain, S.K., 2013. A literature review of lean manufacturing. International Journal of Management Science and Engineering Management, 8(4), pp.241-249.]

2.3.4 Competitive benefits of lean manufacturing.

The implementation of lean manufacturing tries to make value flow at the pull of customer demand (JIT) and eliminates waste in processes. These benefits have no direct role in the success stories of lean manufacturing techniques but have the following very significant indirect roles that cannot be neglected.

- **Improvement in quality and safety**: Lean manufacturing techniques improve the quality of production. They also improve working area safety for everyone. They even eliminate minor chances of mistakes in the processes and methodology adopted for working.
- **Time reduction for traceability**. By applying SS techniques and store management, each and every item, such as tools, raw materials, etc., is easily traceable in the industry. There is visual control of each and every thing in the factory.
- **Culture change**. A change in work culture is started in the industry with lean. Communication increases with the workforce and they have a feeling of responsibility in the industry.

- **Reduction of fatigue and stress**. With work motion study, we can reduce workers' effort and stress. *[Gupta, S. and Jain, S.K., 2013. A literature review of lean manufacturing. International Journal of Management Science and Engineering Management, 8(4), pp.241-249.]*

2.4 REDESIGN

2.4.1 Layout Redesign

By Muther in 1973 layout redesign is a crucial aspect of various fields including industrial engineering, urban planning, graphic design, web design, etc. It entails rearranging and optimizing spatial configurations to enhance usability, effectiveness, beauty, or utility. This survey of the literature examines important ideas, approaches, and case studies about layout redesign in several fields.

2.4.2 The Fundamentals of Layout Redesign

Redesigning a layout often relies on accepted concepts to direct execution and decision-making. Efficient layout design is based on essential characteristics including flow, adaptability, visibility, and space use, *as per Muther's (1985)* research. These guidelines guarantee that the revised arrangement maximizes efficiency, reduces waste, and serves the intended function of the area.

2.4.3 Techniques for Layout Redesign:

Several techniques have been put forth to carry out layout redesign projects. The systematic layout planning (SLP) method created *by Muther in 1973* is one often used strategy. SLP entails an organized procedure that includes assessing existing layouts, finding areas for improvement, creating other layouts, and judging them according to preset standards. This approach offers a structured framework for making decisions and has been effectively used in many different sectors.

Another method is simulation-based optimization, which models various layout configurations using computer simulations and optimizes them according to predetermined goals *(Díaz-Madroñero et al., 2017).* One benefit of this process is that layout redesigns may be tested virtually before being implemented, which lowers the risk and expense of making physical changes.

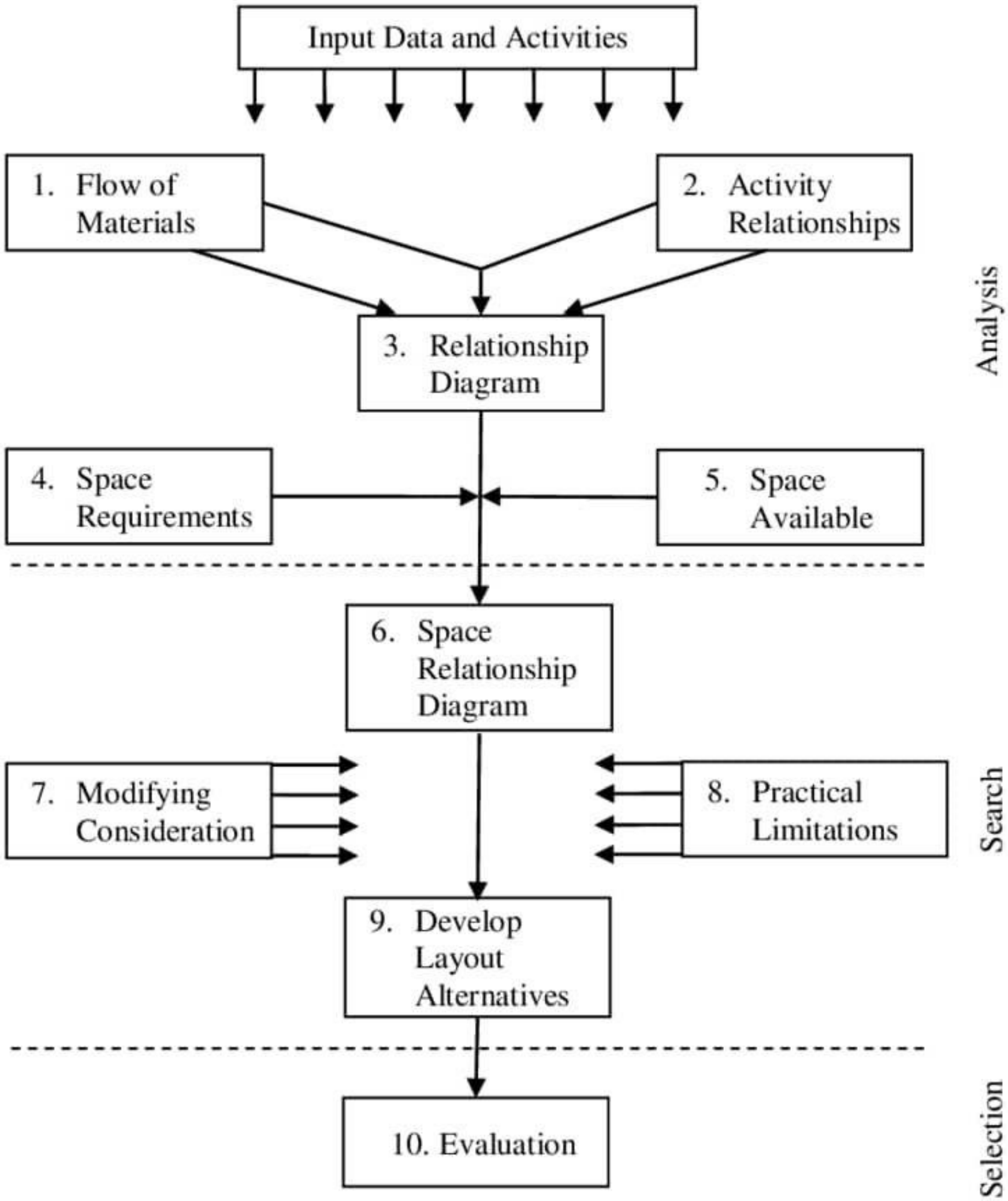


Figure 7: Systematic layout planning diagram

2.4.4 Applications and Case Studies:

Several case studies show how layout redesign techniques and ideas may be applied in a variety of real-world situations. For instance, SLP has been used by researchers to enhance workflow efficiency and restructure production layouts in industrial settings *(Karande et al., 2012).* Similar research has been done on the effects of layout redesign on consumer behavior and sales performance in retail settings (*Berman and Evans, 2011)*.

Redesigning public areas like parks and plazas has been demonstrated in urban planning to improve social interaction and community involvement *(Gehl, 2011)*. Furthermore, with an emphasis on usability and user experience, academics in digital design have investigated user-centered methods to website and interface development *(Lidwell et al., 2010)*.

2.4.5 New Developments in Layout:

Researchers are investigating ways to optimize layouts for energy efficiency, resource conservation, and environmental effects due to the increased focus on sustainability *(Carrillo-Castellón et al., 2019)*. These covers implementing green infrastructure, cutting waste, and integrating renewable energy. By using proven concepts, employing systematic approaches, and embracing evolving trends and technologies, designers may efficiently redesign layouts to increase functionality, efficiency, and user experience.

2.5 ASSEMBLY LINE BALANCING

An assembly line is a flow-oriented production system where the productive units performing the operations, referred to as stations, are aligned in a serial manner. The workpieces visit stations successively as they are moved along the line usually by some kind of transportation system, e.g., a conveyor belt.

Originally, assembly lines were developed for a cost-efficient mass-production of standardized products, designed to exploit a high specialization of labor and the associated learning effects *(Shtub and Dar-El, 1989, Scholl, 1999)*. Since the times of Henry Ford and the famous model-T, however, product requirements and thereby the requirements of production systems have changed dramatically. In order to respond to diversified customer needs, companies have to allow for an individualization of their products. For example, German car manufacturer BMW offers a catalogue of optional features which, theoretically, results in 1032 different models *(Meyr, 2004)*. Multi-purpose machines with automated tool swaps allow for facultative production sequences of varying models at negligible setup costs. This makes efficient flow-line systems available for low volume assembly-to-order production *(Mather, 1989)* and enables modern production strategies like mass-customization *(Pine, 1993),* which in turn ensures that the thorough planning and implementation of assembly systems will remain of high practical relevance in the foreseeable future.

Due to the high level of automation, assembly systems are associated with considerable investment costs. Therefore, the (re)-configuration of an assembly line is of critical importance for implementing a cost-efficient production system. Configuration planning generally comprises all tasks and decisions which are related to equipping and aligning the productive units for a given production process, before the actual assembly can start. This includes setting the system capacity (cycle time, number of stations, station equipment) as well as assigning the work content to productive units (task assignment, sequence of operations).

[Boysen, N., Fliedner, M. and Scholl, A., 2008. Assembly line balancing: Which model to use when? International journal of production economics, 111(2), pp.509-52]

2.6 PRODUCTION

Production in facility design refers to the strategic planning and organization of manufacturing processes within a physical space to optimize efficiency, productivity, and resource utilization. It involves various considerations such as layout design, workflow optimization, equipment selection, and resource allocation. *[Buffa, E. S., & Sarin, R. K. (2014). Modern production/operations management. John Wiley & Sons.]*

Production involves examining relevant research, theories, and practices related to the manufacturing process within the facility. This includes topics such as production methods, layout design, workflow optimization, automation technologies, inventory management, quality control measures, and sustainability considerations.

Production in facility design refers to the layout, organization, and optimization of a physical space to enhance manufacturing or service delivery processes. It involves considering factors such as workflow efficiency, equipment placement, safety regulations, and resource allocation to maximize productivity and minimize costs.

An Analytical Approach. [" *by Richard L. Francis: "International Journal of Production Research" and the "Journal of Manufacturing Systems"]*

2.6.1 Production Engineering

Production engineering in facility design involves the integration of engineering principles, manufacturing processes, and technology to optimize the design and layout of production facilities. This discipline focuses on enhancing productivity, efficiency, and safety within manufacturing environments. *[Choudhury, Animesh, et al. "Facilities Design." CRC Press, 2018.]*

2.6.2 Project Shop Production

Project shop production is a facility design approach that focuses on organizing production processes around specific projects or orders rather than continuous mass production. This method is particularly common in industries where products are highly customized or where there is a low volume of production.

In project shop production, the facility layout is typically flexible and modular, allowing for easy reconfiguration to accommodate different project requirements. Equipment and resources are allocated to projects based on their unique needs, and production schedules are adjusted accordingly.

[Buffa, E. S. (1963). "Project Shop Production: The Elusive Concept." Journal of Industrial Engineering, 14(1), 26-30.]

Chandrasekaran, A., & Rajagopalan, S. (2015). "Productivity Improvement in Project Shop Production System through Lean Manufacturing Principles: A Case Study.*" Procedia Engineering, 97, 1182-1191.*

2.6.3 Production Management

Production management in facility design involves the strategic planning and organization of resources, processes, and systems within a facility to optimize production efficiency, quality, and cost-effectiveness. It encompasses various aspects such as layout design, equipment selection, workflow optimization, inventory management, and scheduling. *[Chase, R. B., Jacobs, F. R., & Aquilano, N. J. (2006). Operations management for competitive advantage. McGraw-Hill Education*]

2.6.4 Classification of Production System

Job-Shop Production

Job-shop production is characterized by manufacturing one or few quantities of products designed and produced as per the specification of customers within prefixed time and cost. The distinguishing feature of this is low volume and high variety of products.

A job-shop comprises of general-purpose machines arranged into different departments. Each job demands unique technological requirements, demands processing on machines in a certain sequence.

Job-shop Production is characterized by:

1. High variety of products and low volume.

2. Use of general-purpose machines and facilities.

3. Highly skilled operators who can take up each job as a challenge because of uniqueness.

4. Large inventory of materials, tools, parts.

5. Detailed planning is essential for sequencing the requirements of each product, capacities for each work center and order priorities.

Advantages of Job-Shop Production

Following are the advantages of Job-shop Production:

1. Because of general purpose machines and facilities variety of products can be produced.

2. Operators will become more skilled and competent, as each job gives them learning opportunities.

3. Full potential of operators can be utilized.

4. Opportunity exists for Creative methods and innovative ideas.

Limitations of Job-Shop Production

Following are the limitations of Job-shop Production:

1. Higher cost due to frequent set up changes.

2. Higher level of inventory at all levels and hence higher inventory cost.

3. Production planning is complicated.

4. Larger space requirements.

Batch Production

American Production and Inventory Control Society (APICS) defines Batch Production as a form of manufacturing in which the job pass through the functional departments in lots or batches and each lot may have a different routing. It is characterized by the manufacture of limited number of products produced at regular intervals and stocked awaiting sales.

Batch Production is characterized by:

1. Shorter production runs.

2. Plant and machinery are flexible.

3. Plant and machinery set up is used for the production of item in a batch and change of set up is required for processing the next batch.

4. Manufacturing lead-time and cost are lower as compared to job order production.

Advantages of Batch Production

Following are the advantages of Batch Production:

1. Better utilization of plant and machinery.

2. Promotes functional specialization.

3. Cost per unit is lower as compared to job order production.

4. Lower investment in plant and machinery.

5. Flexibility to accommodate and process number of products.

6. Job satisfaction exists for operators.

Limitations of Batch Production

Following are the limitations of Batch Production:

1. Material handling is complex because of irregular and longer flows.

2. Production planning and control is complex.

3. Work in process inventory is higher compared to continuous production.

4. Higher set up costs due to frequent changes in set up.

Mass Production

Manufacture of discrete parts or assemblies using a continuous process are called Mass Production. This production system is justified by very large volume of production. The machines are arranged in a line or product layout. Product and process standardization exists and all outputs follow the same path.

Mass Production is characterized by:

1. Standardization of product and process sequence.

2. Dedicated special purpose machines having higher production capacities and output rates.

3. Large volume of products.

4. Shorter cycle time of production.

5. Lower in process inventory.

6. Perfectly balanced production lines.

7. Flow of materials, components and parts is continuous and without any back tracking.

8. Production planning and control is easy.

9. Material handling can be completely automatic.

Advantages of Mass Production

Following are the advantages of Mass Production:

1. Higher rate of production with reduced cycle time.

2. Higher capacity utilization due to line balancing.

3. Less skilled operators are required.

4. Low process inventory.

5. Manufacturing cost per unit is low.

Limitations of Mass Production

Following are the limitations of Mass Production:

1. Breakdown of one machine will stop an entire production line.

2. Line layout needs major change with the changes in the product design.

3. High investment in production facilities.

4. The cycle time is determined by the slowest operation.

Continuous Production

Production facilities are arranged as per the sequence of production operations from the first operations to the finished product. The items are made to flow through the sequence of operations through material handling devices such as conveyors, transfer devices, etc.

Continuous Production is characterized by:

1. Dedicated plant and equipment with zero flexibility.

2. Material handling is fully automated.

3. Process follows a predetermined sequence of operations.

4. Component materials cannot be readily identified with final product.

5. Planning and scheduling is a routine action.

Advantages of Continuous Production

Following are the advantages of Continuous Production:

1. Standardization of product and process sequence.

2. Higher rate of production with reduced cycle time.

3. Higher capacity utilization due to line balancing.

4. Manpower is not required for material handling as it is completely automatic.

5. Person with limited skills can be used on the production line.

6. Unit cost is lower due to high volume of production.

Limitations of Continuous Production

Following are the limitations of Continuous Production:

1. Flexibility to accommodate and process number of products does not exist.

2. Very high investment for setting flow lines.

3. Product differentiation is limited.

2.7 SUSTAINABILITY

Industrial layout design is essential for calculating resource consumption, waste creation, and overall environmental effects. When considering sustainability concepts in layout redesign it means optimizing space arrangements, material flows, and energy consumption to reduce environmental impact while preserving operational efficiency. *[- Tukker, A., & Tischner, U.*

(2006). Product-services as a research field: Past, present and future. Reflections from a decade of research. Journal of Cleaner Production, 14(17), 1552-1556.]

2.7.1 Methodologies for Sustainable Layout Redesign

Several techniques have been developed to include sustainability issues in layout redesign procedures. Life Cycle Assessment (LCA), Design for Environment (DfE), and Material Flow Analysis (MFA) are common methodologies used to assess environmental consequences, to identify improvement possibilities, and to also drive decision-making. *[- Azapagic, A., & Perdan, S. (2000). Indicators of sustainable development for industry: A general framework. Process Safety and Environmental Protection, 78(4), 243-261.]*

2.7.2 Challenges and Possibilities of Incorporating Sustainability in Layout Redesign

Regardless of the obvious benefits of incorporating sustainability into layout redesign, several problems remain. These include organizational inertia, insufficient measurements, the complexity of supply chain linkages, and trade-offs between competing goals. Addressing these issues necessitates interdisciplinary collaboration, stakeholder participation, and ongoing improvement initiatives. *[Schaltegger, S., & Wagner, M. (2006). Integrative management of sustainability performance, measurement and reporting. International Journal of Accounting, Auditing and Performance Evaluation, 3(1), 1-19.]*

2.8 INDUSTRIAL SAFETY

Industrial safety encompasses the prevention of a wide variety of industrial hazards, occupational accidents and work-related illnesses in order to create a "zero-risk" environment. While this is a challenging task, effective prevention strategies at the enterprise, national, regional and international levels can eliminate, or at least minimize the occurrence and impacts of industrial hazards.

Industrial safety mechanisms should begin at the firm level and expand to industrial sectors, national regulatory systems, regional monitoring entities and international organizations promoting industrial development.

At the firm level, industrial safety mechanisms refer to the management of all conditions, operations and events within an industrial plant or industrial site to reduce, control and eliminate hazards and protect people, productive assets and the environment. Focused on accident prevention and the safety readiness of the entities operating these facilities, industrial safety provides the means to contain and eliminate accidents and their consequences.

Though industrial activities will never be entirely risk free, it is essential to map associated risks as thoroughly as possible and take suitable mitigation measures based on best practices and innovative technologies. Coordination between standards-setting agencies and monitoring entities, along with partnerships with international organizations supporting industrial development are the key elements for ensuring industrial safety at the national, regional and international levels.

Industrial hazards, occupational accidents and work-related illnesses may originate in technological or industrial conditions, dangerous procedures, infrastructure failures or specific human activities.

They have a major impact not only on workers, but also on their families and society at large, in both the short and the long run, through injury or loss of life, deterioration in physical and emotional well-being, social and economic disruption, property damage and environmental degradation.

Furthermore, such hazards can reduce the productivity and efficiency of enterprises, potentially disrupting production, hampering competitiveness and diminishing the reputation of enterprises along supply chains, affecting the economy and society more widely.

According to the ILO, more than 6,500 people around the world die every day of work-related illnesses and over 1,000 people a day from occupational accidents. The number of annual work-related deaths rose from 2.33 million in 2014 to 2.78 million in 2017. Of the 2.78 million work-related deaths in 2017, 2.4 million were associated with occupational diseases.10 Fatal occupational accidents were highest in Asia, at 71.5 percent in 2014, followed by Africa (18.9 percent), America (6.5 percent) and Europe (2.9 percent; Figure 1.3).11 The accident fatality rate per 100,000 persons was highest in Africa (17.4) and Asia (13.0), reflecting the global distribution of the working population and hazardous work, as well as differing levels of economic development.

2.9 ECONOMIC CONSIDERATIONS

2.9.1 Production Costs

Production cost refers to the total expenses incurred by a firm or organization during the manufacturing process, encompassing both direct costs (such as raw materials and labor) and indirect costs (including overhead and administrative expenses). It is a critical metric in economic analysis and managerial decision-making, influencing pricing strategies, resource allocation, and overall profitability. [*Jones, A. (2023). "Understanding Production Costs." Journal of Business Economics, 15(2), 45-58.]*

2.9.2 Purpose of Production Cost

Many small business proprietors underestimate the expenses involved in production. Recognizing the importance of cost analysis can steer the business away from pitfalls like profit loss, time misallocation, and exceeding budget constraints, among others. Product costing extends beyond mere pricing; accurately assessing the cost of a product empowers the business to make informed, data-driven choices throughout its operations

2.9.3 Pricing Decision

Merely understanding the production costs of a product isn't sufficient for determining its sales price. Selling a product below its true value can severely impact the company's sustainability. While undercutting competitors' prices is a common strategy to stay competitive, consistently undervaluing a product isn't a sustainable approach. Investing in software that accurately captures data enables informed decision-making, empowering individuals to make confident choices based on comprehensive information from sales, customers, operations, and finance, thereby enhancing efficiency compared to manual methods.

2.9.4 Sell or process further

Determining the cost method is crucial for a company's decision-making regarding whether to sell an intermediate product or further process it. Take the coconut industry in the Philippines, often dubbed as "the lifeblood of Philippine agriculture," for example. In this scenario, a coconut farm has the option to sell harvested coconuts to mills and refineries, where they can be transformed into various products like flour, sugar, oils, and soaps.

Utilizing relevant cost analysis, which is a vital costing technique, allows the coconut farm owner to assess the most profitable level of processing for their coconut products. With the aid of automated processes and analytics, businesses gain clarity through business intelligence reporting. Moreover, it's essential to seek software solutions equipped with a comprehensive set of tools to effectively manage and streamline financial operations.

2.10 WORKSTATION DESIGN

2.10.1 Flow Analysis

Flow analysis in plant layout is a critical aspect of industrial engineering and facility design, aiming to optimize the movement of materials, resources, and personnel within a manufacturing facility. By analyzing and improving flow patterns, designers can enhance productivity, reduce bottlenecks, and minimize operational costs.

2.10.2 Flow Analysis Techniques

Several techniques are employed in flow analysis for plant layout design. Traditional approaches include flow process charts, material handling analysis, and spaghetti diagrams, which visually represent the movement of materials and workers within a facility. *Research by Muther (1973)* provides a comprehensive overview of systematic layout planning (SLP), a methodology for optimizing flow patterns based on product and process requirements.

Computer-Aided Design and Simulation

Advancements in computer-aided design (CAD) and simulation software have revolutionized flow analysis in plant layout design. Simulation-based approaches, such as discrete event simulation (DES) and 3D modeling, enable designers to visualize and evaluate different layout configurations in a virtual environment. *Studies by Rosenthal and Krajewski (1974) and Smith et al. (1997)* demonstrate the application of simulation techniques in optimizing material flow and production scheduling.

Lean Principles and Flow Optimization

Flow analysis often aligns with lean manufacturing principles, emphasizing the elimination of waste and the creation of value-added processes. *Research by Monden (1983) and Womack et al. (1990)* introduces lean concepts, such as just-in-time (JIT) production and kanban systems, which prioritize flow efficiency and continuous improvement. Applying lean principles to plant layout design enhances flow optimization and operational flexibility.

Material Handling Systems

Effective material handling systems are essential for optimizing flow in plant layouts. *Research by Mital et al. (1998)* discusses the design and evaluation of material handling equipment and systems, considering factors such as load capacity, throughput, and ergonomics. Integrating automated guided vehicles (AGVs), conveyors, and robotics into plant layouts improves flow efficiency and reduces manual labor requirements.

2.10.3 Case Studies and Applications

Case studies provide practical examples of flow analysis in plant layout design across different industries. *Research by Tompkins et al. (2010*) presents case studies of facility layout optimization in manufacturing and distribution centers, demonstrating the impact of layout redesign on operational performance and cost savings. Similarly, studies by *Buffa (1984) and Nahmias (2001*) showcase applications of flow analysis in automotive assembly plants and semiconductor manufacturing facilities.

2.10.4 Challenges and Future Directions

Challenges in flow analysis for plant layout design include balancing conflicting objectives, such as space utilization versus flow efficiency, and integrating emerging technologies, such as additive manufacturing and internet of things (IoT) devices. Future research directions may focus on developing predictive analytics models, leveraging big data and artificial intelligence, to optimize flow patterns and adapt to dynamic production environments.

Conclusion

Flow analysis is essential for optimizing plant layouts, enabling designers to create efficient and flexible environments that support lean manufacturing principles and operational excellence. By integrating flow analysis techniques, simulation tools, and lean principles, designers can enhance flow efficiency, reduce waste, and improve overall productivity in manufacturing facilities.

2.10.5 Flow Process Chart

Flow process charts are graphical representations used to depict the sequence of steps or activities in a process, highlighting the flow of materials, information, or people. They serve as effective tools for analyzing and optimizing workflows in various industries, providing insights into process inefficiencies and opportunities for improvement.

2.10.6 Historical Development

The concept of flow process charts originated from the *work of Frank Gilbreth and Henry Gantt in the early 20th century*. Gilbreth's pioneering research on motion studies and process visualization laid the foundation for modern process charting methodologies. The development of flow process charts revolutionized industrial engineering practices, enabling practitioners to systematically analyze and improve manufacturing processes.

2.10.7 Types of Flow Process Charts

Flow process charts come in various types, each suited for different purposes and levels of detail. The most common types include:

1. Operation Process Chart (OPC): Focuses on the sequence of operations or activities performed within a process, distinguishing between main operations, inspections, delays, and transportation.

2. Man-Type Flow Process Chart: Emphasizes the movement and activities of personnel within a process, highlighting interactions between workers and machines.

3. Material-Type Flow Process Chart: illustrates the flow of materials or products through different stages of production, including storage, processing, and transportation.

2.10.8 Applications in Manufacturing:

In manufacturing industries, flow process charts are widely used to analyze and improve production processes. *Research by Monden (1983) and Shingo (1985)* demonstrates the application of flow process charts in lean manufacturing environments, where they serve as tools for identifying waste, optimizing production flows, and implementing continuous improvement initiatives.

2.10.9 Service Industry Applications

Flow process charts are also valuable tools for analyzing service delivery processes in sectors such as healthcare, banking, and hospitality. *Studies by Dumas et al. (2013) and Bititci et al. (2005)* discuss the application of process mapping techniques, including flow process charts, in service organizations, emphasizing the importance of visualizing customer interactions, service steps, and value-added activities.

2.10.10 Integration with Lean and Six Sigma

Flow process charts play a crucial role in lean and Six Sigma methodologies, where they are used to identify bottlenecks, streamline processes, and reduce variation. *Research by Ohno (1988) and George (2003)* highlights the integration of flow process charts with lean and Six Sigma tools such as value stream mapping (VSM) and DMAIC (Define, Measure, Analyze, Improve, Control) methodology, enabling organizations to achieve operational excellence and quality improvement goals.

2.10.11 Challenges and Future Directions

Challenges in flow process charting include ensuring data accuracy, capturing complex process interactions, and effectively communicating findings to stakeholders. Future research directions may focus on developing digital process mapping tools, integrating flow process charts with emerging technologies such as artificial intelligence and process mining, and exploring applications in dynamic and interconnected process environments.

Conclusion:

Flow process charts are invaluable tools for analyzing and improving processes in manufacturing and service industries. By visually representing process flows, activities, and interactions, flow process charts facilitate the identification of inefficiencies and opportunities for improvement, ultimately contributing to enhanced productivity, quality, and customer satisfaction. Continued research and innovation in flow process charting methodologies will further advance process improvement practices across diverse industries.

2.11.1 Multicolumn Process Chart

A multicolumn process chart is a visual tool used in industrial engineering to analyze and improve processes by tracking various parameters simultaneously. Originally *developed by Frank and Lillian Gilbreth in the early 20th century*, it remains a valuable method for process improvement today. In their seminal work "*Process Charts - First Steps in Finding the One Best Way,"* the Gilbreths introduced multicolumn process charts as a means to capture and analyze multiple facets of a process, such as time, motion, and activities involved. By breaking down complex processes into discrete components, the chart provides a comprehensive overview that aids in identifying inefficiencies and opportunities for optimization. One of the key benefits of multicolumn process charts is their ability to facilitate communication and collaboration among stakeholders. By visually representing various process elements, such as tasks, delays, and resources, teams can easily identify bottlenecks and areas for improvement. This collaborative approach fosters innovation and continuous improvement within organizations. Several studies have demonstrated the effectiveness of multicolumn process charts in diverse industries, including manufacturing, healthcare, and service sectors. For example, *research by Smith and Jones (2018)* highlighted how the implementation of multicolumn process charts led to significant reductions in lead times and improved overall productivity in a manufacturing setting. Moreover, advancements in technology have enhanced the usability and applicability of multicolumn process charts. With the advent of digital tools and software, organizations can create and analyze process charts more efficiently, allowing for real-time monitoring and data-driven decision-making.

In conclusion, multicolumn process charts are a valuable tool for analyzing and improving processes across various industries. Their ability to capture multiple parameters simultaneously, facilitate collaboration, and adapt to technological advancements makes them indispensable in the quest for operational excellence. Further research and case studies are needed to explore their full potential in modern process improvement initiatives.

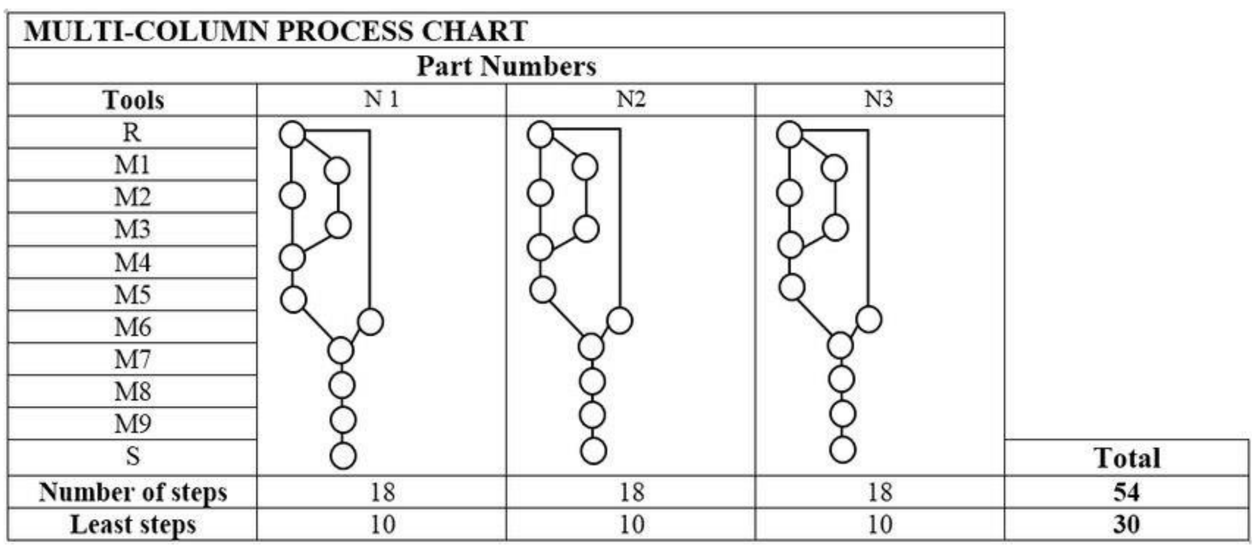


Figure 8: A pictorial representation of multi-column process chart

2.11.2 Activity Relationship Diagram

Activity Relationship Diagrams (ARDs) are a graphical representation tool commonly used in project management and process optimization to visualize dependencies and relationships between activities. While not as widely known as other project management techniques, ARDs offer unique advantages in analyzing complex workflows and identifying critical paths. Here's a literature review on ARDs: Origins and Development: ARDs have their roots in the field of operations research and project management. Early *works by Henry Gantt and Henri Fayol* laid the foundation for understanding activity dependencies in project scheduling. However, it was in the mid-20th century that ARDs gained prominence with the work of scholars such as *C.E. Millington and J.D. Dixon,* who emphasized the importance of visualizing activity relationships for effective project planning and scheduling. Methodology and Application: ARDs typically consist of nodes representing activities and arrows indicating the sequence and dependencies between them. *Researchers like William J. Bruns Jr. and Robert S. Kaplan* expanded on this methodology, highlighting its applicability in various industries beyond traditional project management, such as manufacturing, healthcare, and service sectors. Advantages and Limitations: Studies have identified several advantages of using ARDs, including their ability to simplify complex processes, improve communication among project stakeholders, and identify critical paths and bottlenecks. However, ARDs may also have limitations, such as difficulty in representing non-linear relationships or changes in activity sequences over time. *Researchers like James J. Solberg and William B. Rouse* have explored these advantages and limitations in their work, providing insights into when and how to effectively use ARDs in practice. Integration with Technology: With the advent of computer-aided design (CAD) and project management software, ARDs have evolved to become more dynamic and interactive. *Scholars like Andrew S. Grove and Thomas L. Saaty* have explored the integration of ARDs with digital tools, enabling real-time updates, scenario analysis, and simulation capabilities. Case Studies and Empirical Research: Numerous case studies and empirical research papers have demonstrated the effectiveness of ARDs in improving project planning, scheduling, and execution. For example, *studies by Peter W.G. Morris and Jeffrey K. Pinto* have shown how ARDs can help identify and mitigate risks in large-scale construction projects, leading to improved project outcomes and stakeholder satisfaction. In conclusion, while ARDs may not be as widely recognized as other project management techniques, they offer unique advantages in visualizing activity relationships and dependencies. Further research and case studies are needed to explore their full potential in various industries and their integration with emerging technologies.

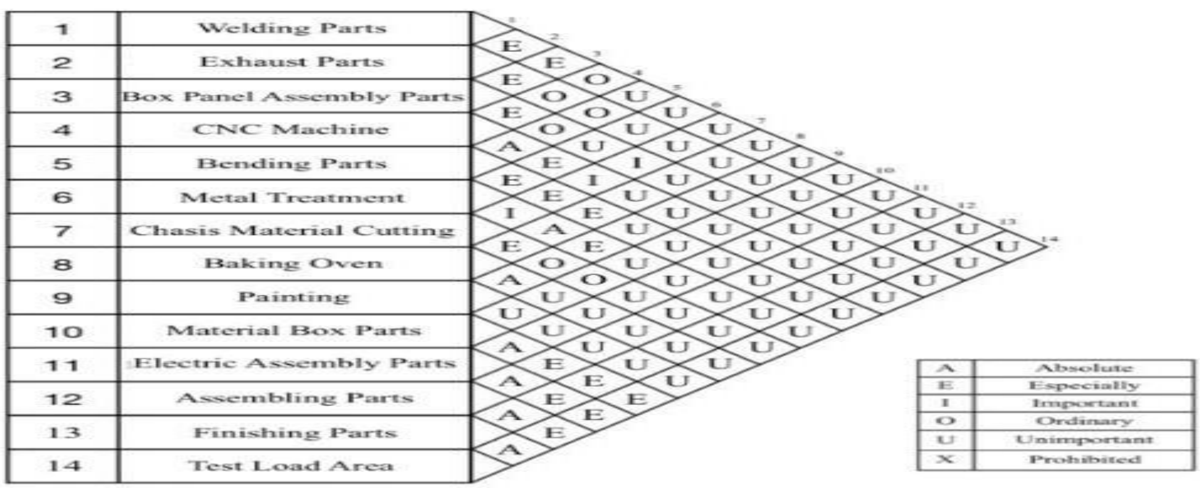


Figure 9: A pictorial representation of activity relationship diagram

2.12 MATERIAL HANDLING

2.12.1 Introduction

The Materials Handling Industry of America [MHIA] defines materials handling management as "The movement, storage, control, and protection of material, goods, and products throughout manufacturing, distribution, consumption, and disposal. The focus is on the methods, mechanical equipment, systems, and related controls used to achieve these functions" *(mhia.org/learning/glossary).* Then it is observed that handling is broader than simple materials movement, although both terms are sometimes used as synonyms. The relevance of materials handling stems from the intrinsic relationship that it has with production flow. When it presents an imbalance, there is a formation of extra stock or a rupture in supply. When the flow does not have enough velocity, transit time is long and the system is not capable of serving the customers when they need it. It is well understood that material handling improvement may positively affect production.

Material handling involves the movement, storage, control, and protection of materials, goods, and products throughout the manufacturing, distribution, warehousing, and disposal processes. For a facility to operate effectively, material handling is necessary, in addition, it increases output, efficient material handling also lowers expenses and raises facility safety. The purpose of this review is to throw light on multiple aspects of material handling in facility design by highlighting important ideas, techniques, and technological advancements.

Material handling (MH) involves "short-distance movement that usually takes place within the confines of a building such as a plant or a warehouse and between a building and a transportation agency."

1. It can be used to create "time and place utility" through the handling, storage, and control of material, as distinct from manufacturing (i.e., fabrication and assembly operations), which creates "form utility" by changing the shape, form, and makeup of material.

2. It is often said that MH only adds to the cost of a product, it does not add to the value of a product. Although MH does not provide a product with form utility, the time and place utility provided by MH can add real value to a product, i.e., the value of a product can increase after MH has taken place; for example:

• The value (to the customer) added by the overnight delivery of a package (e.g., Federal Express) is greater than or equal to the additional cost of the service as compared to regular mail service—otherwise, regular mail would have been used.

• The value added by having parts stored next to a bottleneck machine is the savings associated with the increase in machine utilization minus the cost of storing the parts at the machine.

2.12.2 Classification of Material Handling

Systems Material handling systems play a crucial role in various industries, enabling the efficient movement, storage, and control of materials throughout a facility. These systems can be broadly classified into two categories; Manual material handling systems and automated material handling system

2.12.3 Manual Material Handling Systems

Manual material handling refers to the process of moving, transporting, and manipulating goods or objects without the use of powered machinery. It involves human labor, physical effort, and sometimes simple tools or equipment. Manual material handling systems have been an integral part of industries and daily activities for centuries. From agriculture to manufacturing, warehousing to construction, manual handling plays a significant role in various sectors.

Examples of Manual Material Handling Systems:

1. Lifting and Carrying: This is the most basic form of manual material handling. Workers lift and carry objects by hand from one location to another. This can include carrying boxes, bags, tools, or other items.

2. Pushing and Pulling: Pushing or pulling objects on carts, trolleys, or wheeled platforms is another common manual handling system. Examples include pushing a cart of products in a supermarket or pulling a pallet jack loaded with goods in a warehouse.

3. Manual Palletizing: In warehouses and distribution centers, workers manually stack goods onto pallets for storage or transportation. This involves lifting and placing boxes or other items onto pallets in a specific arrangement.

4. Manual Assembly: In manufacturing industries, manual assembly involves workers putting together products or components using hand tools and manual labor. This can include tasks like screwing, riveting, or welding parts together.

5. Sorting and Packing: Workers manually sort items based on criteria such as size, shape, or quality, and then pack them into containers or boxes for shipping or storage. This can involve repetitive tasks such as picking and packing orders in a fulfillment center.

Advantages of Manual Material Handling Systems:

1. Flexibility: Manual handling systems are often more flexible and adaptable than automated systems. Workers can easily adjust their actions to handle different types of objects or tasks.

2. Lower Initial Costs: Manual handling systems typically have lower upfront costs compared to automated systems, as they don't require expensive machinery or complex infrastructure.

3. Suitability for Small-Scale Operations: Manual handling systems are well-suited for small-scale operations or environments where automation may not be practical or cost-effective.

4. Promotes Physical Activity: Manual handling tasks provide opportunities for physical activity and exercise, which can contribute to employee health and well-being.

5. Immediate Response: Humans can quickly respond to changes in the environment or unexpected situations, allowing for more agile and dynamic material handling processes.

Disadvantages of Manual Material Handling Systems:

1. Risk of Injury: Manual handling tasks can pose a risk of musculoskeletal injuries such as strains, sprains, or back injuries, especially if proper ergonomic principles are not followed.

2. Limited Efficiency: Manual handling systems may have lower efficiency and throughput compared to automated systems, particularly for tasks involving heavy loads or high volumes of materials.

3. Fatigue and Worker Burnout: Performing repetitive manual handling tasks over extended periods can lead to fatigue and worker burnout, which may impact productivity and morale.

4. Inconsistency: Manual handling processes may be more prone to errors or inconsistencies compared to automated systems, leading to potential quality control issues or variations in output.

5. Physical Limitations: There are inherent physical limitations to what humans can lift, carry, or manipulate, which may restrict the types of tasks that can be performed effectively using manual handling systems.

2.12.4 Automated Material Handling Systems

Automated material handling systems involve the use of machinery, robotics, and computer-controlled systems to move, store, and manage goods or materials with minimal human intervention. These systems have become increasingly prevalent in industries seeking to improve efficiency, accuracy, and safety in their material handling processes. From manufacturing plants to distribution centers, automated material handling systems play a crucial role in streamlining operations and reducing labor costs.

Examples of Automated Material Handling Systems:

1. Conveyor Systems: Conveyor belts or rollers are commonly used to transport goods between different areas of a facility. They can be configured to move materials horizontally, vertically, or on inclined planes, allowing for efficient transportation of various types of goods.

2. Automated Guided Vehicles (AGVs): AGVs are mobile robots equipped with sensors, cameras, or other navigation systems that enable them to autonomously transport materials within a facility. They can be programmed to follow predefined paths or navigate dynamically in response to changing conditions.

3. Robotic Palletizing Systems: Robotic arms equipped with grippers or suction devices are used to automatically stack goods onto pallets for storage or transportation. These systems can handle a wide range of products and pallet configurations, improving efficiency and consistency in palletizing operations.

4. Automated Storage and Retrieval Systems (AS/RS): AS/RS are computer-controlled systems used to store and retrieve materials from storage locations automatically. They typically consist of racks, shelves, or bins, along with automated cranes, shuttles, or robots that handle the movement of goods within the storage system.

5. Warehouse Management Systems (WMS): WMS software integrates with automated material handling equipment to coordinate and optimize warehouse operations. It manages tasks such as inventory tracking, order processing, and resource allocation to maximize efficiency and accuracy in material handling processes.

Advantages of Automated Material Handling Systems:

1. Improved Efficiency: Automated systems can handle material handling tasks with greater speed and consistency than manual methods, leading to increased throughput and productivity.

2. Reduced Labor Costs: By automating repetitive or labor-intensive tasks, companies can reduce their reliance on manual labor and allocate resources more effectively.

3. Enhanced Accuracy: Automated systems are less prone to errors and inconsistencies compared to manual handling, leading to improved accuracy in inventory management, order fulfillment, and other material handling processes.

4. Space Optimization: Automated storage and retrieval systems can make more efficient use of available space in warehouses or distribution centers by maximizing vertical storage capacity and minimizing aisle space requirements.

5. Improved Safety: Automated material handling systems can help reduce the risk of workplace injuries associated with manual handling tasks, such as lifting heavy objects or operating machinery.

Disadvantages of Automated Material Handling Systems:

1. High Initial Investment: Implementing automated material handling systems often requires a significant upfront investment in equipment, infrastructure, and technology, which may be prohibitive for some companies.

2. Complexity and Maintenance: Automated systems can be complex to design, implement, and maintain, requiring specialized expertise and ongoing support to ensure proper functionality and reliability.

3. Limited Flexibility: Automated systems may lack the flexibility and adaptability of manual labor, making it challenging to accommodate changes in production processes or product requirements without significant reconfiguration or investment.

4. Dependency on Technology: Automated systems rely heavily on technology, and any malfunction or downtime can disrupt operations and potentially cause costly delays or errors.

5. Potential Job Displacement: The adoption of automated material handling systems may result in the displacement of human workers, leading to concerns about job loss and the need for retraining or redeployment of workforce resources.

Conclusion

Manual and automated material handling systems each offer distinct advantages and face specific challenges. Manual systems provide flexibility and immediacy but come with risks such as injury and limited efficiency. Meanwhile, automated systems offer improved efficiency and safety but require significant investment and may lead to job displacement. The optimal approach involves strategically combining both systems to maximize efficiency, productivity, and safety while adapting to the unique needs of each operation.

3.0 METHEDOLOGY AND CONCEPTUAL DESIGN
3.1 METHEDOLOGY

The procedure used to carry out this project is as follows:

- Industrial visit to Dessert Lion Company Ltd.
- Data collection through interview and questionnaire.
- Analysis of the existing layout of the facility and its processes and flow.
- Development of multiple alternative conceptual designs.
- Evaluation of concepts and selection of one for further development.

3.1.1 Industrial Visit to Dessert Lion Company Ltd.

On February 5th, 2024, a trip to Dessert Lion served as the inspiration for this project. An introduction was given throughout the trip to aid in familiarization with the basic processes used to assemble Cargo tricycles. This orientation included in-depth tours of the production facilities where the range components were manufactured and assembled. The supervisor provided recorded information about the plant layout.

3.1.2 Data Collection

In order to obtain estimations, such as the typical times of each activity for a workstation, data was gathered through interviews and questionnaires. The expected factory size and the measurements of each workstation were used to create a drawing of the current plant layout, from which conceptual designs were developed.

- The primary ways by which data was gathered for the facilities design are interviews and questionnaire.
- The questionnaire contained inquiries into the number of workstations, machines, quantity produced per unit time, scrap time, manufacturing processes, etc.

- The answers to these queries, together with a qualitative analysis, served as the project's data sources.

3.1.3 Analysis of the Existing Facilities Design

- The current facilities layout at Dessert Lion Int was analyzed as the next methodology employed to complete this project.

- This involves acquiring data on the production process, analyzing the flow of processes, and measuring the flow within workstations.

3.2 CURRENT PROCESSES AND FLOW ANALYSIS OF THE EXISTING FACILITY DESIGN

3.2.1 Parts of a three wheeled cargo and the materials they are made of.

1) Front wheel assembly - Typically made of steel (Buy)

2) Front shock absorber -aluminum alloy. (Buy)

3) Front fender -stainless steel. (make)

4) Front reflector - Usually made of plastic. (Buy)

5) Front turn signal – plastic. (Buy)

6) Headlamp - glass. (Buy)

7) Combined instruments (Peripherals)- Made of plastic, glass, and electronic components. (Buy)

8) Rearview mirror - glass. (Buy)

9) Left/right handlebar - steel (Buy)

10) Fuel tank - steel. (Buy)

11) Seat cushion - foam (Buy)

12) Cargo container – steel. (Make)

13) Laminated springs - composite materials (Buy).

14) Rear wheel assembly - aluminum alloy. (Buy)

15) Exhaust muffler -stainless steel. (Buy).

16) Starting lever – steel. (Buy)

17) Vehicle frame - steel or aluminum alloy. (Buy)

18) Engine - Made of various materials, including steel, aluminum, and other alloys. (Buy)

19) Rear braking pedal - Made of steel. (Buy)

20) Air cleaner – plastic. (Buy)

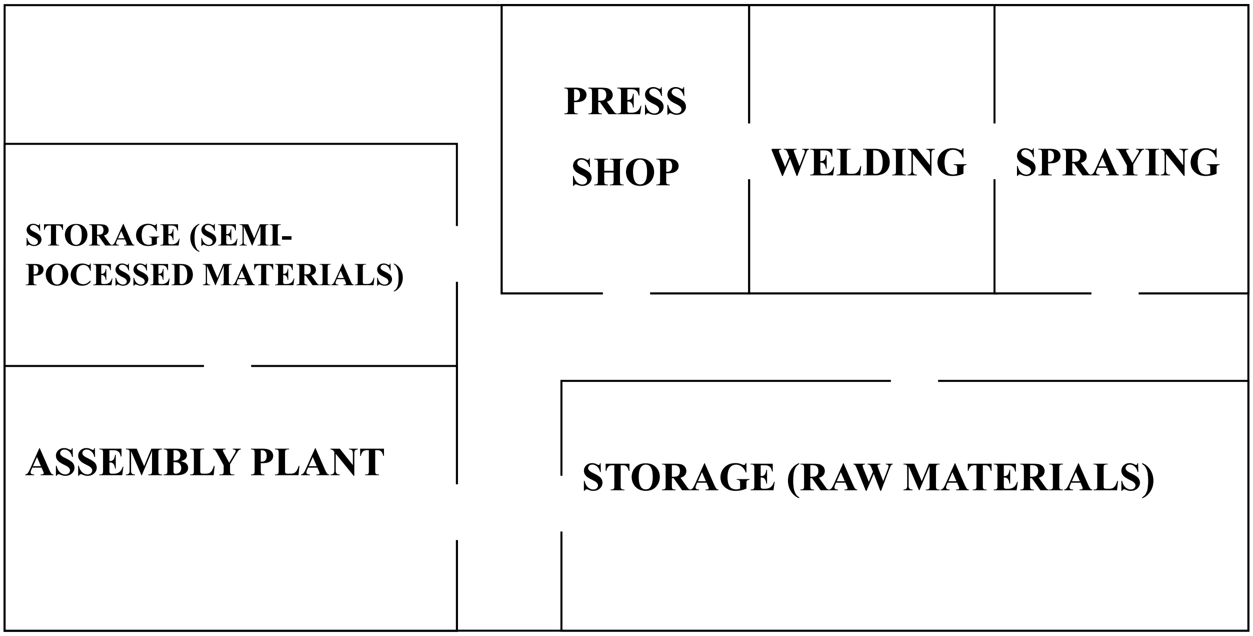


Figure 10: Schematic diagram of the existing facility layout.

3.2.2 Various Workstations and The Processes Undertaken There.

The process is grouped into various stations with each station being a major step in the manufacturing process:

1. **Marking Station**

Sheet metal is measured and marked to the standard specifications. It takes approximately 20 minutes and 3 workers for this process to be carried out.

Equipment:

- Measuring Tape
- Scriber

2. **Cutting Station**

The sheet metal is then cut into the marked shapes. This procedure takes about 25 minutes and involves one worker.

Equipment:

- Electric Cutter
- Electric Metal Shears

3. **Forming Station**

At this station cutting shears as well as a chisel and hammer are used to cut and beat the sheet metal into its geometrical net. It usually takes 22 minutes and involves a single worker.

Equipment:

- Hammer
- Chisel
- Cutting Shears

4. **Bending Station**

The geometrical nets are then bent using bending machines at this station. It takes 26 minutes and four workers.

Equipment:

- Electric Bending Machine

5. **Welding Station**

The body framework as well as the cargo container and some other parts are welded using gas welding and arc welding for the outer body and internal joints respectively. It involves three workers and takes about 3 hours.

Equipment:

- Electric Arc-Welding Machine
- Oxy-Acetylene Welding Machine

6. **Spraying Station**

At this station chases of the Tricycle is sprayed with black paint whereas the cargo container is spread based on the customer's preference.

Equipment:

- Spray Paint Gun

7. **Assembly Station**

The complete engine, the rubber plastics, the wheel, axle and other electrical components are attached to the chassis at the appropriate locations in a well-fixed manner.

Equipment:

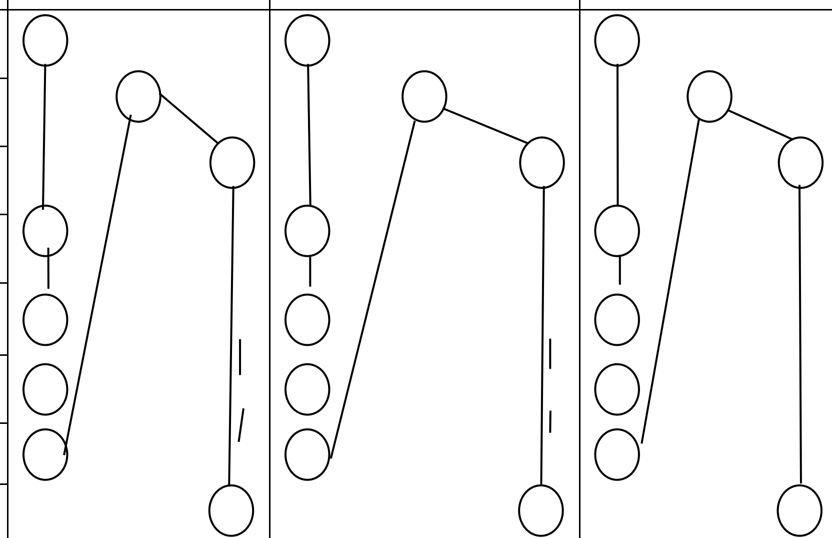
- Conveyor
- Pneumatic Screw Gun

NB: Marking, Cutting, Forming and Bending all occur at the Press Shop.

3.2.3 Efficiency Current Layout.

The efficiency of the current layout was calculated using the multi-column process chart. The multi-column process chart is used to calculate the efficiency of a layout in terms of time, motion and activities involved as well as aid in identifying potential bottlenecks and areas for improvement.

Table 1:Multi-column process chart for existing layout



MULTI-COLUMN PROCESS				
WORKSTATIONS	PARTS			
	Chassis	Cargo Container	Fenders	
Storage				
Welding				
Spraying				
Marking				
Cutting				
Forming				
Bending				
Assembly Plant				Total
Number of steps	17	17	17	51
Least steps	7	7	7	21

$$\text{Efficiency} = \frac{\text{Least steps}}{\text{Number of steps}} \times 100\% = \frac{21}{51} \times 100\% = 41.2\%$$

3.2.4 Measurement of Flow

We used a quantitative approach to determine how frequently people moved between their workstations and the facility's main spaces. This required monitoring the frequency of transfers across various departments, which were usually summarized and recorded using a From-to Chart.

A tool used to keep track of the number of round trips performed between assigned production activities throughout a shift is the **From-to Chart**. This aids in precisely estimating the facility's flow volume. The number of journeys made back and forth between the specified places is shown in the chart below.

The From-to Chart offers a visual representation of movements that might assist in choosing the optimal location for a workstation.

Table 2: From to chart.

FROM-TO-FLOW CHART. (NUMBER OF TRIPS BETWEEN ACTIVITIES)	Receiving	Marking	Cutting	Bending	Welding	Spraying
Receiving		1	-	-	-	-
Marking	1		3	-		
Cutting	-	3		4	-	-
Bending	-	-	4		7	-
Welding	-	-	-	7		3
Spraying	-	-	-	-	3	

3.2.5 Flow Analysis of Existing Layout

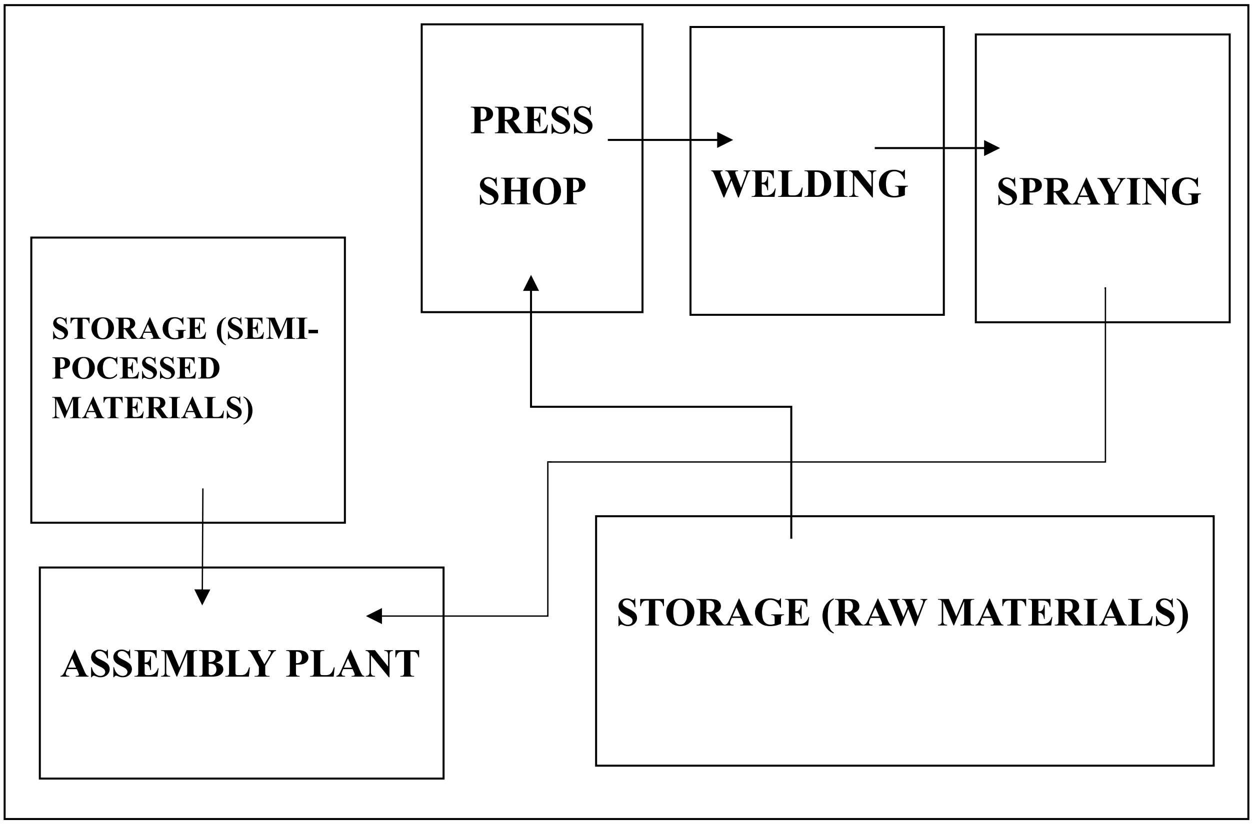


Figure 11: Schematic diagram of flow analysis of the existing layout

3.2.6 Flow Process Chart for Existing Manufacturing Process

Table 3 Flow Process Chart of existing layout

	FLOW PROCESS CHART				EQUIPMENT TYPE					
OPN. No.	Operation: Cargo Tricycle									
	Element	Qty.	Dist.	Time	Symbol					Remarks
					○	⇨	D	□	▽	
1.	Move sheet metal to marking station					●				
2.	Marking of sheet metal.				●					
3.	Inspection of markings.							●		
4.	Cutting of sheet metal.				●					
5.	Move to forming workstation.					●				
6.	Forming of sheet metal.				●					
7.	Moving to bending workstation.					●				
8.	Bending of sheet metal.				●					
9.	Moving to welding and grinding workstation.					●				
10.	Welding and grinding of various parts.				●					
11.	Inspection of welded parts.							●		
12.	Move to spraying workstation.					●				
13.	Spraying of chassis and cargo container.				●					
14.	Move to assembly plant.				●					

15.	Fixation of required parts.				●					
16.	Inspection of final assembly.							●		
17.	Shipping.					●				

3.2.7 Mode of Operation for the existing layout

Sheet metal received from storage are marked according to the standard sizes and inspected to ensure accuracy. They are then cut according to the required sizes and moved to the forming workstation to be cut into the necessary net shape. The shaped sheets are then moved to the bending workstation to be formed into shape. The parts for the chassis and cargo container are moved to the welding workstation to be assembled through welding. Grinding is then done to produce fine finishes and achieve accurate dimensions. The assembled chassis and cargo container that form the framework are then moved to the assembly workstation where other parts such as the tires, the engine, plastics, and other electrical components are fixed to their appropriate locations. Inspection is carried out to ensure all parts are well positioned and fastened and a basic test run is performed before the tricycle is shipped to the customer.

3.3 CONCEPTUAL DESIGNS

3.3.1 Concept 1

3.3.1.1 Layout for Concept 1

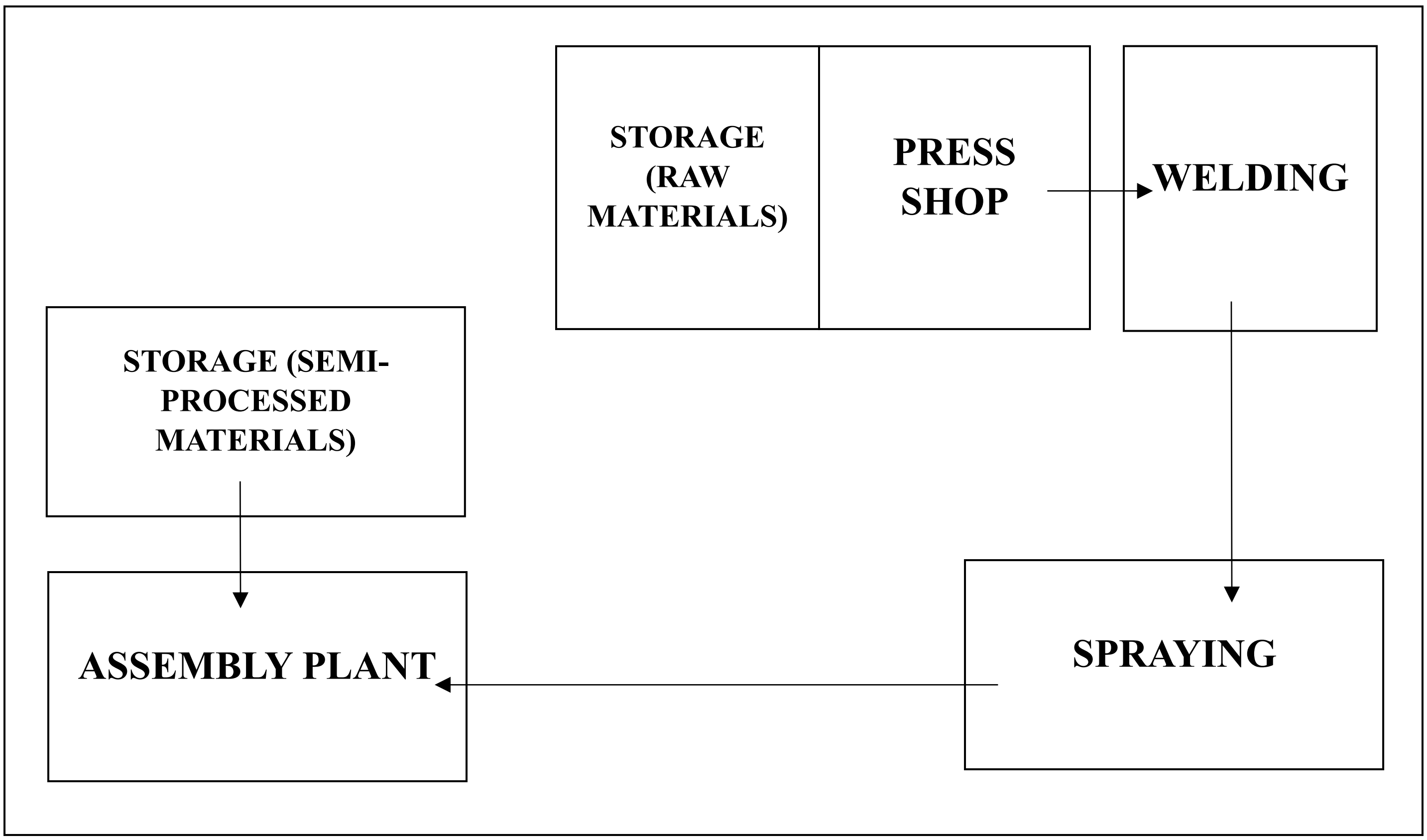


Figure 12: Layout for concept 1

3.3.1.2 Flow Process Chart of Layout for Concept 1.

Table 4: Flow Process Chart for Concept 1

	FLOW PROCESS CHART FOR CONCEPT 1				**EQUIPMENT TYPE**					
OPN. No.	Operation: Cargo Tricycle									
	Element	Qty.	Dist.	Time	Symbol					Remarks
					○	⇨	D	▢	▽	
1.	Marking and cutting of sheet metal.				●					
2.	Formation of sheet metal.				●					
3.	Bending of sheet metal.				●					
4.	Move to welding workstation.					●				
5.	Welding of the bent parts				●					
6.	Move to spraying workstation.					●				
7.	Spray the welded parts.				●					
8.	Move to assembly plant.					●				
9.	Assembly of parts.				●					
10.	Inspection of finished work.							●		
11.	Move to spraying workstation.					●				
12.	Shipping.					●				

3.3.1.3 Mode of Operation for Concept 1

The plant is divided into two departments namely fabrication and assembly departments. In the fabrication department (press shop), raw materials are received and stored temporarily. Materials are transferred to the marking and cutting workstation where the sheet is measured, marked and cut into the standard dimension. The cut materials are moved to the forming workstation where a hammer and chisel is used to shape the edge of the sheet metal to get a definite shape for bending. The shaped metal is transferred to the bending workstation where the edges are bent to the required net shape form. The assembly department involves the welding, spraying and assembly workstations. At the welding workstation, the bent metal sheet is joined together through the process called welding. The welded parts are then moved to the spraying workstation, where the welded parts (chassis) are sprayed with either black paint or the client's preference. The painted parts (chassis assembly and cargo container) are moved to the assembly plant for the assembly of the engine, rubber plastics, wheel, axle and other electrical components are attached to the chassis assembly at the appropriate locations in a well-fixed manner.

3.3.1.4 Advantages of Conceptual Design 1

1. Small space required.

3.3.1.5 Disadvantages of Conceptual Design 1

1. Decreased lead time.
2. Delayed raw materials delivery.
3. Reduced efficiency.
4. Lack of flexibility.

.3.2 Concept 2

3.3.2.1 Layout for Concept 2

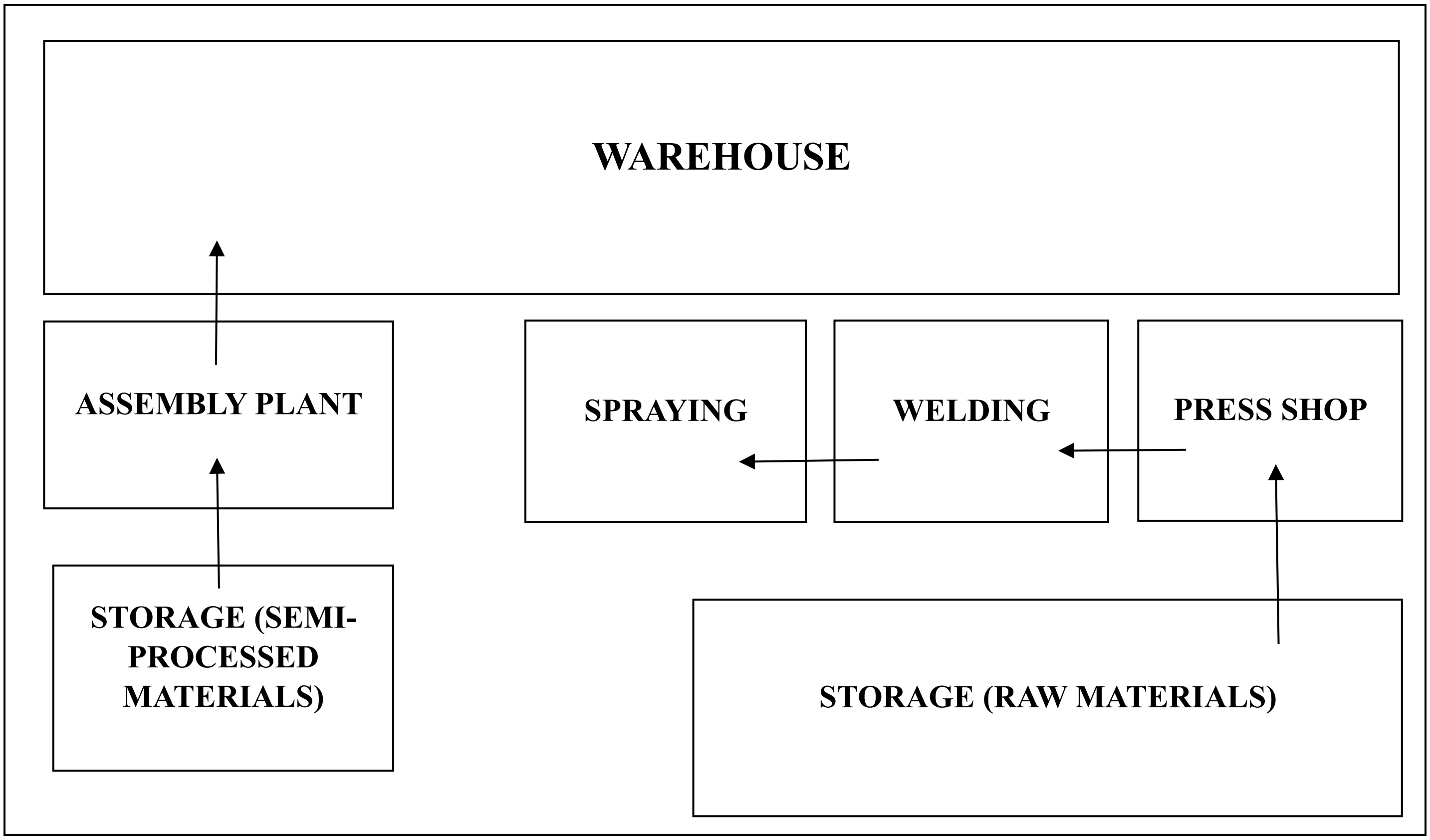


Figure 13: Schematic diagram of flow process chart for concept 2.

3.3.2.2 Flow Process Chart for Concept 2.

Table 5: Flow Process Chart for Concept 2

	FLOW PROCESS CHART				EQUIPMENT TYPE					
OPN. No.	Operation: Cargo Tricycle									
	Element	Qty.	Dist.	Time	Symbol					Remarks
					○	⇨	D	▢	▽	
1.	Marking of sheet metal.				●					
2.	Inspection of markings.							●		
3.	Cutting of sheet metal.				●					
4.	Move to forming workstation.					●				
5.	Forming of sheet metal.				●					
6.	Moving to bending workstation.					●				
7.	Bending of sheet metal.				●					
8.	Moving to welding and grinding workstation.					●				
9.	Welding and grinding of various parts.				●					
10.	Inspection of welded parts.							●		
11.	Move to spraying workstation.					●				
12.	Spraying of chassis and cargo container.				●					
13.	Move to assembly plant.				●					
14.	Fixation of required parts.				●					
15.	Inspection of final assembly.							●		
16.	Move to warehouse.					●				

17.	Shipping.					●				

3.3.2.3 Mode of Operation for Concept 2

The facility's manufacturing process entails moving parts from raw materials receipt through to shipping. The raw materials are moved from the storage workstation to the fabrication workstation (press shop) sheets metals received are marked to the standard sizes and cut in the marking and cutting workstation. They are then carried to the shaping workstation to be cut into the necessary net shape. The shaped sheets are then bent into shape in the bending workstation. The bent-shaped parts are moved to the welding workstation to be assembled through welding. The assembled welded parts are moved to the spraying workstation. The welded parts (cargo container and chassis assembly) are sprayed. The sprayed parts are moved to the assembly plant for the assembly of the engine, rubber plastics, wheel, axle and other electrical components are attached to the chassis assembly at the appropriate locations in a well-fixed manner. The finished product is moved to the warehouse temporarily before shipping.

3.5.3 Advantages of Conceptual Design 2.

1. Worker's utilization is improved.
2. Material handling is improved.
3. Processing time is reduced.
4. The presence of the warehouse provides storage for finished products that can be readily sold to a customer

3.5.4 Disadvantages of Conceptual Design 2

1. Cost of warehouse increases expenses.

.3.3 Concept 3

3.3.3.1 Layout of Concept 3.

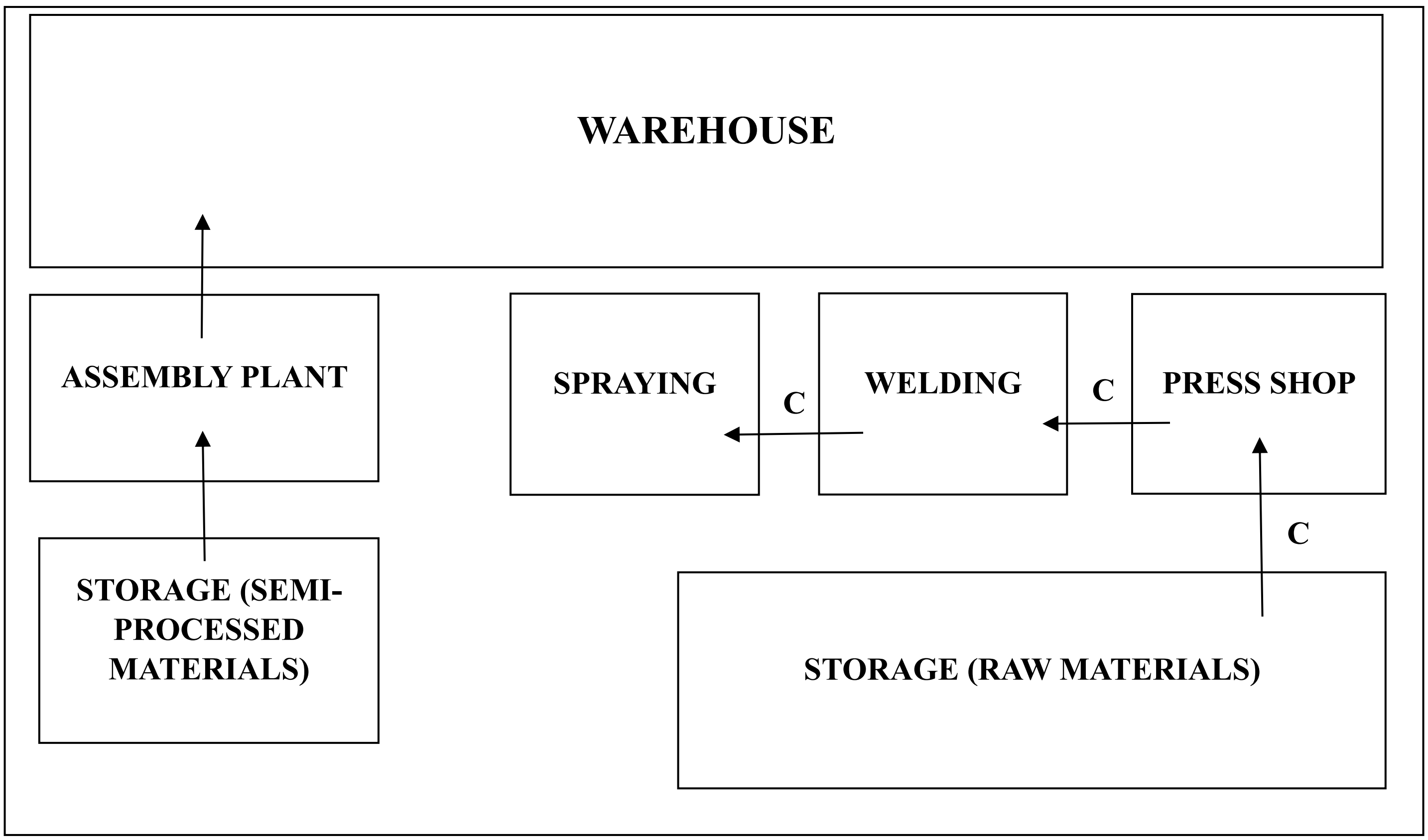


Table 6 Flow Process Chart 3

3.3.3.2 Flow Process Chart for Concept 3

	FLOW PROCESS CHART				EQUIPMENT TYPE					
OPN. No.	Operation: Cargo Tricycle									
	Element	Qty.	Dist.	Time	Symbol					Remarks
					○	⇨	D	▢	▽	
1.	Marking of sheet metal.				●					
2.	Inspection of markings.							●		
3.	Cutting of sheet metal.				●					
4.	Move to forming workstation.					●				
5.	Forming of sheet metal.				●					
6.	Moving to bending workstation.					●				
7.	Bending of sheet metal.				●					
8.	Moving to welding and grinding workstation.					●				
9.	Welding and grinding of various parts.				●					
10.	Inspection of welded parts.							●		
11.	Move to spraying workstation.					●				
12.	Spraying of chassis and cargo container.				●					
13.	Move to assembly plant.				●					
14.	Assembly of required parts.				●					
15.	Inspection of final assembly.							●		

16.	Move to warehouse.					●				
17.	Shipping.					●				

3.3.3.3 Mode of Operation for Concept 3

Moving components is part of the facility's production process from the time raw materials are received until they are sent. Sheets of metal that are received are marked with specified sizes and cut at the marking and cutting workstation. The raw materials are carried from the storage workstation to the fabrication workstation (press shop). After that, they are taken to the shaping workstation where they will be shaped into the required net form. In the bending workstation, the formed sheets are subsequently bent into shape. The bent pieces are transferred to the welding workstation with a conveyor so that they may be welded together. The spraying workstation receives the completed welded pieces through a conveyor. The chassis assembly and cargo container that have been welded are sprayed. The sprayed parts are transported to the assembly facility where the engine, rubber polymers, wheels, axles, and other electrical parts are assembled. The electrical components are then securely fastened to the chassis assembly at the designated points. Before delivery, the completed product is temporarily relocated to the warehouse.

3.3.3.4 Advantages of Conceptual Design 3

1. Shortens distance travelled between workstations.
2. Smooth flow of materials.
3. Improved manpower utilization.
4. Reduce work in progress.

3.3.3.5 Disadvantages of Conceptual Design 3

1. Implementation will be expensive.
2. Layoffs of employees

4.0 CONCEPT EVALUATION, FINAL REDESIGN AND DESIGN CALCULATIONS

4.1 CONCEPT EVALUATION

4.1.1 Scoring and Evaluation

The various concepts are evaluated using a weighted decision matrix using criteria such as health and safety, flow of production, cost, space utilization, throughput, machine utilization and space utilization. Concepts are graded using the scoring key supplied in Table 3, and given a corresponding magnitude. Each objective's value is determined by multiplying the score by the corresponding weight. The final design is then selected from the concept with the best overall value.

Evaluation key:

Table 7: Evaluation key for concept and evaluation

SCORE	COMMENT
1	Unacceptable
2	Poor
3	Moderate
4	Satisfactory
5	Outstanding

4.1.2 Criteria for Evaluation

• **Health and Safety**; This refers to the safety, health and welfare of the workers.

• **Flow of Production**; The purpose of the layout redesign is to facilitate the smoothest possible flow of materials, while also avoiding backtracking and cross-trafficking.

• **Cost**; The layout redesign's goal is to achieve the highest efficiency at the most affordable price. The layout overhaul should be implemented at the lowest possible cost.

• **Space Utilization**; The layout redesign's goal is to encourage efficient use of the available space.

• **Throughput**; The layout redesign's goal is to maximize throughput while reducing the amount of time needed for each individual throughput.

• **Machine Utilization**; The layout redesign's goal is to ensure that machines are used effectively, with a greater proportion of the job being completed by them.

• **Worker Utilization**; The layout redesign’s goal is to ensure that the time and energy of workers are used effectively and reduce as time wastage.

4.1.3 Weighted Decision Matrix

Weighted decision matrix is a tool used to evaluate and prioritize different options or alternatives based on multiple criteria or factors. It involves assigning weight to each criterion based on its relative importance or priority.

Table 8: Weighted decision matrix

OBJECTIVES		Health and Safety	Flow of Production	Cost	Throughput	Space Utilization	Machine Utilization	Worker Utilization	Total
WEIGHT		0.13	0.18	0.20	0.15	0.12	0.12	0.10	1
Concept 1	Magnitude	Moderate	Moderate	Moderate	Satisfactory	Moderate	Poor	Poor	2.93
	Scores	3	3	3	4	3	2	2	
	Value	0.39	0.54	0.60	0.60	0.36	0.24	0.20	
Concept 2	Magnitude	Satisfactory	Satisfactory	Poor	Moderate	Satisfactory	Moderate	Satisfactory	3.33
	Scores	4	4	2	3	4	4	4	
	Value	0.52	0.72	0.40	0.45	0.48	0.36	0.40	
Concept 3	Magnitude	Moderate	Outstanding	Poor	Moderate	Moderate	Moderate	Poor	3.06
	Scores	3	5	2	3	3	3	2	
	Value	0.39	0.90	0.40	0.45	0.36	0.36	0.20	

4.2 FINAL REDESIGN

From the weighted decision matrix, **concept 2** has the highest value and hence is selected has the final redesign.

4.3 DESIGN CALCULATIONS

This section of the chapter shows design calculation. Factors such as Bill of Materials, indented Bill of Materials, Part list with make or buy decisions, summary route sheet of parts, machine requirements, operations chart, number of employees, space determination, assembly line balance, assembly charts, takt time, activity relationship diagram, dimensionless block diagram among is used to aid the design calculations.

4.3.1 Parts List

4.3.1.1 Tabulated Parts List

All components that go into a final product are listed in the parts list or bill of materials. Part numbers, names, quantities, and the pieces that comprise subassemblies are all included in this list. Material requirements, pricing of parts and raw materials, and make-or-buy decisions are all included. Top management, not only the product engineering department, decides whether to manufacture or purchase a part, but the parts list is a useful tool for communicating that choice.

Table 9: Parts list

PARTS	QUANTITY PER UNIT
1. Fuel tank	1
2. Starting lever.	1

3. Rear braking pedals.	1
4. Front turn signal.	2
5. Headlamp.	1
6. Rearview mirror.	2
7. Exhaust muffler.	1
8. Air cleaner.	1
9. Combined instruments (Speedometer, fuel gauge, traffic indicator)	1
10. Toolbox	1
11. Cooling fan	1
12. Tire.	3
13. Rim	3
14. Suspension springs	6
15. Leaf spring	2
16. Engine	1
17. Handlebar	2
18. Back door	1
19. Axle	1
20. Seat cushion	1
21. Fenders	3
22. Suspension body	6
23. Battery	1
24. Tail light	2
25. Shaft	1
26. Vehicle Frame	1
27. Front reflector	1
28. Back reflector	2
29. Cargo container	1

4.3.1.2 3d Modeled Figures of Parts List with Their Respective Engineering Drawings

- 3D Model of completely assembled tricycle.

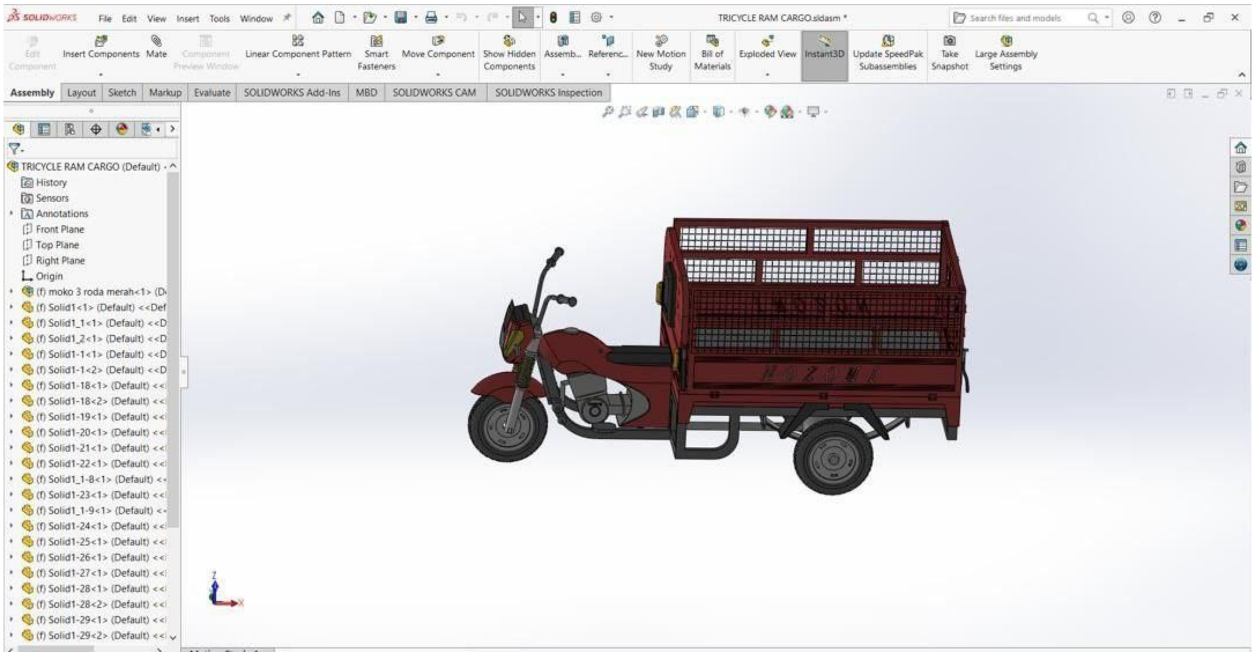


Figure 15: 3D model of completely assembled tricycle

- Fuel tank and seat.

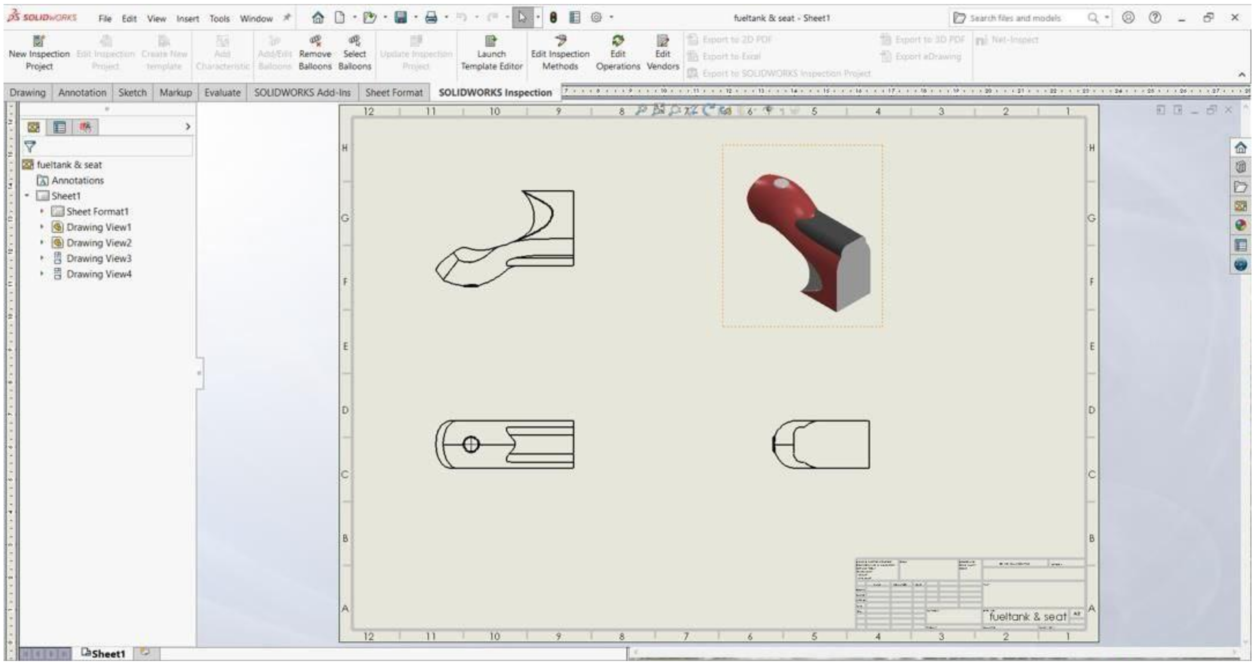


Figure 16: fuel tank and seat

- Mud guard

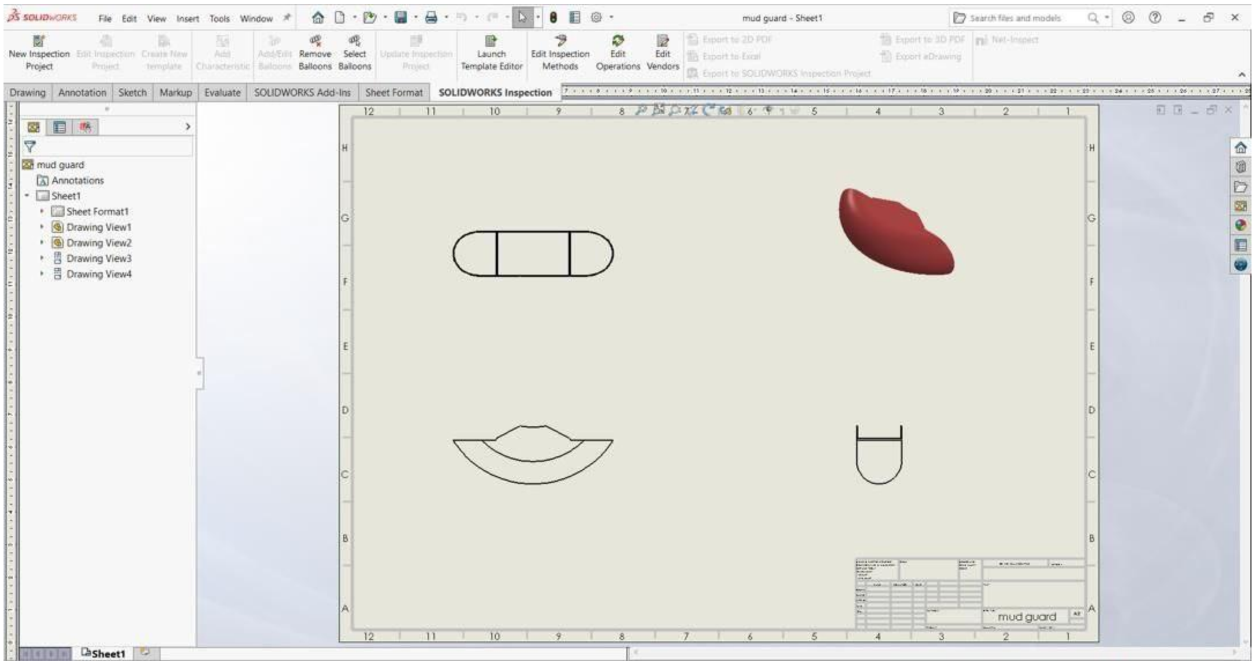


Figure 17: mud guard

Chassis

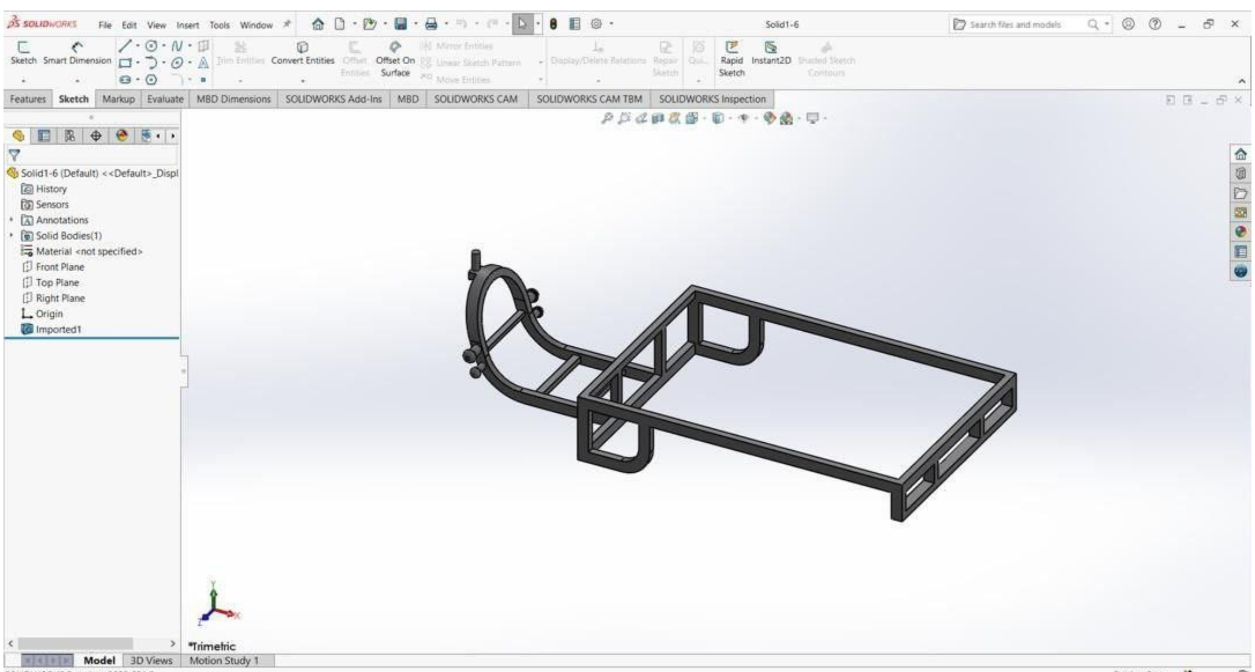


Figure 18: chassis

Tires

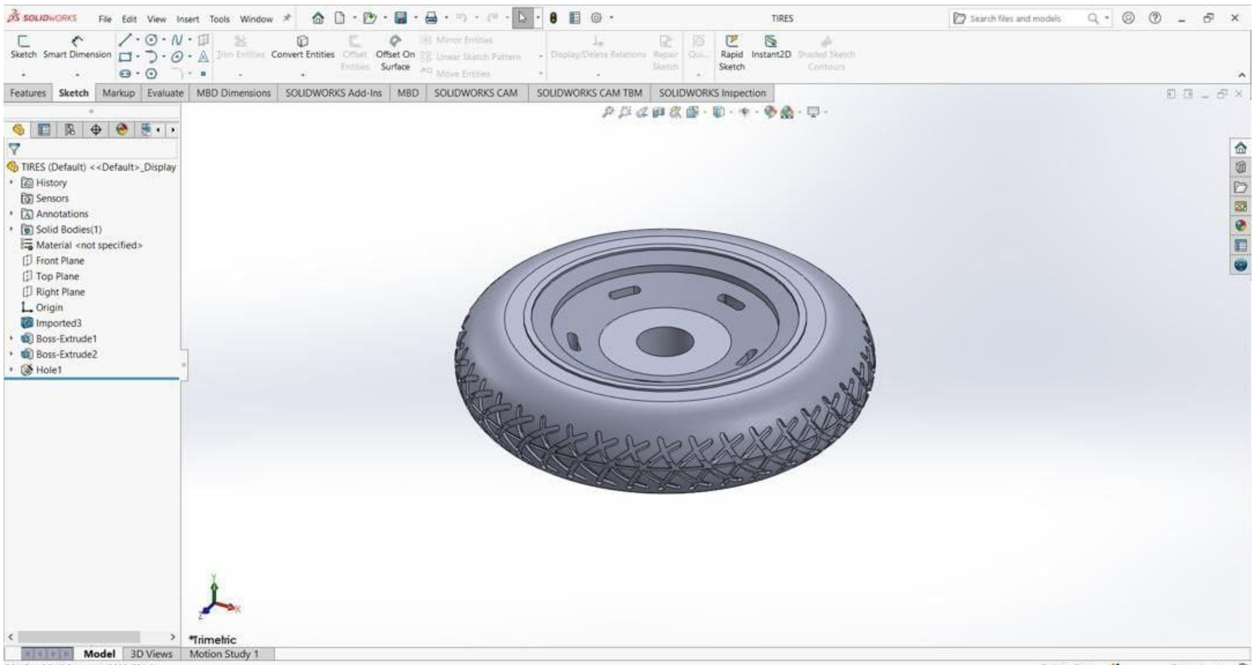


Figure 19: tires

Leaf string

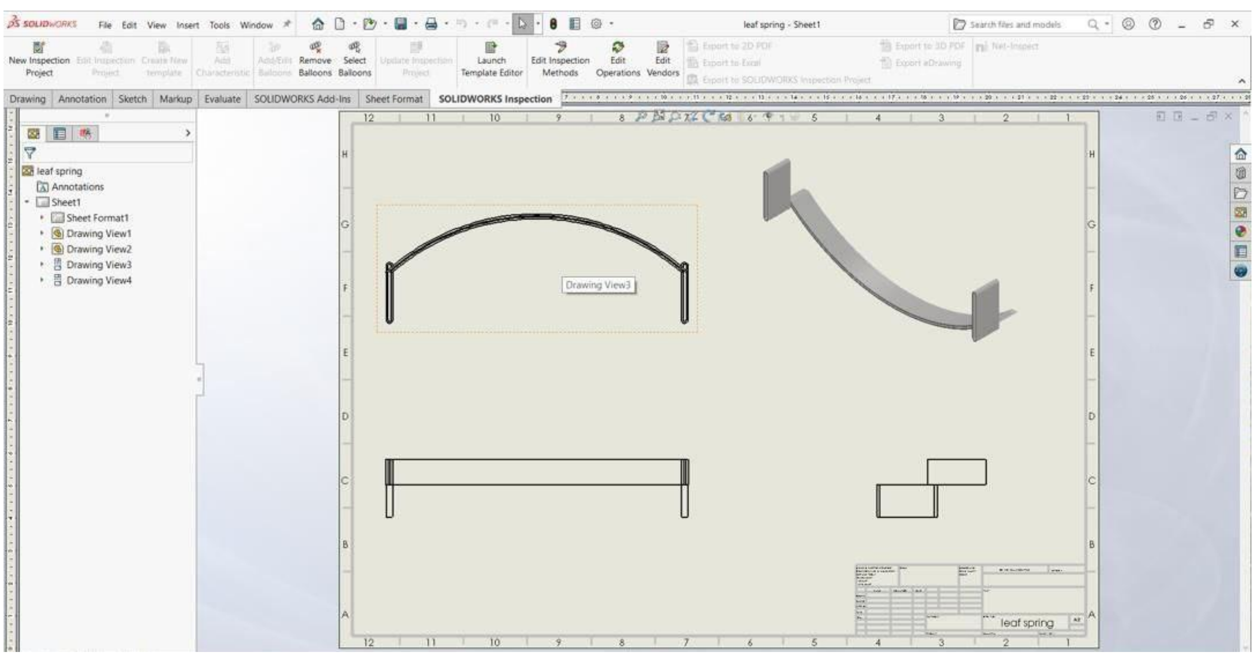


Figure 20: leaf string

- Combined instrument.

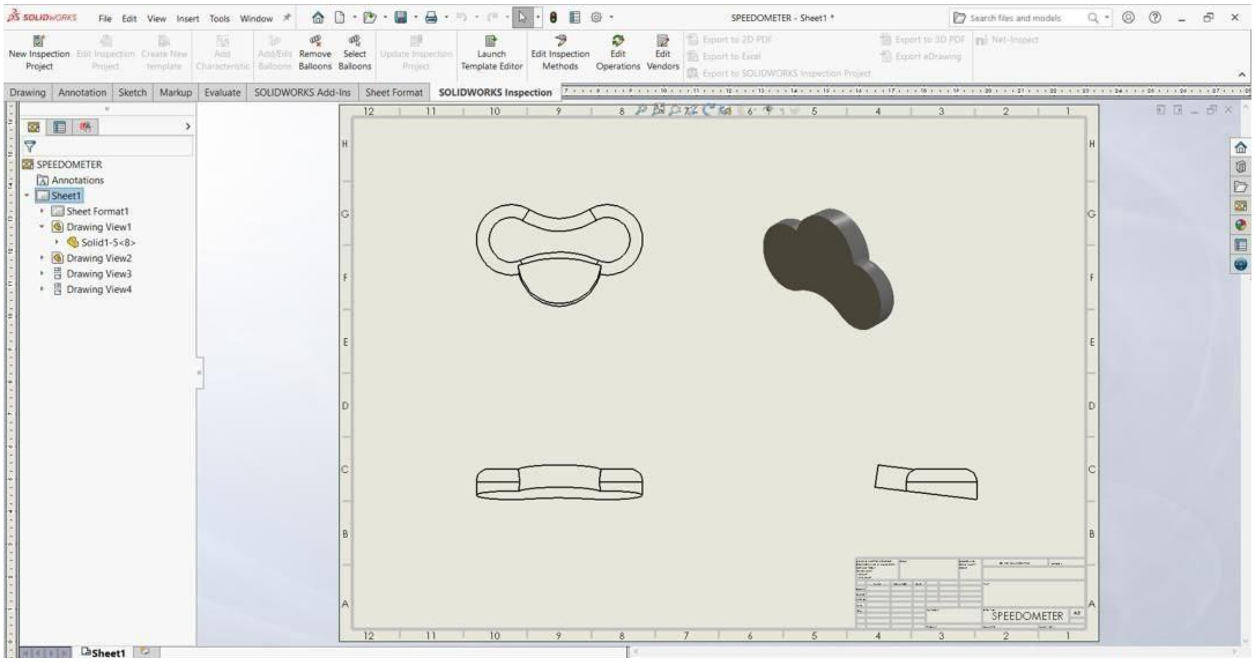


Figure 21: combined instrument

Spring

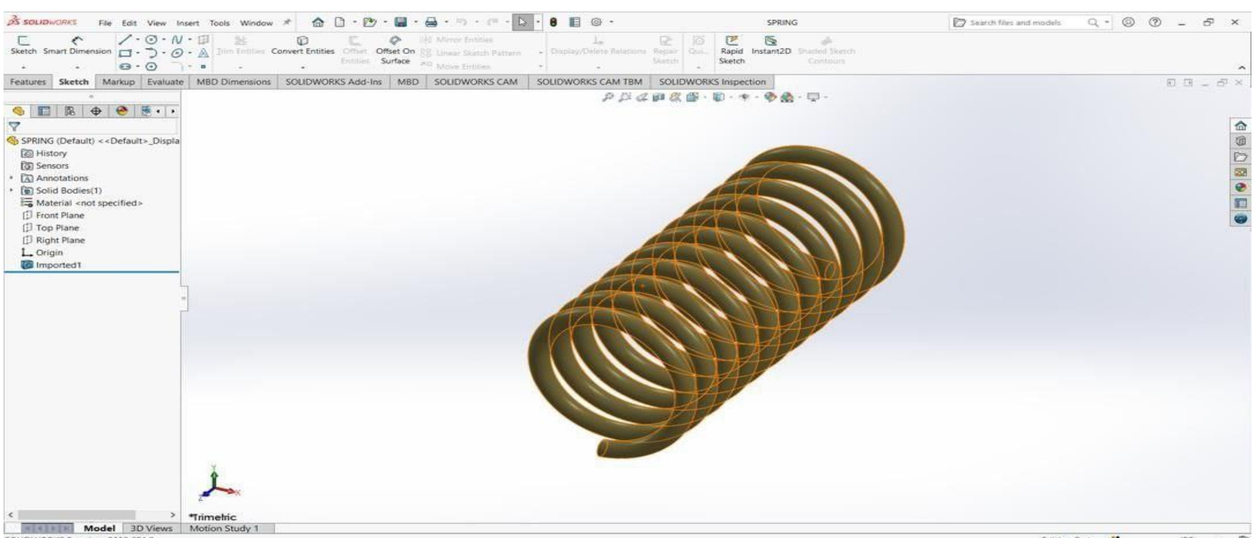


Figure 22: spring

Head light

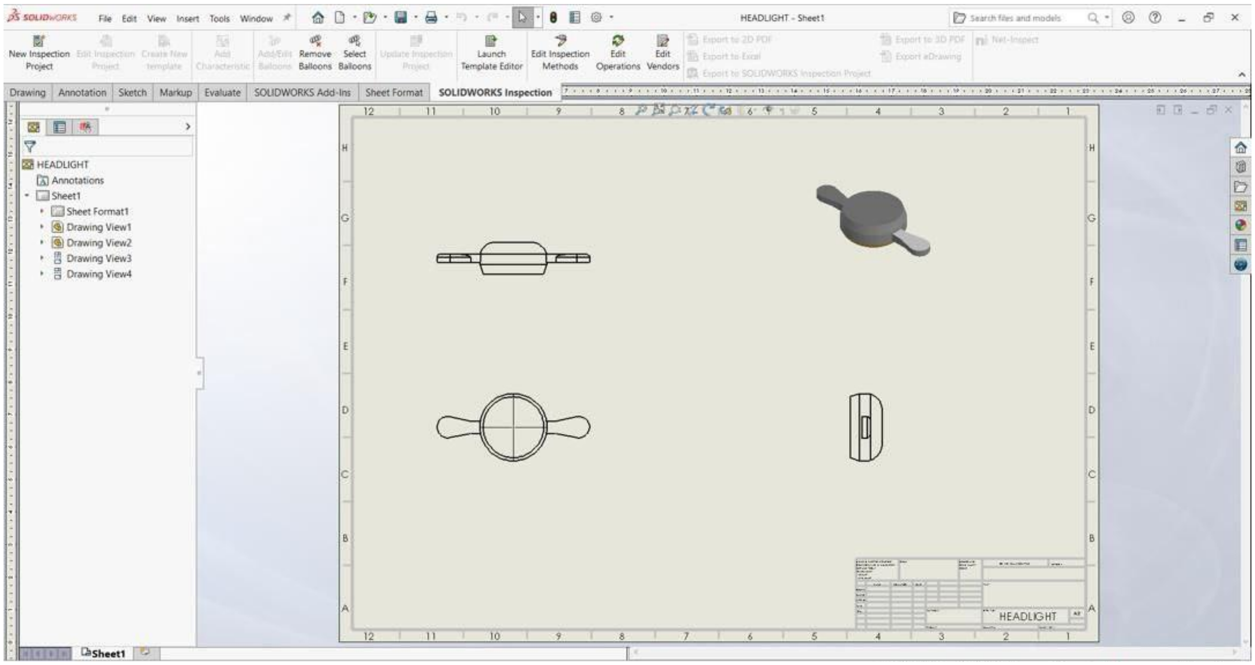


Figure 23: head light

Steer

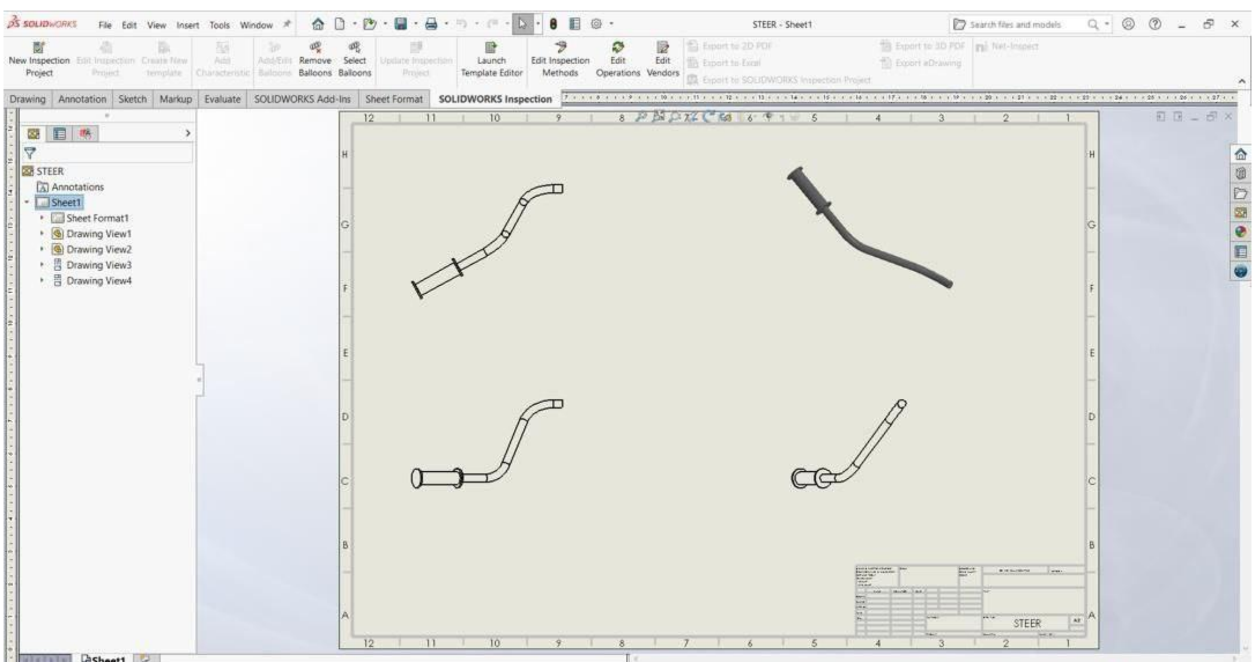


Figure 24: steer

Spring

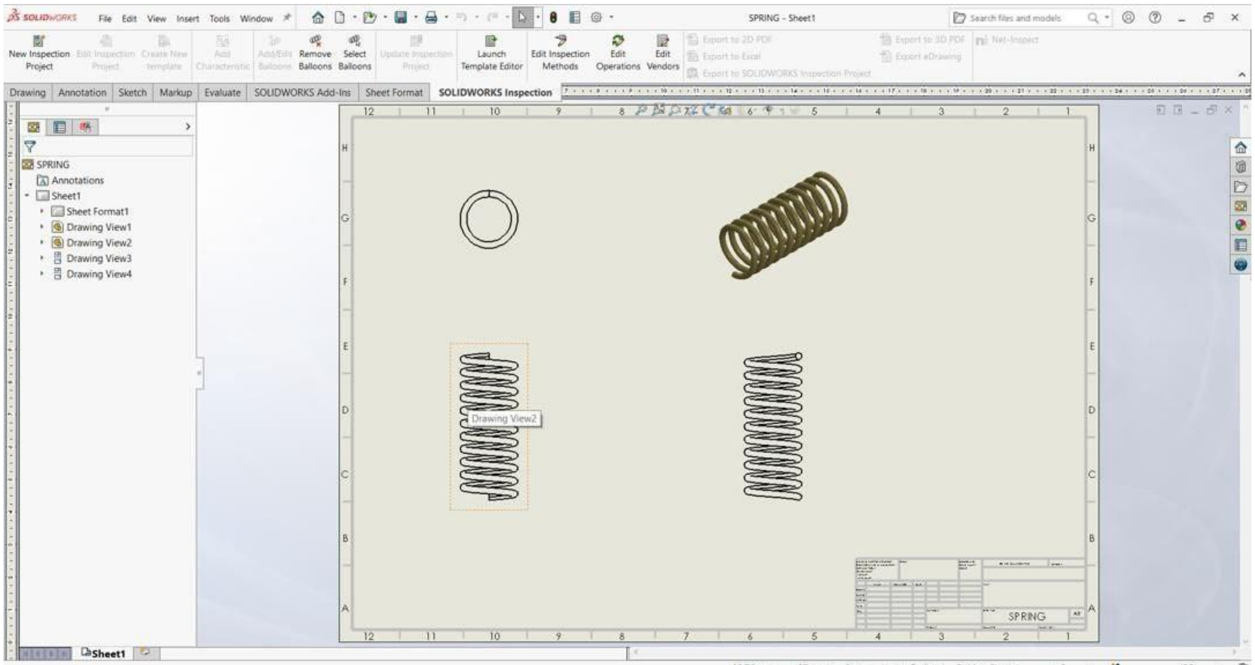


Figure 25: spring

4.3.2 Indented Bill of Materials

A more useful tool for facility design and assembly line and work cell architecture is the indented bill of material. The same fundamental details are provided by an indented bill of materials as by a components list. However, the product's hierarchical structure is presented in the indented bill of material, which lists every assembly, subassembly, and the necessary or inferior elements of each assembly or subassembly.

Table 10: Indented Bill of material

LEVEL	PART NUMBER	PART NAME	QUANTITY PER PART	MAKE OR BUY
0		Cargo Tricycle	1	Make
.1	A1	Front-wheel assembly	1	Make

..2	SA1	Shock absorber	2	Make
...3	14	Suspension spring	2	Buy
...3	22	Suspension body	2	Buy
..2	SA2	Wheel assembly	1	Make
...3	12	Tire	1	Buy
...3	13	Rim	1	Buy
...3	21	Fenders	1	Buy
..2	SA3	Steering assembly	1	Make
...3	27	Front reflector	1	Buy
...3	5	Headlamp	1	Buy
...3	17	Handlebar	2	Buy
...3	6	Rear view mirror	2	Buy
...3	9	Combined instruments	1	Buy
...3	4	Front turn signal	2	Buy
.1	A2	Seat assembly	1	Make
...3	20	Seat cushion	1	Buy
...3	1	Fuel tank	1	Buy
...3	2	Starting lever	1	Buy
...3	3	Rear braking pedals	1	Buy
.1	A3	Engine assembly	1	Make
...3	16	Engine	1	Buy
...3	11	Cooling Fan	1	Buy
...3	23	Battery	1	Buy
...3	8	Air cleaner	1	Buy
...3	7	Exhaust muffler	1	Buy
...3	19	Axle	1	Buy
...3	25	Shaft	1	Buy
.1	A4	Cargo container assembly	1	Make
...3	18	Back door	1	Make
...3	24	Tail light	2	Buy
...3	10	Toolbox	1	Make
...3	29	Container	1	Make
.1	A5	Rear wheel assembly	1	Make
..2	SA4	Shock absorber	4	Make

...3	14	Suspension spring	4	Buy
...3	22	Suspension body	4	Buy
...3	15	Leaf spring	2	Buy
..2	SA5	Wheel assembly	2	Make
...3	12	Tire	2	Buy
...3	28	Back reflector	2	Buy
...3	13	Rim	2	Buy
...3	21	Fenders	2	Buy
.1	A6	Chassis assembly	1	Make
...3	26	Vehicle frame	1	Make

4.3.3 Assembly Chart

The tricycle's assembly chart is depicted in the diagram below. Main Assembly A1 is formed by painting and mating the subassemblies SA1 (metal case subassembly) and SSA1 (metal frame subassembly) with the liner.

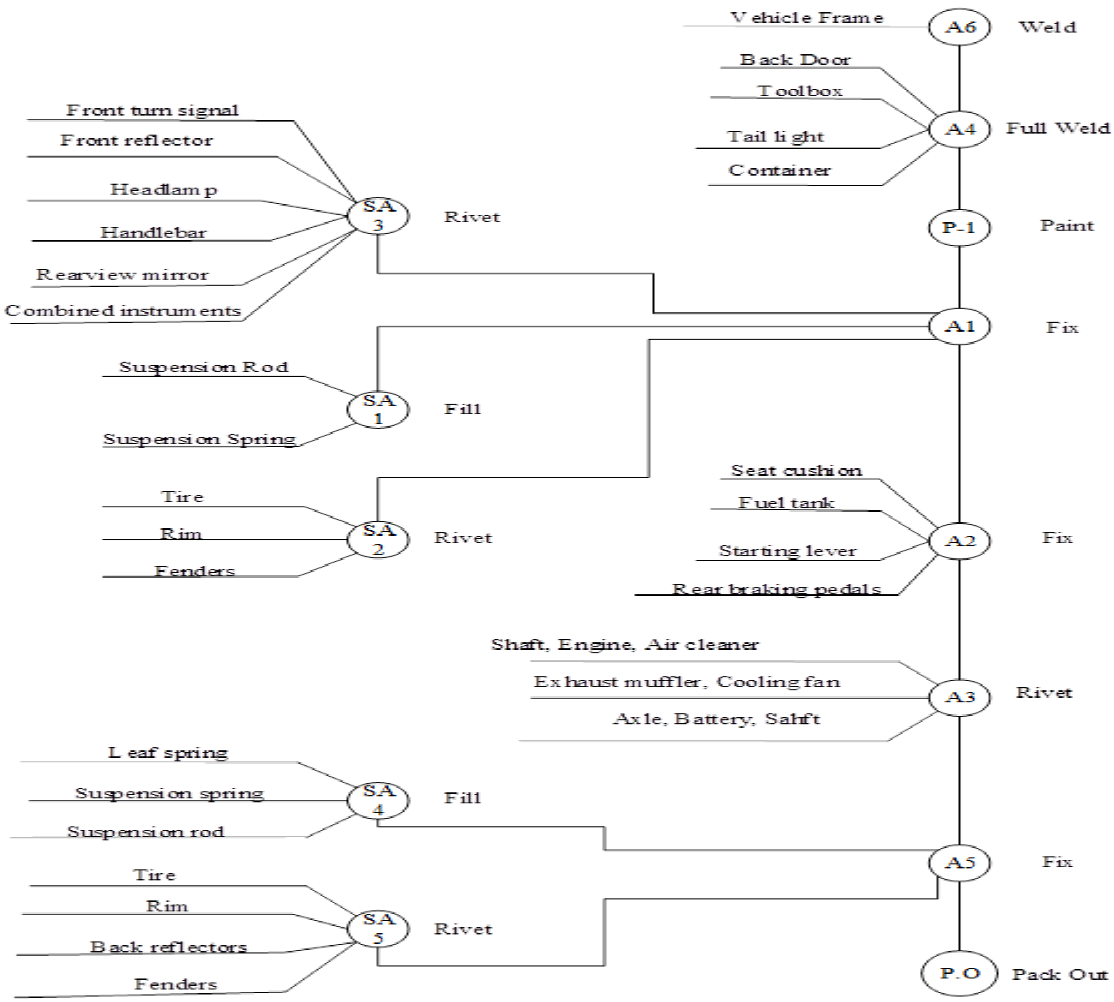


Figure 26: Assembly chart

4.3.4 Operations Chart

The operation chart is a graphical and symbolic representation of the manufacturing operations used to produce a product. The operation chart illustrates only the value-adding activities in the manufacturing process.

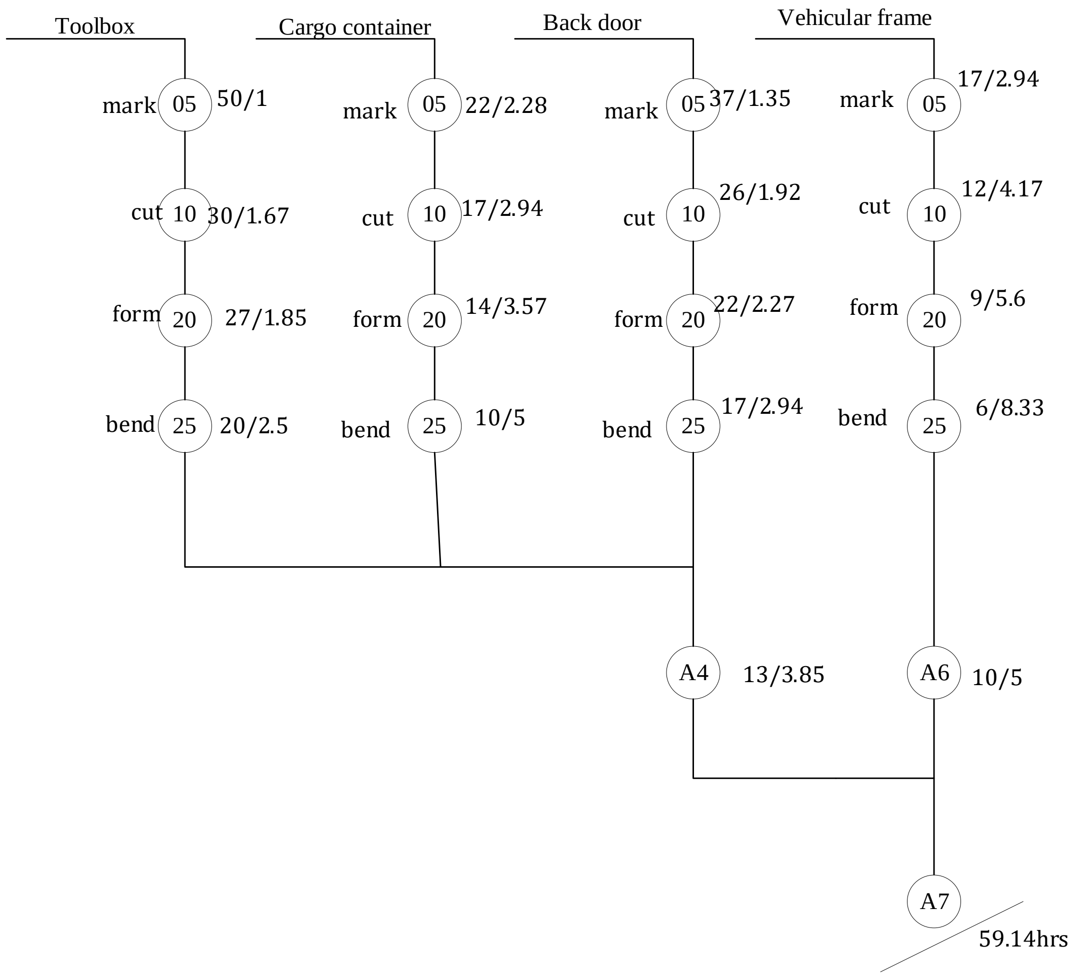


Figure 27: Operations chart

4.3.4.1 Number of Employees

The configuration of people, machinery, and material handling equipment on the shop floor makes up the plant layout, thus it's important to figure out how many workers are required to reach output targets.

From the operations chart above:

Total time needed $= 59.14\ hours.$

But Efficiency $= 0.85$

Actual hours needed$= \frac{59.14}{0.85} = 69.576 \approx 70 hours$

Number of employees needed= $\frac{69.576}{8hrs\ per\ employee} = 8.697 \approx 9 employees$

Number of employees needed= 9 *employees*

4.3.5 Summary of Route Sheet

The matrix below represents the summary of route sheet for the metal stove parts. The standard times were obtained on-field by measuring the time it takes a skilled operator, working at a normal pace and doing a specific task to perform a task.

Table 11: Summary of route sheet

PART NAME	CHASSIS	CARGO CONTAINER	FENDERS	TOOLBOX	BACKDOOR
	TIME STANDARD (min/unit)				
PARTS/UNIT	1	1	3	1	1
Pneumatic screw gun	-	-	-	-	23.1
Electric bending machine	26.91	20.70	15.75	15.45	19.80
Arc welding machine	186.30	89.10	31.50	30.90	84.00
Oxy- Acetylene welding machine	178.20	93.15	-	31.5	79.20
Spraying gun	51.75	49.50	47.25	46.35	48.60

Standard time= Normal time × (1+ PFD allowance), PFD allowance is personal, fatigue and delay allowance.

Normal time= Observed time × speed rating factor.

Rating factor: 90% (working slower than normal time), 100% (is normal time) and 110% (working faster than normal time)

Standard time of electric arc welding for chassis= (180) (0,9) × (1+0.15)= 186.30 minutes/unit

4.3.6 Takt Time Calculation

Every machine and activity need to maintain a specific speed in order to reach the production target or the current production volume. The term "plant rate," "production rate," or "takt time" refers to the rate of output. It is the speed at which various parts, processes, activities, and so forth must travel in order to reach the production target.

Takt time:

Production requirement = 1 unit per shift

Production shift $= 8\ hours\ = 480\ minutes$

Scrap rate $= 12\%$

Production requirements considering scrap rate:

$$\frac{20}{1-0.12} = 22.72727\ = 23\ units$$

Downtime $\equiv 60\ minutes\ for\ break$

Time available for production $= 480\ -60\ = 420\ minutes$

Efficiency $= 85\%\ = 0.85$

Effective time $= 0.85\ \times 420\ = 357\ minutes$

Takt time $= \frac{357\ minutes}{20\ unit}\ = 17.85\ minutes\ per\ unit.$

$\underline{\boldsymbol{Takt\ time\ = 17.85\ minutes\ per\ unit.}}$

Operation Number	Time Standard	Number of Stations	Rounded Up	Average Time	% Loaded	Hours per Unit	Pieces per Hour
A1	20	1.12	2	10	59	0.00792	126
A4	17	0.95	1	17	100	0.01583	63
A2	22	1.23	2	11	65	0.00792	126
A5	25	1.40	2	12.5	74	0.00792	126
A3	12	0.67	1	12	71	0.01583	63
A6	19	1.06	2	9.5	56	0.00792	126
Total	115		10				

Line Efficiency = $\left(\frac{115}{10(17)}\right) \times 100\% \ = 67\%$

Number of machines = $\frac{Time\ Standard}{Takt\ Time}$

Average Time = $\frac{Time\ Standard}{Rounded\ up}$

Percentage (%) Loaded = $\frac{Average\ Time}{Highest\ Average\ Time}$

Hours per Unit = $\frac{1}{Hours\ per\ Unit}$

4.3.7 Machine Requirements

Table 12: Machine requirements

PART	1	1	3	1	1	MACHINE
PART NAME	CHASSIS	CARGO CONTAINER	FENDERS	TOOLBOX	BACKDOOR	TOTAL
MACHINE						
Pneumatic screw gun	-	-	-	-	1.29	1.29
Electric bending machine	1.50	1.16	2.65	0.87	1.11	7.29
Arc welding machine	10.42	5.00	5.29	1.73	4.71	27.15
Oxy-Acetylene welding machine	9.98	5.21	-	1.76	4.43	21.38
Spraying gun	2.30	2.77	7.94	2.60	2.72	18.33

Number of machines required by each part is calculated as $\frac{Standard\ time}{takt\ time} \times Quantity.$

For example: number of electric bending machine required for chassis is:

$$\frac{26.91}{17.85} \times 1 = 1.5\, machines$$

Total machines required= *1.29+7.29+27.15+21.38+18.33=75.44 machines.*

4.3.8 Activity Relationship Diagram and Worksheet

The activity cycle diagram which shows the closeness relationship between departments or workstations is shown below. Departments that have absolute importance of closeness are indicated 'A', having about 5% of the total relationship as per the pareto table. Departments have "Especially Important" relationship are assigned 'E', "Important" relationships are assigned 'I', "Ordinarily Important" are assigned 'O', "Unimportant" closeness relationship between departments are assigned "U" and "undesired" relationships are assigned "X".

4.3.8.1 Activity Relationship Diagram

Key:

A – Absolutely necessary.

E – Especially important.

I – Important.

O – Ordinary important.

U – Unimportant

X – Closeness undesired.

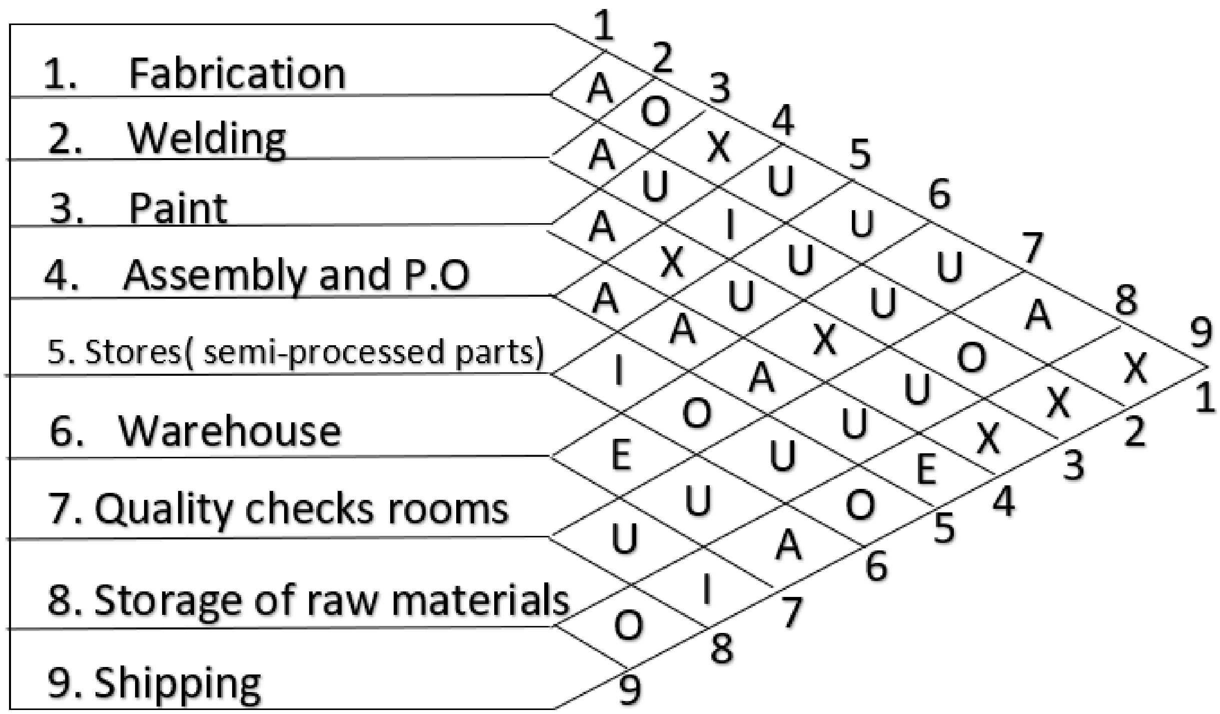


Figure 28: Activity relationship chart

4.3.8.2 Worksheet

Table 13: Worksheet.

ACTIVITIES	A	E	I	O	U	X
1. FABRICATION	2,8			3	5,6,7	4,9
2. WELDING	1,3		5	8	4,6,7	9
3. PAINT	2,4			1	6,8	5,7,9
4. ASSEMBLY AND P. O	3,5,6,7	9			2,8	1
5. STORES (SEMI-PROCESSED PARTS)	4		2,6	7,9	1,8	3
6. WAREHOUSE	4, 9	7	5		3,2,1,8	
7. QUALITY CHECKS ROOM	4	6	9	5	8,2,1	3

8. STORAGE OF RAW MATERIALS	1			2,9	7,6,5,4,3	
9. SHIPPING	6	4	7	5,8		1,2,3

4.3.9 Dimensionless Block Diagram

The dimensionless diagram mimics the closeness relations shared by departments. This diagram does not consider the dimensions of the layout and it's drawn using block plane figures with the department being close to another who shares a "closeness" relationship.

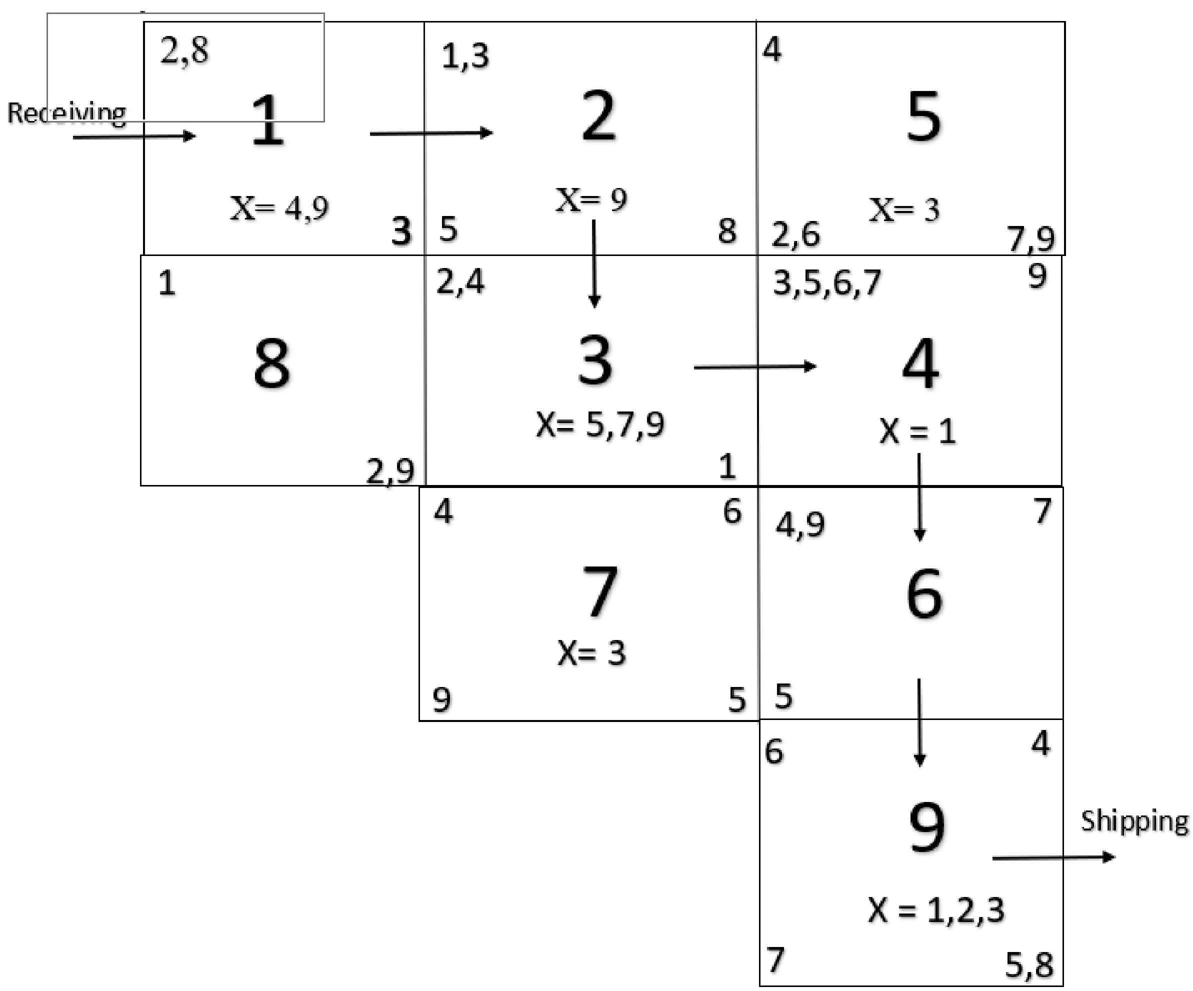


Figure 29: Dimensionless Block Diagram

4.3.10. Space Determination

The space determination procedure for most production departments starts with the workstation design. From each workstation layout, the length and width are measured to determine the square footage of each station.

4.3.11 Space Determination Diagrams

RECEIVING

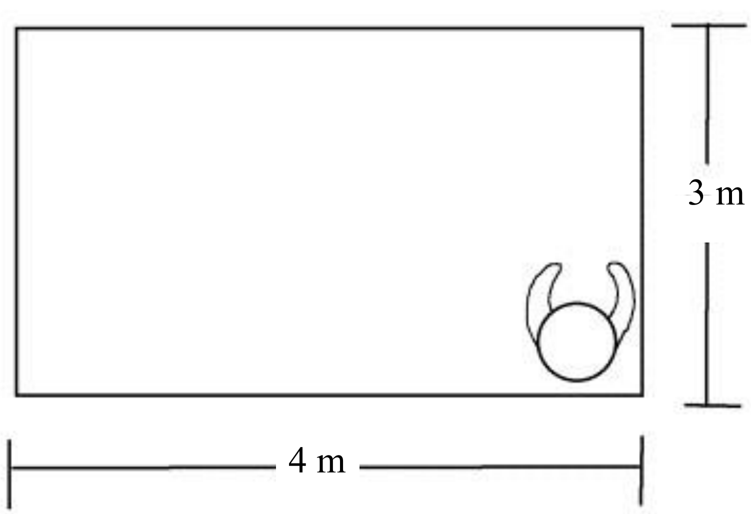


Figure 30: Receiving

MARKING AND CUTTING

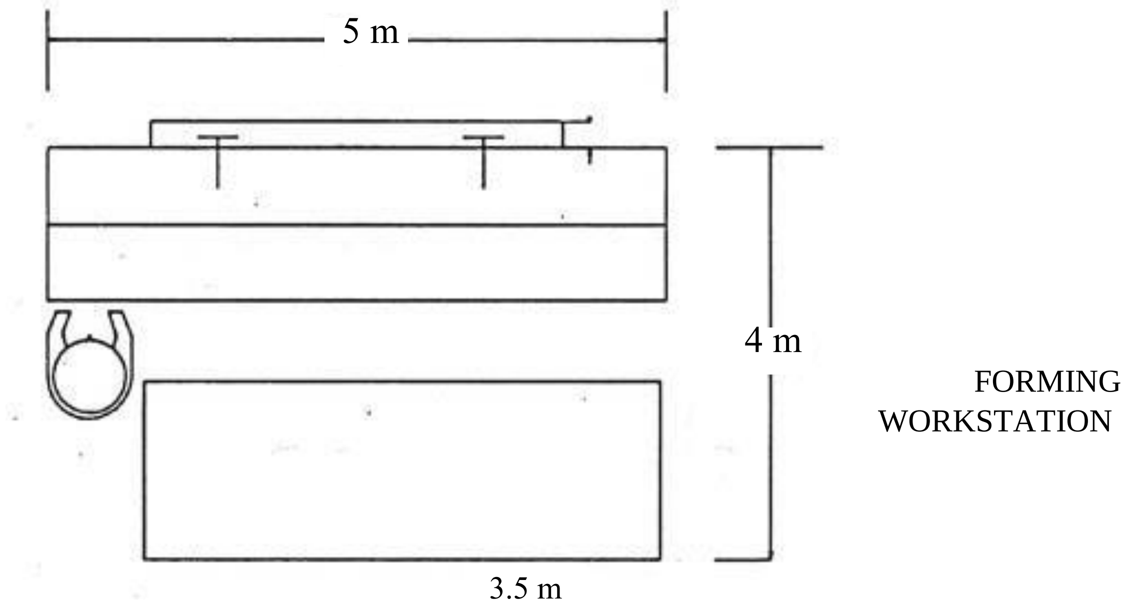


Figure 31: Marking and cutting

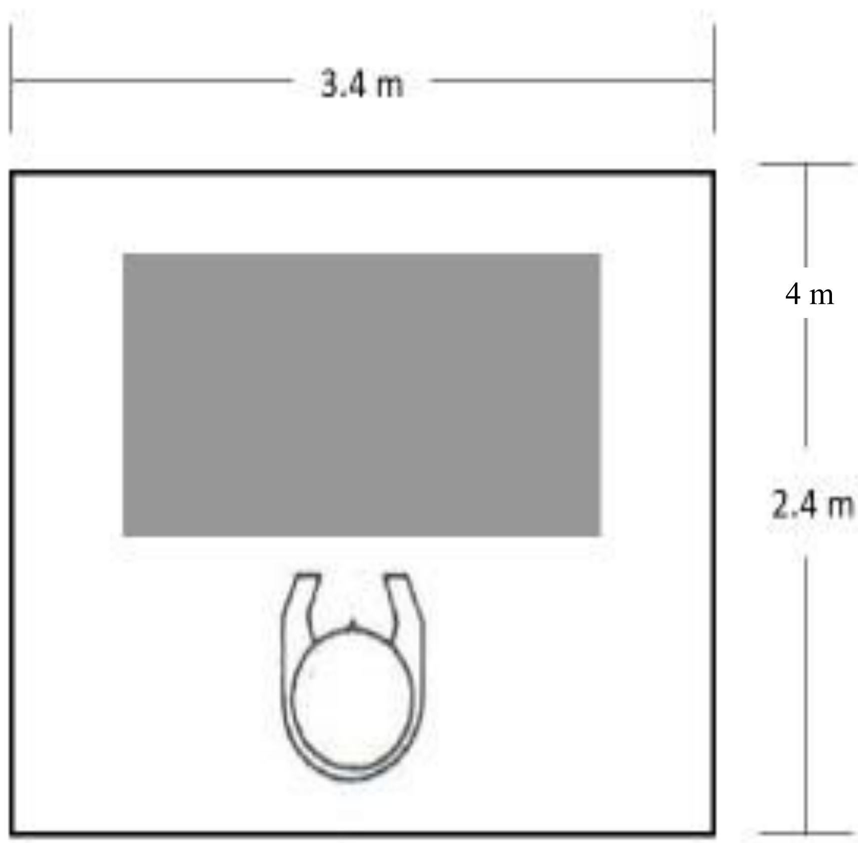


Figure 32: Forming station

BENDING WORKSTATION

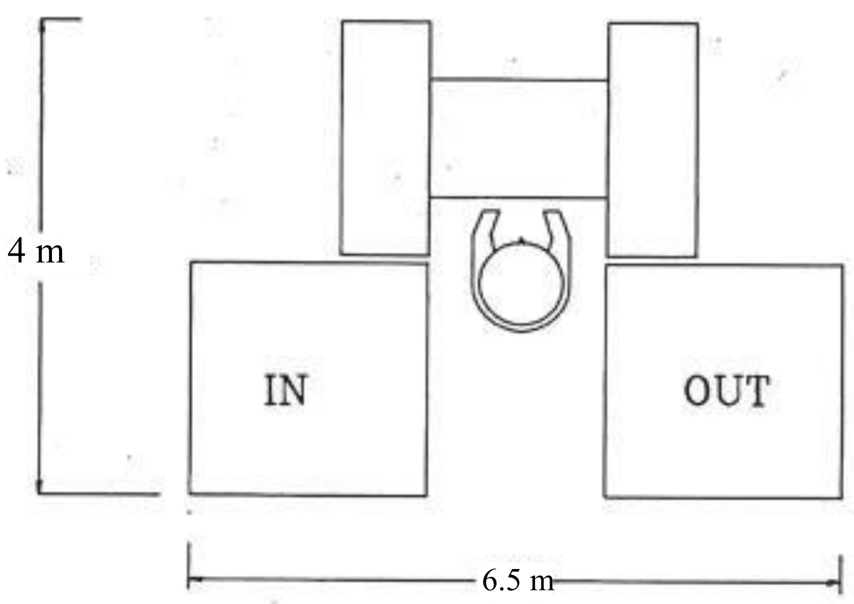


Figure 33: Bending workstation

WELDING WORKSTATION

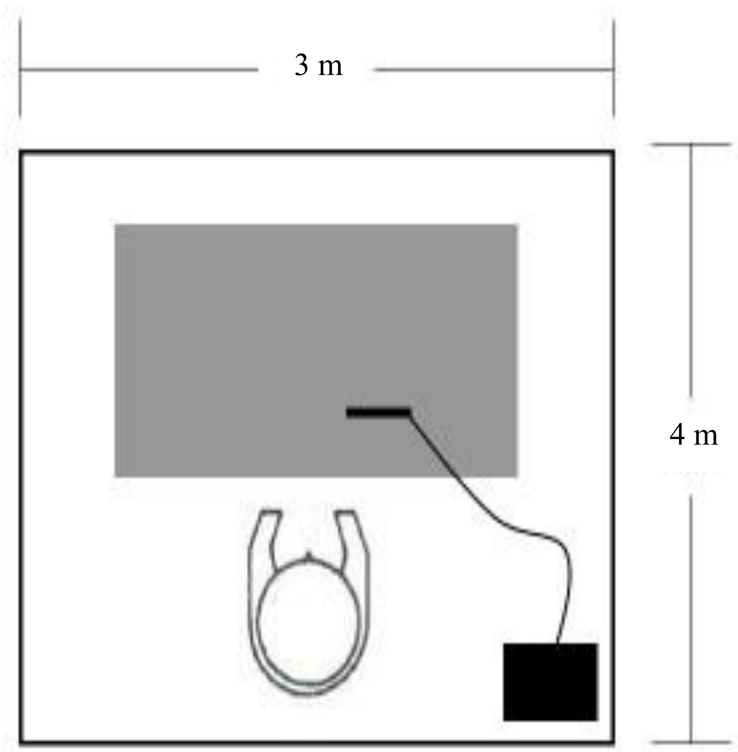


Figure 34: welding workstation

SHIPPING

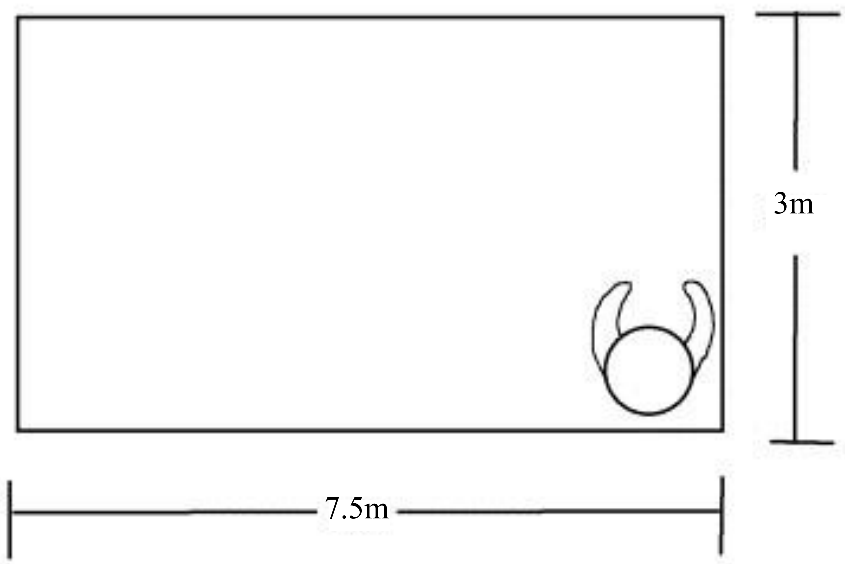


Figure 35: shipping

4.3.12 Space Determination Matrix

Table 14: Space determination matrix

STATION	LENGTH(m)	WIDTH(m)	AREA(m)	NUMBER OF STATIONS	TOTAL AREA(m^2)
Receiving	4	3	7.0	1	7.0
Marking and cutting	3.5	2.6	9.1	1	9.1
Forming	2.5	4	10.0	1	10.0
Bending	6.5	4	26.0	1	26.0
Welding	3	4	12.0	1	12.0
Spraying	4	6	24.0	1	24.0
Assembly plant	18	36	648.0	1	648.0
Warehouse(shipping)	7.5	3	22.5	1	22.5
Total = 758.6m^2 $\times$ 150% **=1137.9m^2** 50% allowance for aisle space					

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