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Production Layout Optimization using CORELAP and CRAFT Algorithm for Job shop Process Industries (A Case of Fasil Engineering Company (FEC), Bahir Dar, Ethiopia)

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BAHIR DAR UNIVERSITY
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FACULTY OF MECHANICAL AND INDUSTRIAL ENGINEERING

MASTER OF SCIENCE IN PRODUCTION ENGINEERING AND MANAGEMENT

MSc. Thesis on:

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By

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Advisor Name: Bereket Haile (Ph.D)

September 2021

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A thesis submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Production Engineering and Management

Advisor Name: Bereket Haile (Ph.D)

September 2021

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DECLARATION

This is to certify that the thesis entitled "Production Layout Optimization using CORELAP and CRAFT Algorithms for Job Shop Process Industries: A Case of Fasil Engineering Company," is submitted in partial fulfillment of the requirements for the degree of Master of Science in Production Engineering and Management under the Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I received during the course of this investigation has been duly acknowledged.

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Approval of thesis for defense results

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of Student	Signature	Date
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As members of the board examiners, we examined this thesis entitled "Production Layout Optimization using CORELAP and CRAFT Algorithm for Job shop Process Industries" (A case of Fasil Engineering Company) by Belachew Mebrat. We hereby certify that the thesis is accepted for fulfilling the requirement for the award of the degree of Master of Science in the Production Engineering and Management in the Faculty of Mechanical and Industrial Engineering.

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LIST OF ABBREVIATIONS

ALDAP: - Automated Layout Design Planning

ARC: - Activity Relationship Chart

COFAD: - Computerized Facilities Design

CORELAP: - Computerized Relationship Layout Planning

CRAFT: - Computerized Relationship Allocation of Facilities Technique

FEC: - Fasil Engineering Company

FLD: - Facility Layout Design

FLP: - Facility Layout Problem

M/C: - Machine

MCRAFT: - Micro Computerized Relationship Allocation of Facilities Technique

PLANET: - Plant Layout Analysis and Evaluation Techniques

PR: - Placement Rating

SLP: - Systematic Layout Planning

TCR: - Total Closeness Rating

TMHC: - Total Material Handling Cost

WPV: - Weighted Placement Value

ABSTRACT

The purpose of the study is to design an effective production layout considering the operation process, variety, and volume of products to improve interrelationships, minimize the overall distance traveled, reduce handling time, enhance production volume, and optimize the total material handling cost. Fasil engineering company was selected as a case study because the manufacturing process had been followed a job-shop process, but the machines were installed without considering the product operation process. As a result, workers have traveled longer distances and consumed high material handling costs rather than handling time and production capacity. The study achieved both adjacency and distance objectives using CORELAP and CRAFT algorithms as a method. First, CORELAP was applied for the maximum interrelationship between departments using a total closeness rating. Then, CRAFT was applied for minimum travel movement by swapping two departments with common boundaries. Both primary and secondary data collection used, such as three-year production volume, initial layout, department dimension, number of available departments, and operation process for each product have been collected. However, the collected data and the analysis are presented in from to relationship charts, relationship charts, tabular and operation process charts. The current and the proposed layout have been designed using solid work software. Indeed, the existing production layout was evaluated in the CRAFT Excel Add-in, then CORELAP followed by the CRAFT excel add-in was developed to optimize the production layout. In addition, a simulation model was developed using ProModel version 7.5 for both the existing and proposed layouts to evaluate the material handling time and production capacity. As a result, the material-handling costs between the existing and the proposed layout were reduced by 74.32% per month, while the total distance traveled was minimized by 22.1%. In addition to this, the production capacity increased in the proposed layout, and the average handling time was saved by 162.03 minutes per month. Those results have been optimized the overall operational efficiency, manufacturing lead-time and productivity effectivity. Therefore, the research concludes that combining two algorithms have optimized the production layout effectively.

***Key words**: CORELAP, CRAFT, ProModel Simulation, Total Material Handling Cost, Distance Traveled, Handling Time, and Production Capacity.*

CHAPTER ONE

INTRODUCTION

1.1 Background and Justification of the Study

In this era of globalization, competition is ever more intense in the manufacturing and service industries. Hence, manufacturing companies have to compete not only locally but also on a global basis. Therefore, reducing manufacturing costs without sacrificing product quality is vital for the survival of manufacturing companies in a global market. Facility layout design, lean management, total quality management, and operation management are some of the approaches that are proven to enhance operational efficiency, improve quality, reduce waste, minimize total manufacturing costs, improve utilization of resources, and keep employees safety (Belachew, Lijalem, Teshale, Gedefaye, & K.Balasundaram, 2020). Facility layout is a systematic arrangement of desired physical facilities and the flow of materials in a well-organized way for better operational efficiency in manufacturing and service industries (Suhardini & Rahmawati, 2019). Similarly, production layout is the location of departments, machines, equipment, humans, and everything needed based on production routines and department functions to achieve minimum production time, maximum workflow, minimum distance traveled, and effective operation in the manufacturing sector (K.Balasundaram, Ashenafi, & Abera, 2016).

Although, the main factor for production layout is improper facility arrangement to operate the required operations because this enhances the total manufacturing cost (Ojaghi & Khademi Alireza, 2015). Moreover, a good plant layout considers different factors, such as operation routine, production volume, machinery, labor, material handling, and product variety for more efficient operation, reducing handling time, reducing traveling distance, increasing production capacity, reducing production time, allowing operation flexibility, effective utilization of manpower, providing workers with safety or comfort, and decreasing material handling costs (Okpala & Chukwumuanya, 2016). However, the placement of physical facilities in an organized flow contributes to the overall operational efficiency and minimizes total operating expenses by 50% (Kulkarni, Bhatwadekar, & Thakur, 2015; Rajesh, Naidu, & Kumar, 2016). Furthermore, a well-organized facility layout creates suitable transportation paths and improves overall operational efficiency.

As Rajesh, Naidu, and Kumar (2016) discussed that there are different techniques in layout design however heuristic method is major approach to find solutions for facility layout problems (FLP) using construction and improvement algorithms. The construction algorithm starts from scratch to maximize interrelationships between departments using total closeness rating (TCR). Automated Layout Design Planning (ALDEP) and Computerized Relationship Layout Planning (CORELAP) are the main techniques for construction algorithms. However, the improvement algorithm starts from the initial layout to reduce travel movement by swapping two or more departments. The Pairwise exchange method, MCRAFT, and Computerized Relative Allocation of Facilities Technique (CRAFT) are types of improvement algorithm, but CRAFT is the most popular method (Priyaranjan Mallick, 2019). Consequently, improvement of plant layout using the CRAFT algorithm reduced production time per product by 8.95% and reduced material handling costs by RP 47,403.90 annually (Rajesh et al., 2016). As Suhardini and Rahmawati (2019) stated computerized layout design has decreased manufacturing lead time by 15% concerning the existing layout using ALDAP over CRAFT techniques. In addition to the heuristic algorithm, the simulation technique is also a method to optimize facility layout design (Zuniga, Moris, Syberfeldt, Fathi, & Rubio Romero, 2020).

Different researchers have been studied to solve facility layout problems, but they have not followed the rule of thumb to assign the department relationship rating (A, E, I, O, U, and X) and have not been placed departments in the placement rating (PR) procedure, but better solutions have been obtained in placement rating. Although, researchers have developed solutions using improvement or construction algorithms independently, combining two algorithms improves the performance of the layout effectively.

Metal industries are a backbone for economic development by producing the required products for the required demand (Dametew, Ketaw, & Frank, 2019). Fasil Engineering Company (FEC) is a job shop process industry that are produced a variety of products in low volume. Some of the products are water tankers, surface steel casings, j-bolts, doors, and windows, etc. It has sixteen departments to perform the required operations when customers order the products. However, departments have not been installed considering the operation process, product volume, and facility movement.

The study emphasis evaluating existing layout performance using the CARFT algorithm, then developing the proposed layout using CORELAP followed by CRAFT Excel Add in to maximize adjacency score and minimize distance traveled. Moreover, simulation models were developed to analyze the material handling time and production volume. Input data for this study is an initial layout, each department area, total production area, three-year customer demand, and the operation process. The Activity Relationship Chart (ARC) develops based on the operation process, production demand, and facility movement. The study focuses on proposing a new production layout for job shop process industries using two algorithms to improve the layout performance in handling cost, handling time, production capacity, and traveled distance.

1.2 Problem Statement

Systematic, methodical arrangements of physical facilities are vital in improving operational efficiency in manufacturing and service industries. However, researchers have developed solutions for facility layout problems (FLP), but the placement of the facilities using the placement rating (PR) procedure has obtained a better placement position (Belachew et al., 2020). The challenge of determining the best alternative layout in a workstation is one of the elements that has a great influence on job shop process industries (Okpala & Chukwumuanya, 2016). However, the reason for redesigning the production layout in job shop process industries is due to changes in production volume, product variety, operation process, and frequently cross-over products between different departments on the production floor. This has a significant impact on operation efficiency, manufacturing costs, work in process, manufacturing lead times, the flow of product, and distance traveled between each department (Rajesh et al., 2016).

Fasil engineering company is manufacturing a variety of products in low volume. However, the workers have traveled 45.5 meters from the raw material stored to the cutting department while 122 parts/products flow per month, and 37.5 meters from the raw material stored to the circular saw department, but 88 parts/products flow per month. Additionally, 26 meters traveled from the assembly department to the welding department, but 114 parts/products flowed per month. Also, 12.5 meters traveled from the drilling section to the finishing department, but 91 parts/products were transported per month (Vaibhav Nyati, M. D. Jaybhaye, & Sardar, 2017). As a result, this excessive transportation distance has a great contribution to operational performance and material handling costs.

The parts/products handling time is a factor for production capacity in the facility layout. However, minimizing the parts/product handling time facilitates operation efficiency. Although the material handling time depends on the traveled distance, since there is a high traveled distance in the fasil engineering company.

The manufacturing process of a case company is a job-shop process. However, the departments are located without considering the operation process interrelationships between departments since a variety of products are produced. This influence has an impact on the total distance traveled, material moving time, and material handling costs. (Virendra, 2017). Finally, this paper is intended to address the above-mentioned problems by developing an optimal layout using the CORELAP and CRAFT algorithms.

The study attempts to answer the following research questions to develop an optimal production company.

1. What types of products are manufactured in the case company and its operation process?
2. How many departments are availabled and its required area?
3. What types of material handling equipments are used and its cost?
4. What types of equipments and how many humans are used to dissimilate and reinstall departments with its cost required?

1.3 Objective of the Study

The research has both general and specific objectives to optimize production layout

1.3.1 General Objective

The main objective of the study is to optimize the production layout for Fasil Engineering Company using CORELAP and CRAFT algorithms.

1.3.2 Specific Objectives

- To identify the actual layout and process flow of the production floor
- To analyze and evaluate the existing production layout
- To propose a new production layout using two algorithms; CORELAP and CRAFT
- To develop a simulation model for both the existing and the proposed layout
- To conduct a cost-benefit analysis between the existing and the proposed layouts

1.4 Scope and Limitation of the Study

Even though the company has different sections, the research focused on the production floor. There are different types of algorithms for solving layout problems. Each of them possesses their own distinguishing characteristics. However, both the CORELAP and CRAFT algorithms follow and the simulation model also measures handling time and production capacity. The goal of the research is to show the reasons, objectives, and steps of the redesign layout and how to improve it again for the job shop process industries in Ethiopia. Moreover, to show the aid of algorithms in the production layout problems, the case was taken to a fasil engineering company. Other companies can follow a similar procedure to design better production layout.

The study is limited to job shop process industries because the back and forth movement of workers is higher since the variety of products within different processes is performed. Developing an optimal layout is difficult since various variables change frequently, but get a near to optimal solution. Determination of the number of products produced is difficult to collect the required data and to obtain the final solution because of the variety of products produced.

1.5 Significance of the Study

Optimizing production layout benefits the company and its customers as well. Since the aim of any job shop process industry is to increase its profit, sales volume, while creating a convenient workplace for its workers, and satisfying the customer should be given the highest priority. The study uses a guideline to design an effective production layout for job shop process industries. The research predicts direction for future researchers since there are few studies in the area. It would offer a comprehensive starting point for more specific productive research for Ethiopian job shop industries and could be use a secondary source for researchers to solve manufacturing and service industry facility layout problems. Furthermore, other job shop process industries are taken as a benchmark for effective workflow and reducing production costs, improving operation efficiency, keeping workers from fatigue, reducing material handling costs, improving material and worker flow, minimizing product movement time, and increasing production volume will satisfy unmet customer demand.

1.6 Research Organization

The research has five main chapters which contain the following descriptions. In chapter one, the introduction part, a background of the study, statement of the problem, research objectives, significance, scope, and limitations have been included. Chapter two is composed of a review of the relevant literature. Various journal articles and conference papers have been reviewed to understand the existing studies and to identify the research gaps. Chapter three contains the details of the research methodology and the steps used to gather and analyze the data from which the findings are drawn. Chapter four contains the data collection, analysis, results, and discussion to evaluate the existing production layout performance and to discuss the findings with relevant literature support. Finally, chapter five develops conclusion, recommendations, and mentions future research areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature section explained relevant literature about facilities layout to understand layout designing procedures and to identify the researchers' gap. Scopus, science direct, web of science databases are used to extract literatures for this study. Literature review includes plant layout, classification of plant layout, objectives of plant layout, the importance of plant layout, stages of systematic layout planning, facility layout design procedures, simulation models, a summary of key literature, and literature gaps are discussed.

2.2 Plant Layout

Plant layout is the systematic physical arrangement of facilities such as machines, equipment, human beings, and workstations in manufacturing and service industries which are interrelated to the production process (Kovács & Kot, 2017). However, the challenges of plant layout design are dynamic behavior, product variety, lack of integration, randomness, and standard procedures. These challenges combined exploit the complexity of facility layout design (Zuniga et al., 2020). Placement of production facilities in an effective routine has a major impact on manufacturing costs, manufacturing lead time, work in process, and productivity (Rajesh et al., 2016). However, the researchers stated effective layout design have been measured where business performance improvement can be realized and improves material handling costs, flexibility, traveling distance, manufacturing lead time, handling time, and overall company efficiency by 50% of total operating expense. Moreover, production resources, including energy, raw materials, labor, machines, equipment, and other facilities, are limited, hence effective use of resources has a major influence on productivity (Kovács & Kot, 2017). As Maulida Hakim and Istiyanti (2015) defined reasons for plant layout design to minimize movement time, improve adjacency score and reduce material handling costs. Finally, effective plant layout design improves the layout performance since industries compute globally.

2.3 Types of Plant Layout

Plant layouts have four main types on the production floor, such as product (flow shop), process (job shop), fixed position, and group technology layout (Bogert, Edwards, Jalali, & Aqlan, 2018). Although process, product, and fixed layout are defined based on the type of workflow, group layout is widely accepted and frequently considered as a hybrid layout (Okpala & Chukwumuanya, 2016).

2.3.1 Product (Flow Shop) Layout

Product layout is a line layout continuously or repetitively when the processes are located according to the operation sequence in a series process. Hence, facilities are organized according to the product sequence on a fixed path, and resources are arranged properly to minimize material movement for the successive manufacturing operations (Belachew et al., 2020; Kulkarni, Bhatwadekar, & Thakur, 2015). Moreover, product layouts are used for high production volumes and a low variety of products (Kovács & Kot, 2017). A Diagram of the product layout is shown in Figure 2.1.

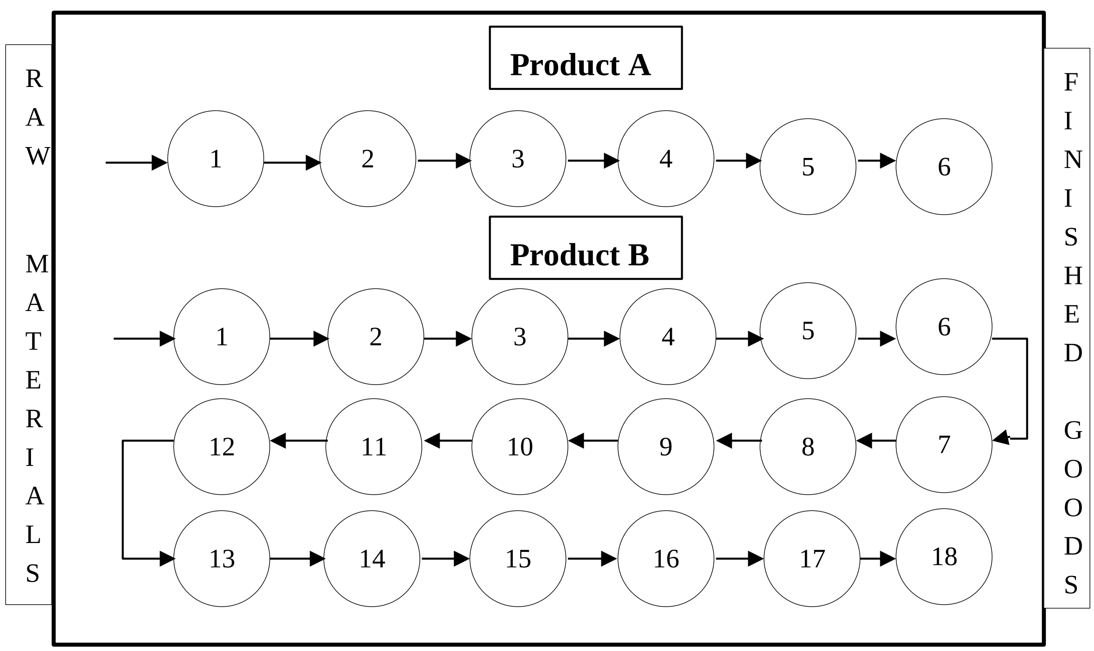

Figure 2. 1 Product (Flow Shop) Layout (Okpala & Chukwumuanya, 2016)

2.3.2 Process (Job Shop) Layout

As Belachew et al. (2020) stated that job shop layout machines are grouped according to the function of machine centers. Since process layout was performed when producing a high variety of products with a low volume of customized products were manufactured

(Kovács & Kot, 2017). Besides this, individual products are routed through various machine centers to obtain the required process designed to facilitate processing items or provide services that present a variety of processing requirements. As Kulkarni et al. (2015) explained that different items have been moved from one workstation to the other to allow operation routines. As a result, process layout has been considered the following characteristics: more flexible, frequent product change over, highly skilled employees, delayed lead time, high work in process, and general-purpose equipment needed (Okpala & Chukwumuanya, 2016). The process layout is shown in Figure 2.2.

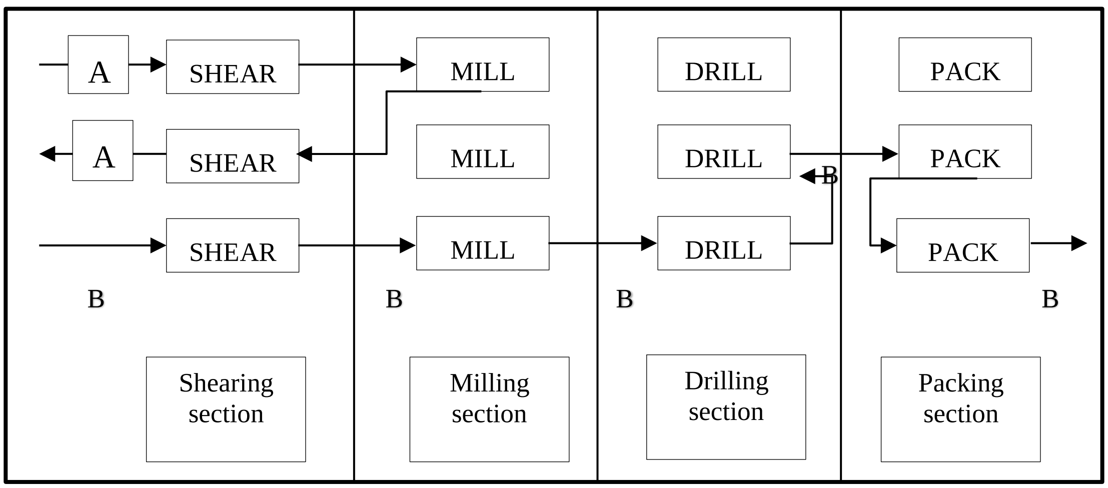

Figure 2. 3 Process (Job shop) Layout (Okpala & Chukwumuanya, 2016)

2.3.3 Fixed Position Layout

A fixed layout is ordinarily available in manufacturing industries that produce large-size products, such as manufacturing of an electrical generator, construction building, and repair of a large airplane. However, machines implementing operations must come to the product rather than the product moving to the machine (Okpala & Chukwumuanya, 2016). Furthermore, a fixed-position layout is used in project production for individual products (Kovács & Kot, 2017). In a fixed layout, production facilities like machines, humans, energy, raw materials, etc are moved to operate on the product (Kulkarni et al., 2015). The Fixed-position layout is shown in Figure 2.3.

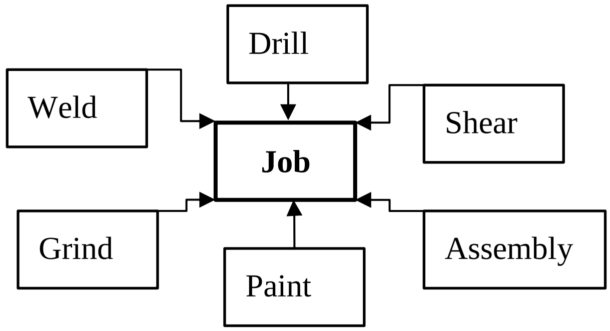

Figure 2. 5 Fixed Position Layout (Okpala & Chukwumuanya, 2016)

2.3.4 Group Technology (Cellular) Layout

Group layout compromises between product and process layout. Since machines are grouped into cells in the process, families of similar parts. These cells are important to place on the factory floor (Kulkarni et al., 2015). It is used when production volumes for individual products are not sufficient to justify product layout, but grouping such products into families (cells) can alleviate the problem. As Kovács and Kot (2017) proposed that group layout is suitable for medium volume and a wide variety of products manufactured as shown in Figure 2.4.

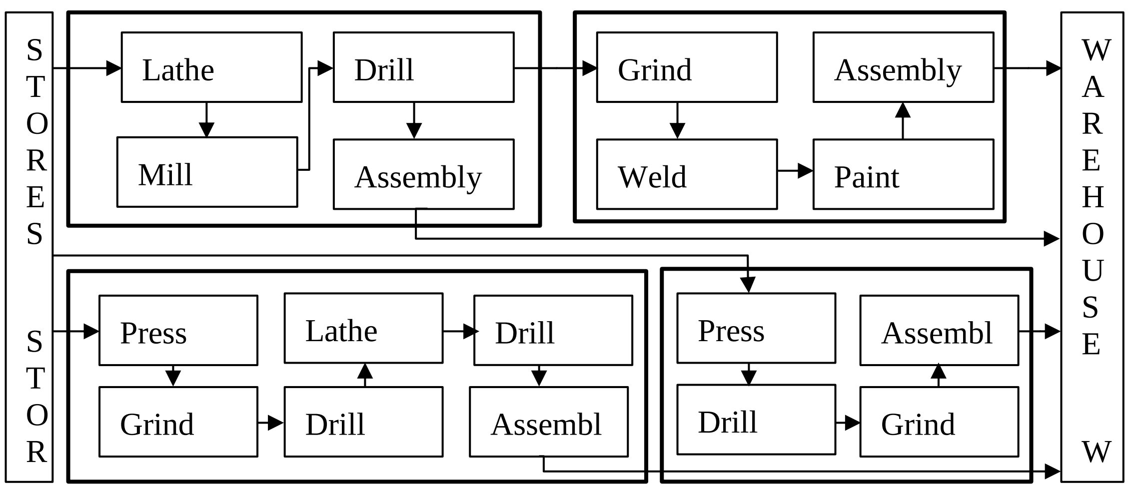

Figure 2. 7 Group (Cellular) Layout (Okpala & Chukwumuanya, 2016)

2.4 Objectives of Plant Layout

As Vandit Hedau (2016) discussed that plant layout has various objectives, but some of them reduce equipment costs, minimize overall operation time, effective utilization of space, keep employees safety and comfort, maintain flexibility of facilities arrangement, minimize traveling distance, reduce handling costs, reduce handling time, make organized material handling equipment, smooth manufacturing process, and well organizational structure. Therefore, to achieve those objectives, effective layout design is mandatory in the manufacturing and service industries.

2.5 Important of Plant Layout

Proper plant layout design in manufacturing and service industries improves operational function, keeps apart for volume flow departments, improves operation efficiency and productivity, and enhances employee safety (Prasad, Rajyalakshmi, & Reddy, 2014). However, plant layout contributes to the overall qualitative features of a layout which may not be immediately quantifiable, including facilitating communication (Virendra, 2017).

2.6 Systematic Layout Planning

Systematic layout planning (SLP) is a process of establishing the workplace layout to create effective material flow and logical relationships between workplaces/workstations for highly interrelationship departments close to each other. It was developed by Muter and follows eleven steps to provide solutions (Ojaghi & Khademi Alireza, 2015; Suhardini et al., 2017). SLP is a step-by-step planning process that permits workers to identify, analyze, visualize, and rate numerous activities, relationships, and alternatives involved in layout development based on input data, the flow of materials, activities of relationships, and relationship diagrams. Furthermore, SLP has three stages. These are problem analysis, search and selection stages (Sembiring, Budiman, Mardhatillah, Tarigan, & Jawira, 2018). It was applied to optimize the current layout for efficiency improvement and reduction of material handling costs. As Suhardini et al. (2017) stated systematic layout planning input data is classified into five categories. These are:

Product (P): Kind of product that is produced

Quantity (Q): The amount of each kind of product produced

Route (R): Operation process for each product

Service (S): Supportive service like controlling room, locker room, etc.

Timing (T): What time is required and how many components are produced in a specified period? The SLP framework is shown in Figure 2.5.

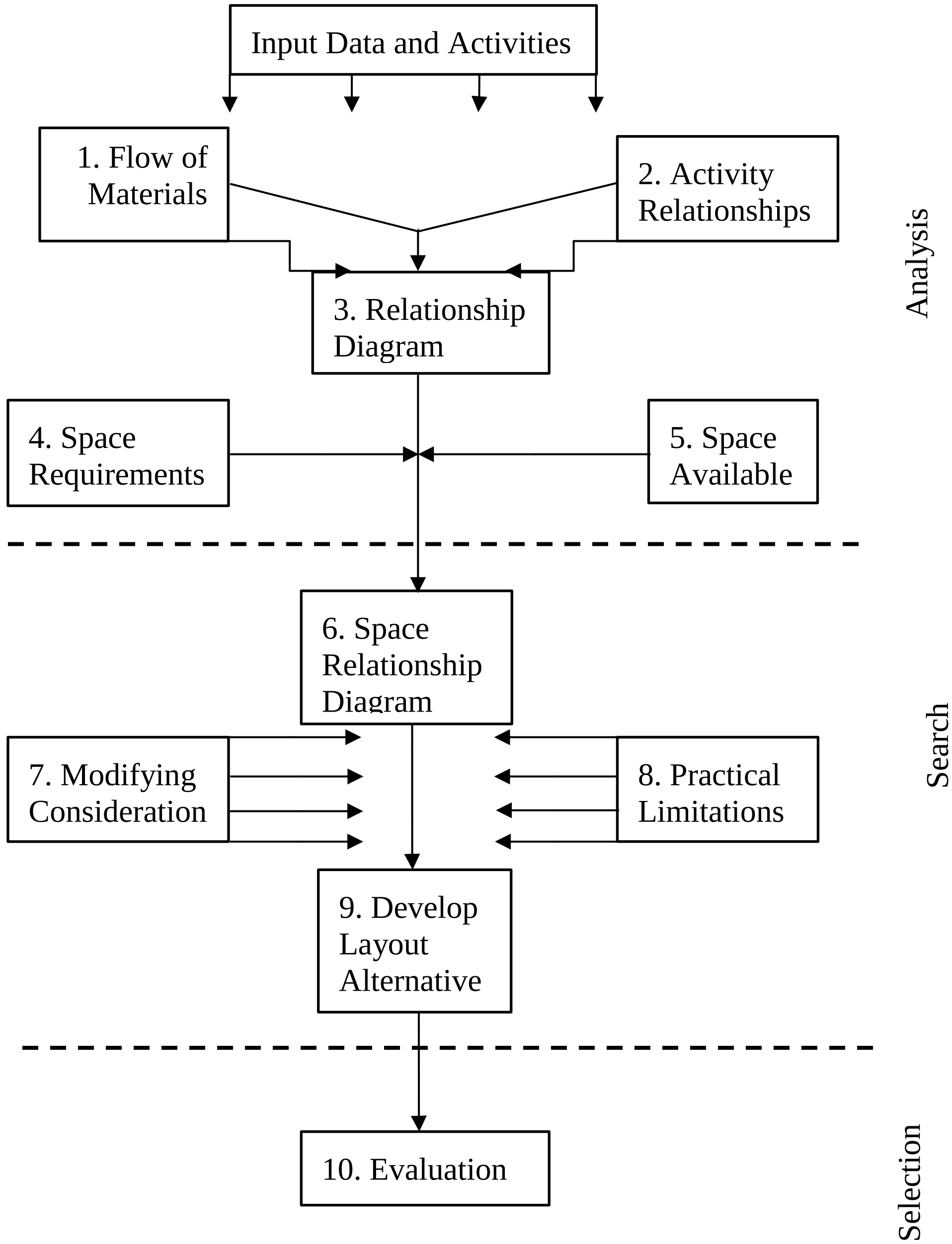

Figure 2. 9 Systematic Layout Planning Procedure (Suhardini, Septiani, & Fauziah, 2017)

2.7 Facilities Layout Design Procedures

The facility layout design procedure is a solution-making mechanism for facility layout problems. There are different procedures for layout problems, such as heuristics algorithms, simulation, and mixed-integer programming are methods for facility layout design (K.Balasundaram et al., 2016). However, mixed-integer programming is used to find an exact solution, but it is so difficult because of the majority of FLPs are heuristic approaches (Bunterngchit, 2018). However, algorithm approaches are a method for developing effective plant layouts to minimize the distance traveled and maximize the relationship between departments. The heuristic algorithms are classified as construction and improvement algorithms (Deshpande, Patil, Baviskar, & Gandhi, 2016). Since, the construction algorithm begins from scratch to design facilitates layout. It includes a graph-based method, Automated Layout Design Planning (ALDEP), Computerized Relationship Layout Planning (CORELAP), and Plant Layout Analysis and Evaluation Techniques (PLANET), while the improvement algorithm improves facilities layout using an initial layout. The improvement routine contains the pairwise exchange method, Computerized Relative Allocation of Facility Technique (CRAFT), and Computerized Facilities Design (COFAD) (Prasad et al., 2014). As a result, the purpose of selecting construction and improvement algorithms is to maximize adjacency scores and reduce the distance traveled. The classification of the heuristic algorithm is shown in Figure 2.6.

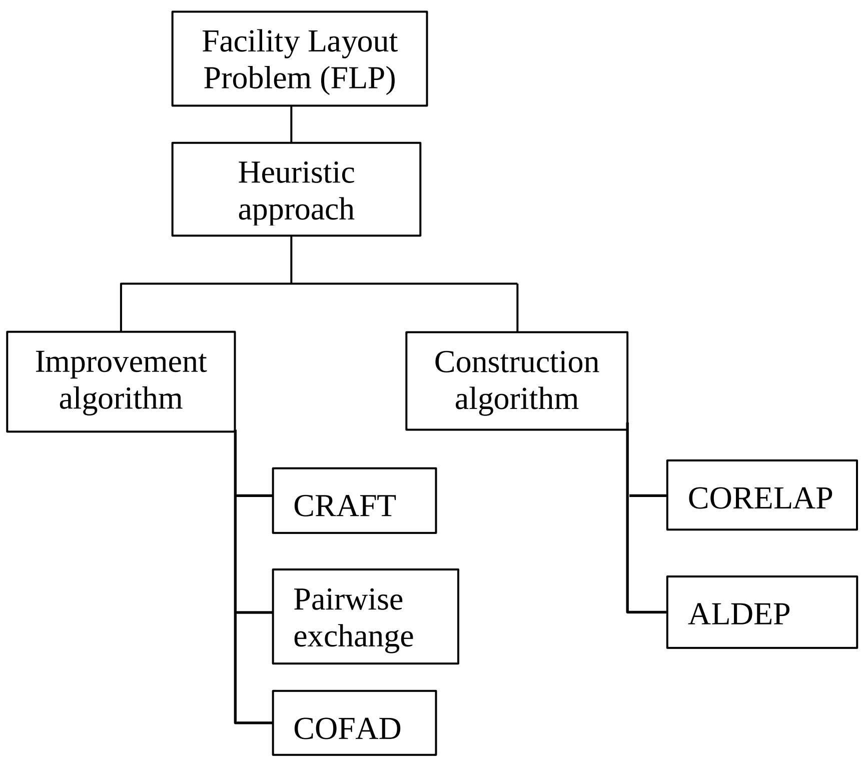

Figure 2. 11 Summary of Layout Alternatives (Virendra, 2017)

2.8 Improvement Algorithm

The improvement algorithm starts from the existing layout by swapping two or more departments to reduce high-traveled movement for high material flow between workstations. The improvement routine comprises CRAFT, MCRAFT, pairwise exchange method, and COFAD (Bunterngchit, 2018).

2.8.1 Computerized Relative Allocation of Facilities Technique (CRAFT)

CRAFT starts from the initial layout to reduce total material handling costs by using two-way or three-way swapping the location of departments (Prasad et al., 2014). It was proposed in 1964 to minimize transportation costs (Virendra, 2017). However, the final solution to plant layout quality depends on the existing layout and requires initial layout, product flow, distance between each section, the unit cost of transporting individual items, number of departments, area of the department, and fixed departments (Priyaranjan Mallick, 2019). It does not give the optimal layout. However, the results are good and near optimal. The limitation of the CRAFT algorithm is that only exchange departments have an equal area and common boundary, and it is tedious to find the least material handling cost. Consequently, CRAFT is more popular than other computer-based layout procedures.

In addition to the CRAFT algorithm, Micro-CRAFT (MCRAFT) is an extension of the CRAFT algorithm. It followed similar procedures as CRAFT, but the major difference is that it is applicable in unequal areas and without common boundaries between workstations, but exchanges only for the rectangular area (Esmaeili Aliabadi & Pourghannad, 2012).

As Vandit Hedau (2016) stated that using the CRAFT algorithm as a method develops solutions for inappropriate transportation costs between workstations by exchanging departments which have frequent product flow. As the author's finding shows that the transportation cost between workstations has been reduced by 27.73%. The CRAFT algorithm is a powerful tool for improving the existing layout without requiring high installation costs since two or more workstations are interchanged. As Prasad et al. (2014) discussed the CRAFT algorithm optimizes the material handling costs by generating five alternative solutions that are 54.56%, 56.5%, 58.56%, 58.31%, and 61.84%. As a result, the CRAFT algorithm is important for minimizing the distance objective function. The procedure of the CRAFT algorithm is shown in Figure 2.7.

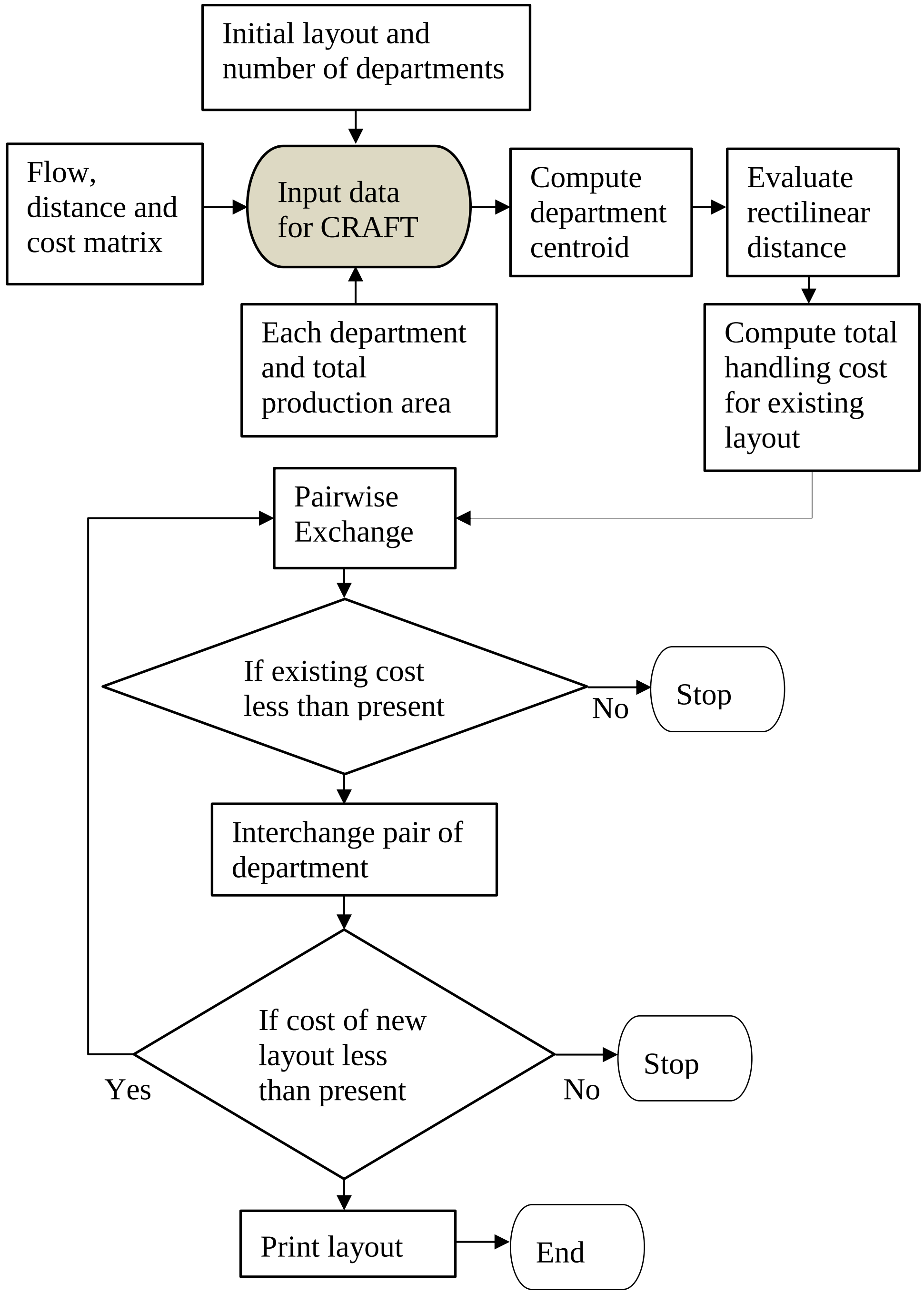

Figure 2. 13 Procedures of CRAFT Techniques (Priyaranjan Mallick, 2019)

2.8.2 CRAFT Excel Add-in

CRAFT can be done using an Add-in for Microsoft Excel developed by Paul A. Jensen (Priyaranjan Mallick, 2019). The researcher stated the CRAFT method without Excel Add-in reduced material handling costs by 0.1%. However, using Excel Add-in CRAFT has reduced material handling costs by 2.4%. It is essential to improve the existing layout that has an equal area and common boundaries. As Mulugeta, Beshah, and Kitaw (2013) stated input data for the Excel Add-in are the total number of departments, department area, flow matrix, and cost matrix. The total production area, number of departments, and fixed/variable department locations are required.

The Procedures of the CRAFT Excel Add-in are shown below.

1) Insert input data into Excel Add-in
2) Click the define facility button and select facility options. Then, display the initial layout and evaluate the initial solution
3) Solve it to find the best-improved layout by switching each department, which are common boundaries and equal area.

2.8.3 Pairwise Exchange Method

The pairwise exchange method is an improvement algorithm that is used for both adjacency and distance-based objectives. Usually, it has been utilized for an equal, and unequal-area departments. However, it applies to less than five departments. It simply states each iteration of all feasible exchanges in the location of department pairs is evaluated one at a time and the pair that results in the largest reduction in total handling costs is selected (Ojaghi, Khademi, Yusof, Renani, & bin Syed Hassan, 2015)

2.9 Construction Algorithm

The construction algorithm generates a layout from blank or from scratch using total closeness rating (TCR) to sequence and locate the required departments. The construction algorithm includes a graph-based method, CORELAP, ALDEP, and PLANET (Virendra, 2017).

2.9.1 Computerized Relationship Planning (CORELAP)

CORELAP is a construction algorithm with activity relationships as a major consideration. It designed the facility layout based on a total closeness rating (Sembiring et al., 2018). However, it expresses the interdepartmental relationships in a close relationship matrix to construct a layout. It builds layouts by locating both rectangular and non-rectangular-shaped departments.

The input data needed in the CORELAP algorithm includes:

- Number of departments
- Area of each department
- Activity relationship diagram
- Weights for activity relationships

The closeness rating between departments i and j is based on the weight assigned to the activity relationship between the two departments. CORELAP has followed both department selection and placement procedures (Sembiring et al., 2018). Placement procedures also have both weighted placement value (WPV) and placement rating (PR) methods.

CORELAP Department Selection Procedures;

1) Assigning numerical values to the closeness rating as A= 4, E= 3, I= 2, O= 1, U= 0 and X =-1
2) Computing TCR (Total Closeness Rating)
3) Select department having the largest TCR first
4) Next department sequenced based on the relationship with selected department closeness priorities A>E>I>O>U. Continue until all departments are sequenced.
5) Departments having an X relationship with the placed departments are labeled as the last-placed departments.

CORELAP Department Placement Procedure using Weighting Placement Value;

The placement procedure is continued from department selection procedures (Rajesh et al., 2016). However, WPV followed the following procedures:

1) Choose the department which was selected first in department selection, have the highest TCR and place it in the middle of the layout drawing
2) Select departments based on department sequence before placing the next department
3) Evaluate all possible locations in a counter-clockwise position, starting at the western edge of the partial layout having a relationship between A, E, O, U, and I with the previously chosen department. When a location is a full adjacency, its weight equals 1.0, and when it is a partial adjacency, its weight equals 0.5.
4) Locate the department which has the largest WPV
5) Repeat the above process until all departments are placed.

CORELAP Department Placement Rating (PR);

As Belachew et al. (2020) defined that improving the production layout by using placement ratings to maximize adjacency based on both adjacent and touching conditions of neighboring departments with the selected departments. Next, evaluate PR value using the sum of the weighted closeness ratings between departments to locate departments with the highest neighbor PR value. It has both department selection and placement procedures. However, department selection criteria are similar to WPV but unique to department placement procedures shown below.

CORELAP Department Placement Procedures in Placement Rating;

1) The first department selected based on TCR value and placed in the middle
2) Department placement is determined by evaluating PR value based on the adjacent and touching conditions of neighboring departments with the selected department for all possible locations around the current layout.
3) The new department is located based on the greatest PR value. Continue this procedure until all departments are placed.

Different authors have followed the CORELAP algorithm in manufacturing industries. As Rajesh et al. (2016) proposed, in oven manufacturing industries using the CORELAP algorithm as a method to solve insufficient space utilization. However, the researchers increased the space utilization by 8.83%. As Belachew et al. (2020) discussed redesigning the plant layout to maximize operational efficiency using the CORELAP algorithm for both WPV and PR. As a result, two scenarios have been developed. However, scenario one using the WPV procedure obtained 71.4% efficiency, and the second scenario was developed in PR and its finding was 73% efficiency. Finally, the researchers concluded that the placement-rating method provided better results than weighting placement value.

2.9.2 Automated Layout Design Planning (ALDEP)

ALDEP is a construction algorithm for designing facilities' layouts from blank (Suhardini & Rahmawati, 2019). As Deshpande et al. (2016) explained, ALDEP requires a relationship chart for each department area, total production area, length and width of facilities, and sweep width. It has both department selection and placement procedures. The first department is selected randomly. Next, select "A" or "E" relationship with the selected department if there is more than one department selected randomly. Continue this process until all departments are selected. The first department of ALDEP starts from the upper left corner and extends downward. For the next sweep, the user determines the width and if minimum requirements are met, it prints out the layout and the score is given. Finally, the layout with the highest score closeness rating is selected as a solution (Suhardini & Rahmawati, 2019).

2.10 ProModel Simulation Optimization

ProModel simulation is an effective optimization tool and is simple to express variables and statements for modeling, and measures the performance of the layout in job shop process industries (Benson, 1997). As Suhardini et al. (2017) discussed using simulation ProModel optimizes the plant layout to reduce processing time and average move time. However, the ProModel simulation program is vital to measure the manufacturing cycle time, waiting time, operation time, average required time in the system, and average move time, especially better for a variety of products.

2.11 Summary of Literatures

Table 2. 1 Summary of Key Article on Layout Related Problems

No	Authors	Problems	Objectives	Method	Findings
1	(Sembiring et al., 2019)	Backtracking movement	To redesign the optimal layout	CRAFT algorithm	Improve time efficiency by 8.95% and MHC by RP 47,403.9 per year
2	(Suhardini et al., 2017)	Inappropriate cross-traffic on the production floor	To meet customer and production capacity	Used SLP & simulation program	Enhance production capacity by 37.5%, and minimize MHC by 10.98%
3	(K.Balasundaram et al., 2016)	Unable to utilize labor efficiency, and ineffective space utilization	To minimize travel distance and total MHC	Use distance between departments and the number of movements per day	Reduction of transportation length by 42.72%
4	(Priyaranjan Mallick, 2019)	Excessive transportation distance	To reduce material flow cost	CRAFT used as a method	Reduce total distance traveled by 34.9%
5	(Kovács & Kot, 2017)	Excessive distance traveled in workers	To design an effective workflow	Mathematical method	Reduced total traveled distance by 6.58% and minimize space utilization by 30%
6	(Mulugeta et al., 2013)	Improper location of machines	To design plant layout in single algorithm and two algorithm	CRAFT and CORELAP algorithm used as a method	CRAFT expense for MHC 3648 birr while CORELAP by CRAFT expense for MHC 3721 birr per month
7	(Sembiring et al., 2018)	Unbalanced space between room and	To create optimum space	CORELAP algorithm	It increases the room usage efficiency by

		students	utilization		14.98% relative to the previous
8	(Prasad et al., 2014)	High material handling cost to move products	To redesign plant layout to improve MHC	CRAFT algorithm used as a method	5 alternative results obtained Alternative 1,2,3,4,5 reduces MHC by 54.56%,56.5%, 58.56%, 58.31% and 61.84% respectively
9	(Vandit Hedau, 2016)	High transportation costs between departments	To exchange departments that have a high workflow	CRAFT algorithm used as a method	Reduces transportation cost between departments by 27.73%
10	(Belachew et al., 2020)	Excessive movement for frequently cross over products	To propose a new plant layout	CORELAP algorithm using WPV & PR	Scenario 1 develops a layout using WPV. Its efficiency is 71.4% and scenario 2 develops a plant layout using PR. Its efficiency is 73%
11	(Rajesh et al., 2016)	Insufficient Space utilization & high MHC	To optimize the existing layout	CORELAP algorithm	Increases space utilization by 8.83%
12	(Suhardini & Rahmawati, 2019)	High manufacturing lead time	To get an optimal layout	ALDEP and CRAFT algorithm	Reduced MLT by 23 minutes and increased adjacency score by 15%

2.12 Literatures Gap

Researchers have developed a solution to the facility layout problem (FLP) in the manufacturing and service industries. Hence, construction and improvement algorithms are widely used for facility layout design. Both construction and improvement algorithms maximize relationships and minimize the distance traveled between workstations. Most authors have been able to redesign or improve plant layout by using construction or improvement algorithms independently. However, no authors have measured facility layout performance using two algorithms and a simulation model.

The CORELAP algorithm is a technique for redesigning facilities' layouts using both weighting placement value (WPV) and placement rating (PR) procedures. However, researchers obtained solutions using WPV techniques, but better decision provide using placement rating (PR).

Heuristic algorithms are important for facility layout problems, but follow the rule of thumb for developing an activity relationship chart to maximize the relationship between departments and improve operational efficiency. The rule of thumb says that to develop the activity relationship chart between departments, have follow the following rating rules. Hence, absolutely necessary (A) and undesirable (X) should be rated below 5%, especially important (E) between 5% and 10%, important (I) rating between 10 and 15%, ordinary (O) rating between 15% and 20%, and the remaining should be rated as unimportant relationship.

Therefore, the study redesigns a production layout to fill the researchers' gap using the CORELAP and CRAFT algorithms.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

To conduct this research discusses detailed procedures about how to address the research objectives by mentioning related literature. This section includes research design (how and why the research achieved the required objectives), methods of data collection, data analysis, data presentation, and research framework.

3.2 Research Design

The research examined both qualitative and quantitative approaches. Qualitative approaches increase flow interrelationships between departments, while quantitative approaches focus on minimizing travel distance for frequent product flow between each department (Arunyanart & Pruekthaisong, 2018). The research follows three stages of systematic layout planning (SLP) techniques that are problem analysis, search, and selection stage (Sembiring et al., 2018). However, the hypothesis is developing using both construction and improvement routines.

Algorithms and simulations are optimization tools for facility layout problems. However, Automated Layout Design Program (ALDEP) and Computerized Relationship Layout Planning (CORELAP) algorithms are the main types of construction routines. Both of them are followed department selection/sequence and department placement/location procedures. However, ALDEP only followed the "A" or "E" relationship to sequence departments, otherwise sequence randomly. This degrades the layout performance (Suhardini & Rahmawati, 2019). But, CORELAP has reasonable department sequencing procedures. The first department is selected based on the highest Total Closeness Rating (TCR). The next department is sequenced concerning the relationship with the selected department (Belachew et al., 2020).

Improvement routine includes pair-wise exchange method, Computerized Relative Allocation of Facilities Technique (CRAFT), and Micro CRAFT are the main algorithms. However, the pairwise exchange method is important when the number of departments is less than five, while CRAFT swaps departments in equal areas and common boundaries between them and is essential for both rectangular and non-rectangular departments.

Even though Micro CRAFT exchanges unequal area and non-common boundaries between departments, however, used only for rectangular departments (Esmaeili Aliabadi & Pourghannad, 2012). As Leonardo and Wee (2014) defined BLOCPLAN is a hybrid algorithm for maximizing adjacency score and minimizing distance traveled. It is applicable for rectangular departments. Furthermore, the simulation model was also used to measure the handling time and production capacity for facility layout problems. As Suhardini et al. (2017) defined increased production capacity by using simulation Promodel to solve inappropriate material flow of the layout by minimizing the processing time. As a result, CORELAP and CRAFT Excel Add-in were selected to achieve both adjacency and distance objectives.

The CORELAP algorithm input data is the number of departments, each department area, total production area, product operation process, facilities movement, and production demand. (Sembiring et al., 2018) While initial layout, number of departments, total production area, each department area, product flow matrix, and unit cost data are necessary for CRAFT Excel Add-in (Vandit Hedau, 2016). CRAFT material handling costs can be expressed in equation 1 (Prasad et al., 2014).

$$\mathrm{TMHC} = \sum_{i=1}^{n}\sum_{j=1}^{n} F_{ij}\, C_{ij}\, D_{ij} \qquad (1)$$

Where TMHC is defined as total material handling cost, F_{ij} is the flow of product between workstation i and j, C_{ij} is the unit cost between workstation i and j for each flow, D_{ij} is the centroid distance between workstation i and j for a specific distance matrix.

The transportation distance between two departments in CRAFT can be evaluated as the rectilinear distance between department centroids that is |Xa – Xb| + |Ya – Yb| for department A and B, where (Xa, Ya) and (Xb, Yb) are the X and Y coordinates of the two departments respectively (Belachew et al., 2020).

Fasil engineering company is manufacturing a variety of products in low volume. Although three-year production volume and manufactured product types were collected to identify customer demand from the company document. After collecting the existing data, evaluate the existing production layout using the CRAFT Excel Add-in. However, to achieve the objective of the study, developed the proposed layout using CORELAP followed by CRAFT Excel Add-in. first applied the CORELAP algorithm and then applied the CRAFT Excel Add-in. CORELAP starts from scratch to optimize the relationship between departments using TCR. TCR is developed based on the adjacency between activity relationship charts (Maulida Hakim & Istiyanti, 2015). The highest TCR department was selected first and the second department was selected based on the relationship (A > E > I > O > U) with the selected department. However, this procedure continued until all departments were sequenced. The next department placement procedure was performed using the placement rating (PR) technique. Although the designed layout is improved by CRAFT Excel Add-in to minimize distance traveled and reduce material handling costs by swapping two departments, which are equal in area and common adjacency until minimum material handling cost, is obtained. Finally, develop a simulation model and a cost-benefit analysis between the existing and the proposed layout.

3.3 Parameter of the Study

As Maulida Hakim and Istiyanti (2015) proposed a reduction in travel distance by 9.017% for production facilities in pharmaceutical companies using the CORELAP algorithm. Furthermore, redesigning the boiler manufacturing layout with the CRAFT algorithm minimizes the total material handling cost by RP 47,403.90 per year (Sembiring et al., 2019). As a result, the decision of this study established in distance traveled, handling time, production capacity, and handling cost.

3.4 Data Collection Method

Both primary and secondary data collection techniques follow

3.4.1 Primary Data Collection

Primary source direct measurement and observation from the company to know the employee traveling distance and to identify available departments (Vandit Hedau, 2016). Measurement of length, width for each department and total production floor using meter tape to know space requirements and to identify the distance traveled between departments (Ojaghi & Khademi Alireza, 2015). Furthermore, direct observation of the production floor to know the number of departments and to know fixed/variable departments. Finally, face-to-face discussion from company operators, manager, and supervisor to determine each product operation process and to obtain better and realistic data (Sembiring et al., 2019).

3.4.2 Secondary Data Collection

The researcher does not directly observe a secondary source. This is a three-year customer demand from company documents and data from previous researchers to develop an activity relationship chart between departments using production volume, operation process, and machine movement (migration) (Sembiring et al., 2018).

3.5 Data Analysis

The data collected from primary and secondary sources is evaluated using construction and improvement routines. Existing production layout analyzed in computerized Relative Allocation for Facility Technique (CRAFT) Excel Add-in. However, based on the existing layout performance develop a new proposed layout using computerized relationship layout planning (CORELAP) followed by CRAFT Excel Add-in. First, CORELAP algorithm was applied using the Total Closeness Rating (TCR) with considering the rule of thumb principles. For instance, the highest product flow departments are located close to each other. After designed a new layout improve it using improvement algorithm that is CRAFT Excel Add-in to obtain proposed layout. Then, a simulation model is applied to both the existing and proposed layout. Hence, the existing and proposed layouts have been analyzed using layout performance measurement criteria. Lastly, conduct a cost-benefit analysis between existing and proposed production layouts to develop a conclusion and recommendation.

3.6 Data Presentation

The collected primary, secondary data, and their analysis are presented in tabular, relationship charts, operation process charts, graphs, and from to charts in addition to the textual descriptions.

3.7 Research Framework

A preliminary assessment was taken to have a general overview of the fasil engineering company. Following the preliminary assessment, a problem statement was stated for optimization of production layout in a company through CORELAP and CRAFT methodologies. The research framework shows how this research performs the required objectives through data collection, analysis, and what tools are organized to develop the proposed production layout shown in Figure 3.1.

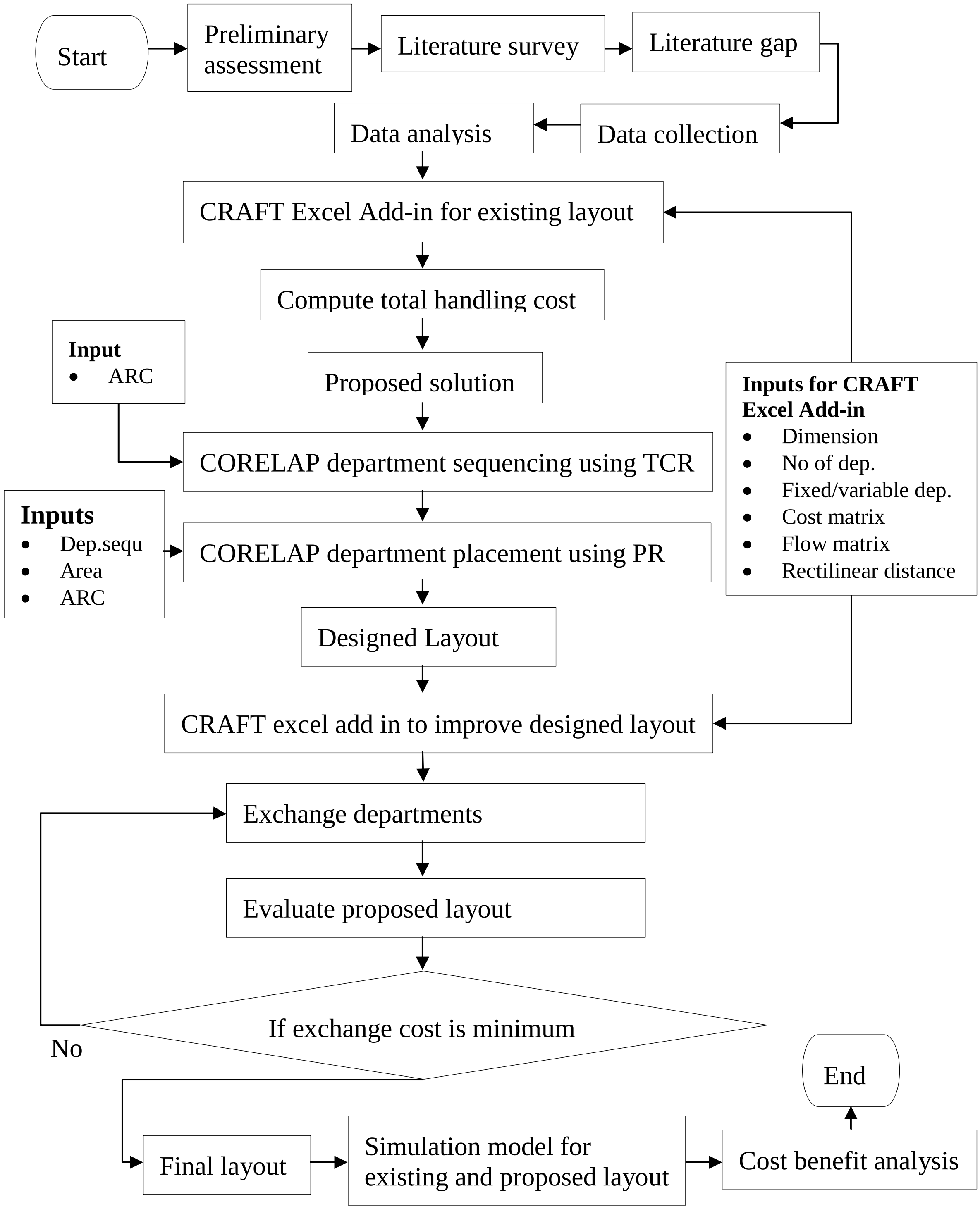

Figure 3. 1 Research Framework

CHAPTER FOUR

DATA COLLECTION, ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This section mentions the collection of the required data from the company to evaluate the existing production layout in terms of total material handling cost, distance traveled, handling time, and production capacity. Although based on the existing production layout analysis, develop the proposed layout using CORELAP followed by CRAFT Excel Add-in. Also, develop a cost-benefit analysis between the existing and the proposed layout. Furthermore, explain the finding of existing and proposed layouts with literature support. Additionally, compare and contrast the existing and proposed layout performance measurements and discussed the importance of the study in job shop process and product layout industries has been discussed.

4.2 Data Collection

As discussed in the methodology section, developing solutions for facility layout problems should identify an existing problem and collect the data from the case company. The recorded data is department length and width for finding their area requirement to determine the space utilization, the total number of departments and type of product produced within its amount to make a relationship diagram, product-moving time, and each product operation process to analyze the interrelationship between each department and to decide the distance traveled from department to department. Finally, a flow matrix and cost matrix are needed to evaluate total material handling costs.

4.2.1 Existing Production Layout

The existing production layout of the company was installed without considering the product interrelationship between departments. However, the company has sixteen departments, such as cutting, bending, drilling, lathe, puncher m/c 1, milling, puncher m/c 2, radial drilling, welding section, circular saw, rolling, hydraulic press, manual bending, assembly, raw material storage, and finishing departments are installed. The existing production layout is located at a dimension of 48 meters by 21 meters, as shown in Figure 4.1.

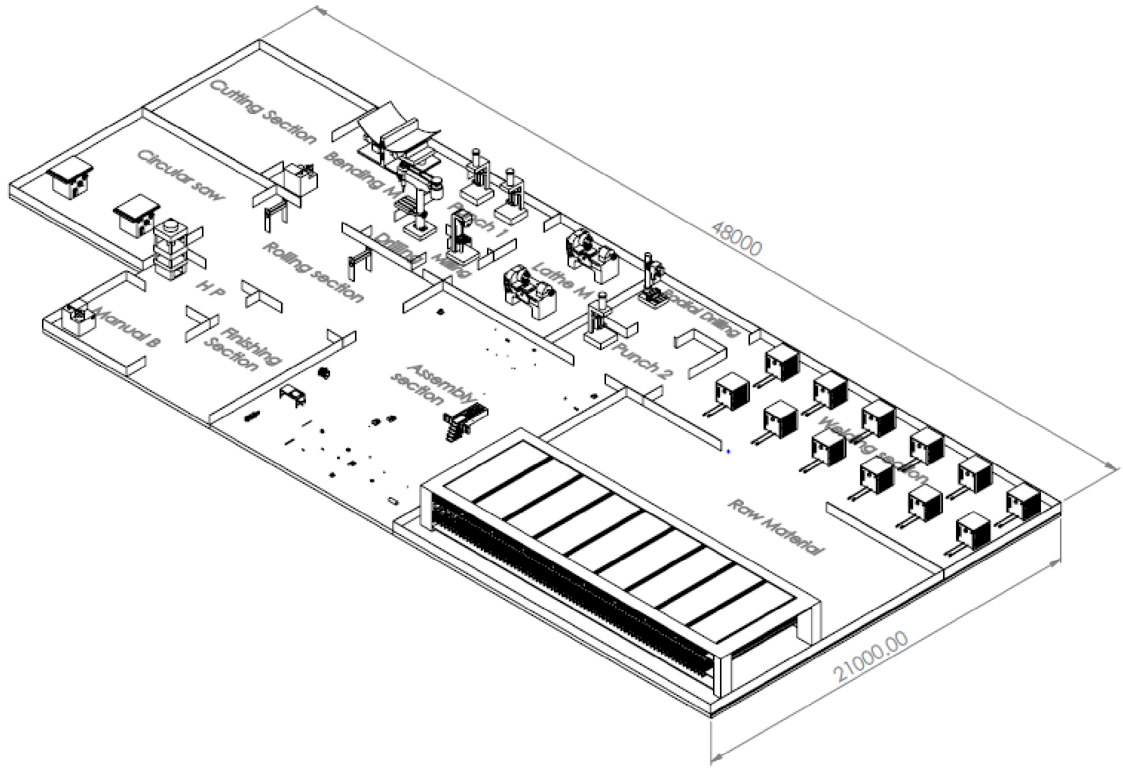

Figure 4. 1 Existing Production Layout

4.2.2 Department Coding

Each department is coded in numerical and lettering form to make easy and space utilization in CRAFT Excel Add-in for data collection and analysis in as shown in Table 4.1.

Table 4. 1 Department Coding

Numbering Code	Lettering Code	Department Name
1	CM	Cutting Machine
2	BM	Bending Machine
3	PM1	Puncher Machine for small size
4	LM	Lathe Machine
5	MM	Milling Machine
6	DM	Drilling Machine
7	CSM	Circular Saw Machine
8	RM	Rolling machine
9	HP	Hydraulic Press
10	MB	Manual Bending
11	FS	Finishing Section
12	AS	Assembly
13	PM2	Puncher Machine for large size
14	RD	Radial Drilling
15	WS	Welding Section
16	RMS	Raw Material Storage

4.2.3 Required Area for Departments

To design the production layout department, dimensions are necessary to analyze the available space requirements and to identify the required distance between each workstation, as shown in Table 4.2.

Table 4. 2 Available Departments Area

Departments	Width (m)	Length (m)	Area (m2)
Cutting Machine	7	7	49
Bending Machine	6	7	42
Puncher Machine for small size	5	4	20
Lathe Machine	6	7	42
Milling Machine	2	3	6
Drilling Machine	3	3	9
Circular Saw Machine	8	8	64
Rolling machine	10	6	60
Hydraulic Press	5	3	15
Manual Bending	5	5	25
Finishing Section	5	8	40
Assembly	11	14	154
Puncher Machine for large size	A1= 6×3, A2= 2×2, A3= 2×1		24
Radial Drilling	A1= 6×2, A2= 2×2, A3=2×1		18
Welding Section	18	7	126
Raw Material Stored	19	14	266

4.2.4 Operation Process of the Products

The product type and volume were recorded for three years, from 2010E.C half year to 2013E.C half year. The available departments and their codes are shown in Table 4.1 and twenty-seven parts/products have been manufactured within this time interval. Each of them has its own operation process. For instance, the operation process chart for surface steel casing and j-bolt products is shown in Figure 4.2, while other operation processes are shown in Table 4.3.

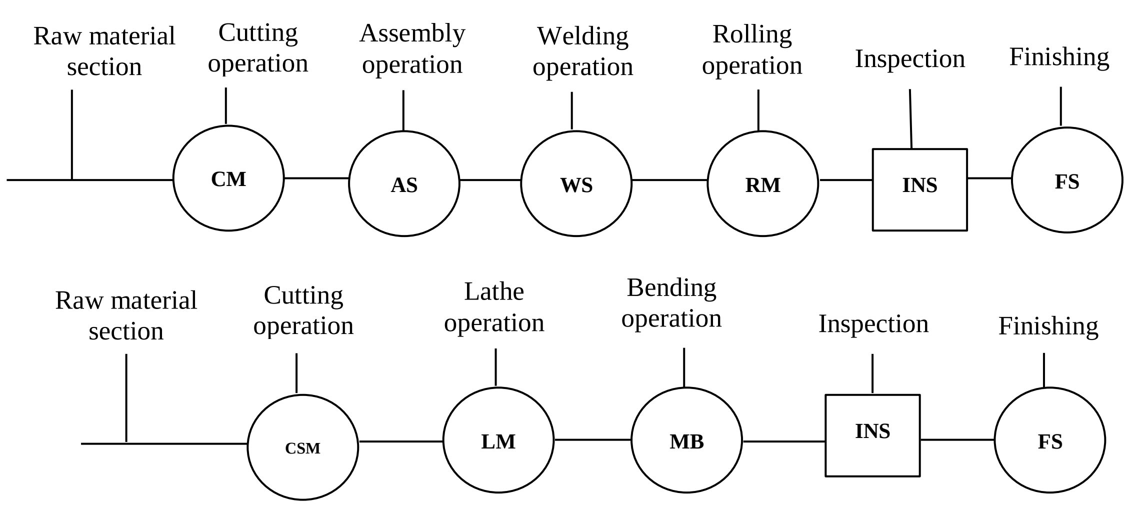

Figure 4. 2 Both surface steel casing and J bolt operation process chart respectively

Table 4. 3 Operation Process for Each Part/Products

Parts/Product Type	**Operation Process**
Water & gas tanker	RMS-CM-RM-RD-BM-AS-WS-FS
Surface Steel Casing	RMS-CM-AS-WS-RM-FS
J bolt	RMS-CSM-LM-MB-FS
Window	RMS-CSM-AS-WS-DM-FS
Door	RMS-CSM-AS-WS-DM-FS
Plate	RMS-CM-DM-FS
Under sluice gate	RMS-CM-DM-FS
Main canal gate	RMS-CM-LM-FS
Secondary canal gate	RMS-CM-WS-DM-FS
Stove mold	RMS-CM-RM-AS-WS-FS
Handwashing facilities	RMS-CM-AS-WS-DM-FS
Concrete mold	RMS-CM-RM-BM-WS-FS
Notice board	RMS-CM-DM-AS-WS-FS
Suggestion box	RMS-CM-AS-WS-DM-FS
Kitchen stove	RMS-CM-WS-RD
ROPE AND WASHER PUMP PARTS	
Concrete wall cover slab with handles	RMS-CM-WS-FS
Pump cover	RMS-CM-BM-DM-FS
Base support	RMS-CSM-AS-WS-FS
Clamp	RMS-CM-PM1-BM-AS-WS-FS
Cover support	RMS-CM-AS-WS-FS
Raising main support	RMS-CM-BM-WS-FS
Holder	RMS-CSM-WS-FS
Galvanized bolt	RMS-CSM-LM
Galvanized solar panel & C-channel connector	RMS-CM-RD-BM-FS
L-Bracket U Channel & pipe holder	RMS-CM-RD-BM-FS
Galvanized U- Bolt with torus	RMS-CSM-LM-HP-FS
Metal shelf	RMS-CM-PM2-BM-AS-WS-FS

4.2.5 Case Company Production Volume

The type of product produced and the amount of manufactured products are obtained from the company documents. However, the water tanker and surface steel casing have three partitions to manufacture a single product, so that each partition has a similar operation process as stated in table 4.3. Therefore, multiplying the monthly production volume by three leads to a production process that is an average of three-water tankers produced in a month. As a result, a nine-operation process is performed as shown in Table 4.4.

Table 4. 4 Three-Year Production Volume for Each Part/Products

No.	Product type	Three-year production volume				Average monthly production volume
		2010E.C For 6 months	2011E.C For 12 Months	2012E.C For 12 Months	2013E.C For 6 Months	
1	Water and gas tanker	12	43	40	13	3×3=9
2	Surface Steel Casing	48	101	83	52	3×8=24
3	J bolt	440		120	231	22
4	Window		314	230	356	25
5	Door	40	174	478	96	22
6	Plate	220	442	367	48	30
7	Under sluice gate	22		13		1
8	Main canal gate	44	32	22		3
9	Secondary canal gate	26	32	6		2
10	Stove mold			104		3
11	Hand washing facilities		6	55	4	2
12	Concrete mold		40	18	14	2
13	Notice board	4	30	36		2
14	Suggestion box	29	40	32		3
15	kitchen stove			104		3
16	Concrete wall cover Slab	24	156	31		6
17	Pump cover	24	156	31		6
18	Base support	24	156	31		6
19	Clamp	24	156	31		6
20	Cover support	24	156	31		6
21	Raising main support	24	156	31		6
22	Holder	24	156	31		6
23	Galvanized bolt	50		144		6
24	Galvanized solar panel c channel			144		4
25	L Bracket u channel pipe holder			32		1
26	Galvanized u bolt with torus			34		1
27	Metal shelf	30	38	84	56	6

4.3 Monthly Production Flow between Department

Based on the process flow of the parts/products in sixteen departments, there are various interactions between them due to different products traveling on a different path. The flow is seen from parts/products moving between the department point of view and machine movement. The back and forth movement of parts between departments was analyzed and then each product operation process, monthly average production volume, and machine movements were considered to build the parts/product flow from to chart matrix. As shown in Figure 4.3, the product flow matrix department one and two movements of product from the cutting machine to the bending machines. However, the transported products are pump cover and raising main support holder its monthly production volume is 6, 6 respectively, thereby 12 products move from cutting machine to bending machine therefore similar procedure follows to develop from to matrix as shown in Figure 4.3.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		12	6	3		33		14				35	6	5	11	
2						6					5	21			8	
3		6														
4									1	22	3					
5																
6											91	2				
7				29								53			6	
8		2									24	3		9		
9											1					
10											22					
11																
12															114	
13		6														
14		14														
15						54		24			58			3		
16	122						88									

Figure 4. 3 Average Monthly Production Volume From to Matrix

4.4 Procedures of CRAFT Excel Add-in

First, select the Add-in tool from Microsoft Excel and input the name of the facility, number of departments, number of fixed/variable points, and distance measured in metric. Hence, the name of the facility is "production layout" as shown in Figure 4.4.

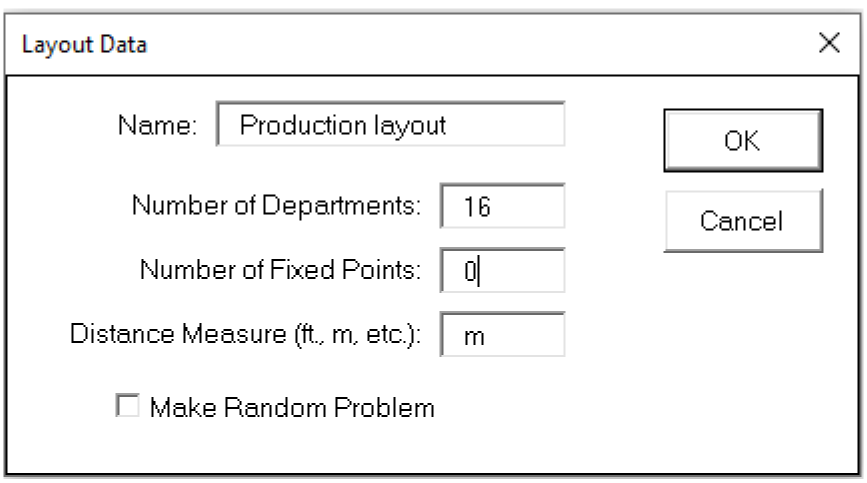

Figure 4. 4 Production Layout Data Entering Dialogue

Pressing an OK button on layout data results in a spreadsheet that allows the user to fill in additional information. The window needs department information that is scale, width, and length as shown in Table 4.5.

Table 4. 5 Facility Information Entering Box

Scale-m/unit	1	Cells
Length-m	21	21
Width-m	48	48
Area-sq. m	1008	1008

Its length and width are 21, 48 meters respectively. When putting the department area into the table, the program automatically calculates cells with the scale-meter per unit as specified by the user. In this case, it is set to indicate that a one-unit cell represents one meter by one-meter area. Next, the facility departmental information table filled with the required data is shown in Table 4.6.

Table 4. 6 Department Information Entering Box

Department	Name	F/V	Area	Cells
Dept. 1	CM	V	49	49
Dept. 2	BM	V	42	42
Dept. 3	PM1	V	20	20
Dept. 4	LM	V	42	42
Dept. 5	MM	V	6	6
Dept. 6	DM	V	9	9
Dept. 7	CSM	V	64	64
Dept. 8	RM	V	60	60
Dept. 9	HP	V	15	15
Dept. 10	MB	V	25	25
Dept. 11	FS	V	40	40
Dept. 12	AS	V	154	154
Dept. 13	PM2	V	24	24
Dept. 14	RD	V	18	18
Dept. 15	WS	V	126	126
Dept. 16	RMS	V	266	266

4.4.1 Flow Matrix for the Existing Layout

The monthly flow of products from department to department had shown in Figure 4.3.

4.4.2 Unit Cost Matrix for the Existing Layout

The unit cost matrix is the amount of money paid to transport individual parts/products between departments to achieve the required operation. There is different material handling equipment, such as conveyors, cranes, industrial trucks, and humans. However, the case company used humans to handle products, but sometimes used trolley when manufacturing tankers and surface steel casings. The trolley is operated by one worker and does not require energy costs like electricity consumption, and fuel only has a material cost. Therefore, the case company uses only one assigned worker for transporting materials between each department. The salary is 3000 birr per month and the company's working time is:

1) working days per month =26
2) working hours per day =8
3) working hours per month (1) × (2) =26×8 = 208 Hr =748,800 second per month

Material handling cost for every second of working hour is

$$= \frac{\text{3000 birr per month}}{\text{748800 second per month}} = 0.004 \; birr \; per \; second \qquad (2)$$

The averagely material transportation time shown in Appendix B is 1.087 meters per second. Therefore, the movement cost evaluated;

$$= \frac{0.004}{1.087} = 0.00368 \text{ birr per meter}$$

However, to evaluate the transportation cost from one department to another, first find the rectilinear distance using x and y centroids as shown in Table 4.7, and then multiply the department rectilinear distance with the movement cost, which is 0.00368 birr per meter. The unit cost between the cutting and bending departments rectilinear distance is 6.5 meters. As a result, 6.5×0.00368 yields 0.02392-birr other departments from the matrix unit transportation cost shown in Figure 4.5.

FROM \ TO	CM	BM	PM1	LM	MM	DM	CSM	RM	HP	MB	FS	AS	PM2	RD	WS	RMS
CM		0.024	0.05	0.064	0.057	0.048	0.029	0.059	0.066	0.081	0.094	0.112	0.093	0.092	0.131	0.167
BM	0.024		0.026	0.04	0.033	0.024	0.05	0.035	0.042	0.057	0.07	0.088	0.069	0.069	0.107	0.144
PM1	0.05	0.026		0.026	0.018	0.017	0.075	0.039	0.064	0.079	0.055	0.074	0.054	0.042	0.092	0.129
LM	0.064	0.04	0.026		0.022	0.031	0.09	0.053	0.079	0.094	0.07	0.048	0.029	0.027	0.066	0.103
MM	0.057	0.033	0.018	0.022		0.009	0.068	0.031	0.057	0.072	0.048	0.055	0.04	0.049	0.088	0.11
DM	0.048	0.024	0.017	0.031	0.009		0.059	0.022	0.048	0.063	0.046	0.064	0.049	0.059	0.098	0.12
CSM	0.029	0.05	0.075	0.09	0.068	0.059		0.037	0.037	0.052	0.064	0.083	0.108	0.118	0.156	0.138
RM	0.059	0.035	0.039	0.053	0.031	0.022	0.037		0.026	0.04	0.035	0.053	0.071	0.081	0.12	0.109
HP	0.066	0.042	0.064	0.079	0.057	0.048	0.037	0.026		0.015	0.028	0.05	0.097	0.107	0.145	0.105
MB	0.081	0.057	0.079	0.094	0.072	0.063	0.052	0.04	0.015		0.024	0.064	0.112	0.121	0.16	0.12
FS	0.094	0.07	0.055	0.07	0.048	0.046	0.064	0.035	0.028	0.024		0.04	0.088	0.097	0.136	0.096
AS	0.112	0.088	0.074	0.048	0.055	0.064	0.083	0.053	0.05	0.064	0.04		0.048	0.057	0.096	0.055
PM2	0.093	0.069	0.054	0.029	0.04	0.049	0.108	0.071	0.097	0.112	0.088	0.048		0.015	0.048	0.075
RD	0.092	0.068	0.042	0.027	0.049	0.059	0.118	0.081	0.107	0.121	0.097	0.057	0.015		0.053	0.09
WS	0.131	0.107	0.092	0.066	0.088	0.098	0.156	0.12	0.145	0.16	0.136	0.096	0.048	0.053		0.04
RMS	0.167	0.144	0.129	0.103	0.11	0.12	0.138	0.109	0.105	0.12	0.096	0.055	0.075	0.09	0.04	

Figure 4. 5 Existing Layout Unit Cost Matrix

4.5 Analysis of Existing Production Layout using CRAFT Excel Add-in

After fulfilling all the above procedures in the MS Excel Add-in, the next is entering the required layout data by clicking the define facility button as shown in Figure 4.6.

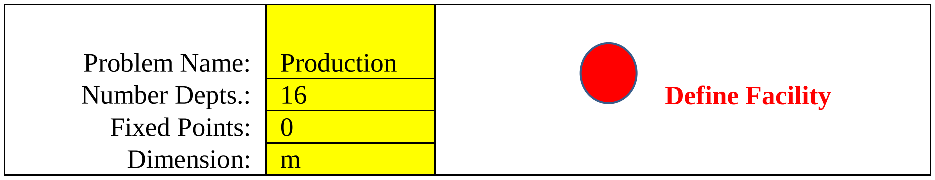

Figure 4. 6 Layout Data Display

The next dialog box provides other processing options. The first option provided a solution method that optimum sequence and the traditional CRAFT method. The optimum sequence will place the department in the layout automatically, while the second option uses the CRAFT method for improving the initial layout. The Leave blank option is available when the user defines the departments' location in the layout. However, sequential is used for similar operations, as a result, the leave blank option is selected. FEC existing layout interdepartmental flow has no specific sequence due to variable product produced, therefore it uses the traditional CRAFT method. Material handling movement of FEC is parallel to the department length and width boundaries of the production, so, use rectilinear distance measure while Euclidean measure is appropriate for movement is via straight lines between two-department centroids as displayed in Figure 4.7.

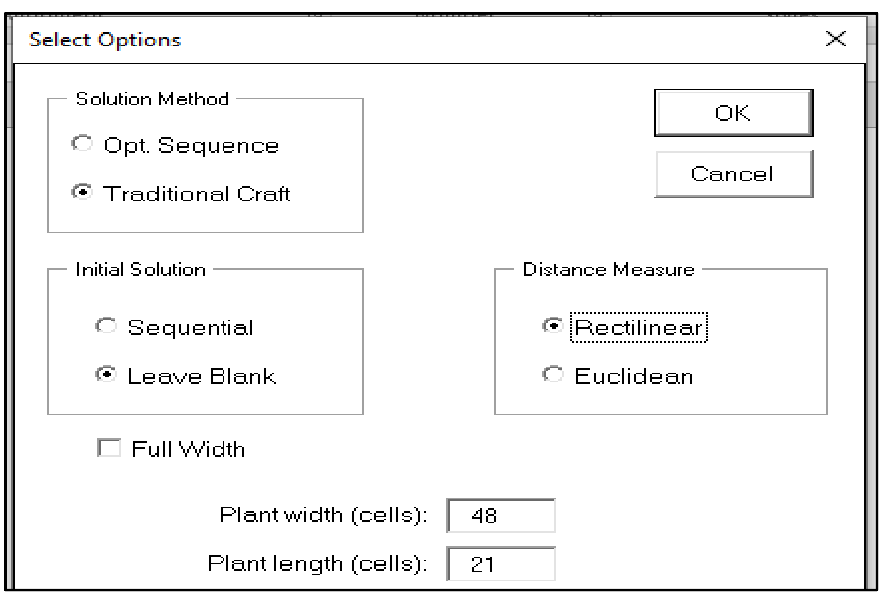

Figure 4. 7 Type of Analysis and Means of Analysis Entering Dialogue Box

When completed all the required data, press the OK button to define the department locations by numbering or coloring the cells with the assigned number or color. At the top of the spreadsheet, the facility layout information is filled for more summarization. The information includes the problem name (production layout in this case), department number, the handling cost associated with the initial layout, dimension, and area of the facilities displayed. However, the department color, area, x, and y centroid are shown in Table 4.7.

Table 4. 7 Department area, Color and Centroid Dialogue Box

Department	**Color**	**Area-required**	**Area-defined**	**x-centroid**	**y-centroid**
CM	1	49	49	3.5	3.5
BM	2	42	42	10	3.5
PM1	3	20	20	15.5	2
LM	4	42	42	21	3.5
MM	5	6	6	17	5.5
DM	6	9	9	14.5	5.5
CSM	7	64	64	4	11
RM	8	60	60	13	10
HP	9	15	15	10.5	14.5
MB	10	25	25	10.5	18.5
FS	11	40	40	15.5	17
AS	12	154	154	23.5	14
PM2	13	24	24	27.33333	4.916667
RD	14	18	18	26.55556	1.611111
WS	15	126	126	39	3.5
RMS	16	266	266	38.5	14

The information has been put in Table 4.7 each department has given a distinct number and color that would represent the department. The area requirement of each department is also given in the area required column. In the next three columns of the program, calculate the area defined for each department in the initial layout, the x and y-centroid of each department.

The user is required to fill in the blank cell layout generated by the program to suit the available area. Consequently, the number of each department located on the blank layout represents the actual production layout and represents unused areas effectively.

Once filled in the layout its area within department numbers, press the evaluate button on the top of the spreadsheet. However, the program gives the designated coloring for each number of departments and evaluates the cost of the initial layout. The program uses the load moved between each department from-to chart and the material handling cost matrix given previously to calculate the cost of the layout. The cost of material handling is calculated as:

$$C = \sum_{i=1}^{n} \sum_{j=1}^{n} F_{ij} C_{ij} D_{ij} \qquad (3)$$

Where

C = the cost of material handling,

F_{ij} = Flow of products between departments i and j,

C_{ij} = Unit cost between departments i and j for each flow,

D_{ij} = Rectilinear distance between departments i and j,

One weakness of this approach is that the traveled distance is evaluated by the rectilinear distance calculation method. Meaning, the material transported assumes to follow the X and Y coordinate distances between the centroids of the two departments under consideration. However, the actual distance traveled is more than the rectilinear distance between the departments. Finally, the program uses the above formula to display the material handling cost of the existing production layout is 2886 birr per month, as shown in Figure 4.8.

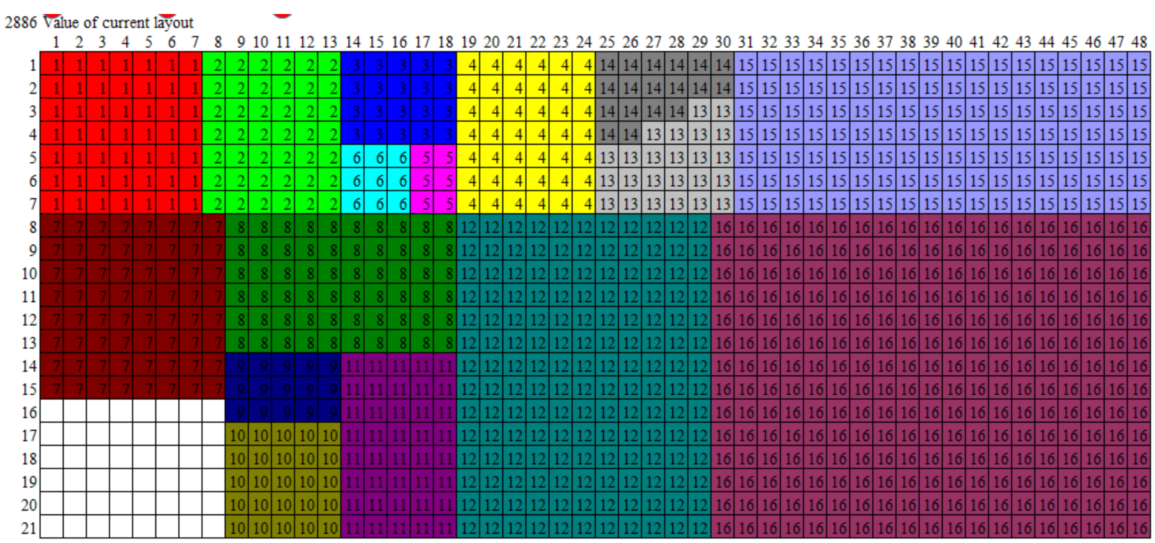

Figure 4. 8 Excel Add-in Existing Production Layout

4.5.1 Flow of Existing Production Layout between Department

When clicking the show flows button, the flow of lines between departmental centroids is displayed. The thick line indicates a large flow cost between cutting to raw material stored and other departments, while the thin line shows a relatively small flow cost between departments shown in Figure 4.9.

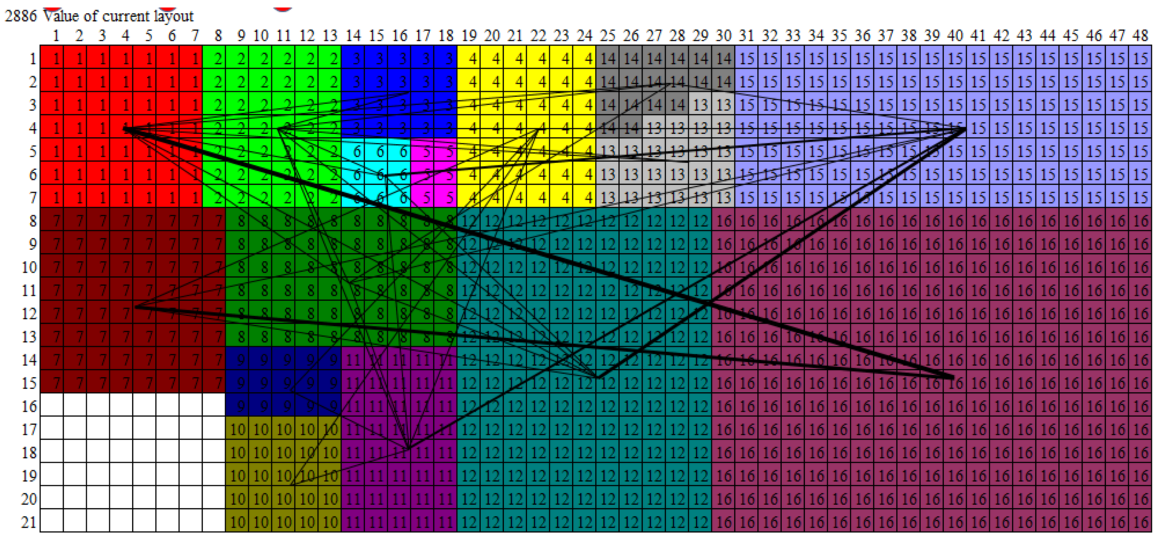

Figure 4. 9 Show Flow Lines for Existing Layout

4.5.2 ProModel Simulation for the Existing Production Layout

The simulation model is used to decide the average product moving time. The case company is manufacturing twenty-seven products. However, there are twenty-three entities with similar operation processes. It simulates eight entities in one model, since the simulation program only accepted eight entities. Therefore, three models were developed for the existing layout in similar department location, simulation time, but different product operation processes and entities. The model requires the available departments with the current layout arrangement, number of manufactured products, each product operation process, department distance, and the time required to move their products between departments. However, the basic requirements for the development of ProModel simulation are location, entities, process, arrivals, and average time in move logic (Suhardini & Rahmawati, 2019). The simulation hour is 208 hours since the company has been performing its operations per month. The simulation model and overall existing production layout simulation results are shown in Figure 4.10 and Table 4.8 respectively.

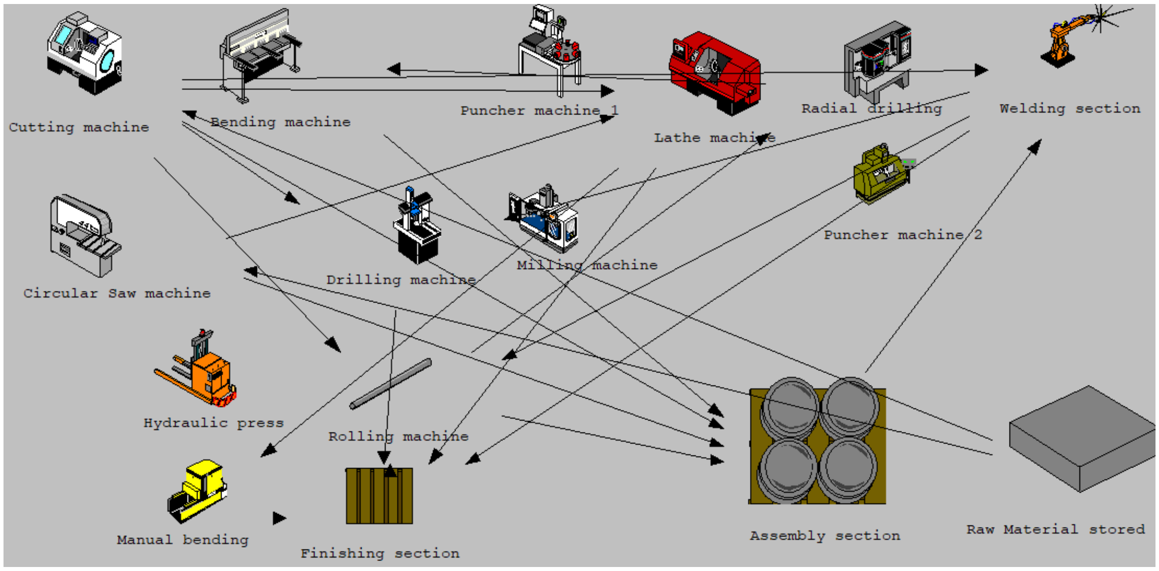

Figure 4. 10 Existing Layout Simulation Model

Overall, general simulation reports of the existing layout are shown in Table 4.8

Table 4. 8 Existing Layout Handling Time Simulation Outputs

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Water and gas tanker	9.00	0.00	27.78	25.99
Surface Steel Casing	24.00	0.00	54.20	52.84
J bolt	22.00	0.00	31.62	31.62
Window and Door	47.00	0.00	90.43	89.83
Plate and under sluice gate	31.00	0.00	34.91	33.65
Main canal gate	3.00	0.00	5.79	3.76
Secondary canal gate	2.00	0.00	3.67	3.67
Stove mold	3.00	0.00	8.98	6.38

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Handwashing facilities and suggestion box	5.00	0.00	10.78	10.78
Concrete mold	2.00	0.00	4.19	4.19
Notice board	2.00	0.00	5.64	4.25
Kitchen stove	3.00	0.00	4.37	4.37
Concrete wall cover slab with handles	6.00	0.00	10.83	10.83
Pump cover	6.00	0.00	11.97	6.51
Base support	6.00	0.00	11.28	11.28
Clamp	6.00	0.00	14.68	14.04

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Cover support	6.00	0.00	14.13	12.75
Raising main support	6.00	0.00	10.83	10.83
Holder	6.00	0.00	10.73	10.73
Galvanized bolt	6.00	0.00	5.69	5.69
Galvanized solar panel Cchannel connector and Lbracket u channel	5.00	0.00	8.25	8.25
Galvanized U Bolt with torus	1.00	0.00	1.48	1.48
Metal shelf	6.00	0.00	20.37	16.19

Total average time in move logic for the existing layout = 355.3 minutes

4.6 Proposed Production Layout

As shown in the existing production layout, flow lines between each department have been installed without considering the flow of products. This leads to high travel distances and high costs for performing the required operations. As a result, it is better to design the production layout considering departmental interrelationships and the operation process. The techniques used are CORELAP followed by the CRAFT Excel Add-in algorithm, as can be discussed in the methodology section. Hence, the CORELAP algorithm ARC was developed by using average monthly production volume as stated in Figure 4.3. The monthly production rating range and percentage rating are shown in Table 4.9 (Deshpande et al., 2016).

Table 4. 9 Activity Relationship Chart Rating Range

	Monthly production rating range	**Available number in the chart**	**Rating**	**Percentage rating**
1	>=122	1	A	0.83%
2	(122-53]	6	E	5%
3	(53-11]	12	I	10%
4	(11-1]	18	O	15%
5	<1	82	U	68.34%
6		1	X	0.83%
Total		120		100%

4.6.1 Activity Relationship Chart for the Proposed Production Layout

The monthly production volume between each department is shown in Figure 4.3 from to chart. Based on monthly production volume develop an activity relationship analysis. For the analysis, the closeness ratings (A, E, I, O, U, X) are assigned to the relationships between the sixteen departments. The activity relationship chart is then drawn by rating A for high parts/product flow, such as raw material stored and the cutting department having a high volume of parts being transported between them. That is a total of 122 materials transported per month, as shown in Figure 4.3. Therefore, the highest ranking has been given to A for their relationship. For interdepartmental relationships having less material flow or no material flow between them, given U and X ratings, signifying there is undesirable closeness. The ARC is drawn in the form of a rhombus shape and consists of two parts in a single shape. The left side shows the reasons for the relationship between departments, which are designated numerically, and the right side is the relationship between departments. The level of importance and the activity relationship chart are shown in Table 4.10 and Figure 4.11 respectively.

Table 4. 10 Level of Importance and Reasons for Movement

Level of importance	**Code**		**Code**	**Reason**
Absolutely necessary	A		1	Flow sequence
Especially important	E		2	Facilities migration
Important	I		3	Not related
Ordinary	O			
Unimportant	U			
Undesirable	X			

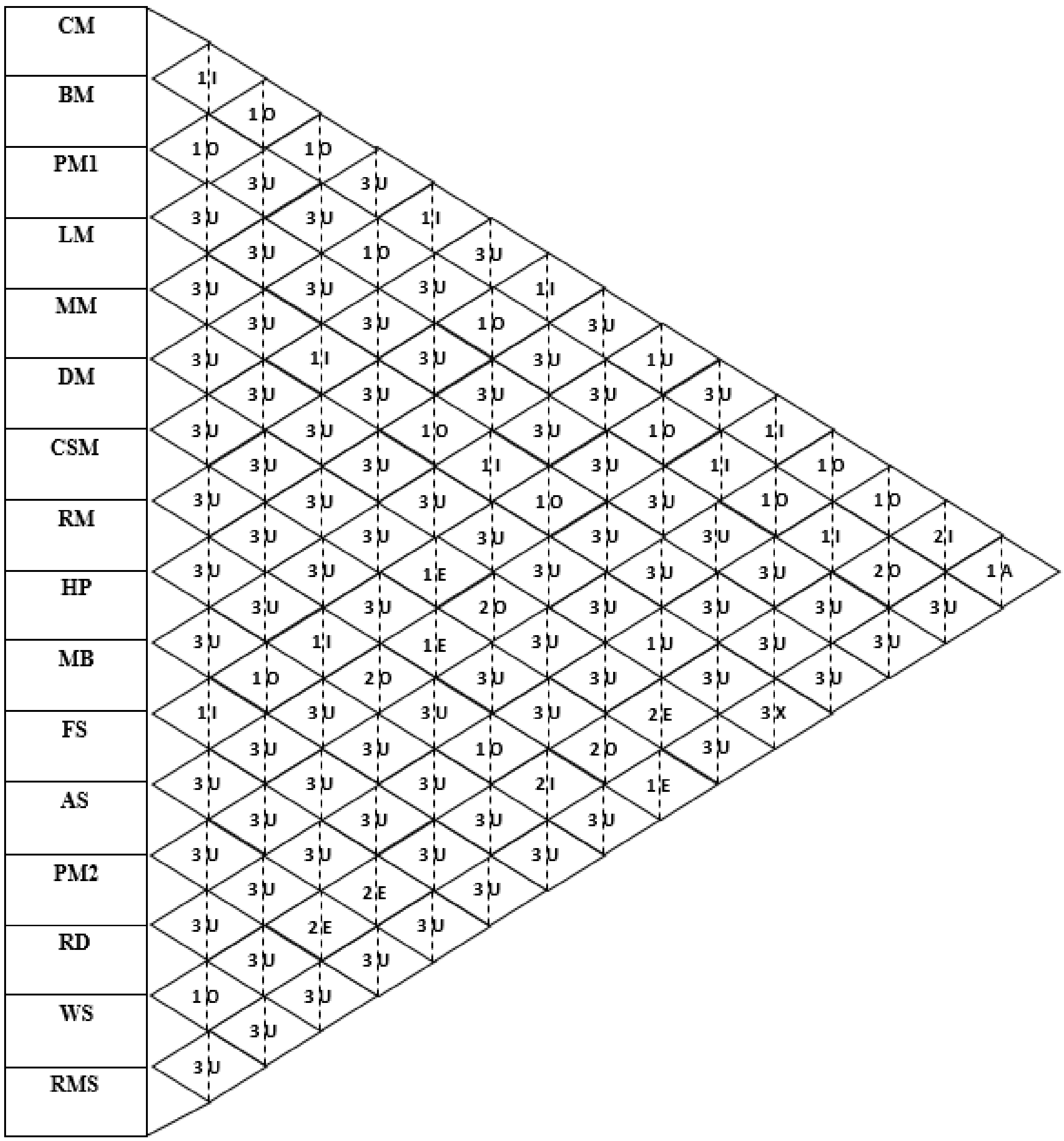

Figure 4. 11 Activity Relationship Chart

4.6.2 CORELAP Department Sequencing Procedures

Assigning numerical values to the closeness rating as A = 4, E = 3, I = 2, O = 1, U = 0 and X =-1, then computing the TCR value of each department. After evaluating TCR, the greatest TCR value was selected, the next department was sequenced to satisfy the highest closeness rating with the selected departments to the closeness priorities A > E > I > O > U. Departments having an X relationship with selected departments are labeled as the last. The TCR and department sequence developed using ARC are shown in Figure 4.12.

	Department relationship																**Summary**						**TCR**	**Order**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	A	E	I	O	U	X		
1	-	I	O	O	U	I	U	I	U	U	U	I	O	O	I	A	1	0	5	4	5	0	18	1
2	I	-	O	U	U	O	U	O	U	U	O	I	O	I	O	U	0	0	3	6	6	0	12	8
3	O	O	-	U	U	U	U	U	U	U	U	U	U	U	U	U	0	0	0	2	13	0	2	14
4	O	U	U	-	U	U	I	U	O	I	O	U	U	U	U	U	0	0	2	3	10	0	7	10
5	U	U	U	U	-	U	U	U	U	U	U	U	U	U	U	X	0	0	0	0	14	1	-1	16
6	I	O	U	U	U	-	U	U	U	U	E	O	U	U	E	U	0	2	1	2	10	0	10	6
7	U	U	U	I	U	U	-	U	U	U	U	E	U	U	O	E	0	2	1	1	11	0	9	3
8	I	O	U	U	U	U	U	-	U	U	I	O	U	O	I	U	0	0	3	3	9	0	9	9
9	U	U	U	O	U	U	U	U	-	U	O	U	U	U	U	U	0	0	0	2	13	0	2	15
10	U	U	U	I	U	U	U	U	U	-	I	U	U	U	U	U	0	0	2	0	13	0	4	11
11	U	O	U	O	U	E	U	I	O	I	-	U	U	U	E	U	0	2	2	3	8	0	13	7
12	I	I	U	U	U	O	E	O	U	U	U	-	U	U	E	U	0	2	2	2	9	0	12	4
13	O	O	U	U	U	U	U	U	U	U	U	U	-	U	U	U	0	0	0	2	13	0	2	13
14	O	I	U	U	U	U	U	O	U	U	U	U	U	-	O	U	0	0	1	3	11	0	5	12
15	I	O	U	U	U	E	O	I	U	U	E	E	U	O	-	U	0	3	2	3	7	0	16	5
16	A	U	U	U	X	U	E	U	U	U	U	U	U	U	U	-	1	1	0	0	12	1	6	2

Figure 4. 12 Total Closeness Rating and Department Sequence

Therefore, the sequence of the departments is **1-16-7-12-15-6-11-2-8-4-10-14-13-3-9-5.**

4.6.3 CORELAP Department Placement Procedure using Placement Rating

The first department is selected based on the highest TCR value placed in the middle. The next department is placed by evaluating PR value based on the adjacent and touching conditions of neighboring departments with the selected department for all possible locations around the current layout. The new department is located based on the greatest PR value. Continue this procedure until all departments are placed. The first entering department placement is shown in Figure 4.13, located in the center of the production floor.

The department sequence is **1-16-7-12-15-6-11-2-8-4-10-14-13-3-9-5** and the department relationship rating value is A=4, E=3, I=2, O=1 and X=-1. Thus, department 1 is located first, as shown in Figure 4.13.

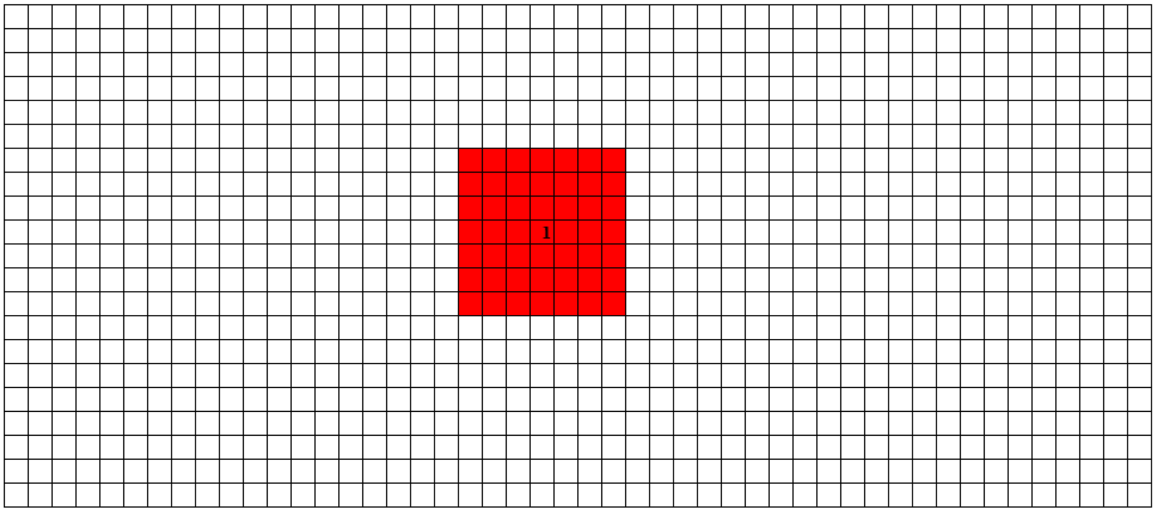

Figure 4. 13 Cutting Department Placement

Next, enter department 16, which has an absolute relationship with the cutting department shown in Figure 4.14.

$PR_1 = A_{[1, 16]} = 4$

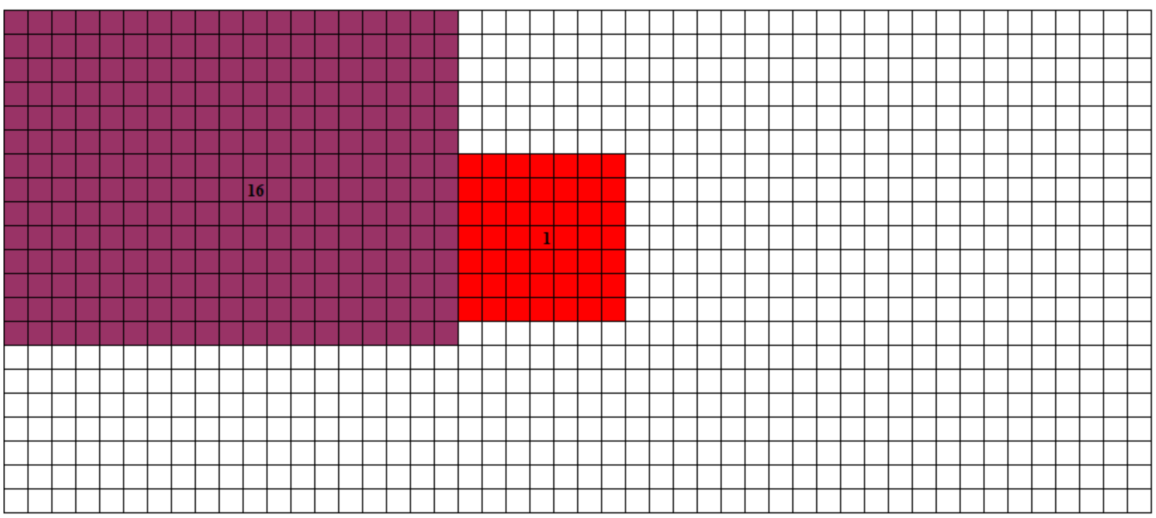

Figure 4. 14 Raw Material Stored Department Placement

Next, enter department 7. That is $PR_2 = E_{[16, 7]} = 3$ and $PR_3 = U_{[1, 7]} = 0$. Therefore, select the highest PR value that is PR_2. Department 7 is located next to department 16 rather than department 1, as shown in Figure 4.15.

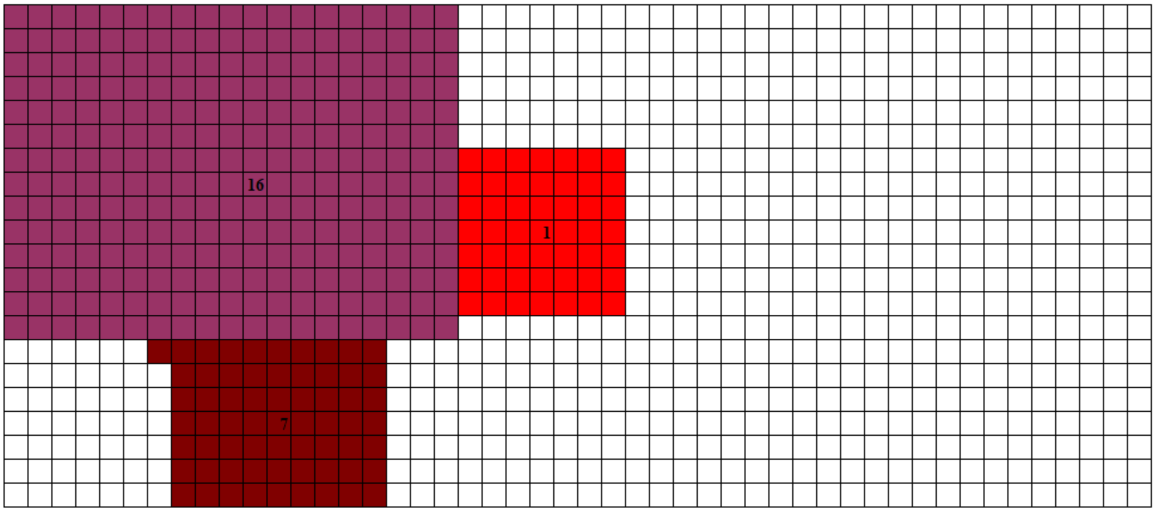

Figure 4. 15 Circular Saw Department Placement

Department 12 is an entering department, but it has an essential relationship with departments one and seven. It is possible to locate between departments 1 and 7, as shown in Figure 4.16.

$PR_4 = I_{[1, 12]} + E_{[7, 12]} = 2+3=5$

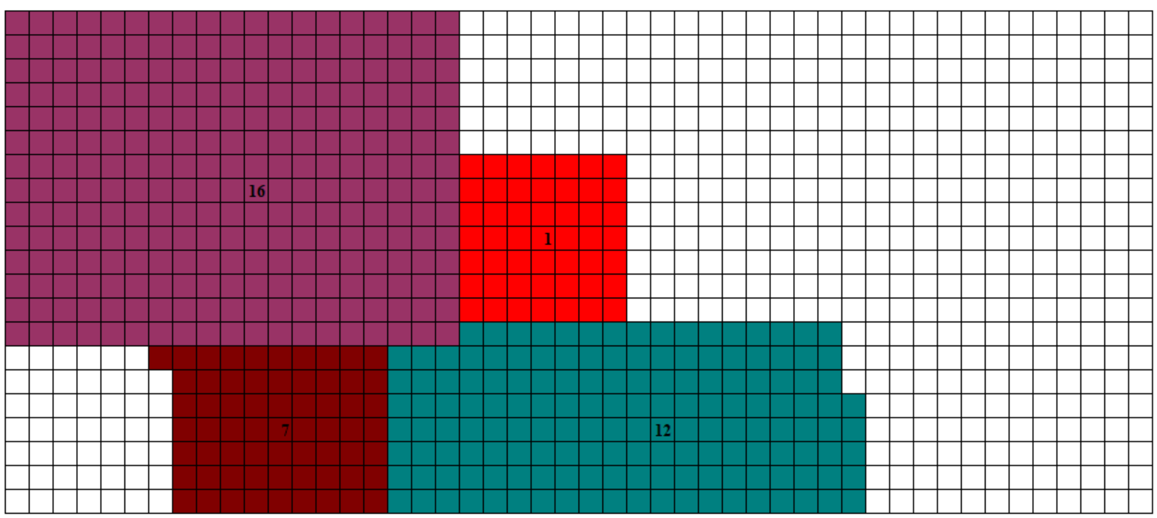

Figure 4. 16 Assembly Department Placement

Next, entering department 15 has a relationship with departments one, twelve, and seven, while the highest PR value is obtained in PR_5. Hence, department fifteen is located neighbor to departments one and twelve, shown in Figure 4.17.

$PR_5 = I_{[1, 15]} + E_{[12, 15]} = 2+3=5$ and $PR_6 = I_{[1, 15]} + O_{[7, 15]} = 2+1=3$ select PR_5

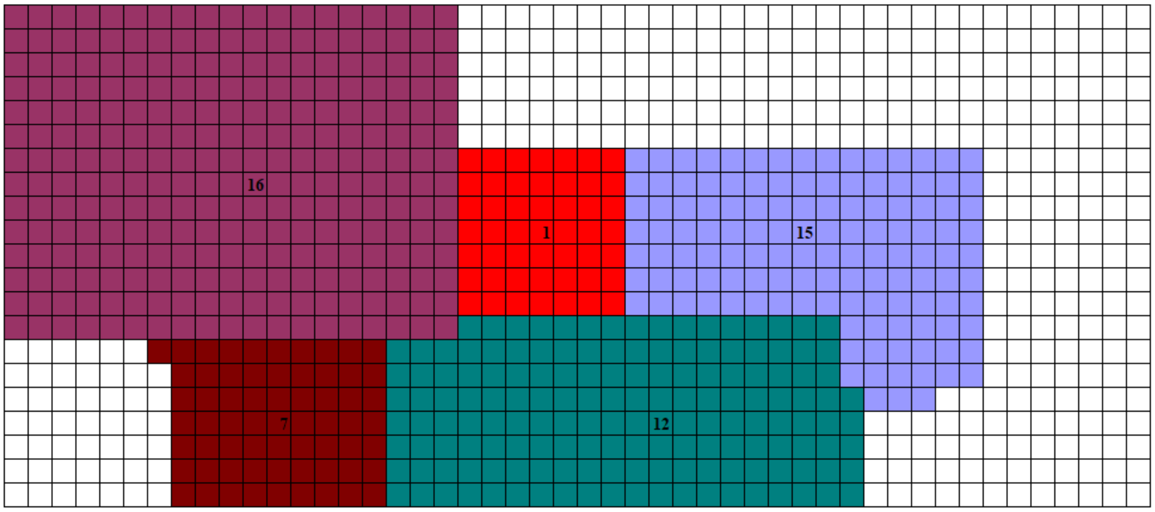

Figure 4. 17 Welding Department Placement

Then, enter department 6, which has a relationship with departments one, fifteen, and twelve. However, the highest relationship is obtained in PR_6 so that the department can be located considering this relationship as shown in Figure 4.18.

$PR_6 = I_{[1, 6]} + E_{[15, 6]} = 2/2+3=4$ and $PR_7 = O_{[12, 6]} + E_{[15, 6]} = 1+3=4$ select PR_6

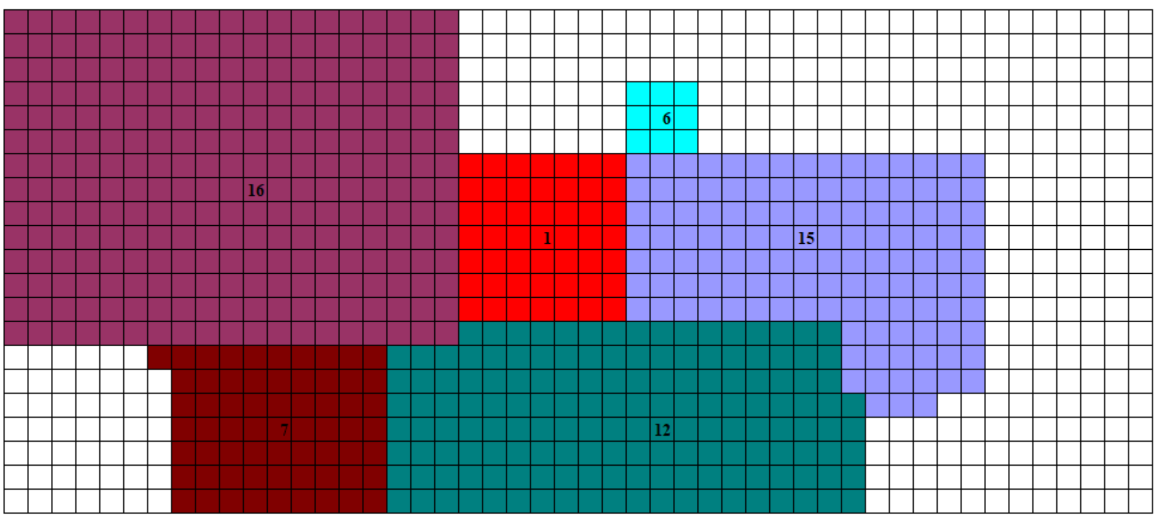

Figure 4. 18 Drilling Department Placement

Department 11 is located after department six places. It has an essential relationship with both departments six and eleven. Therefore, department 11 is placed between departments six and eleven, as shown in Figure 4.19.

$PR_8 = E_{[6, 11]} + E_{[15, 11]} = 3+3=6$

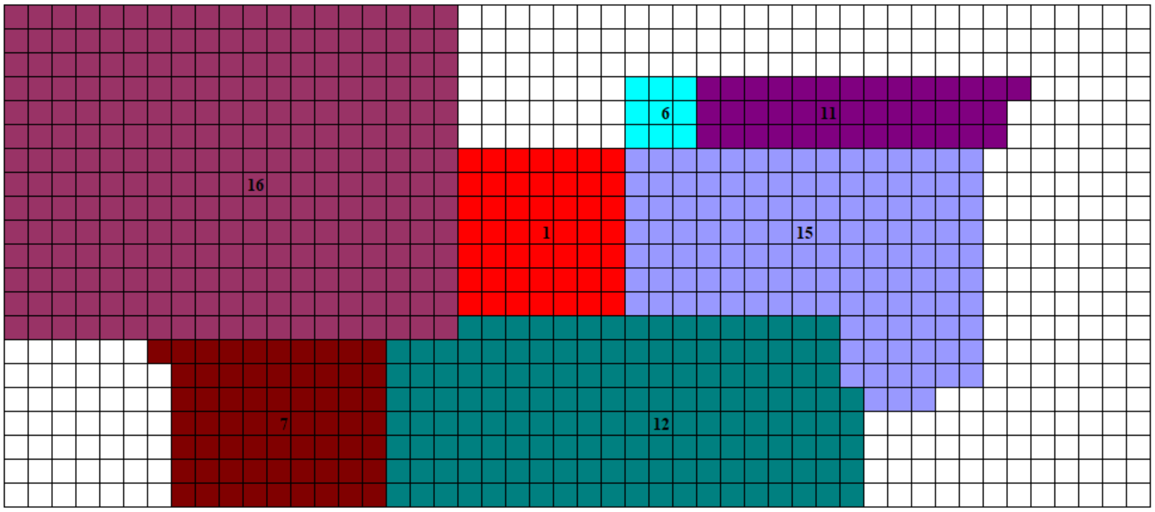

Figure 4. 19 Finishing Department Placement

Next, entering department 2 has an important and ordinary relationship with departments twelve and fifteen. Its PR value is three and it is located near departments twelve and fifteen, as shown in Figure 4.20.

$PR_9 = I_{[12, 2]} + O_{[15, 2]} = 2+1=3$

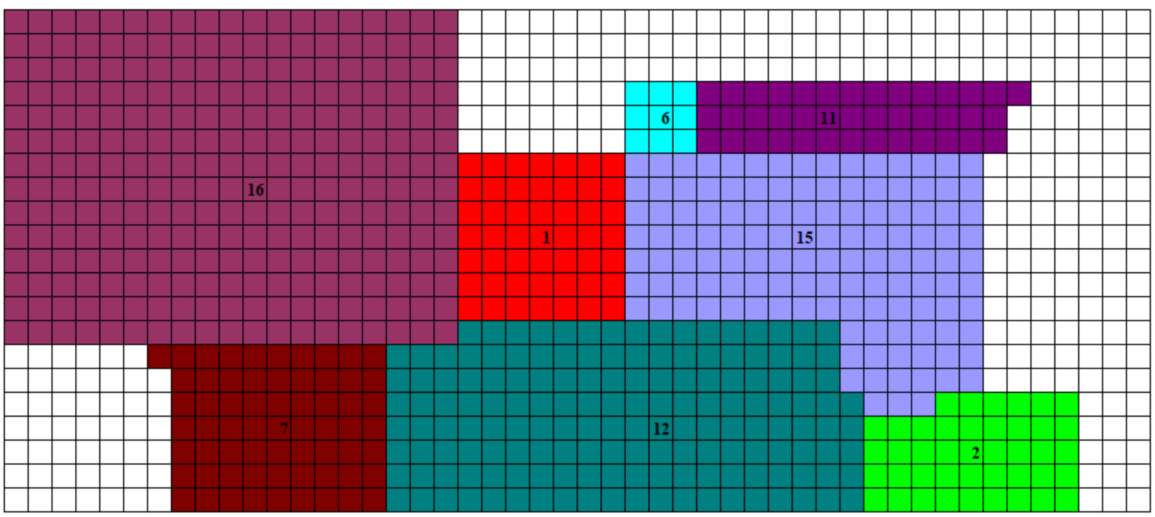

Figure 4. 20 Bending Department Placement

The next step is to enter department 8, has two PR values that are PR10 and PR11. However, the highest PR value was obtained in PR10 with an important and ordinary relationship to department fifteen, two respectively. The location of department eight is shown in Figure 4.21.

$PR_{10} = I_{[15, 8]} + O_{[2, 8]} = 2+1=3$ and $PR_{11} = I_{[1, 8]} = 2$ select PR_{10}

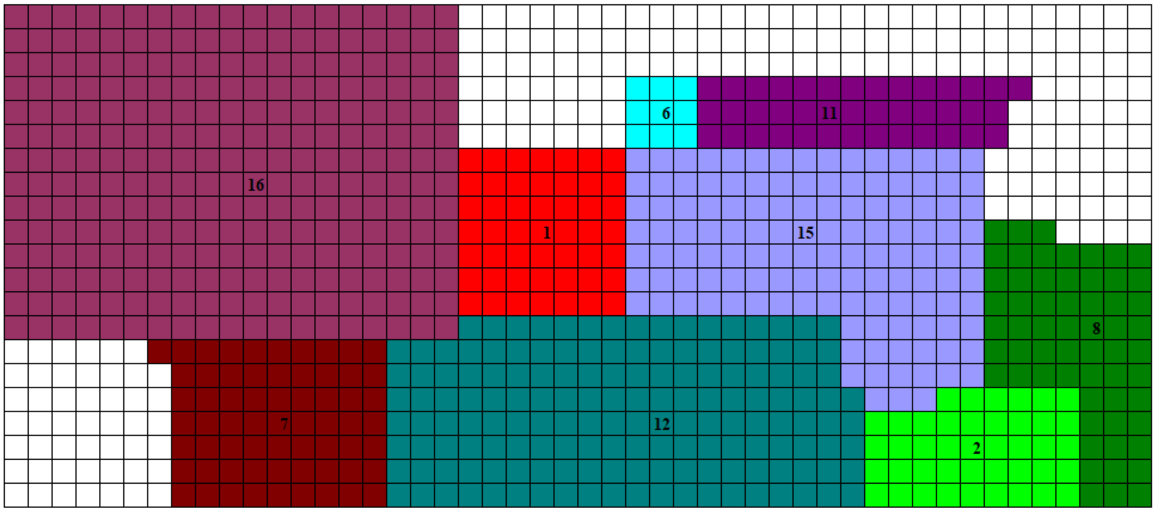

Figure 4. 21 Rolling Department Placement

Next, enter department 4, which has an ordinary relationship with both departments one and eleven. Therefore, select PR_{12} based on designer choice as shown in Figure 4.22.

$PR_{12} = O_{[1, 4]} = 1$ and $PR_{13} = O_{[11, 4] =}$ 1 select PR_{12}

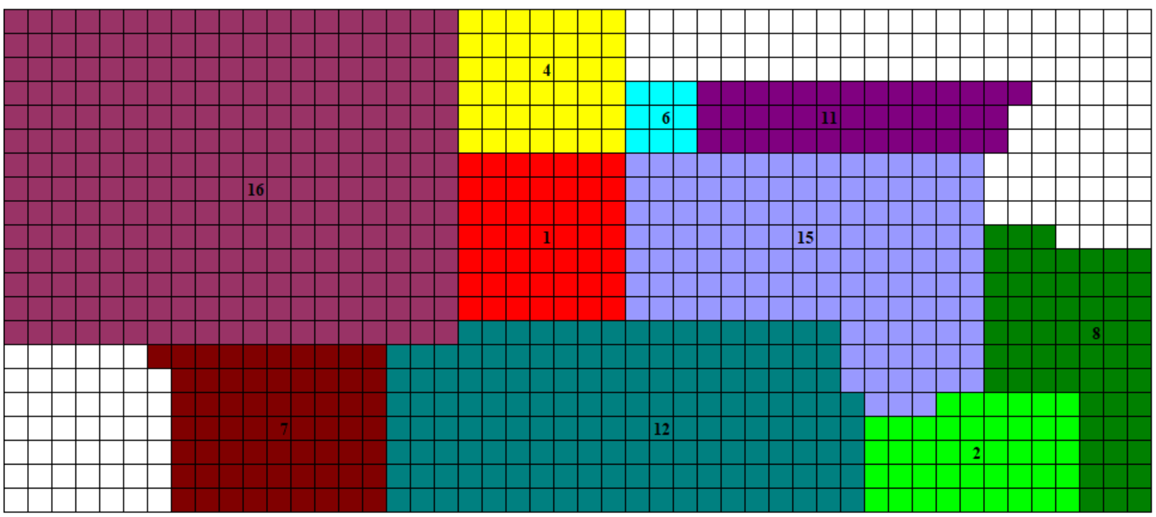

Figure 4. 22 Lathe Department Placement

Department 10 is located after department 4 placed as a result it has an important relationship with departments eleven and four. Therefore, it can be located near departments eleven and four, as shown in Figure 4.23.

$PR_{14} = I_{[11, 10]} + I_{[4, 10]} = 2+2=4$

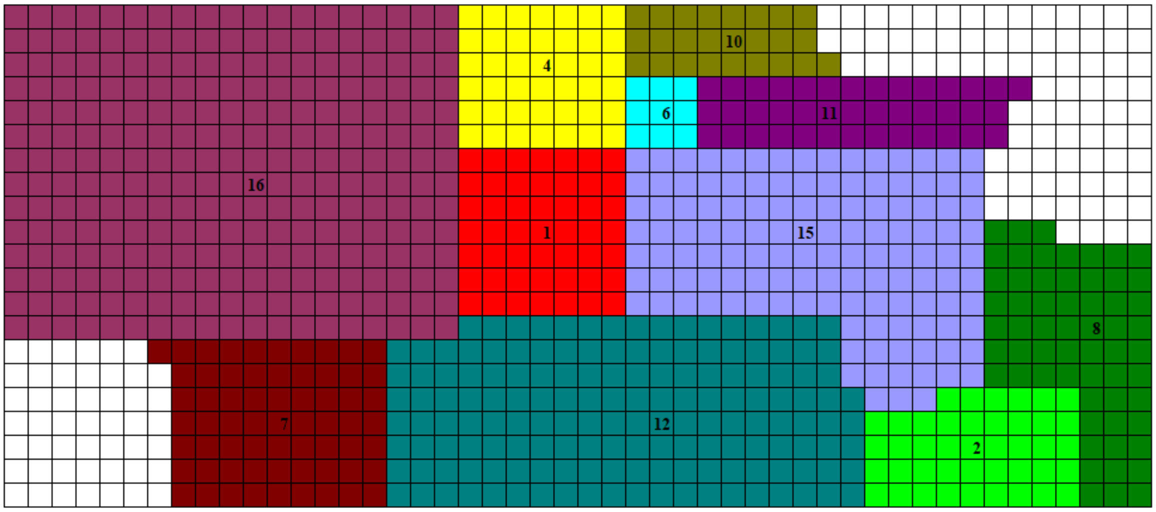

Figure 4. 23 Manual Bending Department Placement

Then, enter department 14, placed between departments fifteen and eight, which is an ordinary relationship with department fourteen shown in Figure 4.24.

$PR_{15} = O_{[15, 14]} + O_{[8, 14]} = 1+1=2$

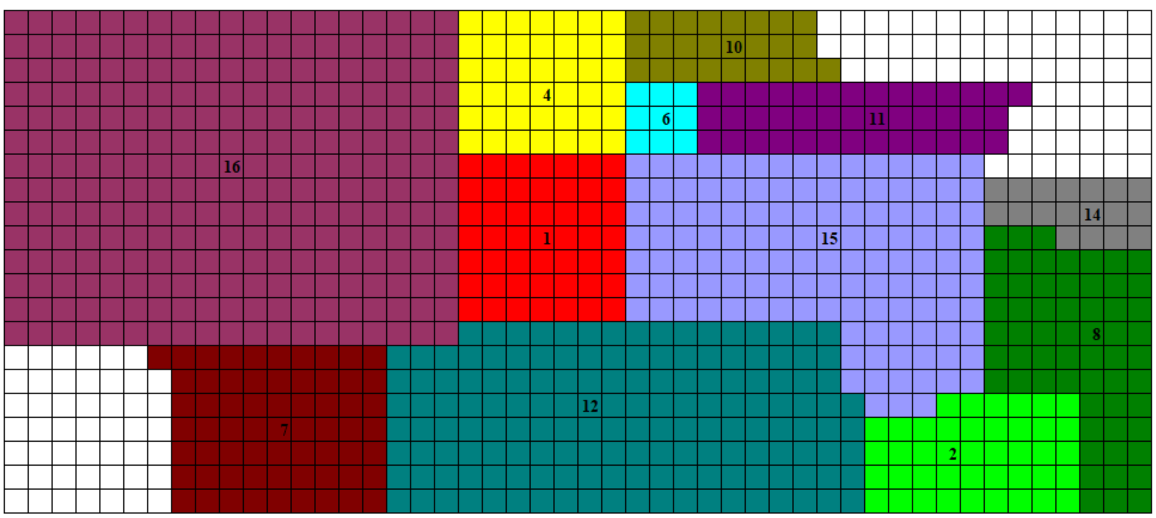

Figure 4. 24 Radial Drilling Department Placement

Next entering department 13

$PR_{16} = U_{[10, 13]} + U_{[11, 13]} = 0$

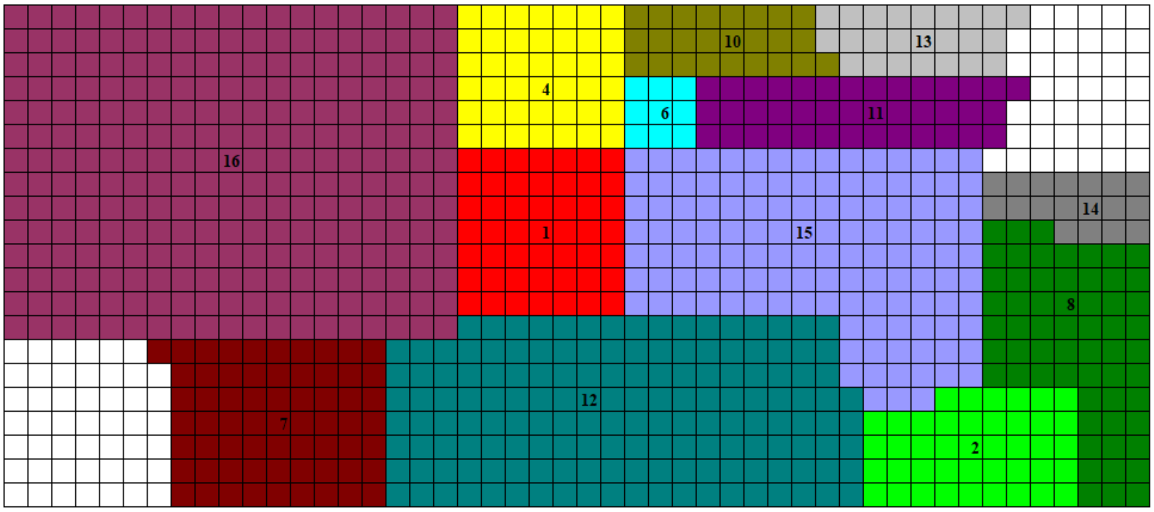

Figure 4. 25 Puncher Machine 2 Placement

Next entering department 3

PR_{17}= unimportant relationship between the department

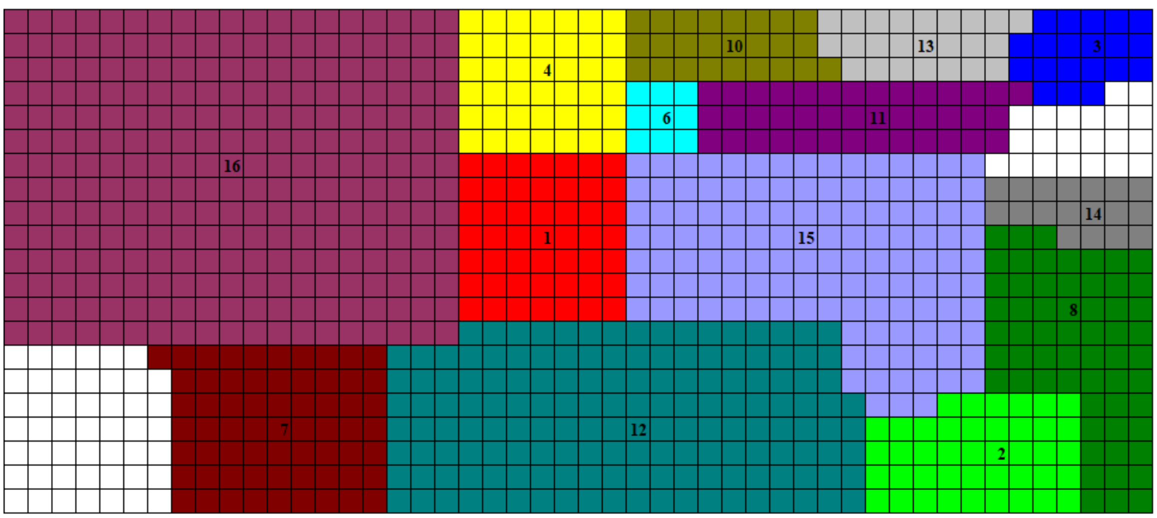

Figure 4. 26 Puncher Machine One Placement

Next, entering department 9 has ordinary relations with department eleven; therefore, it can be located in this relation as shown in Figure 4.27.

PR_{18}= $O_{[11, 9]} = 1$

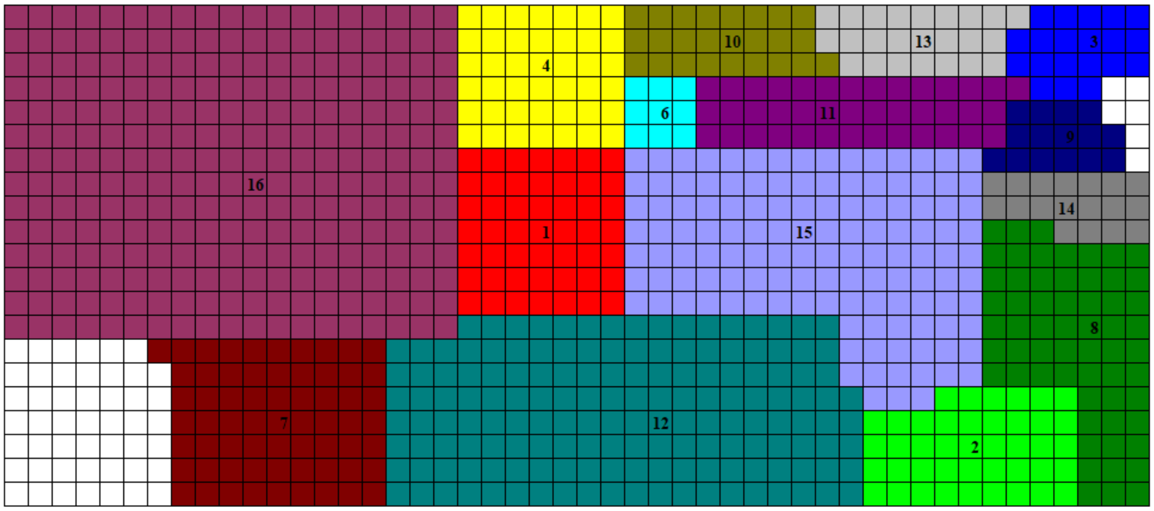

Figure 4. 27 Hydraulic Press Department Placement

Finally, entering department 5 has an unimportant relationship with all departments, especially an undesirable relationship with department sixteen. The placement of department five is shown in Figure 4.28.

PR_{19}= unimportant relationship between the department

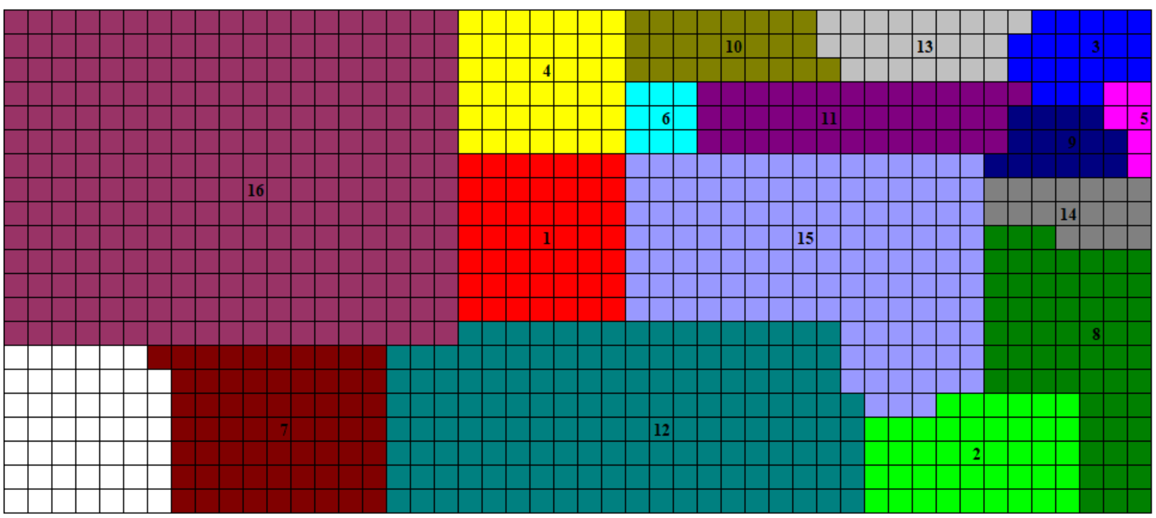

Figure 4. 28 Milling Department Placement and Proposed Layout

The proposed production layout is shown in Figure 4.28. However, to reduce the movement costs, use the CRAFT excel add-in by exchanging two departments which have common adjacency between departments. The required data is similar to the existing production layout but only differs in rectilinear distance due to departments being arranged according to their relationship. As a result, the unit cost matrix should be changed.

4.6.4 Centroid of Proposed Layout

The area of each department and designated colors are similar to the existing production layout, but the X and Y centroid are different because departments are placed considering the production volume and operation sequence shown in Table 4.11.

Table 4. 11 Proposed Layout Centroid

Department	Color	Area-required	Area-defined	x-centroid	y-centroid
CM	1	49	49	22.5	9.5
BM	2	42	42	40.7142868	18.6428566
PM1	3	20	20	45.0499992	1.85000002
LM	4	42	42	22.5	3
MM	5	6	6	47.1666679	4.66666651
DM	6	9	9	27.5	4.5
CSM	7	64	64	11.421875	17.453125
RM	8	60	60	44.9000015	14.1999998
HP	9	15	15	44.1666679	5.63333321
MB	10	25	25	30.1800003	1.53999996
FS	11	40	40	35.6749992	4.4749999
AS	12	154	154	25.9805202	17.1168823
PM2	13	24	24	38.3333321	1.41666663
RD	14	18	18	44.8333321	8.33333302
WS	15	126	126	34.2380943	10.3809528
RMS	16	266	266	9.5	7

The monthly production flow of the proposed production layout is similar to the existing production layout shown in Figure 4.29.

FROM \ TO	CM	BM	PM1	LM	MM	DM	CSM	RM	HP	MB	FS	AS	PM2	RD	WS	RMS
CM		12	6	3		33		14				35	6	5	11	
BM						6					5	21			8	
PM1		6														
LM									1	22	3					
MM																
DM											91	2				
CSM				29								53			6	
RM		2									24	3		9		
HP											1					
MB											22					
FS																
AS															114	
PM2		6														
RD		14														
WS						54		24			58			3		
RMS	122						88									

Figure 4. 29 Proposed Layout From to Chart Matrix

4.6.5 Unit Cost for Proposed Layout

The movement cost is 0.00368 birr per meter as evaluated in the existing production layout. However, the rectilinear distance between the proposed production layout of the cutting department and the bending department is 27.35714 meters, therefore the transportation cost is 27.35714 × 0.00368 yields 0.1007-birr other departments unit cost transportation from to matrix shown in Figure 4.30.

TO

FROM	CM	BM	PM1	LM	MM	DM	CSM	RM	HP	MB	FS	AS	PM2	RD	WS	RMS
CM		0.1007	0.1111	0.0239	0.1086	0.0368	0.07	0.0997	0.094	0.0576	0.067	0.0408	0.088	0.0865	0.0464	0.057
BM	0.1007		0.0778	0.1246	0.0752	0.1007	0.1122	0.0318	0.0606	0.1017	0.0707	0.0598	0.0722	0.0531	0.0542	0.1577
PM1	0.1111	0.0778		0.0003	0.0005	0.0003	0.0004	0.0004	0.0001	0.0002	0.0004	0.0003	0.0002	0.0003	0.0002	0.0002
LM	0.0239	0.1246	0.0003		0.0969	0.0239	0.094	0.1236	0.0894	0.0336	0.0539	0.0648	0.0641	0.1018	0.0704	0.0626
MM	0.1086	0.0752	0.0005	0.0969		0.073	0.1786	0.0434	0.0146	0.074	0.043	0.1238	0.0445	0.0221	0.0686	0.1472
DM	0.0368	0.1007	0.0003	0.0239	0.073		0.1068	0.0997	0.0655	0.001	0.0302	0.0408	0.0512	0.0779	0.0464	0.0754
CSM	0.07	0.1122	0.0004	0.094	0.1786	0.1068		0.1352	0.164	0.1276	0.137	0.0548	0.158	0.1565	0.11	0.0455
RM	0.0997	0.0318	0.0004	0.1236	0.0434	0.0997	0.1352		0.0342	0.1008	0.0697	0.0804	0.0712	0.0218	0.0533	0.1568
HP	0.094	0.0606	0.0001	0.0894	0.0146	0.0655	0.164	0.0342		0.0665	0.0355	0.1092	0.037	0.0124	0.054	0.1326
MB	0.0576	0.1017	0.0002	0.0336	0.074	0.001	0.1276	0.1008	0.0665		0.031	0.0728	0.0305	0.0789	0.0475	0.0962
FS	0.067	0.0707	0.0004	0.0539	0.043	0.0302	0.137	0.0697	0.0355	0.031		0.0822	0.021	0.0479	0.027	0.1056
AS	0.0408	0.0598	0.0003	0.0648	0.1238	0.0408	0.0548	0.0804	0.1092	0.0728	0.0822		0.1032	0.1017	0.0552	0.0979
PM2	0.088	0.0722	0.0002	0.0641	0.0445	0.0512	0.158	0.0712	0.037	0.0305	0.021	0.1032		0.0494	0.0481	0.1267
RD	0.0865	0.0531	0.0003	0.1018	0.0221	0.0779	0.1565	0.0218	0.0124	0.0789	0.0479	0.1017	0.0494		0.0465	0.1349
WS	0.0464	0.0542	0.0002	0.0704	0.0686	0.0464	0.11	0.0533	0.054	0.0475	0.027	0.0552	0.0481	0.0465		0.1035
RMS	0.057	0.1577	0.0002	0.0626	0.1472	0.0754	0.0455	0.1568	0.1326	0.0962	0.1056	0.0979	0.1267	0.1349	0.1035	

Figure 4. 30 Unit Cost Matrix for Proposed Layout

When entering all the above-required data, the CRAFT Excel Add-in program displays departments with their designated color and area. The material handling costs were also evaluated in the program, resulting in 755 birrs per month as shown in Figure 4.31.

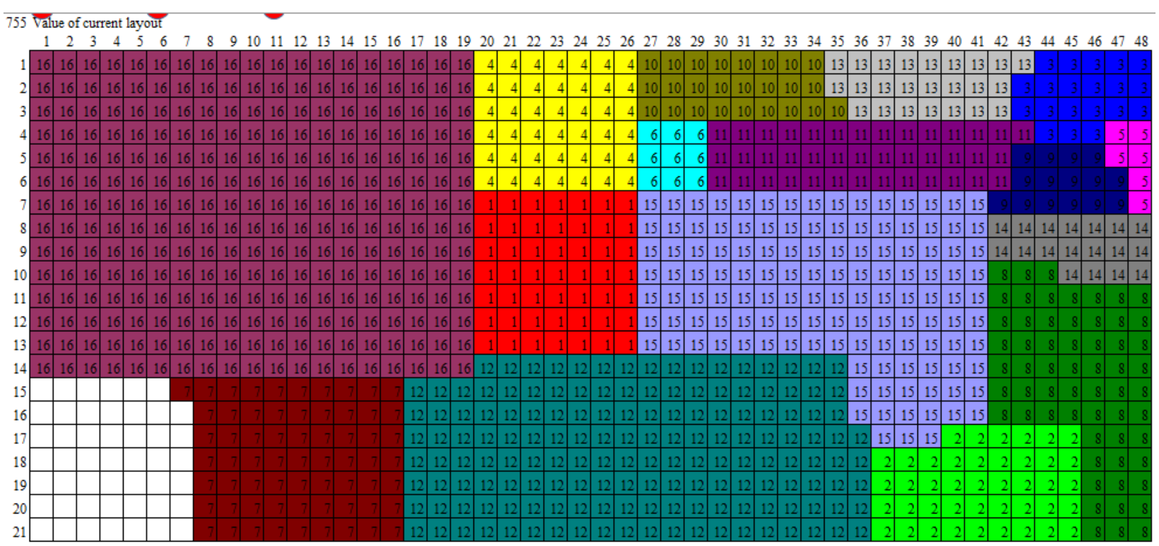

Figure 4. 31 Proposed Layout Initial Solution

4.6.6 Improve Proposed Production Layout in CRAFT Excel Add-in

The program starts the optimization process and selects the best switch between departments that can bring the highest savings in the layout cost. Before making the switch, the program asks the user if the change was made by the dialog box shown in Figure 4.32.

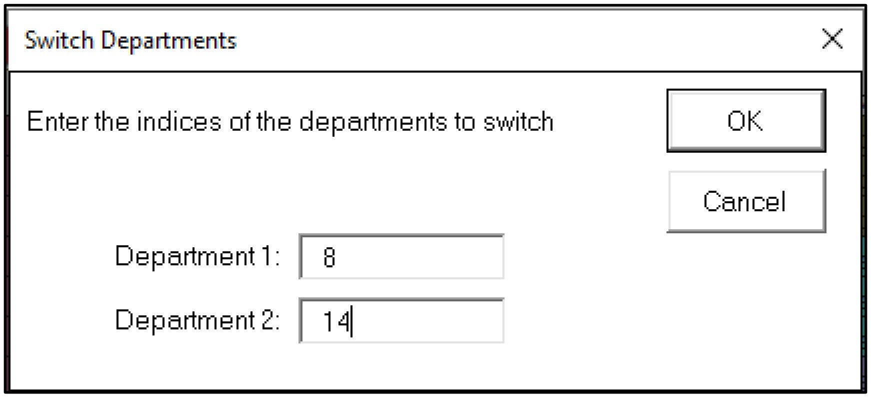

Figure 4. 32 Switching Department 8 and 14

Once the user selects the best switch that is rolling, radial drilling department considering departments having common boundaries, press an OK button, then the final proposed production layout, and its material handling cost is 741 birrs per month as displayed in Figure 4.33.

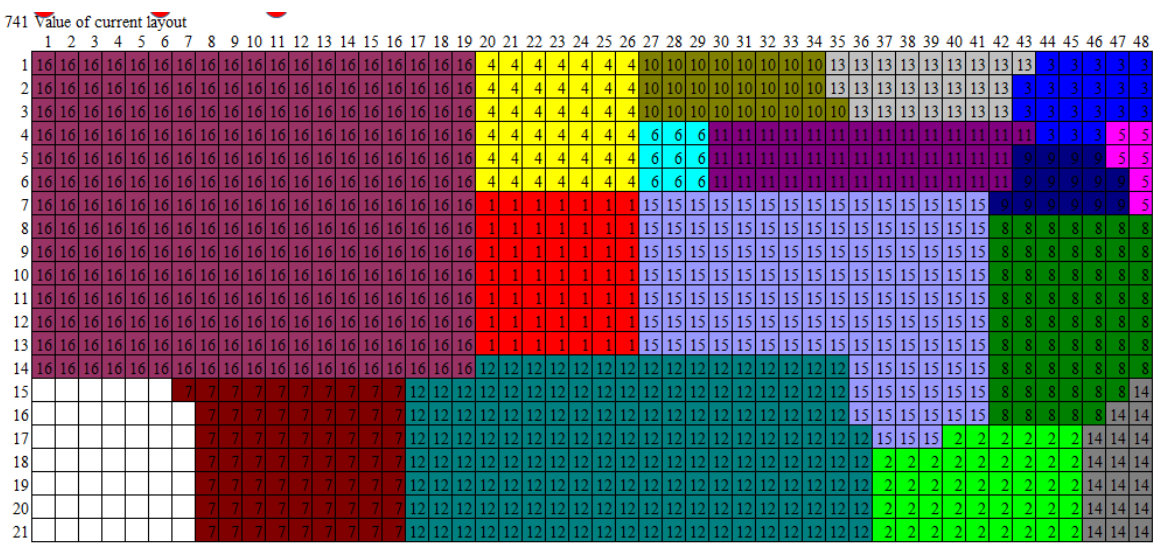

Figure 4. 33 Final Proposed Production Layout

The final proposed production layout solid work layout are shown in Figure 4.34

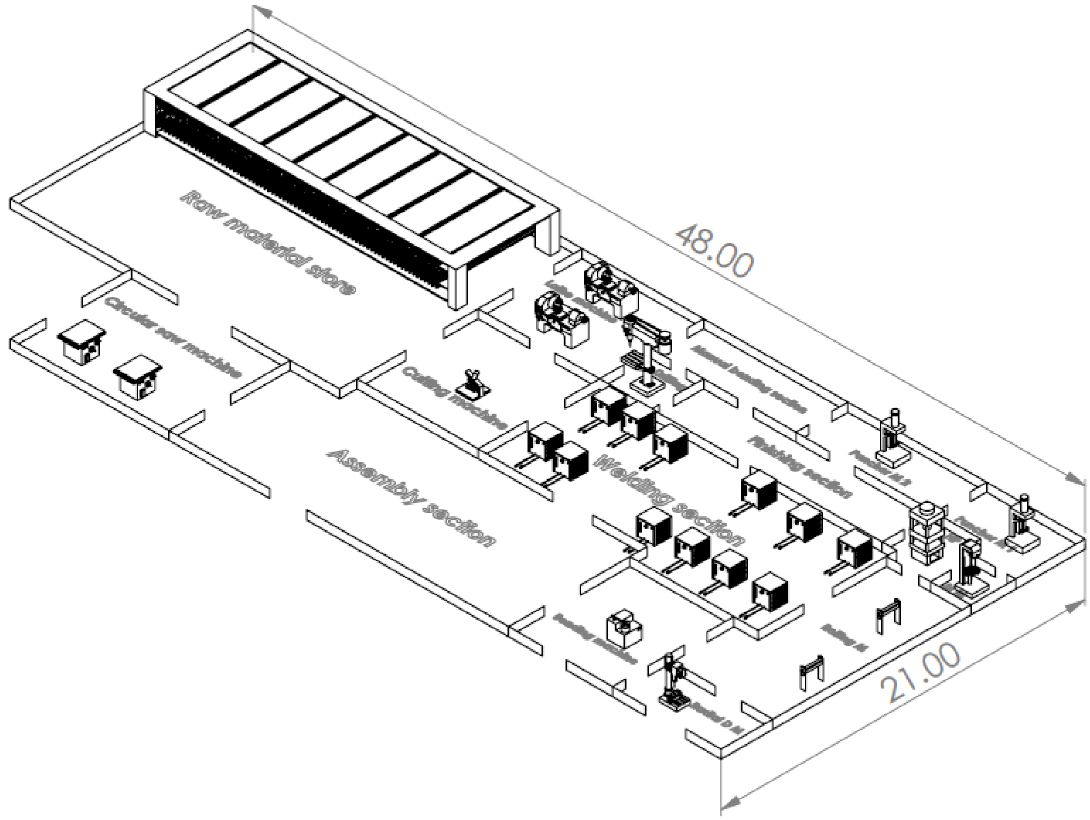

Figure 4. 34 Final Proposed Production Layout

4.6.7 ProModel Simulation for Proposed Production Layout

The simulation model is used to decide on products' average product moving time. The model requires the available departments with the proposed layout arrangement, number of manufactured products per month, each product operation process, department distance, and the time to move products between departments. However, the simulation hour is 208 Hr since the case company used this time to manufacture products per month.

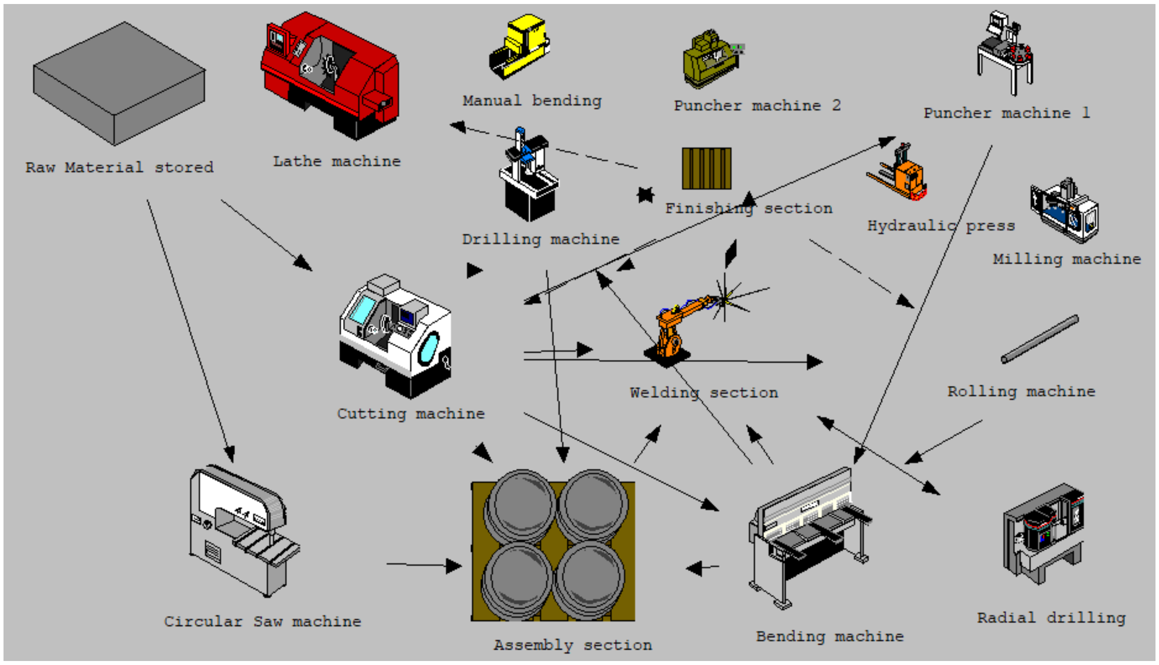

Figure 4. 35 Proposed Layout Simulation Model

Overall, general simulation reports for the proposed layout are shown in Table 4.12.

Table 4. 12 Proposed Layout Handling Time Simulation Outputs

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Water and gas tanker	9.00	0.00	13.24	13.13
Surface Steel Casing	24.00	0.00	23.09	22.81
J bolt	22.00	0.00	18.89	18.66
Window and Door	47.00	0.00	45.39	45.34
Plate and under sluice gate	31.00	0.00	16.31	15.97
Main canal gate	3.00	0.00	1.68	1.68
Secondary canal gate	2.00	0.00	1.50	1.50
Stove mold	3.00	0.00	3.93	3.93

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Handwashing facilities and suggestion box	5.00	0.00	4.77	4.77
Concrete mold	2.00	0.00	2.21	2.21
Notice board	2.00	0.00	2.67	1.80
Kitchen stove	3.00	0.00	2.21	2.21
Concrete wall cover slab with handles	6.00	0.00	3.25	3.25
Pump cover	6.00	0.00	8.61	7.19
Base support	6.00	0.00	4.55	4.55
Clamp	6.00	0.00	9.87	9.87

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Cover support	6.00	0.00	5.93	4.49
Raising main support	6.00	0.00	5.96	5.96
Holder	6.00	0.00	4.55	4.55
Galvanized bolt	6.00	0.00	3.48	3.48
Galvanized solar panel C channel connector and L bracket u channel	5.00	0.00	5.65	5.65
Galvanized U Bolt with torus	1.00	0.00	1.10	1.10
Metal shelf	6.00	0.00	10.58	9.16

Total average time in move logic for the proposed layout = 193.27 minutes

Therefore, the average time spent on moving logic (handling time) between the existing and proposed layout has been saved by 162.03 minutes per month.

4.6.8 Proposed Layout Production Volume Increment Handling Time

Production capacity is one of the layout measurement criteria since an effective plant layout affects production capacity directly or indirectly (Besbes, Affonso, Zolghadri, Masmoudi, & Haddar, 2017). Assume the production capacity will be enhanced by double when the company works more on market assessment and promotion. Therefore, the simulation outputs for the proposed production layout volume increments are shown in Table 4.13.

Table 4. 13 Proposed Layout Volume Increment Handling Time Simulation Outputs

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)
Water and gas tanker	18.00	0.00	34.19	26.26
Surface Steel Casing	48.00	0.00	52.55	45.61
J bolt	44.00	0.00	38.90	37.33
Window and Door	94.00	0.00	91.30	90.68
Plate and under sluice gate	62.00	0.00	33.38	31.95
Main canal gate	6.00	0.00	3.98	3.36
Secondary canal gate	4.00	0.00	19.28	2.99
Stove mold	6.00	0.00	17.30	7.86
Handwashing facilities and suggestion box	10.00	0.00	9.54	9.54
Concrete mold	4.00	0.00	4.42	4.42
Notice board	4.00	0.00	5.34	3.61
Kitchen stove	6.00	0.00	4.41	4.41
Concrete wall cover slab with handles	12.00	0.00	6.51	6.51
Pump cover	12.00	0.00	17.23	14.39
Base support	12.00	0.00	9.39	9.10
Clamp	12.00	0.00	19.74	19.74
Cover support	12.00	0.00	9.59	8.98
Raising main support	12.00	0.00	12.14	11.92
Holder	12.00	0.00	9.10	9.10
Galvanized bolt	12.00	0.00	9.23	6.96
Galvanized solar panel C channel connector and L bracket u channel	10.00	0.00	11.30	11.30
Galvanized U Bolt with torus	2.00	0.00	2.20	2.20
Metal shelf	12.00	0.00	18.61	18.31

4.6.9 Summary of Existing and Proposed Layout

The existing and final proposed layout results are summarized in layout performance measurement as researchers stated in terms of material handling cost, handling time, production volume and distance traveled to transport produced products within departments shown in Table 4.14.

Table 4. 14 Summarized Results of Existing and Proposed Production Layout

Cost	**Existing Layout**	**Proposed Layout**
Total Material Handling Cost	2884 birr	741 birr
Time	**Existing Layout**	**Proposed Layout**
Handling Time	355.3 minutes	193.27 minutes
Distance traveled in meter	**Existing Layout**	**Proposed Layout**
From Cutting to Bending	6.5	27.36
From Cutting to Puncher Machine 1	13.5	30.2
From Cutting to Lathe	17.5	6.5
From Cutting to Drilling	13	10
From Cutting to Rolling	16	23.68
From Cutting to Assembly	30.5	11.1
From Cutting to Puncher Machine 2	25.25	23.92
From Cutting to Radial Drilling	24.94	32.56
From Cutting to Welding	35.5	12.62
From Bending to Drilling	6.5	27.34
From Bending to Finishing	19	19.21
From Bending to Assembly	24	16.26
From Bending to Welding	29	14.74
From Puncher Machine 1 to Bending	7	21.13
From Lathe to Hydraulic Press	21.5	24.3
From Lathe to Manual Bending	25.5	9.14
From Lathe to Finishing	19	14.65
From Drilling to Finishing	12.5	8.2
From Drilling to Assembly	17.5	11.1
From Circular Saw to Lathe	24.5	25.53
From Circular Saw to Assembly	22.5	14.9
From Circular Saw to Welding	42.5	29.89
From Rolling to Bending	9.5	10.98
From Rolling to Finishing	9.5	15.53
From Rolling to Assembly	14.5	24.19
From Rolling to Radial Drilling	21.94	8.87
From Hydraulic Press to Finishing	13.5	9.65
Form Manual Bending to Finishing	6.5	8.43
From Assembly to Welding	26	14.99
From Puncher Machine 2 to Bending	18.75	19.61
From Radial Drilling to Bending	18.44	6.6
From Welding to Drilling	26.5	12.62
From Welding to Rolling	32.5	11.06
From Welding to Finishing	37	7.34
From Welding to Radial Drilling	14.33	19.94
From Raw Material Stored to Cutting	45.5	15.5
From Raw Material Stored to Circular Saw	37.5	12.38
Total Distance	785.65 meter	612.02 meter

Percentage of efficiency in distance traveled reduction

$$=\frac{Existing\ Layout\ distance - Proposed\ Layout\ distance}{Existing\ Layout\ distance} \times 100 \qquad (4)$$

$$= \frac{785.65-612.02}{785.65} \times 100\%$$

= 22.1%

Percentage of efficiency in material handling cost reduction

$$= \frac{Existing\ Layout\ Cost - Proposed\ Layout\ Cost}{Existing\ Layout\ Cost} \times 100\% \qquad (5)$$

$$= \frac{2886 - 741}{2886} \times 100\%$$

= 74.32%

4.7 Cost-Benefit Analysis between Existing and Proposed Layout

The study will be of benefit to the company when it is implement in FEC. To perform the cost-benefit analysis, zmline 30-ton crane, mechanic and laborers select to arrange the available machines. Cutting, bending, lathe, drilling, milling, puncher machine 1, puncher machine 2, radial drilling, rolling, and hydraulic machines were placed on a level production floor without digging the concrete floor. Due to this, a crane with mechanic and laborers select to dismantle and reinstall the proposed location to reduce the rearrangement time and continue the production process without more delay. Other machines such as manual bending, circular saw cutting, air compressors, and welding machines, are simple in weight and easy to dismantle and relocate with human power. Apart from this, the first assumption is that the rearrangement task of the layout will be taken as a project and delegated to a consulting firm having the skills, experience, and capability to take on the challenges. The consultant selection for the project will be undertaken by FEC. Mart posted to invite competitive consultants or if the company has a consultant that is capable of undertaking the rearrangement in a qualified manner, then the project is given to that consultant.

After the consultant has been selected, the cost of the project should be estimated. The project requires one crane for four hours, even though the cost of the crane is 2200 birr per hour. Additionally, one mechanic and two laborers were needed for three days and paid 320 birr for the mechanic and 180 birr per day for labor, as shown in Table 4.15.

Table 4. 15 Total Project Cost

No.	Reasons for cost	Quantity	Cost per quantity per day	Cost per day
1	Mechanic	1	320	320
2	Laborers	2	180	360
Total cost per day for mechanic and laborers				680
Total cost per three days for mechanic and laborers				2,040
No.	**Reasons for cost**	**Quantity**	**Cost per hour**	**Cost per four hour**
3	Crane	1	2,200	8,800
Total project cost				10,840 birr

There are also other costs like production floor adjustment and utilities, miscellaneous costs, and contingency costs. For this case, production floor adjustment and utilities cost are considered 15%, miscellaneous costs 10%, and contingency costs 5% of the total cost of the project.

Production floor adjustment and utilities cost = 1,626 birr

Miscellaneous cost = 1,084 birr

Contingency cost = 542 birr

The total estimated cost of the project is the summation of all the above costs. As a result, the total cost of the project will be:

10,840 birr + 1,626 birr + 1,084 birr +542 birr = 14,092 birr

Therefore, the total cost of the project is estimated at 14,092 birr. As a result, FEC should give the project to the consultant based on this consideration.

However, the material handling cost of the existing production layout is 2886 birr per month, compared to 741 birr for the proposed layout. As a result, the saving in material handling costs is 2145 birr per month. This means the number of months required to compensate for the cost incurred in layout arrangement implementation of the project will be 7 months approximately. Therefore, after seven months, the cost would reach its breakeven point and start profiting.

4.8 Results and Discussion

4.8.1 Important of the Research in Process and Product Layout Industries

Since a variety of products in low volume are manufactured in job shop process industries, however, the workers travel more due to frequently interrelation departments being located far apart. Moreover, distance, material handling cost, manufacturing lead-time, space utilization, operation efficiency, employee safety, and manufacturing costs are the major layout performance measurement criteria (Suhardini & Rahmawati, 2019), (Kulkarni et al., 2015). Job shop process industries use general machines, skilled workers, and must be a flexible operating system for each performed product. Therefore, designing a flexible layout should consider interrelationships between departments in terms of volume flow, operation sequence, and facility movement (Jati, Rahayu, & Salsabila, 2020). However, following effective reasons for developing department relationships increases the performance of the layout. As a result, the study is important for making a solution to the facility layout problem. Not only does FEC, but also other job shop process industries, follow similar procedures. The difference is the product operation process and the number of customized products produced.

As stated in the problem statement, FEC volume flow departments are located far away. Improving the layout by using an improvement algorithm only has not required a significant change since the improvement algorithm exchanges only two departments (Virendra, 2017). Nevertheless, product layout industries are better to select an improvement algorithm rather than a construction algorithm since special-purpose machines are used because this incurs high rearrangement costs. Although, product layout follows the continuous production principle, stoppage of the operation process leads to production loss and customer dissatisfaction as a result choosing improvement algorithm convenient for product layout. In product layout, the products were flowed based on their predefined sequence. Therefore, the optimum sequence solution method and sequential method in the initial solution were selected in CRAFT Excel Add-in. However, traditional crafts and leave blanks are selected for job shop process industries because each product has its own operation process/sequence.

4.8.2 Existing and Proposed Layout Distance Comparison

The existing distance to perform the required operation in FEC was traveled at 785.65 meters, compared to 612.02 meters for the proposed layout. This traveled distance occurs due to the existing layout not considering volume flow, operation process and machine movement (migration). As a result, the study reduced the traveled distance by 22.1%, which has a significant impact on operation efficiency (Priyaranjan Mallick, 2019). Volume flow departments traveled movement shown in Figure 4.36.

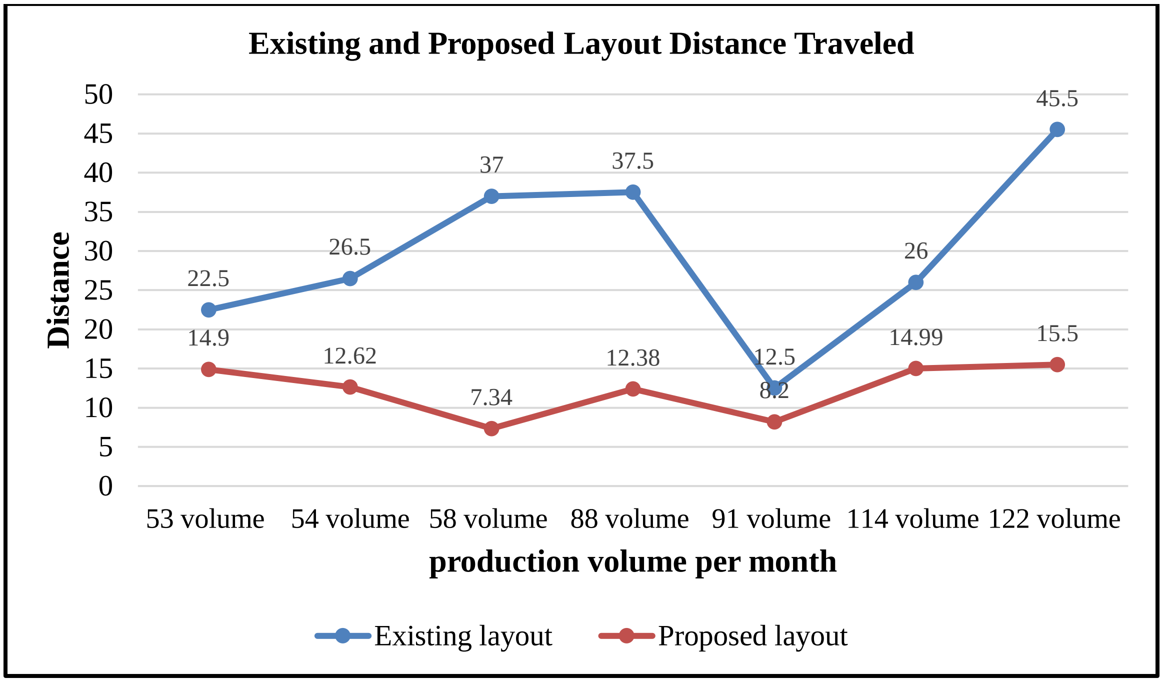

Figure 4. 36 Existing and Proposed Layout Distance Movement

The chart represents the distance traveled for both existing and proposed layouts between 53 and 122 flows of products per month. As shown in the chart, frequently, product flow departments have more movement in the existing layout than in the proposed layout. For instance, 122 parts/products have been transported from raw material stored to the cutting department, but 45.5 meters apart in the existing layout, whereas the proposed layout distance is 15.5 meters, which is reduced by 65.93%. In addition to this, 37.5 meters from raw material stored to the circular saw department in the existing layout but 88-volume flow while the proposed layout traveled 12.38 meters. The distance from the assembly department to the welding department has been moved to 26 meters for the existing layout and 14.99 meters for the proposed layout. However, 114 parts/products have flowed between departments. As a result, the distance traveled by 42.35%

(K.Balasundaram et al., 2016). Additionally, 12.5 meters were apart from the drilling to finishing department, but 91 products were transported per month while reduced to 8.2 meters for the proposed layout. By default in 91 production volume there is slightly distance difference between the existing and proposed layout since the manufactured products traveled near to the optimal layout. Furthermore, the movement from welding to the finishing department traveled 37 meters but 58 volume per month in the existing layout, but 7.34 meters for the proposed layout. Moreover, the existing layout traveled movement between welding and drilling departments was located 26.5 meters apart, but 54 parts/product flow instead of 12.62 for the proposed layout. Finally, 22.5 meters from the circular saw to the assembly departments, 53 products flow in the existing layout, but 14.9 transportation movements for the proposed layout to perform the required operation (Vaibhav Nyati et al., 2017). The graph concludes that the existing layout has more movement while the proposed production layout is reduced because of the layout designed considering flow movement, operation process, and facilities migration.

4.8.3 Existing and Proposed Layout Material Handling Cost Comparison

The total material handling costs for both the existing and the proposed layout were incurred at 2886 and 741 birr per month respectively, as shown in Figure 4.37.

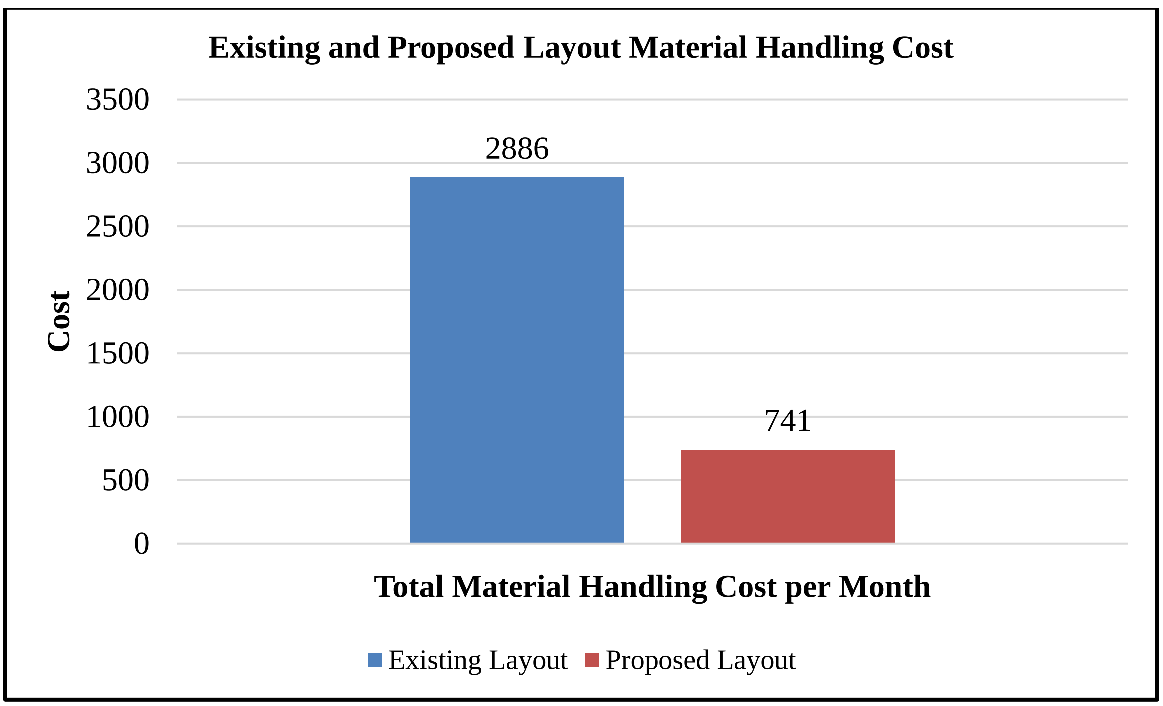

Figure 4. 37 Existing and Proposed Layout Material Handling Cost per Month

The chart concludes that the existing production layout material handling costs are high relative to the proposed production layout. The cause of this handling cost is due to the layout is not considering the material flow, operation sequence, and physical facilities movement. As a result, the proposed production layout total material handling cost per month was reduced by 74.32% (Belachew et al., 2020), (Prasad et al., 2014). Apart from this, the breakeven point analysis was developed using the total project rearrangement cost and the saving cost. As a result, when the company implements the study, it will compensate for the cost incurred after seven months and be the starting point to obtain the benefits shown in Figure 4.38.

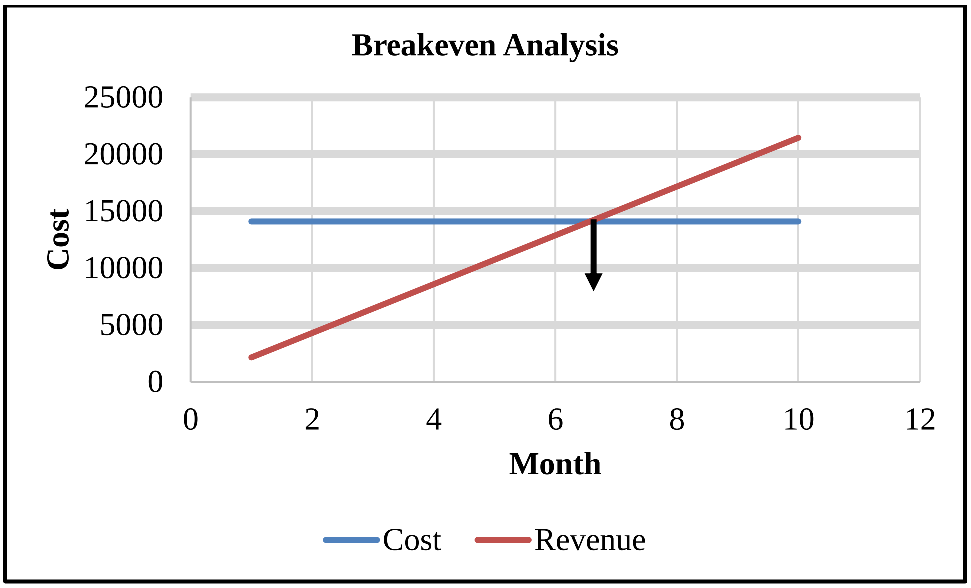

Figure 4. 38 Breakeven Point Analysis

4.8.4 Simulation of Handling Time Outputs

The existing and the proposed layout handling time for FEC products are shown in Figures 4.39 and 4.40 respectively.

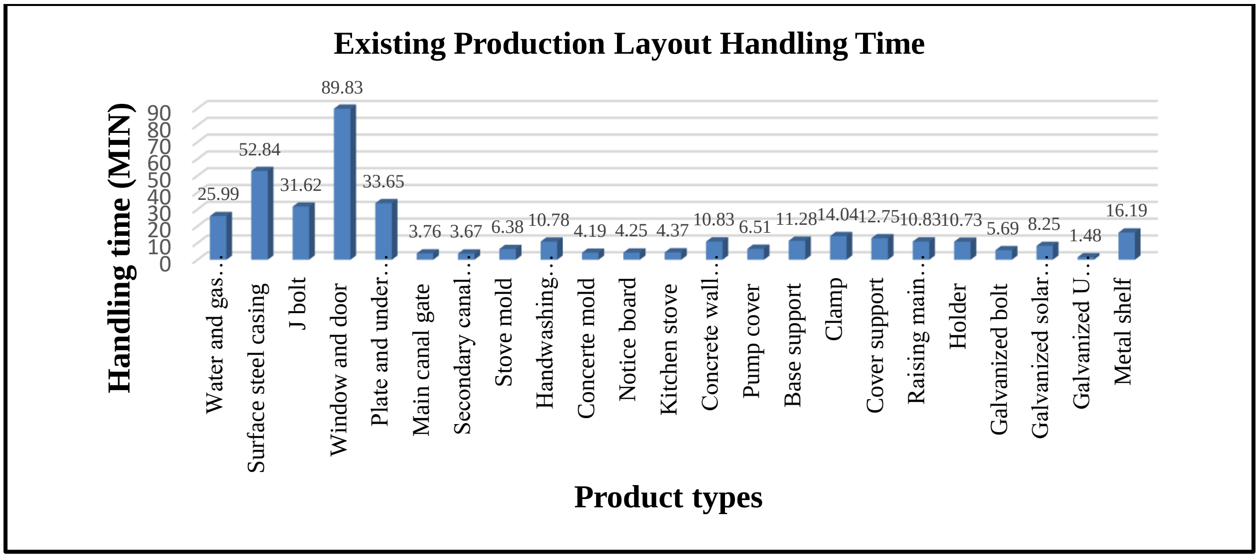

Figure 4. 39 Existing Production Layout Handling Time

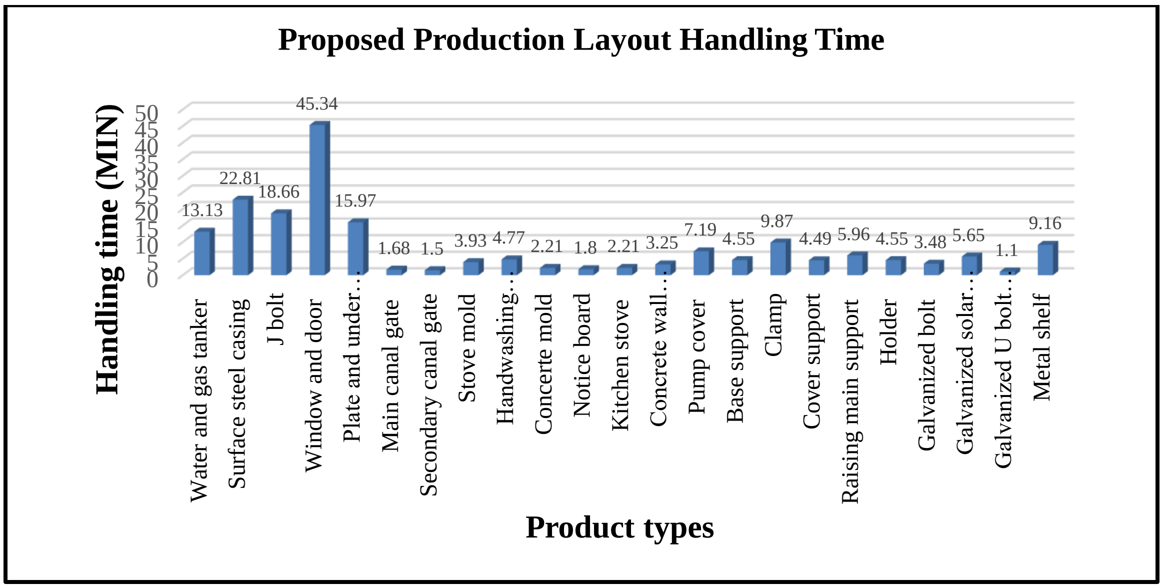

Figure 4. 40 Proposed Production Layout Handling Time

As it can be seen in Figures 4.39 and 4.40, the handling time (move time logic) to transport products from department to department is based on their respective operation process. For instance, the existing and the proposed layout handling time to move products is 355.3 and 193.27 minutes respectively. As a result, the overall existing layout handling time in FEC products is high relative to the proposed layout. This can occur because the layout has not been installed considering the layout principles.

Production capacity is one of the performance measurement criteria in facility layout design. However, assume the production volume increased by double when the company worked more on market assessment and promotion. Therefore, the proposed layout product handling time chart is shown in Figure 4.41.

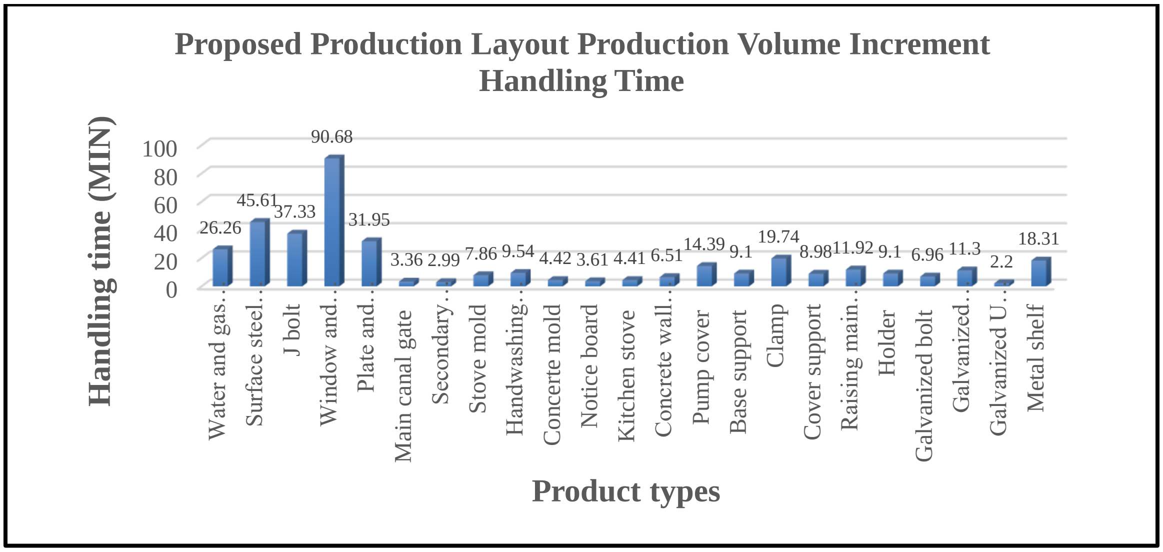

Figure 4. 41 Proposed Production Layout Volume Increment Handling Time

As the simulation output indicates in Figure 4.41, the production volume increase in the proposed layout and required 386.56 minutes for handling time. This means the handling time for the existing layout is 355.3 minutes as shown in Figure 4.39. However, when the production capacity is increased, the handling time is 386.56 minutes in the proposed layout. Therefore, developing an effective layout enhances the production capacity by reducing the handling time.

4.8.5 Summary of Findings

Facility layout design has been found to achieve layout performance such as distance traveled, total material handling cost, manufacturing lead-time, handling time, operational efficiency, worker safety, and improved overall company productivity. However, the study reduced the percentage of efficiency between the existing and proposed production layout for both distance traveled and total material handling costs by 22.1% and 74.32% respectively. In addition to this, the study has improved the material handling time by 162.03 minutes per month and increased the production volume. Although the break-even point of the study to recover the rearrangement costs requires seven months, As a result, following rule of thumb effectively using CORELAP followed by the CRAFT algorithm provides better decisions for facility layout problems by improving the layout performance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study aims to develop a new production layout using a construction and improvement algorithm to optimize the layout of FEC. After careful analysis of the existing and proposed production layout, the following conclusions are drawn.

- The existing production of FEC is less efficient due to frequent interrelation departments that are located far away. To achieve this following the rule of thumb since highly interrelation departments located close to each other. For illustration, raw material storage department has 122 parts/products per month while traveling 45.5 meters. Therefore, transporting volume-flow products long distances has reduced the company's operational efficiency.
- Existing production layout was evaluated by using the CRAFT Excel Add-in program. As a result material handling cost, distance traveled and handling times are 2886 birr per month, 785.65 meters and 355.3 minutes respectively. Then, design the production layout using the CORELAP algorithm, and the total material handling cost is calculated in the CRAFT Excel Add-in its result is 755 birr per month. Still, better results have been obtained, but it can be optimized again.
- Another approach develops the proposed layout by first designing a new production layout in the CORELAP algorithm, then improving it by using the CRAFT Excel Add-in. As a result, the proposed layout material handling cost, distance traveled and handling times are saved by 2145 birr per month, 173.63 meters and, 162.03 minutes respectively. Moreover, the production capacity also enhanced.
- Finally, the new production layout has significant advantages in quantitative and qualitative approaches. The quantitative approach has to reduce the distance traveled, total material handling costs, handling time, and increase production capacity while increasing flexibility, reducing workers' fatigue, and customer satisfaction are qualitative aspects. Apart from this, the proposed layout would have a payback period of seven months to compensate for the total relocation cost and start the required benefit. Therefore, developing a layout using construction and improvement algorithms together rather than as independent applications has achieved both

distance and adjacency objectives simultaneously it is economical and brings optimized solutions.

5.2 Recommendation

Based on the analysis performed, results obtained and conclusions drawn, the following recommendations are proposed to FEC.

- Fasil engineering company should realize that the existing layout is less efficient. Therefore, the company has the awareness that the layout is performing less than expected but has slowed to act on it. The proposed layout has obtained better results than the existing layout. However, no layout can be called the optimal since there might be slightly better than the one on hand due to uncontrollable variables such as manufactured product type, operation process, the volume of product, information flow, and variation of customized products, especially in job shop process industries. Thus, it won't be morally and scientifically genuine to declare that the proposed layout is the only optimal one. However, the company should apply the proposed layout since there is no other better layout in place.
- The construction routine of the new layout and then improving it by improvement routines is effective in designing a new layout. Thus, if FEC plans to redesign a new facility within the existing compound or plans to build another facility. It should use a similar approach to arrive at a near-optimal layout.

5.3 Future Research Areas

After conducting research and analyzing the different aspects of layout design parameters, the following research areas are recommended to be undertaken in the future.

1) Most facility layout problems are dynamic due to different variables being changed from time to time. Hence, considering those variables will design a more reliable and robust plant layout. Additionally, risk variables should be considered for dynamic problems to adjust as per future changes in input variables of the system.
2) Facility layout problems develop the solution using both heuristic algorithms by considering the weight of the finished products when there is used more than one material handling equipment to transport products from station to station.

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APPENDIXES

Appendix A: FEC Manufactured Product Type and Production Volume

	Manufactured product	2010E.C 6months	2011E.C 12 months		2012E.C 12 months		2013E.C 6 months
		From March – August	From September – February	From March – August	From September – February	From March – August	From September – February
1	Water and gas tanker	12	15	28	24	16	13
2	Surface Steel Casing	48	55	46	61	22	57
3	J bolt	440			120		231
4	Window	[illegible]	273	41	152	78	356
5	Door	40	20	154	110	368	96
6	Plate	220	442		92	275	48
7	Under sluice gate	22			13		
8	Main canal gate	44	32		18	4	
9	Secondary canal gate	26	18	14	6		
10	Stob mold				104		
11	Hand washing facilities		6		3	52	4
12	Concrete mold		40		18		14
13	Notice board	4	8	22	20	16	
14	Suggestion box	29		40	32		
15	kitchen stob				104		
16	Concrete wall cover slab with handles	24	156		31		

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17	Pump cover	24	156		31		
18	Base support	24	156		31		
19	Clamp	24	156		31		
20	Cover support	24	156		31		
21	Raising main support	24	156		31		
22	Holder	24	156		31		
23	Galvanized bolt	50				144	
24	Galvanized solar panel c channel					144	
25	L Bracket u channel pipe holder					32	
26	Galvanized u bolt with torus					34	
27	Metal shelf	30		38	84		56

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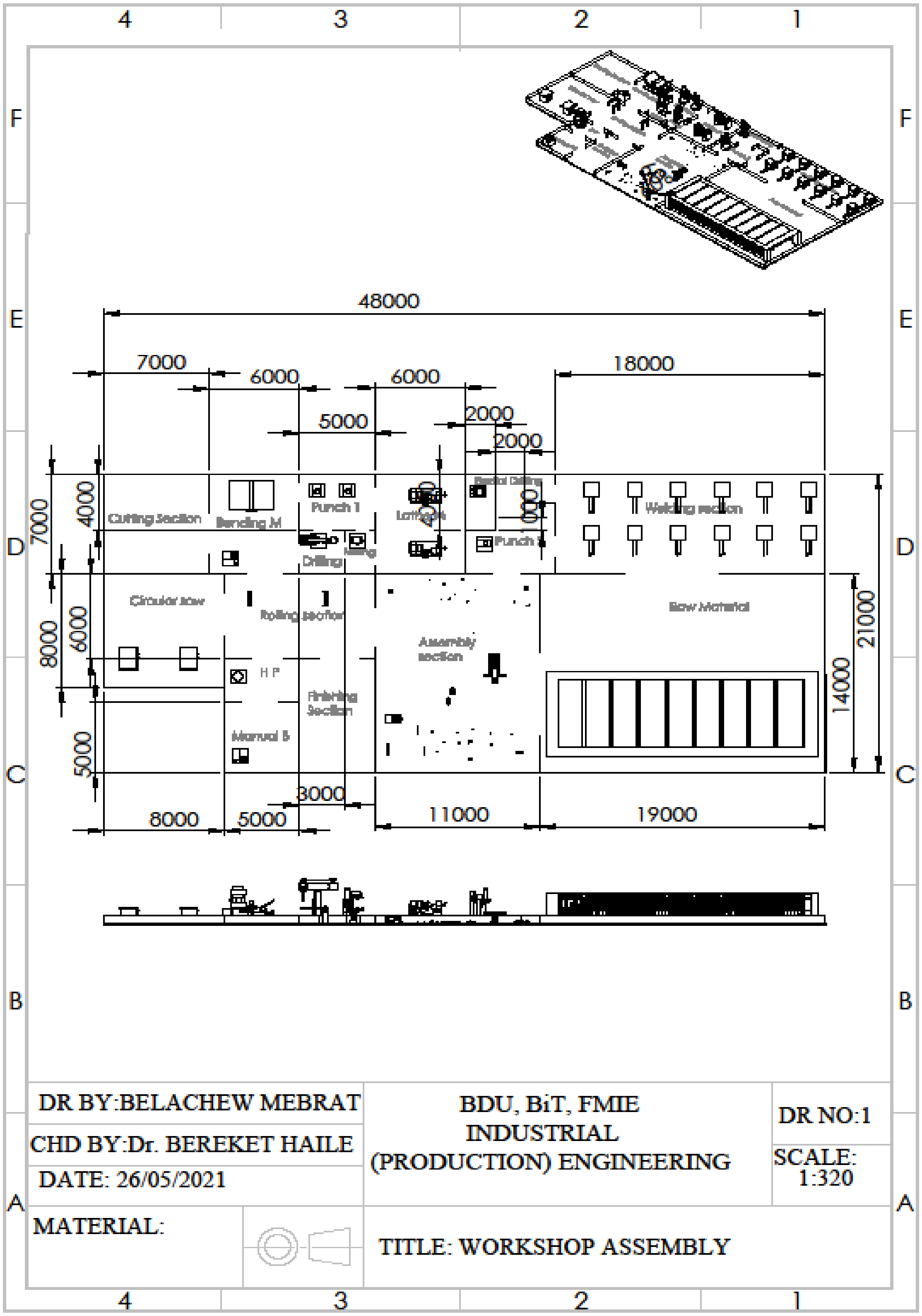
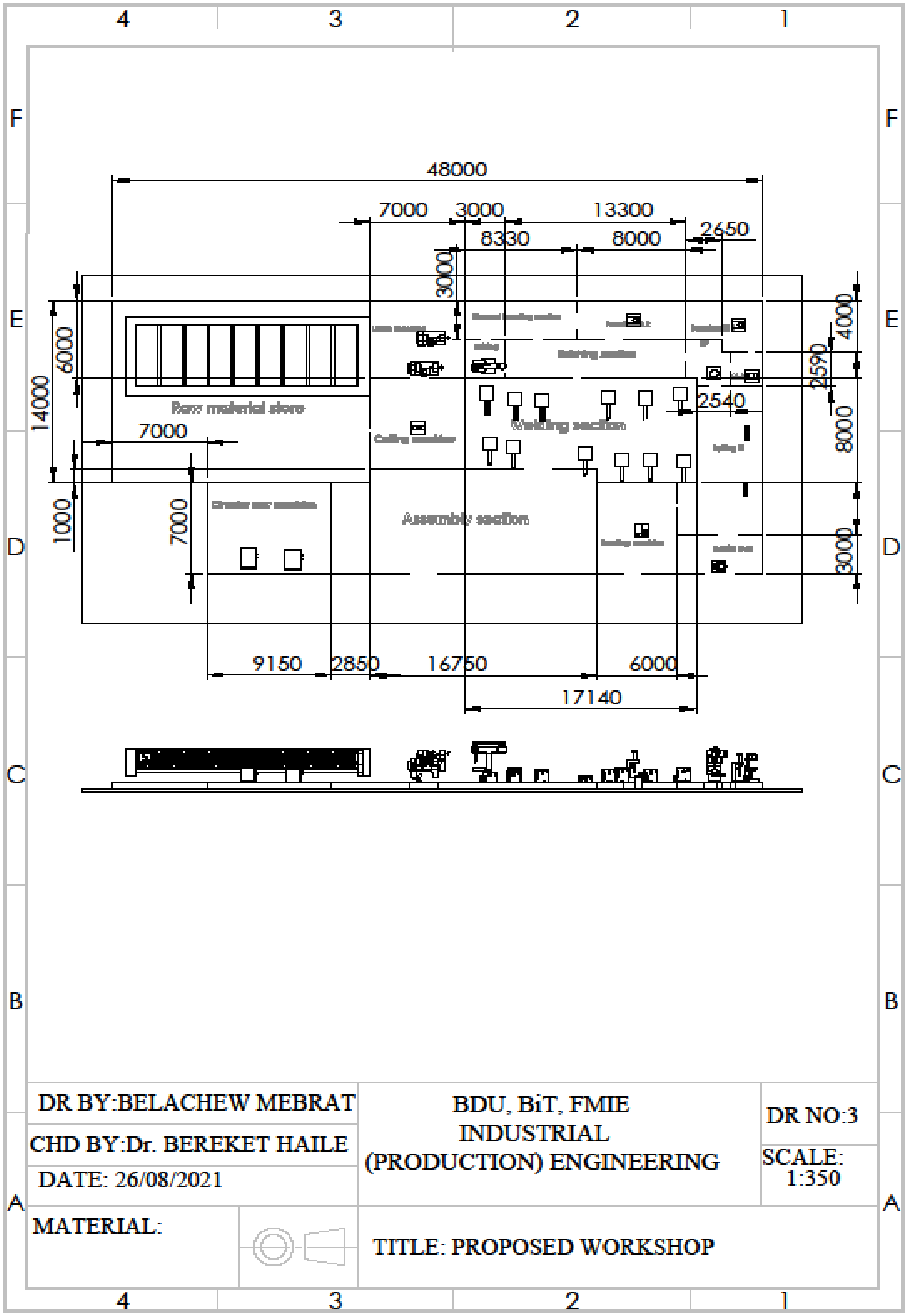
Appendix B: Average Transportation Distance per Second

No.	Parts/product type	Material transported time in meter per second
1	Water and gas tanker	0.96
2	Surface Steel Casing	0.99
3	J bolt	1.02
4	Window	1.05
5	Door	1.01
6	Plate	1.02
7	Under sluice gate	1.03
8	Main canal gate	1.06
9	Secondary canal gate	1.12
10	Stove mold	1.11
11	Hand washing facilities	1.12
12	Concrete mold	1.11
13	Notice board	1.12
14	Suggestion box	1.13
15	kitchen stove	1.21
16	Concrete wall cover Slab	1.11
17	Pump cover	1.12
18	Base support	1.13
19	Clamp	1.14
20	Cover support	1.11
21	Raising main support	1.11
22	Holder	1.12
23	Galvanized bolt	1.08
24	Galvanized solar panel c channel	1.1
25	L Bracket u channel pipe holder	1.12
26	Galvanized u bolt with torus	1.1
27	Metal shelf	1.06
Average distance movement per second		1.087 meter per second

Appendix C: Existing Production Layout Dimensions



Appendix D: Proposed Production Layout Dimensions



Appendix E: Material Handling Time for Each Departments

No.	From - To	MH moving time for existing layout in (second)	MH moving time for proposed layout in (second)
1	CM-BM	5.963	25.1009
2	CM-PM1	12.3853	27.7064
3	CM-LM	16.055	5.963
4	CM-DM	11.9266	9.1743
5	CM-RM	14.6789	21.7248
6	CM-AS	27.9817	10.1835
7	CM-PM2	23.1651	21.945
8	CM-RD	22.8807	29.8716
9	CM-WS	32.5688	11.578
10	BM-DM	5.963	25.0826
11	BM-FS	17.4312	17.6239
12	BM-AS	22.0183	16.9174
13	BM-WS	26.6055	13.5229
14	PM1-BM	6.422	19.3853
15	LM-HP	19.7248	22.2936
16	LM-MB	23.3945	8.3853
17	LM-FS	17.4312	13.4404
18	DM-FS	11.4679	7.5229
19	DM-AS	16.055	10.1835
20	CSM-LM	22.4771	23.422
21	CSM-AS	20.6422	13.6697
22	CSM-WS	38.9908	27.422
23	RM-BM	8.7156	10.0734
24	RM-FS	8.7156	14.2477
25	RM-AS	13.3028	22.1927
26	RM-RD	20.1284	8.1376
27	HP-FS	12.3853	8.8532
28	MB-FS	5.963	7.7339
29	AS-WS	23.8532	13.7523
30	PM2-BM	17.2018	17.9908
31	RD-BM	16.9174	6.055
32	WS-DM	24.3119	11.578
33	WS-RM	29.8165	10.1468
34	WS-FS	33.945	6.7339
35	WS-RD	13.1468	18.2936
36	RMS-CM	41.7431	14.2202
37	RMS-CSM	34.4037	11.3578

Appendix F: Existing Production Layout Products Handling Time

Pars/ product produced	Operation process	No.	Respective operation process move time in minute for each product						
Water & gas tanker	RMS-CM-RM-RD-BM-AS-WS-FS	9	6.2615	2.2018	3.0193	2.5376	3.3027	3.57798	5.09175
Surface Steel Casing	RMS-CM-AS-WS-RM-FS	24	16.697	11.193	9.5413	11.927	3.4862		
J bolt	RMS-CSM-LM-MB-FS	22	12.615	8.2416	8.578	2.1864			
Window and Door	RMS-CSM-AS-WS-DM-FS	47	26.95	16.17	18.685	19.044	8.9832		
Plate and under sluice gate	RMS-CM-DM-FS	31	21.567	6.1621	5.9251				
Main canal gate	RMS-CM-LM-FS	3	2.0872	0.8028	0.8716				
Secondary canal gate	RMS-CM-WS-DM-FS	2	1.3914	1.0856	0.8104	0.3823			
Stove mold	RMS-CM-RM-AS-WS-FS	3	2.0872	0.7339	0.6651	1.1927	1.6973		
Handwashing facilities and suggestion box	RMS-CM-AS-WS-DM-FS	5	3.4786	2.3318	1.9878	2.026	0.9557		
Concrete mold	RMS-CM-RM-BM-WS-FS	2	1.3914	0.4893	0.2905	0.8869	1.1315		
Notice board	RMS-CM-DM-AS-WS-FS	2	1.3914	0.3976	0.5352	0.7951	1.1315		
Kitchen stove	RMS-CM-WS-RD	3	2.0872	1.6284	0.6573				
Concrete wall cover slab with handles	RMS-CM-WS-FS	6	4.1743	3.2569	3.3945				
Pump cover	RMS-CM-BM-DM-FS	6	4.1743	0.5963	0.5963	1.1468			
Base support	RMS-CSM-AS-WS-FS	6	3.4404	2.0642	2.3853	3.3945			
Clamp	RMS-CM-PM1-BM-AS-WS-FS	6	4.1743	1.2385	0.6422	2.2018	2.3853	3.3945	
Cover support	RMS-CM-AS-WS-FS	6	4.1743	2.7982	2.3853	3.3945			
Raising main support	RMS-CM-BM-WS-FS	6	4.1743	0.5963	2.6606	3.3945			
Holder	RMS-CSM-WS-FS	6	3.4404	3.8991	3.3945				
Galvanized bolt	RMS-CSM-LM	6	3.4404	2.2477					
Galvanized solar panel, C-channel connector and L-bracket u channel	RMS-CM-RD-BM-FS	5	3.4786	1.9067	1.4098	1.4526			
Galvanized U- Bolt with torus	RMS-CSM-LM-HP-FS	1	0.5734	0.3746	0.3287	0.2064			
Metal shelf	RMS-CM-PM2-BM-AS-WS-FS	6	4.1743	2.3165	1.7202	2.2018	2.3853	3.3945	

Appendix G: Proposed Production Layout Products Handling Time

Parts/products	Operation process	No.	Respective operation process move time in minute for each product						
Water & gas tanker	RMS-CM-RM-RD-BM-AS-WS-FS	9	2.13303	3.25872	1.22064	0.90825	2.53761	2.062845	1.01008
Surface Steel Casing	RMS-CM-AS-WS-RM-FS	24	5.68808	4.0734	5.50092	4.05872	3.48624		
J bolt	RMS-CSM-LM-MB-FS	22	4.164527	8.588067	3.07461	2.835763			
Window and Door	RMS-CSM-AS-WS-DM-FS	47	8.896943	10.70793	10.77264	9.069433	5.892938		
Plate and under sluice gate	RMS-CM-DM-FS	31	7.347103	4.740055	3.886832				
Main canal gate	RMS-CM-LM-FS	3	0.71101	0.29815	0.67202				
Secondary canal gate	RMS-CM-WS-DM-FS	2	0.474007	0.385933	0.385933	0.250763			
Stove mold	RMS-CM-RM-AS-WS-FS	3	0.71101	1.08624	1.109635	0.687615	0.336695		
Handwashing facilities and suggestion box	RMS-CM-AS-WS-DM-FS	5	1.185017	0.848625	1.146025	0.964833	0.626908		
Concrete mold	RMS-CM-RM-BM-WS-FS	2	0.474007	0.72416	0.33578	0.450763	0.224463		
Notice board	RMS-CM-DM-AS-WS-FS	2	0.474007	0.30581	0.33945	0.45841	0.224463		
Kitchen stove	RMS-CM-WS-RD	3	0.71101	0.5789	0.91468				
Concrete wall cover slab with handles	RMS-CM-WS-FS	6	1.42202	1.1578	0.67339				
Pump cover	RMS-CM-BM-DM-FS	6	1.42202	2.51009	2.50826	0.75229			
Base support	RMS-CSM-AS-WS-FS	6	1.13578	1.36697	1.37523	0.67339			
Clamp	RMS-CM-PM1-BM-AS-WS-FS	6	1.42202	2.77064	1.93853	1.69174	1.37523	0.67339	
Cover support	RMS-CM-AS-WS-FS	6	1.42202	1.01835	1.37523	0.67339			
Raising main support	RMS-CM-BM-WS-FS	6	1.42202	2.51009	1.35229	0.67339			
Holder	RMS-CSM-WS-FS	6	1.13578	2.7422	0.67339				
Galvanized bolt	RMS-CSM-LM	6	1.13578	2.3422					
Galvanized solar panel, C-channel connector and L-bracket u channel	RMS-CM-RD-BM-FS	5	1.185017	2.4893	0.504583	1.468658			
Galvanized U-Bolt with torus	RMS-CSM-LM-HP-FS	1	0.189297	0.390367	0.37156	0.147553			
Metal shelf	RMS-CM-PM2-BM-AS-WS-FS	6	1.42202	2.1945	1.79908	1.69174	1.37523	0.67339	

Appendix H: Proposed Layout Capacity Increment Products Handling Time

Parts/Product	Operation Process	No.	Respective operation process move time in minute for each product						
Water & gas tanker	RMS-CM-RM-RD-BM-AS-WS-FS	18	4.26606	6.51744	2.44128	1.8165	5.07522	4.12569	2.02017
Surface Steel Casing	RMS-CM-AS-WS-RM-FS	48	11.37616	8.1468	11.00184	8.11744	6.97248		
J bolt	RMS-CSM-LM-MB-FS	44	8.329053	17.17613	6.14922	5.671527			
Window and Door	RMS-CSM-AS-WS-DM-FS	94	17.79389	21.41586	21.54527	18.13887	11.78588		
Plate and under sluice gate	RMS-CM-DM-FS	62	14.69421	9.48011	7.773663				
Main canal gate	RMS-CM-LM-FS	6	1.42202	0.5963	1.34404				
Secondary canal gate	RMS-CM-WS-DM-FS	4	0.948013	0.771867	0.771867	0.501527			
Stove mold	RMS-CM-RM-AS-WS-FS	6	1.42202	2.17248	2.21927	1.37523	0.67339		
Handwashing facilities and suggestion box	RMS-CM-AS-WS-DM-FS	10	2.370033	1.69725	2.29205	1.929667	1.253817		
Concrete mold	RMS-CM-RM-BM-WS-FS	4	0.948013	1.44832	0.67156	0.901527	0.448927		
Notice board	RMS-CM-DM-AS-WS-FS	4	0.948013	0.61162	0.6789	0.91682	0.448927		
Kitchen stove	RMS-CM-WS-RD	6	1.42202	1.1578	1.82936				
Concrete wall cover slab with handles	RMS-CM-WS-FS	12	2.84404	2.3156	1.34678				
Pump cover	RMS-CM-BM-DM-FS	12	2.84404	5.02018	5.01652	1.50458			
Base support	RMS-CSM-AS-WS-FS	12	2.27156	2.73394	2.75046	1.34678			
Clamp	RMS-CM-PM1-BM-AS-WS-FS	12	2.84404	5.54128	3.87706	3.38348	2.75046	1.34678	
Cover support	RMS-CM-AS-WS-FS	12	2.84404	2.0367	2.75046	1.34678			
Raising main support	RMS-CM-BM-WS-FS	12	2.84404	5.02018	2.70458	1.34678			
Holder	RMS-CSM-WS-FS	12	2.27156	5.4844	1.34678				
Galvanized bolt	RMS-CSM-LM	12	2.27156	4.6844					
Galvanized solar panel, C-channel connector and L-bracket u channel	RMS-CM-RD-BM-FS	10	2.370033	4.9786	1.009167	2.937317			
Galvanized U-Bolt with torus	RMS-CSM-LM-HP-FS	2	0.378593	0.780733	0.74312	0.295107			
Metal shelf	RMS-CM-PM2-BM-AS-WS-FS	12	2.84404	4.389	3.59816	3.38348	2.75046	1.34678	