ADDIS ABABA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

A Thesis submitted in partial fulfillment of the Degree of Masters of Science in Mechanical Engineering (Manufacturing Engineering)

Title – Design, Analysis, and Performance evaluation of Cellular Manufacturing System for Conventional Manufacturing Factory : A case of Addis Machine Spare Parts Manufacturing Industry

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Submitted in accordance with the requirements for the degree
Master of Science (M.Sc.)

Approved by: Board of Examiners

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Declaration

I declare that the work entitled "Design, Analysis, and Performance evaluation of Cellular Manufacturing System for Conventional Manufacturing Factory : A case of Addis Machine Spare Parts Manufacturing Industry" is an original work that I have completed entirely by myself. It was written under the supervision of Dr. Desalegn Wogaso during my MSc studies at the Addis Ababa Institute of Technology. This work has not been proposed for a degree at this University or any other University.

____________________ ____________________

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This is to certify that the above decleration provide by the candidate is correct to the best of my knowledge.

____________________ ____________________

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Acknowledgement

In the first place, I want to express my gratitude for everything that God has done in my life. Then, I would like to thank my advisor, Dr. Desalegn Wogaso, for the guidance and valuable suggestions throughout the thesis work. My appreciation and love for all of my family is unconditional; they have been my courage and strength when I am exhausted. I would also like to express my gratitude to the personnel at conventional manufacturing Factory (CMF) for providing the relevant data and kind support. Special thanks are deserved by the operational personnel who provided the required data in the available shop.

Last but not least, I would like to thank all of my colleagues and classmates for their valuable and keen attributes; they are always ready to help when needed.

Abstract:

This thesis assessed the performance problems at the Addis Machine Spare Part Conventional Manufacturing Factory (ASPCMF) under the Ethio Engineering Group (EEG). The case factory has been faced a number of manufacturing system challneges according to the data collected from the operations department of the factory. After the analysis performed based on the existing layout evaluation, problems identified were higher idle time of machines and longer travel distances of parts that lead to lower performance. From the study of the previous performance survey done in 2021, the overall performance recorded was 38.03%. After analyzed the existing layout performance using FlexSim software 31.8% performance recorded. This lower performance identified necessitates the requirement to design a new layout and analyzed the performance based on machine utilization and travel distance of parts. Therefore, the purpose to assess the existing manufacturing system based on machine utilization and travel distance of parts led to design, analysis, and evaluate the performance by proposing a cellular manufacturing system. In the design work a 22 part family was created using the Optiz coding system, which was based on hybrid coding system. A method of machine grouping in an incident matrix was developed to form 20 cells. The rank Order clustering algorithm was used to cluster parts and machines within the cell. This minimized 45 duplicated machines in bottlenecks, while increasing the machine utilization of 43 machines in the cluster formed. The designed cell in the cluster was evaluated through grouping efficacy (GE) of parts allotted in cells to achieve optimal effectiveness in cell utilization which was 91% cell efficiency. The CRAFT algorithm used to identify the part flow within the department and the effectiveness of machine arrangement analyzed based on part travel distance that was reduced into 1,425 m from the existing layout 2,236.10 m which increased floor space available so that, an improved layout was proposed. The analysis was performed to evaluate the designed cell, the performance simulation shows that 88.37% of the proposed cellular layout demonstrates significant enhancemenent compared to the existing layout, which was only 31.8 %. The performance simulation was conducted using FlexSim software. Finally,the individual machine utilization percentage was determined and compared between the proposed layout and the existing layout.

Keywords: Incident matrix, idle time, Grouping Efficacy, Rank order clustering algorithm, CRAFT algorithm, FlexSim

List of Acronym

GT - Group Technology

CM- cellular manufacturing

CMF - Conventional Manufacturing Factory

PFA - production flow Analysis

IM - Incident matrix

UGE - utilization based Grouping Efficiency

**EU - ** Exceptional utilization

TCU - Total cellular utilization

GE - Grouping Efficiency

AMSPCMF - Addis Machine Spare Part and Conventional Manufacturing Factory

CRAFT - Computerized Relative Allocation Of Facilities Technique

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Chapter one

1. Introduction

1.1Background of the study

Manufacturing companies have been profoundly affected by unending competition from companies operating in ever-lower-cost countries. In recent years, the small-batch manufacturing industry has had to increase its productivity to compete in international market (Aherwar, 2010).

Cell formation is the first and most important stage in cellular manufacturing, as it involves grouping parts with similar design or manufacturing attributes to create a part family. Every cellular manufacturing system in any organization relies on Group Technology.

Manish et al. (2013) described the necessity of designing a cellular manufacturing system to overcome the problems faced in batch and job-shop manufacturing systems. As part classification and machine layout according to batch production become more common, the importance of adopting the cellular manufacturing system in industries like Addis Machine Spare Part Manufacturing Factory becomes evident.

The adopting of cellular system must use certain new approaches to minimize production costs, throughput time, and improve the quality of the product. Flexibility in the system helps to boost market share and profitability by redesigning the production system according to the principles of group technology (Argish, 2016). Based on examining the significant factors in production system bottlenecks and through performance evaluation of the proposed system, it is necessary to design an efficient cellular system.

Another approach as Li et al. (2005) described simulation studies are frequently performed to assess the benefits and performance of a particular layout. Based on this, for Ethiopian industries with inefficient performance, a manufacturing system is required. This necessitates design, analysis, and performance simulation to achieve efficiency. Findings from observations and gathered data in a Conventional Manufacturing Factory show immense problems regarding machine utilization and part travel distance, which highly affect the performance in the production process. Therefore, the major aim of the study is to design, analysis and performance evaluation of cellular manufacturing system considering machine utilization and production sequence as major parameters. As investigated by Gupta et al. (2004) from the available techniques, CORELAP (Computerized Relationship Layout Planning), ALDEP (Automated Layout Design) and PLANET (Plant Layout Analysis and Evaluation) are three of the most familiar from the construction-type layout category. CRAFT (Computerized Relative Allocation of Facilities Technique) is by far most important improvement layout design, which helps minimize the traveling of parts within departments. The research focuses mainly on the current system of the Conventional Factory's machine utilization by taking it as a case company for improving the current layout.

Table1. 1: Daily machine controlling report in CMF

	Factory: CMF	**work shop: Lathe**			**DATE : 28/7/13**	
S/n	**Machine type**	**Assigned worker**	**Parts produced**	**Cost sheet**	**Machine hour usage**	**Idle time**
					effective	idle
1	Milling machine	Endalelegn	SHAFT	OPRN-1/0460/13	5:20	2:40
2	Milling machine		Pinion gear	OPRN-1/0474/13		8:00
3	Lathe machine	Tadele	PLATE	OPRN-2/3011/13	5:20	2:40
4	Cnc Milling machine		Spur gear	OPRN-1/0483/13		8:00
5	Milling machine	Solomon	Small-bushing	OPRN-2/3008/13		8:00
6	Conventional lathe machine		Small roller	OPRN-2/3008/13		8:00
7	Conventional lathe machine	Beletu	T-BOLT	OPRN-5/10061/13	5:20	2:40

8	Cnc Milling machine		Nut	OPRN-2/3008/13		8:00
9	Milling machine	Abreham	Transfer gear	OPRN-2/3008/13		8:00
10	Milling machine	Yeshewamebrat	T-BOLT	OPRN-5/10061/13	5:20	8:00

(Source: Data gathered from Conventional Manufacturing Company)

Table1. 2: Daily product status controlling report

	daily Product status control report										ISSUE NO.02	Page 1of 1		
	Factory: -CMF		work shop: -LM& MM						status		DATE: -28/7/13			
s/n	Item description	Customer	Cost sheet	Job order	order quantity	starting date	operation	daily target	actual	daily performance	overall performance	delivery date	remark	
1	SHAFT	HORIZON PLANTATION	OPRN-1/0460/13	4-8-3330/13	2	22/7/13	L	1		25%	20%	26/8/13		
2	PLATE	ETHIO CEMENT	OPRN-2/3011/13	4-8-3287/13	289	24/3/13	L	5	1	90%	20%	24/4/13		
3	T BOLT	KESSEM SUGER FACTORY PROJECT	OPRN-5/10061/13	4-8-3312/13	3000	6/6/2013	L	150	60	40%	29%	30/7/13		
4	Small roller	MUGHER CEMENT FACTORY	OPRN-2/3008/13	4-8-3282/13	1000	17/3/13	L	70	44	63%	59%	21/4/13		
5	STAINLESS STEEL PIN	BISRAT PLC	OPRN-1/0432/13	4-8-3316/13	50	19/6/13	L	2		50%	35%	13/7/13		
6	PINION GEAR	AFRICA PLC	OPRN-1.0474/13	4-8-3322/13	5	15/7/13	M	1	1	100%	60%	7/8/2013		
7	T BOLT	KESSEM SUGER FACTORY PROJECT	OPRN-5/10061/13	4-8-3311/13	3000	6/6/2013	M	100	29	29%	29%	30/7/13		
8	PLATE	ETHIO CEMENT	OPRN-2/3011/13	4-8-3287/13	289	24/3/13	M	1		5%	20%	24/4/13		

(Source: Data gathered from Conventional Manufacturing Company)

1.3. Problem statement

According to the assessment of problems in a Conventional Manufacturing Factory, higher idle time with the record of 8:00 hours,and sum total of 2,236.10 meter part travel distance were identified using Craft algorithm. The existing layout has increased the part travel distance imminently when parts transferred from one machine to another due to the lack of standardized facility arrangement. The existing process layout has a significant contribution for this since, it has increased the idle time of machineries when similar parts were not processed easily in the available shop. Hence, the performance analysis executed in the FlexSim software which used each machine's setup and process time in the existing layout shows 31.8% machine performance. The performance was also recorded an average daily machine performance of 38.03 % for the indicated machines stated in the daily machine performance table1.1. This prompted us to examine the impact of idle time as a critical parameter on daily and overall performance in the company. Regarding part travel distance, the travel extent in the production sequence of some parts, which further visits other sections within the factory shop, shows a problem. The parts requiring further manufacturing include gears, T-bolts, shafts, and others. The machine performance percentage leads to further examine the existing layout machines using both Craft algorithm and FlexSim software to understand the current problems in the machine utilization and part processing. So that, the need to design an improved layout by creating part family and rank order clustering efficient cellulalr layout created. The efficiency of the performance analysis using evaluation methods with Grouping Efficacy (GE) were the key to solve the existing problems identified. Therefore, it was essential to improve the idle time of machinery and minimize part travel distance by carefully examining these parameters. Therefore, the gaps found in the above-stated problems, in line with the literature review, was serve to develop methods through design, analysis, and evaluation in the performance of cellular manufacturing systems to enhance the performance of the company. The machine performance report in the table presented was used as comparison for the analysis of the current performance inline with the model layout in FlexSim and it is based on the study conducted at A.A.U. (**Performance survey and recommendation for betterment of Addis Machinery and Spare parts Manufacturing Industry (AMSMI)) by Dr. Mesfin Gizaw, Dr. Getasew Ashagrie and Behailu Mamo in 2021.**

1.4. Objective of the research

1.4.1 General objective

The general objective of the research is to assess the performance of the existing manufacturing system and design a cell based on hybrid coding system and Rank order clustering, analyze machine utilization of cells using FlexSim software and evaluate the performance of a cellular manufacturing system based on Grouping Efficacy (GE) for Addis Machine Spare Part Conventional Manufacturing Company.

1.4.2 Specific objectives

❖ To analyze and evaluate the performance of the existing manufacturing system. This can be achieved through:

- ✓ The data collected in the operations department from the machine arrangement, performance level and product cycle time of parts.
- ✓ Analyze the data collected using Craft algorithm to assess the parts travel distance in the existing layout and cost for the existing layout.

- ✓ Comparison made between the existing performance survey conducted previously with the analysis executed using FlexSim software to evaluate the outcomes using machine utilizations.

❖ To design a cellular manufacturing system, by creating a part family for parts and machine grouping to process part families in cells.

The existing process layout shows poor performance due to the arrangement of machines. Based on the outcome from FlexSim analysis executed interms of machine utilization as well the higher travel distance of parts using Craft Algorithm. This could be optimized by designing a cellular manufacturing system through:

- ✓ Create a family of parts having a similar designing or manufacturing attribute using the Optzi hybrid coding system.
- ✓ Clustered the group of part families with machines using Rank Order clustering. This improved the machine capacity in each cell due to the used Rank order clustering so that, elimination of bottlenecks and exceptional utilization in cells achieved.

❖ To evaluate the designed cellular manufacturing system through grouping efficacy. This can be achieved through:

- ✓ Evaluate the cluster formed using Grouping Efficacy, shows how the cells are utilized each machines in the cluster formed. This minimize duplicated machines and increased machine capacity within each cell in the cellular layout created. So that, similar parts processed in the same clusters formed and the travel of parts out of the cells is very low for further process.

❖ To simulate the performance of the proposed cellular manufacturing system using FlexSim software and evaluate through machine utilization percentage. This can be achieved:

- ✓ The cellular layout in the model represented and insert each machines setup time, process time using FlexSim software so that, each machines utilization and performance analyzed after run the simulation.

1.5 Scope and limitations of the research

The scope of the research area includes designing cells by grouping parts into part families, considering design and manufacturing attributes, grouping machines into cells based on processing part families, and clustering machines with parts using the Rank Order clustering algorithm. The designed cell is analyzed based on the machine utilization percentage of the cells, taking into account grouping efficacy. The CRAFT algorithm was used to demonstrate part flow in the department and to evaluate the simulation performance of the proposed and existing layouts using FlexSim software. Although the study plans to use both algorithms and simulations to construct cellular systems, it is limited to the inclusion of other plant layout tools. Hence, different algorithms that consider various parameters can be used to achieve different layouts.

1.6. Significance of the research

The level of poor machine utilization and production sequencing for some parts is high, as observed from the company data. This indicates the need to examine higher performance problems in the company that may result from these factors. Hence, it is important to examine the existing performance of the case industry to fill these gaps. Therefore, conducting research to consider the contribution of design, analysis, and evaluation in the performance simulation of a cellular manufacturing system is a major and immediate cause to enhance the current performance.

1.7 Motivation for the research

❖ The Primary goal is to solve problems in local manufacturing industries through detailed studies that address existing production system problems. When challenges are encountered in identifying and applying scientific techniques in real production systems, such as industries, previously acquired industry experience becomes a very motivating condition to conduct the research. In this case, the prompt interest comes from previous experience in the metal industry to resolve existing problems by gathering relevant data. The under utilization and idle time of machines in the existing layout was imminent. So that, designing cellular layout which could enhance machine utilizations in cells and minimize part travel distance were key parameters to analyze the output of both layouts. Therefore, proposing a cellular system design to enhance the performance of the current case company is an area of great interest to conduct the research.

1.8 Research Questions

1. What are the major problems and performance levels of the manufacturing system in the Conventional Manufacturing Factory?

2. What are the main parameters for evaluating the existing system and forming machine part grouping?
3. What is the performance level of the proposed cellular manufacturing system?

1.9 Organization of thesis

This paper contains five chapters. The first chapter presents the introduction, problem statement, objectives, scope, and limitations of the study. The second chapter reviews the related literature by introducing cellular manufacturing and the types of design, modeling, analysis, and evaluation of the system using simulation. In the third chapter, data collection and analysis of the case company is presented to find the existing problem in the area. It also covers the design of cellular systems based on the analysis of the CRAFT algorithm and rank order clustering grouping algorithm. Chapter four will cover the simulation results and a discussion of the designed cell comparison with the existing ones. Finally, recommendations for future work and conclusions are presented in Chapter five.

Chapter two

2. Literature review

2.1 Introduction

This chapter presents literature on process layout, cell formation techniques, modeling, and the evaluation of performance in cellular manufacturing.

2.1.2 Traditional layout

Nouri et al. (2014) described traditional process layout system implemented in the past decades in the manufacturing industries. This the flow line and job shop process couldn't shorten the cycle time of products due to the arrangement of machines based on operation sequence. Therefore, it proposed cellular manufacturing system as an alternative modern approach to tackle the earliest traditional approach. This comprised of both flowline and flexibility of job shop which considered as successful application of Group technology.

(Bennett, 2015) presented the process layout advantage is limited where only the number of processes executed are in fixed area. The huge disadvantages listed are higher product cycle's, excessive material movement and hgher set-up time. Hence, using Group technology proposed as a solution to alleviate traditional process layout problems.

U. Tarigan et al. (2019) investigated the production system of a furniture company using traditional process layout. The previous design of the production facility has contributed for higher lead time and travel distance of parts. Therefore, an improved layout designed using value stream mapping and lean manufacturing to overcome non-value added activities and shorten cycle time. The modified layout improved the lead time required for processing parts as well parts travel distance. The used Rank order clustering has resulted better outcome of the redesign layout.

Pablo et al. (2021) reviewed several layout planning methods and presented different techniques for facility layout design. From the majorly discussed parameters for facility layout includes operation cost, machine efficiency and productivity addressed. The most widely expressed criteria's required for facility design involved the distance between facilities, material handling cost and production flexibility. The construction algorithm and improvement algorithm's used to create the layout. The evaluation methods for efficient facility layout presented are simulation, Fuzzy and ANP modeling.

2.2 Group Technology

Kamal et al. (2014) described Group Technology emerged as a backbone for recent manufacturing systems. The comparison made on the previous process and flow line industries with their drawbacks. As the respond to the market is very low in the traditional process layout there are stated factors contributed to such conditions. The length in the product cycle and product variety problems issued. Therfore, the implementation of Group Technology advanced the problems arised in traditional layout. The implementation of Group Technology relied on the principles of cellular manufacturing created more efficient layout, low product cycle and quick change over time.

Nguyen et al. (2021) investigated the various methods such as classification and coding, production flow analysis and clustering for implementing Group Technology. The early batch and job shop industries benefited by transforming their manufacturing system in terms of material flow time, distance and setup time. The study presented the significance of Group Technology for advancing the traditional way of flow line processes to be more flexible and efficient in production system. The methods of changing the previous facility layout discussed are algorithms and spiral modeling softwares.

Ravindera et al. (2014) stated the various Group Technology implementation methods over traditional process layout. Fo this, identifying part families and rearrarengemnt of machines are key mandates for successful transformation of process layout. The successful application includes group layout, short product cycle and planned machine sequence. Therefore, it is found efficient cellular manufacturing system leads with proper implementation of Group Technology has resulted better output in machine utilization, lower material movment and cost.

2.3 Performance indicators of manufacturing system

Andrew et al. (2019) described the steps followed in the improvement of production processes. From the explained parameters for productivity and efficiency measurements, the physical facility layout arrangement is the most important for the performance indicators. A performance measurement system involved a series of measurement used to quantify the efficiency of the process. The identified performance indicators are production time, standardization of facilities and the utilization of machines to process parts.

Li et al. (2018) presented several key performance indicators for measuring process industries and discrete processes. Based on the ISO 22400, a total of 38 KPIs performance measurements proposed to evaluate the performance of manufacturing operations. The KPIs standards described interms of formula, measuring unit and timing. From this, the main three categories are time, quality and logistics. The time measurements consists of data related to duration of a production process. Planned operation time and actual operation time which further subdivided into production time and down time.

Shivasharana et al. (2016) investigated organizations key performance indicators and mentioned some of the relevant measurement tools. Standardized all processes within the organization discussed in detail. For this, the Over all productivity and efficiency is vital further expressed interms of time. Over all productivity measured in equipment utilization and the machine available time for process. The machine available time depend on hours worked productively and idle time. Therefore, the value of the KPi shouldn't less than 90% based on the available production hour of the process.

Carl et al. (2016) discussed various KPIs measurements used for process industries. The key performance indicators mentioned are wastes in operation time, down time of the available machines and scrap in raw materials. The reasons further listed for lower performance are waste, down time, operation, maintenance and quality. The Over all equipment efficiency is caliberated in percentage of scheduled operation time, percentage of actual performed machine time, quality. The Overall equipment efficiency generally served as the main key for performance measurement tool.

2.4 Cellular manufacturing

(Haddar, 2008) described cellular manufacturing as a philosophy for the production concept that consists of grouping and taking advantage of parts with similar designs or manufacturing attributes.

The Optiz coding and classification approach, which allows parts to be coded based on geometrical similarities, was developed to design the cellular system. Hence, the design similarity or manufacturing attribute helps to produce a cluster of products using an algorithm or some kind of relationship metrics.

The measure of similarity and an algorithm for changing this measure to develop relationships among clusters are used to create machine cells and family of products (Lin, 2011).

Based on Optiz coding system, creating a manufacturing cell requires a collection of machines, but distinct types of machines can be grouped in various designs of machine arrangements for production. Therefore, to design a cellular system, breaking down the whole system into smaller subsystems that are easier to manage than the whole is essential. This helps to eliminate non-value-added activities and increase production flow in cells.

2.5 Design of cellular manufacturing system

Wintao et al. (2019) categorized machines and parts in the machine-part matrix by multiplying zero and one numbers with the values in rows and columns. Rank Order Clustering was used to form cells by grouping machines. The design of the cellular manufacturing system is based on travel times between cells as considerations. Therefore, the proposed layout minimizes tool distance, and the gaps are a lack of evaluation for the designed cell through simulation performance.

Singh et al. (2014) stated that the demand for center bolt production was greater than other production processes in the company's product. The problem identified is the arrangement of machines and layout design based on large part travel distance. The reduction of the manufacturing lead-time in the center bolt is the finding by comparing the shop floor’s previous production state and future production state. Limitations include the lack of evaluation in simulation.

Xu et al. (2021) investigated the design of cellular manufacturing system by considering the make span of client orders as random. Considering the effect of work distribution in cells and processing requirements for cell design. Three heuristic algorithms were compared as a method by developing two algorithms and combining the second algorithm to increase machine utilization. Since all products are categorized separately, limitations include the difficulty of balancing work distributed in cells and the flexibility of cells in different processing requirements.

Chandra et al. (2014) proposed a modified layout by assigning machines in a linear layout model, taking into account the reduction of material travel distance and machine idle time. Since the alternate layout is created by production sequence, it is possible to minimize machine idle time as well. The Arena software is used for Simulation performance and verifying the performance of the S-shape layout. The Findings show that it is a better layout than the U-shape layout. The limitation is that only machines are considered, not other factors.

Kumar et al. (2013) investigated products in the fastener industry by identifying parts and production systems, preparing a machine list for parts with similar attributes, and categorizing them as a part family. By analyzing the production flow analysis of the system, the routing path determines the material flow path. A cell formed based on the production system in an incident matrix and using the Rank Order clustering technique. As a result, the cell formed by the matrix helps to reduce part travel distance and lead time. The limitation is that only cell formed, no further cell design and performance simulation carried out.

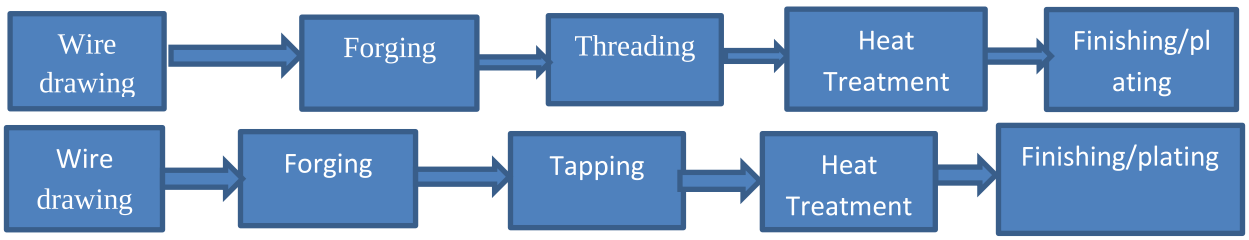


Figure 2. 1: Bolt forging Department and Nut Forging Department

Dan et al. (2012) investigated previous cell-forming approaches such as Part-Coding analysis, array-based grouping, and graph partitioning. Suggested that none of these approaches yield the best result considering the multi-parameter assumption. A hybrid technique was identified to solve complex combinatory problems and produce the best results. The approaches currently used are heuristic algorithms for solving complex combinatory problems. However, meta-heuristic techniques have a longer processing time and the disadvantage of not providing the required result in a short period.

2.6 Modeling of cell formation

(Tamal, 2017) investigated cellular design by forming machine cells and classifying parts as families. By using a mathematical model, it is possible to reduce the inter-cell and intra-cell material flow. The proposed technique resulted in a better cell formation solution. The limitation is the huge computing effort required to find a solution in a short time.

Sasi et al.(2018) proposed a mathematical model based on part and machine assigning. They developed a model that sets input parameters of part type, machine type, and decision variables. The findings in the model improved machine utilization by assigning machines as well as reducing the factory's cost. The limited assumptions of part travel between cells and the lack of performance simulation are gaps in the study.

Sutrisno et al. (2016) stated that the previous concerns in cellular manufacturing were to reduce inter-cell and intra-cell material handling costs. The findings in the research focused and shifted to new factors such as production planning and layout problem to determine efficient cell layout. Model assumptions such a demand and operating time were used for machine-part matrix formulation. The gap is that different demands in the production system occur, therefore the assumption must include more production parameters.

Ghaffari et al. (2018) explained the difficulty of implementing cellular manufacturing in some sectors because of a lack of tools for transferring parts with a large weight or load. The proposed mathematical assumption in this study aids in reducing the distance between inter-cell and intra cell. The model considered tool changes and route selection for comparison of alternate part routes. The limitation of the proposed model is the quantity of machines available to process additional products.

(Das, 2007) proposed a mathematical model based on machine availability, machine failure, and the average time required repairing the failed machine. Machine capacity improved by Calculating the cumulative mean machine breakdown time and repair. The drawbacks is the lack of performance simulation.

Preeti et al.(2011) investigated the most challenging factor in cell design has been the production of machine cells. Mathematics, graph theory, and array-based models were all studied in this work. The findings suggest that graph-theory groups machine cells based on information from the part processing, whereas mathematical models solve the grouping of machine parts using mathematical formulation. The limitation of the study is that it only provides a theoretical description of cellular models.

Abdulla et al. (2016) investigated the reduction of part travel distance for proposed layout using the model assumption of random part arrival. Machines and parts were grouped using an incidence matrix. In this zero-one matrix, a “one” signifies the part's visit to the concerned machine, while a zero indicates avoid. The proposed technique used part frequency, visiting machines and identifying the machine with the smallest non-zero frequency from the incidence matrix. Similar results were found using production sequence in the production flow analysis and the Rank Order Clustering algorithm.

(Ronald, 2013) proposed a cell design model based on fixed demand and machine capacity. By explaining different studies previously, they used a quantitative algorithm to form cells, which was first described by Mccauley. Another proposed similarity coefficient by Rajagopalan, proposed the theory of Graphs in 1980, in a groundbreaking study, King proposed Rank order clustering of the part-machine incidence matrix for creating cells, which resulted a long time investigated research into algorithmic ways for classifying parts and machines into cells based on the one-zero part-machine matrix.

2.7 Performance analysis of cellular manufacturing

Roque et al. (2019) investigated the flow control in the u-cell arrangement of cellular manufacturing. The findings considered the evaluation of part travel in the system, resulting in inventory reduction and production volumes. Performance analyses combined push and pull systems for effective flow control. The gap is only inventory in the production rate considered.

Sharma et al. (2019) investigated analytic hierarchy process (AHP) and analytic network process (ANP) models to determine cell evaluation criteria. By assigning weights based on the zero-one matrix, the analytic hierarchy approach was chosen because it is simple to use and provides a good evaluation of the binary matrix's outcome. The limitation is the lack of comparison for the outcome based on simulation.

Jabid et al. (2013) investigated statistical analysis to evaluate particle swarm optimization and genetic algorithm. Performance was evaluated using a uniform distribution for layout models based on production demand. The evaluation resulted in the identification of the best cell configuration by comparing the processing time of production demand. However, a limitation of the study is the lack of simulation to evaluate the binary weight result.

Van et al. (2001) investigated cell layout evaluation using open queuing network models. The evaluation found the result of each cell's aggregate output and analyzed the output as a cumulative result. The previous model suggested a design problem and resolved it by grouping parts and machines. The result of the model considered random arrival parts. However, the identified gap is the lack of simulation for evaluating the state dynamically.

(Ghosh T. , 2011) proposed a hybrid algorithm of centroid linkage clustering with Rank order clustering to evaluate machine part grouping. The result was determined by a similarity coefficient method created in the machine-part matrix of incident matrix. The applied similarity coefficient formula linked each machine group in the Rank order clustering to find the relation between individual machine groups and central distance between cells. The proposed technique resulted in only one exceeding value from the heuristic results and was identical to the single clustering approaches.

Dao et al. (2014) proposed a zero - one digit to create manufacturing cells through an incidence matrix by determining the exceptional elements in the matrix within the cell as void or zeros. The finding results were created by adding more cells to the remaining exceptional elements and compared performance results to genetic algorithms. However, the drawback is that the grouping efficiency used and grouping efficacy could have resulted in a better outcome.

Kamalakanna et al. (2019) stated the previous research focused on single-cell evaluation because evaluating in vast consideration provides poor results in performance. The investigated finding used a genetic algorithm to address cell layout issues by considering product sequence and part processing. The result is almost similar to the similarity coefficient and single clustering approach.

Masmoudi et al. (2008) investigated the different approaches used in cell formation techniques. They determined that simulation is the best compared to the performance results of deterministic and queuing models. The elimination of exceptional elements through simulation models leads to better cell formation. The authors Suggested that simulation models are the most powerful techniques of all for performance measurement. However, the identified gap is the lack of detailed analysis of the cell formation method.

Tarun et al. (2016) investigated previous rank order algorithms that only considered machine-part grouping. The findings revealed the Modified rank order clustering technique, which uses a binary weight ratio for grouping machines and parts. The results of the modified technique create cells with equal work distribution and minimized bottlenecks in machines. However, the identified gap is the lack of performance simulation.

2.8 Analysis of cellular manufacturing

Anand et al. (2016) proposed a combined algorithm to solve the cellular layout problem. They used the Rank order clustering (ROC) and bond energy algorithm (BEA) to identify Part families and cluster them into families. Machine cells were formed using the proposed algorithm, and the cellular system performance was measured using grouping efficiency. However, the gap in this study is the consideration of production sequence of parts and the used grouping efficiency without simulation.

(Amruthnath, 2016) performed an analysis of parts and machines using the modified rank order algorithm. The manufacturing data of the company was analyzed by assigning a weight factor to the parts based on cycle time and production volume. Cells were formed based on the final result obtained from each of the matrix reults. However, there is a gap in measuring performance in the formed layout.

(Shiyas, 2020) investigated the machine part problem using a genetic algorithm and the machine part incident matrix as an input method. A new model was proposed with the objective of minimizing exceptional cells, and different machines with weights were grouped into each individual cell.

(Okechukwu, 2016) presented different layout types and models with their respective advantage and disadvantages. Various approaches to the layout models were described based on machine arrangement, work in process (WIP), setup time and lead time. Cellular layout was proposed as a recent technology with better performance than the others. However there are gaps in proposing analytical methods intensively.

Javadian et al. (2010) investigated cell layout problem using heuristic algorithms such as genetic algorithm, ant colony optimization and simulated annealing approach. The findings revealed the two important factors for cell design are production sequence and production volume. The genetic algorithm resulted in a better outcome quickly by minimizing inter cellular movement and voids. The gap is only taking into account a single parameter for cell design.

(Suer, 2019) investigated the flow shop production system using processing time and the demand for products processed in each machine. The findings in this paper show a reduction in the number of machines used for different processing of parts. Based on three mathematical modeling approaches, a flexible flow shop is designed by considering part processing time and production rate. The machines are grouped machines are based on the relative similarity between the ratios of parts classified as part family. However, other parameters of cell design such as cell utilization and simulation, are not considered.

Firoozi et al. (2011) identified layout planning in cell based on material flow and the department relationship among cells. A mathematical model was developed to solve the facility layout by considering the batch flow of parts in departments. Therefore, a U- shape cell arrangement is proposed to overcome problems in the previous machine arrangement. Although the developed algorithm solved the cell formation problem, it is restricted to small-scale problems. There is a gap in the need for a more comprehensive approach to solve larger facility problems.

(Reddy, 2014) designed a layout using the CRAFT algorithm, considering the transfer of parts between departments as an input. In this layout technique, traveling cost, travelling distance, and part flows are analyzed based on the initial layout and the final layout resulting from multiple iterations. Although the findings show an improved layout, there are gaps in considering large-scale industry data with regard to machine utilization and simulation performance. The input data used for CRAFT algorithm are:

1. Initial layout data
2. Material flow data
3. Number of departments
4. Area of departments and location of departments

The material flow data serves to identify transfer of parts between departments and to show the flow from one department to another. The material handling cost is also calculated based on the assignment of parts in their respective departments.

The general procedure of CRAFT algorithm described as follows. (Reddy, 2014)

1) Set the input data for number of departments, width and length.

2) Select the centroid distance for calculating the distance from one department center to another and use the rectilinear approach to calculate the department supposed to be square.

3) Determine the total material handling cost based on the initial layout data from the flow chart.

4) Switch departments from the flow matrix data to acquire the most cost-effective material handling cost. This helps to reduce part travel distance and manufacturing cost.

5) Iterate repetitively until no further switch is available, resulting in the least flow matrix cost.

2.9 Summary of literature review

In the literature, design techniques of part family, machine grouping, and heuristic have been proposed for cell formation based on three major categories. Additionally, the analysis is presented based on grouping efficiency and grouping efficacy. The modeling is done by assuming machine capacity, production sequence, and, routing. The performance evaluation includes the similarity coefficient method, discrete methods, and simulation.

2.10 Gaps identified from literature review

The identified gaps in the literature are considerations of a single parameter based on production time, production sequence, setup time or product cycle time for cell formation in the used rank order clustering technique. Modeling cells based on deterministic approaches by setting pre determined objectives of static situations in the models by evaluating only the occurrence of states without showing the real dynamic states in the process. And queuing models, which shows only the sequence of operations waiting in line held in storage or stand for further processing rather than simulation performance, are also gaps. There are only a few literatures available concerning real industry cases which considered the analysis of machines in the existing system based on the major problems identified and assessed the performance problems in the machines through product cycle time, utilization and machines arrangement. After identifying the current arranegement it was essential to rearrange the existing layout and evaluate the performance of machines using simulation for effective cell design, by using major parameters of parts movement between machines, product cycle time considered in the production system. Therefore, it is required to design cellular systems based on creating part families having similar processing and cluster by considering an integrated approach of product cycle time and production sequence of parts to minimize parts movement between machines and enhance machine utilizations.

Chapter three

3. Materials and methods

3.1. Materials

This chapter presents the software's used in the thesis. Craft algorithm for layout design and FlexSim software for simulation of the proposed layout.

3.2. Research methods

The methodologies of data collection followed for the research to achieve the objective include the use of primary and secondary data. Primarily, the case study company is used to identify the core problems and potential bottlenecks in the production areas. The General methodology follow to achieve the objectives of this thesis are presented in figure 3.1.

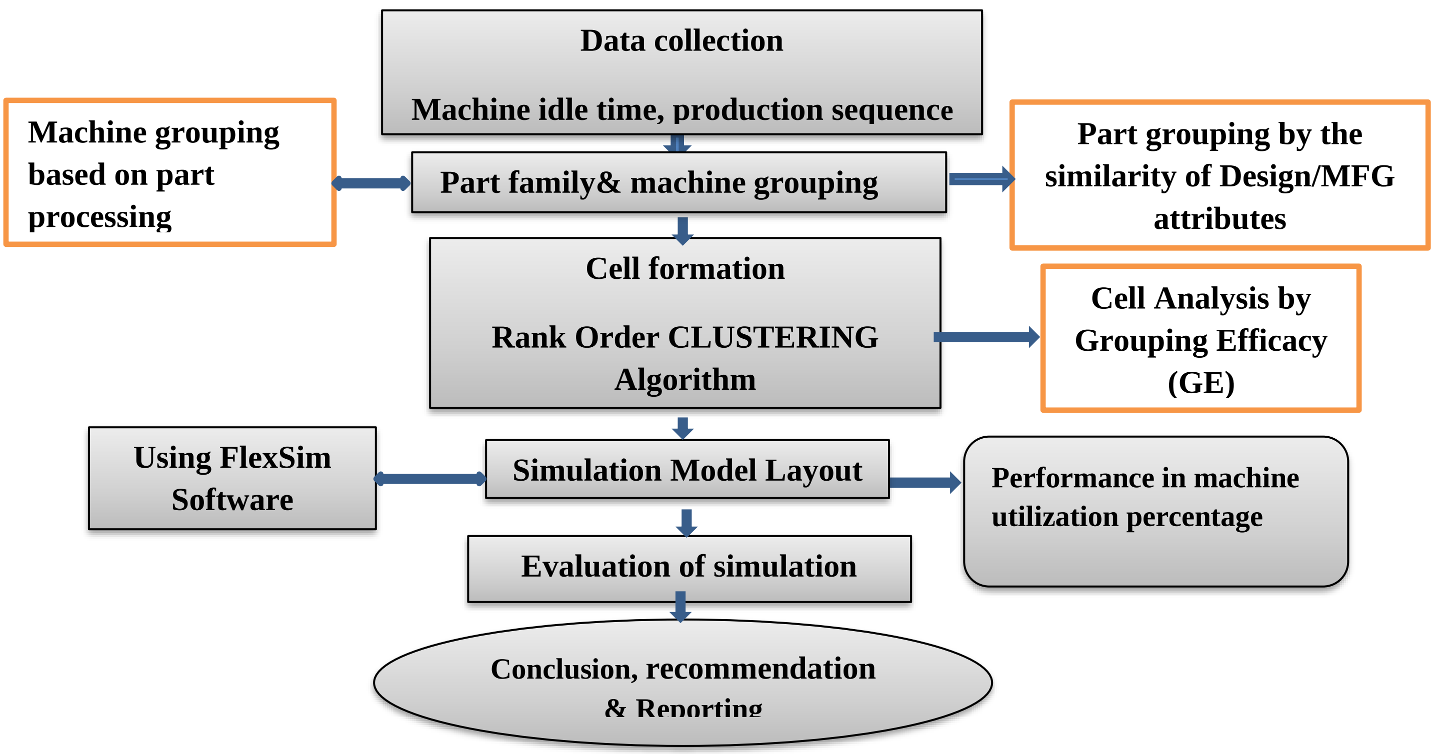


Figure 3. 1: General Methodology

3.2.1. Introduction to FlexSim

What is FlexSim simulation software and its procedure?

FlexSim is 3D simulation software that models manufacturing systems, simulates performance, predicts and visualizes business systems in a various industries such as manufacturing, healthcare, warehousing, mining, logistics, and others. It is a powerful and user friendly software. Recently, FlexSim has found wide application in various simulation areas of manufacturing, such as production industries to validate the modeling of real system scenarios. The procedure for using FlexSim is as follows:

FlexSim procedure: First, run the FlexSim software. When the Start screen window appears, click on "create a new model" in the left menu. The model units dialog box will open, where you can specify measurement units such as (Time units, Length units, Fluid units, and Model start time. Create the basic processor object from the Process Flow section under the Standard Library.

- ❖ The modeling Procedures involve the following steps:

Procedure 1: Drag the source icon from the Source Section under the Fixed Resource Tool and place it into Modeling window. Then drag Queue icon frpm the Fixed Resource Tool again to insert a Queue into the modeling window.

Procedure 2: Drag the Processor icon from the Fixed Resource Tool and place it into the modeling window.

Under this, you can insert each machine's processing and set up time. This allows you to analyze each machine's utilization scenario in our case. Click and drag the Sink icon from the Fixed Resource Tool to insert it into the modeling window. Connect each modeling object by using the " Connect Object" item in the toolbox. After setting, the appropriate unit parameters, click "OK" and set the basic entity used by the specific tool. After connecting the modeling objects, insert properties for the model as shown below:

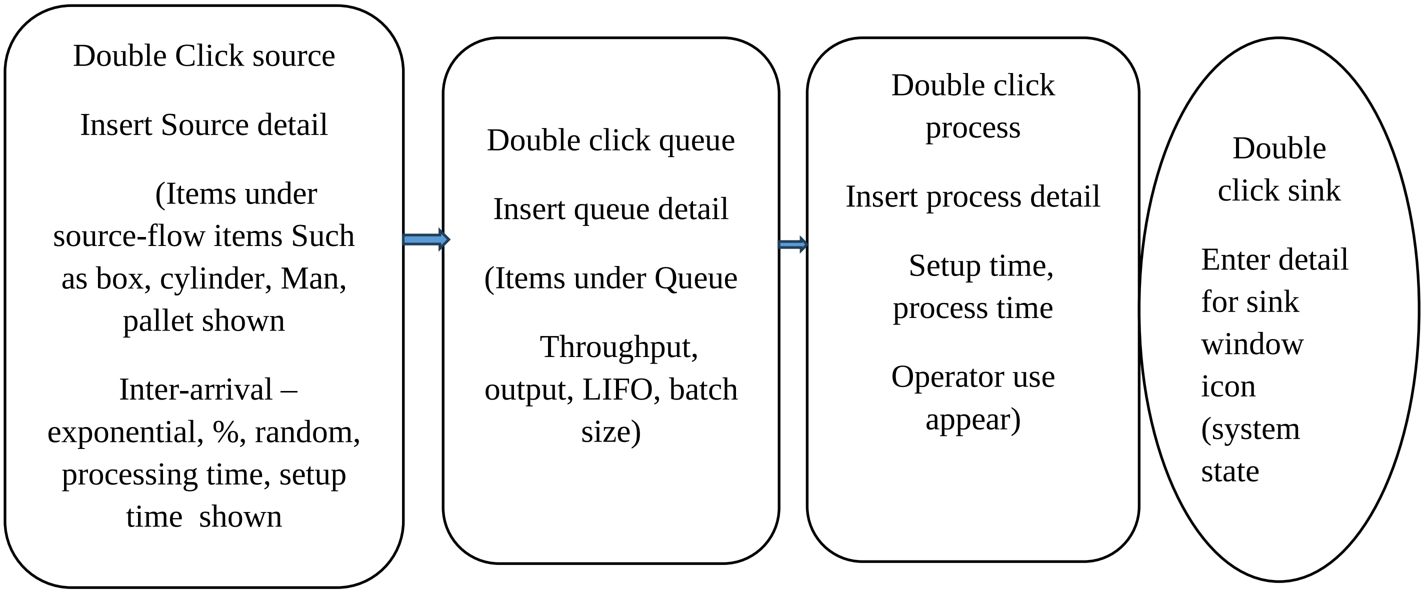


Figure 3. 2: procedure in FlexSim modeling

Fnally, the simulation for the model is displayed by clicking the run button in the upper toolbox, which is the green button. The simulation experiment control bar, appearing in the tool bar, helps run each experiment in the model. After conducting the experiment, it is possible to generate a report using the simulation experiment control tool. There are three items in the task bar: generate report, export report, and view-result tools. Therefore, by representing each machine in the layout and inserting each machine’s processing and setup time, the simulation is performed for 8 hours, which is 28,800 seconds, as in the real industry case scenario.

3.2.2. Background of the company

Ethio-Engineering Group (EEG) is an industrial firm controlled by the government, which was established in accordance with the Federal Democratic Republic of Ethiopia (FDRE) law and Council of Ministers Regulation No.475/2020 by September 20, 2020. In its new establishment, the EEG will precede its task under the supervision of the Public Enterprises Holding and Administration Agency. EEG is expected to significantly impact Ethiopia's industrialization by taking the lead in doing so. Its short-term target is to enable existing industries, such as COMESA, to play a significant role in expected market competition. Establishment objectives that are directly in line with ADDIS MACHINE AND SPARE PARTS MANUFACTURING INDUSTRY. Addis Machinery and Spare Parts Manufacturing Industry (AMSMI) was established in 1945 in accordance with a pact between the governments of the Czech Republic and Ethiopia to establish factories that could generate military supplies for the army. The company mainly targeted the Ethiopian Defense Force, which includes the army, air force, navy, and other governmental institutions. The company targeted simple bullet ammunition, metal and wood craft, medals, badges, tools, and defense force-related spare parts. To achieve its mission needs, the company focused on supplying defense-related products using a military tool. The company operates under different names such as the Majestic Hailesilassie ammunition factory, Addis Engineering, and Hibret Machine Tools Engineering Complex, and since recently, the Hibret Manufacturing and Machine Building Industry (HMMBI), and now it is named the Addis Machines and Spare parts Manufacturing Industry (AMSMI). The detailed steps of the data collection and data analysis methods are described as follows.

3.2.3. Data collection methods

The data collection involved both primary and secondary sources. The primary data gathered from the Conventional Factory operation department includes the following:

- List of available machine types and products
- Manufacturing process of products
- Machine arrangements and performance level of machines

3.2.4. Available machine types and products

According to the data collected from the operation department, there are 56 lathe machines and 32 milling machines available. This includes 18 CNC lathe machines, 30 conventional lathe machines, four heavy-duty machines, and one turret lath machine. The total available machinery in the CMF is expressed in table 3.1.

Table 3. 1: machines in CMF

S/n	Machines in CMF	Quantity
1	Conventional Lathe machine	36
2	CNC Lathe machine	15
3	Heavy Duty lathe machine	4
4	Vertical Milling machine	15
5	Universal Milling machine	3

6	Horizontal Milling machine	6
7	Drill Machine	2
8	CNC Milling machine	4
9	Slotting Milling Machine	3
	Total = 88 machines in CMF	

As indicated in the table 3.1, the total number of available machines in the Conventional Manufacturing Factory is described.

Table 3.2 shows the manufacturing process of products in a conventional factory, which shows the 3 years manufacturing data for the industry from 2012 to 2014.

Table 3. 2: Manufacturing data in CMF

S/n	**Parts produced in CMF**	**Manufacturing process**	**Quantity**
1	Shaft	Lathe ⟹ Milling ⟹ slotting ⟹ milling ⟹ Heat treatment grinding(external)	9
2	Plate	Shearing ⟹ welding	289
3	T bolt	Lathe ⟹ milling	
4	Small roller	Cnc lathe ⟹ heat treatment	1000
5	Stainless steel pin	Lathe ⟹ milling ⟹ grinding(external)	289
6	Pinion gear	Lathe ⟹ milling ⟹ Heat treatment ⟹ grinding(external)	5
7	Spur gear big	Cnc lathe ⟹ slotting ⟹ heat treatment ⟹ grinding(internal)	1
8	Spur gear small	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(internal)	4

9	Transfer gear	Lathe ➡ milling ➡heat treatment ➡ grinding(external)	5
10	Small bushing	Lathe➡milling ➡heat treatment	1000
11	Nut	Lathe ➡miling➡ heat treatment	309
12	Hexagon nut	Lathe ➡milling	1180
13	Spiral gear	lathe ➡ milling ➡heat treatment➡ Grinding(external)	5
14	Warm gear	Lathe ➡ milling ➡ gear hobbing	4
15	Allen bolt	Lathe ➡milling ➡ heat treatment	36
16	Allen head bolt thread length 50mm	Lathe ➡milling ➡ heat treatment	800
17	Alteration of 15 KV hook	Lathe	617
18	Bevel gear	Lathe ➡milling ➡ heat treatment➡ grinding(external)	2
19	Bevel gear for slotting machines	Lathe ➡milling ➡ heat treatment➡ grinding(internal)	7
20	Boiler traveling greater T-bolt with nut	Lathe ➡milling ➡ heat treatment	3000
21	Bolt with nut	Lathe ➡milling	160
22	Bronze coupling	Cnc Lathe ➡cnc milling ➡ bench work	1000
23	Bushing	lathe ➡ heat treatment ➡ grinding	1701
24	Bushing spur gear	Cnc lathe➡slotting ➡ heat ➡ treatment grinding(internal)	1200
25	Bushing with pin	Lathe➡ heat treatment ➡grinding	360
26	chain for feeding table	Shearing➡ bending ➡milling ➡ heat treatment	400
27	chain pin with nut and washer	Lathe ➡ milling➡ heat treatment	17

28	compression spring right hand	Cnc lathe ⟹ wire edm ⟹bench ⟹ work heat treatment	4
29	compression spring left hand	Cnc lathe ⟹ wire edm ⟹bench ⟹ work heat treatment	4
30	connecting shaft pin	Cnc lathe	1
31	crusher chute flange bolt with nut	Lathe ⟹ milling ⟹ heat treatment	7
32	crusher shaft	Lathe ⟹ milling ⟹ heat treatment	15
33	Double end stud bolt with nut	Lathe ⟹ heat treatment	500
34	Driven and driver helical gear	Lathe ⟹ slotting ⟹ milling ⟹ heat treatment	23
35	Dumbbell assembly	Lathe ⟹ heat treatment	72
36	Flight 524-190	Lathe ⟹ milling	50
37	Fly wheel gear	Lathe ⟹ cnc milling ⟹ slotting ⟹ heat treatment grinding (internal)	9
38	Gear shaft	Lathe ⟹ milling	11
39	Helical gear	Lathe ⟹ milling ⟹ slotting ⟹ heat treatment	7
40	Helical gear driven and drive	Lathe ⟹ milling ⟹ slotting ⟹ heat treatment	14
41	Helical pinion gear	Lathe ⟹ milling ⟹ Lathe ⟹ heat treatment grinding(internal)	5
42	High - low shifter slider	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(external)	7
43	Integrated spline shaft	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(external)	9
44	Bronze warm gear	Lathe ⟹ milling ⟹ gear hobbing	15
45	Internal ring gear	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(internal)	12

46	Internal spline spur gear	Lathe ⟹ milling ⟹ slotting ⟹ heat treatment	7
47	Key 40*25*300mm	Lathe ⟹ milling	670
48	Leaf spring support	shearing ⟹ welding	56
49	M16 bolt with nut & washer	Lathe ⟹ heat treatment	450
50	M16 die holder for bolt M/c	Lathe ⟹ milling	77
51	M18 bolt with nut & washer	Lathe ⟹ heat treatment	400
52	Mixer gear assembly	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(external)	6
53	Pinion gear	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding (external)	8
54	Pipe	Lathe ⟹ milling	15
55	Planetary gear	Lathe ⟹ milling ⟹ heat treatment	4
56	Planetary gear shaft	Lathe ⟹ milling ⟹ bench work ⟹ heat treatment ⟹ grinding (external)	7
57	Push pin M16	Lathe ⟹ heat treatment ⟹ grinding (external) ⟹ welding ⟹ Fastening	12
58	Pvc bushing	Lathe ⟹ milling	500
59	Roller	Lathe ⟹ milling ⟹ heat treatment	80
60	nut	Lathe ⟹ milling ⟹ heat treatment	600
61	Roller with bushing & pin (big)	Lathe ⟹ milling ⟹	70
62	Roller with bushing & pin (small)	Lathe ⟹ heat treatment ⟹ grinding	150
63	shaft	Lathe ⟹ milling ⟹ heat treatment ⟹ grinding(external)	67

64	shaft with pin	Cnc lathe ⇒ Cnc milling ⇒ grinding(external)	56
65	shaft with sprocket wheel	lathe ⇒ milling ⇒ heat treatment ⇒ grinding(external)	60
66	shank bushing	Lathe ⇒ heat treatment ⇒ grinding	79
67	shaft with six key & key way	Lathe ⇒ milling	56
68	sleeve of crank press b/n gear & crank shaft	Lathe ⇒ slotting ⇒ gear hobbing ⇒ heat treatment ⇒ grinding(external)	6
69	slide bar natural reverse gear	Lathe ⇒ slotting ⇒ milling ⇒ heat treatment	7
70	small shaft with two keys	Lathe ⇒ milling ⇒ heat treatment	6
71	spiral bevel gear	Lathe ⇒ milling ⇒ heat treatment ⇒ grinding (external)	7
72	spiral die	Lathe ⇒ milling ⇒ heat treatment ⇒ grinding(externl)	9
73	spiral gear shaft	Lathe ⇒ slotting ⇒ milling ⇒ heat treatment ⇒ grinding(external)	11
74	spline shaft	Lathe ⇒ milling ⇒ heat treatment ⇒ grinding(external)	13
75	Spring	Cnc lathe ⇒ wire edm ⇒ bench ⇒ work heat treatment	42
76	Spur gear	Lathe ⇒ milling ⇒ slotting ⇒ heat treatment	10
77	Stainless steel pin	Cnc lathe ⇒ conventional milling ⇒ heat treatment	60
78	Stainless steel shaft	Lathe ⇒ milling ⇒ grinding(external)	22
79	steering pin with nut, washer & bushing	Lathe ⇒ milling ⇒ bench work ⇒ grinding(internal)	45
80	Sun gear	Lathe ⇒ milling ⇒ drilling ⇒ heat treatment ⇒ grinding(internal)	14

81	T-bolt with nut	Lathe ➡milling ➡heat treatment	6
82	U-bolt with 2 nut & washer	Lathe ➡milling ➡heat treatment	9
83	Washer for M14 bolt M/c	Lathe ➡heat treatment	12
84	Wheel gear	Lathe ➡ milling	13
85	Cam shaft	Lathe ➡milling ➡heat treatment	6
86	Flange	Lathe	15
87	Rack and pinion gear	Lathe ➡milling ➡heat treatment ➡ grinding(external)	4
88	plain bevel gear	Lathe ➡milling ➡heat treatment ➡ grinding(eternal)	7
89	warm shaft with warm gear	Lathe ➡ milling ➡ gear hobbing	12
90	washer & spring washer	Cnc lathe ➡ wire edm ➡ bench work➡ heat treatment	13
91	spear	Lathe ➡milling ➡ heat treatment	9
92	Chain link	Plasma ➡combined shearing ➡ milling ➡heat treatment	8
93	Dumbbell	Lathe ➡ heat treatment	120

3.2.5. Data analysis

3.2.6. Analyzing the existing manufacturing system

After collecting the manufacturing process data as indicated above, the analysis was presented for the existing manufacturing system in a Conventional Manufacturing Factory. Although different parts are produced in CMF, parts following the same manufacturing process were categorized under the following conditions: The total available 196 parts are grouped in the list of 21 parts below, which have a common manufacturing process.

1. Gear– spur gear, helical gear, worm gear, sun gear, planetary gear, rack &pinion gear, transfer gear, bronze worm gear, spiral bevel gear, pinion gear, differential helical gear, bevel gear

The manufacturing process is, lathe ➡ milling ➡ slotting ➡ heat treatment

The manufacturing process for sun gear is: lathe ➡ milling ➡ drilling ➡ heat treatment ➡ grinding

2. Shaft – gear shaft, spline shaft, mixer shaft, spiral gear shaft, small shaft with two key way, connecting shaft, pinion shaft, helical gear shaft, dumbbell shaft, shaft for sprocket wheel, crusher shaft

The manufacturing process involves lathe ➡ milling ➡ heat treatment ➡ grinding

mixer shaft: Lathe ➡ milling ➡ heat treatment

shaft with two key way: Cnc lathe

3. coupling – bronze coupling, sprocket wheel coupling

The manufacturing process is Cnc lathe ➡ cnc milling ➡ bench work

4. Bushing – big bushing, small bushing, pvc bushing, insert bushing, bushing spur gear, shank bushing

The manufacturing process lathe ➡ heat treatment ➡ grinding

bushing spur gear: cnc lathe ➡ slotting ➡ heat treatment ➡ grinding

5. Nut – nut, hexagonal nut, esk nut, M20 nut, moon shape ring nut, small nut, ring nut, nut for dumbbell,

The manufacturing process is: lathe ➡ milling

Lathe ➡ milling ➡ heat treatment (dumb bell)

6. Pin – steering pin, big pin, small pin, locking pin, push pin, connecting shaft pin, chain pin with nut and washer, bushing with pin,

The manufacturing process is: Lathe ➡ milling ➡ heat treatment

Lathe ➡ heat treatment ➡ grinding (bushing with pin,

Cnc lathe ➡ cnc mill ➡ grinding (connecting shaft pin)

7. Bolt – bolt with nut & washer, bolt with nut, bolt, ck bolt, Allen bolt, hexagon bolt, wheel bolt, stud bolt, hexagonal bolt with nut half thread, hexagonal bolt with full thread, double stud bolt, esk bolt

The manufacturing process is: Lathe ➡ milling ➡ heat treatment

Lathe ➡ milling (esk nut, M20 nut, ring nut, hexagon bolt, Allen bolt, wheel bolt, Esk bolt, hexagon bolt with nut half thread)

8. Roller – small roller, big roller

The manufacturing process involves: Cnc lathe ➡ heat treatment (small roller)

➡ Lathe ➡ heat treatment (big roller)

9. Chain – chain link, feed table chain assembly (shearing ➡ bending ➡ milling ➡ heat treatment

The manufacturing process involves: plasma ➡ combined shearing ➡ milling ➡ heat treatment

10. Spring washers

The manufacturing process involves: Cnc lathe ➡ wire edm ➡ bench work ➡ heat treatment

11. Sleeve –

The manufacturing process involves: Lathe ➡ slotting ➡ gear hobbing ➡ heat treatment

12. Screw left and right – closing & opening screw

The manufacturing process involves: lathe ➡ milling ➡ slotting ➡ second lathe ➡ milling

13. Closing cup – gate valve

The manufacturing process involves: Lathe ➡ milling

14. Tube for drainage –

The manufacturing process involves: Lathe ➡ milling

15. Spear –

The manufacturing process involves: lathe ➡ milling ➡ heat treatment

16. key way hook for alternation

Processed in lathe operation only

17. Plate – supporter plate, plate for chain

The manufacturing process involves: shearing ➡ welding

18. Key- big key & small key

Processed in: lathe ➡milling

19. Boiler traveling with greater nut-

The manufacturing process involves: lathe ➡ milling ➡ heat treatment

20. Collet 06 for alternation

The manufacturing process involves: Cnc lathe ➡ cnc mill ➡ grinding

21. Dumbbell – 1- 20 kg dumbbell assembly

The manufacturing process involves: Lathe ➡ heat treatment

Although the factory produces many parts, these are currently some of the most commonly produced parts. As evidence, the following inspection checklist obtained from the quality department is attached.

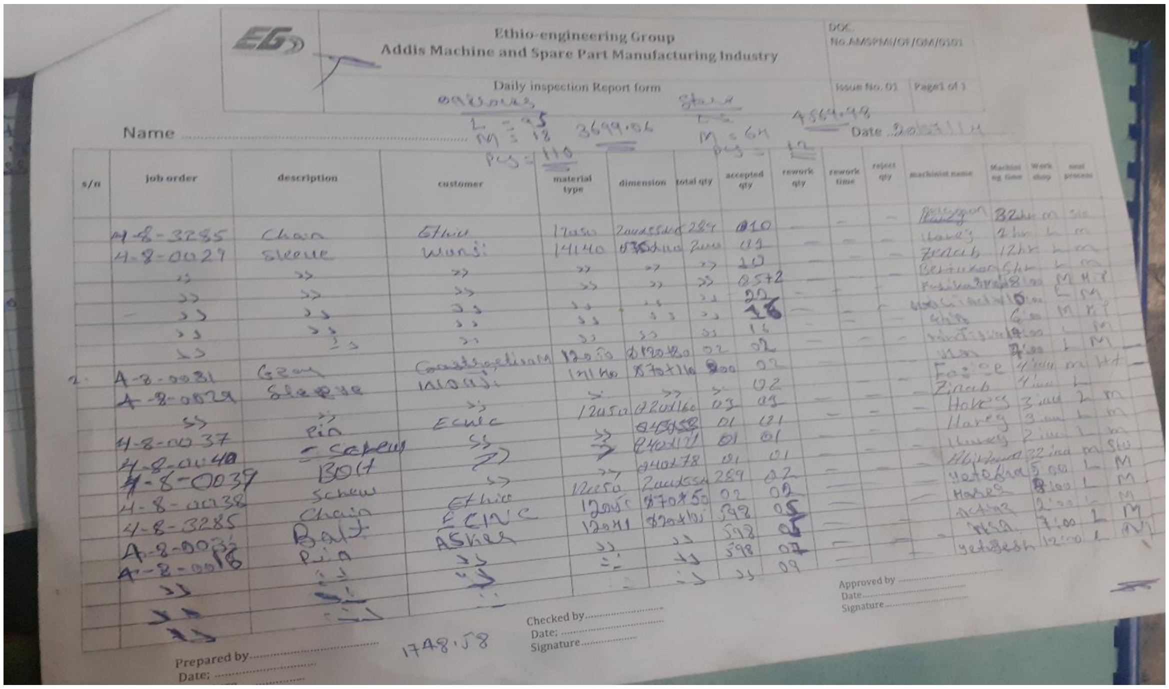

Ethio-engineering Group
Addis Machine and Spare Part Manufacturing Industry
Daily inspection Report form
Name
Date
s/n | job order | description | customer | material type | dimension | total qty | accepted qty | rework qty | rework time | reject qty | machinist name | Machining time | Work shop | next process
Prepared by
Date;
Checked by
Date;
Signature
Approved by
Date
Signature

Figure 3. 3 : Daily inspection sheet

Source: Data from the quality department in CMF

According to the data gathered in the production system, the machining and setup times for some parts are large. The machining time for some parts was slightly longer than expected. Table 3.3 provides additional data:

Table 3. 3: product operation and cycle time

s/n	Product item	Operation	setup time	product cycle time
1	Shaft	Raw material preparation	15 min	2:35 hr.
		Lathe	20 min	2hr.
		Milling	50 min	5:25hr.
		Grinding	30 min	2:30hr
2	Gear	Operation	Set up time	product cycle time
		Raw material preparation	10 min	30 min

		Lathe	60 min	2hr.
		Milling	4hr.	20hr.
		Heat treatment	20 min	55min
		Grinding	30 min	1:30hr.
3	Coupling bolt	operation	Set up time	Product cycle time
		Raw material preparation	30 min	1:10hr.
		Milling	1:20hr.	6:20hr.
		Heat treatment	10 min	55 min
4	Feed table chain assembly	Operation	Set up time	Product cycle
		Lathe	1hr.	1:30 hr.
		Milling	50 min	2 hr.
5	Roller	Operation	Set up time	Product cycle time
		Raw material preparation	15 min	35 min
		Lathe	3hr.	8hr.
		Assembly	2hr.	24hr.
6	pin	Operation	Set up time	Product cycle time
		Raw material preparation	30 min	1:30hr.
		Lathe	1:10 hr.	3:50hr.
		Heat treatment	1hr.	4hr.
7	Supporter plate	Operation	Set up time	Product cycle time
		Raw material preparation	15 min	1hr.
		Lathe	35 min	4:50hr.
		Grinding	20 min	3:20hr.
		Lathe	25 min	2:20hr.
		Assembly	2hr.	1hr.
8	Nut	Operation	Set up time	Product cycle time
		Raw material preparation	15 min	2:20hr.
		Lathe	1:35hr.	2:20hr.
		Heat treatment	5hr.	3hr.
		Colouring	30 min	1hr.
9	Alternation of motor shaft bearing	Operation	Set up time	Product cycle time
		Raw material preparation	20 min	1hr.

		Lathe	30 min	3hr.
		Grinding	15 min	1:30hr.
		Lathe	10 min	1:10hr.
		Assembly	35 min	1hr.
10	Hollow block	Operation	Set up time	Product cycle time
		Raw material preparation	15 min	1hr.
		Lathe	35 min	2hr.
		Assembly	2hr.	5hr.
11	Sleeve	Operation	Set up time	Product cycle time
		Lathe	2:20hr.	14:20hr.
		Slotting	20 min	3:20hr.
		Gear hobbing	20 min	4:20hr.
		Heat treatment	30 min	4:30hr.
		Grinding	20 min	2:20hr.
		Assembly	25 min	1hr.
12	Bushing	Operation	Set up time	Product cycle time
		Raw material preparation	15min	30 min
		Cnc lathe	20 min	3:20hr.
		Cnc milling	15min	35min
		Grinding	20 min	30min
		Heat treatment	1:10 hr.	2hr.
13	Stud bolt	Operation	Set up time	Product cycle time
		Raw material preparation	50 min	2hr.
		Lathe	1:30hr.	2:45hr.
		Heat treatment	50 min	1hr.
14	Screw	Operation	Set up time	Product cycle time
		Raw material preparation	1:30hr.	2hr.
		Lathe	30 min	6:20hr.
15	Gate valve	Operation	Set up time	Product cycle time
		Raw material preparation	30 min	1hr.
		Assembly of 5 parts	50 min	6hr.
		Surface finishing	40 min	1:30hr.

16	Closing cup	Operation	Set up time	Product cycle time
		Raw material preparation	1hr.	30 min
		Lathe	1:30hr.	4:45hr.
		Milling	10 min	50 min
		Surface hardening	1:20hr.	2hr.
17	Foundation bolt	Operation	Set up time	Product cycle time
		Raw material preparation	35 min	30 min
		Milling	10 min	2hr.
		Heat treatment	20 min	5o min
		Assembly	50 min	2hr.

Following the current production system in a Conventional Manufacturing Factory, a standard operation flow chart was developed for the main parts listed in figure 3.3. The following standard operation procedure was prepared for a Conventional Manufacturing Factory based on the assessment of recent production activities.

The following standard procedure prepared based on the production activity of CMF and developed to further understand the process plan of parts which were processed in the available machine

The sequence of operations were included starting from the raw material which required setup time as initial process for shaft.

Product type – Shaft

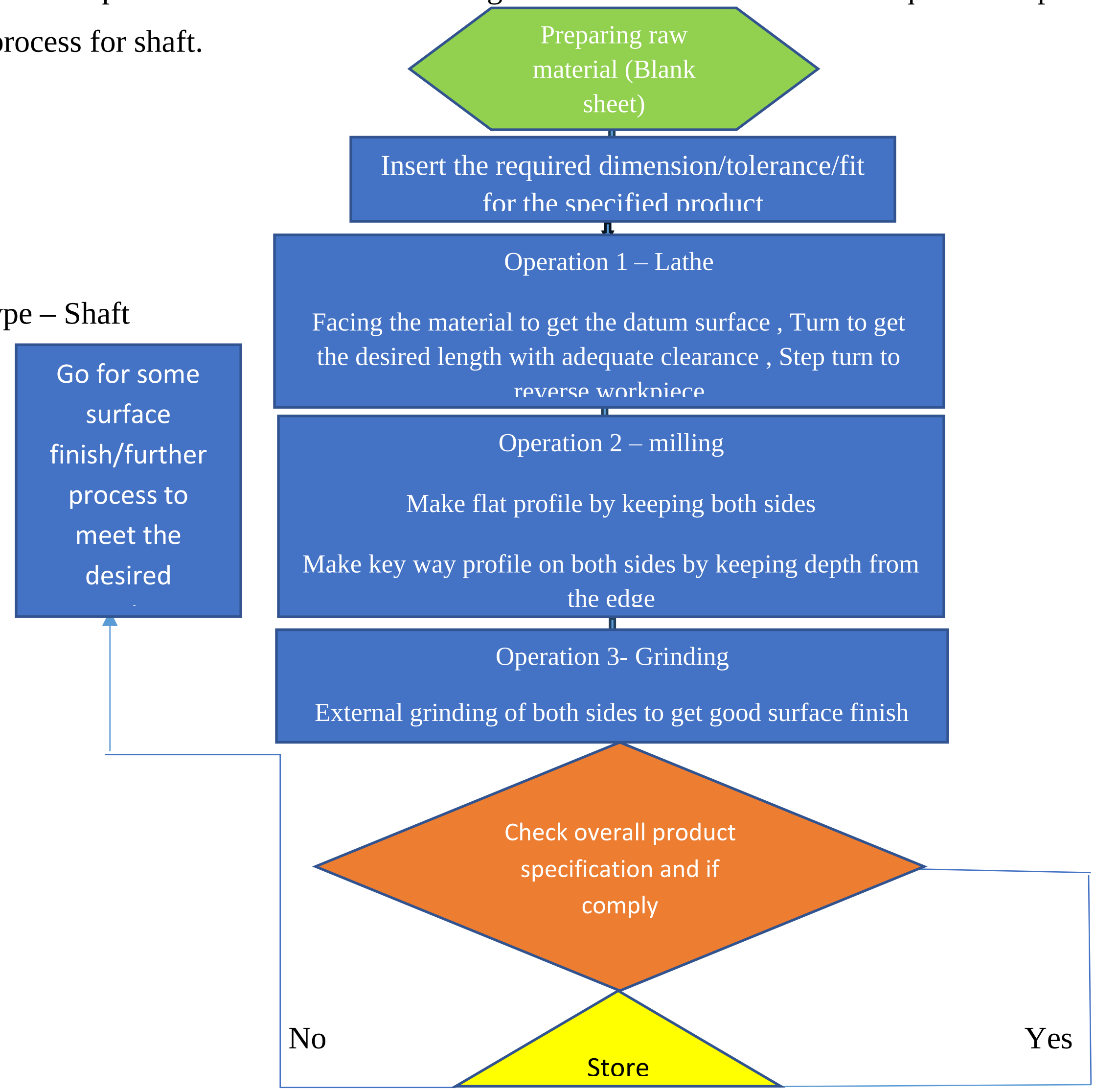


Figure 3. 4: process flow chart for shaft

The sequence of operations were included starting from the raw material which required setup time as initial process for gear. Product type - Gear

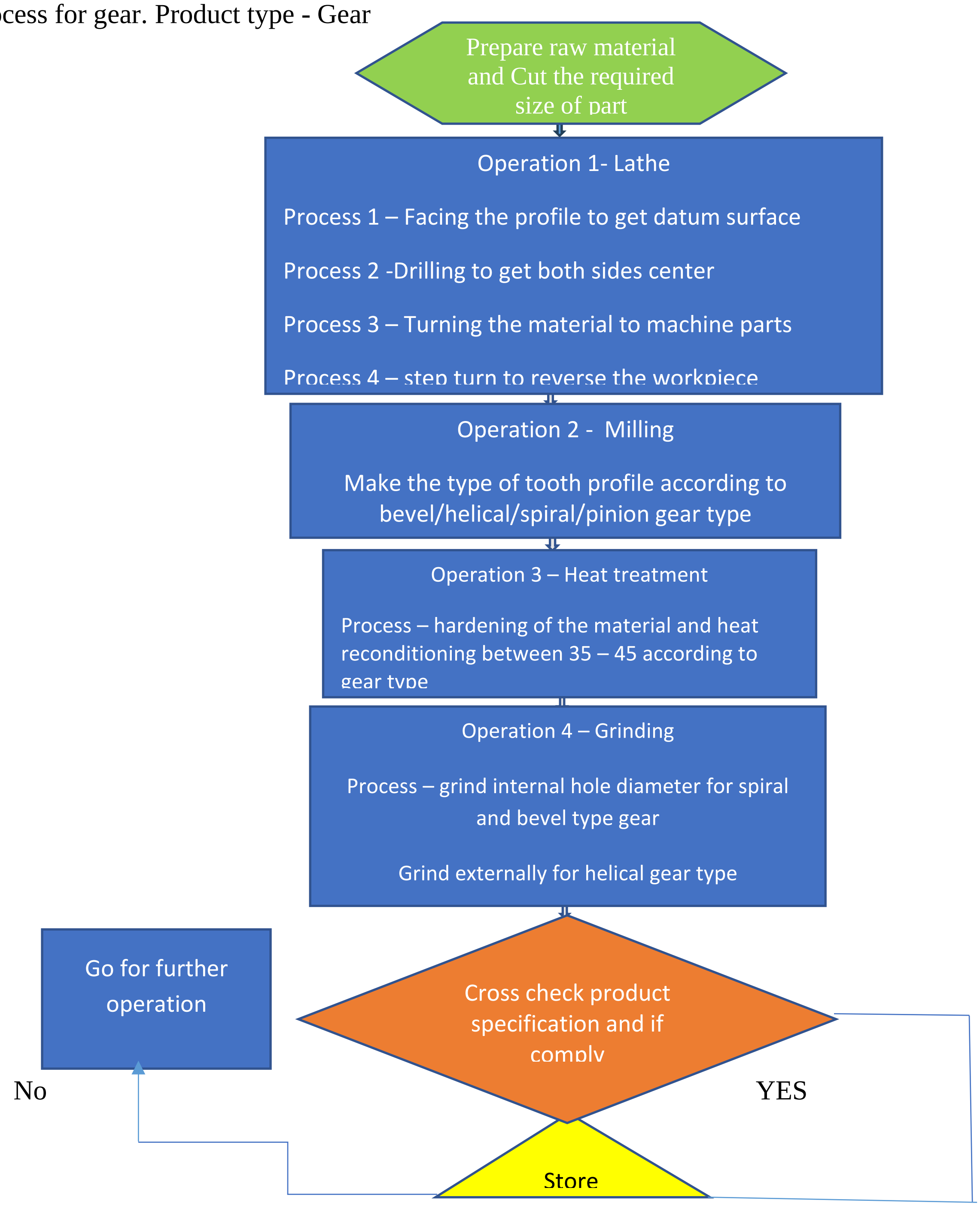


Figure 3. 5: process flow chart for gear

The sequence of operations were included for coupling bolt starting from the raw material which required setup time as initial process for raw material.

Product type - Coupling bolt

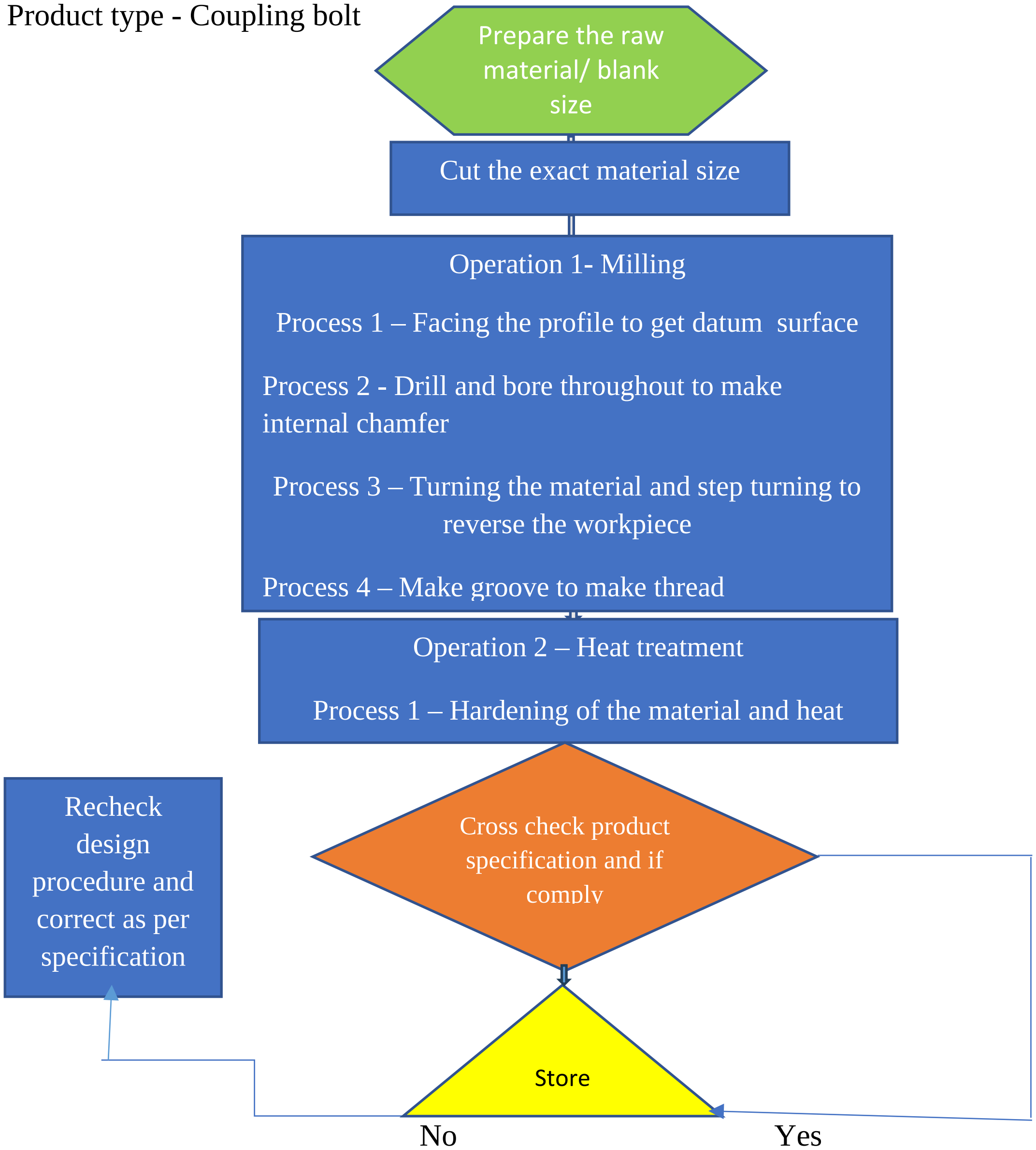


Figure 3. 6: process flow chart for coupling bolt

The sequence of operations were included starting from the raw material which required setup time as initial process.

Product type - Feed table chain assembly

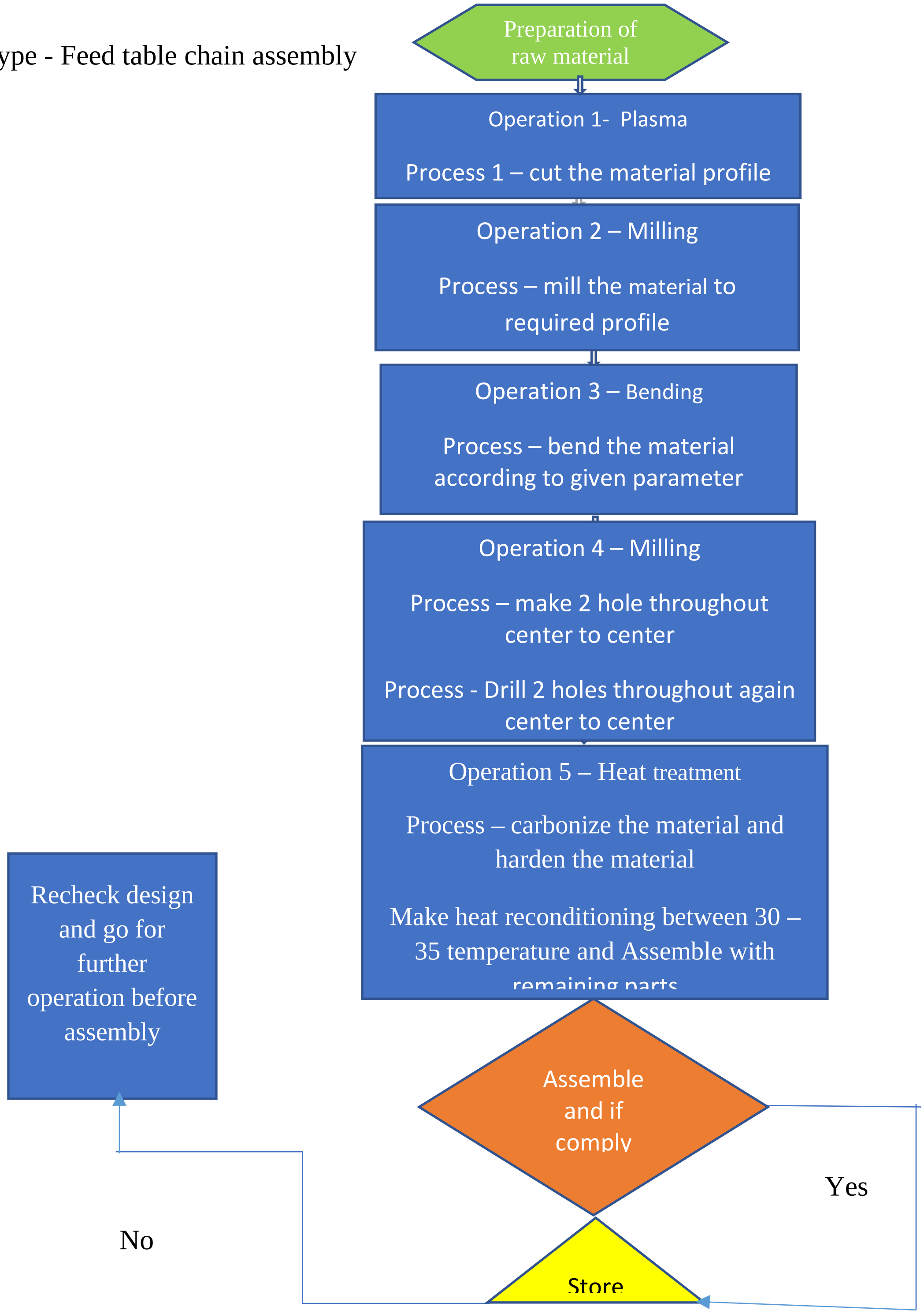


Figure 3. 7: process flow chart for feed table chain assembly

Product type - Roller

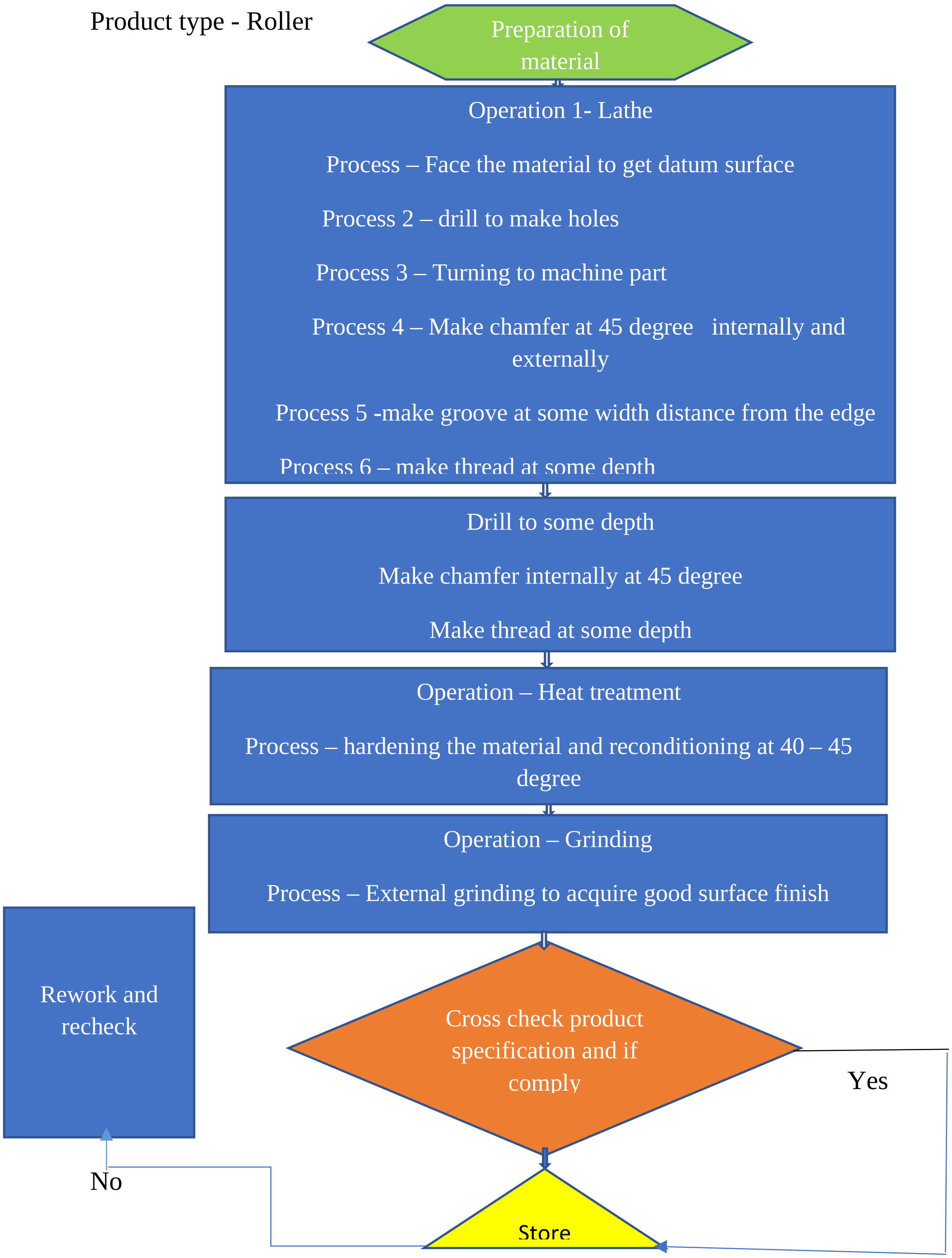


Figure 3. 8: process flow chart for roller

The sequence of operations were included starting from the raw material which required setup time as initial process for pin.

Product type - Pin

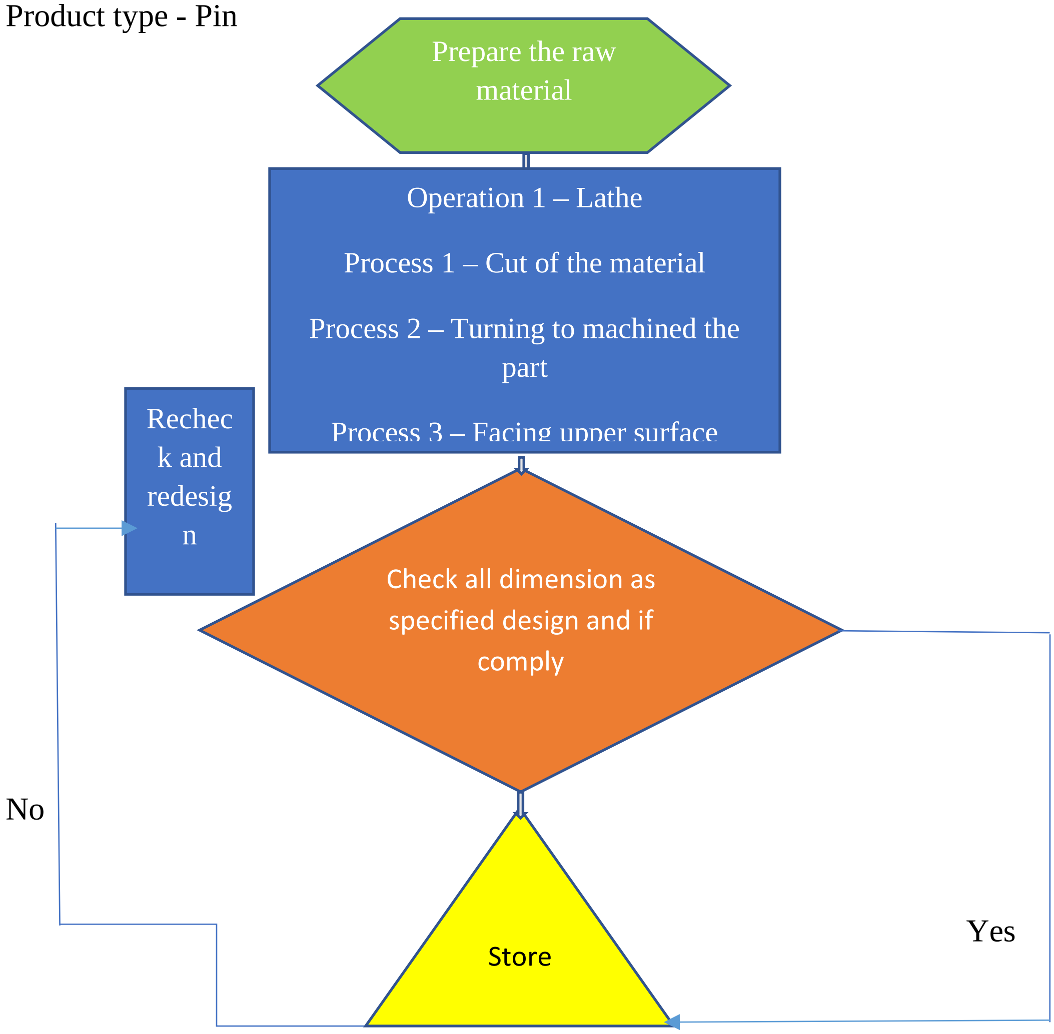


Figure 3. 9: process flow chart for pin

The sequence of operations were included starting from the raw material which required setup time as initial process for supporter plate.

Product type - Supporter plate

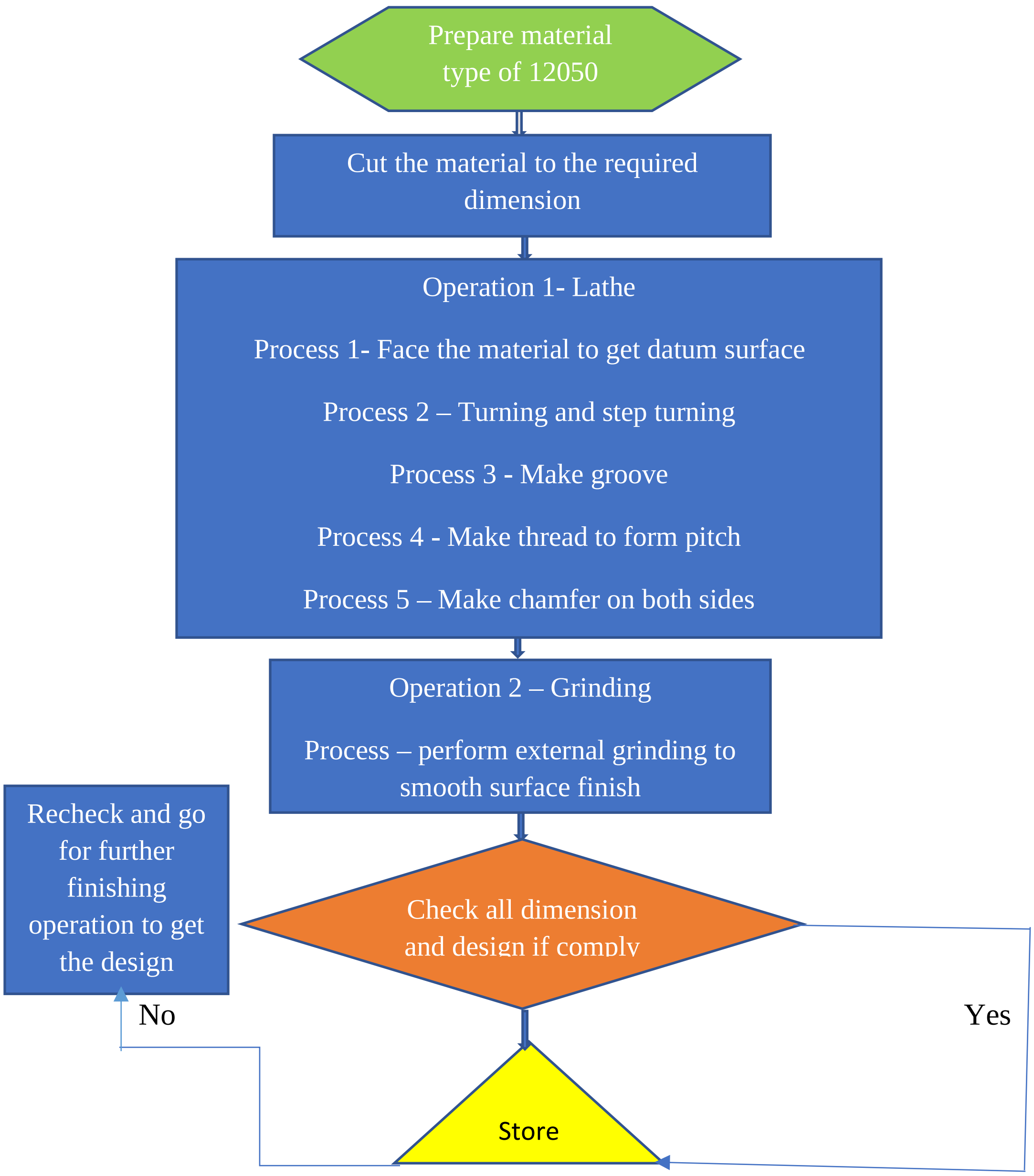


Figure 3. 10: process flow chart for supporter plate

The sequence of operations were included starting from the raw material which required setup time as initial process for Nut.

Product type - Nut

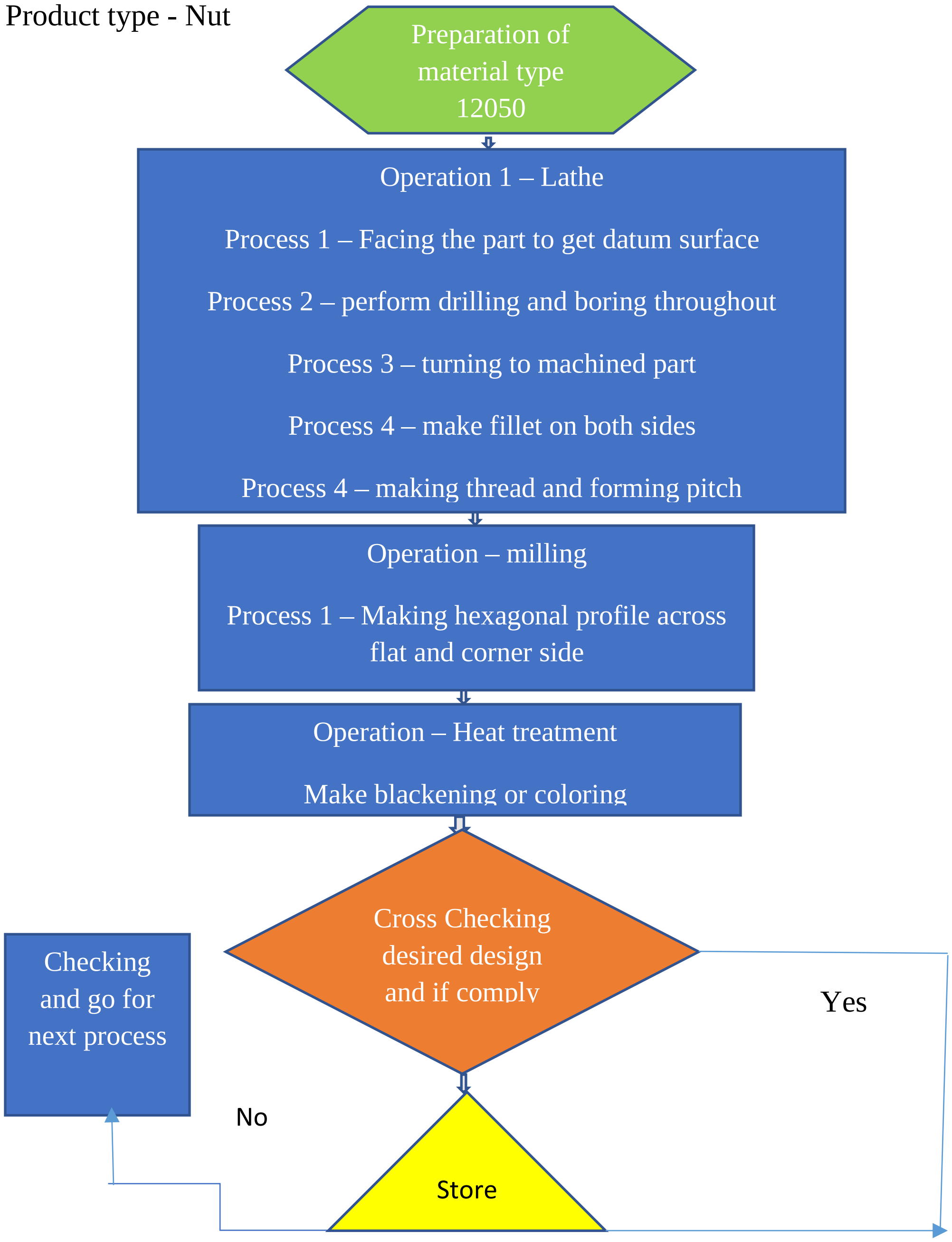


Figure 3. 11: process flow chart for nut

The sequence of operations were included starting from the raw material which required setup time as initial process for Alteration of motor shaft bearing.

Product type - Alternation of motor shaft bearing

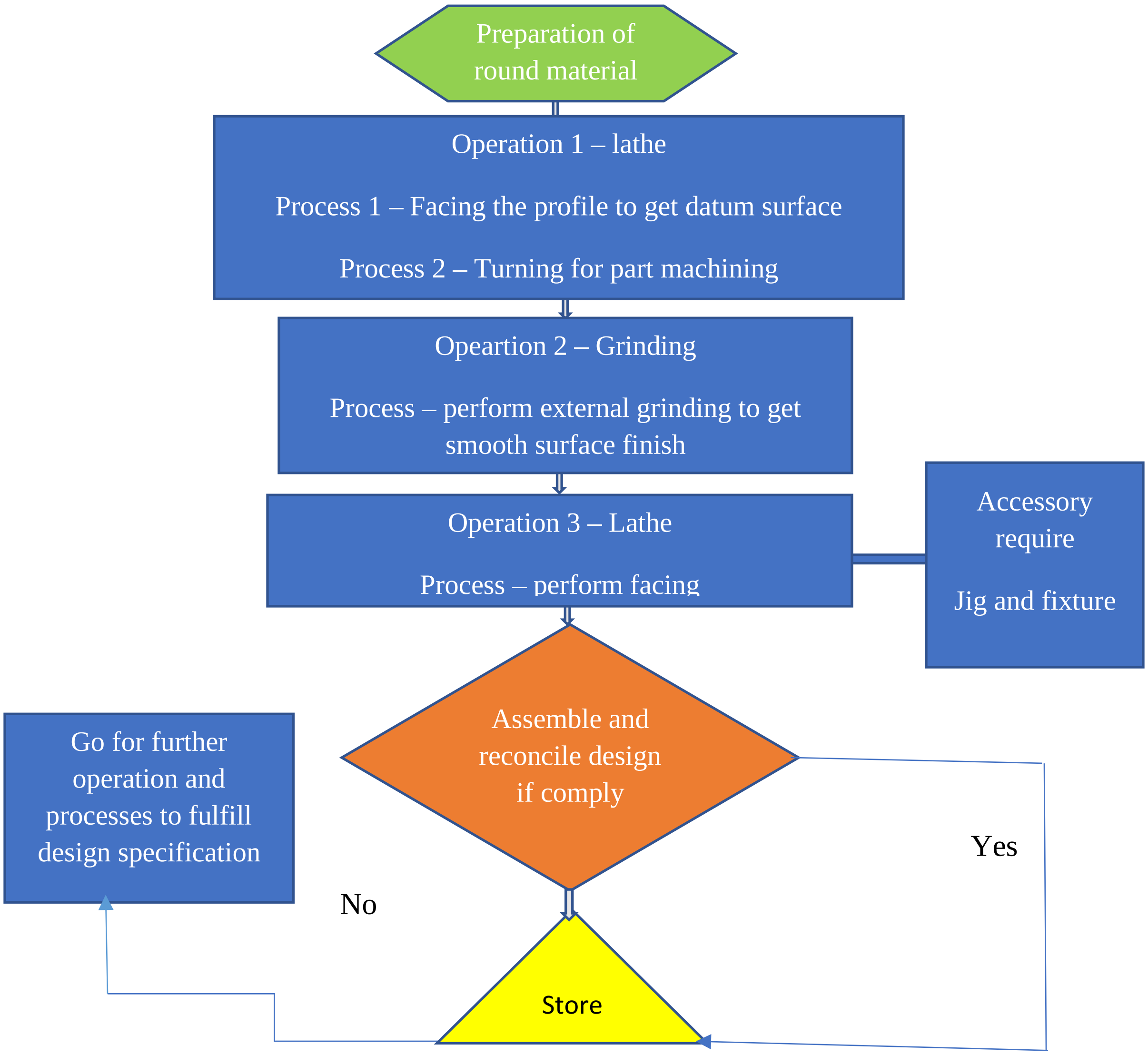


Figure 3. 12: process flow chart for alteration of motor shaft bearing

The sequence of operations were included starting from the raw material which required setup time as initial process hollow block.

Product type - Hollow block

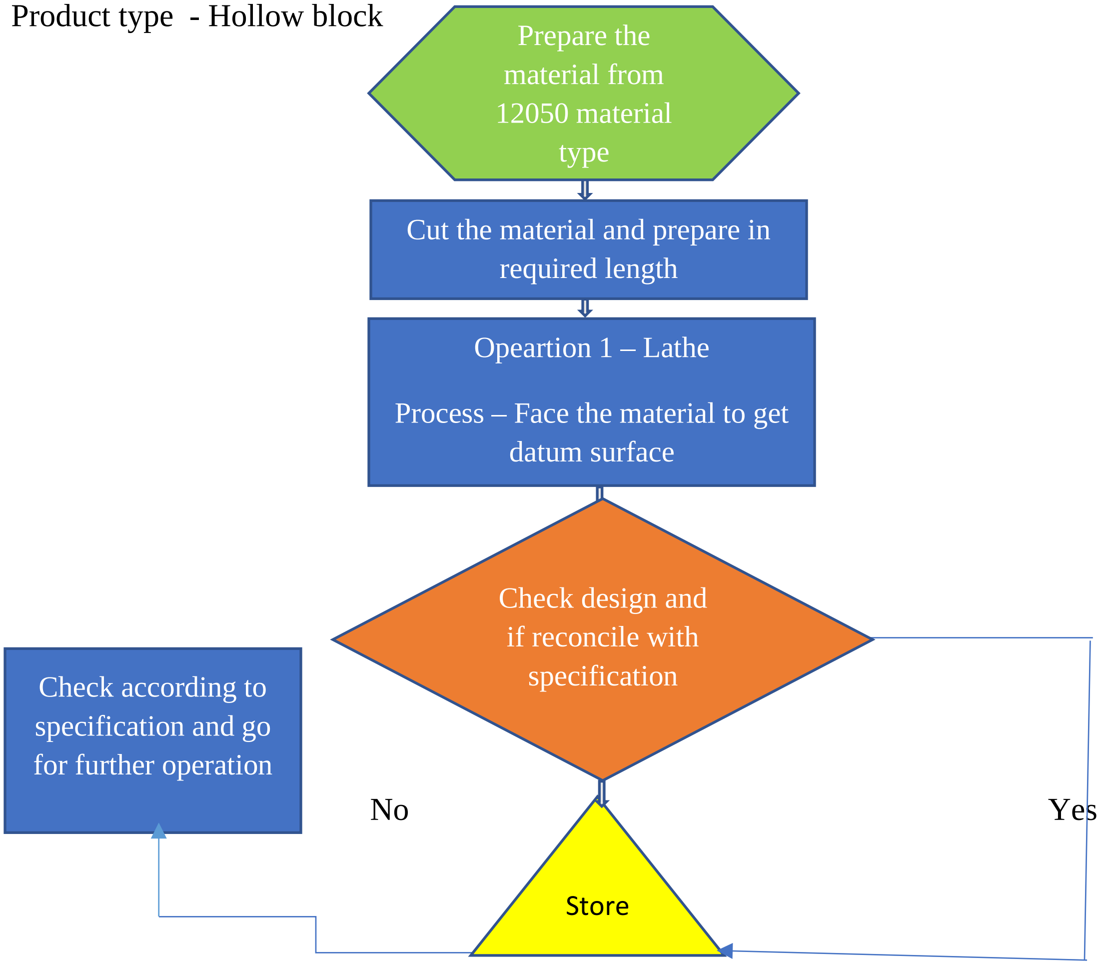


Figure 3. 13: process flow chart for hollow block

The sequence of operations were included in figure 3.14 starting from the raw material which required setup time as initial process for sleeve.

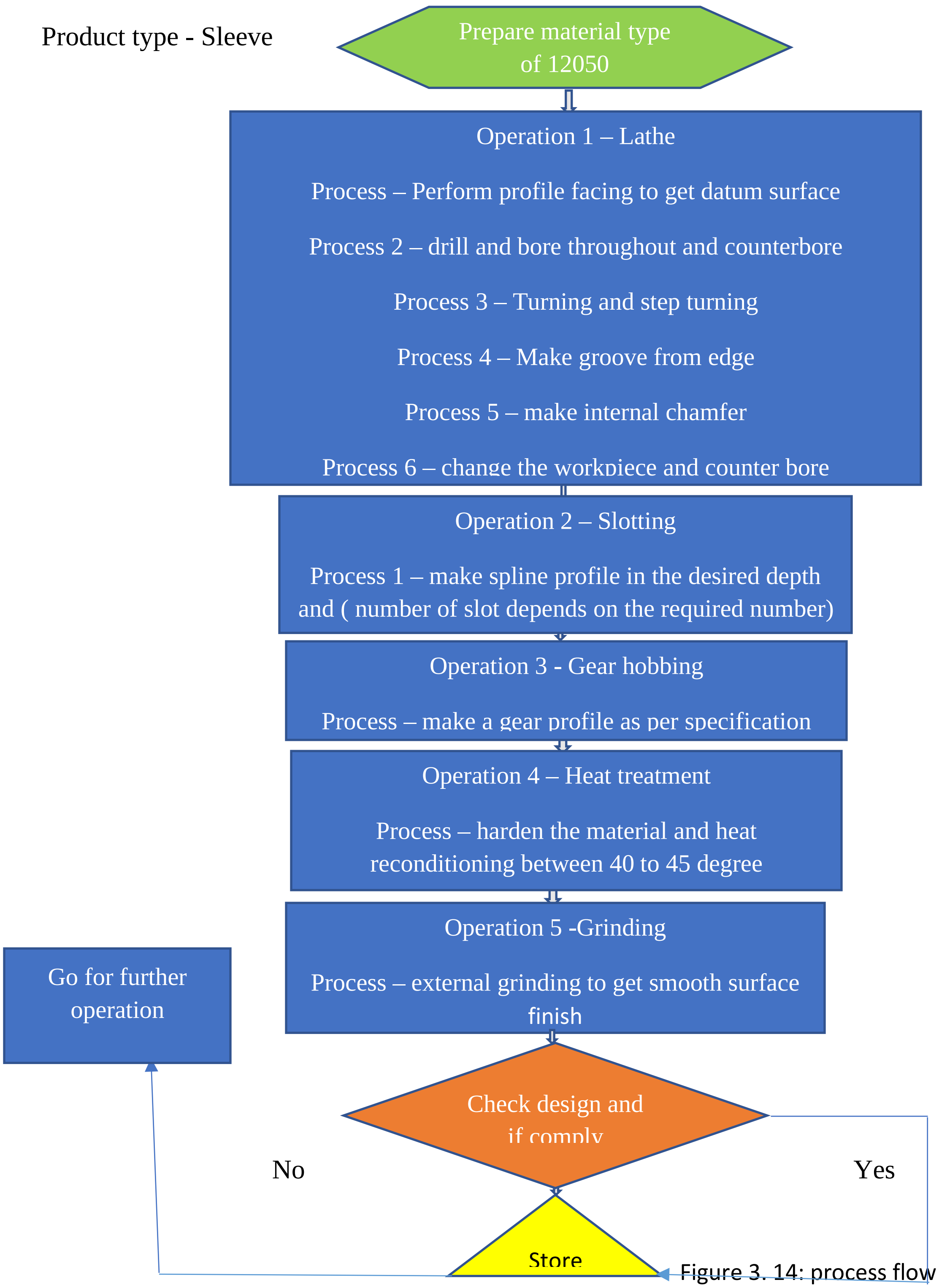


Figure 3. 14: process flow chart for sleeve

Item description - Bushing

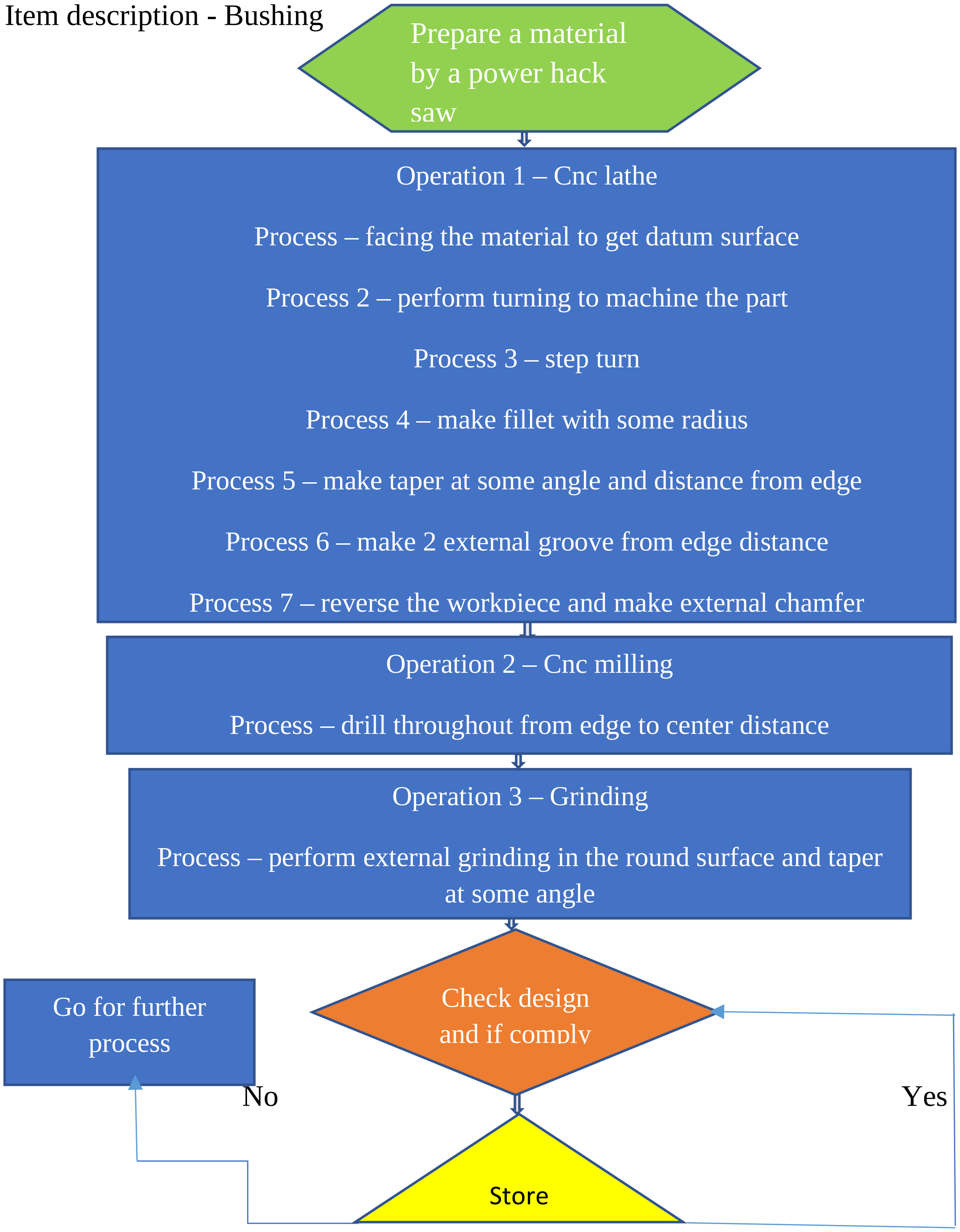


Figure 3. 15: process flow chart for process chart flow for bushing

The sequence of operations were included starting from the raw material which required setup time as initial process for bushing.

Item description - Stud bolt

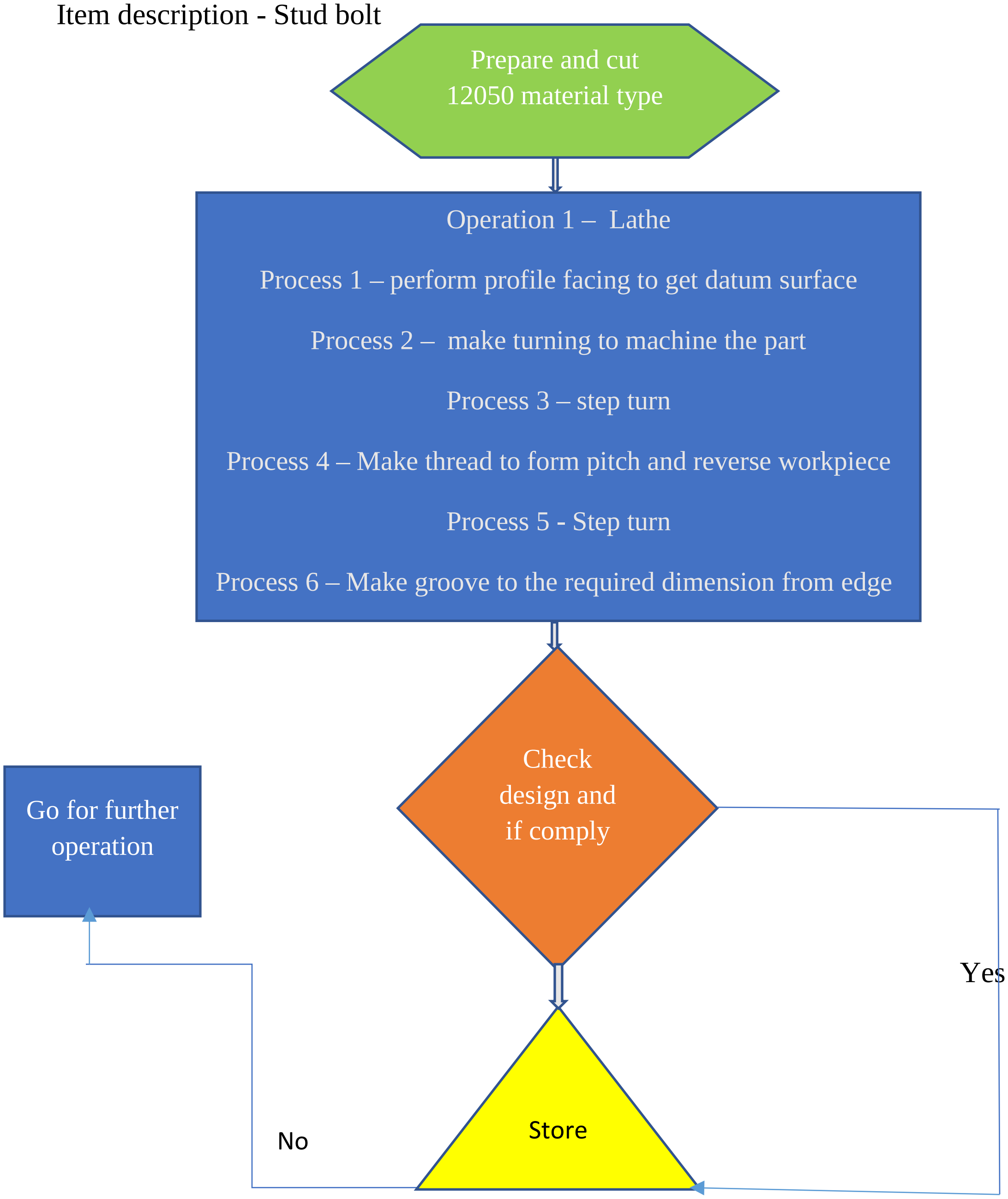


Figure 3. 16: process flow chart for stud bolt

The sequence of operations were included starting from the raw material which required setup time as initial process for Stud bolt.

3.3. Analysis of functional and cellular layout using CRAFT algorithm

Analyses of the current manufacturing system using the CRAFT algorithm was as follows: the matrix flow shows parts movement in each department, and for the purpose of analyses, each cell is divided into a 1.5 m unit found in the scale-m/unit of Craft algorithm. This was calculated from the input data obtained from the total factory area. The total area of the existing factory is 1,728.09 m2, from this it was found that the length is 109.86 m and the width is 15.73m. Therefore, it is used in the algorithm used below to analyse each department.

Table 3. 4: CRAFT input data

Functional layout(Department)	Machines
1	1-12(Conventional Lathe machine)
2	13-21(Conventional Lathe machine)
3	22-26(Conventional Lathe machine)
4	27-33(Conventional Lathe machine)
5	34-41(Cnc lathe machine)
6	35-50(CnC lathe machine)
7	42-44(Heavy duty lathe machine)
8	51-54(Heavy duty lathe machine)
9	55-56(Cnc lathe & lathe)
10	57-65(Vertical, horizontal milling)
11	66-71(Drill, Cnc mill, vertical milling)
12	72-77(Milling, slotting)
13	78-82(Horizontal milling, vertical milling, cnc milling)
14	83-88(Vertical milling, universal milling)

The layout data was calculated based on the input data which was presented in the analysis of table 3.4. Therefore, as an input for The Craft algorithm the number of departments available in the functional layout were 14 as indicated in the above table 3.4. The measurement used was meter, the total length of the factory was 109.86 m and the total width was 15.73 m which is taken from the existing layout data. However, we were used only the width of machines occupied the space in the existing layout which was 16.5 m and the length was 87 m. After the layout data was inserted the facility defined and the algorithm analyzed each of the input data's inserted and resulted the facility informations such as the Flow matrix, Cost matrix for the layout generated.

Layout Data

Layout Data

Problem Name:	Production
Number Depts.:	14
Fixed Points:	0
Dimension:	m

Define Facility

Facility Information

Scale-m/unit	1.5	Cells
Length-m	87	58
Width-m	16.5	11
Area-sq.m	1435.5	638

Department Information

	Name	F/V	Area	Cells
Dept. 1	D 1	V	14	7
Dept. 2	D 2	V	14	7
Dept. 3	D 3	V	14	7
Dept. 4	D 4	V	14	7
Dept. 5	D 5	V	14	7
Dept. 6	D 6	V	14	7
Dept. 7	D 7	V	14	7
Dept. 8	D 8	V	14	7
Dept. 9	D 9	V	14	7
Dept. 10	D 10	V	14	7
Dept. 11	D 11	V	14	7
Dept. 12	D 12	V	14	7
Dept. 13	D 13	V	14	7
Dept. 14	D 14	V	14	7

Figure 3. 17: CRAFT layout data

The figure 3.16 expressed the layout data generated using Craft algorithm as an input for the Craft algorithm, the number of departments available in the functional layout 14 were inserted.

Flow Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14
D 1		19		16			21		21	22	19			24
D 2	22			26	24		26			21		16		
D 3	17	18				23	23	16	27	25		19	27	
D 4			27		18		16			22				
D 5		26	27						18			19		17
D 6			16				25		21			25	17	17
D 7			15	19	25	23			15	25		18		
D 8							27							
D 9		17	15		26	18					21		21	16
D 10	23								15		18	15	23	
D 11		19				19	26			21				
D 12				16		25				24	21			18
D 13					22									
D 14	24	16	21	25		15		17		26		25	17	

Figure 3. 18: Flow matrix

The flow matrix shows each parts movement within the departments in the defined facility using Craft algorithm.

Cost Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14
D 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D 14	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 3. 19: Cost matrix

The cost matrix described below shows initial cost was 11227RS in India. 1RS is equivalent with 0.68 birr in Ethiopia. So that, this becames equal with 7,634.36 birr in Ethiopia, for unit machine available in the 14 Departments. Therefore for the 88 machines available Total cost will be 88*7,634.36 birr = 671,823.68 birr which is very expensive interms of cost spend for material handling purpose in the existing layout.

Init. Cost	11227

Iterations: 8

Index	Init. Seq.
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14

Iter.	Type	Action	Cost
1	Switch:	14 and 8	10297
2	Switch:	9 and 6	9844
3	Switch:	14 and 3	9530
4	Switch:	12 and 10	9432
5	Switch:	4 and 14	9347
6	Switch:	10 and 11	9277
7	Switch:	3 and 7	9219
8	Switch:	4 and 1	9171

Figure 3. 20: CRAFT algorithm department flow

After the layout was generated using the algorithm, the cost of the final layout calculated expressed in figure 3.18 and the the sequence of each department with respect to the switch for the departments was generated as indicated in figure 3.19. This showed after each input data was inserted and calculated the cost of each departments arrangement in the resulted layout. Finally, it showed a better low cost arrangement of each departments in the layout created with in the algorithm and indicated to made the switch for the departments inorder to get the optimal layout arrangement.

According to figure 3.20 the initial layout created after each departments flow anayzed with the used algorithm and the final iteration resulted after switch made for the departments.

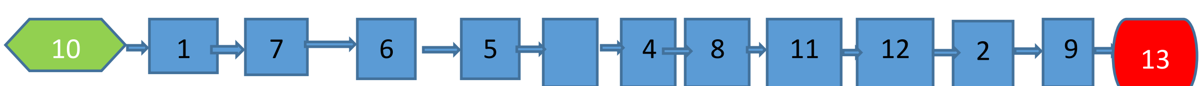
y-centroid	Sequence
13.2142859	10
0.78571427	1
9.0714283	7
7.78571415	6
6.21428585	5
18.9285717	14
3.5	3
4.92857122	4
10.5	8
14.7857141	11
16.0714283	12
2.07142854	2
11.9285717	9
17.5	13

11392 Initial layout

	1	2	3	4	5	6	7	8	9	10	11
1	2	2	2	2	2	0	0	0	0	0	0
2	2	2	12	12	12	0	0	0	0	0	0
3	12	12	12	12	7	0	0	0	0	0	0
4	7	7	7	7	7	0	0	0	0	0	0
5	7	8	8	8	8	0	0	0	0	0	0
6	8	8	8	5	5	0	0	0	0	0	0
7	5	5	5	5	5	0	0	0	0	0	0
8	4	4	4	4	4	0	0	0	0	0	0
9	4	4	3	3	3	0	0	0	0	0	0
10	3	3	3	3	9	0	0	0	0	0	0
11	9	9	9	9	9	0	0	0	0	0	0
12	9	13	13	13	13	0	0	0	0	0	0
13	13	13	13	1	1	0	0	0	0	0	0
14	1	1	1	1	1	0	0	0	0	0	0
15	10	10	10	10	10	0	0	0	0	0	0
16	10	10	11	11	11	0	0	0	0	0	0
17	11	11	11	11	14	0	0	0	0	0	0
18	14	14	14	14	14	0	0	0	0	0	0
19	14	6	6	6	6	0	0	0	0	0	0
20	6	6	6	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0

Figure 3. 21: Department switch

Figure 3.20 showed the departments flow in the created layout within the algorithm and the possible switch for each departments. Therefore, based on the analysis of the CRAFT algorithm the sequence of machine departments for functional layout after the switch was:



This sequence is generated by iteration of input data for some time, there are switched departments after initial sequence.

3.4. CRAFT analysis based on manufacturing sequence

The cell design was executed first by identifying parts in the Conventional Manufacturing Factory and classifying them as part families based on design/manufacturing attributes and grouping machines in the cell for processing part families based on processing similarity.

Table 3. 5: Analyses of production sequence in cell arrangement

Parts	Cellular arrangement
1 sleeve	1-76-21(lathe, mill/slotting, gear hobbing)
2 Gear	2-78-76 (lathe, cnc mill, slotting)
3 Shaft	3-78-68(lathe, cnc milling, heat treatment)
4 Coupling	34-78(cnc lathe, cnc mill)
5 Bushing	2-68-46(lathe, heat treatment, grinding)
6 Nut	2-78-68(lathe, cnc mill, heat treatment)
7 Bolt	2-78-68(lathe, cnc mill, heat treatment)
8 Roller	34-68-2-68(cnc lathe, cnc mill, lathe, heat treatment)
9 Chain	9-78-68(lathe, cnc mill, heat treatment)
10 Spring washers	34-7-66-68 (cnc lathe, lathe, cnc milling, heat treatment)
11 Screw left & right opener	2-78-76-2-78(lathe, cnc milling, slotting, lathe, cnc mill
12 Closing cups	2-78 (lathe, cnc mill)
13 Tube for drainage	2-78(lathe, cnc mill)
14 Spear	2-78-68(lathe, cnc mill, heat treatment)
15 key way hook for alternation	2(lathe)
16 Plate	3-60(shearing, heat treatment)
17 Key	2-78(lathe, cnc mill)
18 Boiler traveling with greater nut	2-78-68(lathe, cnc mill, heat treatment)
19 Collet 06 for alternation	34-78-46(cnc lathe, cnc mill, cnc lathe
20 Dumbbell 1 -20 kg	1-68(lathe, heat treatment)

Table 3.5 consisted the parts and production sequence of the cellular arrangement used as an input for Craft algorithm. After the required inputs inserted in the algorithm which was similarly used for the analysis of functional layout before. The initial input data of 20 cell created with part family inserted in the algorithm and the layout data generated for the cellular arrangement.

Layout Data

Problem Name:	Production
Number Depts.:	10
Fixed Points:	0
Dimension:	m

Define Facility

Facility Information

Scale-m/unit	1	Cells
Length-m	15.77	16
Width-m	86.36	87
Area-sq.m	1361.9	1392

Department Information

	Name	F/V	Area	Cells
Dept. 1	D 1	V	10	10
Dept. 2	D 2	V	10	10
Dept. 3	D 3	V	10	10
Dept. 4	D 4	V	10	10
Dept. 5	D 5	V	10	10
Dept. 6	D 6	V	10	10
Dept. 7	D 7	V	10	10
Dept. 8	D 8	V	10	10
Dept. 9	D 9	V	10	10
Dept. 10	D 10	V	10	10

Flow Matrix

FROM \ TO	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9
D 1			15		13		15		
D 2				11		19		13	
D 3				14	15				

The flow matrix expressed the flow of each part within the department and reveald the From/To matrix of prats and machines in the algorithm.

Facility Layout

Problem Name:	Production	Method:	Traditional
Number Depts.:	10	Layout:	Aisle
Length(cells):	16	Fill Departments:	No
Width(cells):	87	Measure:	Rectilinear
Area (cells):	1392	Number Aisles:	3
Cost:	2842	Dept. Width:	5

Department	Color	\rea-require	\rea-define(	x-centroid	y-centroid	Sequence
D 1	1	10	10	2.5	1	1
D 2	2	10	10	2.5	11	2
D 3	3	10	10	2.5	3	3
D 4	4	10	10	2.5	7	4
D 5	5	10	10	2.5	15	5
D 6	6	10	10	2.5	9	6
D 7	7	10	10	2.5	13	7
D 8	8	10	10	7.5	13	8
D 9	9	10	10	7.5	15	9
D 10	10	10	10	2.5	5	10

Figure 3. 22: Facility layout

Figure 3.21 indicate the facility layout created after analyzed each parts flow in the machines for the used cell arrangement. The cost for the initial layout created based on the number of parts movment with in the department. So that, the switches made after the initial cost further optimized the initial cost and finally, the better layout is generated after repetitive iterations. Based on the cell layout analyzed in the above table 3.22 the cost matrix for unit machines calculated was 2,842RS in India which is an equivalent of 1,932.56 birr in Ethiopia, since 1RS is equivalent with 0.68 birr. Therefore, it was the total cost of 2,842RS*0.68birr*88 machines = 170,065.28 birr calculated for the 88 machines by multiplying the unit cost with total machines. The cell layout shows better cost as compared with the existing layout interms of material handling cost. The Comparison made between functional and cell layout based on manufacturing sequence created the better layout in the cell arrangement.

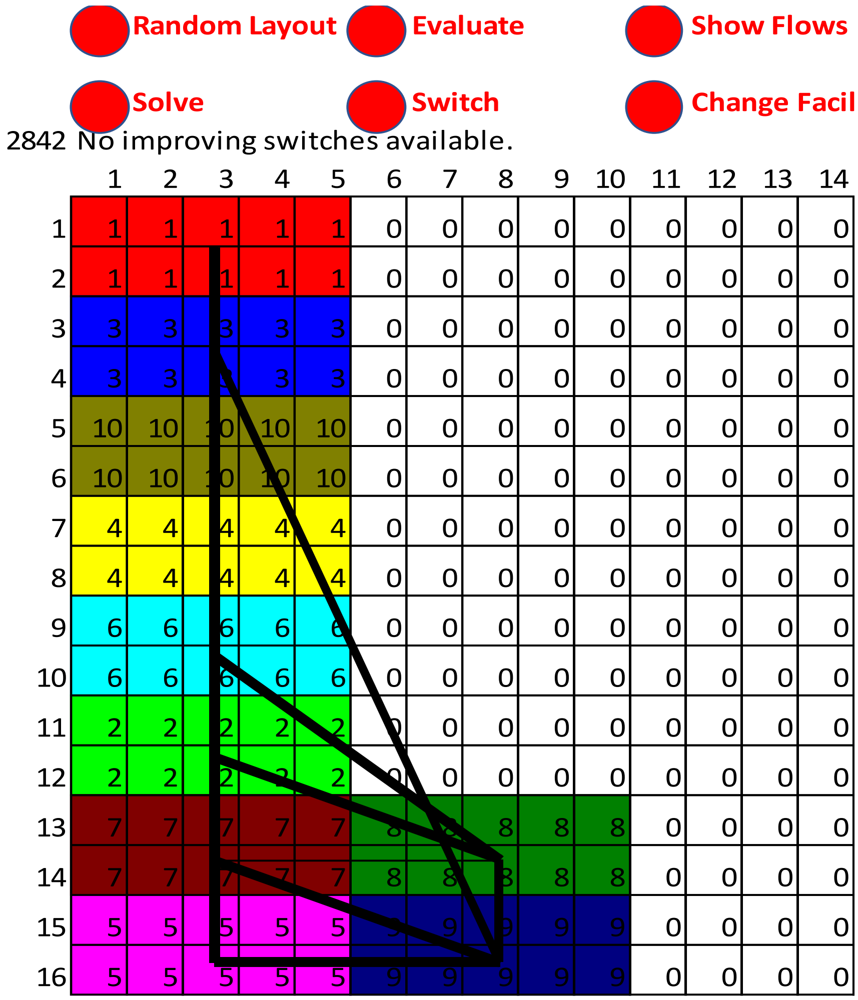


Figure 3. 23: part flow in cell layout

The results obtained by using the craft algorithm show that the cellular layout is the most cost effective compared with the functional layout, and the layout type shown above recommends further enhancement of the existing layout. After analyzing the existing manufacturing process using the CRAFT algorithm, the flow of parts between machines is classified as follows. After analysis using the CRAFT algorithm, the previous 14 functional departments were reduced to 10 cell departments based on the production sequence of parts.

Table 3. 6: CRAFT analyses in cellular department

Cell 1	Cell 6
Lathe machine	Cnc lathe machine
Slotting machine	Cnc milling machine
Gear hobber Machine	Lathe machine
Cell 2	Heat treatment
Lathe machine	Cnc mill machine
Cnc milling machine	Heat treatment
Slotting machine	Cell 9
Cell 3	Lathe machine
Lathe machine	Cnc milling machine
Cnc milling machine	Slotting machine
Heat treatment	Cnc milling machine
Cell 4	Cell 10
Cnc lathe machine	Shearing machine
Cnc milling machine	Heat treatment
Cell 5	Cell 7
Lathe machine	Combination shearing machine
Heat treatment	Cnc milling machine
Grinding machine	Lathe machine
	Cnc milling machine

3.5 Analytical performance of existing layout (manufacturing system)

3.5.1. Machine arrangements and performance level

Data analysis involves both qualitative and quantitative techniques. Based on the limited data available, it is preferable to consider conditions : Consider the full functionality of the 32 milling and 56 lathe machines as active.

Table 3.7 explains the performance of machines – the daily performance for the machines taken from the company data. It showed daily performance percentage and recorded based on the production time of each machines.

Table 3. 7: Machine performance in CMF

Machine Type	Machine ID	Total Production Hours	Daily Performance (%)	Total production time	Total idle time
10 Convectional Lathe machines	01-0168	5;15hr	64%	5;15hr	2;15hr
5 Conventional lathe machines	01-0140	5;15hr	0%	0hr	2;00 -10;20hr
3 Conventional lathe machines	01-0169	0hr	29%	2;30hr	2;00 -10;20hr
16 Conventional lathe machines	01-0138	0hr	0%	0hr	2;00 -10;20hr
14 Cnc lathe machines	01-0106	0hr	0%	0hr	2;00 -10;20hr
2 Cnc lathe machines	01-0760	0hr	0%	0hr	2;00 -10;20hr
5 Cnc lathe machines	01-0747	5;15hr	64%	5;15hr	2;00 -10;20hr
13 Conventional Milling machines	01-0170	0hr	0%		5;15hr

13 Conventional Milling machines	01-0214	2:30hr	64%	5;15hr	2;00 -10;20hr
1 Cnc Milling machin	01-0113	0hr	0%	0hr	5;15hr
9 Conventional Milling machines	01-0230	0hr	0%	0hr	2;00 -10;20hr
9 Conventional Milling machines	01-0743	0hr	0%	0hr	2;00 -10;20hr

(Source: data gathered from the CMF)

Table 3.7 showed the daily production activity of CMF gathered from the company operation department. According to the available data from the company,the machine production time, idle time and daily performance was reported. The report showed from the totally available 36 conventional lathe machines 10 were with 64% performance, 23 with 0% performance which showed the machines were completely idle. 3 machines were with 29% performance. From the totally available 15 cnc lathe machines 5 machines exhibit 64% performance, 10 cnc lathe machines were 0% which implicated completely idle condition. From the totally 33 conventional milling machines 13 conventional milling machines performed 64% and 20 conventional machines showed completely idle performance with 0% performance. 4 cnc milling machine showed 0% completely idle performance out of the available cnc milling machine.

conventional lathe machine	performance (100%)	Total available
10 machines	64%	36 machines
7 machines	0%	36 machines
3 machines	29%	36 machines
16 machines	0%	36 machines
Cnc lathe machine	Performance (100%)	Total available
8 machines	0%	15 machines
2 machines	0%	15 machines
5 machines	64%	15 machines
Conventional milling machine	Performance (100%)	Total available
13 machines	64%	33 machines
10 machines	0%	33 machines
10 machines	0%	33 machines
Cnc milling machine	Performance (100%)	Total available
4 machines	0%	4 machine

Figure 3. 24: Performance analysis of machines in CMF

Figure 3.24 indicated performance of each machines out of the totally avialble machines. From the totally available 36 conventional lathe machines 10 machines exhibit 64% performance, 3 machines with 29% performance and 23 with 0% which is under performance. From the totally available 15 cnc lathe machines, 5 machines performed 64%, 10 machines under performed with 0%. There were 33 conventional milling machines, 13 machines were with 64% performance and 20 machines shown completely idle condition. 4 cnc milling machine exhibit 0% with under performance.

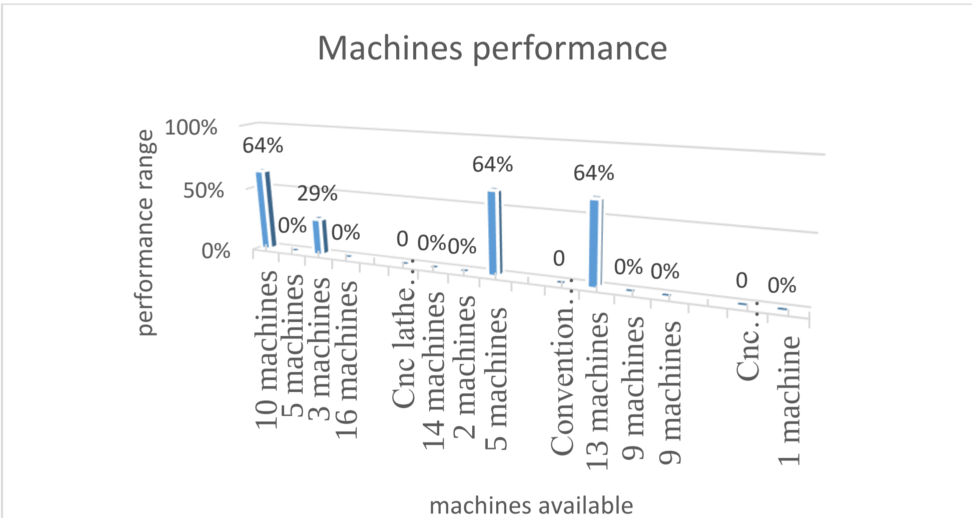


Figure 3. 25: analyses of overall machine utilization

The analysis presented accordingly as gathered from the company data.The data indicate how the underutilization of machines in a conventional factory affects overall performance. Therefore, the following data are presented based on the machine utilization percentage. Therefore, From the 88 machines totally available in the factory, 31 busy and 57 idle machines were identified based on their performance analysis as indicated in figure 3.23.

Table 3. 8: Busy and idle machines in CMF

		performance	
machines	machines available	number of Busy machines	Number of idle machines
conventional lathe m/c	36	13	23

cnc lathe m/c	15	5	10
conventional milling m/c	33	13	20
cnc milling m/c	4	0	4
	Total m/c available 88		
Sum	**88**	**31**	**57**

The analysis in table 3.9 indicated the number of busy machines and idle machines from the totally available 88 machines. From the 34 conventional lathe machines, 13 machines were busy and involved in production whereas 21 machines left idle without any production activity. 21 cnc machines available for production but only 5 were busy in production activity, the rest 16 machines were left idle. From the 31 conventional milling machines available for production, 13 machines were busy and 18 machines left idle. The remaining 2 cnc milling machines not involved in the production so that, contribute for the idle time increment.

conventional lathe machine	performance (100%)	Total available
10 machines	64%	36 machines
7 machines	0%	36 machines
3 machines	29%	36 machines
16 machines	0%	36 machines
Cnc lathe machine	Performance (100%)	Total available
8 machines	0%	15 machines
2 machines	0%	15 machines
5 machines	64%	15 machines
Conventional milling machine	Performance (100%)	Total available
13 machines	64%	33 machines
10 machines	0%	33 machines
10 machines	0%	33 machines
Cnc milling machine	Performance (100%)	Total available
4 machines	0%	4 machine

Figure 3. 26 : machines available and performance

The available machines in the company and the machines performance presented in figure 3.10. Therefore, it was used for the identification of busy machines and idle from the totally available machines according to the data gathered from CMF.

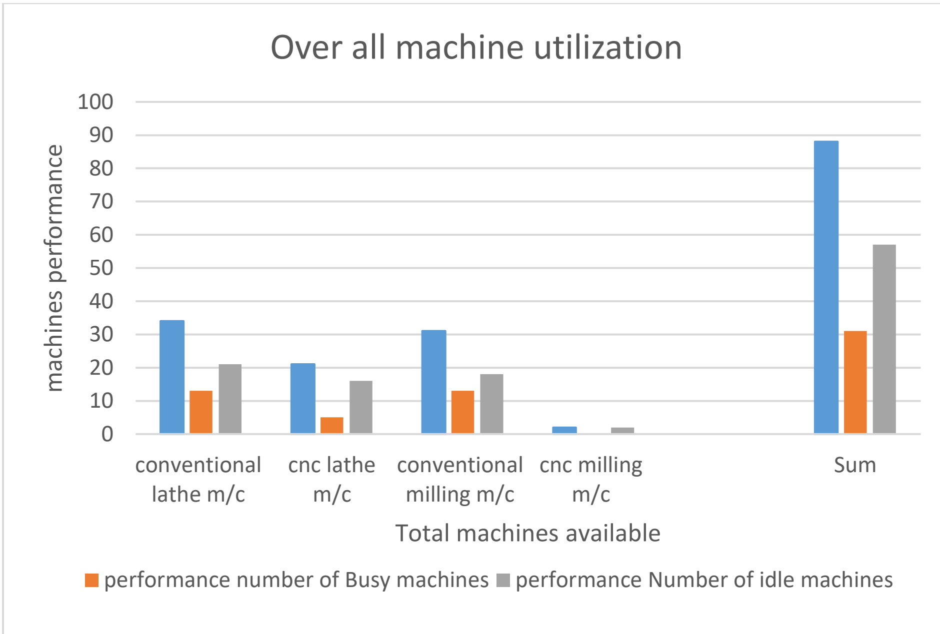


Figure 3. 27: Idle and busy machines in graph

Therefore, based on the above data, the number of idle and busy machines is expressed as

No.of idle machines = 57/88*100% = 64.77%

No.of busy machines = 31/88*100% = 35.22%

After the data analysis referred to the company data, it was found how the idle machines contributed on the underutilization of overall machines performance of the company.

Existing layout distance – represents the total travel distance in the existing layout. The table 3.10. shows the distance of parts movement in CMF.

Table 3. 9: Travel distance of existing parts in CMF

i to j	X(m)	Rectilinear(m)
From (i)	To (j)	
34	76	170.16
1	57	176.92
35	58	57.55
36	67	33.86
60	Heat treatment	94.9
3	Heat treatment	115.89
4	Heat treatment	75.89
37	Heat treatment	81.4
69	Heat treatment	201.95
38	Grinding machine 1	169.01
5	77	186.44
6	6	25.89
7	63	56.8
8	65	54.7
9	68	61.78
11	72	25.89

12	70	90.89
13	73	118.41
39	75	107.22
13	Heat treatment	80.15
14	Heat treatment	83.79
81	Grinding machine 2	166.61
	Sum total (m)	2,236.10 m

Therefore, as indicated in table 3.10, the total travelling distance of the parts is 2,236.10 m. The performance of the existing layout was 31.8%.

3.6. Cellular manufacturing system design

The cell design was executed first by identifying parts in Conventional Manufacturing Factory and classifying them as a part a family using Optiz Coding system. Based on design/ manufacturing attributes and grouping machines in the cell for processing part families based on processing similarity.

Step1: Identifying parts based on their attributes in design, considering part shape, size& other similar features for forming of a family. Identifying parts based on manufacturing attributes such as diameter, length, surface finish, geometry, etc.…

Step 2: Grouping machines into cells based on similarity of the manufacturing process for parts (production sequence).

Step 3: Dan et al. (2011) explained grouping parts and machines using the Rank Order clustering algorithm as the most effective way to reduce underutilization in cells based on the efficiency of the technique in minimizing the exceptional elements in bottlenecks and duplication of machines during cell formation. This executes by assigning the available parts to columns and machines in rows by forming a machine-part matrix incident. Recently, the coding procedure for the Optiz coding system follows the following conditions.

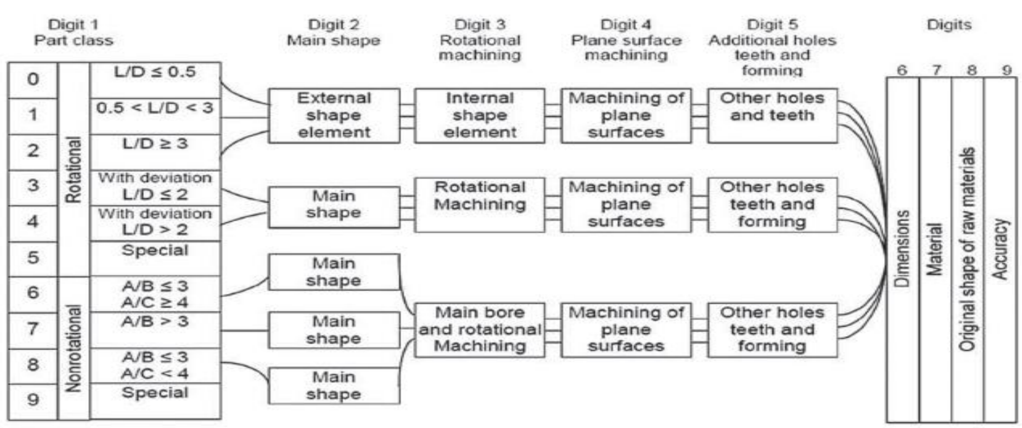


Figure 3. 28:Optiz coding system

Primary digits:

Digit1: Indicates whether the part rotates as well as the basic dimension ratio (length/width if not rotating, length/diameter if rotating).

Digit 2: Primary exterior shape: Slightly dependent on digit 1.

Digit 3: Internal primary shape.

Digit 4: specifications for plane surface machining.

Digit 5: Auxiliary features like additional holes, etc.

Secondary digits:

Digit 6: Dimensions

Digit 7: Work material

Digit 8: Original Shape of raw material

Digit 9: Accuracy requirement

3.6.1 Optiz coding system and it's frame work

It is simpler to recognize the part design and manufacturing attributes based on the coding system structure. According to the design or manufacturing attributes of the part in the database, the factory can get the information. This system, which is based on a hybrid code structure, has 18 digits. The following is a description of the features and coding systems. (Ghosh P. K., 2012)

Attribute 1: The general shape of the part

Rotational:

- (CA1-1) R-BAR
- (CA2-2) R-tube
- (CA3-3) R-hexagonal bar

Non rotational

- (CA1 -4) NR -plate

- (CA1 -5) NR – square bar
- (CA1- 6) NR – sheet plate
- (CA1 -7) NR – Rectangular bar

Attribute 2: Material

- (CA2-1): Aluminum alloys
- (CA2 – 2): Copper zinc alloys
- (CA3 – 3): Steels
- (CA4 – 4): Cast irons
- (CA5 – 5): Plastics

Attribute 3: maximum diameter

- (CA3 -1): D≤0.75 in
- (CA3 – 2): 0.75 in ≤D≤ 1.75 $inch$
- (CA3 – 3): 1.50 in ≤ $D \leq 4\ inch$
- (CA4 – 4): D ≥≥ $4 inch$
- (CA4 – 4): N/A (non - rotational part)

Attribute 4: overall length

- (CA4-1): L ≤ 6 inch
- (CA4-2): $6 \leq L \leq 18\ inch$

(CA4-3): 18 < L ≤ 60 $inch$

- (CA4 – 4): L > 60 inch

Attribute 5: diameter of inside hole

- (CA5 -1) d ≤ 0.5 in
- (CA5 – 2) 0.5 < d ≤ 1 in
- (CA5 – 3) 1.0 < d≤ 5.0 in

- (CA5 – 4) d > 5.0 in

	Diameter D or length of edge A (mm)		Material		Initial shape		Accuracy in coding digit
0	≤ 20	0	grey cast iron	0	round bar	0	no accuracy specified
1	> 20 ≤ 50	1	nodular graphitic cast iron and malleable cast iron	1	bright drawn round bar	1	2
2	> 50 ≤ 100	2	steel ≤ 42 kg/mm2 (St - steel)	2	triangular, square, hexagonal or other bar	2	3
3	> 100 ≤ 160	3	steel > 42 kg/mm2 (C and Ck steel)	3	tubing	3	4
4	> 160 ≤ 250	4	steel 2 + 3 heat -treated	4	angle, U-,T- and similar sections	4	5
5	> 250 ≤ 400	5	alloy steel	5	sheet	5	2 + 3
6	> 400 ≤ 600	6	alloy steel heat - treated	6	plates and slabs	6	2 + 4
7	> 600 ≤ 1000	7	non-ferrous metal	7	cast or forged component	7	2 + 5
8	> 1000 ≤ 2000	8	light alloy	8	welded group	8	3 + 4
9	> 2000	9	other materials	9	pre-machined component	9	(2 + 3) + 4 + 5

Figure 3. 29: Optiz supplementary code (Anderson, 1992)

Based on the above criteria parts in Conventional Shop are assigned to the following category.

1. Gear - Since, it's rotational the Attribute was 1 and the material type steel bar, the length/diameter ratio was : L/D = 223.2/126 = 1.77, therefore, it was assigned to part class of digit 1. The code for gear was 16336 3400. The original shape of raw material was 25 mm diameter with 84 mm length of blank material. The sequence of operation was Cnc lathe ⇒ slotting ⇒ Gear hobbing ⇒ heat treatment ⇒ Grinding. The code for Sun gear was 12050 2400 and L/D = 44.1/98.9 = 0.44, it's rotational and the material type was steel bar, the original shape of the raw material was 30 mm diameter with 100 mm length.

The attributes were 1: it was rotational part and (CA1-1) R-Bar

Attribute 2: the material was – (CA3 -3): steels

Attribute 3: maximum diameter (CA4-4): since its diameter was 4.96 inch, it was assigned with D ≥ 4 inch.

Attribute 4: overall length was (CA4-4): Since it's: $L \leq 6\ inch$

Attribute 5: inside hole diameter was 0.5 therefore, it was assigned to (CA5-1) for d ≤ 0.5 inch.

2 Shaft – the material type was steel bar, since the L/D= 70/29.6 = 2.36. Therefore, it was assigned to digit 1 for part class category and the code for shaft was 15630 1400 and the sequence of operation was Lathe milling ⟹ slotting ⟹ milling ⟹ heat treatment ⟹ grinding.

The attributes assigned in the rotational part of (CA1-1) R-Bar

Attribute 2: since the material type was steel, assigned in (CA3 -3) category

Attribute 3: since its diameter is 1.88 inch and assigned between D $1.5 inch \leq D \leq 4$ in maximum diameter (CA3-3).

Attribute 4: overall length was (CA4-1): Since overall length was 4 in assigned between $L \leq 6\ inch$

Attribute 5: inside hole diameter was 0.7 inch. therefore, it is assigned to (CA5-1): $d \leq 0.75$ inch

3 coupling – the material is steel and L/D = 110/48 = 2.29, therefore it assigned to digit 1for part class category. The code assigned as 16360 1300 and the original shape of the raw material is 5x12mm. The sequence of operation was cnc lathe ⟹ cnc milling.

Attribute 1: the part was rotational and assigned with (CA1-5) R- bar

Attribute 2: the material was steel so that, assigned in (CA3 -3).

Attribute 3: Since it has the maximum diameter of 1.88 assigned between $1.5 \leq D \leq 4$ inch. It was categorized with (CA3-3).

Attribute 4: overall length was 3.89 so that, assigned to: $L \leq 6\ inch$ with (CA4-1) category.

Attribute 5: inside hole diameter was 0.7 inch therefore, it assigned to (CA5-1): $d \leq 0.5$ inch.

4 Bushing – the material type was steel bar and L/W = 99/45 = 2.2, therefore assigned to digit 1 for part class category. The original shape of the raw material was 20x900. The code assigned to 16360 1300. The sequence of operation was cnc lathe ⟹ cnc milling ⟹ grinding.

The attributes are 1: the part was rotational and (CA1- 1) R-bar

Attribute 2: the material was steel so that, assigned in (CA3 -3) category.

Attribute 3: has the maximum diameter of 1.77 inch and has between $1.5 \leq D \leq 4$ inch assigned with (CA3-3) category.

Attribute 4: overall length was 3.89 inch and has between $L \leq 6\ inch$ assigned with (CA4-1) category.

Attribute 5: inside hole diameter was 0.78 inch between $0.5 < d \leq 1$ inch

assigned to category of (CA5-2)

5 Nut – the material was cast iron, the ratio of L/W = 26/46.8 = 0.55, therefore it assigned to digit 1 for part class category. The code assigned to 15342 1070. The original shape of the raw material was 45x2mm. The sequence of operation was lathe ⟹ milling ⟹ heat treatment.

The attributes are 1: the part shape was non- rotational type and (CA1-1) R- bar

Attribute 2: the material was – (CA4 -4): cast iron

Attribute 3: since the diameter has maximum diameter of 1.84 inch between $1.5 \leq D \leq 4$ inch. Assigned to (CA3-3) category.

Attribute 4: overall length was (CA4-1): since it has 1.02 inch assigned to: $L \leq 6\ inch$.

Attribute 5: inside hole diameter was 0.98 inch between $0.5 < d \leq 1$ inch therefore, it assigned to (CA5-2) category.

6 Pin – the material was cast iron, L/W = 114.6/35.5 = 3.22 therefore, assigned to digit 2 for part class category. The code assigned 23110 1000. The original shape of the raw material was 6x25mm and 30x115mm. The sequence of operation was lathe ⟹ heat treatment ⟹grinding.

The attributes were 1: the shape of the part was non- rotational and (CA1-1) R-bar

Attribute 2: the material was cast iron assigned in (CA4 -4) category.

Attribute 3: has the maximum diameter of 1.39 between 0.75 $inch \leq$ D ≤1.75 inch so that, assigned to (CA3-2) category.

Attribute 4: overall length was 4.5 inch and assigned to: L≤ $6\ inch$ with (CA4-1) category.

Attribute 5: inside hole diameter was 0.23 inch between d≤ 0.5 inch therefore, it assigned to (CA5-1) category.

7 Bolt – the material type was cast iron, its L/W = 131.2/31 = 4.23 therefore, it assigned to digit 2 for part class category. The code has 25100 1070. The original shape of the raw material was 45x230 and the sequence of operation was lathe ⟹ heat treatment.

The attributes were 1: the part with non- rotational and (CA1-1) R- bar

Attribute 2: the material was – (CA4 -4): cast iron

Attribute 3: has maximum diameter of 1.22 inch in (CA3-2) category: since, it has diameter between 0.75 $inch \leq$ D ≤ 1.75 inch.

Attribute 4: overall length was (CA4-1): since it has 5 inch assigned to: L≤ $6\ inch$

Attribute 5: inside hole diameter was 0.78 inch therefore, it assigned to (CA5-2): 0.5 < d≤ 1 inch

8 Roller – the material was steel and A/B = 274.5/63.5 = 4.3 therefore, assigned to digit 7 since, A/B > 3 for part class category. The original shape of the raw material was 45x270mm. The code has 76610 2350. The sequence of operation was cnc lathe ⟹ heat treatment.

The attributes were: 1 the shape of the part has non- rotational and (CA1-7) NR- rectangular bar

Attribute 2: the material was – (CA3 -3): steels

Attribute 3: since it has diameter of 2.5 maximum diameter and between 1.5 inch ≤ D ≤4 inch. Categorized in (CA3-3).

Attribute 4: overall length was (CA4-1): since it has 10.8 inch it assigned to: $6 \leq L \leq 18\ inch$

Attribute 5: inside hole diameter was 1.77 inch therefore, it assigned to (CA5-3): 1 ≤ d ≤ 5 inch

9 Chain- the material was cast iron and A/B = 274.5/63.5 = 4.3 since, A/B > 3 for part class category therefore, it has assigned to digit 6 for part class category. The code has 66610 3070 and the original shape of the raw material was 300x165x12 mm. The sequence of operation was cnc ⟹ ⟹ milling ⟹ bending ⟹ heat treatment.

The attributes were 1: it has type of non- rotational shape and (CA1-5) NR- square bar

Attribute 2: the material was – (CA4 - 4): cast iron

Attribute 3: has maximum diameter of 6.24 inch with (CA4-4) and between D ≥ 4 inch

Attribute 4: overall length has (CA4-2): since it is 11.4 inch it assigned to: $6\ inch \leq L \leq 18\ inch$

Attribute 5: inside hole diameter was 3.93 inch therefore, it assigned to (CA5-4): 1in < d≤ 5 in

10 Spring washers – the material was steel and L/W =100/35 = 2.85 therefore it assigned to digit 1 for part class category. The code has 16670 1300 and the original shape of the raw material was 35x100mm. The sequence of the operation was cnc lathe ⟹ wire edm ⟹ bench ⟹ heat treatment.

The attributes were 1: the part with non- rotational and (CA1-1) R- bar

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: since, its diameter has 1.33 inch and has maximum diameter (CA3- 2): and between $0.75\ inch \leq$ D ≤ 1.75 inch

Attribute 4: overall length was (CA4-1): since it has 5.8 inch it assigned to: L≤ $6\ inch$

Attribute 5: inside hole diameter was 0.98 inch therefore, it has assigned to (CA5-2): 0.5 < d≤ 1 inch.

11 Sleeve – the material was cast iron and A/B = 125/30 = 0.96 A/B = 274.5/63.5 = 4.3 therefore, it assigned to digit 6 since, A/B ≤ 3 for part class category. It has code of 65342 1020 and the original shape of the raw material was 130x125mm. The sequence of operation was lathe ⟹ slotting ⟹ gear hobbing ⟹ heat treatment ⟹ grinding.

The attributes were 1: the part has non- rotational and (CA1-5) NR- square bar

Attribute 2: the material has – (CA4 -4): cast iron

Attribute 3: maximum diameter (CA4- 4): since it has diameter of 5.11 inch and between $D \geq 4$ inch

Attribute 4: overall length is (CA4-1): since it has 4.9 inch it assigned to: $L \leq 6\ inch$

Attribute 5: diameter of inside hole was 3.93 inch therefore, it assigned to (CA5- 3): $1 < d \leq 5$ inch.

12 Screw left and right – the material was stainless steel and L/D = 91/34 = 2.67 therefore, it assigned to digit 1 for part class category. It has code of 15120 1230. The original shape of the raw material was 35x760mm and has no sequence of operation after lathe and processed only in lathe.

The attributes were 1: the shape of the part was rotational and (CA2 -2) R-tube

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: maximum diameter (CA3- 2): since its diameter has 1.5 inch and between $0.75\ in \leq D \leq 1.75$ inch

Attribute 4: overall length assigned in (CA4-1): since it has 3.58 inch between $L \leq 6\ in$ch

Attribute 5: inside hole diameter was 0.5 inch therefore, it assigned to (CA5-2): $0.5 < d \leq 1$ inch

13 Closing cup – the material was mild steel and L/W = 180/135 = 1.33 therefore has assigned to digit 1 for part class category. The original shape of the material was 45x30mm and it has code of 15320 3900. The sequence of operation was lathe ⟹ mill.

The attributes were 1: the part with non- rotational and (CA1-1) R- bar

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: maximum diameter (CA4- 4): since it has diameter is 5.31 inch and it's $D \geq 4$ inch

Attribute 4: overall length is (CA4- 2): since it is 7.08 inch it assigned to: 6 $inch \leq L \leq 18\ inch$

Attribute 5: inside hole diameter is 3.93 inch therefore, it assigned to (CA5- 3): 1 < d ≤ 5 inch

14 Tube for drainage – the material was steel and L/W = 64/30 = 2.13 therefore, it assigned to digit 1 for part class category. The original shape of the raw material was 30x61mm and it has code of 16500 1330. The sequence of operation was lathe ⟹ mill.

The attributes are 1: the part was non- rotational and (CA2 -2) R-tube

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA3- 2): since its diameter of 1.18 inch and between 0.75 $inch \leq$ D ≤ 1.75 inch.

Attribute 4: overall length was (CA4-1): since it has 2.5 inch and assigned to: L≤ 6 $inch$

Attribute 5: inside hole diameter was 0.5 inch therefore, it assigned to (CA5- 1): d≤ 0.5 inch

15 Spear – the material was D2 material and it has L/D = 250/20 = 12.5 and the original shape of the raw material was 20x250mm. It has code of 23010 0300 and the sequence of operation was lathe ⟹ mill ⟹ heat treatment.

The attributes were 1: the part shape was rotational type and (CA1- 1) R-bar

Attribute 2: the material has – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA3-1): since it has diameter of 0.7 inch and between D ≤ 0.75 inch

Attribute 4: overall length was (CA4- 2): since it has 9.84 inch assigned to: 6 inch $\leq L \leq 18\ inch$

Attribute 5: inside hole diameter is 0.39 inch therefore, it assigned to (CA5- 1): d≤ 0.5 inch

16 key way hook for alternation – the material type was alternation and it has A/B = 110/12.5 = 8.8 since, A/B > 3 for part class category it assigned to digit 7 for part class category.It has code of 73010 0400 and the original shape of the raw material was 115x14 and processed only in lathe.

The attributes were 1: the part shape was non- rotational type and (CA1-5) NR- square bar

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA3- 1): since, it has diameter of 0.49 inch and between D ≤ 0.75 inch

Attribute 4: overall length is (CA4-1): since it has 4.33 inch it assigned to: L≤ 6 *inch*

Attribute 5: inside hole diameter was 0.09 inch therefore, it assigned to (CA5- 1): d ≤ 0.5 inch

17 Plate – the material type was D2 and A/B = 60/30.05 = 1.99 therefore it assigned to digit 6 for part class category since, A/B ≤ 3 for part class category. It has code of 63202 1660 and the original shape of the raw material was 40x175mm. The sequence of operation was lathe ⟹ grinding / combined shearing ⟹ welding

The attributes were 1: the part has non- rotational type and (CA1- 4) NR- plate

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA3- 2): since, it has diameter of 1.18 inch and between 0.75 *inch* ≤ D ≤ 1.75 inch

Attribute 4: overall length of (CA4-1): since it has 2.36 inch it assigned to: L≤ 6 *inch*

Attribute 5: inside hole diameter is 0.5 inch therefore, it assigned to (CA5- 1): d≤ 0.5 inch

18 Key- the material was steel and A/B = 120/25 = 4.8 therefore it assigned to digit 7 for part class category sine, A/B > 3 for part class category. It has The code of 76532 1320. The sequence of operation was lathe⟹milling

The attributes were 1: the part shape was non- rotational type and (CA1-5) NR- square bar

Attribute 2: the material was – (CA3- 3): steels

Attribute 3: has maximum diameter (CA3- 2): since, it has diameter of 0.98 inch and between 0.75 $inch$ ≤ D ≤ 1.75 inch

Attribute 4: overall length has (CA4-1): since it has 4.72 inch its assigned to: L≤ 6 $inch$

Attribute 5: inside hole diameter has 0.39 inch therefore, it is assigned to (CA5-1): d ≤ 0.5 inch

19 Boiler traveling with greater nut- the material was D2 material type and it has L/W = 60/40 = 1.5 therefore it assigned to digit 1 category. It has code of 12000 1000 and the sequence of operation was lathe ⟹ milling ⟹ heat treatment.

The attributes were 1: the part general shape was non- rotational type and (CA1-1) R- bar

Attribute 2: the material was – (CA4 -4): cast iron

Attribute 3: has maximum diameter (CA3-3): since it has diameter of 2.36 inch and between 1.5 inch ≤ D ≤ 4 inch

Attribute 4: overall length has (CA4-1): since, it has 1.57 inch it assigned to: L≤ 6 $inch$

Attribute 5: inside hole diameter has 0.78 inch therefore, it assigned to (CA5-2): 0.5 < d≤ 1 inch

20 Collet 06 for alternation – the material was D2 type and it has A/B = 50/80 = 0.625. Since, A/B < 3 assigned to code 6 for the part of the class category and it has code of 64610 2020. The original shape of the material was 80x50mm. The sequence of operation was cnc lathe ⟹ cnc milling ⟹ grinding.

The attributes were 1: the general part was non- rotational type and (CA1-7) NR- rectangular bar

Attribute 2: the material was – (CA4 -4): cast iron

Attribute 3: has maximum diameter (CA3-3): since it has diameter of 1.98 inch and between 1.5 inch and 4 inch

Attribute 4: overall length has (CA4-1): since it has 3.14 inch and assigned to: L$\leq 6\ inch$

Attribute 5: inside hole diameter has 0.7 inch. Therefore, it assigned to (CA5-2): 0.5 < d inch

21 Dumbbell – The material was mild steel and L/D = 400/37 = 10.8 therefore, it has assigned to digit 2 for part class category. It has code of 25638 1930. The sequence of operation was lathe ⇒ heat treatment.

The attributes were 1: the part general shape has rotational type and (CA2- 2) R-tube

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA3-2): since, it has diameter of 1.45 inch and between $0.75\ inch \leq$ D $\leq$ 1.75 inch

Attribute 4: overall length of (CA4- 2): since, it has 15.7 inch and assigned to: 6 inch $\leq L \leq 18\ inch$

Attribute 5: inside hole diameter has 0.5 inch therefore, it assigned to (CA5- 1): d $\leq$ 0.5 inch

22 Die – The type of material was D2 and A/B = 160/80 = 2 with the original shape of the raw material was 80x160mm. Since, A/B $\leq$ 3 it assigned to digit 6 for part class category. It has code of 63360 2320. The sequence of operation was cnc milling ⇒bench work ⇒heat treatment⇒ grinding.

The attributes were 1: the part general shape was non- rotational type and (CA1- 7) NR-rectangular bar

Attribute 2: the material was – (CA3 - 3): steels

Attribute 3: has maximum diameter (CA4- 4): since, it has diameter of 6.2 inch and it’s D $\geq$ 4 inch

Attribute 4: The overall length 3.14 inch so that, it assigned to: L$\leq 6\ inch$ and (CA4-1) part category.

Attribute 5 The inside hole diameter has 0.5 inch therefore, it assigned to (CA5- 1) part category because it has d$\leq$ 0.5 inch.

3.6.2 Rank order clustering of machine and parts in CMF

(Bhuyan, 2017) described the rank order clustering approach as one of the most common array-based methods for clustering machines and parts. It was proposed by King (1980) using a matrix manipulation method to cluster machines and parts in MCIM (Machine - Component Incidence Matrix). The steps for rank order clustering are described as follows:

Step. Clustering of machine and parts in CMF

Step 1 forms the component – machine matrix of m for machines and n as parts.

Step 2 Draw the component – machine incident matrix using production sequence

Step 3 Assign the binary weight ratio to rows and re-arrange the order descended in rows based on the computed value

Step 4 Assign a binary weight ratio for columns and rank in order of descending

Step 5 After computing, step 4 and 5 shuffle the rows and columns if there is a change in the rank. If there is no change in the iteration, stop and rank the final order of rows in descending to form a cluster.

The table 3.10 below descibed the parts and machines arrangement in the incident matrix. So that, parts arranged in column and machines arranged in row order. Row ascending – giving binary weight row values from right to left and we get values from 1 up to 4,194,304, which are indexed above in the row table.

Table 3. 10: Machine – part matrix

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	
2	Parts/Machines	Gear	Shaft	Coupling	Bushing	Nut	Pin	Bolt	Roller	Chain	Spring	Sleeve	Screw
3	Lathe m/c 1	1											
4	Lathe m/c 2		1										
5	Lathe m/c 3				1								
6	Lathe m/c 4					1							
7	Lathe m/c 5						1						
8	Lathe m/c 6							1					
9	Lathe m/c 7								1				
10	Lathe m/c 8											1	
11	Lathe m/c 9												
12	Lathe m/c 10												
13	Lathe m/c 11												
14	Lathe m/c 12												
15	Lathe m/c 13												
16	Lathe m/c 14												
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26	Lathe m/c 24												
27	Lathe m/c 25												
28	Lathe m/c 26												
29	Lathe m/c 27												
30	Lathe m/c 28												
31	Lathe m/c 29												
32	Lathe m/c 30												
33	Lathe m/c 31												
34	Lathe m/c 32												
35	Lathe m/c 33												
36	Lathe m/c 34												
37	Lathe m/c 35												
38	Lathe m/c 36												
39	Heavy duty lath m/c 1												
40	Heavy duty lathe m/c 2												

As table 3.11 indicated the value in the rank changed due to the initial row and column's iterated with the values given in the row ascending. Therefore, further iterations done until no row and column values changed.

Table 3. 11: Row ascending

	M	N	O	P	Q	R	S	T	U	V	W	X	Y	
1	1024	512	256	128	64	32	16	8	4	2	1			
2	Screw	Closing cup	Tube for drainage	Spear	Key way	Plate	Key	Boiler with nut	Collet	Dumb bell	Die	Value	Rank	Ran
3												2097152	1	
4												1048576	2	
5												524288	3	
6												262144	4	
7												131072	5	
8												65536	6	
9												32768	7	
10												2048	8	
11	1											1024	9	
12		1										512	10	
13			1									256	11	
14				1								128	12	
15					1							64	13	
16						1						32	14	
17							1					16	15	
18								1				8	16	
19										1		2	17	
20														

The table below 3.11 shows the changed value for the ranks due to the iterations done in the column.

Table 3. 11: Column ascending

G28

	A	B	C	D	E	F	G	H	I	J	K	L	M
40	Heavy duty lathe m/c 2												
41	Heavy duty lathe m/c 3												
42	Heavy duty lathe m/c 4												
43	Cnc lathe m/c 1			1									
44	Cnc lathe m/c 2				1								
45	Cnc lathe m/c 3				1					1			
46	Cnc lathe m/c 4						1						
47	Cnc lathe m/c 5								1				
48	Cnc lathe m/c 6										1		
49	Cnc lathe m/c 7												
50	Cnc lathe m/c 8												
51	Cnc lathe m/c 9												
52	Cnc lathe m/c 10												
53	Cnc lathe m/c 11												
54	Cnc lathe m/c 12												
55	Cnc lathe m/c 13												
56	Cnc lathe m/c 14												
57	Cnc lathe m/c 15												
58	Universal milling m/c 1		1										
59	Universal milling m/c 2					1							
60	Universal milling m/c 3												
61	Horizontal milling m/c 1												
62	Horizontal milling m/c 2				1								
63	Horizontal milling m/c 3								1				
64	Horizontal milling m/c 4									1			
65	Horizontal milling m/c 5												
66	Horizontal milling m/c 6												
67	Drill machine 1												
68	Drill machine 2												
69	Vertical milling m/c 1												
70	Vertical milling m/c 2												
71	Vertical milling m/c 3												
72	Vertical milling m/c 4												
73	Vertical milling m/c 5							1					
74	Vertical milling m/c 6												
75	Vertical milling m/c 7												
76	Vertical milling m/c 8												
77	Vertical milling m/c 9												
78	Vertical milling m/c 10												
79	Vertical milling m/c 11												

Sheet1 Sheet2

As indicated in table 3.12 the rank values in the column changed due to the iterations done so that, further iterations done to get the final cluster. Based on the column values entered in the iterations the result occurred. Therefore, further iterations done to get the final cluster until no change occurred in the rows and columns.

Table 3. 12: Row ascending

1		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1			
2	Parts/Machines	Gear	Shaft	Coupling	Bushing	Nut	Pin	Bolt	Roller	Chain	Spring	Sleeve	Screw	Closing cup	be for draina	Spear	Key way	Plate	Key	oiler with r	Collet	Dumb bel	Die	Value	Rank	Rank all
3	Lathe m/c 1	1																						2E+06	1	5
4	Lathe m/c 2		1																					2E+06	2	7
5	Lathe m/c 3				1																			524288	3	14
6	Lathe m/c 4					1																		262144	4	16
7	Lathe m/c 5						1																	131072	5	18
8	Lathe m/c 6							1																65536	6	20
9	Lathe m/c 7								1															32768	7	22
10	Lathe m/c 8											1												2048	8	28
11	Lathe m/c 9												1											1024	9	29
12	Lathe m/c 10													1										512	10	31
13	Lathe m/c 11														1									256	11	32
14	Lathe m/c 12															1								128	12	35
15	Lathe m/c 13																1							64	13	37
16	Lathe m/c 14																	1						32	14	38
17	Lathe m/c 15																		1					16	15	40
18	Lathe m/c 16																			1				8	16	41
19	Lathe m/c 17																					1		2	17	44
20	Lathe m/c 18																									
21	Lathe m/c 19																									
22	Lathe m/c 20																									
23	Lathe m/c 21																									
24	Lathe m/c 22																									
25	Lathe m/c 23																									
26	Lathe m/c 24																									
27	Lathe m/c 25																									
28	Lathe m/c 26																									
29	Lathe m/c 27																									
30	Lathe m/c 28																									
31	Lathe m/c 29																									
32	Lathe m/c 30																									
33	Lathe m/c 31																									
34	Lathe m/c 32																									
35	Lathe m/c 33																									
36	Lathe m/c 34																									
37	Lathe m/c 35																									
38	Lathe m/c 36																									
39	Heavy duty lath m/c 1																									
40	Heavy duty lathe m/c 2																									
41	Heavy duty lathe m/c 3																									
42	Heavy duty lathe m/c 4																									
43	Cnc lathe m/c 1			1																				1E+06	1	11
44	Cnc lathe m/c 2				1																			524288	3	13
45	Cnc lathe m/c 3				1					1														540672	2	12
46	Cnc lathe m/c 4						1																	131072	4	19

The values in the rank explained in table 3.13 shows the change in the rank values were occurred. This resulted from the iteration binary values given based on the assigned rank order.

Table 3. 13: Rank ascending

Z28

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1			
2	Parts/Machines	Gear	Shaft	Coupling	Bushing	Nut	Pin	Bolt	Roller	Chain	Spring	Sleeve	Screw	Closing cu	be for draina	Spear	Key way	Plate	Key	oiler with r	Collet	Dumb bel	Die	Value	Rank	Rank all
3	Lathe m/c 1	1																						2E+06	1	5
4	Lathe m/c 2		1																					2E+06	2	7
5	Lathe m/c 3				1																			524288	3	14
6	Lathe m/c 4					1																		262144	4	16
7	Lathe m/c 5						1																	131072	5	18
8	Lathe m/c 6							1																65536	6	20
9	Lathe m/c 7								1															32768	7	22
10	Lathe m/c 8											1												2048	8	28
11	Lathe m/c 9												1											1024	9	29
12	Lathe m/c 10													1										512	10	31
13	Lathe m/c 11														1									256	11	32
14	Lathe m/c 12															1								128	12	35
15	Lathe m/c 13																1							64	13	37
16	Lathe m/c 14																	1						32	14	38
17	Lathe m/c 15																		1					16	15	40
18	Lathe m/c 16																			1				8	16	41
19	Lathe m/c 17																					1		2	17	44
20	Lathe m/c 18																									
21	Lathe m/c 19																									
22	Lathe m/c 20																									
23	Lathe m/c 21																									
24	Lathe m/c 22																									
25	Lathe m/c 23																									
26	Lathe m/c 24																									
27	Lathe m/c 25																									
28	Lathe m/c 26																									
29	Lathe m/c 27																									
30	Lathe m/c 28																									
31	Lathe m/c 29																									
32	Lathe m/c 30																									
33	Lathe m/c 31																									
34	Lathe m/c 32																									
35	Lathe m/c 33																									
36	Lathe m/c 34																									
37	Lathe m/c 35																									
38	Lathe m/c 36																									
39	Heavy duty lath m/c 1																									
40	Heavy duty lathe m/c 2																									

The row values changed due to the changed in table 3.14 column's value therefore, further change in rows required to rearrange rank and columns.

Table 3. 14: Row ascending

G28

	A	B	C	D	E	F	G	H	I	J	K	L	M
97	Gear hobbing	1										1	
98		4194304	2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	
99													
100		4194304	2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	
101						Column Ascending							
102	Parts/Machines	Gear	Shaft	Coupling	Bushing	Nut	Pin	Bolt	Roller	Chain	Spring	Sleeve	Screw
103	Heat treatment	1	1		1	1	1	1	1	1	1	1	
104	Grinding	1	1		1								
105	Slotting milling machine 1	1			1								
106	Gear hobbing	1										1	
107	Lathe machine 1	1											
108	Slotting milling machine 2		1									1	
109	Lathe machine 2		1										
110	Universal milling machine 1		1										
111	Cnc milling machine 2			1			1						
112	Cnc milling machine 1			1									
113	Cnc lathe machine 1			1									
114	Cnc lathe machine 3				1					1			
115	Cnc lathe machine 2				1								
116	Lathe machine 3				1								
117	Horizontal milling machine 2				1								
118	Lathe machine 4					1							
119	Universal milling machine 2					1							
120	Lathe machine 5						1						
121	Cnc lathe machine 4						1						
122	Lathe machine 6							1					
123	Horizontal milling machine 3								1				
124	Lathe machine 7								1				
125	Cnc lathe machine 5								1				
126	Horizontal milling machine 4									1			
127	plasma									1			
128	Cnc lathe machine 6										1		
129	Wire edm										1		
130	Lathe machine 8											1	
131	Lathe machine 9												
132	Vertical milling machine 1												
133	Lathe machine 10												
134	Lathe machine 11												
135	Horizontal milling machine 1												
136	Vertical milling machine 2												

The results changed in the column based on the binary weight value are described below in table 3.15, there were reshuffles between columns due to the change in the column's value.

Table 3. 15: : Rank order clustering

	A	B	C	D	E	F	G	H	I	J	K	L	M
121	Cnc lathe machine 4						1						
122	Lathe machine 6							1					
123	Horizontal milling machine 3								1				
124	Lathe machine 7								1				
125	Cnc lathe machine 5								1				
126	Horizontal milling machine 4									1			
127	plasma									1			
128	Cnc lathe machine 6										1		
129	Wire edm										1		
130	Lathe machine 8											1	
131	Lathe machine 9												1
132	Vertical milling machine 1												1
133	Lathe machine 10												
134	Lathe machine 11												
135	Horizontal milling machine 1												
136	Vertical milling machine 2												
137	Lathe machine 12												
138	Vertical milling machine 3												
139	Lathe machine 13												
140	Lathe machine 14												
141	welding												
142	Lathe machine 15												
143	Lathe machine 16												
144	Cnc lathe machine 7												
145	Cnc milling machine 3												
146	Lathe machine 17												
147	Cnc lathe machine 8												
148	Cnc milling machine 4												
149		70,368,744,177,664	54,700,703,481,856	240,518,168,576	61,604,863,410,176	35,185,982,701,568	35,322,213,695,488	35,184,439,197,696	35,184,430,809,088	35,184,378,380,288	35,184,373,661,696	39,582,418,927,616	8,796,093,218,816
150		1	3	17	2	7	6	8	9	10	12	5	16
151													
152		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024
153	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Pin	Nut	Bolt	Roller	Chain	Boiler with nut	Spring
154	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1
155	Grinding	1	1	1	1								
156	Slotting milling machine 1	1	1										
157	Gear hobbing	1				1							
158	Lathe machine 1	1											
159	Slotting milling machine 2			1		1							
160	Lathe machine 2			1									
161	Universal milling machine 1			1									

Ascending column from bottom to top by binary weight value from 2^0 to 2^{10} which resulted from 1 to 512 as indicated below on the table 3.16. Rearranging rows based on the rank value and reshuffle the row values.

Table 3. 16: Rearranged row in ROC

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
					Column ascending											
Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Pin	Nut	Bolt	Roller	Chain	Boiler with nut	Spring	Spear	Dumb bell	Collet	Screw
Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Grinding	1	1	1	1											1	
Slotting milling machine	1	1														1
Gear hobbing	1				1											
Lathe machine 1	1															
Cnc lathe machine 3		1								1						
Cnc lathe machine 2		1														
Lathe machine 3		1														
Horizontal milling machine 2		1														
Slotting milling machine 2			1		1											
Lathe machine 2			1													
Universal milling machine 1			1													
Lathe machine 8					1											
Cnc milling machine 2						1										
Lathe machine 5						1										
Cnc lathe machine 4						1										
Lathe machine 4							1									
Universal milling machine 2							1									
Lathe machine 6								1								
Horizontal milling machine 3									1							
Lathe machine 7									1							
Cnc lathe machine 5									1							
Horizontal milling machine 4										1	1					
plasma										1						
Cnc lathe machine 6												1				
Wire edm												1				
Vertical milling machine 3													1			
Lathe machine 12													1			
Lathe machine 17														1		
Cnc lathe machine 8														1		
Cnc lathe machine 7															1	
Cnc milling machine 3															1	
Lathe machine 9																1
Vertical milling machine 1																1
Cnc milling machine 1																
Cnc lathe machine 1																
Lathe machine 15																
Lathe machine 10																
Lathe machine 11																
Horizontal milling machine 1																
Vertical milling machine 2																
Lathe machine 13																
Lathe machine 14																
welding																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	17,042,430,230,528	15,908,558,864,384	13,224,204,304,384	13,194,139,533,312	9,914,932,002,816	8,797,972,070,400	8,796,294,348,800	8,796,126,576,640	8,796,122,382,336	9,070,974,074,880	8,796,095,119,360	8,796,093,808,640	8,796,093,218,816	8,796,093,071,360	4,398,046,523,392	2,199,023,258,624
	1	2	3	4	5	7	8	9	10	6	11	12	13	14	15	16

Gear	Bushing	Shaft	Die	Sleeve	Pin	Nut	Bolt	Roller	Chain	Boiler with nut	Spring	Spear	Dumb bell	Collet	Screw	Coupling	Key	Closing cap	Tube for drainage	Key way	Plate	valve
														1								
														1								
													1									
													1									
			1																			
70,368,744,177,664	61,604,863,410,176	54,700,703,481,856	52,776,558,133,248	35,182,418,927,616	35,322,213,695,488	35,185,982,701,568	35,184,439,197,696	35,184,430,809,088	35,184,378,380,288	35,184,376,283,136	35,184,373,661,696	35,184,372,891,904	35,184,372,088,832	17,592,186,044,416	8,796,093,218,816	240,518,168,576	33,554,432	32768	28672	512	384	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

Step 3) Rearrange columns based on the rank value – Assign the binary weight ratio to rows and re-arrange the order descended in rows based on the computed value. This described in the below table3.17.

Table 3. 17: Rearranged columns in Roc

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
255	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Pin	Nut	Bolt	Roller	Boiler with nut	Spring	Spear	Dumb bell
256	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	
257	Grinding	1	1	1	1										
258	Slotting milling machine	1	1												
259	Gear hobbing	1				1									
260	Lathe machine 1	1													
261	Cnc lathe machine 3		1				1								
262	Cnc lathe machine 2		1												
263	Lathe machine 3		1												
264	Horizontal milling machine 2		1												
265	Slotting milling machine 2			1		1									
266	Lathe machine 2			1											
267	Universal milling machine 1			1											
268	Lathe machine 8					1									
269	Cnc milling machine 2							1							
270	Lathe machine 5							1							
271	Cnc lathe machine 4							1							
272	Lathe machine 4								1						
273	Universal milling machine 2								1						
274	Lathe machine 6									1					
275	Horizontal milling machine 3										1				
276	Lathe machine 7										1				
277	Cnc lathe machine 5										1				
278	Horizontal milling machine 4						1					1			
279	plasma						1								
280	Cnc lathe machine 6												1		
281	Wire edm												1		
282	Vertical milling machine 3													1	
283	Lathe machine 12													1	
284	Lathe machine 17														
285	Cnc lathe machine 8														
286	Cnc lathe machine 7														
287	Cnc milling machine 3														
288	Lathe machine 9														
289	Vertical milling machine 1														
290	Cnc milling machine 1														
291	Cnc lathe machine 1														
292	Lathe machine 15														
293	Lathe machine 10														
294	Lathe machine 11														
295	Horizontal milling machine 1														
296	Vertical milling machine 2														
297	Lathe machine 13														
298	Lathe machine 14														
299	welding														
300		1	2	3	4	5	6	7	8	9	10	11	12	13	

The steps in the cluster followed were changing column's in ascending order which resulted the column's change. This resulted from the binary weight assigned in the rank values described in the table 3.18.

Table 3. 18: Rearranged column in ROC

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
302								Rearranging columns										
303																		
304	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Pin	Nut	Bolt	Roller	Boiler with nut	Spring	Spear	Dumb bell	Collet	Screw	Coupling
305	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
306	Grinding	1	1	1	1											1		
307	Slotting milling machine	1	1														1	
308	Gear hobbing	1				1												
309	Lathe machine 1	1																
310	Cnc lathe machine 3		1				1											
311	Cnc lathe machine 2		1															
312	Lathe machine 3		1															
313	Horizontal milling machine 2		1															
314	Slotting milling machine 2			1		1												
315	Lathe machine 2			1														
316	Universal milling machine 1			1														
317	Lathe machine 8					1												
318	Cnc lathe machine 5										1							
319	Cnc lathe machine 6												1					
320	Cnc milling machine 2							1										
321	plasma						1											
322	Lathe machine 5							1										
323	Cnc lathe machine 4							1										
324	Lathe machine 4								1									
325	Universal milling machine 2								1									
326	Lathe machine 6									1								
327	Horizontal milling machine 3										1							
328	Lathe machine 7										1							
329	Wire edm												1					
330	Vertical milling machine 3													1				
331	Lathe machine 12													1				
332	Lathe machine 17														1			
333	Cnc lathe machine 8														1			
334	Cnc lathe machine 7															1		
335	Cnc milling machine 3															1		
336	Lathe machine 9																1	
337	Vertical milling machine 1																1	
338	Cnc milling machine 1																	
339	Cnc lathe machine 1																	
340	Lathe machine 15																	
341	Lathe machine 10																	
342	Lathe machine 11																	
343	Horizontal milling machine 1																	
344	Vertical milling machine 2																	
345	Lathe machine 13																	
346	Lathe machine 14																	
347	welding																	
348		17,042,430,230,528	15,908,558,864,384	13,224,204,304,384	13,194,139,533,312	9,914,932,002,816	9,071,105,146,880	8,796,462,120,960	8,796,118,188,032	8,796,097,216,512	8,797,169,909,760	8,796,093,022,208	8,796,630,417,408	8,796,093,415,424	8,796,093,120,512	4,398,046,535,680	2,199,023,261,696	26
349		1	2	3	4	5	6	9	10	11	7	14	8	12	13	15	16	

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
298	Lathe machine 11																				1			4	39
299	Horizontal milling machine 1																				1			4	40
300	Vertical milling machine 2																				1			4	41
301	Lathe machine 13																					1		2	42
302	Lathe machine 14																						1	1	43
303	welding																						1	1	44
304		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
305																									

Step 4) After rearranging columns if there is no change in the row rank value stop and go to clustering. If there is a change in row value go to next iteration. In our case there is a change in the row rank value therefore, we will go to further iteration until no change occurs in row rank value.

Table 3. 19: Iteration for row value in ROC

	A	B	C	D	E	F	G	H	I	J	K	L	
303													
304	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Pin	Nut	Bolt	Roller	Boiler with nut	Spring
305	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	
306	Grinding	1	1	1	1								
307	Slotting milling machine 1	1	1										
308	Gear hobbing	1				1							
309	Lathe machine 1	1											
310	Cnc lathe machine 3		1				1						
311	Cnc lathe machine 2		1										
312	Lathe machine 3		1										
313	Horizontal milling machine 2		1										
314	Slotting milling machine 2			1		1							
315	Lathe machine 2			1									
316	Universal milling machine 1			1									
317	Lathe machine 8					1							
318	Cnc lathe machine 5										1		
319	Cnc lathe machine 6												
320	Cnc milling machine 2							1					
321	plasma						1						
322	Lathe machine 5							1					
323	Cnc lathe machine 4							1					
324	Lathe machine 4								1				
325	Universal milling machine 2								1				
326	Lathe machine 6									1			
327	Horizontal milling machine 3										1		
328	Lathe machine 7										1		
329	Wire edm												
330	Vertical milling machine 3												
331	Lathe machine 12												
332	Lathe machine 17												
333	Cnc lathe machine 8												
334	Cnc lathe machine 7												
335	Cnc milling machine 3												
336	Lathe machine 9												
337	Vertical milling machine 1												
338	Cnc milling machine 1												
339	Cnc lathe machine 1												
340	Lathe machine 15												
341	Lathe machine 10												
342	Lathe machine 11												
343	Horizontal milling machine 1												
344	Vertical milling machine 2												

The change in the rank value for the row required further iteration and will go for additional iteration.

Table 3. 20: : Row value further iteration

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
349		1	2	3	4	5	6	9	10	11	7	14	8	12	13	15	16	
350																		
351																		
352		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	
353	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Roller	Spring	Pin	Nut	Bolt	Spear	Dumb bell	Boiler with nut	Collet	Screw	Coupling
354	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
355	Grinding	1	1	1	1											1		
356	Slotting milling machine	1	1														1	
357	Gear hobbing	1				1												
358	Lathe machine 1	1																
359	Cnc lathe machine 3		1				1											
360	Cnc lathe machine 2		1															
361	Lathe machine 3		1															
362	Horizontal milling machine 2		1															
363	Slotting milling machine 2			1		1												
364	Lathe machine 2			1														
365	Universal milling machine 1			1														
366	Lathe machine 8					1												
367	Cnc lathe machine 5							1										
368	Cnc lathe machine 6								1									
369	Cnc milling machine 2									1								
370	plasma						1											
371	Lathe machine 5									1								
372	Cnc lathe machine 4									1								
373	Lathe machine 4										1							
374	Universal milling machine 2										1							
375	Lathe machine 6											1						
376	Horizontal milling machine 3							1										
377	Lathe machine 7							1										
378	Wire edm								1									
379	Vertical milling machine 3												1					
380	Lathe machine 12												1					
381	Lathe machine 17													1				
382	Cnc lathe machine 8													1				
383	Cnc lathe machine 7															1		
384	Cnc milling machine 3															1		
385	Lathe machine 9																1	
386	Vertical milling machine 1																1	
387	Cnc milling machine 1																	
388	Cnc lathe machine 1																	
389	Lathe machine 15																	
390	Lathe machine 10																	
391	Lathe machine 11																	
392	Horizontal milling machine 1																	
393	Vertical milling machine 2																	
394	Lathe machine 13																	
395	Lathe machine 14																	
396	welding																	
397																		
398																		
399																		
400		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	
401	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Roller	Spring	Pin	Nut	Bolt	Spear	Dumb bell	Boiler with nut	Collet	Screw	Coupling
402	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
403	Grinding	1	1	1	1											1		

Sheet1 Sheet2

The change in the rank value for the column required further iteration and will go for additional iteration.

Table 3. 21: Column value further iteration

399											
400	64	32	16	8	4	2	1				
401	Screw	Coupling	Key	Claring cup	Tube for drainage	Key way	Plate	value	Rank		
402								4194048	1	8,796,093,022,208	
403								3932288	2	4,398,046,511,104	
404	1							3145792	3	2,199,023,255,552	
405								2228224	4	1,099,511,627,776	
406								2097152	5	549,755,813,888	
407								1114112	6	274,877,906,944	
408								1048576	7	137,438,953,472	
409								1048576	8	68,719,476,736	
410								1048576	9	34,359,738,368	
411								655360	10	17,179,869,184	
412								524288	11	8,589,934,592	
413								524288	12	4,294,967,296	
414								131072	13	2,147,483,648	
415								65,536	14	1,073,741,824	
416			1					32784	15	536,870,912	
417								32768	16	268,435,456	
418								32768	17	134,217,728	0
419								16384	18	67,108,864	0
420								16384	19	33,554,432	0
421		1						8224	20	16777216	0
422								8192	21	8388608	0
423								8192	22	4194304	0
424								4096	23	2097152	0
425								4096	24	1048576	0
426								2048	25	524288	0
427								1024	26	262144	0
428								1024	27	131072	0
429								512	28	65536	0
430								512	29	32768	
431								128	30	16384	
432								128	31	8192	
433	1							64	32	4096	
434	1							64	33	2048	
435		1						32	34	1024	
436		1						32	35	512	
437			1					16	36	256	
438				1				8	37	128	
439					1			4	38	64	
440					1			4	39	32	
441					1			4	40	16	
442						1		2	41	8	
443							1	1	42	4	
444							1	1	43	2	
445	2,199,023,261,696	16778752	536,871,168	128	112	8	6			1	
446	16	18	17	19	20	21	22				
447											
448											
449											
450											
451	64	32	16	8	4	2	1				
452	Screw	Key	Coupling	Claring cup	Tube for drainage	Key way	Plate	value	Rank		
453								4194048	1		
454								3932288	2		

:

The change in the rank value for the row required further iteration and will go for additional iteration.

Table 3. 22: Final iteration of row values in ROC

449									Rearranging Columns									
450																		
451		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	
452	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Roller	Spring	Pin	Nut	Bolt	Spear	Dumb bell	Bailer with nut	Collet	Screw	Key
453	Heat treatment	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
454	Grinding	1	1	1	1											1		
455	Slotting milling machine	1	1														1	
456	Gear hobbing	1				1												
457	Lathe machine 1	1																
458	Cnc lathe machine 3		1				1											
459	Cnc lathe machine 2		1															
460	Lathe machine 3		1															
461	Horizontal milling machine 2		1															
462	Slotting milling machine 2			1		1												
463	Lathe machine 2			1														
464	Universal milling machine 1			1														
465	Lathe machine 8					1												
466	plasma						1											
467	Horizontal milling machine 3							1										
468	Lathe machine 7							1										
469	Cnc lathe machine 5							1										
470	Cnc lathe machine 6								1									
471	Wire edm								1									
472	Cnc milling machine 2									1								
473	Lathe machine 5									1								
474	Cnc lathe machine 4									1								
475	Lathe machine 4										1							
476	Universal milling machine 2										1							
477	Lathe machine 6											1						
478	Vertical milling machine 3												1					
479	Lathe machine 12												1					
480	Lathe machine 17													1				
481	Cnc lathe machine 8													1				
482	Cnc lathe machine 7															1		
483	Cnc milling machine 3															1		
484	Lathe machine 9																1	
485	Vertical milling machine 1																1	
486	Cnc milling machine 1																	
487	Cnc lathe machine 1																	
488	Lathe machine 15																	
489	Lathe machine 10																	
490	Lathe machine 11																	
491	Horizontal milling machine 1																	
492	Vertical milling machine 2																	
493	Lathe machine 13																	
494	Lathe machine 14																	
495	welding																	
496																		
497		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
498																		
499																		
500																		
501					Final - cluster	Since, there is no change in raw and column the iteration will stop here!												
502																		

223	Universal milling machine 2							1													
224	Lathe machine 6								1												
225	Horizontal milling machine 3									1									1		
226	Lathe machine 7									1											
227	Cnc lathe machine 5									1											
228	Horizontal milling machine 4										1	1									
229	plasma										1										
230	Cnc lathe machine 6												1								
231	Wire edm												1								
232	Vertical milling machine 3													1							
233	Lathe machine 12													1							
234	Lathe machine 17														1						
235	Cnc lathe machine 8														1						
236	Cnc lathe machine 7															1					
237	Cnc milling machine 3															1					
238	Lathe machine 9																1				
239	Vertical milling machine 1																1				
240	Cnc milling machine 1																	1			
241	Cnc lathe machine 1																	1			
242	Lathe machine 15																		1		
243	Lathe machine 10																			1	
244	Lathe machine 11																				1
245	Horizontal milling machine 1																				1
246	Vertical milling machine 2																				1
247	Lathe machine 13																				
248	Lathe machine 14																				
249	welding																				
250		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
251																					
252		17,042,430,230,528	15,908,558,864,384	13,224,204,304,384	13,194,139,533,312	9,914,932,002,816	8,797,972,070,400	8,796,294,348,800	8,796,126,576,640	8,796,122,382,336	9,070,974,074,880	8,796,095,119,360	8,796,093,808,640	8,796,093,218,816	8,796,093,071,360	4,398,046,523,392	2,199,023,258,624	1,073,742,592	16777344	64	56
253		1	2	3	4	5	7	8	9	10	6	11	12	13	14	15	16	17	18	19	20
254		2097152	1048576	524288	262144	131072	65536	32768	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4

Step 5) There is no change in row values after reshuffling columns. Since, the cluster result is formed as indicated above 3.24 table.

Finally, the rank values can't further change. Therefore, stop the iteration here and the final cluster shown as follows:

Table 3. 23: Final clustering in ROC

505					Final - clusterow and column the iteration will stop here!																					
506																										
507	Parts/Machines	Gear	Bushing	Shaft	Die	Sleeve	Chain	Roller	Spring	Pin	Nut	Bolt	Spear	Dumb bell	Boiler with nu	Collet	Screw	Key	Couplin	Closing cu	for drai	Key way	Plate	value	Rank	
508	Heat treat m/c	1	1	1	1	1	1	1	1	1	1	1	1	1	1										1	8,796,093,022,208
509	Grinding	1	1	1	1											1									2	4,398,046,511,104
510	Slotting miill m/c1	1	1														1								3	2,199,023,255,552
511	Gear hobbing	1				1																			4	1,099,511,627,776
512	Lathe m/c 1	1																							5	549,755,813,888
513	Cnc lathe m/c 3		1				1																		6	274,877,906,944
514	Cnc lathe m/c 2		1																						7	137,438,953,472
515	Lathe m/c 3		1																						8	68,719,476,736
516	Horizontal milling m/c 2		1																						9	34,359,738,368
517	Slotting mill m/c 2			1		1																			10	17,179,869,184
518	Lathe machine 2			1																					11	8,589,934,592
519	Universal milling m/c 1			1																					12	4,294,967,296
520	Lathe machine 8					1																			13	2,147,483,648
521	plasma						1																		14	1,073,741,824
522	Horizontal mill m/c 3							1										1							15	536,870,912
523	Lathe machine 7							1																	16	268,435,456
524	Cnc lathe machine 5							1																	17	134,217,728
525	Cnc lathe machine 6								1																18	67,108,864
526	Wire edm								1																19	33,554,432
527	Cnc milling machine 2									1									1						20	16777216
528	Lathe machine 5									1															21	8388608
529	Cnc lathe machine 4									1															22	4194304
530	Lathe machine 4										1														23	2097152
531	Universal milling machine 2										1														24	1048576
532	Lathe machine 6											1													25	524288
533	Vertical milling machine 3												1												26	262144
534	Lathe machine 12												1												27	131072
535	Lathe machine 17													1											28	65536
536	Cnc lathe machine 8													1											29	32768
537	Cnc lathe machine 7															1									30	16384
538	Cnc milling machine 3															1									31	8192
539	Lathe machine 9																1								32	4096
540	Vertical milling machine 1																1								33	2048
541	Cnc milling machine 1																		1						34	1024
542	Cnc lathe machine 1																		1						35	512
543	Lathe machine 15																	1							36	256
544	Lathe machine 10																			1					37	128
545	Lathe machine 11																				1				38	64
546	Horizontal milling machine 1																				1				39	32
547	Vertical milling machine 2																				1				40	16
548	Lathe machine 13																					1			41	8
549	Lathe machine 14																						1		42	4
550	welding																						1		43	2

Sheet1 Sheet2

Based on the cluster formed above in table 3.25, the cells formed and machines within each cell are explained below:

Cell 1 contains machines {Heat treatment 1, Grinding, Slotting M/c 1, Gear hobbing m/c 1 and Lathe m/c 1} – process parts of Gear, bushing and boiler with nut.

Cell 2 contains M3, M3 and M5 which are {Cnc lathe m/c 3, Cnc lathe m/c 2, lathe m/c 3, Horizontal milling m/c 2} – Process Bushing parts.

Cell 3 contains M2, M4 and M 10 which are {Slotting mill m/c 2, Lathe m/c 2, Universal milling m/c 1} - process parts Shaft.

Cell 4 contains machines {Lathe m/c} – process sleeve parts.

Cell 5 contains machines {Plasma m/c} process chain parts.

Cell 6 contains machines which are Horizontal mill machine process chain parts.

Cell 7 contains machines {lathe m/c 7, horizontal mill m/c, cnc lathe m/c 5} process roller and key parts.

Cell 8 contains machines {wire edm, cnc lathe m/c 6} process spring parts.

Cell 9 contains machines {cnc milling m/c2, lathe m/c 5, cnc lathe m/c 4} process pin parts.

Cell 10 contains machines {lathe m/c4, universal milling m/c 2}

Cell 11 contains machines {lathe m/c 6} process bolt parts.

Cell 12 contains machines {vertical milling m/c 3, lathe m/c 12} process spear parts.

Cell 13 contains machines {lathe m/c 17, cnc lathe m/c 8} process dumbbell parts.

Cell 14 contains machines {lathe m/c 17, cnc lathe m/c 8} process dumbbell parts.

Cell 15 contains machines {cnc lathe m/c 7, cnc milling m/c 3} process collet parts.

Cell 16 contains machines {lathe m/c 9, vertical milling m/c 1} process screw parts.

Cell 17 contains machines {cnc milling m/c 1, cnc lathe m/c 1} process coupling parts and closing cap.

Cell 18 contains machines {lathe m/c 11, horizontal milling m/c 1, vertical milling m/c 2} process tube for drainage parts.

Cell 19 contains machines {lathe m/c 13} process keyway parts.

Cell 20 contains machines {lathe m/c 14, welding m/c} process plate parts.

3.6.3. Evaluation of the designed cellular manufacturing system

The method to evaluate the goodness of the designed cell system was using Grouping Efficacy (GE) = $\frac{E+E_e}{E+E_v}$ = 1-$\frac{E_{v}+E_e}{E+E_v}$ ………………Equation 3. 1.Grouping Efficacy

using equation by tamal as a performance metric measure for the cell system. (Tamal, 2017).

Where E = Total number of 1s in incidence matrix

E_e= Total number of exceptional elements and E_v= Total number of voids

$E = 67\ is\ total\ number\ of\ 1\ in\ incidence\ matrix$

Ee = 22 is the total number of exceptional elements in the incidence matrix

Ev -30 is the total number of voids in the incidence matrix.

Grouping efficacy = $\frac{E+E_e}{E+E_v} = \frac{67+22}{67+30} \frac{=89}{97}$ = 0.91% = 0.91*100 = 91%, which shows the performance in the grouping efficacy is very high and efficient cell is created.

3.3.1 Cluster analysis based on cell efficiency

An efficient cell is designed based on considering all operations in block diagonal form. This will eliminate intercellular movement between cells. However, void in the block diagonal form indicate some parts in the specific part family doesn't visit some of the machines available in the cell. This doesn't mean the machines in the cell are idle. Therefore, cell efficiency can be calculated as follows:

$\eta = \frac{\alpha}{1+\beta}$ x 100 %..Equation 3. 2: Cell efficiency

$$\alpha = \frac{Total\ number\ of\ operations\ in\ block\ diagonal\ form}{Total\ number\ of\ operations} == \frac{39}{43} = 0.9069$$

$$where, 39\ is\ the\ number\ of\ operations\ in\ block\ diagonal's\ form.$$

43 is the total number of operations in the cell.

$$\beta = \frac{Total\ number\ of\ voids\ in\ block\ diagonal\ form}{Total\ voids\ in\ the\ matrix} = \frac{30}{879} = 0.034$$

$$\eta = \frac{\alpha}{1+\beta} \text{ x } 100 = \frac{0.9069}{1+0.034} x100\% = 0.877\text{x}100\% = 87.7\%$$

$$where, 30\ is\ the\ total\ number\ of\ voids\ in\ the\ block\ diagonal\ form$$

879 is the total voids in the matrix.

Therefore, the cell efficiency is 87.7% as indicated above.

3.3.2Cluster analysis based on machine utilization

M/c utilization = $\frac{No1}{\sum_{k=1}^{nc} mk*ck}$ …Equation 3. 3: machine utilization

$$\frac{39}{5*1+4*1+3*1+3*1+2*1+3*1+2*1+1*1+2*1+2*1+2*1+2*1+2*1+3*1+1*1+2*1} = 39/39 = 100\%$$

It shows 100% machine utilization in the cells.

where, $No1\ is\ the\ total\ number\ of\ operations\ in\ the\ block\ diagonal\ form$

$$\sum_{k=1}^{nc} mk * ck\ \ is\ the\ multiplication\ of\ each\ cell\ with\ 1.$$

Therefore, based on the above analysis of the cluster formed, the efficient cell resulted.

3.7. Analysis of proposed cellular manufacturing system

The proposed cell was designed based on the grouping of parts using hybrid coding system. After clustering parts and machines in the used rank order clustering method. The cell formed for processing the parts so that, machines were grouped based on the similarity of processing parts in cells. Each of the cells processed parts as family were created. Therefore, 20 cells created and 43 machines assigned with the used rank order method. Since, the duplicated machines in the current process industry were reduced and the cluster formed enhances machine capacity within each cell. Therefore, the 43 machines performance analyzed using the grouping efficacy, machine utilization and cell analysis techniques. The table 3.2.7. provides the data available in the proposed system. According to the available data from the cluster formed, the machine utilization was reported. The report showed from the totally available 14 conventional lathe machines 11 were with 90 % performance, 1 with 14 % performance and the other 1with 11% which showed the machines were idle. 1 machine were with 63 % performance. From the totally available 9 cnc lathe machines 6 machines exhibit 98 % performance, 1cnc lathe machines were 3% and the other one with 1% performance which implicated completely idle condition. From the totally 7 conventional milling machines 2 conventional milling machines performed 100 % performance and 1 conventional milling machine 90% performance. 2 cnc lathe machines showed below the average performance with 21 and 24%. 2 cnc lathe machines show completely idle performance with 1% performance and 12% performance. 1 cnc milling machine showed 100% performance out of the available cnc milling machine. 3 cnc millling machines exhibit 99%, 1Welding machine show 98% and Wire edm machine performed 100%. Gear hobbing machine performed 36%, plasma machine show 1% performance. The slotting machines performed 1% and another slotting machine with 10%. The Grinding machine performed 98%. Therefore, based on the cluster formed the performance analysis executed. The cell analysis result explained efficient utilization of cells with 87.7% as depicted in cluster analysis based on cell efficiency.

conventional lathe machine	**performance (100%)**	**Total available**
11machines	90%	14 machines
1 machines	14%	14 machines
1 machines	63%	14 machines
1 machines	11%	14 machines
Cnc lathe machine	Performance (100%)	Total available
6 machines	98%	9 machines
1 machines	3%	9 machines
1 machines	1%	9 machines
Conventional milling machine	Performance (100%)	Total available
2 machines	100%	7 machines
1 machines	90%	7 machines
1 machines	24%	7 machines
1 machines	1%	7 machines
1 machines	21%	7 machines
1 machines	12%	
Cnc milling machine	Performance (100%)	Total available

3 machine	99%	3 machine
Welding machine	98%	1 machine
Wire edm machine	100%	1 machine
Gear hobbing machine	36%	1 machine
plasma machine	1%	1 machine
slotting machine	1%	2 machine
slotting machine	10%	2 machine
Grinding machine	98%	1 machine

Table 3. 24: Analysis of proposed system

After the analysis executed using the cluster formed each machines utilization and performance expressed in figure 3.28. The machines available listed in vertical axis and their performance indicated in horizontal axis. The blue color represented each machines performance and the orange color represent machines available. The analysis done revealed 6 machines performed above 90%, 11 machines nearly approach to 90% performance, 3 machines with 100%, 4 machines with 99%, 1machine with 63% and 10 machines performed below the average.

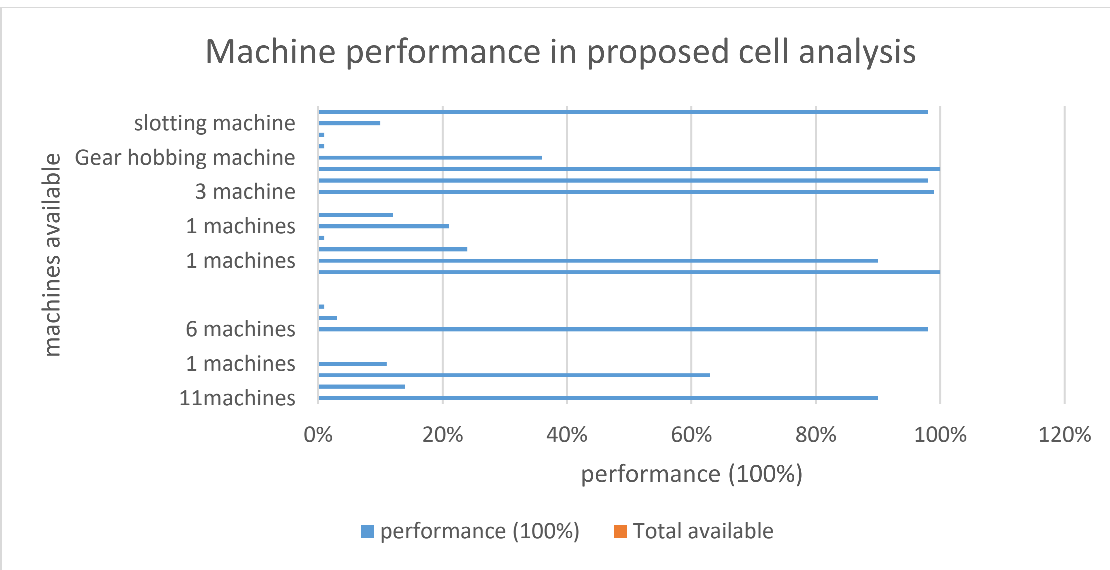


Figure 3. 30: Machine utilization in cells

Therefore, the cell efficiency was 87.7%, as indicated above, and the proposed system demonstrates 87.7% machine utilization percentage. The cell utilization resulted from cell analysis in the cluster analysis based on cell efficiency and evaluation of grouping efficacy in the cluster formed above.

3.7.1. Proposed layout distance – represents the total travel distance of parts in the proposed layout. The following table 3.27 shows the distance of parts movement in CMF. Where i and j represent the part movement from the existing department to processing department, the rectilinear distance between the departments is expressed in meter.

Table 3. 25: Proposed layout distance

i to j (From (i)	X(m) To (j)	Rectilinear(m)
34	76	123.64 m
1	57/77	30.79 m
35	58	80.79 m
36	67	83.64 m
60	h.t1	75.89 m
3	h.t 2	90 m
4	h.t 3	90 m
37	h.t 4	34.19 m
69	h.t 5	84.19 m
38	grind 1	55.3 m
5	77	92.19 m
6	6	75.89 m
7	63	35.89 m
8	65	86.19 m
9	68	21 m
11	72	44.59 m
12	70	49.59 m
13	73	44.59 m
39	75	25.89 m
13	h.t 6	73.79 m
14	h.t 7	37.16 m
81	grind.2	90 m
	Sum total	1,425m

Chapter Four

4. Result and Discussion

4.1 performance simulation of existing & proposed layout

Simulation is the process of generating a virtual system that represents a real-world system scenario based on a system behavior model. It is helpful in understanding the operation and system behavior. The simulation of the system was executed using FlexSim simulation software. Using this software, existing and proposed layout simulations were performed to understand the model behaviors. Therefore, it is possible to compare the performance of the modeled layout system.

4.1.1 Performance Simulation of existing layout

A simulation of 196 parts, grouped within a 22-part family, was executed for the existing layout using FlexSim software. A screenshot of the simulation of the existing layout was presented here, based on the production sequence of parts within the current layout machine arrangement. Each machine's input parameters of processing time and setup time were entered, which were the data gathered from the conventional manufacturing company. Therefore, the simulation result was recorded based on the above parameters, and each busy and idle machine scenario was analyzed with the utilization of each machine. After representing each machine in the model layout and inserting each machine's processing and setup time, the simulation was performed for 8 hours, which was 28, 800 seconds , considering the CMF daily production system.

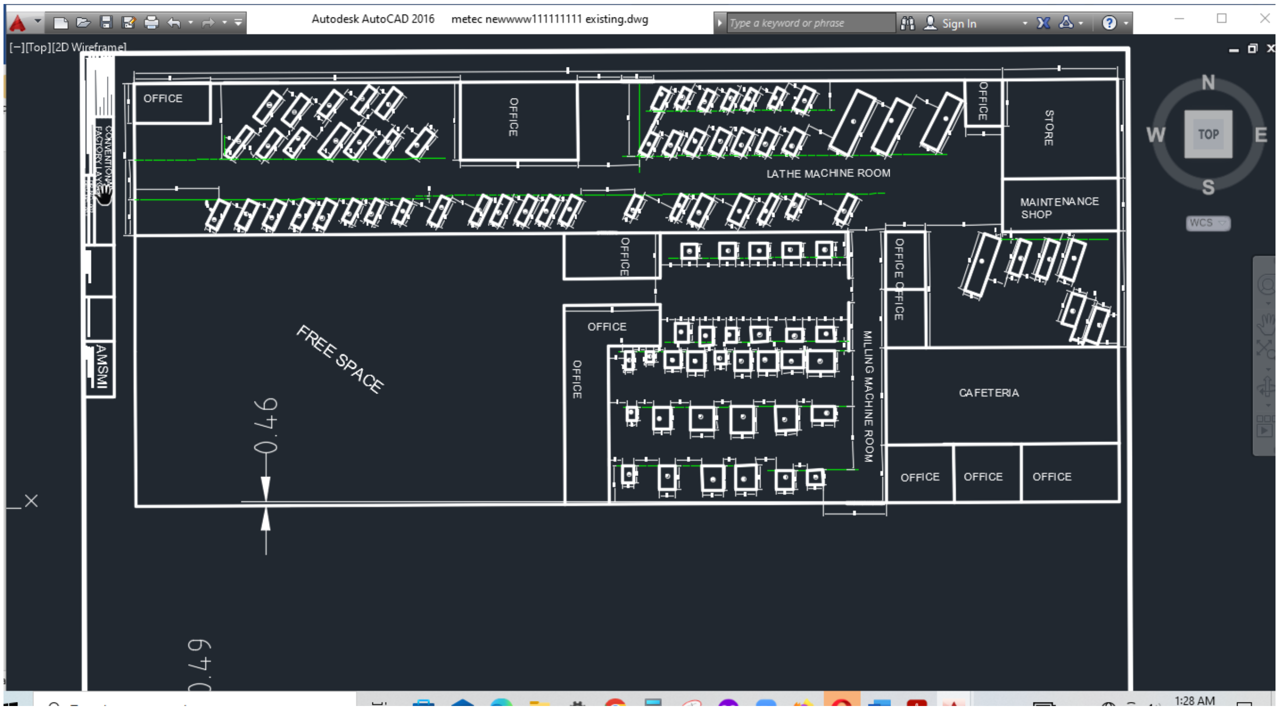


Figure 4. 1: Existing layout of CMF

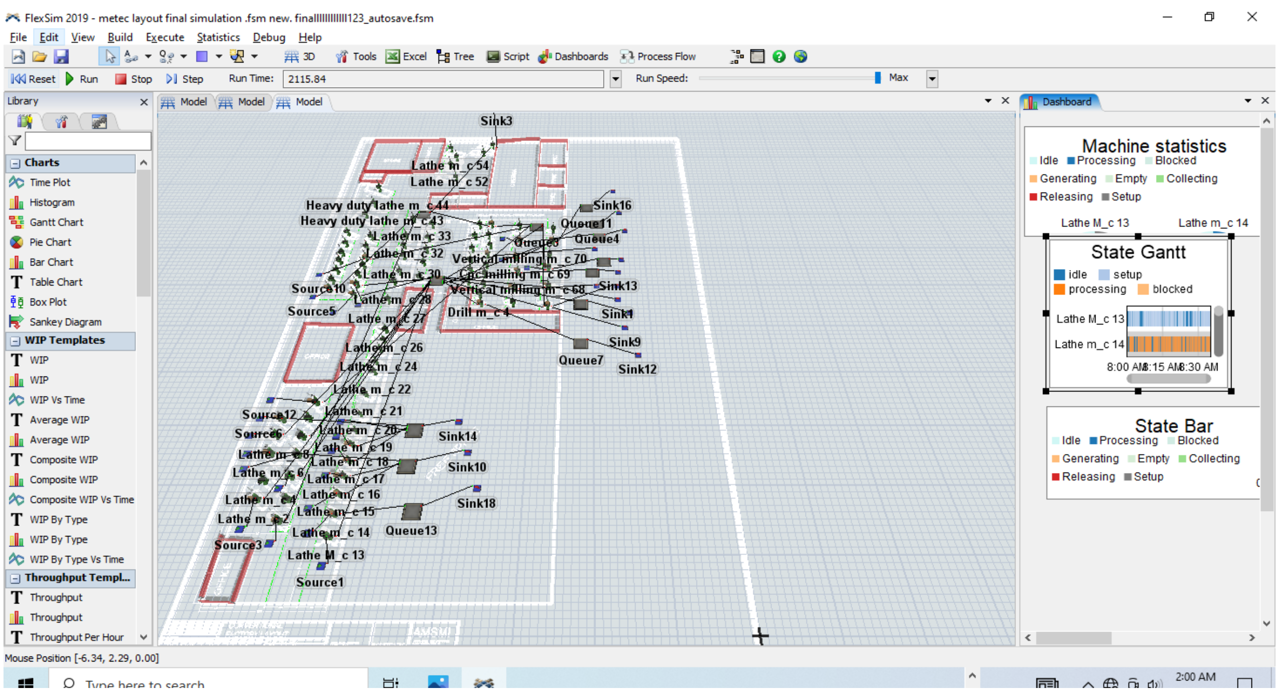


Figure 4. 2: Simulation of existing layout (CMF) performance in FlexSim

Based on the results from the simulation of the existing layout using FlexSim, the overall performance analysis presented as follows: the number of idle machines were 58 and the number of busy machines were 28. Therefore, the total percentage number of idle machines out of the total available 88 machines was 60/88*100% = 68.18%, and the number of busy machines out of the total available 88 machines was 28/88*100% = 31.8%. The dashboard on the right side displays state pie analysis for the current simulation. The blue section represents processing/busy machines, and the light green section represents idle machines. This indicates the underutilization of the existing machines, which greatly contributes to lower performance.

4.1.2. Machine statistics report of existing layout in FlexSim

The figure 4.3 represents each machine's processing time and idle time in the existing layout. The blue section represents processing, and the light green section represents idle machines. The State Pie shows the performance of each machine. The simulation of each machine's statistics report for the existing layout is presented below.

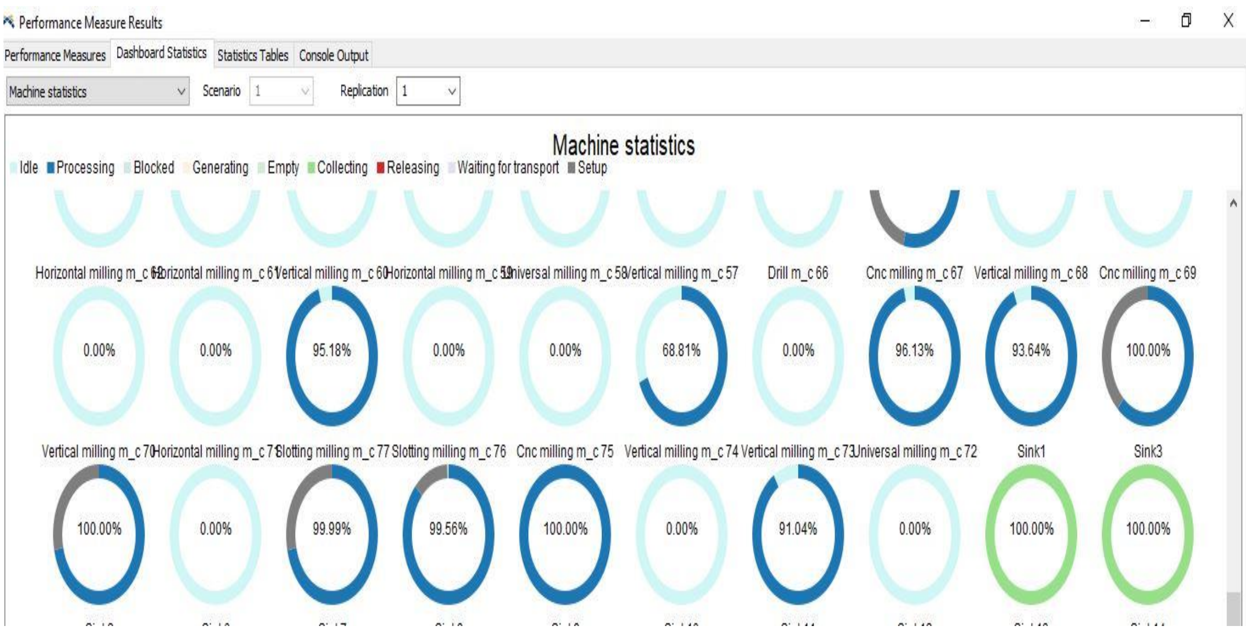


Figure 4. 3: CMF Machine statistics in FlexSim

In addition to the performance simulation mentioned above, the state bar graph of parts is displayed in figure 4.4 . This figure described the current arrangement of each machine's performance. The figure shows the performance and utilization of each machine. The simulation results, expressed in a state bar for each machine, indicate the amount of time each machine is busy or idle.

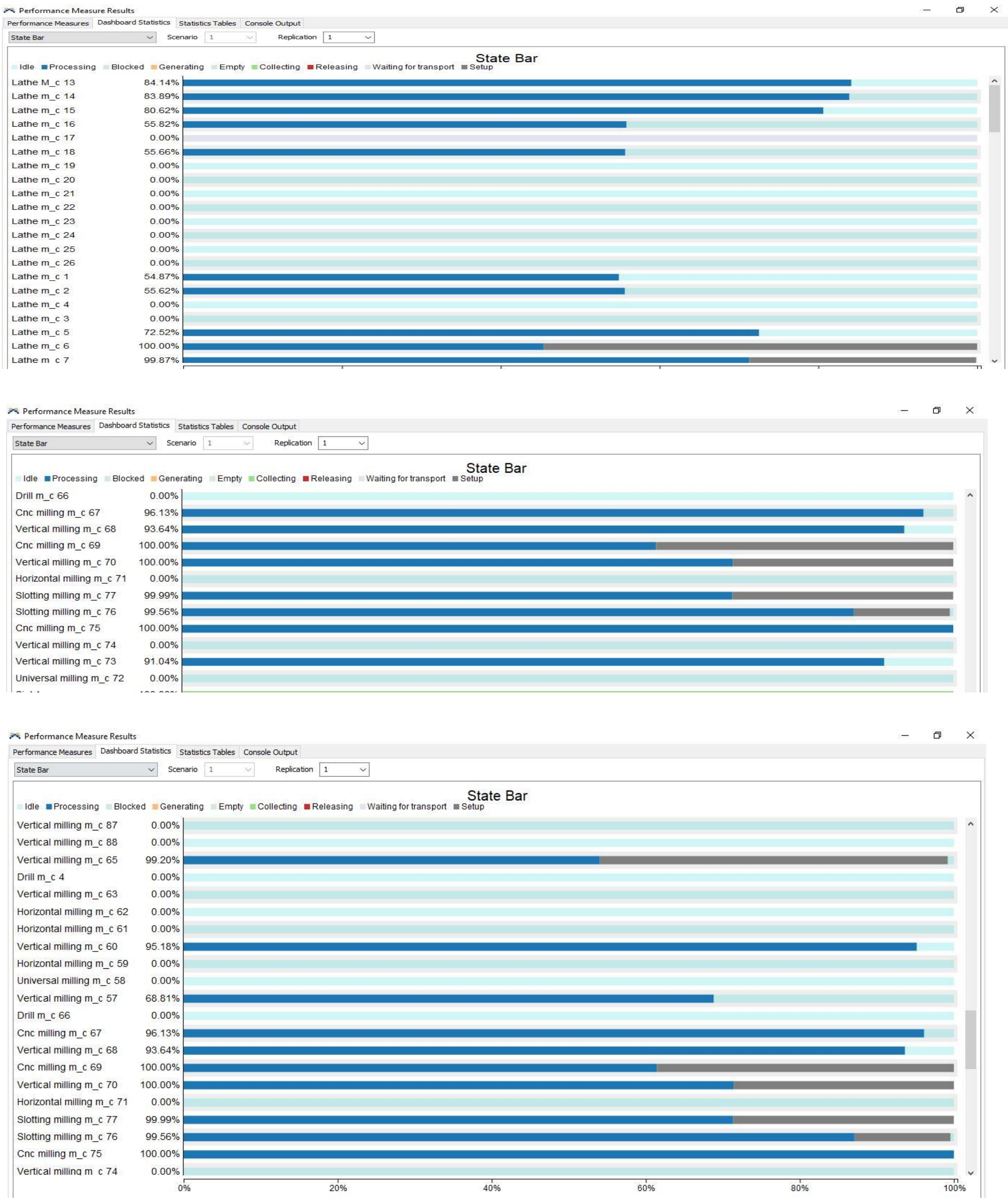


Figure 4. 4: Machine performance and utilization in FlexSim

From the state bar result depicted above, it is easier to understand each machine's idle and busy performance. It shows how the underutilization of each machine affects the performance of the company, and it is important to propose a better machine layout to enhance performance. Also, as indicated earlier the total traveling distance of parts is 2,236.10 m in the existing layout.

Further analysis is executed using ExpertFit in FlexSim, which is widely used by analysts performing discrete-event simulation studies of real-world systems in the application areas of defense, manufacturing, transportation, healthcare, contact centers, and communications networks. For these application areas , ExpertFit will take the selected distribution and put it into the proper format for direct input to Flexsim. It is also applicable in diverse disciplines such as reliability engineering, mining, Monte Carlo simulation, physics and risk analysis. ExpertFit is the result of 33 years of statistical research and has thousands of user organizations worldwide. Using FlexSim - Expert fit, which is a powerful statistical distribution, is applicable to further examine the existing system.

Table 4. 1: ExpertFit analysis of existing layout

Data Characteristic	Value	
1	Source file	
2	Observation type	Real valued
3	Number of observations	39
4	Minimum observation	0.01000
5	Maximum observation	1.00000
6	Mean	0.68179
7	Median	0.90000
8	Variance	0.15527

9	Coefficient of variation	0.57795
10	Skewness	-0.86743

ExpertFit models the random downtimes of a machine along with a random busy time of a machine length followed by a downtime of random length. For this, it is the gamma density function applied to the list of available data. From the available company data statistics, we can take machine busy and idle time, which can be described in the shape function. In our case, we have taken 39 observations from the available data samples. After inserting the 39 data, we will get the mean variance and coefficient of variance in the data samples. we were put the values found here accordingly.

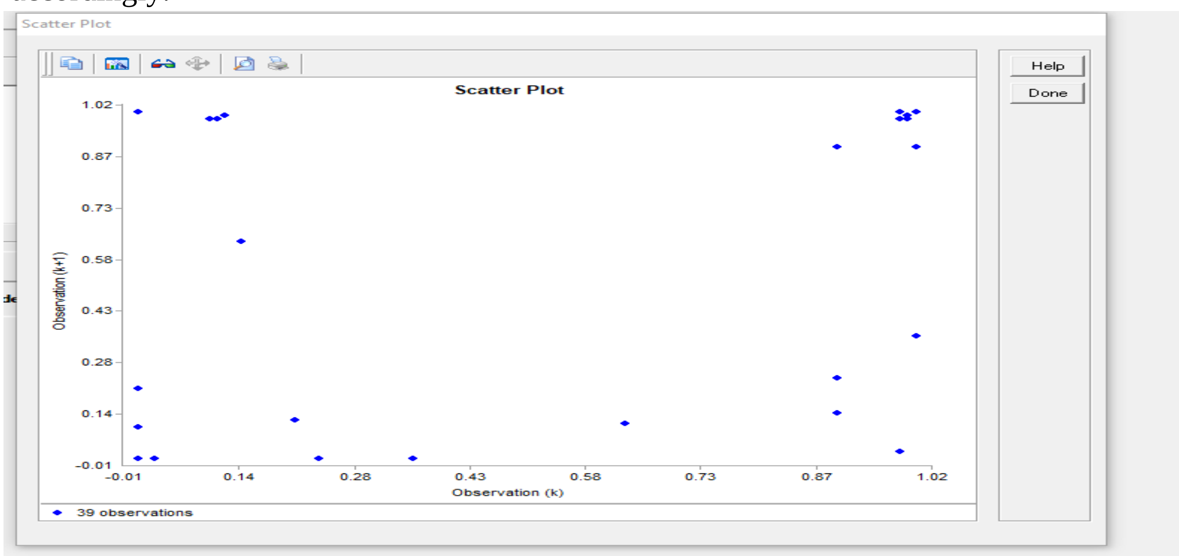


Figure 4. 5: scatter plot for data samples

From the above data samples, it is easier to understand that only 9 samples are approximate to 100% (1) in the confidence interval. 2 samples are near to 90%. 1 is beyond 50%, which is 58%, and the rest 12 are below the 40% range in the correlation analysis. Additionally, 15 are almost null. This reveals the majority of the data samples from the observations are below the expected average value (50%), indicating low machine processing and higher idleness.

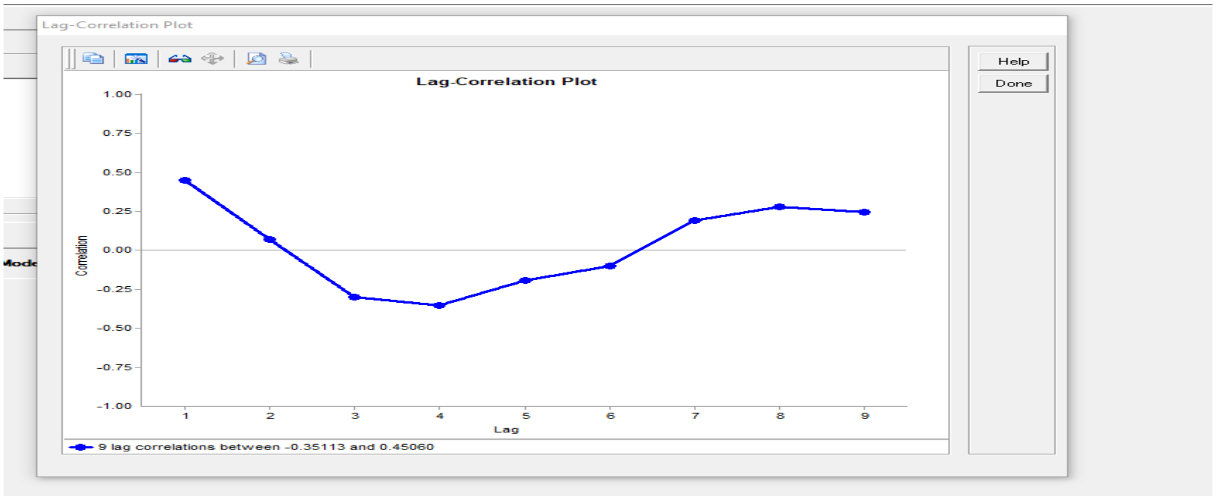


Figure 4. 6: log correlation analysis of data samples

The figure 4.6 shows frequency – comparison plot for the data samples in the ExpertFit analysis. Based on the analysis there were significant idle varibles which implicatd the existing layout has significant downtime and lesser busy machines. The blue bar represents the machine utilization time, while the red bar represents the idle time in the machine utilization, as observed from the samples above. Therefore, based on the existing model simulation and the caculated analytical solution, the current layout reveals a significant number of idle machines.

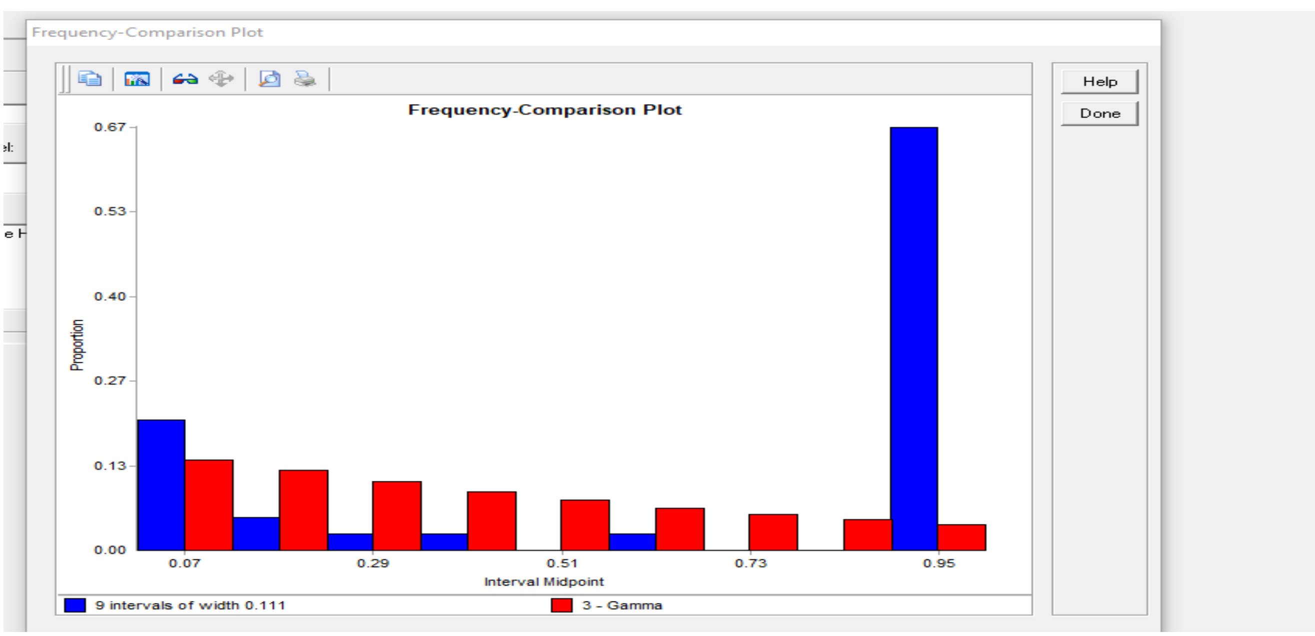


Figure 4. 7: Frequenccy - comparison of data samples

4.2 Simulation of proposed layout

A simulation of proposed layout was executed using FlexSim software. After clustering parts and machines in the used rank order clustering method. The cell formed for processing the parts so that, machines were grouped based on the similarity of processing parts in cells. Each of the cells processed parts as family were created. Therefore, 21 cells created and 43 machines assigned with the used rank order method. A screenshot of the simulation of the proposed layout is presented here, based on the production sequence of parts within the current layout machine arrangement. Each machine's input parameters of processing time and setup time were entered. Therefore, the simulation result was recorded based on the above parameters, and each busy and idle machine scenario was analyzed with the utilization of each machine. After representing each machine in the model layout and inserting each machine's processing and setup time, the simulation was performed for 8 hours, which was 28, 800 seconds , considering the CMF daily production system.

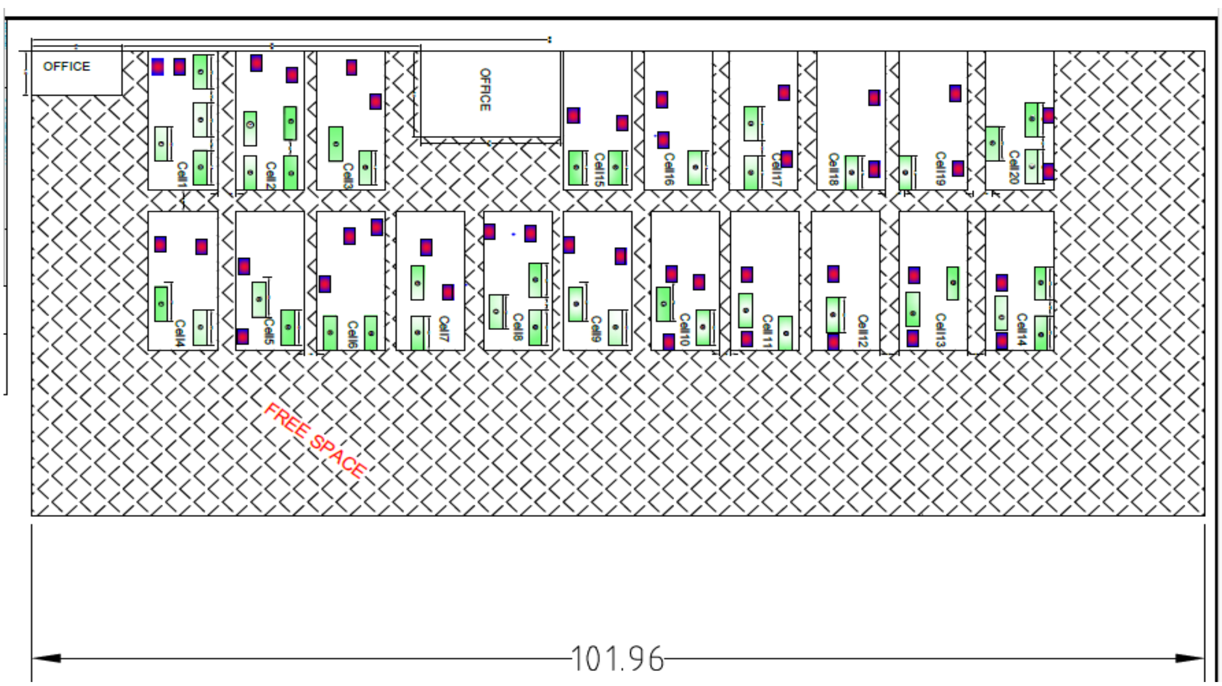


Figure 4. 8*: proposed Cell layout*

The performance and utilization of each machine expressed based on the results from FlexSim, the overall performance analysis was expressed as follows: the blue items represent processing/busy machines, and the light green items represent idle machines.

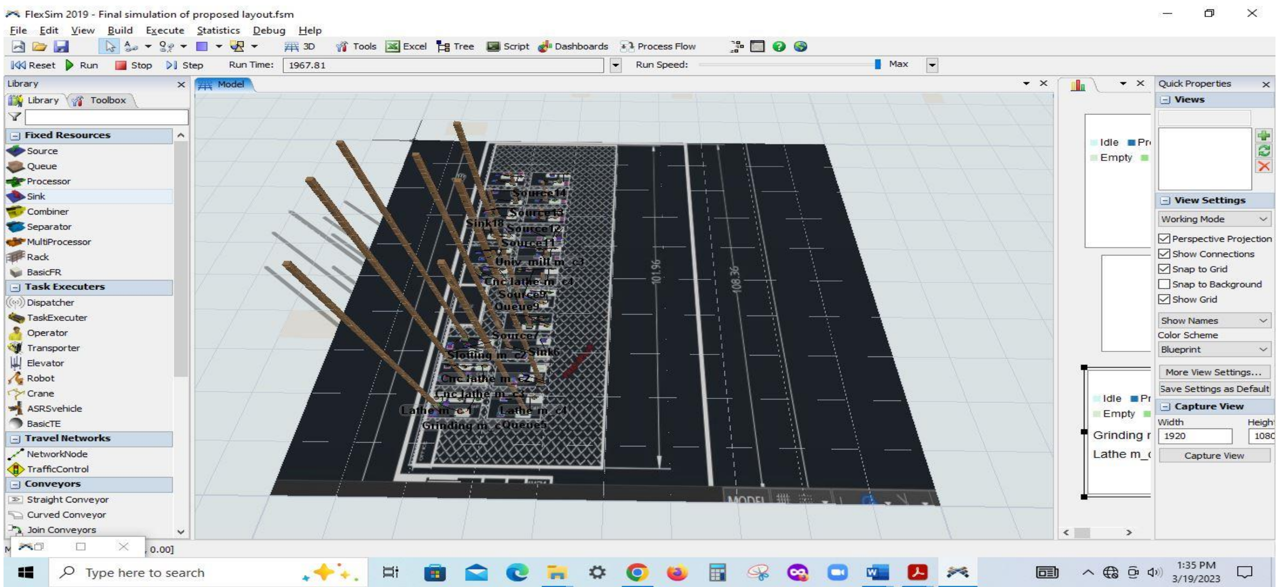


Figure 4. 9 *:simulation performance of proposed cellular layout in FlexSim*

As indicated by the above figure 4.9 cell analysis and clustering, there were 43 machines available for efficient utilizion, and the duplicated machines have been reduced.

The number of idle machines was 5, and the number of busy machines was 38. Therefore the percentage of idle machines out of the total 43 machines was 38/43*100% = 88.37%, and the percentage of busy machines out of the total available 43 machines was 5/43*100% = 11.62%. This describes the proposed layout machine performance as follows in figure 4.10.

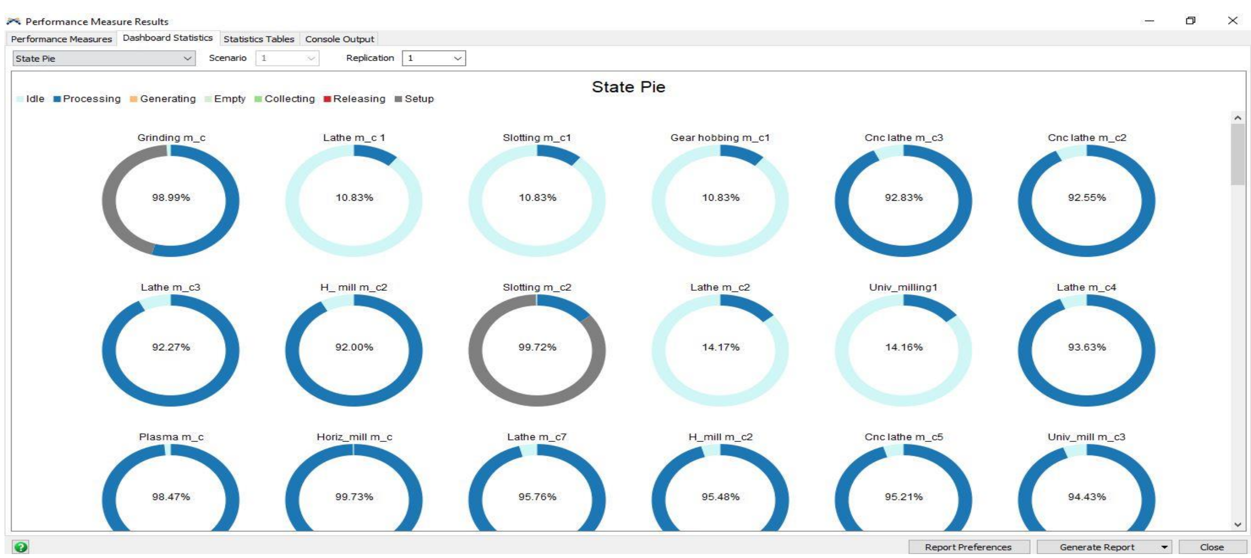
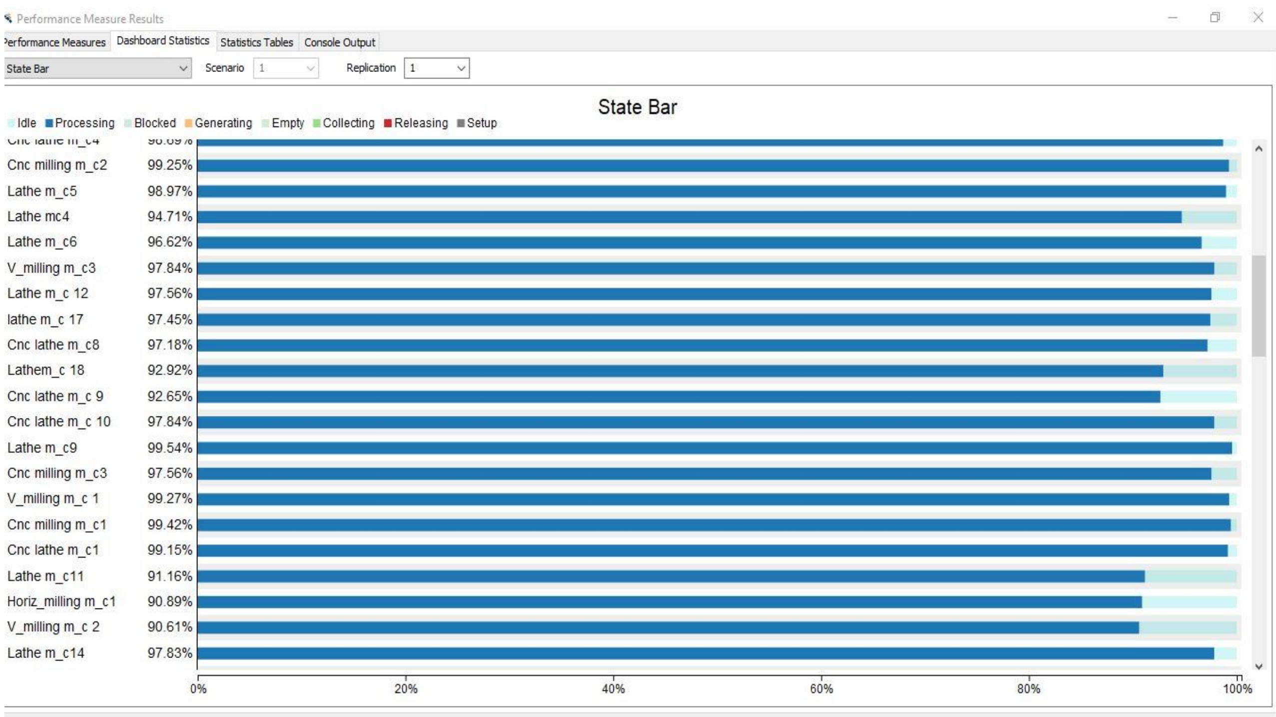


Figure 4. 10 : Machine statistics in FlexSim

In addition to the performance simulation mentioned above figure 4.10, the figure below 4.11 described the proposed layout of each machine's performance. The following table shows the performance and utilization of each machine. The state bar in the graph indicates the performance and utilization of each machine, as recorded in the machine statitics report from the simulation.

Figure 4. 11 : Machine statistics of proposed system in FlexSim



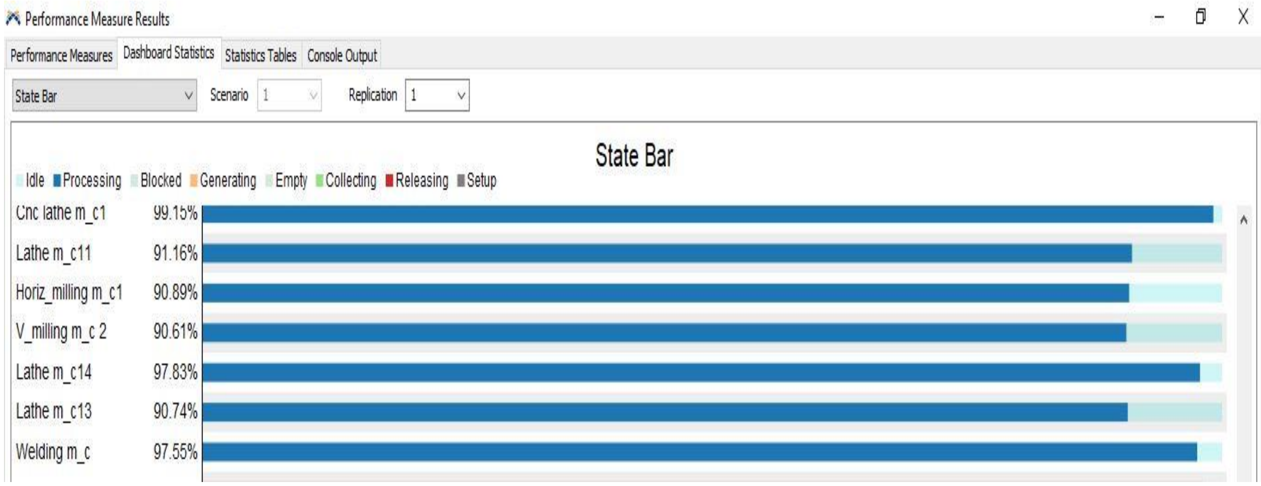


Figure 4. 12:Machine statistics report

Therefore, based on the cluster analysis and FlexSim software, the machine utilization resulted in 88.37%.

Furthermore, as indicated in the previous analysis, the total traveling distance of parts is 1,425 m. The overall performance of the proposed system, according to the analysis and FlexSim performance simulation, is 88.37% .

4.1.8 Comparison of simulation results

The following table 4.13 shows the comparison result of the existing and proposed layout. Based on the analysis done using Craft algorithm and FlexSim simulation the results described.

Existing layout

Figure 4. 13 : FlexSim performance result in existing layout

The total travelling distance of parts in the existing layout is 2,236.10 m. And the existing layout performance is 31.8%.

Proposed layout

Figure 4. 14: proposed layout FlexSim performance

The total travelling distance of parts in the proposed layout is 1,425 m. This minimized distance occurred due to the layout optimized using Craft algorithm. The overall performance is 88.37% according to the analysis executed in the cluster formed by Rank order clustering and simulation using FlexSim. The proposed layout has better performance due to the resulted cluster using Rank order algorithm. The cluster formed 20 cells which grouped parts having similar process in the common cells. This helped to gain efficient cellular layout which minimized the product cycle time of parts with increasing machine utilization and evaluated through grouping efficacy. The performance measured resulted using the grouping efficacy is very high with 91%. This revealed an efficient cell layout was designed. After cell design conducted, the analysis was performed using cell efficiency and machine utilization. Finally, FlexSim software used to evaluate the performance for the cell design and has shown 88.37% in machine utilization.

4.1.9. Comparison between existing system and proposed system – The comparison was made for the existing and proposed layout in terms of travel distance. This expressed in the below table 4.2 indicated the floor space utilization between existing and proposed layout.

Table 4. 2: Comparison between existing and proposed system

Travel distance (parts)	existing system	proposed system
Floor space	2,236.10 m	1,425 m
Consumptions (CRAFT)	671,823.68 birr	170,065.28 birr

Sapnah et al. (2017) expressed Mean Squared Error as the fundamental performance measurement. The three performance metrics proposed were Sum of Squared Error (SSE), Root Mean Squared Error (RMSE) and Mean Squared Error (MSE). Described as the most widely used and effective performance measurement.

Mean error between analytical and simulation was expressed as follows:

Mean error = $\frac{Analytical\ solution - Simulation}{Analytical\ solution} * 100\ \%$ …Equation 4. 1

Mean error = $\frac{35.22 - 31.8}{35.22} * 100 = 9.7$ mean values less than 10 are acceptable in the observed condition in literatures however, not certain evidences were found about the minimum and maximum values of mean error range.

Chapter Five

5.Conclusion and Recommendations

5.1 Conclusions

Manufacturing industries had previously relied on the traditional mass production approach which was difficult to meet customer demand. However, recently, batch and job shop industries have emerged as leaders in meeting market demand by adopting different approaches. As a result, there is a need to reevaluate the current layout and production system of the conventional manufacturing system, as there are challenges in meeting customer demand. To address these challenges and improve performance and resource utilization, the implementation of cellular manufacturing systems is necessary. In this research, the CRAFT algorithm used for analyzing part travel distance in the existing layout and FlexSim simulation software were used to assessed the performance level of both the existing and proposed layout. The analysis reveals that many parts in the existing system travel longer distances in production than expected, resulting the following conclusions are made

- ❖ It was found that many parts which travel in the existing system took a much longer distance in production than expected which has a total part travel distance of 2,236.10 m. From this, gears, shafts, chains, rollers…etc were some of the parts. This resulted in huge waste in the resources and time of the factory, since there is longer back and forth movement of parts in the production process.
- ❖ After the current layout was analyzed, the new layout was designed with the CRAFT algorithm, both evaluated through the machine utilization in FlexSim simulation software and Grouping Efficacy. The proposed layout was much better with the machine utilization with 88.37%, cost reduced calculated was 170,065.28 birr from 671,823.68 birr and floor space utilization of 1,425 m from 2,236.10 m. Therefore, in doing so, there was an improvement in machine utilization of 88.37% which helped to reduced part movement within the factory into 1425m. In addition, wasting resources and time on the factory by transporting the parts over long distances resulted in expensive costs as compared with the proposed layout. Therefore, it is required to design a new layout to overcome this.
- ❖ The designed cellular manufacturing system helps to minimize 35 duplicated machines existing in the conventional factory. The duplicated machines in the current process industry

are reduced, since the cluster formed enhances the remaining 43 machine capacity within each cell. Therefore, machine performance increased.

- ❖ The proposed cellular layout resulted in a reduction of part travel distance from 2,236.10 m to 1:425 m. Existing layout and proposed layout described below.

	The travel distance of parts in the existing layout	
i to j (part travel from machine in CMF)	X(m) (parts travel to machine in CMF)	Rectilinear(m) (Total travel distance of parts)
From (i)	To (j)	
34	76	170.16
1	57	176.92
35	58	57.55
36	67	33.86
60	Heat treatment	94.9
3	Heat treatment	115.89
4	Heat treatment	75.89
37	Heat treatment	81.4
69	Heat treatment	201.95
38	Grinding machine 1	169.01
5	77	186.44
6	6	25.89
7	63	56.8
8	65	54.7
9	68	61.78
11	72	25.89
12	70	90.89
13	73	118.41
39	75	107.22
13	Heat treatment	80.15
14	Heat treatment	83.79
81	Grinding machine 2	166.61
	Sum total (m)	2,236.10 m

Proposed layout distance – travel distance of parts in Cellular layout.

i to j (part travel from machine in CMF)	X(m) (part travel to machine)	Rectilinear(m)

From (i)	To (j)	
34	76	123.64 m
1	57/77	30.79 m
35	58	80.79 m
36	67	83.64 m
60	h.t1	75.89 m
3	h.t 2	90 m
4	h.t 3	90 m
37	h.t 4	34.19 m
69	h.t 5	84.19 m
38	grind 1	55.3 m
5	77	92.19 m
6	6	75.89 m
7	63	35.89 m
8	65	86.19 m
9	68	21 m
11	72	44.59 m
12	70	49.59 m
13	73	44.59 m
39	75	25.89 m
13	h.t 6	73.79 m
14	h.t 7	37.16 m
81	grind.2	90 m
	Sum total	1,425m

❖ It's also the result of the CRAFT algorithm to minimize cost consumption from 671,823.68 birr to 170,065.28 birr when the cost matrix was analyzed based on material flow in the existing and cell layout. Finally, using FlexSim software. The simulation result was compared between the existing and proposed layout. The outcome shows the improvement of machine utilization percentage from 31.8% to 88.37%. The result was analyzed through FlexSim software based on the machine utilization and it shows 31.8% performance for the existing layout. The proposed cellular layout shows 88.37% machine uutilization in FlexSim. This resulted from both cell analysis and the FlexSim simulation.

5.2 Recommendations

Based on the analysis result and conclusions drawn, the recommendations are provided here for CMF as follows.

- ❖ The company has encountered huge waste of resources based on existing system analysis, which shows higher idle time and longer part travel distance. So, it is recommended to use the proposed layout due to the improvements made in reducing the travel distance of parts and better machine utilization. Therefore, it is recommended to rearrange the machines available in the CMF layout as proposed. This could enhance the existing system performance and equipment efficiency.
- ❖ The endeavor to minimize cost includes the reduction of duplicated machines available in the factory. Since the design of cellular systems groups different machines together and engages the overall utilization of machine capacity. Therefore, it is recommended to reduce duplicated machines based on the design and cluster analysis resulting from the proposed layout.
- ❖ Though the improved layout resulted in a better outcome regarding machine utilization and travel distance, it is not the only and optimal layout which is uniquely described. However, it is suggested to rearrange the existing layout with the proposed layout which is improved and better to use.
- ❖ It is recommended to use material handling-system to minimize labor-intensive and long time to transport parts within departments so that carrying over parts between facilities could be less. This saves resources, time and operation activities between shops as well in faster product exit from cells to store.
- ❖ The construction of a new facility layout requires higher costs, so, it is recommended to review the existing layout as compared with the proposed one. So that, it's better to optimize the existing layout by including the proposed layout parameters and rearranging machines based on a cellular arrangement system. Therefore, it will be possible to enhance the performance of the factory.

5.3. Future Research Areas

After conducting the research and analyzing the various layout design, cellular manufacturing design, and performance evaluation, the following research areas are recommended to be included in the future works.

- ✓ There are several computerized algorithms for layout design. From this, Craft layout algorithm was used to develop layout design and Rank order clustering used to ceate cells. These algorithms helped much in this research as other algorithms served to develop other facility designs. Developing facility layouts using Craft algorithm required several iterations to find the better layout also Rank order algorithm takes huge time for larger data so that, it will be useful if other tools such as heuristic techniques used for developing layout. There were other tools addressed in the literature so that, using some of metaheruistc techniques such as Tabu search, Simmulated Annealing are efficient in solving large data with some consideration time. Therefore, by including this algorithms in the future works will reduce the effort to get the desired layout design.
- ✓ In this research, both algorithms and simulations used to evaluate cellular systems. Efficent cell was created and evaluated through Grouping Efficacy. However, include other evaluation methods could also optimized which considered multiple parameters can be used to achieve more efficient layout in future works.

- ✓ The designed cell was analyzed based on the machine utilization percentage of the cells, taking into account grouping efficacy. Therefore, using other performance optimization methods such as Ant-colony optimizations and Hybrid bond algorithms could be used in future works.

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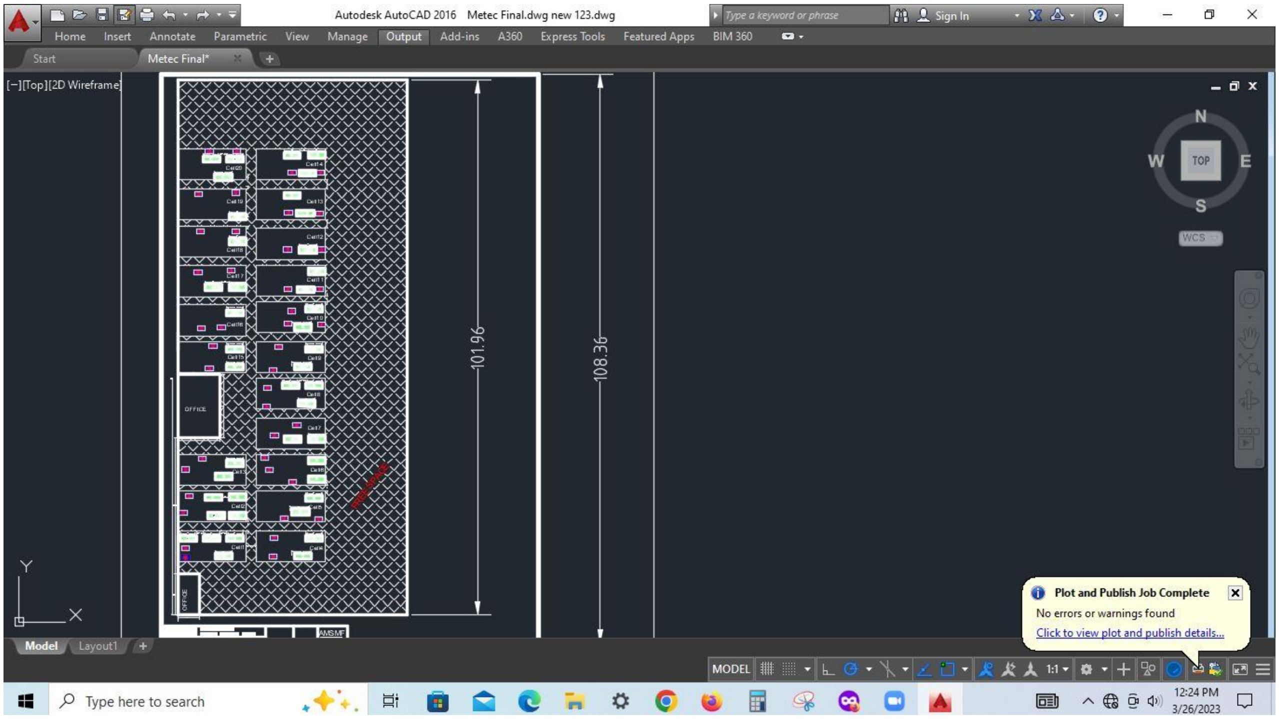
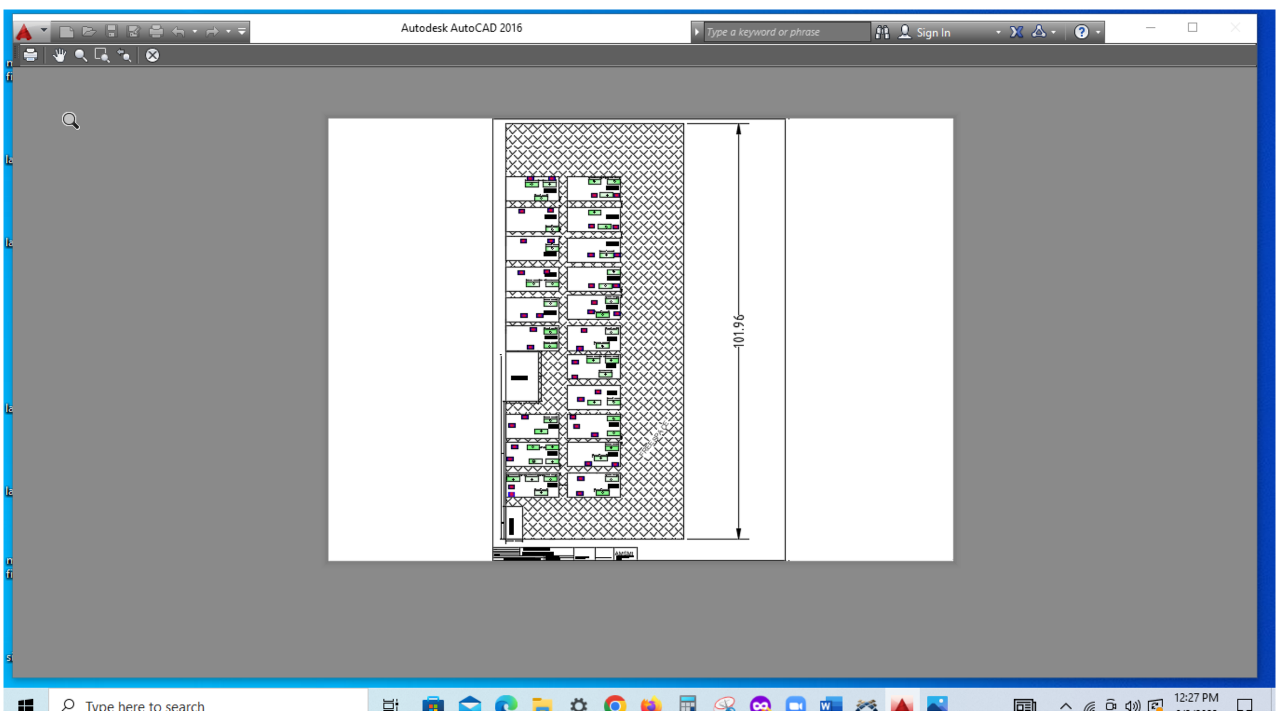
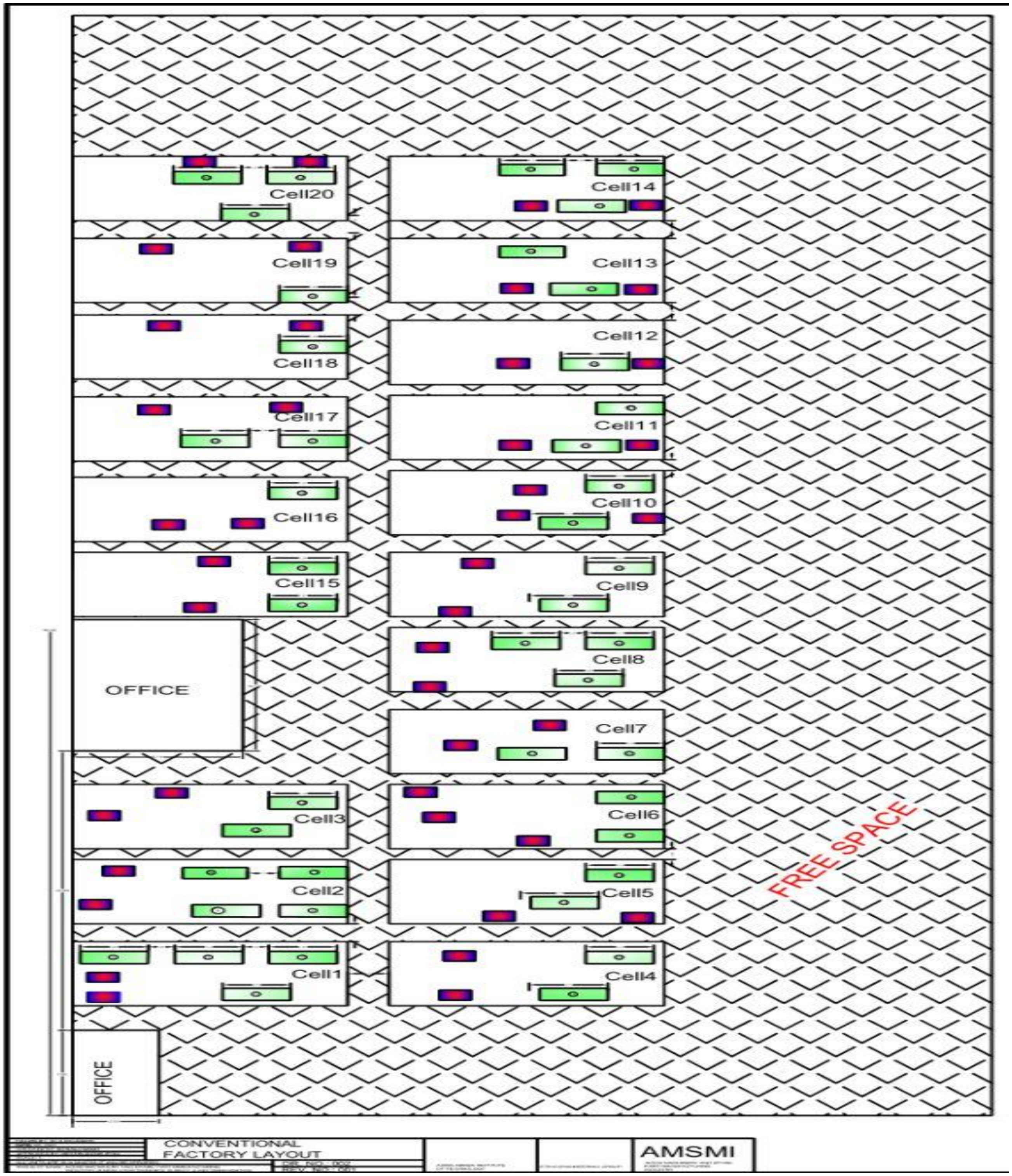
Appendix A: *proposed Cell layout in FlexSim*






Cell20
Cell14
Cell19
Cell13
Cell18
Cell12
Cell17
Cell11
Cell16
Cell10
Cell15
Cell9
OFFICE
Cell8
Cell7
Cell3
Cell6
FREE SPACE
Cell2
Cell5
Cell1
Cell4
OFFICE
CONVENTIONAL
FACTORY LAYOUT
AMSMI

Appendix B: Metec layout