Enhancing Performance of Spare Part Manufacturing Industry through Job-Shop Scheduling System: A Case of Addis Machine and Spare Parts Manufacturing Industry (AMSMI)

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Enhancing Performance of Spare Part Manufacturing Industry through Job-Shop Scheduling System: A Case of Addis Machine and Spare Parts Manufacturing Industry (AMSMI).**" is the result of my own research carried out under the supervision of Dr. Kassu Jilcha (Associate Professor). It has not been presented as a thesis in any other university and all source of material used for this thesis are duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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Abstract

Industries nowadays must be able to quickly adapt with the customer and improve production performance to survive in the competitive edge. This study aims at enhancing performance of spare part manufacturing industry through job shop scheduling by taking Addis Machine and Spare Parts Manufacturing Industry (AMSMI) as a cases study. The study combines scheduling and model simulation as methodological techniques to optimize numerous performance indicators in the production system. The study also identifying critical success factors affecting performance of manufacturing industry and major key production performance indicators, through different literature review. Moreover, brief evaluations of solution techniques for Flexible Job Shop Scheduling Problem (FJSSP) are addressed. Due to poor production schedule attainment, the company (AMSMI) is facing long lead time of products (make span), idleness of machine and high work in process (WIP). To address those problems, detail shop floor assessment and analysis of current scheduling system (First Come-First Serve) and other alternative schedule scenarios (Longest Processing Time and Generic shifting Bottleneck) are conducted using Lekin and Arena simulation software. As the analysis shows, in the current scheduling system makespan, product output, machine utilization and works in process (WIP) are 1100 minutes, 126, 31.44% and 470.01 respectively, whereas in the optimum scheduling model (Generic Shifting Bottleneck Algorithm), makespan, product output, machine utilization and work in process (WIP) are 1043 minutes, 131, 36.06% and 432.08 respectively. So it is concluded as, using the proposed scheduling model (Generic Shifting Bottleneck Algorithm) can increases makespan, machine utilization and product output by 5.1%, 4.6% and 3.8% respectively, and decreased work in process (WIP) by 8%. Therefore, this research implies that combining scheduling and model simulation to use as the performance enhancement approach can optimize several performance indicators simultaneously, in spare part manufacturing industries.

Key words: *Performance, FJSSP, Generic SB Algorithm, makespan, machine utilization, WIP*

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Acronyms

KPI – key Performance Indicators

FJSSP – Flexible Job Shop Scheduling Problem

JSSP – Job Shop Scheduling Problem

FCFS – First Come First Serve

LPT – Longest Processing Time

Generic SB – Generic Shifting Bottleneck

WIP – Work In Process

AMSMI -- Addis Machine Spare part Manufacturing Industry

CMI – Conventional Manufacturing Industry

HMMBI -- Hibret Manufacturing and Machine Building Industry

MIDI – Metal Industry Development Industry

JICA – Japan International Cooperation

ABMI – Akaki Basic Metals Industry

BPR -- Business Process Reengineering

BSC -- Business Score Card

TQM -- Total Quality Management

GDP – Gross Domestic Production

OEE -- Overall Equipment Effectiveness

WIP –Work-in-process

LT –Lead Time

OTIF –On-time-in-full

CPU –Cost per Unit

FL– Fuzzy logic

ANN –Artificial Neural Networks

GLS –Genetic Local Search

PPC –Production Planning and Controlling

AAiT –Addis Ababa Institute of Technology

Chapter One

1. Background and Justification of Research

1.1 Introduction

Nowadays there is a need for business enterprises to measure, analyze and improve performance as they encounter increasing competition from an ever-changing business environment (Bogale, 2016). Furthermore, a number of proposals have been put forward with regard to developing more appropriate performance improvement methods, in order to more effectively cope with the significant competitive issues of increasingly sophisticated customers practices and product differentiation (Tomas, 2011).

In spare part manufacturing where product differentiation is widely perceived, production scheduling, which is a core part of the planning and control of production units, lies at the heart of the performance of manufacturing organizations. This means production scheduling determines organizational performance (Mapokgole & Mbohwa, 2013). Due to this, a need for efficient scheduling has greatly increased in recent decades owing to market demands for flexibility and order flow times.

Performance criteria such as machine utilization, manufacturing lead times, inventory costs, meeting due dates, customer satisfaction, and quality of products are all dependent on how efficiently the jobs are scheduled in the system (Metta, 2008). Hence, it becomes increasingly important to develop effective scheduling approaches that help in achieving the performance objectives. Schedules are assignment problems that specify in time which tasks must be completed and how the factory's resources should be used to carry out the plan. This action should be taken skillfully by a manufacturing organization to control and manage the performance of a production process (Buckner et al., 2015).

Most of the real world job shop manufacturing companies aim at successfully meeting the customer needs while improving the performance efficiency (Tamilarasi & Anantha kumar, 2010). A manufacturing job-shop produces many different items having different routings of operations, usually in small lots. This has a significant impact on shop floor management, and makes it difficult to predict bottleneck sections. As a result, the flow time and the amount of work-in-process are usually large (Moreira, 2010). These features emphasize the need for effective schedule of jobs, in order to estimate, as accurately as possible, deadlines and production costs for the jobs at hand.

Addis Machine and Spare Parts Manufacturing Industry (AMSMI) is government owned metal industry among nine industries ruled under the Ethio-engineering Group. The company is located in Addis Ababa at Lideta Kifle-Ketema around Mexico Square. The company was known by the name "Hibret Manufacturing and Machine Building Industry (HMMBI)". AMSMI produces variety of different metal products like automotive tools and spare part, different logistic products, assembly of machineries and different products by customer orders. The industry is formed through the consolidation of six factories namely Machine Body and Structure Production Factory, Conventional Manufacturing Factory, Precision Manufacturing Factory, Machine Automation Factory, Bolt and Nut Production and Material Treatment and Engineering Factory. Even though, the industry has high capacity of production, current the actual production is running under its capacity.

This study aims at enhancing production performance of Addis Machine and Spare Parts Manufacturing Industry (AMSMI) using Flexible Job Shop Scheduling (FJSS) technique and simulation models. The existing scheduling system and two scenarios of scheduling model are analyzed for production of Conventional Manufacturing Factory (CMF), and proposed the optimal schedule which is Generic Shifting Bottleneck Algorithm. As the final result of this study indicates, shifting the existing (FCFS) scheduling system to the proposed (Generic SB) scheduling system, performance of Makespan, machine utilization and product output are increased by 5.1%, 4.6% and 3.8% respectively, and reduced work in process (WIP) by 8%.

Therefore, this research can be a good implication of study for enhancing performance of spare part manufacturing through job shop scheduling system.

1.2 Justification of Research

The metalworking sector is instrumental to promote the growth of other labor-intensive industries as it carries the potential for indigenous technological progress that enhances performance in related industries. This involves the supply of capital goods, accessories, spare parts, and machining services to the latter (Abebe, 2012). Most importantly, the metalworking sector provides better opportunity for the employment and experimentation of new technologies Thus, in growing economies like Ethiopia, the metalworking sector is critical for the growth and development of other industries.

The study by Lemma (2021) demonstrates the overview performance status of Ethiopian metal industry and other manufacturing sectors. As it is shown in Table 1.1 percentage of performance in Ethiopian metal industry is 68.65, which is the lowest performance among the other's manufacturing sectors due to its low attainable capacity. Therefore, there is a need for detail study on causes and solutions for poor performance of metal manufacturing sector.

Table: 1.1 Ethiopian industry sectors overview (Lemma, 2021)

No	Industry Sector	No. of Factories	Planned Capacity %	Actual Capacity %	Performance %
1	Agro-Processing	687	85.32	69.01	80.88
2	Paint industry	11	75.71	62.31	82.3
3	Textile and Garment	77	80.51	67.13	83.38
4	Leather Industry	141	84.15	59.02	70.14
5	Cement industry	14	87.73	62.13	70.82
6	Chemical Industry	183	79.86	64.03	80.18
7	Food & Beverage	20	70.32	57.01	81.07
8	Metal Industry	243	82.21	56.44	**68.65**

The international comparison of Basic Metal Engineering Industry (BMEI) policy frameworks and the Basic Metal Engineering Industry (BMEI) Firm-level Study revealed that Ethiopia's metal engineering industries have the potential to contribute to import substitution (JICA,

2010). International Standard for Industrial Classification classified metal industry into basic metal and engineering industry (Mulugata, 2018).

- Basic Metal Industries that deal with production of metal from ore, scrap and conversion of billet, slabs etc. into primary metal products such as metal sheet, tubes, bars, wires, cables and nails.
- Metal Engineering Industries convert primary metal products into secondary products such as metallic structures, tanks, and pressure vessels, spare parts and machineries.

Metal industries are considered as the backbone for the growth and industrial revolutions of the nations. Moreover, in the time being the growth of metal engineering industry is the key to the dynamic capability of economic performance and strengths (Dametew et al., 2020). Among metal engineering industries in Ethiopia, spare part manufacturing industries are significant ones in terms of substitute imported machine spare parts and accessories. Hence enhancing performance of spare part manufacturing industries enlarges supply of spare part on the market.

Next to Akaki Basic Metals Industry (ABMI), Addis Machine and Spare Parts Manufacturing Industry (AMSMI) is the second largest manufacturing industry, with high production capacity of spare parts manufacturing, in Ethiopia (MIDI report, 2014 E.C). It produces wide variety of spare parts, low to high-precision metal and fabricated sheet metals. Therefore, Addis Machine and Spare Parts Manufacturing Industry (AMSMI) is taken as a case study to do the research on performance enhancement of spare part manufacturing.

There are seven different performance enhancement methodologies for manufacturing industry. In most cases, which methodology to be chosen depends on why there is a need to enhance and what you are looking to enhance. Various tools are proposed through different studies to enhance the performance of all manufacturing activities stated by (Abduletif et al., 2015) are business process reengineering (BPR), business score card (BSC), benchmarking,

ISO 9001:2000, total quality management (TQM), kaizen, scheduling, line balancing and queue system.

Due to high-variety production and complexity feature of spare part manufacturing, the researcher chooses scheduling system among others tools to enhance performance of manufacturing. As (Velaga, 2016) states, a good production schedule can offer an excellent guideline for managing complex and high-variety production.

Most Spare part manufacturing industries have job shop type of manufacturing in which high variety of spare part with small lot are produced. Job shop manufacturing industries regularly face difficulty with production management due to the following features.

- A variety of small quantity orders (jobs) are received from customers with unpredictable process requirements at unpredictable times
- Jobs may have different quantities, material requirements, precedence relations and target lead times
- An operation may require a single resource or it may simultaneously require multiple resources like machines, workers, etc.
- Setup times and cycle times of any operation may vary with job and it may depend on job sequence

Due to those prominent features, the main challenges and issues tackled to Job shop managers are dealing with customer-imposed lead times and estimating completion times of jobs. As a result, there is a need for effective scheduling system in job shop type of manufacturing like spare part manufacturing industries. Therefore, it is very appropriate to focus on scheduling system to enhance production performance of spare part manufacturing industries.

1.3 Problem Statement

As many studies finding proved, many companies fail to improve their work performances due to lack of knowledge how to improve it. In turn, it results in failure to meet customer requirements in their product on time delivery and products quality (Abduletif et al., 2015).

Currently in Ethiopia, overall performance of basic metal industries, in terms of market share, production capacity, global competitiveness and integrated resource utilizations are lower extent of stages. In addition, the industries' performance and GDP contributions are at infant stages (Dametew et al., 2020). Moreover, systematic studies to understand the factors associated with production performance in metal sector are few (Workneh & Desalegn, 2015).

Even if Addis Machine and Spare Parts Manufacturing Industry (AMSMI) is one of the largest spare part manufacturing industries in our country, the production is running below its installed capacity. The industry has installed production capacity of 425 tons of various spare parts per year but currently it is utilizing approximately 53% of its capacity (Company Report, 2014 E.C). The actual production and performance trends are below the expected installed capacity. Often, capacity disturbances cause real problems regarding the performance of production units. In other way, low capacity utilization in the factory can be an indication for poor performance of production (Kuuse, 2021).

Among the total spare part orders received by the company, 75-80% of the products are performed at Conventional Manufacturing Factory (CMF) (Company Profile). Due to poor production schedule attainment in this factory, long lead time of products (make span), idleness of machine and high work in process (WIP) are clearly observed at the shop floor. Those result in missing delivery deadline of customer orders and poor production performance of the company.

1.4 Research Questions

Based on the stated problems, this study addresses the following research questions:

- What are the critical successes factors affecting performance of manufacturing industry?
- What are the major indicators that measure the performance of Addis Machine and Spare Part Manufacturing Industry?

- What is the existing production performance of Addis Machine and Spare Part Manufacturing Industry?
- How to enhance the performance of the production system in Addis Machine and Spare Part Manufacturing Industry?

1.5 Objective of the Study

1.5.1 General Objective:

The general objective of this study is to enhancing performance of Addis Machine and Spare Parts Manufacturing Industry (AMSMI) through Job-Shop scheduling system.

1.5.2 Specific Objectives:

- To identify the critical success factors affecting performance of manufacturing industry.
- To identify the indicators that measures the performance of Addis Machine and Spare Part Manufacturing Industry.
- To assess the existing production performance of Addis Machine and Spare Part Manufacturing Industry.
- To propose performance enhancement methods and solutions for Addis Machine and Spare Part Manufacturing Industry.

1.6 Scope of the Study

Addis Machine and Spare Parts Manufacturing Industry (AMSMI) were formed through the consolidation of six factories namely: Machine Building Factory, Material Treatment and Engineering Factory, Precision Manufacturing Factory, Machine Body and Structure Production Factory, Conventional Manufacturing Factory and Bolts and nuts Production Factory. But since this study focus on production system in Conventional Manufacturing Factory. Production in the remaining factories is not addressed in this research. In addition, the study is bound on performance enhancement through scheduling system.

1.7 Significance of the Study

The significance of this research goes to Addis Machine and Spare Parts Manufacturing Industry (AMSMI). The study gives directional framework to enhance production performance through examining scheduling problem. Likewise, the study can explore solution to the dissatisfaction of customer due to long lead time of products. In addition, the proposed technique of performance enhancement brings concrete changes in other spare part manufacturing industries. Moreover, the research discoveries can be used as an input for academicians, research scholars, and any interested party.

1.8 Organization of the Study

The study is organized in six chapters. The first chapter is about Background and Justification of Research which contain introduction, justification of research, problem statement, objective, significance and scope of the study.

The second chapter deals with related Literature Review. Different relevant books, internet websites, senior research work, articles and journal related to the study title were conducted.

Chapter three presents Research Design and Methodology. Methodologies to accomplish the objective of the thesis and overall research framework are present in this chapter.

The fourth chapter presents Data Presentation and Analysis. It contains data collection from primary and secondary data, problem formulation, performance analysis, proposed model and result discussion are present in this chapter.

Finally, Conclusions and Recommendations are covered in the last section which is chapter five.

1.9 Limitation of the Study

The researcher was limited to select the peak advanced production scheduling software for data analysis. It is due to the restricted accessibility of the required software. However, the researcher selected the suitable scheduling software among the accessible software by analyzing the features of scheduling problem in the case study.

Chapter Two

2. Literature Review

2.1 Introduction

In this section different literature review on manufacturing performance, factors affecting manufacturing performance, performance measures/indicators, performance enhancement models/tools, Job-Shop scheduling problem (JSSP) and solution techniques of Job-Shop Scheduling Problem (JSSP) have been presented from different views of researchers. Finally, overall concept of literatures, different case studies and the gaps of literature study are presented in summary.

2.2 Manufacturing Performance

Continuous increase in firm performance is now every company's goal. This is due to the fact that businesses may only experience development and advancement through performance. Because businesses are continually looking for effective and efficient results, evaluating and analyzing business performance is crucial (Ali, 2022). Moreover, continuous performance is the objective of any organization because only through performance, are organizations able to grow and progress. As many scholars often agree, concept of performance is uncertain but it is a function of time and organizational context (kariithi, 2017).

Many experts define performance in different ways. Performance is the ability to meet certain criteria's, the time it takes, and the path used to get there and, it is also about how successful a business is in generating and sustaining value (Memon & Tahir, 2012). According to Fauzi et al., (2010), performance is the organization's ability to attain its goals by using resources in an efficient and effective manner. Seifu (2007) states the performance of the operations has to be improved continually in all aspects, and it is driven by the hunt of increasing productivity, flexibility and continuously changing competitive environment. Zineb et.al. (2019) describe performance associated with three fundamental dimensions: effectiveness, efficiency and relevance. And it is explained as the ability of a company to achieve the desired objectives by

using fewer resources and the adequacy between the desired objectives and the means used to achieve them.

Company performance should be judged against a specific objective to see whether the objective is achieved. Without an objective, the company has no criterion for choosing among alternative investment strategies and projects (Tapanya, 2004). According to Barnes (2008), operations performance objectives in the organization are speed, quality, cost, dependability and flexibility. However, it is doubtful that an organization can excel simultaneously at all of the five operations performance objectives. They should choose which performance objectives need priority. This may result in having to 'trade-off' less than excellent performance in one aspect of operations in order to achieve excellence in another. The operations performance objectives and their competitive relation are listed in Table 2.1.

Table: 2.1 Performance objectives vs. their competitive ability (Barnes, 2008)

Performance Objective	Competitive Ability
Cost	Low price
Quality	High quality
Speed	Fast delivery
Dependability	Reliable delivery
Flexibility	Frequent new products/services Wide range of products/services Changing the volume of product/service deliveries Changing the timing of product/service deliveries

In conclusion, due to the dynamic nature of manufacturing environment, the performance of organizations is changed radically. Moreover, there are different performance objectives in the organization like speed, quality, cost, dependability and flexibility. However, it is unconfident that an organization can achieve simultaneously at all operations performance objectives. For this reason, an organization should pick a specific performance objective to understand what things that is expected with the performance. Therefore, since this study is about performance enhancement through scheduling, the picked objectives by the researcher among the other performance objectives are speed and dependability, which are related with each other. Excellent operations performance in time, indicates how quickly a delivery can be made after

an order is received; while the complementary characteristic of accuracy deals with delivering goods and services to the agreed schedule.

2.3 Factors affecting manufacturing performance

The factors influencing organizational performance are often interrelated or complementary in their impact, and they reflect the fact that effective organizational performance needs a systems approach to solving performance related problems or creating effective measures for the performance of the organization. Organizational performance is influenced greatly by the systems which support it. Key components to consider for this factor include raw materials, equipment, procedures, work instructions, work environment, power, information technology and communication systems (Satyendra, 2020).

According to Muhesin & Salih (2020) statement, organizational performance is affected by several factors that varies and differs with jobs. It is difficult to contain all these factors since all internal and external phenomena will affect the performance. Hence, the most important factors affecting the performance are human resource, work nature and technical issues. In other way Bunteng (2022) state organizational performance as it is the result of many business factors, such as work processes, team / group relationships, business culture, policy image, leadership, and climate which drive innovation. Cera & Kusaku (2020) also pointed out the first inflicting factors for performance that should be taken into consideration is that the evaluation of performance and career opportunities is significantly affected by the characteristics of the local work environment and its constituting elements, including organizational culture, skills knowledge, flexibility and managerial practices.

To support performance enhancement in the organization, it is vital to find performance factors that support the performance strategy set by the organization. Tangen (2004) presents an extensive set of performance factors from a litterateur survey and categorizes them under process, product, resources and control. Type of factors affecting performance and categories according to their relation are listed in Figure 2.1.

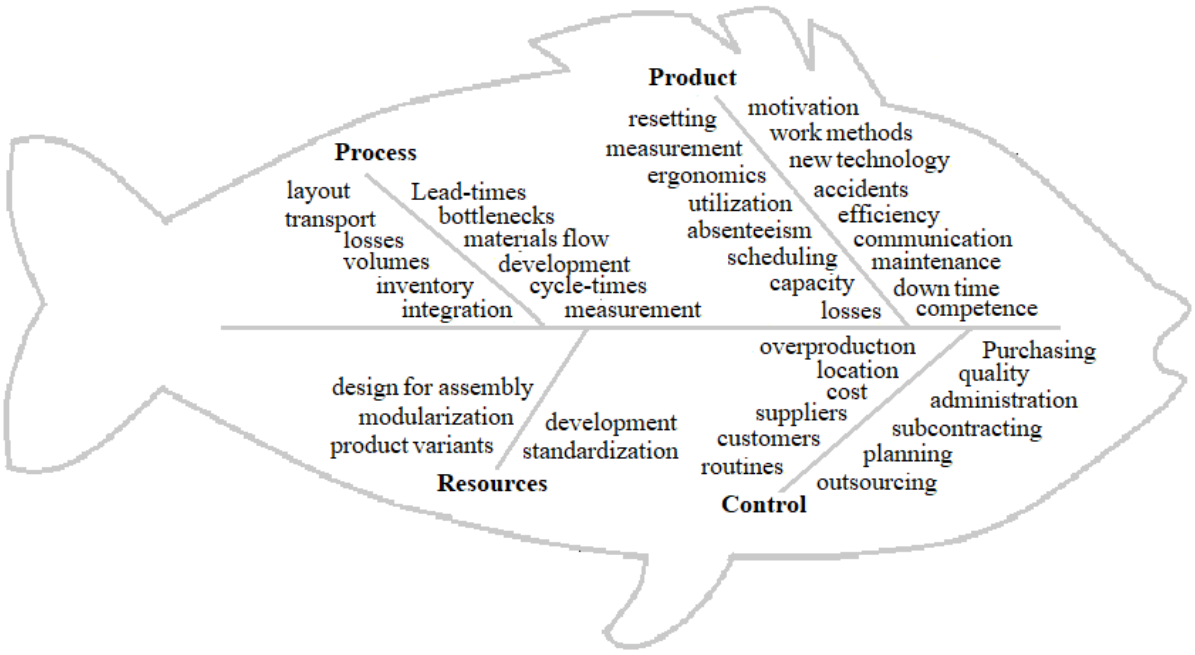


Figure: 2.1 Performance factors (Tangen, 2004) (Modified)

Performance enhancement become very critical efforts in manufacturing sector due to there are different factors affecting manufacturing performance. Many studies state so many causes or factors affecting performance of organization, which can be categorized under process, product, resources and control aspects. Moreover, the factors may differ from one organization to the other organization but they are interconnected or paired in their impact on the organization. Therefore, an organization should build its own systematic and actual measures for organization performance.

2.4 Manufacturing performance measures/indicators

In today's competitive, dynamic, and unpredictable business environments, it is necessary to measure and improve manufacturing performance to be able to compete in the market and satisfy the need for meeting dynamic customers' demands for a variety of products, fast and reliable delivery (Tesfaye & Girma, 2020). Due to the dynamic nature of manufacturing industries and environment, the performance of organizations is changed drastically. Hence,

performance should be measured continuously through critical address on what to measure, how to measure and when to implement in the organization (Wube et al., 2017). Moreover, measuring the performance of an organization should be ensures that strategic activities are aligned to the strategic plan (Schwandt, 2009).

All high-performance organizations, whether public or private, are, and must be, interested in developing and deploying effective performance measurement and performance management systems, since it is only through such systems that they can remain high-performance organizations (Will Artley, 2001). The performance measurement system plays a very important role due to its major functions that are beneficial to companies. It encompasses a set of measures that enable managers to control processes and to make decisions in order to improve business performance and achieve organizational excellence (Zineb et.al., 2019).

Measuring the performance of a system can provide exact answers regarding the performance of the system. The system in question is observed directly no details are abstracted away, and no simplifying assumptions need to be made regarding the behavior of the system (Seifu, 2007). Hence, performance measures or indicators should be used as a tool to understand, manage, measure and improve what our organizations do. This framework should contain consistent set of key performance indicators or measures (Tomas, 2011).

The manufacturing sector thrives on implementing efficiency initiatives through measuring and improving Key Performance Indicators (KPIs) (Yang et al., 2021). Key performance indicators (KPIs) are quantifiable measures of performance over time for a specific objective and should be the indicators of advanced, forward-looking, and immediate responses (Yu-Tien Cheng, 2011). In other way Heini et al. (2007) describe performance indicator as a variable that expresses quantitatively the effectiveness or efficiency or both, of a part of or a whole process, or system, against a given norm or target and objectives. Besides, key performance indicators are distinguished in their performance measurement matrix between indicators that measure internal aspects, and those that measure external aspects of the organization, as shown in Table 2.2.

Table: 2.2 The performance measurement matrix (Heini et al., 2007)

	Non-cost	Cost
External	Numbers of repeat buyers Numbers of customer complaints Market share	Competitive cost position Relative R&D expenditure
Internal	Design cycle time Percent on-time delivery Numbers of new products	Design cost Material cost Manufacturing cost

In another view, Kuuse (2021) states ten (10) most important manufacturing performance indicators (KPIs), which are summarized in Table 2.3. He also states that good manufacturing performance indicators should be quantifiable, measurable, attainable, actionable and reflect strategic goals.

Table: 2.3 Key performance indicators (KPIs) (Kuuse, 2021) Modified

S.N	Key Performance Indicator (KPI)		Formula
1	Overall Equipment Effectiveness (OEE)	Measures the percentage of time that a machine or production line produces good quality articles during the scheduled time.	OEE = Availability x Performance x Quality
2	Work-in-process (WIP)	Measures the value of raw materials or subassemblies that have entered the manufacturing process, before obtaining the finished good.	WIP = Manufacturing Lead Time x Production Flow Value
3	Lead Time (LT)	Measures how well your company processes orders and how quickly customer needs are fulfilled. Also called order cycle time.	LT = Order Delivery Date – Order Request Date
4	On-time-in-full (OTIF)	Measures the number of orders which had been delivered with the right quality and the right quantity on time to the customer.	OTIF = Number of perfect orders / Total number of orders
5	Cost per Unit (CPU)	Measure the company's cost to create or produce one product unit and plays an integral part in the organization's work.	CPU = (Direct Material Costs + Direct Labor Costs + Manufacturing Overhead) / Total units produced

6	Production Downtime	Measures off-line period when no products are produced and the manufacturing process is paused for some reason.	Production Downtime = Idle time/Planned operating time
7	Inventory Turnover Ratio	Measure of how many times your average inventory is "turned" or sold in a certain period of time.	Inventory Turnover Ratio = Cost of goods sold / Avg. Inventory
8	Production Schedule Attainment	Measures the accuracy of production schedules to produce a certain amount of output according to the plan.	Production Schedule Attainment = Completed planned work / Planned work
9	Defect Rate	Measures how many units of production are defective, or unusable, out of a specific number of units.	Defect Rate = Number of Defects / Units Produced x 100
10	Capacity Utilization Rate	Measures the percentage of an organization's potential output that is actually being realized.	Capacity Utilization Rate = (Actual Output / Potential Output) x 100

In this study, lead time, production schedule attainment and (work in process) are taken as performance indicators of the case company since they are the main competitive factors among job-shop manufacturing industry. Those indicators provide leaders insights into how they are performing as planned schedule and delivery date.

Production Schedule Attainment reflects how well production is planned and how efficiently the production workers meet their targets. It is also an ability of a production to execute a plan: match the schedule of production or delivery to gradually produce certain amount of output according to a contracted plan, and to meet expectancies of the customers and corporate strategy (Kuuse, 2021). In a big number of successful business organizations a rate of schedule attainment, being one of the primal business objectives and success measures, is continually controlled and improved through a complex of specific approaches (Lauzier, 2022).

Lead time is one of the main competitive factors among companies. It begins with the first receipt of a customer order and ends with customer receipt of the product or service. Ability of quick delivery influences export, sales and thereby revenue. If duration between the ordering period and the delivery varies from the expected time, lead time variability will occur (Utama, 2017). Hence, lead time variability will make the schedule attainment challenging.

When the concept of manufacturing performance measures is wrapped up, acting a constant performance indicator can be tough as the performance of organizations is changed drastically. Hence, performance should be measured continuously through critical address on what to measure, how to measure and when to implement in the organization. Likewise, performance objective for the organization should be aligned with performance measures or indicators.

2.5 Performance enhancement models/tools

Manufacturing firms nowadays are more focusing on enhancing production performance in terms of capacity utilization to survive in the competitive market. This can be achieved through the application of appropriate performance enhancement methods and tools. (Mulugeta, 2020). Performance enhancement is methodology to find the root causes of a performance problem and make improvements. Moreover, performance analysis is one of the promising tools employed for assessing performance and then taking the necessary measures for improvements of existing performance deficiencies (Grunberg, 2004).

A number of performance improvement methods in manufacturing view have been stated by Grünberg (2007) from the areas of logistics, quality, production engineering and system behavior, as shown in Table 2.4.

Table: 2.4 Performance improvement methods and addressing area (Grünberg, 2007)

Addressing area	Performance improvement methods
Logistics	Just In Time (JIT)
	Supply Chain Management (SCM)
	Theory Of Constraints (TOC)
Quality	Total Quality Management (TQM)
	Business Process Improvement (BPI)
	Six Sigma Production engineering
Production Engineering	Total Production Maintenance (TPM)
	Lean Production
	Demand Flow Technology (DFT)
	Read a plant fast
	Simulation

	Process mapping
	Single Minute Change of Die (SMED)
	Five S Other
System behavior	Decision Support
	Continuous improvement

According to Abduletif et al. (2015) most common and major performance enhancement tools for manufacturing or service; are business process reengineering (BPR), business score card (BSC), benchmarking, ISO 9001:2000, total quality management (TQM), kaizen, scheduling, line balancing and queue system. Before selecting particular performance improvement tool, enterprises need to be clear in the aim to improve and expected outcomes and types of improvements required. Comparison of performance improvement tools is shown in Table 2.5.

Table: 2.5 Performance improvement tools comparison (Abduletif et al., 2015)

Tools	**Scope**	**Main improvements**	**Time in months**	**Resources**
BPR	Process & people	Process	6-12	high investment
BSC	Holistic model	Cascading	4-6	Low investment
ISO 9000:2000	Processes and documentation	Process control	6-9	Assessment cost
TQM	Processes and products	Continuity	24-36	Consultant costs
Kaizen	Processes or functions	Attitude	24-36	Consultant costs
Scheduling	Processes and people	Make span	24-36	Scheduler costs
Line balancing	Processes and facilities	Flow	36-60	Consultant costs
Queue model	Processes, system and people	Service	48-60	Technology costs

A Performance enhancement program in the organizations is implemented through using different performance enhancement tools, which has to aims to connect the organizational goals with the performance objectives. These help to increase the impact of any enhancement initiative (Tomas, 2011). In this study, scheduling system is chosen as performance enhancement method due to the agreed opening objective and simulation since production engineering is the addressing area in the study.

Scheduling is an important problem that appears mainly in manufacturing industries. It is well known that good schedules contribute greatly to the overall performance of a company (Bahman & Ruben, 2014). Scheduling refers to the process of allocating available production resources to complete a certain set of tasks in a given time period while satisfying company's objectives. It can also decide the work flow, machine utilization and the machine layout (Abduletif et al., 2015). Hence, it has been decided to improve the performance of the model factory using relevant scheduling techniques with time parameter.

There is an opportunity to enhance the production performance in make-to-order manufacturing without capacity expansion if the workload is efficiently scheduled (Buchmeister et al., 2021). In production line system at several industrial environments, Job Shop Scheduling (JSS) is an important activity to enhance the performance. The growing complexities of operations and product-mix have increased the problem complexity of the Job Shop. Over the last decade, research in scheduling has observed a steady increase in importance of machine allocation and jobs scheduling sequence (Luchoomun et al., 2014). Nowadays in most manufacturing, different analytical and graphical techniques for job shop scheduling problems has received considerable attention to enhance manufacturing performance (Lemma, 2021). There are different techniques for job shop scheduling problems (JSSPs), stated in Section 2.7.

Even if there are several performance enhancement methods described through different studies, the choice of methods for implementation is determined by the objective area in which the organization needs to address. The areas are around logistics, quality, production engineering and system behavior of manufacturing. However, before to start finding techniques for performance enhancement, there should be careful measurement of performance and identification of factors affecting performance of manufacturing.

For this study, simulation is chosen for performance improvement methods since the researcher needs to address the area of production engineering. In addition, due to complexities of operations and product-mix in job shop manufacturing, scheduling system is the chosen as crucial method for performance enhancement.

2.6 Job-Shop Scheduling Problem (JSSP)

Job shop scheduling problem (JSSP) is a classical operation research problem or combinational optimization problem that involves a finite set of jobs to be processed on a finite set of machines. Each job comprises a set of operations that must be performed on one machine within a certain set of capable machines with various constraints and costs, in a given job-dependent order (Yang et al., 2021).

JSSP is among the worst class of NP-hard problems. Because of its large solution space, it is considered to be comparatively one of the hardest problems to solve. However, there is still a lot of room for improvement in the existing techniques. "If there are n jobs and m machines the number of theoretically possible solutions is equal to $(n!)^m$". Among these solutions, the optimal solution for a certain measure of performance can be found after checking all the possible alternatives. But the checking of all the possible alternatives can only be possible in small size problems (JSS, 2007).

The aim of the problem is to find the optimum schedule for allocating shared resources over time to competing activities, in which multiple jobs are processed on several machines. In the given n jobs, where each must be processed by m machines over the course of multiple processes, each operation uses one of the m machines for a set of time period. Each machine can only handle one operation at a time, and once processing starts on a particular machine, it has to continue until it is finished. The processes of a job assigned must be finished in a particular sequence (Magalhães-mendes, 2009). Therefore, the challenge is coming up with a schedule for the machine operations while taking precedence constraints into account.

2.6.1 Performance Evaluation Criterion on Job Shop Scheduling Problem

As Abdolrazzagh-Nezhad & Abdullah, (2017), Anand & Panneerselvam, (2015), Oyetunji, (2009), state, several performance evaluation criterions on job shop scheduling problem that most researches are based are Makespan (Cmax), Total flow time (∑Ci), Maximum tardiness (Tmax), Total tardiness (∑Ti), Total number of tardy (late) jobs, Utilization of machines and Utilization of workers.

2.6.2 Constraints for the Job Shop Scheduling Problem

Constraints for the job shop scheduling problem are the number of operations for each job is finite, the processing time for each operation in a particular machine is defined, there is a pre-defined sequence of operations that has to be maintained to complete each job, a machine can process only one job at a time, each job visits each machine only once and the system cannot be interrupted until each operation of each job is finished.(Chaudhry & Khan, 2016) (Chakraborty & Bhowmik, 2015) (Hasan, 2009)

2.6.3 Classification of Job-Shop Scheduling Problem (JSSP)

Although JSSPs have overlapping characteristics, they can be classified with respect to several facets. The job arrival process, the inventory policy, duration time processing and job attributes are the most widely used among those facets. Based the study by (Abdolrazzagh-Nezhad & Abdullah, 2017), there are fourteen (14) classification of Job-Shop Scheduling Problem (JSSP), shown in Figure 2.2.

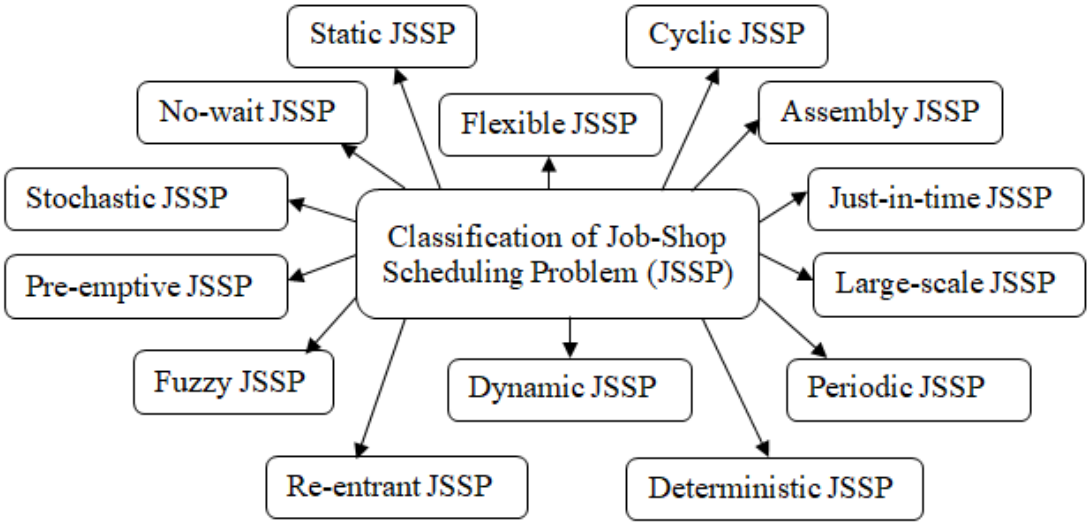


Figure: 2.2: Fourteen classes of JSSP (Abdolrazzagh-Nezhad & Abdullah, 2017)

Since, production environment of the case company in this research is flexible job shop manufacturing, the scheduling problem is categorized under flexible job shop scheduling problem.

Among categories of job shop scheduling problems, flexible job shop scheduling problems (FJSSPs) are one of the most significant problems in up-to-date manufacturing systems (Alabajee & Fadhil, 2020). It is a NP-hard combinatorial optimization problem, and is considered difficult to solve due to their NP-hard nature (Xie et al., 2019).

A flexible job shop problem (FJSSP) is an extension of the classical JSS problem that allows an operation to be processed by any machine from a given set of alternative machines (Chaudhry & Khan, 2016). Besides, it will be providing approximations related to real-world scheduling situations, yet combination regarding routing as well as sequencing problems presenting more complexity in comparison to classical JSP (Campo et al., 2022).

2.7 Solution techniques for Job-Shop Scheduling Problem (JSSP)

A number of solution techniques to handle the JSSP have been developed over the years through different studies. There are two groups of techniques, which are able to solve job shop scheduling problem (JSSP), known as exact (optimization) approaches and approximate approaches (Buchmeister et al., 2021). A complete classification is shown in Figure 2.3.

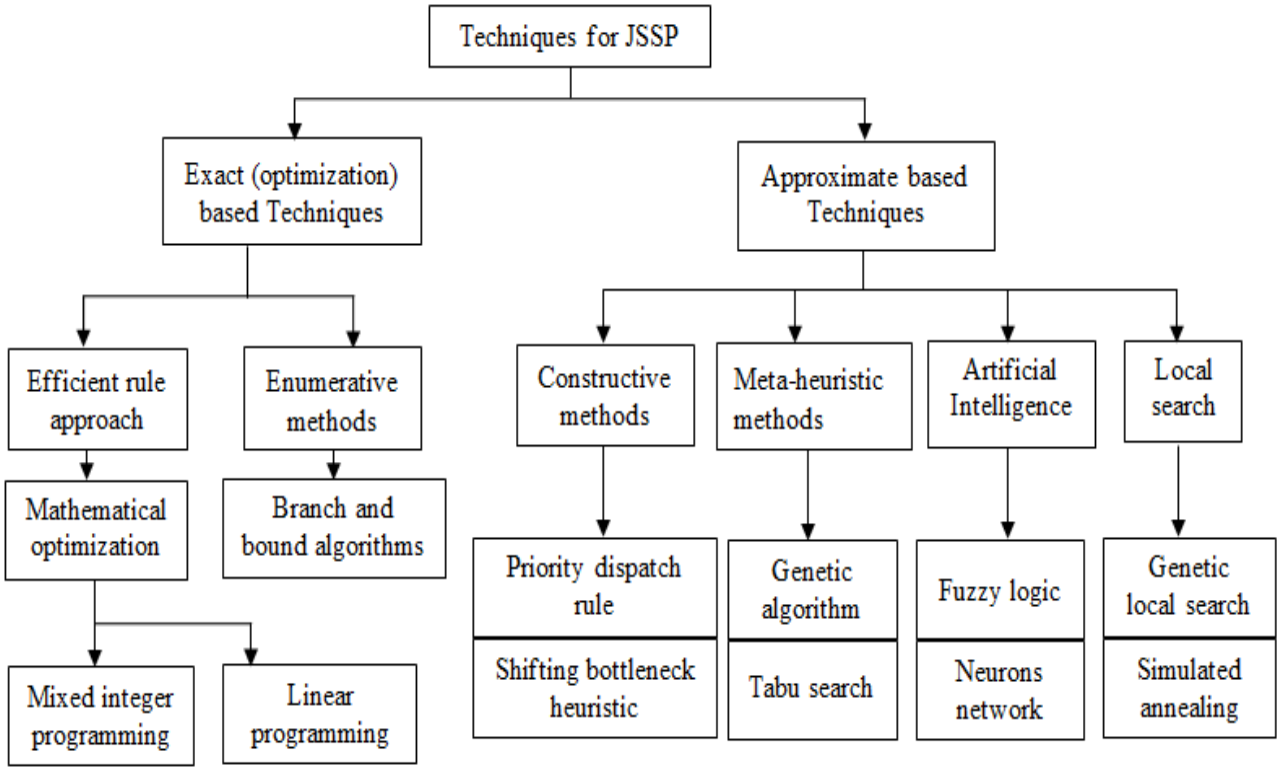


Figure: 2.3: Solution approaches to JSSP (Buchmeister et al., 2021)

2.7.1 Exact (Optimization) Based Techniques

Exact (optimization) techniques are based on mathematical optimization that includes either mixed or linear integer programming. The techniques are used for simple and small size of scheduling problems. Comparing to approximate techniques, they do much guarantee for the optimal solutions (Kharroubi, 2016).

Random Search Algorithms for Solving the Routing and Wavelength Assignment in WDM Networks

2.7.1.1 Efficient rule-based approach

Effective rule-based procedures were the first ones used in the scheduling field. A number of fundamental rules that exactly specify the processing order and result in an exact optimal outcome can be developed using the input data. Every problem is distinct and can be resolved

in polynomial time using efficient rule-based methods (Zhang et al., 2019). Mathematical optimization is an efficient rule-based approach, which is a field of applied mathematics that allows optimal decision from set of alternatives using linear and mixed integer programming. One of the most common applications of mathematical programing is solving various planning and scheduling problems (Tompkins, 2003).

2.7.1.2 Enumerative methods

Enumeration methods in scheduling are used to solve combinatorial optimization problems where decision variables are binary, expressing that a solution is chosen or not. This leads to a lot of possible solutions with the difficulty of selecting and finding solutions that are more optimal than others (Enumerative methods). Under enumeration methods branch and bound (BB) Algorithm is a general purpose approach to implicitly enumerate the feasible region. It works based on a few simple principles to avoid enumerating every solution point explicitly (Kianfar, 2011). Branch-and bound (B&B) method is an effective method to solve the scheduling problem with a better solution because it can calculate the lower bound of the some subsets. In can obtain the optimal solution for more complex problems. However because of its complexity, it is difficult to have real practical applications. Moreover, for larger scale problems, it takes too much time and cannot complete calculations in a good responding time (J. Zhang et al., 2019).

2.7.2 Approximate Based Techniques

Approximation based approaches offer a good alternative for solving the JSSP in terms of the quality of solution and computational time. However, these techniques do not promise optimality, but still solutions are feasible and near to optimum. Another main advantage of these techniques is simplicity when implemented in practice. These techniques are based on more sophisticated heuristics algorithms that can be applied to more complex and larger problems (Kumar, 2017).

2.7.2.1 Constructive methods

Construction type algorithms are considered as the fast and simplest heuristic approach, but the quality of the solution found did not provide satisfactory results (Nordin & Lee, 2016). They include two usual methods: priority dispatch rule and shifting bottleneck heuristic.

Priority rules are also named as dispatching rules, scheduling rules, and heuristic rules. The idea of these rules is to apply them suitably in the construction phase of the schedules. The rules are often used to select suitable operation to be scheduled. According to (Hasan, 2009), based on factors such as processing time, due date, setup time, and arrival time, the rules can be classified into groups namely Shortest processing time, Longest processing time, Shortest remaining processing time, Longest remaining processing time, First come first serve, Smallest number of remaining operations, Longest number of remaining operations and Random rules.

Shifting bottleneck heuristic in classical JSSPs, the machine that takes the longest processing time to complete a set of jobs, is usually considered as the bottleneck machine. However, depending on the objectives of the scheduling problems, the definition might differ. This method detects the machine that is causing the bottleneck and does the appropriate swaps or reordering to enhance the quality of the solution (Hasan, 2009).

2.7.2.2 Meta-heuristic methods

The Genetic Algorithm is a Meta heuristic technique, which can be used to address maximization optimization problem. The genetic algorithm is based on how natural populations change through time in accordance with the survival of the fittest concept of natural selection. It starts with initial solution called Populations and it is filled with chromosome. Each chromosomal element is called gene. Job is represented by each gene in chromosome and the job sequence in a schedule based on the position of the gene (Kumar & Babu, 2014).

Tabu Search is a commonly used meta-heuristic for optimizing model parameters. The basic idea of Tabu Search is to punish moves that take the solution into formerly visited search spaces (also known as tabu). Tabu Search is often regarded as integrating memory structures

into local search strategies. However, does deterministically accept non-improving solutions in order to prevent getting stuck in local minimums (Liang, 2020). The Tabu Search brings in flexible storage structure and corresponding taboo standard to avoid indirect search and clear some tabooed excellent condition by freezing off standard taboo and then guarantee diverse search to fulfill overall optimization. Though, the search performance of the Tabu search algorithm totally depends on the neighborhood structure and initial solution (Mohan et al., 2019).

2.7.2.3 Artificial intelligence

Fuzzy logic (FL) and Neural Networks (ANN) is a new approach to job scheduling developed to achieve a near optimal schedule in small scale establishments. FL is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. During the past several years, FL and its application to control problems have emerged as one of the most prosperous areas for research in the application of fuzzy set theory (Odii et al., 2016).

Artificial Neural Networks are an information processing technique based on the way biological nervous systems, such as the brain, process information. The fundamental concept of ANNs is the structure of the information processing system. Composed of a large number of highly interconnected processing units (‘‘neurons’’) connected into networks, a neural network system uses the human-like technique of learning by example to resolve problems (Metaxiotis & Psarras, 2003).

2.7.2.4 Local search

Local search are very close to optimal solutions and it incorporates neighborhood search into genetic algorism. The result of such incorporation is often called Genetic Local Search (GLS) (Yamada & Nakano, 2005). The other extension of local optimization technique is simulated annealing, which refers to the technique of simulation of the physical annealing process in conjunction with an annealing schedule of temperature decrease (Gallo & Capozzi, 2019).

In order to have a clear insight about Flexible Job-shop environment and various techniques of solving the problems, a detailed review of twenty (20) research papers including their functional objective, methodology, technique and findings have been presented in APPENDIX-II. Various techniques ranging from exact (optimization) to approximate approach have been proposed.

In general, looking at literatures that have been written so far, massive issues associated with flexible job shop scheduling problem (FJSSP) have been addressed by many scholars. Yet, it still proves to be an attracting and blooming area of research. FJSSPs are considered difficult to solve due to their NP-hard nature. At different eras, many researchers have tried to develop efficient solution techniques/methods to solve FJSSP and the methods become more efficient and powerful from time to time.

Based on the revised theories and research papers on solution techniques for flexible job-shop scheduling problem, strength and weakness of different methods are compared and contrast as shown in Table 2.6.

Table: 2.6 Comparison of solution techniques for Job-Shop Scheduling Problem (JSSP)

Techniques for JSSP		Strength	Weakness
Exact based Techniques	Mathematical programming and branch and bound algorithms	Achieve the exact optimal solution in polynomial time	Only small-scale problems can be resolved
Approximate based Techniques	Constructive Methods	Consume short time to solve FJSSP	Infeasible solutions may be generated
	Meta-heuristic Methods	More sophisticated approaches to balance good efficient results with time consuming	Some are easy to fall into local optimum
	Artificial intelligence Methods	Deal with random job arrivals and machine breakdowns	Dissatisfied training approximation and generalization
	Local Search Methods	Optimum solution can be achieved if enough time is given	Need too much time

Among the different solution techniques for FJSSP, approximate based techniques have been more efficient as compared to the exact based techniques. As well, from the approximate based

techniques, Meta-heuristics is the most popular techniques as it takes the advantage of the strengths of the other methods to find better solutions. On the other hand, shifting bottleneck heuristic have been the most widely used in the domain of meta-heuristic algorisms.

2.8 Production Scheduling Software for Manufacturing

Advanced Planning and Scheduling Software have become a must for modern-day manufacturing operations as customer demand for increased product assortment, fast delivery, and downward cost pressures become prevalent. Job shops use many methods for scheduling their high-variety production. The methods include whiteboards, excel applications, LEKIN software and project management software like MS Project (Velaga, 2016). Production planning software provides the right platform to track, analyze, and optimize the process of manufacturing with automated scheduling mechanisms, and quality control loops. List of some best production planning software and their comparison is summarized in Table 2.7 (Scheduling Software).

Table: 2.7 Comparison of production scheduling software (Scheduling Software) (modified)

S.N	Scheduling Software	Reporting dashboard	Rescheduling tool	Distinctive Feature
1	Frepple	Yes	Yes	Predictive capacity
2	OpenPro	Yes	No	Track different manufacturing modes
3	DYNAMIC 3i	No	No	Production forecasting
4	MRPeasy	Yes	Yes	Estimation of cost and lead times
5	Katana MRP	Yes	No	Inventory optimization
6	Lekin	Yes	Yes	Different scheduling algorism

Even through, the researcher have been facing limitations on accessing some list of scheduling software, as it is stated in Section 1.9, however, suitable scheduling software for the problem in the case study (LEKIN software) was choosen and applied. LEKIN software has many extensive features like; containing different basic workspace environments, different performance measures, various heuristics and dispatching rules, and graphic tool for comparative analysis of different schedules with complete graphic printouts (Nikhil et al.,

2020). Therefore, it can generate proper and efficient schedules for flexible job shop scheduling to be applied practically.

2.9 Conceptual Framework

A conceptual framework is a visual representation in research that helps to illustrate the expected relationship between cause and effect. It is also called a conceptual model or research model. Different variables and the assumed relationships between those variables are included in the model and reflect the expectations. In this study, production performance enhancement is the dependent variable with Job Shop Scheduling Problem (JSSP) of confounding variable and the independent variables are machine utilization, Work In Process (WIP), lead time and machine layout, as shown in Table 2.4.

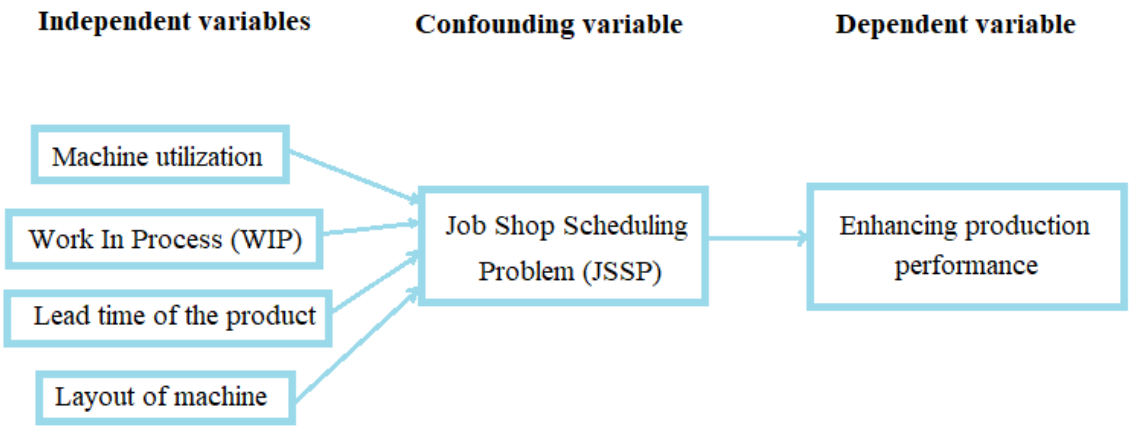


Figure: 2.4 Conceptual framework for production performance (author)

2.10 Literature Gap

Literatures on various techniques of flexible job shop scheduling problems were reported so far. However, it is observed that there is a gap on combination of scheduling and simulation model to evaluate different performance indicators concurrently. Moreover, even some scheduling research activities have been moved from academic exercises to serious attempts to solve practical problems in companies, it is still unusual and less attempt.

Therefore, this study performs practical implementation of scheduling techniques and simulation of flexible job shop scheduling problems (FJSSP) model to evaluate different performance indicators simultaneously.

Chapter Three

3. Research Design and Methodology

This chapter illustrates the research approaches that were used throughout the research process, the appropriate framework of the study and the strategy for answering the research questions. It helps to identify and understand research instruments to be employed and shows how the research result at the end will be made in line with achieving the objective of the study. Research methodology of this study follows the procedures listed under this section.

3.1 Research Design

A research design is a strategy for answering the research question using empirical data. Creating a research design means making decisions about overall research objectives, approach, sampling methods, data collection methods, data analysis methods.

A well-planned research design helps to ensure that methods match the research objectives and use of right kind of analysis for the data.

The research methodology and procedures of this study followed are illustrated in Figure 3.1. The process starts with existing shop floor study and ends with proposed improved approach.

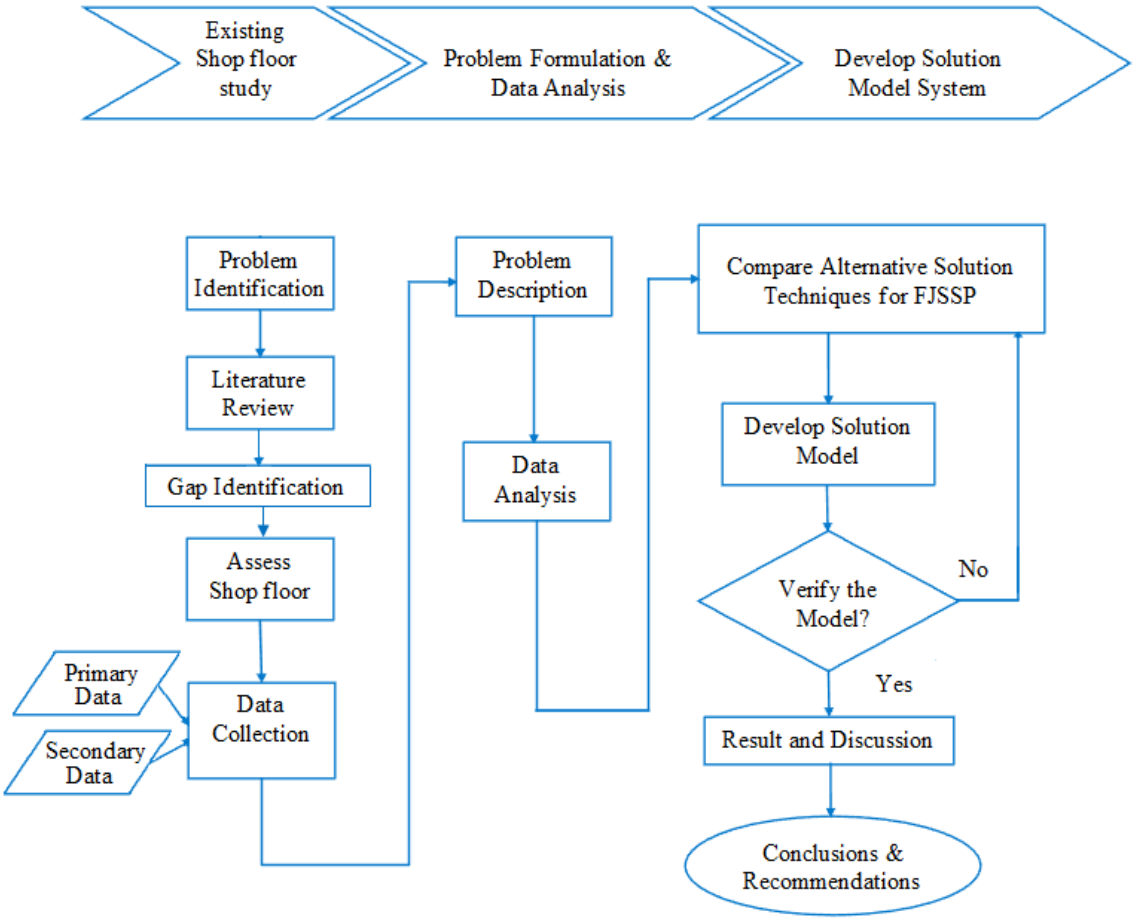


Figure: 3.1 Research Framework

3.2 Assess Existing Shop Floor

Understanding and examining of shop floor condition is primary and essential step before data collection. A detailed shop floor investigation has been completed to gain a better understanding of the working environment. Through comprehensive shop floor assessment, useful data, containing design capacity of production, actual capacity of production, potential customers, product type (jobs), dispatching procedure, order scheduling method, machine layout, Available active machines, work in process inventory, congestion level at the shop floor have been assessed. Type of data, the method and focus group where the data have been collected is summarized in Table 3.1.

Table: 3.1 Elements in the shop floor assessment

Shop Floor Assessment		
Type of data	**Data collection method**	**Focus Groups**
Design capacity of the company	Document files	Production Planning and Controlling department (PPC)
Actual capacity of the company	Document files	Production Planning and Controlling department (PPC)
Potential customers	Order receipt template	Marketing Department
Product type (jobs)	Order receipt template	Marketing Department
Dispatching procedure	Interview & Document files	Production Planning and Controlling department (PPC)
Order scheduling methods	Interview & Document files	Production Planning and Controlling department (PPC)
Machine type and layout in the shop floor	Direct observation	Shop floor at Conventional Manufacturing Factory
Available active machines	Direct observation	Shop floor at Conventional Manufacturing Factory
Work in process inventory	Direct observation	Shop floor at Conventional Manufacturing Factory
Congestion level at the shop floor	Direct observation	Shop floor at Conventional Manufacturing Factory

3.3 Data collection method

Both primary and secondary data have been collected from different sources, believed to be the main sources of information.

3.3.1 Primary Data

The primary data was obtained from the original source of information. It were more reliable and have more confidence level of decision-making with the trusted analysis having direct contact with occurrence of the events (Jilcha, 2016). Primary data were collected through structured interview, discussion, structured check list, direct observation and direct measuring. The data includes process parameters, machine parameters and the system parameters.

- The process parameters such as, types of products, product routing (operation sequence) and processing time (include setup time) were collected through direct observation, structured check list and interviews with operators and supervisors and direct time measurement using stopwatch.
- The machine parameter data such as type of machines and number of active machines were collected using interviews with machinist and direct observation at the shop floor.
- The system parameter data for instance machine layout and master production schedule (MPS) were collected through interview with the planers, direct observation at the shop floor and from guide documents in production planning and controlling (PPC).

Major primary data collection method was conducted through interview with sales expert, factory managers, supervisor, planers and machine operators, to understand the current scheduling system and performance of the factory. Then direct observation was conducted on machine layout, active machines, operation sequence and type of products in Conventional Manufacturing Factory (CMF). In addition, structured check lists were used to keep track of what needs to be done and to ensure that the data collection is according to the requirements. List of expected attributes items and performance indicators on the check lists are, shown in APPENDIX IV.

Secondary data

The secondary data refers to data that was collected by someone other than the user. This data source gives insights of the research area of the current state-of-the art method and makes some sort of research gap that needs to be filled by the researcher. This secondary data sources could be internal and external data sources of information that may cover a wide range of areas (Jilcha, 2016).

The secondary data were collected from periodic reports, procedures, manuals and existing document file of the company. The data also obtained from trustworthy journals, books, different articles, websites, proceedings, publications and other sources were considered for the review. Broad reviews of different literatures from different sources on the subject matter were

used to do the research. Literature survey on production performance, factors affecting manufacturing performance, performance measures/indicators, performance enhancement models/tools, Job-Shop scheduling problem (JSSP) and solution techniques of Job-Shop Scheduling Problem (JSSP) have been intensively reviewed from different relevant books, internet websites, senior research work, articles and journals. Finally, different case studies and the gap in literature study are presented.

Contents of primary and secondary data, collected under process, machine and system parameters are shown in Table 3.2.

Table: 3.2 Data type and method

Data Collection		
Type of data		**Data collection method**
Process Parameter	Type of product (jobs)	Order receipt template & Direct observation
	Product routing (operation sequence)	Route sheets & Direct observation
	Machine sequence	Route sheets & Direct observation
	processing time (include setup time)	Direct measurement (using stopwatch)
Machine Parameter	Type of machines	Direct observation & interview
	Number of active machines	Direct observation & interview
System Parameter	Machine layout	Direct observation & Layout sheet
	Master Production Schedule (MPS) Order scheduling methods	Interview & document file in production planning and controlling department (PPC)
	Capacity of production (annual report)	Operation Department

3.4 Problem Description and Formulation

Problem formulated is exceedingly important, as it comprises of several simultaneous objectives and several resources which must be allocated to meet the objective, which are to minimize the time required to complete the entire process being scheduled and to maximize the utilization of machines. Therefore, problem of case factory (FJSSP) was formulated clearly by defining each set of jobs, operations, machines with corresponding sequences, parameters, variables, constraints (assumptions) and objective function, as it is illustrated below.

Variables used in flexible job shop scheduling problem (FJSSP) are:-

- There are a set of 18 jobs $\{J_1, J_2, J_3, ..., J_{18}\}$ to be processed on m machines.
- The set of 16 machines is noted as: $M = \{M_1, M_2, ..., M_{16}\}$.

The problem is subjected to the following constraints (assumptions):-

- All jobs are available at time t = 0.
- All machines are available at time t = 0.
- Each machine can process only one job at a time.
- Each job visits each machine only once.
- No job splitting.
- Setup times is assumed to be small & included in the processing time.
- Processing time is deterministic & constant.
- No pre-emption of operations is allowed, that is, an operation once started cannot be interrupted.

Objective functions are:-

- Minimize a maximum completion time over all jobs (Min. Cmax)
- Maximize machine utilization
- Minimize work in process (WIP)

3.5 Data Validation and Reliability

Data validation is a decisional procedure ending with an acceptance or refusal of data as acceptable. The decisional procedure is generally based on rules expressing the acceptable combinations of values. Reliable data, on the other hand, refers to data that can be a trusted basis for analysis and decision-making. It means that data is complete and accurate, and it is a crucial foundation for building data trust across the organization (Zio et al., 2016). The major input data for this study is time of operation on each machine. Therefore, the time is recorded using stop-watch devise and number of observation is calculated as follow

N (sample size) = Z^2 P (1-P) / d^2 Where, N is the sample size, Z is level of confidence, P is the sample proportion, expressed as a decimal, d is the margin of error, expressed as a decimal, (Pourhoseingholi et al., 2013)

According to the standard normal distribution, z = 1.65 (for a level of confidence of 95%), tolerated margin of error (d) = 0.05 (since it is wanted to know the real proportion within 5%) and estimated proportion of the population that presents the characteristic (P) is considered to be 0.009. Therefore, N = 1.65^2 * 0.009 * (1-0.009) / 0.05^2 = 9.7. In conclusion, in order to conduct a reliable scheduling analysis, it is preferable to conduct the operation time with at least ten (10) number of observation cycle.

3.6 Data Analysis Tools

In this study, the collected are presented in different form of tables, and has been analyzed using Microsoft Excel, Lekin FJSS software and Arena simulation software.

- **Microsoft Excel**

Microsoft Excel is the industry leading spreadsheet software program, a powerful data visualization and analysis tool. It is used in this study for data filtering, plenty of formulas to work with data and data analysis and interpretation.

- **Lekin FJSS software**

Lekin is a scheduling system developed at the Stern School of Business and the major parts of the system were designed and coded by Columbia University students (Nikhil et al., 2020). It is an interactive scheduling system for different machine environments and built in dispatching rules and simple heuristic for research and teaching purpose.

- **Arena simulation software**

Arena is discrete event simulation and automation software developed by Systems Modeling, which uses the SIMAN processor and simulation language (Dornheim, 2003). In Arena, the user builds an experiment model by placing modules (boxes of different shapes) that represent processes or logic. Connector lines are used to join these modules together and to specify the flow of entities. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and entity relative to real-life objects is subject to the modeler. Statistical data, such as cycle time, throughput, machine utilization and WIP (work in process) levels, can be recorded and made output as reports.

3.7 Data analysis and Presentation

Data analysis starts with the collection of data followed by data processing by various data processing methods. Both quantitative and qualitative data analysis were conducted to answer the basic questions raised in the problem statement using data processing tools and software. Quantitative data obtained from primary and secondary data were analyzed using office word format, excel, table and chart, and the qualitative data have been also analyzed by integrating the outcomes from the quantitative data analysis.

Depending on the problem formulation, existing scheduling system and alternative schedules were analyzed using LEKIN software with desired objective functions and subjected constraints. Different proposed alternative solution techniques for Flexible Job-Shop Scheduling Problem (FJSSP) were compared and propose the efficient solution to solve the problem with optimum schedule of jobs. In addition, Arena simulation software was used to analyze and validate the proposed solution. The jobs have been scheduled on the machine with

different alternative orders, in such a way that all expected objective functions are optimized to enhance the performance of the shop floor.

Then the results were discussed to show how much each performance of the shop floor is enhanced when comparing to the existing scheduling system. Finally, conclusions were drawn from the result discussion and recommendations have been given based on those concluded points.

3.8 Ethical consideration

Ethical permission was gotten from the School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology (AAiT). Official letters were written from the School of Mechanical and Industrial Engineering to Addis Machine and Spare Parts Manufacturing Industry (AMSMI). The purpose of the study was explained to the company and informed that the information they provided is required for educational purpose and kept confidential. In addition, the employee's identities would not be publicized related to the information they provided. To this end, feedback and copy of paper showing the result and the proposed solution obtained from the study will be given to Addis Machine and Spare Parts Manufacturing Industry (AMSMI).

3.9 Result Dissemination

The result of this study will be submitted and presented to the Addis Ababa University, AAiT, School of Mechanical and Industrial Engineering. It will also be communicated to Addis Machine and Spare Parts Manufacturing Industry (AMSMI).

Chapter Four

4. Data Analysis and Presentation

4.1 Data Collection and Presentation

Different data were collected and presented using text form, tabular form, image, flow chart and other methods. These methods help in adding the visual aspect to data which makes it much more comfortable and quicker to understand.

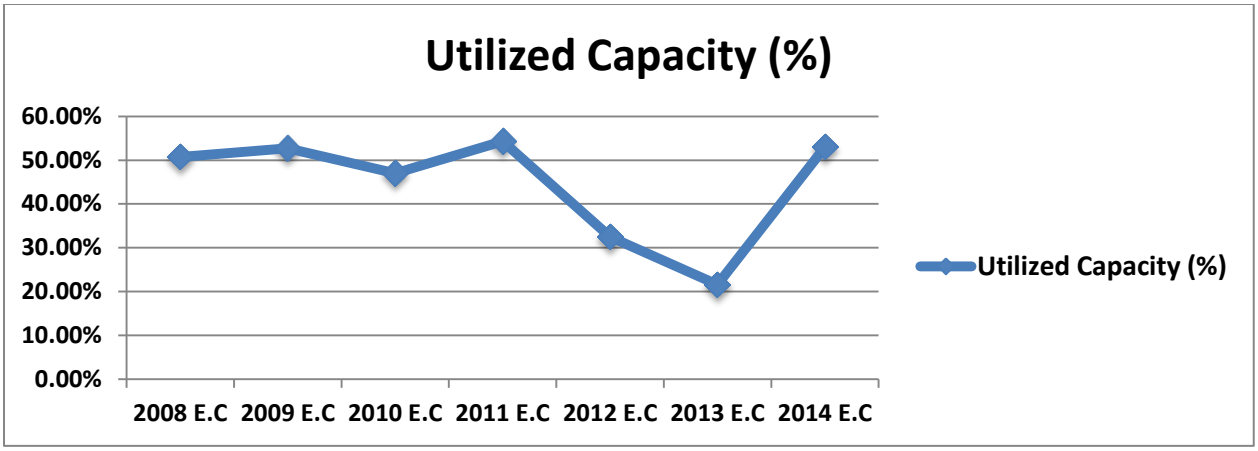
Primary and secondary data were collected from different source of data on spare part production capacity, potential customer, job items, production process flow, scheduling system, machine type, machine layout, processing sequence and processing time, as it is presented under this section.

4.1.1 Spare Part Production Capacity of the Industry

Addis Machine and Spare Parts Manufacturing Industry (AMSMI) has installed production capacity of 425 tons of various spare parts per year. However, as Table 4.1 shows, yearly actual production of the industry is running below its installed capacity.

Table: 4.1 Spare part production capacity of the company (Company report, 2014 E.C.)

Year (Ethiopian Calendar)	2008 E.C	2009 E.C	2010 E.C	2011 E.C	2012 E.C	2013 E.C	2014 E.C
Installed Capacity (ton)	425	425	425	425	425	425	425
Actual Capacity (ton)	215.35	223.9	199.62	230.63	138.21	91.64	225.13
Utilized Capacity (%)	50.7%	52.7%	47.0%	54.3%	32.5%	21.6%	53.0%



4.1.2 Potential Customer of the Company and their Products

There are number of customers in Addis Machine and Spare Parts Manufacturing Industry (AMSMI). Though this study addressees the potential customer's products which are produced in Conventional Manufacturing Factory. Table 4.2 presents potential customers including the product type they purchase.

Table: 4.2 Potential customers of the company and their products

S.N	Potential Customer	Product type
1	Ethiopian Construction Work Corporation (ECWC)	Spur Gear
		Compressor Helical Gear
		Coupling Spline
		Coupling Hub
		Gear Coupling
		Reducing Flange
		Motor Pulley
		Threaded Shaft
2	Sugar Factory (Wonji Showa, Kessem, Fincha, Tana Beles, Omo Kuraz 3)	Cam Shaft Gear
		Integrated Spline Shaft
		Worm Gear
		Worm Shaft
		Spiral Bevel Gear
		Spiral Bevel Gear Shaft
3	Defense Construction Materials Manufacturing Enterprise	Clutch Sprocket
		Concrete Mixer Gear
		Internal Ring Gear
		Fly wheel

4.1.3 Production Process Flow and Scheduling System

Addis Machine and Spare Part Manufacturing Industry is Job Order Company which produces its products after receiving orders from its clients. Ever since its production rate is dependent on the customer order size, products may pass through one or more factory.

Lead time of products starts from receiving an order in marketing department, and goes to PPC department for dispatching the job tickets to different factories. The job tickets may dispatch to one, two or more factories with specified delivery date. Scheduling and determination of delivery date for products is performed by PPC workroom at operation department. The workers in this workroom schedule products by following First-Come, First-Serve (FCFS) scheduling system through considering current products performed on the shop floor. Then delivery date of each product will be set and announce to customers. Attainment of job schedule is also controlled by this department (PPC) after dispatching job orders to factories. Even if FCFS scheduling is simple to perform and fair to the customer, it has been observed that there is ignorance of due date and long completion time.

After customers agree on the price and delivery date, production will be going under the direction of PPC department. Manufacturing flow process of the company is shown in Figure 4.1.

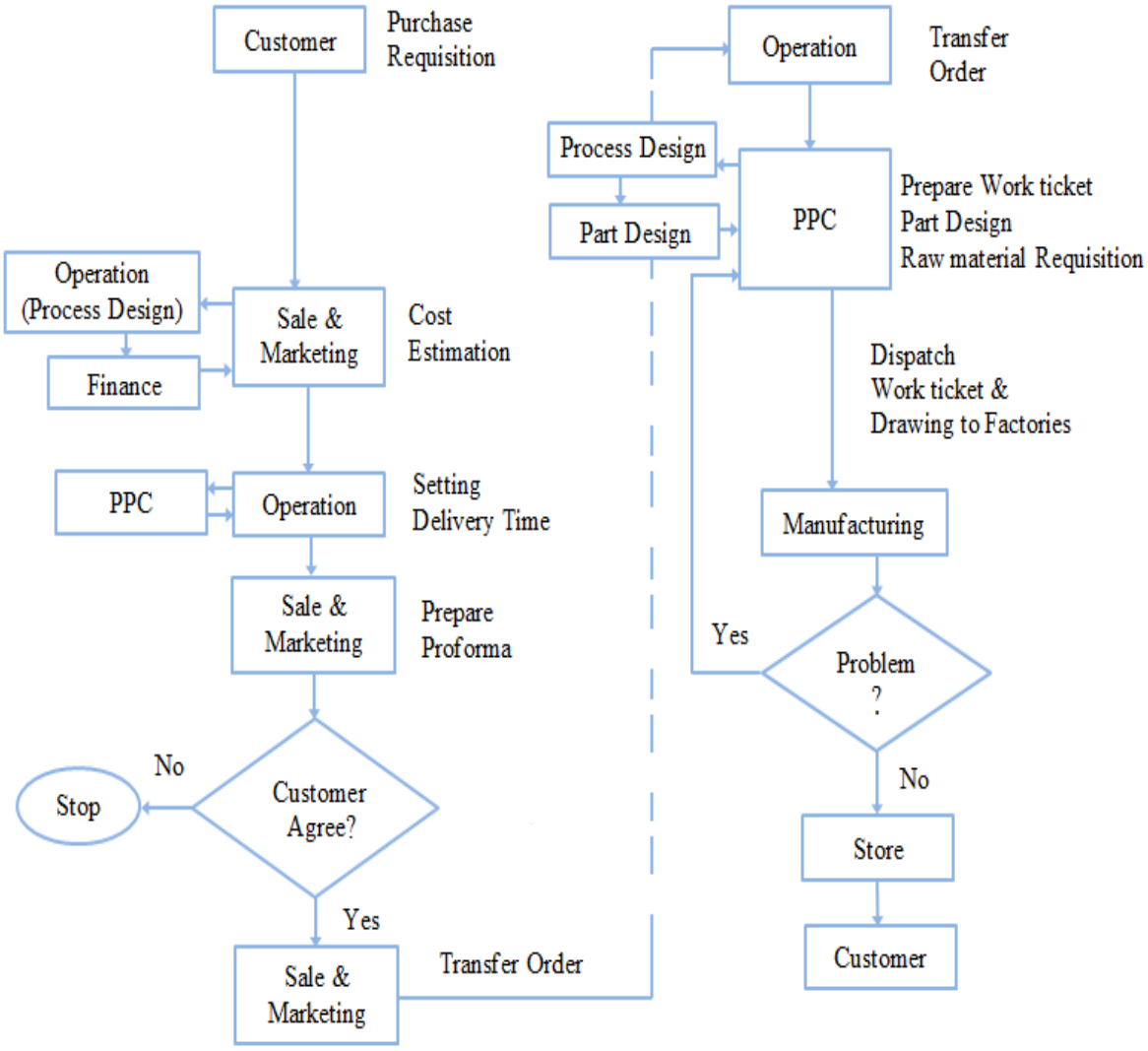


Figure: 4.1 Manufacturing process flow of AMSMI (author)

4.1.4 Machine Type and Layout of the Factory

Conventional Manufacturing Factory (CMF) performs operations like conventional lathe operation, conventional milling operation, drilling operation, cutting operation and grinding operation and it is performed manually.

Due to the variety of products and low production volumes of spare part orders, the factory has implemented flexible Job Shop manufacturing system. This system allows an operation to be processed on a machine out of a set of alternatives, which enlarges extra dimension of complexity. The machines performing similar type of operations are grouped together and gathered at one location, which is known as process layout. In CMF there are five cluster of machines namely: Lathe Operation, Milling Operation, Drilling Operation, Gear Cutting and Grinding Operation.

The flows of material through the facilities from one functional area to another differ from product to product. Totally in all functional area, there are 16 types of machines and 34 numbers of active machines in CMF. Types of machines in each functional area are shown in Table 4.3 and machine layout of the factory is shown in Figure 4.3.

Table: 4.3 Type of machines and corresponding functional area

S.N	Functional Area	Machine Type	Qty.
1	Lathe Operation	Conv. Heavy Duty Lathe Machine	1
		Conv. Medium Lathe Machine	3
		Conv. Light Lathe Machine	5
2	Milling Operation	Conv. Plano Miller Machine	1
		Conv. Vertical Miller Machine	2
		Conv. Medium Milling Machine	4
		Conv. Light Milling Machine	6
3	Drilling Operation	Light Drilling Machine	2
		Radial Drill Press Machine	1
		Slotting Machine	2
4	Gear Cutting	Gear Hobbing Machine	1
		Gear Shaving Machine	1
		Inter Spline Cutting Machine	1
		Spiral Bevel Gear Cutting Machine	1
5	Grinding Operation	Surface Grinding Machine	2
		Spline Grinding Machine	1
Total			**34**

Production layout is the arrangement of machines, processing equipment and departments to achieve greatest process flow and efficiency of Men, Materials, Machines and Methods in the production system. The objective of layout design is to deliver smooth flow of workers, materials and information through the production system. Production plant layout is also the method to arrange the right equipment at the right place to permit effective processing. The advantage of production layout is for effective utilization of space and to get minimal throughput time.

As shown in Figure 4.2, existing layout of machine in Conventional Manufacturing Factory (CMF) is process type of layout in which all machines performing similar type of operations are grouped at one functional area. The flow paths of material through the facilities from one functional area to another vary from product to product. Usually the paths are long and there are possibilities of backtracking. Process layout is normally used when there are varieties of products with low production volumes.

Therefore, the existing layout of the factory is an appropriate type of layout since production type of the factory is job-shop production and there is no need of improvement in existing machine layout of the Conventional Manufacturing Factory (CMF).

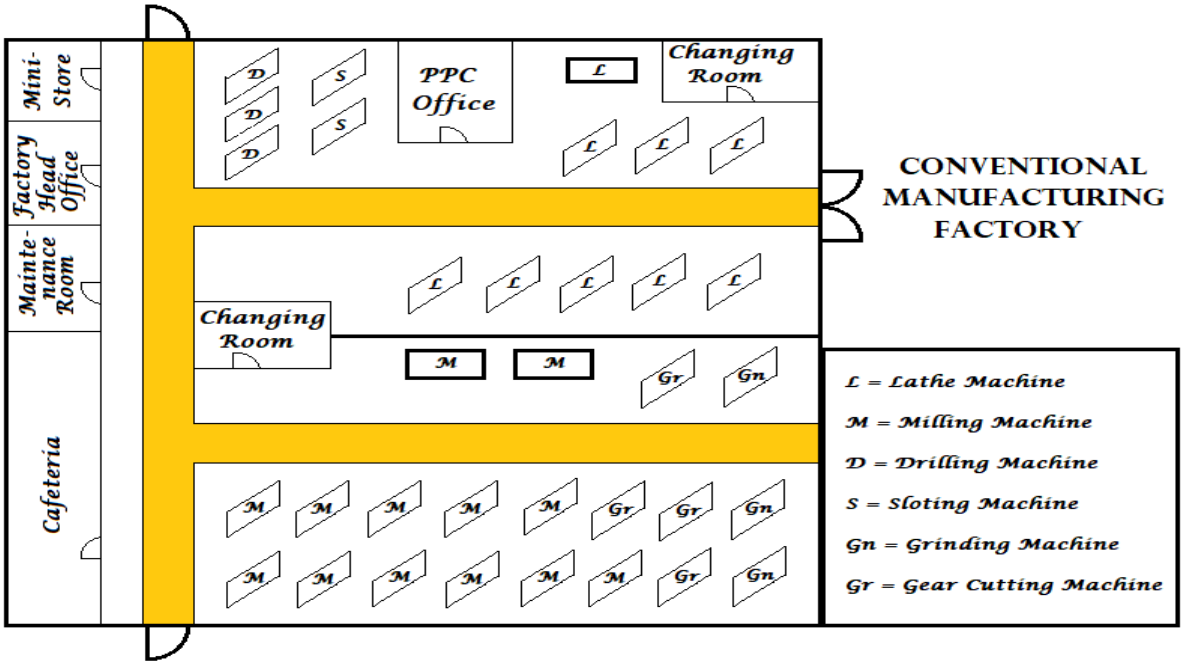


Figure: 4.2 Layout of Machines in CMF (author)

4.1.5 Data collected through time-study (stop-watch device)

Based on the data recorded in Conventional Manufacturing Factory (CMF) at Addis Machine and Spare Part Manufacturing Industry (AMSMI), there are 18 potential customer's products (jobs) and 16 type of machines on which jobs are processed. The precedence constraint or processing sequence for each part (job) and the machines on which each job is processed was collected from route sheets and direct observation. Processing time of each operation for each job was recorded using stop-watch device in 10 times of observations, as it is determine in Section 3.5. Setup time on the machine for processing a particular job was included in the processing time. The summations of time in each process, which is observed in 10 cycles, were averaged to find the Operation-time or Basic time. Processing sequence and operation-time (10 cycles) of each process in each job is shown in APPENDEX-I.

4.2 Performance Analysis on Existing Scheduling System

This section incorporates the analyses to show the performance evaluation of current scheduling system (First-Come, First-Serve (FCFS)) with different performance measures using Lekin software and Arena simulation software.

4.2.1 Lekin Simulation Analysis

Lekin simulation analysis was performed for scheduling 18 types of jobs in 16 types of machines. The eighteen (18) types of jobs are, Spur Gear (J1), Compressor Helical Gear (J2), Coupling Spline (J3), Coupling Hub (J4), Gear Coupling (J5), Reducing Flange (J6), Motor Pulley (J7), Threaded Shaft (J8), Cam Shaft Gear (J9), Integrated Spline Shaft (J10), Worm Gear (J11), Worm Shaft (J12), Spiral Bevel Gear (J13), Spiral Bevel Gear Shaft (J14), Clutch Sprocket (J15), Concrete Mixer Gear (J16), Internal Ring Gear (J17) and Fly wheel (J18).

These jobs are processed on 16 machines namely Conventional Heavy Duty Lathe Machine (M1), Conventional Medium Lathe Machine (M2), Conventional Light Lathe Machine (M3), Conventional Plano Miller Machine (M4), Conventional Vertical Miller Machine (M5), Conventional Medium Milling Machine (M6), Conventional Light Milling Machine (M7), Light Drilling Machine (M8), Radial Drill Press Machine (M9), Slotting Machine (M10), Gear Hobbing Machine (M11), Gear Shaving Machine (M12), Inter Spline Cutting Machine (M13), Spiral Bevel Gear Cutting Machine (M14), Surface Grinding Machine (M15) and Spline Grinding Machine (M16).

From collected recorded time and machine sequence stated in APPENDEX-I, routing matrix containing the selected jobs and precedence constraints of machines is presented in Table 4.4.

Table: 4.4 Routing Matrix the eighteen (18) jobs and sixteen (16) machines

Jobs	Operation Precedence Constraints					Tot. Time
J1	M3 (58)	M9 (11)	M7 (22)	M11 (65)	-	156
J2	M3 (93)	M6 (14)	M8 (11)	M11 (95)	-	213
J3	M3 (61)	M7 (12)	M13 (70)	M16 (31)	-	174
J4	M3 (136)	M10 (43)	M7 (27)	-	-	206
J5	M1 (188)	M4 (41)	M13 (129)	-	-	358
J6	M2 (135)	M10 (20)	M6 (29)	M15 (91)	-	275

J7	M1 (191)	M4 (211)	-	-	-	402
J8	M3 (129)	M15 (94)	-	-	-	223
J9	M3 (183)	M6 (26)	M9 (20)	M11 (97)	M15 (51)	377
J10	M2 (134)	M6 (58)	M16 (127)	-	-	319
J11	M2 (78)	M7 (18)	M9 (12)	M11 (73)	-	181
J12	M2 (149)	M6 (57)	M12 (102)	-	-	308
J13	M3 (81)	M6 (15)	M10 (11)	M14 (92)	M15 (38)	237
J14	M2 (131)	M6 (48)	M14 (119)	-	-	298
J15	M3 (91)	M8 (16)	M6 (27)	M11 (112)	-	246
J16	M1 (159)	M5 (18)	M12 (124)	-	-	301
J17	M1 (142)	M4 (58)	M12 (102)	-	-	302
J18	M1 (221)	M5 (31)	M11 (168)	-	-	420

According to FJSSP formulated in Section 3.4, the routing matrix feed into Lekin software to schedule based on FCFS priority rule. After running the analysis, the Gantt chart that shows the sequences of jobs on the machines, and generated results of different performance indicators are presented in Figure 4.3 and Table 4.5 respectively.

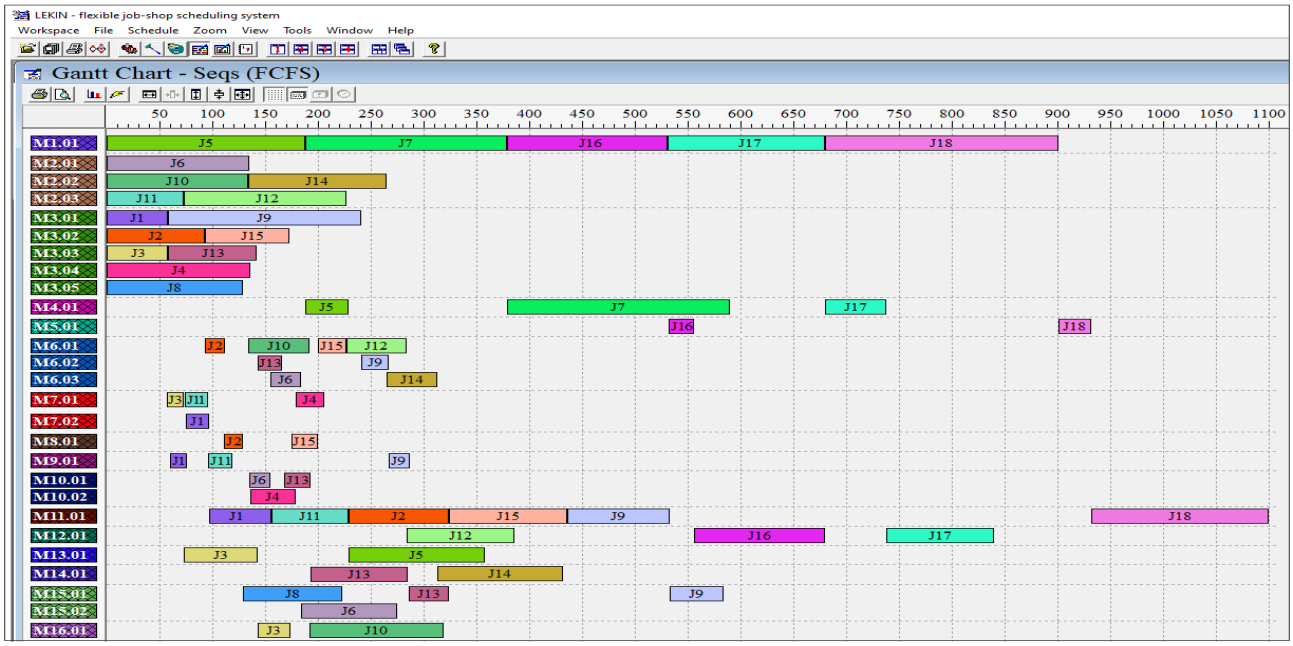


Figure: 4.3 Gant chart for existing job schedule (First-Come, First-Serve)

Table: 4.5 Shop performance of existing job schedule (First-Come, First-Serve)

Running Time	Makespan (Cmax)	Max Tardiness	No. of Late Jobs	Total Tardiness	Total Weighted Flow Time	Total Weighted Tardiness
1	1100	1100	18	9876	9876	9876

4.2.2 Arena Simulation model and Analysis

The simulation model was built using Arena simulation software for existing scheduling system of job shop production using job sequence on the machine and the recorded processing time of operations in machine shops through stopwatch. The objective of the model was to determine how the model could flow to imitate a real system and to analyze performance of machine utilization and work in process (WIP). Simulating the model using Arena simulation software is demonstrated into six types of different modules, as shown in Figure 4.4.

- Create module: - Creating job, the time between arrivals would be random exponential, the value would be 2 minutes, entities per arrival would be 1, and maximum arrivals would be infinite. (Arrival time is determined by dividing interval of ordering time to order quantity).
- Station module: - Defines a station corresponding to a physical or logical location where each machine and processing of job occurs.
- Assign module: - Assign time and sequence of machine for each job, and assign of job sequence on each machine by define all entity sequence and attributes.
- Route module: - It transfers an entity to the station visitation sequence defined for the entity.
- Process module: - It represents the machine and processing method in the simulating the process, seize delay release is selected in the field action, add a machine and its quantity as a resource, type of distribution or method of specifying the delay parameters is expression and process time of exponential
- Dispose of the module: - This module is intended as the ending point for entities in an emulation model.

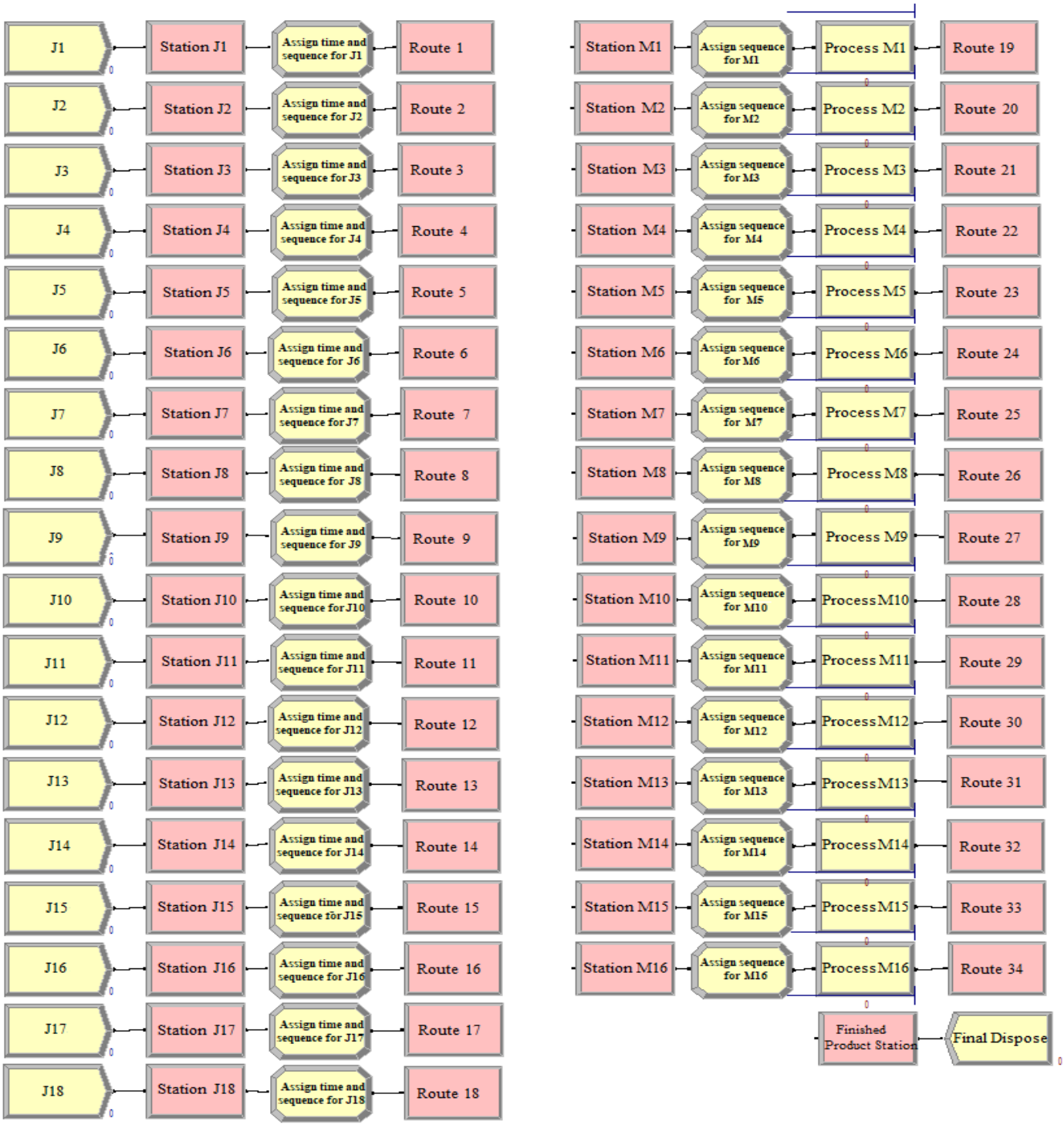


Figure: 4.4 Simulation modeling of CMF process

After simulate the model it directed to run the process for ten (10) times of replication with forty (40) hours of replication length and eight (8) hours per day, since currently the company works one shift per day. The output obtained from simulation run using First-Come, First-Serve (FCFS) schedule is shown in APPENDIX III and summarized in Table 4.6.

Table: 4.6 Output of performance indicators in First-Come, First-Serve (FCFS) schedule

Jobs	Number in	Number out	Total time (hr.)	work in process (WIP)	Machine	Machine Utilization (%)
J 1	134	15	35.95	76.85	M 1	82
J 2	66	7	36.44	50.82	M 2	56
J 3	123	13	29.81	80.66	M 3	86
J 4	102	11	36.61	26.05	M 4	28
J 5	59	7	34.83	3.15	M 5	4
J 6	78	9	37.40	17.83	M 6	23
J 7	36	4	34.89	4.73	M 7	8
J 8	97	7	23.00	2.21	M 8	5
J 9	36	4	36.47	5.21	M 9	7
J 10	67	6	29.30	3.94	M 10	9
J 11	92	10	34.73	53.28	M 11	56
J 12	57	6	33.41	27.10	M 12	31
J 13	65	8	25.76	18.49	M 13	23
J 14	51	5	32.68	16.36	M 14	31
J 15	45	6	39.77	26.62	M 15	31
J 16	32	4	40.05	22.06	M 16	23
J 17	27	2	40.10	18.77		
J 18	18	2	43.97	15.86		
Total	**1185**	**126**	**625.16**	**470.01**		
Average						**31.44**

4.3 Proposed Improvement approach

Depending on the problem formulation, different alternative solution techniques for flexible Job-Shop scheduling problem (FJSSP) were analyzed and compared using LEKIN software with objective function of makespan. In generated output, the optimal schedules of jobs were gained from dispatching rule (Longest Processing Time) and heuristic methods (Generic Shifting Bottleneck algorithm). Moreover, the simulation models were built using Arena

simulation software for both scheduling system and analyze performance of product output, machine utilization and work in process (WIP).

4.3.1 Scenario One: Longest Processing Time (LPT) Rule

The longest processing time methods assign highest priority to jobs with the longest processing time. When scheduling longer jobs at the beginning of the schedule, the schedulers can reduce a large amount of much more time consuming jobs at the end of the job schedule. This form of job sequencing is extremely beneficial to manufacturers as it ensures that long jobs have time to complete before they are needed. The Gantt chart that shows the sequences of jobs on the machines and generated results of different performance indicators based on LPT priority rule using Lekin flexible job shop scheduling system is shown in Figure 4.5 and Table 4.7 respectively.

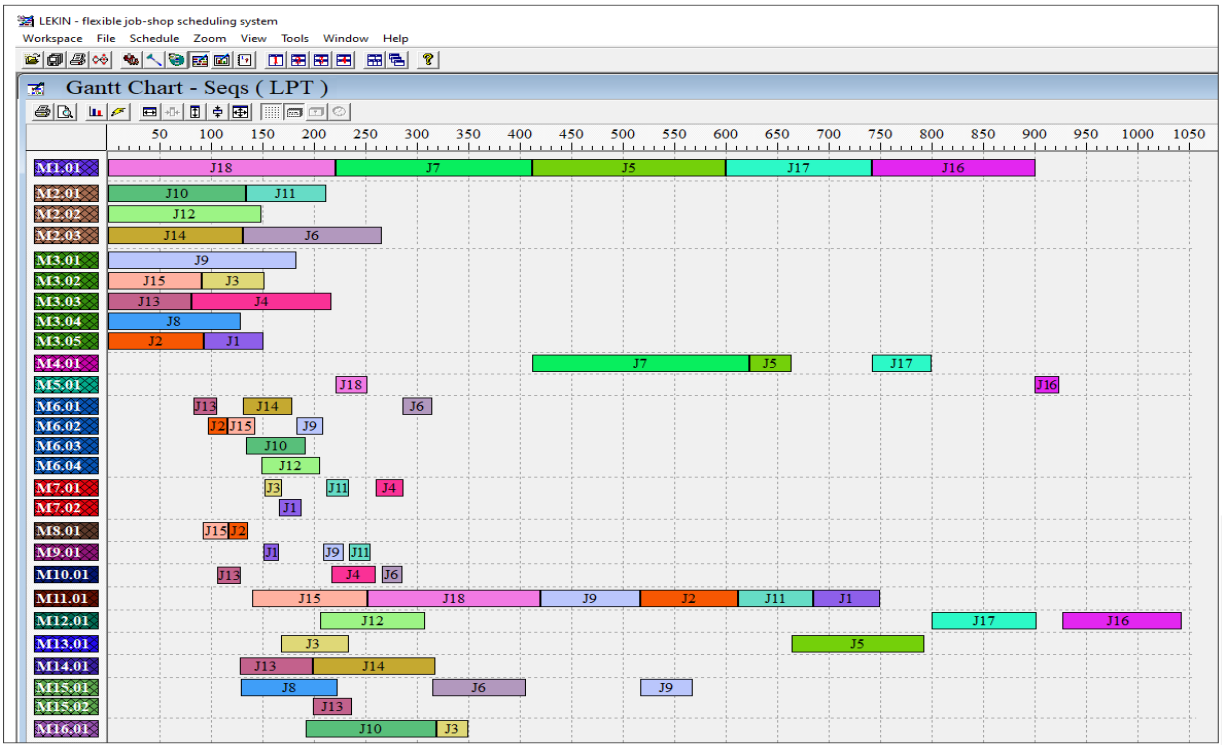


Figure: 4.5 Gant chart for scenario one scheduling (Longest Processing Time)

Table: 4.7 Shop performance of existing job schedule (Longest Processing Time)

Running Time	Makespan	Max Tardiness	No. of Late Jobs	Total Tardiness	Total Weighted Flow Time	Total Weighted Tardiness
1	1043	1043	18	9090	9090	9090

The simulation model also built using Arena simulation software for Longest Processing Time (LPT) scheduling system. The generated output of different performance obtained from simulation run is shown in APPENDIX III and summarized in Table 4.8.

Table: 4.8 Output of performance indicators in Longest Processing Time (LPT) schedule

Jobs	Number in	Number out	Total time (hr.)	work in process (WIP)	Machine	Machine Utilization (%)
J 1	30	4	45.50	71.49	M 1	83
J 2	37	5	49.39	45.89	M 2	60
J 3	74	8	37.33	74.46	M 3	89
J 4	78	9	41.47	22.84	M 4	32
J 5	39	4	50.59	1.26	M 5	6
J 6	56	7	43.47	50.49	M 6	60
J 7	37	5	41.60	2.31	M 7	10
J 8	99	12	44.75	16.85	M 8	7
J 9	40	5	44.57	1.21	M 9	10
J 10	116	13	38.89	1.36	M 10	12
J 11	43	5	46.55	25.81	M 11	29
J 12	72	9	40.59	22.26	M 12	33
J 13	94	11	40.75	1.40	M 13	28
J 14	79	9	38.16	17.26	M 14	26
J 15	89	11	41.88	28.02	M 15	35
J 16	34	3	51.87	14.87	M 16	26
J 17	25	3	50.69	19.55		
J 18	54	7	41.40	23.05		
Total	**1096**	**130**	**789.44**	**440.37**		
Average						**34.13**

4.3.2 Scenario Two: Generic Shifting Bottleneck Algorithm

The Generic Shifting Bottleneck Heuristic determines optimal sequence for bottleneck machine with considering precedence constraints of jobs. One bottle machine was chosen in each round of iterations and the process order of all the jobs on the bottle machine was fixed,

so the process could be repeated until whole machine orders were fixed. Assuming that the jobs are actually competing for the same resources (machines) then there will always be one or more resources that act as a 'bottleneck' in the processing. This heuristic or 'rule of thumb' procedure minimizes the effect of the bottleneck. The Gantt chart that shows the sequences of jobs on the machines and generated results of different performance indicators based on Generic Shifting Bottleneck Algorithm using Lekin flexible job shop scheduling system is shown in Figure 4.6 and Table 4.9 respectively.

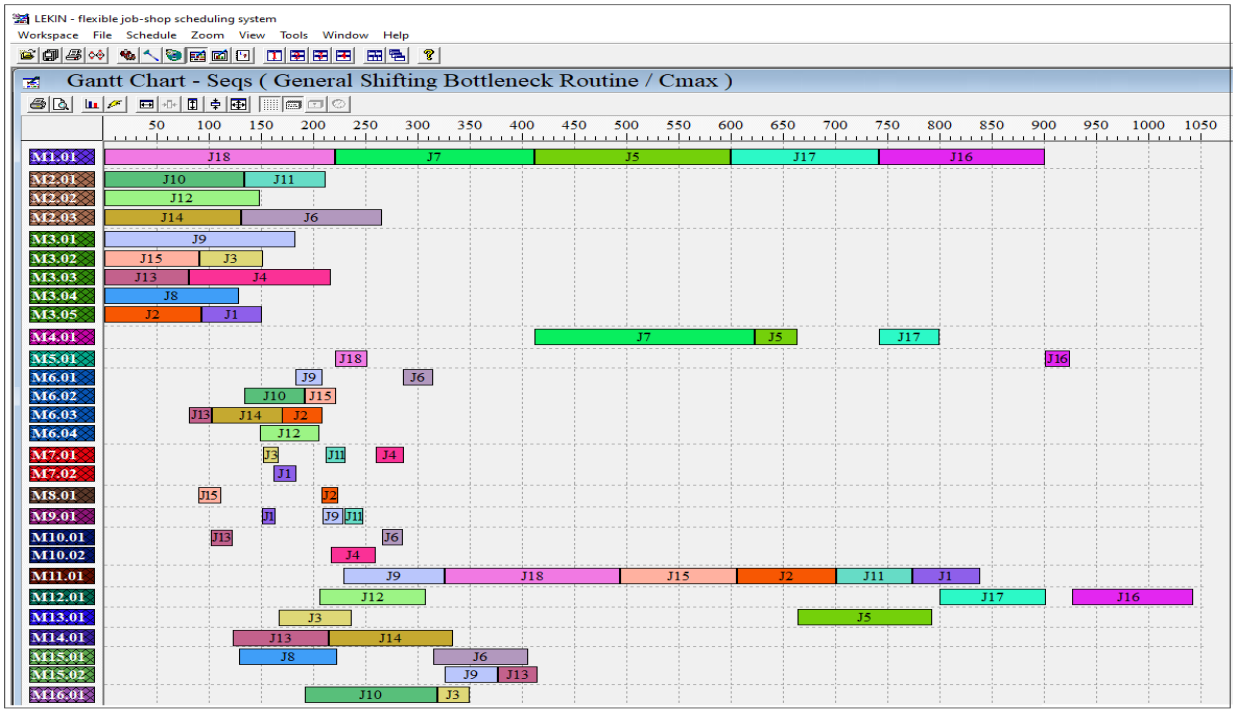


Figure: 4.6 Gant chart for scenario two scheduling (Generic Shifting Bottleneck)

Table: 4.9 Shop performance of existing job schedule (Generic Shifting Bottleneck)

Running Time	Makespan (Cmax)	Max Tardiness	No. of Late Jobs	Total Tardiness	Total Weighted Flow Time	Total Weighted Tardiness
1	1043	1043	18	7610	7610	7610

After Lekin analysis, simulation model was built using Arena simulation software for generic shifting bottleneck scheduling system. The generated output of different performance obtained from simulation run is shown in APPENDIX III and summarized in Table 4.10.

Table: 4.10 Output of performance indicators in Generic Shifting Bottleneck schedule

Jobs	Number in	Number out	Total time (hr.)	work in process (WIP)	Machine	Machine Utilization (%)
J 1	34	4	69.01	74.85	M 1	84
J 2	40	5	56.66	46.82	M 2	63
J 3	79	8	37.23	73.66	M 3	91
J 4	97	10	46.08	20.05	M 4	35
J 5	36	6	50.84	1.15	M 5	6
J 6	69	7	43.26	16.83	M 6	34
J 7	45	5	46.28	3.73	M 7	11
J 8	126	16	53.28	1.21	M 8	8
J 9	74	12	50.59	1.21	M 9	12
J 10	78	14	41.40	3.24	M 10	12
J 11	36	4	46.83	50.28	M 11	34
J 12	90	9	40.19	24.10	M 12	28
J 13	67	7	44.81	12.49	M 13	31
J 14	83	8	40.53	24.15	M 14	38
J 15	46	3	45.80	26.62	M 15	62
J 16	27	5	76.03	17.06	M 16	28
J 17	31	3	70.88	22.25		
J 18	56	5	39.03	12.36		
Total	**1114**	**131**	**898.72**	**432.08**		
Average						**36.06**

4.3.3 Proposed Production Process Flow

Total lead time is defined as the time it takes for a customer to receive a good or service from the time the customer places the order or performs a purchase transaction. Total lead time can illustrate the performance of several components of the organization and may be more useful in evaluating and improving operations to improve customer lead time (Lead Time). It has three components of order processing time, production lead time and delivery lead time, as it is illustrated below.

- Order processing time: this is the time from when a customer places an order through to purchase order or production orders are generated until production begins on that

particular order. This can be also viewed as the administration time of that order before production or processing starts.

- Production lead time: this is only the time where the product is produced or manufactured. This time includes all value added and idle times during the production process.
- Delivery lead time: this is the time it takes for the product to be delivered to the customer once the product has been produced and all relevant production activities such as quality testing completed and the item is released for delivery

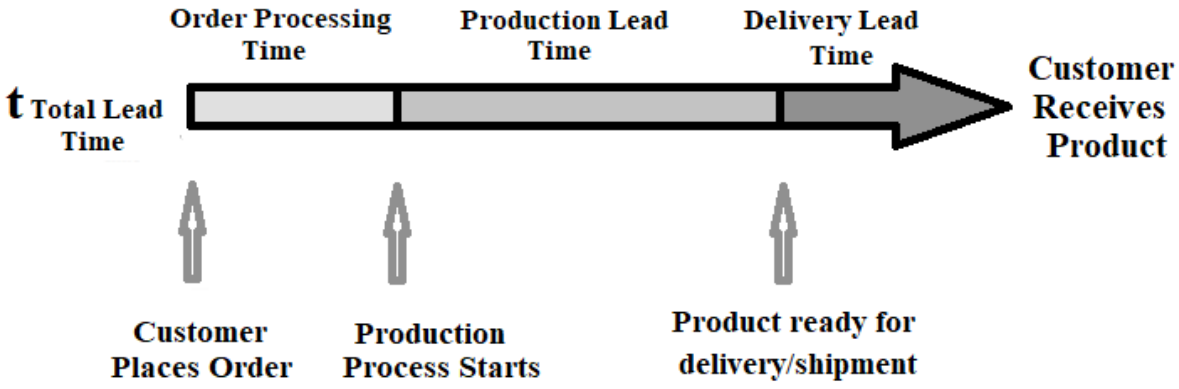


Figure: 4.7 Component of total lead time (Lead Time)

As presented in section 4.1.3, current production process flow has long and complex track of order processing path. After the customer places his or her order in sales and marketing, the order flows into three departments (process design, finance and PPC) for cost estimation and setting delivery time. This makes the process lengthy, and customers to be fed up and dissatisfied. Therefore, to minimize those complications, the researcher proposes new production process flow with reformed flow of order processing path, as it is shown in Figure 4.8. In the proposed production flow, required experts of finance, process design and planning would shift to sales and marketing department, and able to prepare Proforma at the same place. This can help to cut down unnecessary travel time within the company and reduce customer

query time for ordering and total lead time. As a result, it makes easy to control the schedule when new orders are arriving and also increase customer satisfaction.

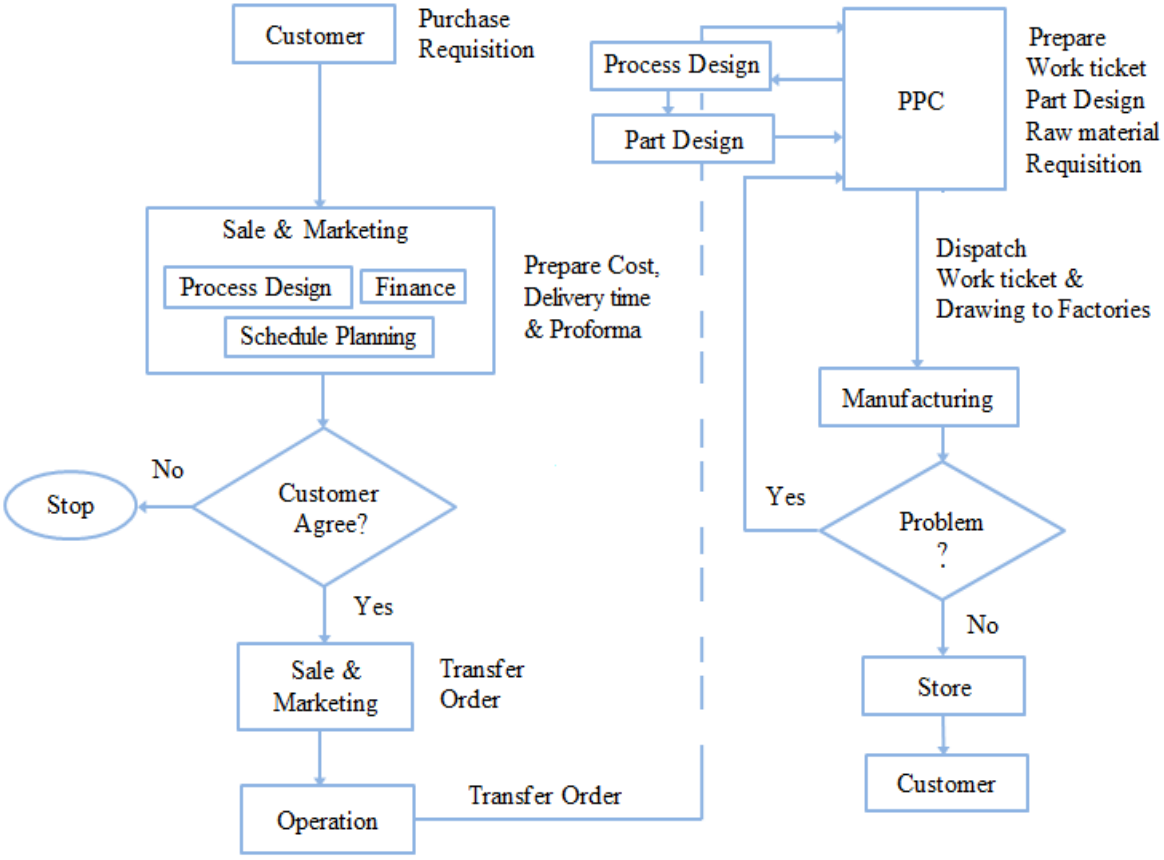


Figure: 4.8 Proposed manufacturing process flow for AMSMI

4.4 Model Validation

Simulation models are approximate imitations of real-world systems and they never exactly imitate the real-world system. Due to that, a model should be validated to the degree needed for the model's intended purpose or application. Therefore, the researcher use 'practical approaches' to validate the simulation models by tracing final simulation results and comparing them with observed outcomes to determine how close is that. Production rate of the factory and completion time of each job are taken as output parameters to compare simulation model with the real system. Moreover, the current production rate of conversional

manufacturing factory (CMF) was determined from the past three (3) month recorded production output, as presented in Table 4.11.

Table: 4.11 Current production rate of conversional manufacturing factory (CMF)

Month	03-2015 E.C				04-2015 E.C				05-2015 E.C				Average
week	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	
Production rate / week													
Ethiopian Construction	66	58	44	88	42	64	81	52	53	55	71	90	63.6667
Sugar Factory	34	31	22	46	20	32	45	31	25	29	19	51	32.0833
Defense Construction	27	24	16	36	18	29	32	23	11	22	15	35	24
												Total	**119.75**

Recorded completion time of each job in the real manufacturing system using Generic SB schedule and simulation outcome of product output and job completion time is presented in Table 4.12.

Table: 4.12 Output of performance indicators in Generic Shifting Bottleneck schedule

Generic Shifting Bottleneck Schedule Model				
Jobs	Recorded time (min)	Simulation Model Output		
		Number out	Time (hr)	Time/unit (min)
J 1	838	4	69.01	762.58
J 2	701	5	56.66	679.97
J 3	349	8	37.23	279.20
J 4	288	10	46.08	276.48
J 5	792	6	50.84	760.32
J 6	403	7	43.26	370.76
J 7	624	5	46.28	555.36
J 8	222	16	53.28	199.80
J 9	377	12	50.59	354.38
J 10	318	14	41.40	295.74
J 11	772	4	46.83	702.52
J 12	308	9	40.19	267.96
J 13	413	7	44.81	384.09
J 14	334	8	40.53	303.94
J 15	604	3	45.80	549.64

J 16	1043	5	76.03	1011.71
J 17	900	3	70.88	828.00
J 18	493	5	39.03	468.35
Total	**9779**	**131**	**899**	**9051**

As per the industry standards, acceptable limit difference between numerical works for validation is between 3 to 5%. But depending on the complexity of the problem, the models used up to 5 to 10% is also acceptable (Sargent, 2010).

- Percentage of error for Production rate = (131 - 119.75) * 100 / 131 = 8.59 %
- Percentage of error for Completion job time = (9779 – 9051) * 100 / 9779 = 7.44 %

Since percentage of error for both parameters is below ten (10) %, then the proposed model can be used as a realistic approach that represents the real production system. Therefore, the proposed solution model is validated to be applicable.

4.5 Result Discussion

Formulated flexible job shop scheduling problem (FJSSP) for Conventional Manufacturing Factory (CMF) in Section 3.4 is solved using Lekin scheduling software that has eight dispatching rule and five heuristics methods, based on the existing scheduling system (FCFS) and alternative schedule scenarios (LPT and Generic SB). Processing time for each job on their processing machine were collected from the factory and feed it to the software according to processing sequence of machines. After processing the inputs, results generated show the optimal performance measures with different dispatching rules and heuristic algorisms. The result has revealed that Longest Processing Time and Generic Shifting Bottleneck Algorithm yields optimal schedule with the objective to minimize makespan. Summarized performance measures obtained for existing scheduling system (FCFS) and alternative schedule scenarios (LPT and Generic SB) are shown in Table 4.13.

Table: 4.13 Performance measures for alternative schedule models using Lekin software

Schedule	Time	Cmax	Tmax	∑Uj	∑Cj	∑Tj	∑wjUj	∑wjTj
FCFS	1	1100	1100	18	9876	9876	9876	9876
LPT	1	1043	1043	18	9090	9090	9090	9090
General SB Routine	1	1043	1043	18	7610	7610	7610	7610

Where, Cmax – Makespan, Tmax -- Maximum Tardiness, ∑Uj -- Number of Late jobs, ∑Cj -- Total Flow Time, ∑Tj -- Total Tardiness, ∑WCj -- Total Weight Flow Time, ∑WTj -- Total Weighted Tardiness

As it is shown in Table 4.13, the performances measures show scheduling with Generic Shifting Bottleneck Algorithm have minimum value of makespan and tardiness among the three schedule scenarios. In the current scheduling system of the factory (FCFS), makespan (1100 minutes) and total tardiness (9876 minutes) are somehow longer than the optimum

schedule makespan (1043 minutes) and total tardiness (7610 minutes). Therefore, when the schedule is changed from existing scheduling system (FCFS) to Generic Shifting Bottleneck, makespan and total tardiness are reduced by 5.1% and 22.9% respectively.

Similar simulation runs had been performed using Arena software for the existing scheduling system (FCFS priority rule) and the other two alternative schedule scenarios (LTP dispatching rule and Generic SB Algorithm). The objective of simulating the models is to evaluate the other side of performance indicators (product output, machine utilization and work in process), and to validate the model with the real production system in the shop floor. For each schedule model, processing time and sequence of machines and jobs are feed to the software to analyze their performance, and generated results for all models with selected performance indicators are summarized in Table 4.14.

Table: 4.14 Performance measures for alternative schedule models using Arena software

Scheduling model	Number out	work in process (WIP)	Machine Utilization (%)
First-Come, First-Serve (FCFS)	126	470.01	31.44
Longest Processing Time (LPT)	130	440.37	34.13
Generic Shifting Bottleneck Algorithm	131	432.08	36.06

As shown in Table 4.14, the performance indicators show Generic Shifting Bottleneck scheduling model has better performance compared to the other model. The product output (131) and machine utilization (36.06%) in the optimum schedule are higher than the product output (126) and machine utilization (31.44%) of the current scheduling system (FCFS) respectively. There are also low works in process inventory (432.08) than the current scheduling system (470.01). Therefore, scheduling using Generic Shifting Bottleneck can increase the product output and machine utilization by 3.8% and 4.6% respectively, and minimize work in process (WIP) inventory by 8%.

Therefore, since the aim of scheduling is focused on minimizing lead time, work in process and machine utilization, the researcher proposes Generic Shifting Bottleneck scheduling model as improved approach for performance of Conventional Manufacturing Industry (CMF).

The Gantt chart or the job sequence on each machine (machine loading) generated by the Lekin software using Generic Shifting Bottleneck scheduling techniques is shown in Table 4.15.

Table: 4.15 Gantt chart of machine loading with optimum schedule

Generic Shifting Bottleneck Schedule			
Machine Code	Job-sequences	Machine Code	Job-sequences
M1.01	J 18 > J 7 > J 5 > J 17 > J 16	M6.04	J 12
M2.01	J 10 > J 11	M7.01	J 3 > J 11 > J 4
M2.02	J 12	M7.02	J 1
M2.03	J 14 > J 6	M8.01	J 15 > J 2
M3.01	J 9	M9.01	J 1 > J 9 > J 11
M3.02	J 15 > J 3	M10.01	J 13 > J 6
M3.03	J 13 > J 4	M10.02	J 4
M3.04	J 8	M11.01	J 9 > J 18 > J 15 > J 2 > J 11 > J 1
M3.05	J 2 > J 1	M12.01	J 12 > J 17 > J 16
M4.01	J 7 > J 5 > J 17	M13.01	J 3 > J 5
M5.01	J 18 > J 6	M14.01	J 13 > J 14
M6.01	J 9 > J 6	M15.01	J 8 > J 6
M6.02	J 10 > J 15	M15.02	J 9 > J 13
M6.03	J 13 > J 14 > J 2	M16.01	J 10 > J 3

Chapter Five

5. Conclusions and Recommendations

5.1 Conclusions

In this research, performance analysis using scheduling system and simulation model is performed for Addis Machine and Spare Parts Manufacturing Industry (AMSMI) using Lekin and Arena simulation software. The study starts by identifying major indicators of production performance in the company and, analyses existing scheduling system (FCFS priority rule) under selected performance parameter. The key performance indicators (KPIs) of the company are lead time, work in process and machine utilization. Further, two alternative scenarios of scheduling system modeling (LTP dispatching rule and Generic SB Algorithm) are proposed using Lekin software and simulated using Arena software to compare and evaluate multiple performance measures. The result designates that Generic SB scheduling model has best performance indicators in the shop floor.

Accordingly, the proposed model analysis (Generic SB Algorithm) shows incremental in performance of, machine utilization and product output by 4.6% and 3.8% respectively and, reduced makespan and work in process (WIP) by 5.1% and 8%, when shifting the existing (FCFS) scheduling system to Generic SB scheduling system. In addition, the proposed simulation model is validated using ‘practical approaches’ and found percentage of error is in between 5 to 10%, which is acceptable as per most industry standards. Therefore, the proposed model is beneficial to the company to enhance its production performance.

Based on the result of this study, the researcher concluded that combining scheduling and simulation model for performance improvement method can optimize different aspect of performance measures. In addition it is concluded that identifying the key performance indicators (KPIs) for manufacturing industry is the first essential activity to achieving performance objective of the industry.

5.2 Recommendations

Based on the drawn conclusions the researcher recommends the company to implement the proposed scheduling model and production process flow to enhance the existing performance of the company. Besides the following additional recommendations are forwarded:

- Clearly define performance objectives which need to be achieved and deploy it in the form strategy at every level of the organization.
- Select and revise regularly the key performance indicators and the critical success factors influencing the performance through observing attentively the evolution of the performance indicators in the production process.
- Use advanced planning and scheduling software like Lekin to help planners save time while providing greater agility in updating ever-changing priorities, production schedules, and inventory plans.
- Regularly control of production process against the schedule to reach success with schedule attainment and recognize obstacles which may endanger the schedule attainment, and try to minimize them.
- Give a training to machine operator on the given schedule and try to perform all the jobs right the first time to minimize rework and the chances to attain a schedule.

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APPENDIX-I: Recorded processing time for each job in CMF

Part Name (Job)	**Spur Gear (J1)**					**Compressor Helical Gear (J2)**			
Precedence Constraints	Conv. Light Lathe Machine (M3)	Conv. Light Milling Machine (M9)	Radial Drill Press Machine (M7)	Gear Hobbing Machine (M11)		Conv. Light Lathe Machine (M3)	Conv. Medium Milling Machine (M6)	Light Drilling Machine (M8)	Gear Hobbing Machine (M11)
No. of Machine	5	1	6	1		5	4	2	1
Round	Recorded processing Time (minute)					Recorded processing Time (minute)			
1st	56	13	22	63		92	14	13	97
2nd	58	11	22	65		93	15	12	90
3rd	56	12	21	64		95	13	10	94
4th	60	9	24	67		93	14	10	94
5th	58	11	22	64		94	15	11	96
6th	55	10	22	63		92	13	13	97
7th	59	14	21	64		92	11	11	92
8th	61	12	22	65		93	14	9	96
9th	53	8	26	67		96	18	12	99
10th	60	13	20	65		93	14	11	95
Avg. Proc. Time (min)	**58**	**11**	**22**	**65**		**93**	**14**	**11**	**95**
Total Completion Time (min)				**156**					**213**

Part Name (Job)	**Coupling Spline (J3)**					**Coupling Hub (J4)**			

Precedence Constraints	Conv. Light Lathe Machine (M3)	Conv. Light Milling Machine (M7)	Inter Spline Cutting Machine (M13)	Spline Grinding Machine (M16)		Conv. Light Lathe Machine (M3)	Slotting Machine (M10)	Conv. Light Milling Machine (M7)
No. of Machine	5	6	1	1		5	2	6
Round	Recorded processing Time (minute)					Recorded processing Time (minute)		
1st	61	13	67	30		136	43	26
2nd	62	11	69	34		133	41	27
3rd	59	10	67	33		136	40	26
4th	60	12	72	32		135	44	25
5th	62	12	74	27		138	45	29
6th	61	13	69	29		136	43	26
7th	61	10	71	33		132	40	26
8th	60	11	68	34		137	41	27
9th	65	17	71	30		140	47	30
10th	61	12	70	31		136	43	27
Avr. Proc. Time (min)	**61**	**12**	**70**	**31**		**136**	**43**	**27**
Total Copm. Time (min)				**174**				**206**

Part Name (Job)	**Gear Coupling (J5)**				**Reducing Flange (J6)**			
Precedence Constraints	Conv. Heavy Duty Lathe Machine (M1)	Conv. Plano Miller Machine (M4)	Inter Spline Cutting Machine (M13)		Conv. Medium Lathe Machine (M2)	Slotting Machine (M10)	Conv. Medium Milling Machine (M6)	Surface Grinding Machine (M15)
No. of Machine	1	1	1		3	2	4	2
Round	Recorded processing Time (minute)				Recorded processing Time (minute)			
1st	189	43	127		131	20	29	93
2nd	186	41	129		134	22	29	93

3rd	187	41	132		135	18	28	91
4th	190	39	126		139	21	27	91
5th	186	42	130		135	21	30	89
6th	185	39	123		136	16	25	86
7th	185	40	128		133	21	28	92
8th	188	42	133		136	19	29	92
9th	193	44	131		135	24	33	94
10th	188	41	129		135	20	29	91
Avr. Proc. Time (min)	**188**	**41**	**129**		**135**	**20**	**29**	**91**
Total Copm. Time (min)			**358**					**275**

Part Name (Job)	**Motor Pulley (J7)**			**Threaded Shaft (J8)**			**Cam Shaft Gear (J9)**				
Precedence Constraints	Conv. Heavy Duty Lathe Machine (M1)	Conv. Plano Miller Machine (M4)		Conv. Light Lathe Machine (M3)	Surface Grinding Machine (M15)		Conv. Light Lathe Machine (M3)	Conv. Medium Milling Machine (M6)	Radial Drill Press Machine (M9)	Gear Hobbing Machine (M11)	Surface Grinding Machine (M15)
No. of Machine	1	1		5	2		5	4	1	1	2
Round	Recorded processing Time (minute)			Recorded processing Time (minute)			Recorded processing Time (minute)				
1st	193	211		128	96		184	24	21	97	52
2nd	189	211		129	93		183	26	19	96	51
3rd	192	208		128	94		182	26	20	96	53
4th	193	213		131	93		185	27	18	99	50
5th	189	212		127	94		183	25	20	98	51
6th	189	207		124	92		180	21	17	93	48
7th	188	210		128	93		182	26	18	95	50

8th	193	209		129	92		183	29	21	97	54
9th	197	215		133	101		188	28	25	101	52
10th	191	211		129	94		183	26	20	97	51
Avr. Proc. Time (min)	**191**	**211**		**129**	**94**		**183**	**26**	**20**	**97**	**51**
Total Copm. Time (min)		**402**			**223**						**377**

Part Name (Job)	**Integrated Spline Shaft (J10)**				**Worm Gear (J11)**			
Precedence Constraints	Conv. Medium Lathe Machine (M2)	Conv. Medium Milling Machine (M6)	Spline Grinding Machine (M16)		Conv. Medium Lathe Machine (M2)	Conv. Light Milling Machine (M7)	Radial Drill Press Machine (M9)	Gear Hobbing Machine (M11)
No. of Machine	3	4	2		3	6	1	1
Round	Recorded processing Time (minute)				Recorded processing Time (minute)			
1st	134	61	127		77	18	12	72
2nd	135	56	125		80	17	13	73
3rd	134	58	127		78	18	11	73
4th	130	57	126		78	19	12	75
5th	136	57	130		76	20	12	73
6th	130	57	123		73	14	8	68
7th	134	55	124		79	16	12	72
8th	135	59	128		79	19	12	74
9th	138	65	131		81	22	16	76
10th	134	58	127		78	18	12	73
Avr. Proc. Time (min)	**134**	**58**	**127**		**78**	**18**	**12**	**73**
Total Copm. Time (min)			**319**					**181**

Part Name (Job)	Worm Shaft (J12)		Spiral Bevel Gear (J13)

Precedence Constraints	Conv. Medium Lathe Machine (M2)	Conv. Medium Milling Machine (M6)	Gear Shaving Machine (M12)		Conv. Light Lathe Machine (M3)	Conv. Medium Milling Machine (M6)	Slotting Machine (M10)	Spiral Bevel Gear Cutting Machine (M14)	Surface Grinding Machine (M15)
No. of Machine	3	4	1		5	4	2	1	2
Round	Recorded processing Time (minute)				Recorded processing Time (minute)				
1st	152	54	101		80	15	11	92	37
2nd	146	57	102		81	14	13	91	39
3rd	150	57	99		83	15	11	93	38
4th	146	55	100		82	16	10	92	37
5th	150	61	106		81	16	12	93	38
6th	145	55	99		76	11	7	88	33
7th	145	56	101		80	13	12	90	38
8th	149	58	102		84	16	12	94	39
9th	156	58	105		84	19	15	96	41
10th	149	57	102		81	15	11	92	38
Avr. Proc. Time (min)	**149**	**57**	**102**		**81**	**15**	**11**	**92**	**38**
Total Copm. Time (min)			**308**						**237**

Part Name (Job)	**Spiral Bevel Gear Shaft (J14)**				**Clutch Sprocket (J15)**			
Precedence Constraints	Conv. Medium Lathe Machine (M2)	Conv. Medium Milling Machine (M6)	Spiral Bevel Gear Cutting Machine (M14)		Conv. Light Lathe Machine (M3)	Light Drilling Machine (M8)	Conv. Medium Milling Machine (M6)	Gear Hobbing Machine (M11)
No. of Machine	3	4	1		5	2	4	1
Round	Recorded processing Time (minute)				Recorded processing Time (minute)			

1st	128	46	116		91	15	28	113
2nd	136	45	122		92	16	26	111
3rd	131	51	118		90	16	27	112
4th	132	49	118		92	17	26	110
5th	129	50	121		91	15	27	112
6th	124	42	112		87	11	24	109
7th	135	44	121		91	15	25	110
8th	132	52	119		91	17	28	113
9th	132	50	120		95	19	32	117
10th	131	48	119		91	16	27	112
Avr. Proc. Time (min)	**131**	**48**	**119**		**91**	**16**	**27**	**112**
Total Copm. Time (min)			**298**					**246**

Part Name (Job)	**Concrete Mixer Gear (J16)**				**Internal Ring Gear (J17)**				**Fly wheel (J18)**		
Precedence Constraints	Conv. Heavy Duty Lathe Machine (M1)	Conv. Vertical Miller Machine (M5)	Gear Shaving Machine (M12)		Conv. Heavy Duty Lathe Machine (M1)	Conv. Plano Miller Machine (M4)	Gear Shaving Machine (M12)		Conv. Heavy Duty Lathe Machine (M1)	Conv. Vertical Miller Machine (M5)	Gear Hobbing Machine (M11)
No. of Machine	1	2	1		1	1	1		1	2	1
Round	Recorded processing Time (minute)				Recorded processing Time (minute)				Recorded processing Time (minute)		
1st	158	19	124		143	57	102		221	31	169
2nd	160	18	125		142	59	101		219	32	167
3rd	159	17	123		142	58	103		221	31	168
4th	158	18	124		141	57	102		220	30	167
5th	159	18	123		143	58	104		222	33	168
6th	154	15	120		139	53	98		217	27	165
7th	159	17	124		141	58	100		218	31	166

8th	160	18	124		143	59	104		222	32	169
9th	162	23	128		147	61	106		225	35	173
10th	159	18	124		142	58	102		221	31	168
Avr. Proc. Time (min)	**159**	**18**	**124**		**142**	**58**	**102**		**221**	**31**	**168**
Total Copm. Time (min)			**301**				**302**				**420**

APPENDIX-II: Summary of literature review on FJSSP

S/N	Author and publisher	Research title	Objective Function	Research Methodology	JSSP Technique	Result/Finding
1	(Bai et al., 2016)	'Flexible open shop scheduling problem to minimize makespan'	Minimize the makespan	-The asymptotic optimality of the general dense scheduling (GDS) algorithm is proven by the boundedness hypothesis. -For moderate-scale problems, the differential evolution algorithm is employed to obtain high-quality solutions. -A series of random experiments are conducted to demonstrate the effectiveness of the proposed algorithms.	Differential evolution algorithm	Reveal the convergence of the GDS-based heuristics and the effectiveness of the DE algorithm.
2	(Anshulika & Bewoor, 2017)	'A Genetic Algorithm Approach for Solving a Flexible Job Shop Scheduling Problem'	Maximizing total Profit	-Scheduling problem for multi-part, multi-period, and multi-operation with parallel machines is formulated -Genetic Algorithm & Integer Programming was programmed using Matlab software and applied to case study	Genetic Algorithm & Integer Programming .	Optimal profit and satisfied constraints
3	(Ziaee, 2018)	'A Mixed Integer Linear Programming Model for Flexible Job Shop	Minimize makespan	- Developed new proposed Mixed Integer Linear Programing (MILP) model -Compared with those of the best known mathematical model	Mixed Integer Linear Programing (MILP)	larger FJSP optimally solved in reasonable time

		Scheduling Problem'				
4	(Liouane et al., 2007)	'Ant systems & Local Search Optimization for flexible Job Shop Scheduling Production'	Minimize makespan	-Two closely related approaches combining Meta-heuristic with local search are developed -The efficiency of the developed method is compared with others algorithm with illustrate example	Meta-heuristic (Tabu Search) with local search	Ant systems with local search meta-heuristic effectively outperform all other alternative techniques.
5	(Elazeem et al., 2011)	'Optimality of the flexible job shop scheduling problem'	Minimize makespan	-Primal problem & Dual problem (Abdou's problem) is introduced. -The method of finding the optimal solution of Abdou's problem is Illustrated - The relationship between the optimal value of the primal problem Abdou's problem is defined.	mathematical model	Optimal solution of Abdou's problem and primal problem could be used as a quality measurement.
6	(Campo et al., 2022)	'Flexible Job Shop Scheduling Problem with Fuzzy Times and Due-Windows: Minimizing Weighted Tardiness and Earliness Using Genetic Algorithms'	Weighted tardiness/earliness.	- Genetic algorithm is proposed by integrating fuzzy logic - Implemented in case study of a fabric finishing production system - Compared with four heuristics adapted to the FJSSP such as earliest due date, critical reason, shortest processing time, and Monte Carlo simulation	Genetic algorithm & fuzzy logic	Efficient performance & solutions (computing time over perform more than 30%)
7	(Schoonenberg, 2013)	'Mathematical Optimization in Flexible Job Shop Scheduling Modeling, Analysis, and Case Studies'	Makespan, weighted average of completion times and tardiness	-Mathematical optimization models are formulated - Priority rules, MILP & Time indexed model incorporated into an iterative procedure -Evaluate objective functions	Priority rules, MILP & Time indexed model	Increase the output of the multi-task cell as well as the machine utilization.

8	(G. Zhang et al., 2019)	'Solving flexible job shop scheduling problems in manufacturing with Quantum Annealing'	Minimize Makespan	-Flexible job shop scheduling problems in various sizes are computed with QA -Demonstrating the efficiency of the approach regarding solutions quality and computing time. -For the evaluation of the proposed approach, the solutions are compared in a scientific benchmark with other algorithms	Quantum Annealing	High potential for solving FJSSP in a time efficient manner.
9	(Ortiz Barrios et al., 2016)	'Integration of Dispatching Algorithm and AHP-TOPSIS Method for Flexible Job-Shop Scheduling Problem: A Case Study from the Apparel Industry'	Minimizing average tardiness	-Proposed an integration of Dispatching Algorithm -Apply and empirical study to case study - Validate the proposed method	Dispatching Algorithm	Scalable and adaptable proposed integration of Dispatching Algorithm in any FJSS
10	(Cayo & Onal, 2020)	'A shifting bottleneck procedure with multiple objectives in a complex manufacturing environment'	Minimize total tardiness and total setup time	-Problem description and scheduling objective - Current scheduling practices and process description - Proposed shifting bottleneck procedure	Shifting Bottleneck Procedure	Efficient production schedule than current methods with minimal computation cost
11	(Kassu & Eshetie, 2015)	'Job Shop Scheduling Problem for Machine Shop with Shifting Heuristic Bottleneck'	Minimize makespan	-Literature Review - Model Representation and algorithm -Routing matrix for case study (data collection) -Apply different simulation run using heuristic options -Select the optimum technique and evaluate the objective function	Shifting bottleneck algorithm	Reduction in total Makespan & identification of least utilized and busiest machines

12	(Tesfaye, 2020)	'Optimization of Job Shop Scheduling Problem'	Minimize makespan	- Literature Review -Routing matrix for case study (data collection) -Apply alternative schedule using heuristic algorithm -Select the optimum technique and evaluate the objective function	Shifting bottleneck heuristic	Total 20.69% reduction in total Makespan as compared to the current schedule
13	(Getachew & Berhan, 2015)	'Simulation And Comparison Analysis of Due Date Assignment Methods Using Scheduling Rules in A Job Shop Production System'	Mean flow time, tardy jobs and average tardiness	-Literature Review -Routing matrix for case study (data collection) - Used flow time due date (FTDD) and total work content (TWK) for setting due dates of jobs - Use scheduling rules shortest processing time (SPT), earliest due date (EDD) and critical ratio (CR) for the scheduling of jobs. - Use least significant difference (LSD) method for performing comparisons	Dispatching rules	FTDD methods is more reliable compared to TWK when evaluated by SPT, EDD and CR scheduling rules
14	(Desta, 2011)	'Optimize Reactive job shop schedule to improve production through heuristic methods'	Minimize makespan	- Literature Review - Routing matrix for case study (data collection) - Analyze current scheduling system -Apply alternative schedule using heuristic algorithm - Select the optimum technique and evaluate the objective function	Shifting bottleneck heuristic	Reduce makespan from 803 min. to 707 min. and 27.1% improvement in machine utilization
15	(Lemma, 2021)	'Productivity Improvement through Job Shop Scheduling Problem'	Minimize makespan	- Literature Review - Routing matrix for case study (data collection) - Analyze current scheduling system - Select the optimum model and evaluate the objective function - Model Verification and Validation	Local search & Shifting bottleneck	Total 5.96% reduction in total Makespan and productivity improved by 7.54%

16	(Ho & Tay, 2008)	'Solving Multiple-Objective Flexible Job Shop Problems by Evolution and Local Search'	Minimize makespan	- Problem Definition - Literature Review - Propose combined guided local search (GLS) with Evolutionary algorithm (EA) - Experiment result and Analysis	local search & Evolutionary algorithm (EA)	High quality, wide range, and efficient performance of Pareto-optimal solutions
17	(Vital-Soto & Olivares-Aguila, 2021)	'Flexible Job-Shop Scheduling Problem with Sequencing Flexibility for Just-In-Time Production Systems'	Minimize the sum of weighted earliness and weighted tardiness	- Literature Review - Mathematical formulation for the Flexible Job Shop Scheduling (FJSPS)-Just In Time (JIT) - Experimentation (testing the mathematical formulation)	Mixed Integer Linear Programming (MILP)	MILP Formulation with sequence flexibility and just-in-time deliveries.
18	(Fattahi et al., 2009)	'Flexible job shop scheduling with overlapping in operations'	Makespan and Machines utilization	- Literature Review - Problem description and formulation - Propose solving approach (Scheduling algorithm, Assignment algorithm, Simulated annealing) - validate or computational experiment on performance of proposed Algorithm	Simulated annealing	Efficient and effective proposed SA algorithm compared to the traditional optimization technique
19	(G. Zhang et al., 2019)	'Solving flexible job shop scheduling problems with transportation time based on improved genetic algorithm'	Minimize makespan	- Literature Review - Problem description and mathematics modeling - Propose improved Genetic Algorithm - Computational experiment and result on performance of proposed Algorithm	Genetic algorithm (GA)	Valid and feasible proposed mathematical model and modified GA

20	(Dang & Tang, 2021)	'Real-Time Data Scheduling of Flexible Job in Papermaking Workshop Based on Deep Learning and Improved Fuzzy Algorithm'	Minimize makespan	- Literature Review - Propose scheduling model based on fuzzy logic and genetic optimization (novel real-time data scheduling method) - Verify feasibility of model by an example	Fuzzy Algorithm & Genetic optimization (deep Learning)	proposed method is much better than the three traditional scheduling methods

APPENDIX-III: Selected simulation model output from Arena

Table - Shop performance of First-Come, First-Serve schedule under selected measures

10:02:57AM **Category by Replication** March 8 , 2023

First Come – First Served (FCFS) Schedule

Replication 8 Start Time: 00 Stop Time: 40 Hours

Key Performance Indicators

System

	Average
Number Out	126

Entity Time Units: Hours

	Number In	Number Out	WIP	Total Time
	Value	Value	Average	Average
Job 1	134	15	76.8532	35.945
Job 2	66	7	50.8227	36.4396
Job 3	123	13	80.6642	29.8133
Job 4	102	11	26.0454	36.608
Job 5	59	7	3.1545	34.8333
Job 6	78	9	17.8309	37.398
Job 7	36	4	4.7273	34.888
Job 8	97	7	2.2136	22.995
Job 9	36	4	5.2086	36.472
Job 10	67	6	3.9449	29.295
Job 11	92	10	53.2805	34.7316
Job 12	57	6	27.0996	33.408
Job 13	65	8	18.4915	25.76
Job 14	51	5	16.3626	32.6841
Job 15	45	6	26.6188	39.767
Job 16	32	4	22.0568	40.052
Job 17	27	2	18.7685	40.096
Job 18	18	2	15.8642	43.9733

First Come – First Served (FCFS) Schedule

Replication 8 Start Time: 00 Stop Time: 40 Hours

Resource

Usage

Scheduled Utilization	Value
M 1	0.82
M 2	0.56
M 3	0.86
M 4	0.28
M 5	0.04
M 6	0.23
M 7	0.08
M 8	0.05
M 9	0.07
M 10	0.09
M 11	0.56
M 12	0.31
M 13	0.23
M 14	0.21
M 15	0.31
M 16	0.23

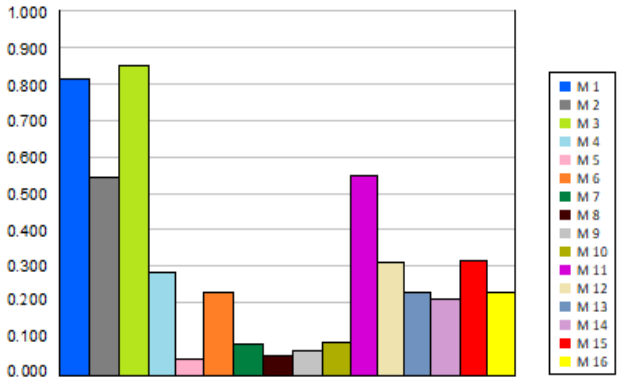


Table - Shop performance of Longest Processing Time schedule under selected measures

11:13:25AM **Category by Replication** March 8 , 2023

Longest Processing Time (LPT) Schedule

Replication 5 Start Time: 00 Stop Time: 40 Hours

Key Performance Indicators

System

	Average
Number Out	130

Entity Time Units: Hours

	Number In Value	Number Out Value	WIP Average	Total Time Average
Job 1	30	4	71.4872	45.5
Job 2	37	5	45.8887	49.3891
Job 3	74	8	74.4582	37.3333
Job 4	78	9	22.8414	41.472
Job 5	39	4	1.2645	50.5855
Job 6	56	7	25.8069	43.47
Job 7	37	5	2.3123	41.6
Job 8	99	12	16.8515	44.748
Job 9	40	5	1.2136	44.5716
Job 10	116	13	1.3649	38.8895
Job 11	43	5	50.4880	46.55
Job 12	72	9	22.2556	40.5855
Job 13	94	11	1.3986	40.7495
Job 14	79	9	17.2576	38.16
Job 15	89	11	28.0178	41.8751
Job 16	34	3	14.8698	51.87
Job 17	25	3	19.5455	50.688
Job 18	54	7	23.0485	41.4

Longest Processing Time (LPT) Schedule

Replication 5 Start Time: 00 Stop Time: 40 Hours

Resource

Usage

Scheduled Utilization	Value
M 1	0.83
M 2	0.60
M 3	0.89
M 4	0.32
M 5	0.06
M 6	0.60
M 7	0.10
M 8	0.07
M 9	0.10
M 10	0.12
M 11	0.29
M 12	0.33
M 13	0.28
M 14	0.26
M 15	0.35
M 16	0.26

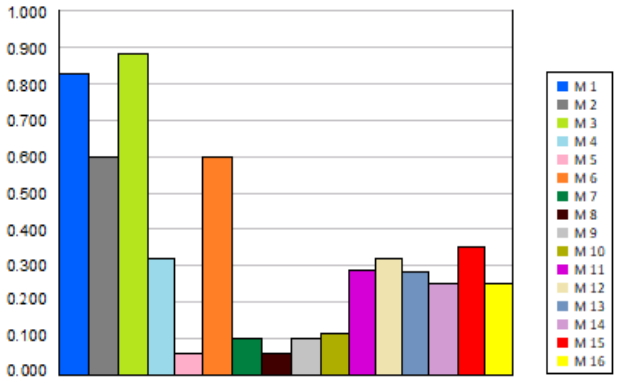


Table - Shop performance of Generic Shifting Bottleneck schedules under selected measures

12:08:03AM **Category by Replication** March 8 , 2023

Generic Shifting Bottleneck Schedule

Replication 7 Start Time: 00 Stop Time: 40 Hours

Key Performance Indicators

System

	Average
Number Out	131

Entity Time Units: Hours

	Number In Value	Number Out Value	WIP Average	Total Time Average
Job 1	34	4	74.8532	69.006
Job 2	40	5	46.8227	56.6641
Job 3	79	8	73.6642	37.2266
Job 4	97	10	20.0454	46.08
Job 5	36	6	1.1545	50.8386
Job 6	69	7	16.8309	43.2553
Job 7	45	5	3.7273	46.28
Job 8	126	16	1.2136	53.28
Job 9	74	12	1.2086	50.5855
Job 10	78	14	3.2449	41.4
Job 11	36	4	50.2805	46.8346
Job 12	90	9	24.0996	40.194
Job 13	67	7	12.4915	44.8105
Job 14	83	8	24.1549	40.5253
Job 15	46	3	26.6188	45.8033
Job 16	27	5	17.0568	76.032
Job 17	31	3	22.2541	70.876
Job 18	56	5	12.3626	39.0291

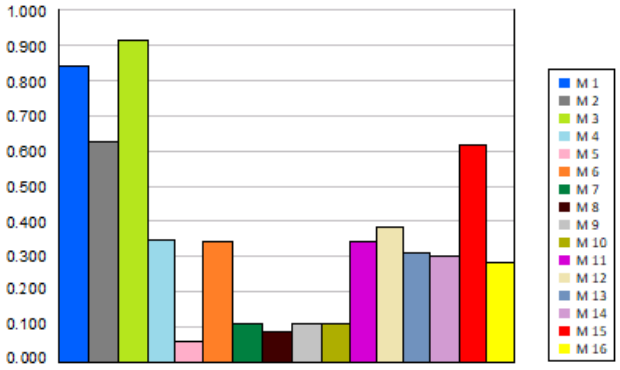
Generic Shifting Bottleneck Schedule

Replication 7 Start Time: 00 Stop Time: 40 Hours

Resource

Usage

Scheduled Utilization	Value
M 1	0.84
M 2	0.63
M 3	0.91
M 4	0.35
M 5	0.06
M 6	0.34
M 7	0.11
M 8	0.08
M 9	0.12
M 10	0.12
M 11	0.34
M 12	0.38
M 13	0.31
M 14	0.30
M 15	0.62
M 16	0.28



APPENDIX-IV: Structured Check List

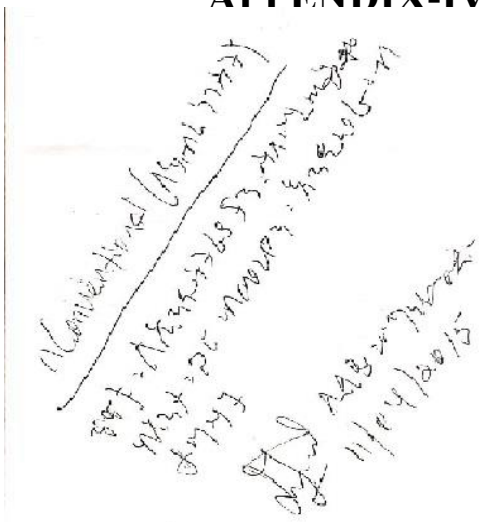
Table- List of expected attributes items

1	How much is the design production capacity of the company?	
2	How much is the actual production capacity of the company?	
3	What is the current production process flow in the company?	
4	What type of scheduling methods is the company using?	
5	What are the performance indicators in the factory?	
6	What are the performance objectives of the company?	
7	Who are the potential customers?	
8	What are the products purchases by potential customers?	
9	What type of layout the factory is using?	
10	Which are the available active machines in the factory?	

Table- Jobs and machines routing

Type of jobs	Machine Sequence	Processing time		Type of machines	Qty.
J 1				M 1	
J 2				M 2	
J 3				.	
.				.	
.				.	
.				.	
.				.	
.				.	
.				.	
J 16				.	
J 17				M 15	
J 18				M 16	

APPENDIX-IV: Data Collection Request Form



AAiT
Addis Ababa Institute of Technology
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School of Mechanical and Industrial Engineering
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Tel: +251 (0)111 232414
email: dean.smie@aait.edu.et

Date: - 10 - 04 - 15

DATA COLLECTION REQUEST FORM

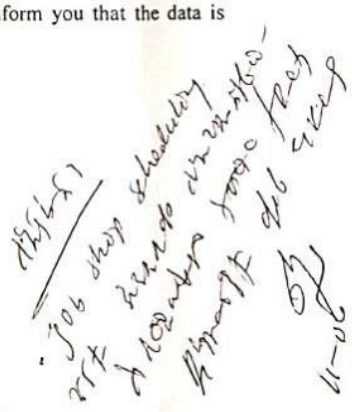
To:- Ethio-engineering Group Addis Machine and Spare Part Manufacturing Industry

Mr./Mrs. Misgana Setu Ayenalem, is a BSc/MSc/PhD student in our School at, Addis Ababa Institute of Technology, Addis Ababa University at this Moment he/she is doing his/her thesis/ Project/ term paper entitled

"Enhancing Performance Through Job-shop Scheduling".

In order to successfully complete his/her paper, the student wants to obtain information from your factory/Industry /Organization.

The School strongly appreciates for any sort of assistance you provide to our student related to his/her thesis/ Project/ term paper. In addition, we would like to inform you that the data is required for educational purpose.

Thank you in advance for your cooperation.

Dr. Araya Abera
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Addis Ababa Institute of Technology
Addis Ababa University