Addis Ababa University

Institute of Technology

School of Mechanical and Industrial Engineering

Post Graduate Program in Industrial Engineering

Title: - Productivity Improvement through Job Shop Scheduling Problem

(The case study of Akaki Basic Metal Industry)

Prepared by: - Negash Lemma

Submitted To: - Dr. Gezahegn Tesfaye

September , 2021

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

This is to certify that the thesis prepared by Negash Lemma, entitled: Productivity Improvement through Job shop scheduling problem: Case Study of Akaki Basic Metal Industry and submitted in partial fulfillment of the requirements for the degree of Master of Science (Mechanical and Industrial Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by Examining Committee:

Dr. Birhanu Beshah _____________________ ____________________

Internal Examiner Signature Date

Dr. Marertu Wakuma______________________ ___________________

External Examiner Signature Date

Dr. Gezahegn Tesfaye_____________________ ______________________

Advisor Signature Date

_____________________ ___________________

Co-Advisor Signature Date

Dr. Yilma Tadesse _____________________ ______________________

School Dean Signature Date

Declaration

I hereby declare that the work which is being presented in this thesis entitled "Productivity Improvement through Job shop scheduling problem: Case Study of Akaki Basic Metal Industry" is original work of my own, has not been presented for a degree of any other university and that all sources of material used for the thesis have been duly acknowledged.

__________________________ __________________

Negash Lemma Date

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

_______________________ _______________________

Dr. Gezahegn Tesfaye Date

Acknowledgment

First and foremost I would like to thank the almighty ***GOD and his mother the Virgin Marry*** for giving me the courage, and strength to start and complete the research. Next, I would like to express my deepest, and thanks to my advisor ***Dr. Gezahegn Tesfaye*** for his unreserved and continuous assistance to complete this research. His encouragement, excellent guidance, creative suggestions, and critical comments have greatly contributed to this thesis.

I am also really indebted to ***Mr.Birhanu T. and Mr.Edossa D.*** for their genuine encouragement, motivation, and I have learned a great deal of knowledge, and skills from both. I would like to thank my friends and classmates; it was also such a nice time that I had all of the support was fantastic.

I would also like to acknowledge the management staff member and workers of the Akaki Basic Metal Manufacturing Industry, and different organizations for their cooperation and assistance to get valuable information for the research, and who have responded to my questionnaires and interviews.

Last but not least, grateful acknowledgment to all my family members My Dad, Mom, Sisters, and Brothers for their love and for providing me the opportunity to be where I am, for all their love and whom never gives up in giving their support to me in all aspects of life.

Abstract

Productivity is the measure of how efficiently inputs are converted into outputs in the manufacturing industries. Metal manufacturing industries want to produce large quantities of productivities in shorter make-spans in order to stay and compete in the global market. So, Job shop scheduling problem is an important approach in the field of the scheduling problem to improve productivity and optimize the make-span.

Due to this reason, Akaki Basic Metal Industry (ABMI) has faced a problem to determine the proper allocation of jobs on the machines that can optimize the make-span and productivity improvement. Therefore, the purpose of this study is to minimize the make-span and improve the productivity of the ABMI machine shop using shifting bottleneck and local search algorithms.

To undertake this research, primary and secondary data were used for seven jobs(products) with six workstations that arrived during the research period. Finally, the findings of the study using shifting bottleneck and local search algorithms showed that the make-span is reduced from 470 to 442minutes by a 5.96% improvement. The productivity also improved by 7.54% per machine/ shift improvement.

Keywords: *Productivity, JSSP, Make-span, DASH, Local search.*

Table of Contents

List of Figures

List of Tables

List of Acronyms

ABMI-Akaki Basic Metal Industry

PAM-Productivity accounting model

PI-Productivity Improvement

GTP-I-Growth transformation plan one

GTP-II-Growth transformation plan two

MFP-Multi-factor productivity

OR-Operation research

ILO-International Labor Organization

GNP-Gross national product

GDP-Gross domestic production

JSS-Job-shop scheduling

JSSP-Job-shop scheduling problem

EDD-Earliest due date

LPT-Largest processing time

SPT-Shortest processing time

CR-Critical ratio

CDS-Campbell Dudek and Smith

NEH-Nawaz Enscor and Ham

MS–Micro-soft

PCU- Planned Capacity Utilization

ACU-Actual Capacity Utilization

Chapter One

Background and Justification of Research

1.1 Introduction

Productivity is the measure of inputs are converted to outputs in the manufacturing industry (Duran, Cetindere, & Aksu, 2015). So, productivity improvement (PI) is the result of managing and intervening in manufacturing processes (Tadiyos, 2018). In this era, several challenges are facing the make-span and productivity of the manufacturing sector (Bayeh, 2019).

Job shop scheduling problems is helps to finding the sequential allocation of jobs on the given resources and jobs that optimizes a particular objective function. This method consists of set of ‘n’ jobs with a number of ‘m’ machines (Ramkumar et al., 2011). So, the Job Shop Scheduling Problem (JSSP) is an important approach that contains different applications in manufacturing scheduling problems (Bewoor, 2016). It is used to optimize make-span for process-based manufacturing sectors than others approach like; line balancing, flow-shop scheduling, etc. and improve the productivity of the manufacturing industry (Alzahrani, 2019). It is also the most popular scheduling problem attracted by many authors due to its practical or theoretical importance and complexity (Tesfaye, 2020).

Several studies have reported various productivity improvement techniques; like lean manufacturing (Choomlucksana et al., 2015), (Nunesca & Amorado, 2015), ergonomics (M. D. Singh et al., 2015), cellular manufacturing (Biswas, 2013), work-study (S. A. Gujar, 2018), line balancing (Shukla et al., 2018), (Bayeh, 2019), (Aregawi Yemane et al., 2020), method-study (Mishra, 2015), string diagram (Shah et al., 2014), etc. to improve productivity in the manufacturing sectors. Some techniques are based on technology, employee, process, product, and material (Mazumder, 2014). However, productivity improvement through job shop scheduling problems has not been emphasized by the existing literature. As the result, it is difficult for many industries to optimize make-span and improve their productivity.

The Ethiopian metal manufacturing sector faces a large make-span which is taken as the cause of low productivity (Tadiyos, 2018). To mitigate this problem, it is apparent to apply a JSSP, which is one of the process-based techniques that can reduce the make-span and improve the productivity of manufacturing sectors (T. V. Kumar & Babu, 2014). The mitigation of make-span in any manufacturing industry was more useful to improve productivity; because make-span and productivity were considered as a coined phase (Mazumder, 2014).

Generally, the Ethiopian metal manufacturing industries could be considered as the lowest contribution. The below table indicates the overview of the Ethiopian metal industry concerning other manufacturing sectors.

Table: 1.Ethiopian industry sectors overview

Nº	*Industry Sector*	*#Factories*	*# Employees*	*Planned Capacity. %*	*Actual Capacity. %*	*Perf. %*
1.	Agro-Processing	687	68,759	85.32	69.01	80.88
2.	Paint industry	11	12,845	75.71	62.31	82.30
3.	Textile and Garment	77	19,214	80.51	67.13	83.38
4.	Leather Industry	141	14,101	84.15	59.02	70.14
5.	Cement industry	14	12,478	87.73	62.13	70.82
6.	Chemical Industry	183	10,926	79.86	64.03	80.18
7.	Food & Beverage	20	10,547	70.32	57.01	81.07
8.	Metal Industry	243	13,431	82.21	56.44	**68.65**

Source: (Tadiyos, 2018)

The above table indicates the metal industries Vs. the Ethiopian manufacturing industries' average of planned to produce and attained capacity, while the metal industry installed capacity and achieved capacity shows the lowest capacity among others manufacturing sectors. So, due to these reasons the metal manufacturing sectors were selected among other sectors. According to (Ethiopian association of basic metals & engineering report, 2020) the maximum productivity among the metal manufacturing industries was 96.27% and the minimum productivity was 44.74% as indicated in the figure below.

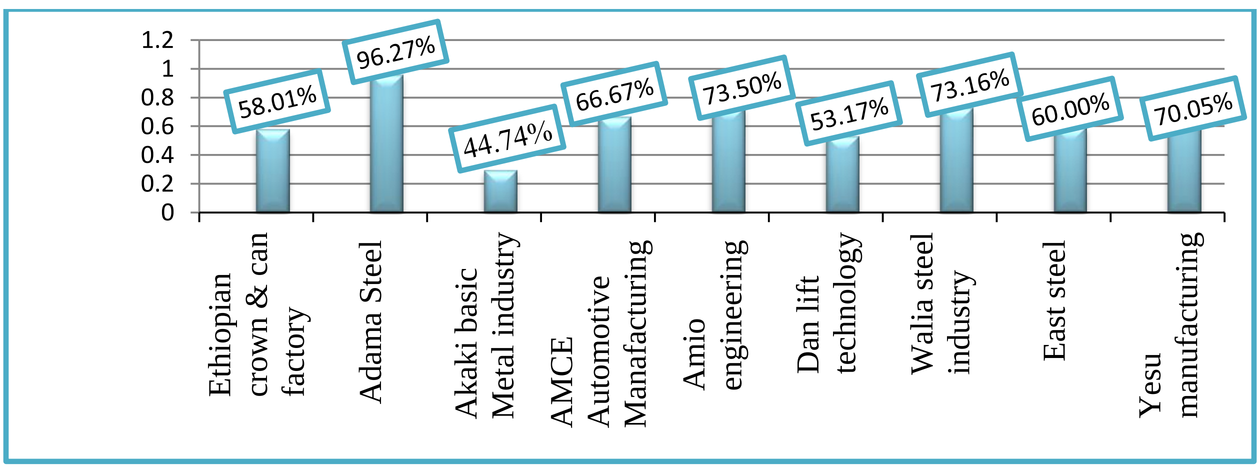


Figure: 1: The major Ethiopian metal industries performance status

(Ethiopian association of basic metals & engineering report, 2020)

Based on the above figure, the Adama steel manufacturing plant has a relatively higher performance status; whereas; Akaki Basic Metal Industry has the lowest. Due to this reason the Akaki Basic Metal Industry was selected as a case study.

In metal manufacturing industries, assigning the jobs with the given machines is difficult due to many operations done manually. So, arena simulation, and Lekin, software are some tools helpful ways to build up machine shop schedules. These approaches assist to solve the critical factors of the machine shop scheduling problem (Shukla et al., 2018). Generally, this research focuses on productivity improvement through job shop scheduling problems by identifying the make-span scheduling problems and suggests productivity improvement methods by taking Akaki Basic Metal Industry (ABMI) as a case study.

1.2 Background and Justification of the case study

Different manufacturing industries categorizes under micro small, medium and large scales based on their capital investment, number of employees, and it is known that Ethiopia is not well known for its competent manufacturing industries. Akaki Basic Metal Industry is a large-scale business organization mainly engaged in the manufacturing and sale of spare parts, hand tools, cutlery, and so on. It contains different production workshops with multipurpose machinery and located in the south of Addis Ababa about 25km on the Addis Ababa/Nazareth main road and about 3km east of the village of Akaki. It was initially established as the public enter pries in 1989 in the name of Akaki Spare parts and Hand Tools Factory.

Metal products are scheduled as it passes through a manufacturing process in a shop and it failed to meet the planned productivity in a targeted make-span. The reason for unmeet plan associated with poor scheduling, lack of raw materials, absenteeism of workers, maintenance, and so on are some factors for longer make-span and lower productivity of Akaki Basic Metal Industry (C. Ferreira, 2020). So, reducing make-span and improving productivity was one of the main concerns of metal manufacturing sectors (Alene, 2020). Thus, the job shop scheduling problem is the most important method that can help to improve productivity in the metal products industry.

1.3 Problem statement

The existing productivity and make-span of Akaki basic metal industry as statistical data report indicated the planned & actual productivity and make-span were failed to meet. When comparing the productivity targeted with actual productivity was only met 27.07% and the planned make-span with the actual make-span was 59.74% (Company's statistical report, 2020).

According to the six-year make-span and productivity report surveyed by the researcher, the Akaki basic metal industry faced the following major problems concerning the issue of the failure to meet planned and actual make-span and productivity. Like: workers absenteeism, breakdown of machines, lacks of raw materials, improper allocation of jobs on the given machines, and so on are considered factors during the research work. Among them, the improper allocation of jobs on the given machines was the main reason, why because the Akaki Basic Metal Industry follows the first come first server system, and the next breakdown of machines, lack of raw materials, operator’s absenteeism or late-in and early-out, etc. (Respondents, 2020).

Due to these reasons, the longer make-span and lower productivity showed in the workstation. Therefore, the main contribution of this research is to reduce the makes-pan and improve the productivity through the job shop scheduling problem of the Akaki Basic Metal Industry, and to make it competitive on the global stage.

1.4 Research Questions

The above problem statement can be specified in terms of the following research questions:

1. What is the existing productivity of the Akaki Basic Metal Industry?
2. Which factors are lowering productivity in Akaki Basic Metal Industry?
3. What methods are used to improve productivity in Akaki Basic Metal Industry?

1.5 Objectives

1.5.1 General objectives

The main objective of the study was to improve productivity through the job shop scheduling problem approach at Akaki Basic Metal Industry.

1.5.2 Specific objectives

The specific objectives of the research include:

- Assess the existing productivity of the Akaki Basic Metal Industry.
- Identify the factors that lowering the productivity of the Akaki Basic Metal Industry.

- Propose productivity improvement methods for the Akaki Basic Metal Industry.
- Suggest a possible solution to improve the productivity of the Akaki Basic Metal Industry.

1.6 Scope of the Study

The case company contains different product types and shops such as foundry shop, machine shop, forging shop, and laboratories & quality control shop. The scope of the study bound on productivity improvement through the job shop scheduling problem approach and focuses on machine shop scheduling to identify and solve production scheduling problems for productivity improvement in Akaki Basic Metal Industry.

1.7 Significance of the Study

The study outcome benefits the Akaki Basic Metal Industry and other manufacturing sectors by applying the productivity improvement technique helps to improve the status of productivity factors available in the industry. Moreover, the improvement technique brings tangible changes in the manufacturing process of metal. The study findings are also, used as an input for academicians, research institutes, and any interested party who dares to learn about the productivity improvement techniques, and it can also be used as an input in other factories under this sub-sector with no or little modification.

1.8 Organization of the study

The paper was organized into five chapters. Chapter one was an introductory part, like research questions, problem statement, objectives, scope, and significance of the study. Chapter two: literature review about productivity improvement, job shop scheduling problems, review of studies of productivity improvement in manufacturing sectors, and gaps. Chapter three: research methodology, and method of data analysis discussed. Chapter four: deals with results and discussion. Chapter five: conclusion, recommendation, and future research area.

Chapter Two

Literature Review

2.1 Introduction

In this section literature review on the basics of productivity, productivity improvement methods, job shop scheduling problems, and productivity improvement through job shop scheduling problems by different authors, and modeling approaches for productivity improvement which have been done so far will be presented in detail. It is also part of this section that describes factors that affecting productivity. Finally, the literature reviews on this area have been undertaken a literature summary, and gaps identified from the literature were presented.

2.2. Productivity

The definitions of productivity are based on the perspective of an individual or organization, due to this reason; the authors put their meaning for it. As Angerasa, (2018) defined, productivity is the main factor on which manufacturing sectors convert inputs into output. Productivity increases when output increases than inputs, which makes the existing resources more productively efficient (S. P. Singh, 2016).

2.2.1 Factors affecting productivity

Productivity improvement is an important issue in different manufacturing sectors in order to stay alive in the competitive market because it is one of the major determinants that enable manufacturing organizations to compete in the global market (Tadiyos, 2018). According to Eilon et al., (2019) productivity is a procedure that transfers a set of input into a set of output. But, productivity can be affected by controllable (internal) factors and uncontrollable (external) factors. However, there are multidimensional productivity factors related to human, machine, material, method, process, and organizational factors (Tesfaye, 2020).

2.2.2 Productivity Measurement

Productivity measurement is helpful to indicate particular factors, which might have caused to decrease in productivity. The basic objective of productivity measurement is to find out some ideas to improve productivity and apply them in the field of resource utilization. So, at the industry level productivity measurement is very helpful and comparisons of productivity change within the manufacturing industry (Eilon et al., 2019). Generally, the importance of productivity measures is to provide little guidance for both public and private economic policy (Tadiyos, 2018). Productivity measures are useful in motivation improvement, estimating resources requirements, organizational improvement, resource reallocation, operation control, etc. (Sci et al., 2015).

Productivity measurement can be measured by total productivity, partial productivity, and multi-factor productivity (Chhabra, 2019). According to Eilon et al., (2019) to measure the productivity of a particular period, the same types of data are collected for that period and obtain the productivity measurement. Hence, for productivity measurement, and to develop the company productivity, the appropriate input, and output units, compatible with others have to be used.

The productivity of a manufacturing system can be defined as the amount of work accomplished per unit of time using available resources (Firake & Inamdar, 2014). Productivity is a relation between output produced through the manufacturing process and input used to produce output. Therefore, minimizing the factors related to machine, material, and labor brings an opportunity to improve productivity (Yogesh, 2018).

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \quad (2.1)$$

Productivity is also confused with terms like efficiency and effectiveness. Efficiency and effectiveness are two different terms. Efficiency indicates how well the resources are utilized to accomplish the result. Productivity is the measure of effectiveness and efficiency to which inputs are utilized for the creation of outputs. In the manufacturing industry; output is taken as the number of goods manufactured, and input is the employers, machinery, and other resources required to produce those goods within a given time (Firake & Inamdar, 2014).

2.2.3 Productivity measurement models

Productivity measurement models are available to measure productivity at the micro-levels. At the macro level, the models should be proposed for the manufacturing industry. The below major classification were possible approaches on which they should construct (Eilon et al., 2019).

- ✓ Production function models
- ✓ Financial ratios as measures of productivity
- ✓ Production-based models

- ✓ Surrogate models
- ✓ Systems approach based models
- ✓ Productivity accounting model
- ✓ Economic utility models

a) Production function models

This model represents the traditional attempts to measure the productivity of any manufacturing industry. It also considers production as a major activity of manufacturing organizations. Therefore, the measurement of productivity was similar to the measurement of productivity of production function. Production function was perceived as a function of several input factors (Tadiyos, 2018).

b) Financial ratios as the measurement of productivity

Financial ratios are used to evaluate the financial performance of the company. Productivity was based greatly on the activity, and stability of concern. Therefore, areas like creditors' turnover, liquidity, profitability, stability, stock, and coverage are concerned for productivity measurement. Thus, if the above factors are favorable, it would indicate more productivity (Eilon et al., 2019).

c) Production-based models

Production-based models grouped into two classes (S. P. Singh, 2016):-

- ✓ Models rely on output as value addition and value of production.

Models based on output as the value of production

According to A. Moktadir, (2017) explained, there are three kinds of productivity measurement indexes in manufacturing industries.

- ✓ Single productivity-index => Out-put per single input,
- ✓ Total productivity-index => Total out-put per all input, and
- ✓ Total factor productivity-index => Net out-put per total factor input.

where, Net-output = Out-put – Intermediate goods/services

- ✓ Total factor input = Labor + Capital

Models depends on output as value addition

According to Firake & Inamdar, (2014) states that value-added is to enhance the market value of location, and availability of products. It emphasizes too much on labor and has limitations.

d) Partial productivity models

These models are used for small set-up in highly affecting factors of productivity. Key activities that connected with total productivity were stated under this model. With help of data records, productivity under the partial productivity approach can be measured (Duran, Cetindere, & Emre, 2015).

- ✓ Productivity-index = Actual-pay per standard-pay; Here,
- ✓ Actual-pay means a pay; paid for the labor
- ✓ Standard-pay = Standard-rate of pay * Hours-worked

e) Systems approach based models

As Firake & Inamdar, (2014) stated that, the activities of productivity measurement were reduced to measure the output created concerning input consumed during the manufacturing process.

f) Productivity accounting model

The Productivity accounting model was used to measure the productivity through total out-put to total in-put. It is also grounded on basic accounts of industries (Eilon et al., 2019). According to Tadiyos, (2018) stated the model may help in areas of improvement, and take into account all outputs and inputs for the measurement of productivity. The productivity-accounting model was the model under the above-mentioned conditions that were satisfied.

g) Economic-utility models

This approach was recommended for the use of multi-ratios that reflecting on the particular economic-utility function. The ratio concept of out-put into input was not followed in this model. It was useful in the measurement of productivity at the macro-level instead of the micro-level (Duran, Cetindere, & Emre, 2015).

2.2.4. Productivity improvement

Productivity Improvement (PI) is the result of managing and intervening in manufacturing processes. It is considered expensive when it was not aware of the benefits to achieve the execution due to diligence (Tadiyos, 2018). Some factors affect productivity negatively and positively; where some they controlled & others cannot be controlled due to different limitations (Jadayil et al., 2017). Aspects dealt with improving productivity were discussed as below.

2.2.4.1. Productivity improvement-based on indices of productivity

a) Labor based productivity

Labor-based productivity is an important factor that affecting productivity. The allocation of the right labor on the right job, labor-training, proper maintenance of machines, incentive payment, the flow of raw materials, proper allocation of jobs on a given resource, and working conditions are the procedure considered under labor-based productivity (Jadayil et al., 2017) and (Angerasa, 2018). Labor-productivity = total out-put per labor-input

- Labor productivity increased when increasing the efficiency of labor and reducing labor time (Tadiyos, 2018).

b) Material-based productivity

Material productivity increased when designing the suitable minimum consumption of material, and preparation of bill of materials that prevent excessive use of materials. Bill of materials indicates the specified units raw materials required for produce goods at right time, and price from the right source. Material productivity is based on how the material was utilized effectively in its' finished products. Material productivity = total output per material input (Tadiyos, 2018).

c) Machine-based productivity

Machine productivity increased through proper maintenance, optimum uses of machine time, proper scheduling of jobs, and loading work to avoid bottlenecks of machines. Machine-productivity= total output per machine input (Jadayil et al., 2017)**.**

d) Capital-based productivity

For any productivity, facilities of tools, machines, land, etc. were required for assets of manufacturing industries. Thus, the capital was required for such assets (Alzahrani, 2019). Capital-based productivity depends on how effectively assets are utilized. In the manufacturing process incurs salaries of labor employed on keeping store, planning, inspection, recording, etc. were capital based. Capital-based productivity = total output per capital input (Tadiyos, 2018).

2.2.4.2. Productivity improvement through work-study

Work-study was an important tool to obtain higher productivity. Improve the efficiency of manufacturing, requires effective use of equipment, labor, etc. and this can be achieved through work-study (S. Gujar & Moroliya, 2018). Productivity was affected by different factors such as land, labor, material, machine, and capital (M. D. Singh et al., 2015).

2.2.4.3. Productivity Improvement through job shop scheduling

The job shop scheduling, in which we must determine the order or sequence for processing a set of jobs through several machines in an optimum manner, has received considerable attention. Due to this case, there are different approaches or techniques for improving productivity in job shop scheduling as below mentioned categories (Leusin et al., 2018):

- Analytical techniques and
- Graphical techniques

Analytical techniques: it is the mathematical approach of assigning jobs to machines/ work centers that are derived to optimize certain criteria and obtain an exact solution. To assign jobs to the existing resources with the recorded time was provided by the scheduling technique. The scheduling techniques were described as dispatching rules for ordering jobs to the existing resources. In manufacturing sectors, job shop scheduling problems were applying the priority or dispatching rules with a process designed to provide the best solutions for the complex problems (Lemma, 2019).

According to Chang et al., (2015), some different analytical techniques or methods provide exact, and approximation solutions in job shop scheduling (JSS), such as exact methods like branch & bound relaxation, and linear programming. Generally, JSS uses various representations in its model and consists of a set of M_i machines when i=1, 2, 3...m, N_j jobs and when j=1, 2, 3…n, and a plan which assigning these jobs on the given machines in some desired orders.

Each job contains the specified number of activities performed on the given machines, their setup times, and processing times. The JSSP deals with the search for optimal scheduling and sequencing of the operations on the given machines within the specified orders (Sharma & Jain, 2016).

Graphical methods: it provides approximation optimal or near-optimal solutions, and allows to forecast problems early enough to take corrective action, which provide alternative plans; and different graphical methods provide an approximation or near to optimal solutions in job shop scheduling problems, such as dispatching rules and simulation-based approaches (Nawara, 2013).

Dispatching rules are used to solve sequencing problems, and provide optimal solutions for complex problems in a real-time production environment, and optimize the job shop-scheduling problem, and are categorized into dynamic and static rules. Static rules unchanged with the function of time or do not rely on time, but dynamic rules are time-dependent rules (L. Kumar, 2014).

2.3. Job shop scheduling

Job shop scheduling was described as the group of manufacturing activities where the production resources are collected as the function and work passes through different routes. It was characterized by a single product designed and manufactured in the given period (Waschneck et al., 2017).

Job-shop scheduling (JSS) is a schedule planning for low volume systems with many variations in requirements and allocation of shared resources over time to competing activities. In the job-shop scheduling problem (JSSP) environment, there are '**J**' jobs to be processed on '**M**' machines with a certain objective function to be minimized. JSSP with J jobs to be processed on more than two machines has been classified as a combinatorial problem. Thus, it was used to determine the optimum orders of jobs on the given machines that optimize the make-span through different algorithms (Dave, 2016).

Job shop production equipment is usually of a general-purpose nature to provide the flexibility necessitated by the variation in size, shape, quantity, precision, and type of product. Usually, similar machines are grouped into work centers, and originally each machine can perform a variety of tasks. The job scheduling problem consists of determining the order or sequence in which the machines will process the jobs to optimize some measure of performance and to minimize the make-span, job shop scheduling problem is considered as an optimization approach (Alzahrani et al., 2019).

Therefore, scheduling is one of the critical problems in a manufacturing system, and the problem in scheduling focuses on how to allocate the limited resources of production (Naveen & Babu, 2013). So, job shop scheduling problems became to ensure maximum utilization of the plant at minimum cost (Wolde et al., 2018).

2.3.1 Characteristics of Job Shop scheduling

The nature of a wide variety of products and the plants in which they are produced gives certain characteristics common to virtually all job shops and the following characteristics are stated by (Abdolrazzagh-Nezhad & Abdullah, 2017):

- At any time there are a large number of orders at various stages of completion.
- Orders make conflicting demands on facilities and manpower.
- Every order differs to some extent. It is difficult, therefore, to predict accurately the time required to complete operations.
- The workflow is intermittent and orders can be sidetracked.
- There is usually a queue of work at each machine and it is often difficult to determine which order in the queue should have priority.
- Many changes are resulting from scrap, rework, machine breakdown, material shortages, engineering changes, and rush orders.
- Schedules and shop loads are rarely altered due to the very heavy clerical workload required to make the alterations.

2.3.2 Constraints for the Job Shop Scheduling

There are three main constraints for the job shop scheduling problem:

- ✓ No task for a job can be started until the previous task for that job is completed.
- ✓ A machine can only work on one task at a time.
- ✓ A task, once started, must run to completion.

2.3.3 Performance Evaluation Criterion of Job Shop Scheduling Problems

The performance evaluation criterion is the criterion for evaluating the performance of the shop that plays a critical role in the scheduling process such as:

- ✓ Make-span
- ✓ Lateness
- ✓ The average number of jobs in the shop
- ✓ Utilization of machines
- ✓ Utilization of workers

2.4 Modeling and Simulation in Job Shop Scheduling

The process modeling and simulation are modeling techniques available to support companies in gaining a better understanding of their manufacturing system behaviors, and processes; and so helping them in decision making. Process modeling provides management with a static structural approach to improve productivity, providing a holistic perspective on how the jobs operate and provide a means of documenting the jobs processes. It also allows management to study the dynamics of the jobs, and to consider the effects of changes without risk (Tilahun, 2018).

Simulation models allow to test potential changes in an existing system without disturbing it or to evaluate the design of a new system without building it. Simulation early in the design cycle is important, because, the cost to repair mistakes increases dramatically the later in the product life cycle the error is detected, and for some purposes, simulations are better than the analysis of real data. With real data, it is never possible to perfectly know the real-world process that caused a particular measured situation, because of the too complex interactions inherent in large systems (Shukla et al., 2018).

In a simulation, the analyst controls all the factors making up the data and can manipulate them systematically to see directly how specific problems and assumptions affect the analysis. Because simulation software keeps track of statistics about model elements, performance can be evaluated by analyzing the model data. One important, but often difficult task for the simulator is to define a suitable level of representation with respect to the overall objectives of the simulation study. System modeling can be used to study an existing system under various scenarios without modifying it, or for planning the construction of a new system that does not exist yet. System models are developed in order to evaluate some functional or non-functional properties of the system. Functional properties include throughput, mean execution time, reliability; and non-functional properties include deadlock freedom, usability, responsiveness, and others (Imseitif et al., 2019).

Simulation is one of several alternative methods of analyzing systems, and analytical modeling involves building a system description using some formal, mathematical notation. Unfortunately, mathematical analysis is limited to a relatively small number of simple systems, and the opportunity to represent manufacturing systems in this way is felt to be limited. Based on the state of the system simulation can be categorized as using either a continuous or discrete-time representation. Systems may have a discrete or continuous state. In some systems, the state changes all time, not just at the time of some discrete events. The status of components is continuously changing with respect to time (Tilahun, 2018).

Manufacturing, industrial and service sectors have been the most common fields of simulation applications. Simulation in general is to pretend that one deals with a real thing while working with an imitation. The imitation is a computer model of simulated reality. So that, models are important to describe reality, experimenting with them can save money, and time (Eshetu, 2017). The correct and validated simulation model in fact can substitute the real system as long as the underlying assumptions are met. General, simulation is a practical methodology for understanding the high-level dynamics of a complex manufacturing system and it has several strengths including risk avoidance, time compression, component integration, control physical scaling, and repeatability (Yemane, 2013).

In manufacturing industries modeling and analysis are important to help ensure good system performance, the integration and complexity of systems often make purely analytic tools difficult to use. Hence, simulation remains one of the most widely used tools to fill this need. Several commercially available software packages are in use both in industry, and academia, including arena, simu8, and witness. Such packages and simulations in general, have experienced great improvements with recent advances in computational technologies (Tilahun, 2018).

The specific improvements include graphical user interfaces to facilitate model-building, integration with spreadsheets, and databases for better data management, and powerful capabilities to visualize, and animate model execution. The simulation was found to be a very useful means of analyzing the dynamics of materials flow through a manufacturing industry; for example, to (Shukla et al., 2018):

- Identify current or potential bottlenecks and their impact on profitability.
- Examine the effects of random equipment breakdowns and the potential impact of different maintenance strategies.
- Analyze the relative impact on the material flow velocity of reducing process variability in alternative targeted areas.
- Check on the overall ability of the industry to respond to different assumed rates of demand increase and identification of what resources will be the first to come under pressure.

2.5. Arena Simulation Software

The Arena modeling system from systems modeling corporation was a flexible approach that allows the creation of animated simulation models that accurately represent virtually any system. Arena simulation an object-oriented design for entirely graphical model development and simulation analysts place graphical objects, called modules on a layout in order to define system components such as machines, operators, and material handling devices (Tilahun, 2018).

2.6. Lekin® Scheduling 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. Lekin® was created as an educational tool with the main purpose of introducing the students to scheduling theory and its applications. Besides that, the system's extensibility allows, and encourages using it in algorithm development. This development has been partially supported by the National Science Foundation. Machine environment involves flow-shop, flexible job shop, job-shop, and flexible flow-shop.

Dispatching rules used in Lekin® include EDD, MS, LPT, SPT, and CR rules.

- Terminology in Lekin®
- Processing Time (t_j)

Processing time (**t_j**) includes both setup time and actual processing time.

Ready Time (r_j):-It is the time at which job **J** is available for processing.

Due Date (d_j):-It is the time at which the job **J** is to be completed.

Make-span (Cj):-It is the time at which the job **J** is completed in a sequence.

The performance measures for evaluating schedules are usually functioning of job make-span. Some, sample performance measures are flow time, lateness, tardiness, etc.

Flow Time (F_j):-It is the amount of time job **J** spends in the system. Flow time is a measure that indicates the waiting time of the jobs in the system. This in turn gives some idea about in-process inventory due to a schedule. It is the difference between the make-span and ready time of a job J. $\mathbf{F_j = C_j - r_j}$

Lateness (L_j):-It is the amount of time by which the completion of job J differs from the due date. $\mathbf{L_j = C_j - d_j}$

Tardiness (T_j):- it is the lateness of the job **J** if it fails to meet its due date or Zero, otherwise

$T_j = \max\{0, C_j - d_j\}$

Interfaces of Lekin®

- Job pool window
- Sequence window
- Gantt chart (schedule) window
- Graphical user interface

Application of Lekin®

Here we use the scheduler for solving the job shop scheduling problems in a company, the general job shop scheduling mathematical model without the machine availability constraint. In general, variables are as follows (Balasundaram, 2018):

- ✓ Make-span (C_{max})
- ✓ Maximum-tardiness (T_{max})
- ✓ Total flow-time (C_j)
- ✓ Total-tardiness (T_j)
- ✓ Total weighted flow time ($W_j C_j$) and
- ✓ Total weighted tardiness ($W_j T_j$)

2.7. Productivity Improvement in Metal Manufacturing Industry

Productivity improvement is never-ending work in an organization. It can be done by optimizing the system, simplifying the method, reducing set-up time, and reducing variation (P. Kumar, 2017). According to Othman et al., (2012), and Reddy et al., (2018) to achieve an effective productivity improvement; using multi-skilled manpower in manufacturing industries.

As described by Biswas, (2013) the productivity can be improved through the cellular manufacturing approach which is the application of the principles of group technology in manufacturing. Cellular manufacturing helps to create a concept known as single or one-piece flow. Equipment and the workstations are arranged in sequences to allow for a smooth flow of materials and components through the process.

According to Soltany et al., (2013) cost reduction is one of the methods applied for improving the productivity of organizations through supply chain management techniques. The study was conducted by Hassanein et al., (2014) also mentioned the productivity improvement methods in the manufacturing sectors, during manufacturing any products, mainly focused on time and motion study. However, the above-mentioned researcher's perspectives are argued each other have to improve productivity in the manufacturing industry, one is focused on supply chain management techniques and the other is relying on time and motion study to enhance productivity.

As studied by Legesse & Singh, (2014) and Yogesh, (2018) lean manufacturing is a productivity improvement method or approach that considers the expenditure of resources on non-value-added activities to be a waste. Value-added activities are activities that are necessary to create value for the end customer. Value is defined as any activity carried out during producing a product/service that the customer would be willing to pay for it. The objective of lean manufacturing was to create the value for customer by consuming the least amount of resources to design the product. Productivity improvements can made through lean methods for particular situation (Choomlucksana et al., 2015).

As studied by Baskar, (2015) the NEH algorithm is a technique that is used to minimize the makespan in combination with simulation for a fixed number of runs. The popular NEH algorithm is considered the parent algorithm to find the initial solution, and the makespan was minimized. The improvement is up to 4.67% through MINITAB software. However, productivity improvement was not considered, in this study.

According to Kassu & Eshetie, (2015) the job shop scheduling problem for the machine shop is to determine the optimum orders of jobs on the given machines and reduce the make-span of the manufacturing system using the shifting bottleneck algorithm. However, the paper focuses only on optimum total make-span through shifting bottleneck algorithm; it is not considered the improvement of productivity by using present resources.

The other approach proposed by Nunesca & Amorado, (2015) for productivity improvement through lean manufacturing tools is aimed to use and apply lean tools as a method of improving productivity in manufacturing sectors lead to standardize cycle time and minimize wastes. And also, Rathod et al., (2016) showed to improve productivity through optimization of cycle time by lean manufacturing techniques for reduction of non-value-added activity.

According to Mentesinot, (2017) the improvement in the ergonomics systems is an important task to enhance the productivity of the manufacturing sector. The works presented in Balasundaram, (2018) reduce the total make-span of specific jobs and improving the performance of the manufacturing system through job shop scheduling problems. However, in this paper, productivity improvement was not considered.

According to M. A. Moktadir et al., (2017) the improvement of productivity gained through reducing work content by applying work-study in the manufacturing industry. As stated by Gujar & Moroliya, (2018) productivity can be improved through the application of work-study. Labor and machine productivity increases when an industry produces more goods by using the existing resources such as time, machinery, and manpower. Sometimes specific problems such as machine break down, machine set up time, improper scheduling jobs, quality problems, performance level, and absenteeism of workers may hamper the productivity in manufacturing industries (Kulkarni et al., 2018).

Productivity improvement is an everlasting continuous activity in manufacturing industries wants to deliver products on time for customers. Integration of lean and work-study approaches are methods used to improve productivity in the manufacturing industry (P. Ferreira et al., 2018).

However, according to Wolde et al., (2018) to achieve the planned production volume, a company needs to establish an optimal production sequence. To obtain the targeted volumes, there is different production scenarios were developed based on the make-spans. Among the various flow shop scheduling heuristics, Campbell, Dudek, and Smith (CDC), and Nawaz, Enscor, and Ham (NEH) methods yielded an optimal production sequence with a considerable reduction of a make-span.

Kulkarni et al., (2018) improve the productivity for coil winding using the string diagram technique and arena software to determine the cycle time and insertion processes for the existing shop floor layout. And propose a revised layout to reduce material movement in the shop and improvement methods. However, according to Tadiyos, (2018) to improve the productivity of the manufacturing industries through human resource development method.

As studied by Bayeh, (2019) to improve the productivity of manufacturing sectors use the line balancing approach. Besides, productivity improvement can also obtain by various techniques and methods, which consist of technology, employee, task, process, product, and material-based techniques. Job shop scheduling problem was one of the process-based technique that can increase productivity, machine, material, and labor utilization in the manufacturing industry (Shukla et al., 2018).

As discussed above by different researchers, productivity may improve through lean, ergonomics, cellular manufacturing, work-study, and line balancing in the case of a garment, textile, leather, and so on. However, there is no much study on metal manufacturing industries, and this study will follow the job shop scheduling approach to improve productivity in the case of a metal manufacturing company and suggest possible solutions to improve the planned volume of productivity.

Literature summary and Gap

There are different published and unpublished literature’s that are related to productivity improvement, for Ethiopian manufacturing industries through different techniques and approaches in the research paper. And also to obtain enough information and the best understanding the literature reviewed from different sources. Among them some articles, reports, and thesis are the main ones. In this research, different literatures have been reviewed to analyze the gaps in productivity improvement.

Table: 2. Summary of literature gaps

No.	Authors or researchers name	Techniques or methods used by Authors or researchers											
		Multi-skilled person	Motion and time study	Cellular manufacturing methods	Supply chain management	JSSP	Lean mfg. tools	Ergonomics systems	FSSP	Integration of lean & work-study	String diagram and arena software.	Through human resource	Line balancing
1	Reddy et al., (2018)	√							√			√	√
2	Hassanein et al., (2014)		√							√			
3	Biswas, (2013)			√				√					
4	Soltany et al., (2013)				√								
5	S. Gujar & Moroliya, (2018)	√	√	√						√			
6	Kassu & Eshetie, (2015)					√		√	√				
7	Nunesca & Amorado, (2015)						√	√					

8	Rathod et al., (2016)						√						√
9	Yogesh, (2018)						√						
10	Choomlucksana et al., (2015)			√			√				√		
11	Mentesinot, (2017)	√						√				√	
12	M. A. Moktadir et al., (2017)		√		√					√			
13	Wolde et al., (2018)								√				
14	P. Ferreira et al., (2018)		√				√	√		√			
15	Kulkarni et al., (2018)			√	√						√		
16	Tadiyos, (2018)	√										√	
17	Shukla et al., (2018)												√
18	Shah et al., (2014)		√								√		
19	Bayeh, (2019)												√
20	Alene, (2020)								√				
Percentages of use techniques		20%	25%	20%	15%	5%	25%	25%	20%	20%	15%	15%	20%

There are different literatures, which related to productivity improvement through work-study, lean manufacturing, cellular manufacturing, line balancing, ergonomics, flow shop methods, and so on are used as the methods to improve productivity in different manufacturing sectors. The metal manufacturing sector was one of the challenging manufacturing sectors in Ethiopia. In today's highly competitive market manufacturers face the challenge of reducing make-span and productivity improvement. However, every company has its objectives and way of decision-making processes. Due to the misunderstanding among the objectives of each organization and non-integrated decision-making processes, there has been a need for some new ways, which help to resolve those conflicts.

Generally, the reviewed literatures discussed above, most of them are focused on the manufacturing industry to solve the problems that facing the productivity of the organization through different approaches like lean, work-study, line balancing, and so on. However, very little literature is focusing on the metal manufacturing industry to solve the problems that attack the productivity of the organization. Therefore, the main goal of this study is to improve productivity by proper scheduling of jobs on the existing resources/machines, and also to minimize the make-span, and improve the productivity for the existing resources for the selected case company.

Chapter Three

Research Design and Methodology

3.1 Introduction

This chapter aims to highlight methods and analysis of data to respond to research questions. It helps to understand and identify the research methods to carry out and the ultimate aim of the thesis. Besides, the selection method is based on the problems identified, training of the researcher, resources available, and audience for research.

3.2 Literature Survey

The literature survey has done to improve and deeply understand what was previously done on productivity improvement through job shop scheduling and also to find out important techniques and gaps from related articles, journals, government & no government studies, books, and reports to improve the productivity of the Akaki Basic Metal Industry.

3.3 Research Approach

This research method helps us to collect data and information about the practical problems of the existing situation and to explain basic concepts regarding the metal manufacturing scheduling process through the allocation of resources(production scheduling), breakdown of machines (maintenance planning), and other challenges or factors examine to search alternative potential solution for the problem. The data obtained in this study were mainly from primary data collection such as questionnaires, interviews, and observation, and from secondary sources such as recorded data of the production scheduling through time study.

3.4 Research design

Research designs are plans and procedures for research that span the decisions from broad assumptions to detailed methods and techniques of data collection and analysis process (Legesse & Singh, 2014). The overall decision involves which design should be used to study a topic and the selection of research design is based on the research problem, researcher's experience, and audience for study. To obtain the objective of this study the researcher expected to use the job shop scheduling process and collect data using a variety of procedures. Therefore, this proposed study intends to use the case study as a research design to study how to improve production through the job shop scheduling approach.

3.5. Data collection methods

Data collection methods are the fundamental activity that enables to accomplish the study. To accomplish this study, different data collection techniques were used i.e. primary and secondary data was used for the study of six (6) years of total productivity report of the selected company.

3.5.1. Primary data collection methods: - it is direct data collection from the make-span through several approaches to get a better understanding of the problem area. The methods used in collecting the primary data are direct observation and face-to-face interviews.

Direct observation:-during the visit of the manufacturing process through observation of proper assigning of job on the work station machines, machines and operators idle, and raw materials availability.

Informal discussion & interviews are conducted to assess the current working condition of job shop station and factors related to high make-span, incur a high cost, and low productivity.

Time study: - used to do with a stopwatch to collect the time taken of each process within the workstations to assess processing times for each job on each machine.

3.5.2. Secondary data collection methods: - the sources of the secondary data include annual reports of the company's six consecutive years of production reports data from the production planning and controlling department, different websites, past thesis, articles, and journals related to the study. This helps to identify how other authors defined and improved productivity, the data sources that others used and this helps to discover how this research is related to other studies to analyze the relative total and partial productivity trends of the Akaki basic metal industry.

3.6. Sampling Strategy

This section consists of a description of sample size, target population, and sampling procedure used to evaluate the observed time of each element.

3.6.1 Targeted-population

In statistics, the researcher was interested to obtain information about a total collection of elements, which have referred to as the population. Population defines as the complete set of events that contain common behaviors in which the researcher was interested (Legesse & Singh, 2014). As Akaki basic metal industry manual report of May 2020, there is a total 232 manpower; and from this, 196 were male, and 36 were female. From these 183 workers were direct laborers engaged in the manufacturing process; the other staff was working in the administrative area.

3.6.2 Sample Size

Sampling is the process of obtaining information from the subset (sample) of the larger group (population). The sampling method was applied in the study of the random sampling method. Simple random sampling was the sampling method in which every member of the population has an equal and independent chance to be chosen. To get a reasonable sample size that supports the research findings, different equations were used as mentioned below (Eshetu, 2017).

$$S_i = \frac{Z^2 * p(1-p)}{c^2} \quad (3.1)$$

$$S_t = \frac{S_i}{1 + \frac{S_i - 1}{N}} \quad (3.2)$$

When: S_i = Initial Sample Size, S_t= Target Sample Size, Z = confidence levels were (1.645 for 90% confidence level, 1.96 for 95% confidence level and 2.576 for 99% confidence level),

c = confidence interval that described as decimal; 0.08 = ±8

p = percentage choice described as decimal 0.5

N = Population = 183 workers

$$S_i = \frac{Z^2 * p(1-p)}{c^2} = \frac{(1.645)^2 * 0.5(1-0.5)}{(0.08)^2} = 105.704$$

$$S_t = \frac{S_i}{1 + \frac{S_i - 1}{N}} = \frac{105.704}{1 + \frac{(105.704 - 1)}{183}} = 67.235 \approx 67$$

3.6.3 Sampling-procedure

The stratified random sampling was used to achieve desired representation from various workers subgroups in the population. The event was selected through the existing subgroups in the population that were less or more reproduced in the sample. After sampling the subgroup, sampling proportional to size relies on the relative numbers of workers in each section were used. Sample should optimum fulfills requirements and reliability. The proportionate allocation was used with sampling fractions in the strata that are proportionate to the total population (Eresi, 2019).

Table: 3. Target respondents

Position of respondent	**# of respondents**	Sample size
Maintenance manager & team	16	16*(67/183)=6
Inventory Manager & team	8	8*(67/183)=3
PPC manager & team	11	11*(67/183)=4
Purchasing Department & team	8	8*(67/183)=3
Quality Control Team	5	5*(67/183)=2

Production Supervisors	30	30*(67/183)=11
Senior Operators	104	104*(67/183)=38
Total	183	Total sample size=67

Source: Researcher

3.7. Data analysis and presentation Tools

To achieve the objective of this study, the data was collected through face-to-face interviews, direct observation, time study, and secondary data were analyzed. The data analysis methods perceived in this research works were; fishbone diagram, Lekin software scheduler, and arena simulation software were selected.

Thus, these data were interpreted through a descriptive method of data analysis by using MS–Excel, and Lekin's approaches were selected as the appropriate approaches to analyze and verify the collected data. And Arena simulation software was selected for validation of the proposed solution of make-span and productivity improvement, that achieved by Lekin's approaches and finally, a conclusion and recommendation were reached.

3.8 Research Framework

The research methodology and procedures of this study followed are illustrated in the below figure. The process starts with the preliminary study & defining the problem and ends with conclusions, recommendations, and future works.

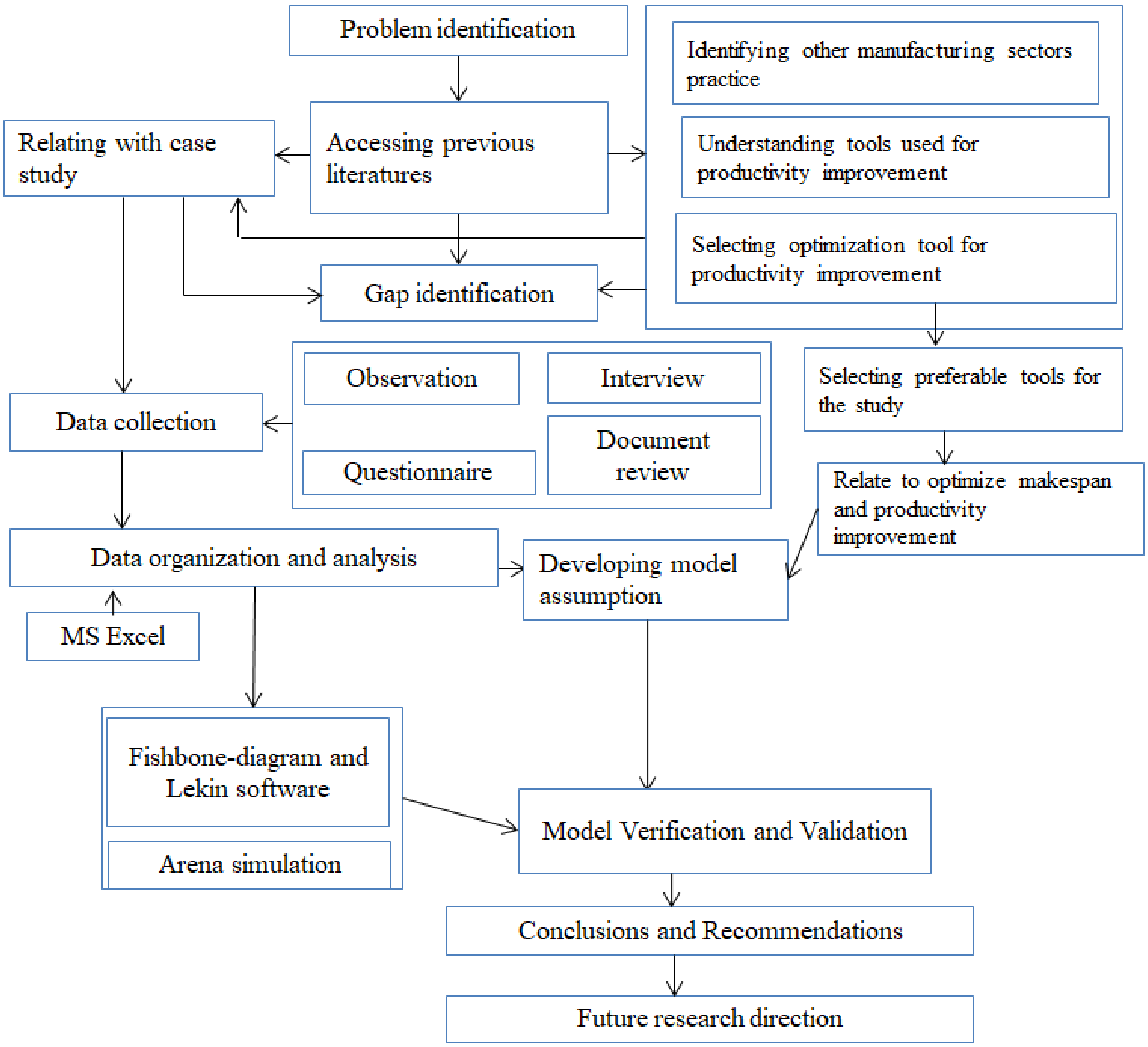


Figure: 2.Research framework

Chapter Four

Data Analysis and Presentation

4.1 Data Collection and Analysis

Data was collected from the company by distributed formal questioners to different department managers, production supervisors, and senior operators of the manufacturing industry and also, to understand productivity-related problems in the industry, informal discussion & interview (through mobile and email; b/se of covid-19), observation has been conducted with different level of workers, time-study and surveying literature (like company document report, etc.).

Data collection and analysis for developing a Lekin model were important methods based on the accuracy of data to allocate the job to a given resource. Initially, data collection starts through observing and identifying different activities done in the machine shop. Then, the numbers of jobs in the shop were determined the processing time for each activity measured in minutes, and ten (10) measurements for each task were recorded using a stopwatch. In addition to making it more accurate, the collected data, production reports, allocation of jobs on a given machine and production plans are considered.

The time required to complete a task depends on a lot of factors such as the task, operator, properties of raw materials, working environment, the quality level of product, the hour of the day, and the psychology of the operator. It's not expected that the operator would work all day without some interruptions at the workplace. Allowances like personal fatigue and delay allowances would be considered for calculating the standard time value for each operation (Shukla et al., 2018).

But, for this study, standard times were not taken into account, while the distributions of collected time for each activity were considered. Why because the processing time of each activity was variable and their distribution represents a real system. Generally, the main factors of lowering the productivity of the Akaki Basic Metal Industry were collected through questioners, observation, informal discussions & interviews, time study (stopwatch device), and from the company's written documents or reports. The findings are presented in the following sections.

4.1.1 Data collected & identified through questionnaires distribution

Response Rate

The study targeted a sample size of 67 respondents from which 52 filled in and returned the questionnaires in good time giving a response rate of 77.612%. This response rate was sufficient to make conclusions for the study as it acted as a representative. According to (Gebremedhn, 2017), a response rate of 70 % and over is excellent based on the assertion, the response rate was excellent.

Respondents Profile

The job position of the respondents and how long they had worked in that position in the industry ensured that the survey results were valid and reliable. The respondents were asked to indicate whether they held the positions of different departments such as; maintenance manager, inventory management, procurement manager or purchasing manager, production planning and control team manager, Quality department team, production supervisors, and senior operators of the company and the findings are given in the following Figure.

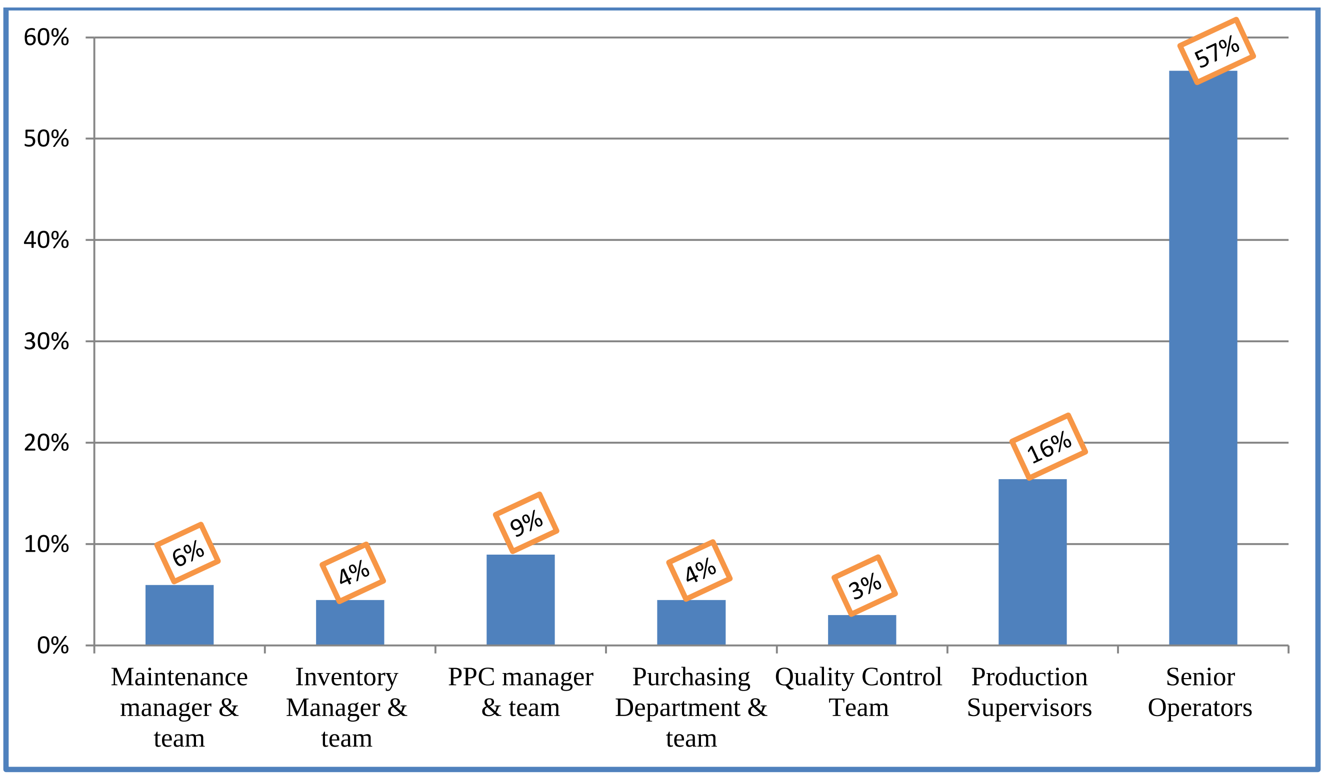


Figure: 3.Respondent positions vs. percentage of response

From Figure:3, the majority (57%) of the respondents were senior operators, (16%) production supervisors, (3%) Quality control teams, (9%) production planning control managers, & teams, (4%) purchasing managers, (4%) inventory managers and (6%) the maintenance manager and team. This means that the majority of the respondents were senior operators and production supervisors were in a good position to give relevant information on the productivity and factors that affect the productivity of the company.

Work experience of workers in the company

The employer's working experience based on the number of years they had worked in the mentioned work position was useful for the study. The workers were asked to indicate whether they had worked in that particular position for less than two years, 2-5 years, 5-10 years, or over 10 years, and the findings are shown in the table below.

Table: 4. Work experience of workers in the company

Working experience	# of Employers	Percentage %
less than two years' experience	13	6%
2-5 years' experience	53	23%
5-10 years' experience	69	30%
over 10 years of experience	97	42%
Total	232	100%

(Company Report, 2020)

From the above table, the majority of the workers were (42%) indicated to have worked in the organization for more than 10 years which are senior operators are high-value consideration, (30%) indicated to have worked for a period of 5 to 10 years while (23%) indicated to have worked in the company for 2 to 5 years and (6%) were indicated to have worked not more than 2 years. This implies that, the majority of the respondents had worked for a considerable period and that they were in good information relating to this research.

4.1.2. Problems related to low productivity in the Akaki basic metal industry

Based on the surveyed pieces of questionnaires, the main reasons related to low productivity in Akaki Basic Metal Industry were analyzed. The respondents were asked to prioritize the problem based on the company frequently occurred major problems which are around sixteen (16) major problems that are responsible for low productivity in Akaki Basic Metal Industry. These questions were distributed to the respondents of the case company to prioritize the problem and the findings of the respondents are shown in the table below.

Rating scale: 1=Low Affecting Productivity, 2=Medium Affecting Productivity, and 3=Highly Affecting Productivity

Table 5. Surveyed data responsible for low productivity

Nº	Problems related to low-productivity	3	2	1
1.	Improper allocation of resources	42	6	4
2.	Machine failure/ breakdowns	33	14	5
3.	Absenteeism of operators/workers	21	15	16
4.	Inputs (Raw materials) shortages/problems	16	18	18
5.	Power Shortage	7	9	36
6.	Cleaning problems	12	15	25
7.	Capital or Financial related problems	12	16	24
8.	Management related problems	9	15	28
9.	Process related problems	17	26	9
10.	Workers-skill problems	13	18	21
11.	PPC- problems	16	10	26
12.	Market-related problem	9	15	28
13.	Quality -related problems	14	14	24
14.	Structure and culture-related problems	13	12	27
15.	Working condition-related problems	14	12	26
16.	Infrastructures -related problems	18	15	19
	Others (Please specify)……………			

(Respondents, 2020)

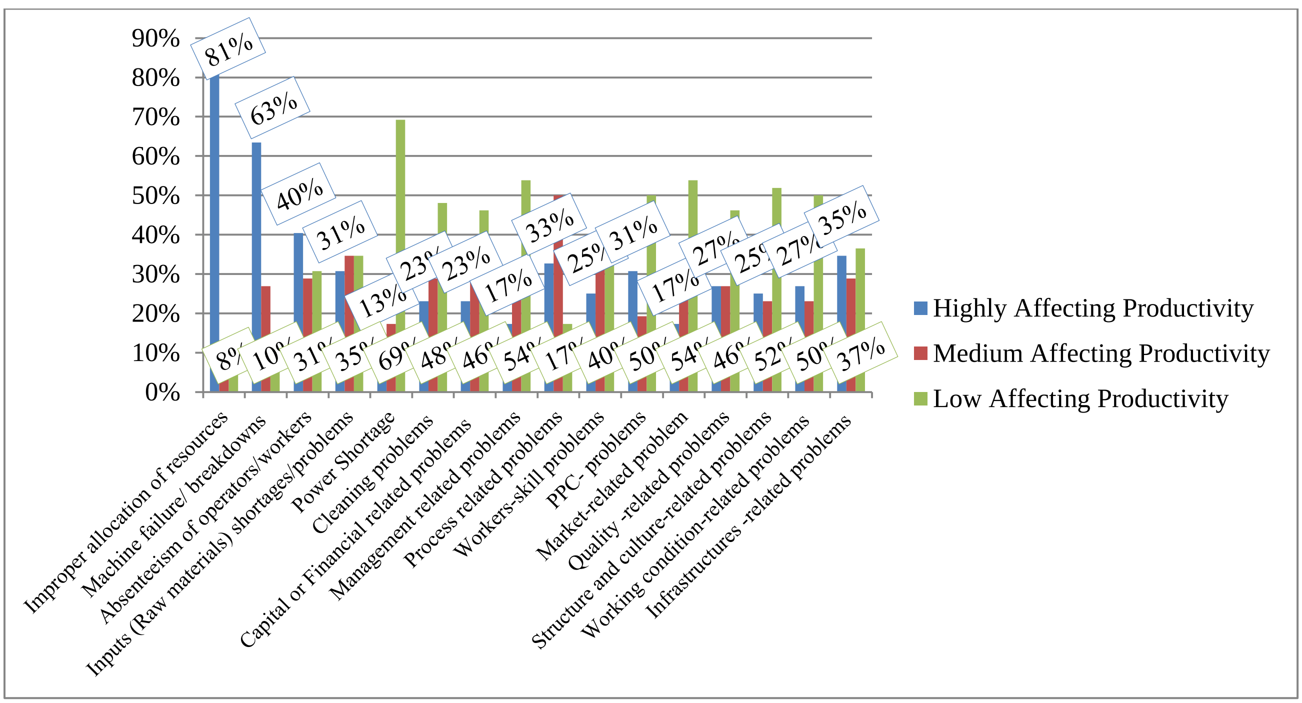


Figure: 4.The major problem of the company for lowering the productivity

(Respondents, 2020)

From the above figure, the respondents have prioritized the major problems at Akaki Basic Metal Industry; like are the improper allocation of resources (81%), machine failure/breakdown (63%), and absenteeism of workers (40%), infrastructures (35%), and process-related problems (33%), and so on are the critical problems that affect the productivity of the Akaki Basic Metal Industry.

4.1.3. Data collected & identified through observation

During observation processes, the researcher understood the critical factors or problems that responsible for lowering productivity in Akaki basic metal industry. These problems are:

- ✓ Improper allocation of jobs on the existing resources
- ✓ Absenteeism of workers
- ✓ Number of failed machines

4.1.4. Data collected through informal discussion and interview

During the informal discussion and interview of the researcher with different levels of workers that are participated in the Akaki Basic Metal Industry, the researcher understood and obtained the critical factors or problems that responsible for lowering productivity in the case study from the respondents. These problems are:

- ✓ Lack of raw materials and inputs availability
- ✓ Fluctuation and interruption of power and electric energy
- ✓ Breakdown of machines, etc…

4.1.5. Data obtained from review literature and company document report

- ✓ Targeted production capacity of company
- ✓ Actual production capacity of company
- ✓ Planned make-span of the company
- ✓ Actual make-span of the company
- ✓ Turnover of labor
- ✓ Related information from different articles, etc…

4.2. Factors affecting the productivity of Akaki Basic Metal Industry

Based on the observations, interviewed personnel (sometimes through mobile phone, because of pandemic Covid-19 issue), it was identified that improper allocation of jobs on the given resource, human resource (skilled manpower), absenteeism & turnover of workers, amount of machinery and equipment breakdown, raw material availability and make-span are the critical problems associated in the Akaki Basic Metal Manufacturing Industry that affect their productivity.

Therefore, depending on the obtained data by the above methods and referring to the annual report of the planning and control department, the factors or problems which are influencing and lowering the productivity of the case company were summarized in the below table.

Table: 6. Factors affecting the productivity of Akaki Basic Metal Industry

Shops	Improper allocation of resource time lose	Cleaning time lose	Machine failure time lose	Absenteeism of operator time lose	Raw/M. shortage of time lose	Power Shortage of time lose	Total time lose
Foundry	5985.15	2731.81	6785.41	6784.27	7247.17	351.32	29885.13
M/c shop	9965.74	6454.52	7996.47	5416.24	7200.94	3171.57	40205.48
Forging	4292.13	791.31	1732.73	1789.79	892.31	547.72	10045.99
Laboratory	1857.73	1812.33	757.21	863.74	875.16	369.23	6535.4
Total time lose	22100.75	11789.97	17271.82	14854.04	16215.58	4439.84	**86672**

(Production planning and control report, 2020)**(**Modified)

As discussed in the above table, the Akaki Basic Metal Industry has four sections; such as foundry, machine shop, forging, and laboratory sections. Among these sections, the machine shop section was selected as a specific focus area of the study. The reason to select this section was more affected (i.e. more time lose) than other sections as demonstrated on the above table around forty-six percent (46%), and in this section variety of machine components & spare parts are produced as per the customers' specification and thus it is a job shop production system.

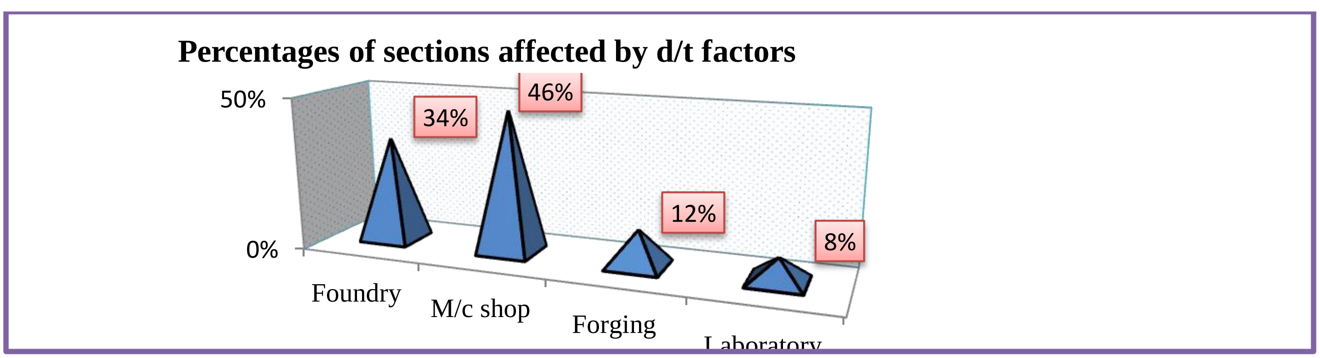


Figure: 5.Percentages of ABMI sections affected by d/t factors
(Production planning and control report, 2020)(Modified)

As the above figure indicates also, among the other shop, the machine shop is more affected by different problems. So, the machine shop was selected as a specific focus area of the study among others.

4.3 Major factor of time in Akaki basic metal industry for machine shop

From the company recorded data, the major factor of time on the manufacturing process in the company which is allocation resource time, cleaning time, machine breakdown, absenteeism of operator, raw material shortage, and power shortage was listed in the below table.

Table 7. The major factor of losing time in ABMI in machine shop sections

Sections	Allocation resource time lose	Cleaning time lose	Machine failure time lose	Absenteeism of operator time lose	Raw material shortage time lose	Power Shortage time lose
Cutting	1985.15	1731.01	1785.1	784.27	1247.07	521.32
Turning	1091.03	701.71	781.03	987.07	741.12	597.47
Drilling	1292.13	901.31	1232.13	789.39	952.31	647.92
Gear cutting	1857.23	1712.13	957.21	873.24	895.56	469.23
Milling	1978.19	821.07	1878.29	1247.19	1972.74	423.26
Grinding	1762.01	587.29	1362.71	735.08	1392.14	512.37

(Production planning and control report, 2020)**(**Modified)

4.4. Data collected through time-study (stop-watch device)

The data collected through time-study (stop-watch device) the researcher use the stopwatch device to the obtained processing time for each operation and time loss of machine downtime that responsible for lowering and delaying the productivity of the case study. The time was taken for each operation in ten (10) cycles. The summations of times ten (10) cycles for each operation were averaged to obtain the average operation-time called observed or basic time. The researcher obtained the processing time for some jobs that required six workstations for manufacturing the productivity of the machine shops as demonstrated in the below table. The reason, to record the processing time for some jobs was the company produces these products at that time.

$$\text{Ave. observed} - \text{time} = \frac{\text{Sum of times recorded to work each operation}}{\text{No.of observations}}$$ (Duran, Cetindere, & Emre, 2015)

Table 8. Recorded processing time for each operation in machine shops

Jobs	*Recorded time on cutting machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	25	27	24	23	33	25	28	37	24	33	28
Sprocket gear	31	27	26	24	23	25	21	27	24	23	25

Stepped shaft	44	47	43	45	49	46	51	45	50	49	47
Spur gear	58	50	57	55	59	57	50	54	55	59	56
Fitting	25	27	46	36	42	35	25	46	36	42	36
Bearing housing	36	37	21	28	31	22	37	33	31	25	30
Steel balls	32	42	32	32	37	33	33	32	33	37	34
Jobs	*Recorded time on turning machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	42	31	37	35	32	35	41	36	35	32	36
Sprocket gear	30	29	28	30	48	29	39	48	30	48	36
Stepped shaft	42	44	46	42	42	42	44	47	42	52	44
Spur gear	23	29	23	29	21	24	19	25	21	28	24
Fitting	23	22	25	25	21	23	24	27	22	26	24
Bearing housing	32	31	23	25	24	36	31	21	35	32	29
Steel balls	15	13	13	15	14	15	13	13	15	14	14
Jobs	*Recorded time on drilling machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	19	21	27	26	23	29	19	24	23	27	24
Sprocket gear	37	48	49	51	46	47	43	47	49	48	47
Stepped shaft	29	21	23	29	26	31	27	25	29	26	27
Spur gear	22	21	23	27	22	31	27	29	26	28	26
Fitting	37	40	43	42	39	39	42	45	47	39	41
Bearing housing	33	38	41	34	26	42	38	39	34	37	36
Steel balls	27	23	28	26	28	31	25	27	29	26	27
Jobs	*Recorded time on the gear-cutting machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	27	24	26	29	32	29	27	26	29	31	28
Sprocket gear	22	23	31	35	22	27	25	31	37	28	28
Stepped shaft	38	42	43	36	38	33	41	43	37	39	39
Spur gear	42	38	41	43	44	47	38	44	43	46	43
Fitting	46	39	45	39	41	43	46	45	39	47	43
Bearing housing	41	36	49	46	45	43	36	47	46	48	44
Steel balls	48	49	50	47	45	48	49	51	47	46	48
Jobs	*Recorded time on a milling machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	32	28	33	27	33	31	28	34	29	33	31
Sprocket gear	31	32	27	26	27	26	27	29	31	27	28
Stepped shaft	46	43	47	45	42	46	45	46	45	45	45
Spur gear	59	51	54	56	57	58	51	54	56	53	55
Fitting	26	27	26	31	32	30	27	29	31	33	29
Bearing housing	36	37	28	33	31	33	37	28	34	37	33
Steel balls	32	39	32	40	36	37	33	32	38	36	36

Jobs	*Recorded time on grinding machine (minutes)*										*Averages (minutes)*
	1	2	3	4	5	6	7	8	9	10	
Roller	34	32	29	27	32	35	32	29	27	32	31
Sprocket gear	32	31	29	27	32	34	32	28	27	32	31
Stepped shaft	46	41	46	45	48	46	47	46	46	45	46
Spur gear	51	50		56	59	57	50	54	55	59	55
Fitting	28	26	54	31	32	35	26	37	36	32	31
Bearing housing	29	35	32	34	30	33	35	32	31	30	32
Steel balls	42	40	42	43	42	43	41	42	43	44	42

Source: Recorded time through stopwatch by researcher

4.5 Arena Input Analyzer

The analysis involves the identification of the theoretical distribution that represents the input data. The use of input data in the model specifying the theoretical distributions in arena simulation program code. The input analyzer tools built-in the arena was used to convert the collected data into probability distributions to be used in the simulation model. The process of deciding the theoretical distribution for a set of data involves goodness of fit-test. These tests were dependent on observed data distribution and theoretical distribution. When the difference between observed data distribution and theoretical distribution was minimum, it may state with a level of certainty that input data come from the set of data with the same theoretical distribution (Shukla et al., 2018).

In addition to these, it is capable of determining the quality or fitness of probability distribution functions to input data and generate high-quality data plots. Therefore, the gathered data was processed in input-analyzer methods built-in arena simulation, and findings were used to set the type of probability distribution function. To determine which distribution present, it tried to select which were simple to describe, implement, and are reasonably efficient as well, and the distributions that are occurring in the continuous simulation are Uniform, Exponential, Erlang, Gamma, Weibull, Normal, Lognormal, Beta, and Triangular (Wolde et al., 2018). The data's input to the arena as per the existing job shop scheduling.

Table 9. Input analyzer data distribution function of each operation of machine shops

Nº	Operations or Jobs	Distributions
	Cutting work stations	
1.	Roller	30.5 + 12 * BETA(0.903, 1.12)
2.	Sprocket gear	27.5 + 21 * BETA(0.447, 0.513)
3.	Stepped shaft	POIS(44.3)
4.	Spur gear	18.5 + 11 * BETA(0.744, 0.692)

5.	Fitting	20.5 + 7 * BETA(1.37, 1.5)
6.	Bearing housing	20.5 + 16 * BETA(0.925, 0.846)
7.	Steel balls	12.5 + 3 * BETA(0.766, 0.766)
	Turning work stations	
8.	Roller	30.5 + 12 * BETA(0.903, 1.12)
9.	Sprocket gear	27.5 + 21 * BETA(0.447, 0.513)
10.	Stepped shaft	POIS(44.3)
11.	Spur gear	18.5 + 11 * BETA(0.744, 0.692)
12.	Fitting	20.5 + 7 * BETA(1.37, 1.5)
13.	Bearing housing	20.5 + 16 * BETA(0.925, 0.846)
14.	Steel balls	12.5 + 3 * BETA(0.766, 0.766)
	Drilling work stations	
15.	Roller	POIS(23.8)
16.	Sprocket gear	NORM(46.5, 3.75)
17.	Stepped shaft	TRIA(20.5, 29, 31.5)
18.	Spur gear	20.5 + 11 * BETA(0.98, 1.12)
19.	Fitting	TRIA(36.5, 39, 47.5)
20.	Bearing housing	NORM(36.2, 4.42)
21.	Steel balls	NORM(27, 2.1)
	Gear-cutting work stations	
22.	Roller	23.5 + 9 * BETA(1.35, 1.34)
23.	Sprocket gear	21.5 + 16 * BETA(0.491, 0.699)
24.	Stepped shaft	32.5 + 11 * BETA(1.03, 0.713)
25.	Spur gear	37.5 + 10 * BETA(0.917, 0.881)
26.	Fitting	POIS(43)
27.	Bearing housing	POIS(43.7)
28.	Steel balls	NORM(48, 1.73)
	Milling work stations	
29.	Roller	26.5 + 8 * BETA(1.14, 1.02)
30.	Sprocket gear	25.5 + LOGN(2.92, 3.21)
31.	Stepped shaft	TRIA(41.5, 46, 47.5)
32.	Spur gear	50.5 + 9 * BETA(0.804, 0.84)
33.	Fitting	25.5 + 8 * BETA(0.649, 0.754)
34.	Bearing housing	27.5 + 10 * BETA(0.573, 0.399)
35.	Steel balls	31.5 + 9 * BETA(0.502, 0.628)
	Grinding work stations	
36.	Roller	26.5 + 9 * BETA(0.804, 0.84)
37.	Sprocket gear	26.5 + 8 * BETA(0.802, 0.843)
38.	Stepped shaft	NORM(45.6, 1.74)
39.	Spur gear	49.5 + 10 * BETA(0.483, 0.473)
40.	Fitting	POIS(33.7)
41.	Bearing housing	28.5 + 7 * BETA(0.871, 0.823)
42.	Steel balls	NORM(42.2, 1.08)

Source: Researcher

The recorded data was performed for estimating input parameters. The order of jobs, processing time, and the required resources are collected during the manufacturing process. The collected data were analyzed with an input analyzer of Arena simulation to determine the distribution of input parameters. To determine its fitness the smallest squared error of the distributions was taken. and the sample input analyzer data distribution function for machine shop manufacturing processes of job shop scheduling is shown in the figure below.

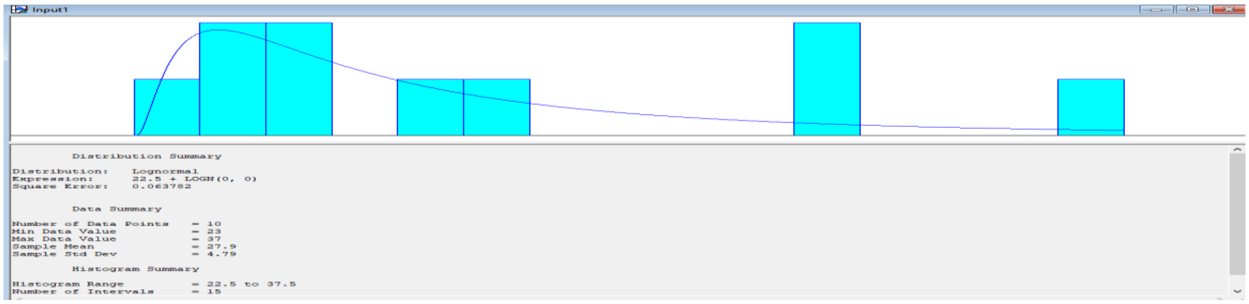


Figure: 6. Input analyzer distribution function for machine shop operations

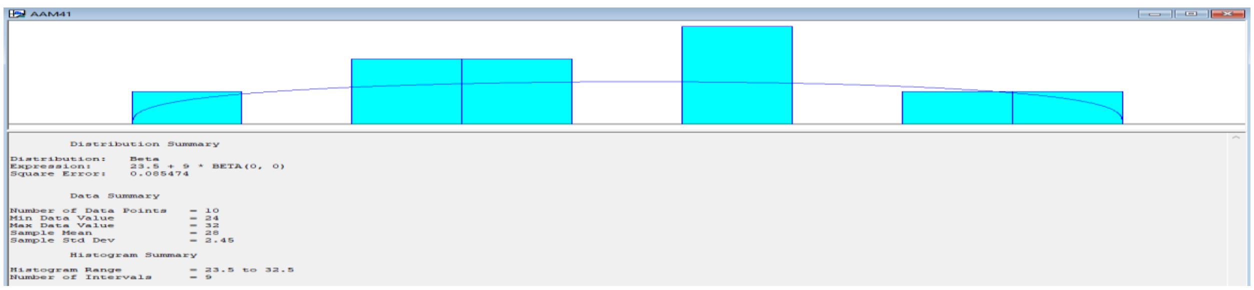


Figure: 7. Input analyzer distribution function for machine shop operations

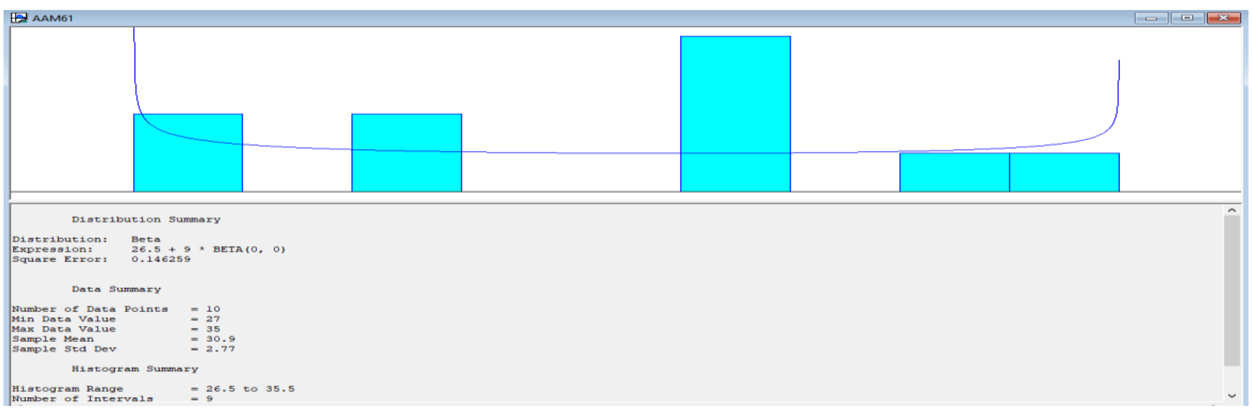


Figure: 8. Input analyzer distribution function for machine shop operations

Based on the data recorded from the machine shop of the Akaki Basic Metal Industry contain seven jobs, Roller (J_1), Sprocket-gear (J_2), Shaft (J_3), Spur-gear (J_4), Fitting (J_5), Bearing (J_6), and Steel-balls(J_7) and also the jobs required below machines; Cutting machine (M_1), Turning machine (M_2), Lathe machine (M_3), Milling machine (M_4), Drilling machine (M_5) and Grinding machine (M_6). The processing sequence of machines on which each job to be processed was collected from the company's production route sheet for the individual part and the job shop scheduling problem of Akaki Basic Metal Industry was formulated as shown in the table below, and it was solved under the following assumptions:

- ✓ All machines are available during the scheduling period
- ✓ All jobs are available or ready to be processed at a time $t_0 = 0$ & $r_j = 0$
- ✓ Each machine process one job only at a time
- ✓ Each job will visits each machine once at most.
- ✓ Pre-emption of operations is not allowed
- ✓ No job splitting
- ✓ Setup times for different jobs are neglected
- ✓ Processing time is deterministic
- ✓ Transportation times between different machines are neglected.

Table: 10.Routing matrix for seven jobs and six machines

Nº	Jobs	Averages of recorded time for each machine section (minutes)					
		M_1	M_2	M_3	M_4	M_5	M_6
1.	Roller(J_1)	28	36	24	28	31	31
2.	Sprocket gear(J_2)	25	36	47	28	28	31
3.	Stepped shaft(J_3)	47	44	27	39	45	46
4.	Spur gear(J_4)	46	24	26	43	45	55
5.	Fitting(J_5)	36	24	41	43	29	31
6.	Bearing housing(J_6)	30	29	36	44	33	32
7.	Steel balls(J_7)	34	14	27	48	36	42

(Company's recorded processing time from each section, 2020)

Besides, the above table also indicates that the routing matrix for seven jobs and six machines to schedule the jobs with the machines or work center and the jobs scheduling was allocated by the Lekin scheduler software package for the existing manufacturing process of the company. Therefore, the data fed into the Lekin scheduler software package, and make-span were obtained through the dispatching and heuristic approaches. Since the Akaki Basic Metal Industry job allocation or scheduling was followed the first to come first services (FCFS/FIFO) method and for this method, the Gantt-chart was developed by using the Lekin scheduler software package to obtain the total make-span of a manufacturing process of the company. The data also, entered into the Lekin schedule software to determine the proper allocation of jobs on the existing resources and optimum make-span through different scenarios as mentioned below figure.

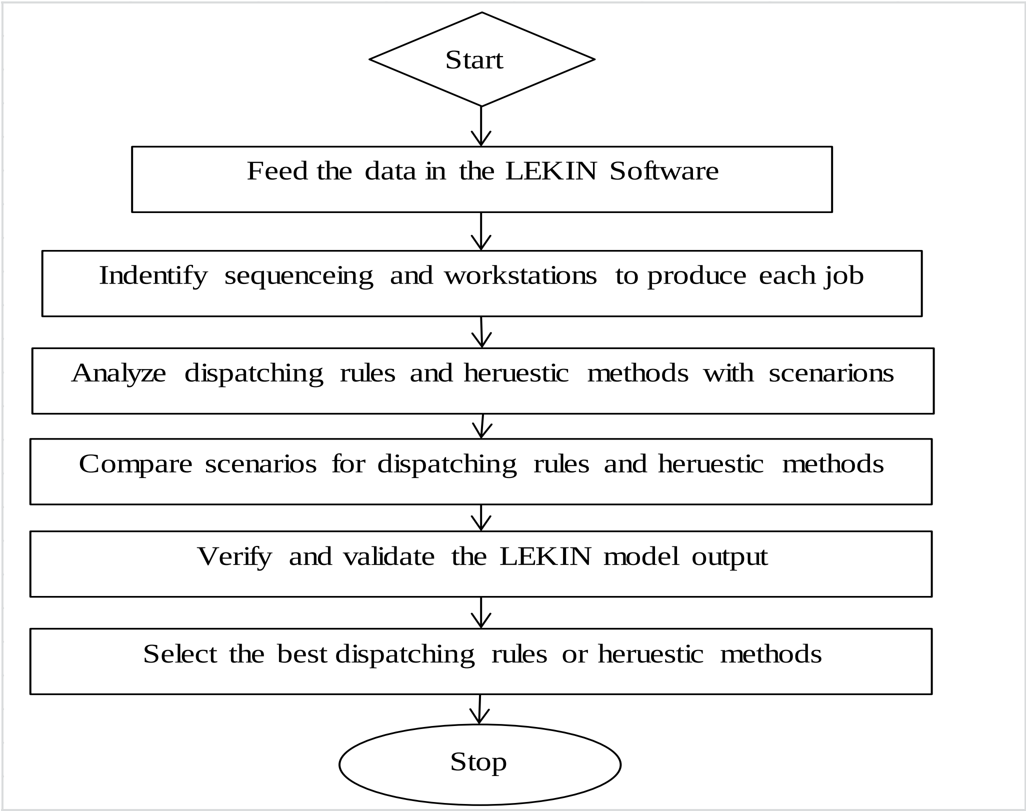


Figure: 9.The modeling procedure of jobs for optimum make-span and resource utilization

4.6 Make-span analysis for existing scheduled

The Gantt chart that shows the sequences of jobs or machine loading for the existing schedule indicated by Lekin's flexible job shop scheduling system that company using method (FIFO) is presented in the figure below.

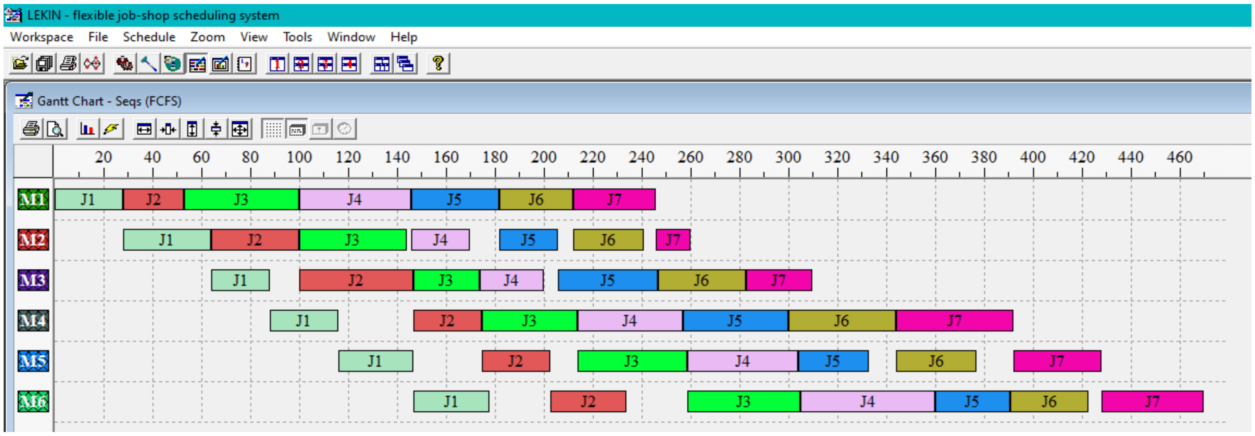


Figure: 10.Existing scheduling technique by using Lekin scheduling software package

Based on the above-indicated figure, the make-span was 470 minutes per shift respectively. To optimize this make-span, the researcher used other scheduling techniques. The Gantt chart shows the sequences of jobs for the optimal schedule developed by the Lekin software.

4.7 Productivity analysis for existing scheduled

According to Eilon et al., (2019) explained about data for the productivity improvement model needs to gather any value of input and output. Inputs were classified as labor, material, capital, energy, etc., and outputs were classified into the product in the machine shop. And also to improve the productivity of a particular period, the same data was collected for the period. The data required is dependent on the model chosen, and the data collecting is also based on the situation.

Table: 11. Akaki Basic Metal Industry's planned and actual outputs

Years	2015	2016	2017	2018	2019	2020	Average
Planned output (0000) (unit)	13,750	15,890	17,550	19,850	21,231	23,627	18649.67
Actual output (0000) (unit)	7,753	8,775	8,551	8,602	8,371	8,013	8344.17
Planned make-span (min.)	105,240	121,060	110,180	108,617	101,720	100,931	107958
Actual make-span (min.)	120,531	149,981	165,732	167,673	168,803	168,951	156945.17
No. of Machines (No.)	36	38	37	38	39	37	38

(Company Report, 2015-2020) (Modified).

The above table indicates the company's planned and actual output, make-span, and the number of machines in the machine shop of Akaki Basic Metal Industry annual reports. Based on this table, the researcher indicates the declination of actual output to meet the targeted output.

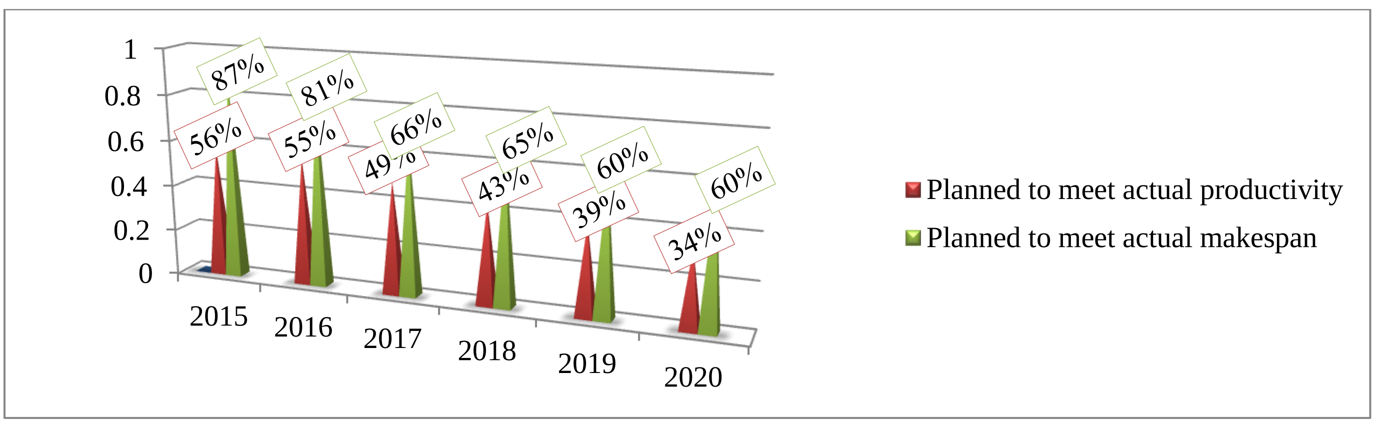


Figure 11: Percentages of planned to meet actual of makespan and productivity

Machine Productivity:

It is one of the techniques used in the Akaki Basic Metal Industry to measure the productivity of the machines by converting the raw inputs into a useful product. In Akaki Basic Metal Industry of spare part manufacture, measure its productivity by considering both the labor and machine productivity (Nunesca & Amorado, 2015). Labor, materials, energy, and others productivity measurements are not taken into consideration, they were assumed as constant in this study.

To calculate the machine productivity, the following data is to be considered:

- The total machines in the machine shop must be counted.
- The output of the machine shop needs to be counted or calculated.
- The total working hours in the factory need to be noted down.

In this case, the machine productivity can be calculated by using the formulae given below:

$$\textbf{Machine Productivity} = \frac{\textbf{Total number of spare parts produced}}{\textbf{Total number of machines used in the machine shop}}$$ (Tadiyos, 2018)

To calculate the machine productivity of akaki basic metal industry, from the above-given table averagely for existing methods:

$$\text{Productivity} = \frac{8344.17*10000 \text{ units}}{38\text{machines}*12*24\text{shifts}}$$ =7624.43 units/ machine / shift or

$$\text{Productivity} = \frac{8344.17*10000\text{units}}{38\text{machines}*12*24*470\text{minutes}}$$ =16.22units/machine/minutes

Where, 38machines= Average number of machines in machine shop

12=number of months in one year

24=number of shifts in one month

470 minutes=total makespan in one shift

The productivity of the akaki basic metal industry, as the existing data obtained from annual report through mathematical approach 7624.43 units/machine/shift averagely.

Generally, the Akaki basic metal industry was one among the Ethiopian metal & engineering industries with a planned capacity of manufacturing 18649.67units per annum on average. However, currently, it is performing under the capacity of about 44.740% annually due to several reasons.

Fishbone diagram analysis

It is an effective method used to know the relationship between problems that lowering productivity to study used in manufacturing includes methods, machines, manpower, maintenance, and so on are some factors. Therefore; the figure below shows how input parameters like materials, labor-skill, experience, machines, training, etc. are the factors responsible for lowing productivity in the manufacturing industries.

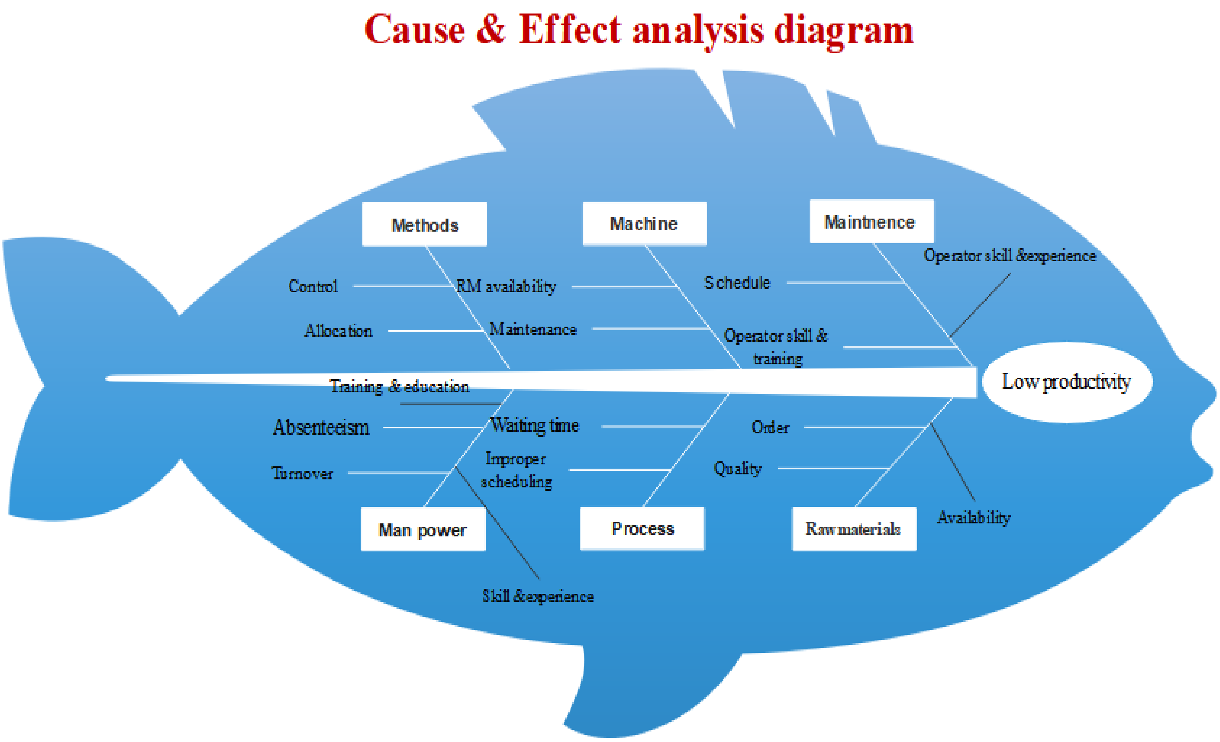


Figure 12.Productivity factors cause & effect diagram

4.8 Proposed solution

The Gantt chart that shows the sequences of jobs or machine loading for the optimal schedule developed by the Lekin flexible job shop scheduling system using shifting bottleneck (DASH) and local search algorithms are presented in the below figures. The best optimal solution was found through Shifting Bottleneck (DASH) and Local search methods rather than the company used method (FIFO).

Optimum make-span for a new scheduled

The optimal make-span was obtained through the Lekin scheduling software package that shows the sequences of jobs on the existing machines. Based on the result obtained by the Lekin scheduling software package, the manufacturing processing time of the company, specifically, for the machine shop was done as below figure.

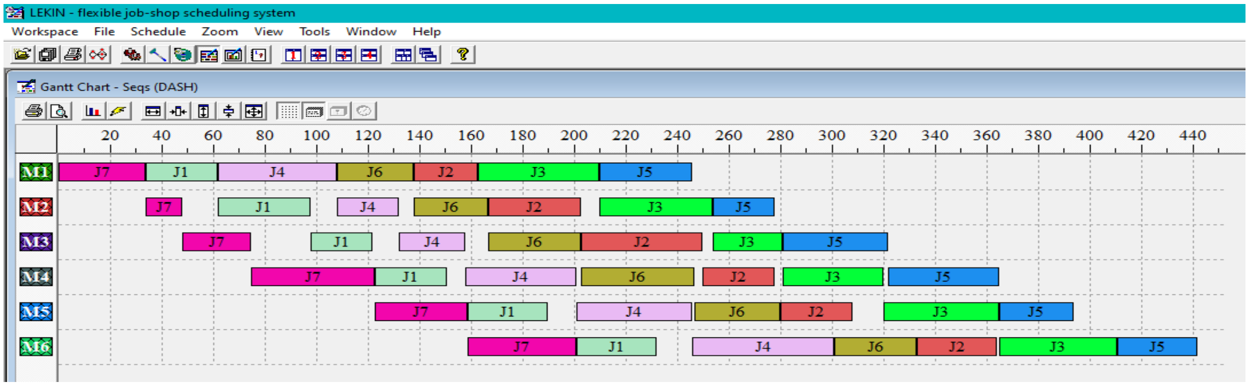


Figure: 13. Gantt-chart for optimum job sequence scenario one

In scenario one, the findings of the Lekin run through Shifting Bottleneck (DASH) approach resulted in the minimum make-span of 442 minutes/machine/shift with job sequences of **J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5;** when compare with the company used method (FIFO).

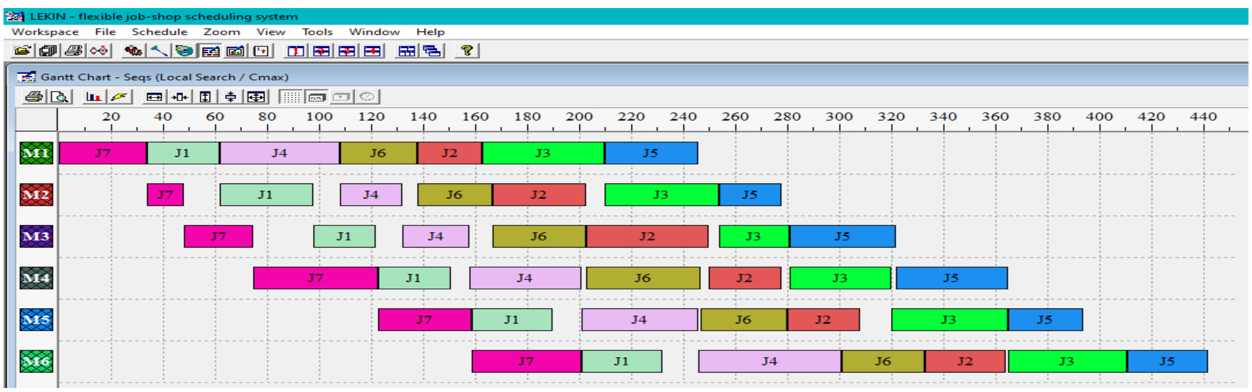


Figure: 14. Gantt-chart for optimum job sequence scenario two

In scenario two, the findings of the Lekin run through Local search approach resulted in the minimum make-span of 442 minutes/machine/shift with job sequences of **J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5**. It is the same with scenario one. So, based on the result obtained by the Shifting Bottleneck (DASH) and Local search approaches, the make-span of the machine shop was reduced by 28 minutes/shift. However, around four (4) cycles were there, in a shift as the researcher perceived from respondents. Thus, the reduced make-span of machine-shop per cycle was 7 minutes/machine or around 5.96% reduced per shift.

Productivity analysis for a new scheduled

Based on the optimum make-span achieved by Shifting Bottleneck (DASH) and Local search approaches, the productivity of the machine shop was calculated as below:

$$\text{Productivity} = \frac{8344.17*10000\ \text{units}}{38\text{machines}*12*24*442\text{minutes}} = 17.25\text{units/machine/minutes}$$ or

$$\text{Productivity} = 8108.52\text{units/ machine / shift}$$

Where, 38machines= Average number of machines in machine shop

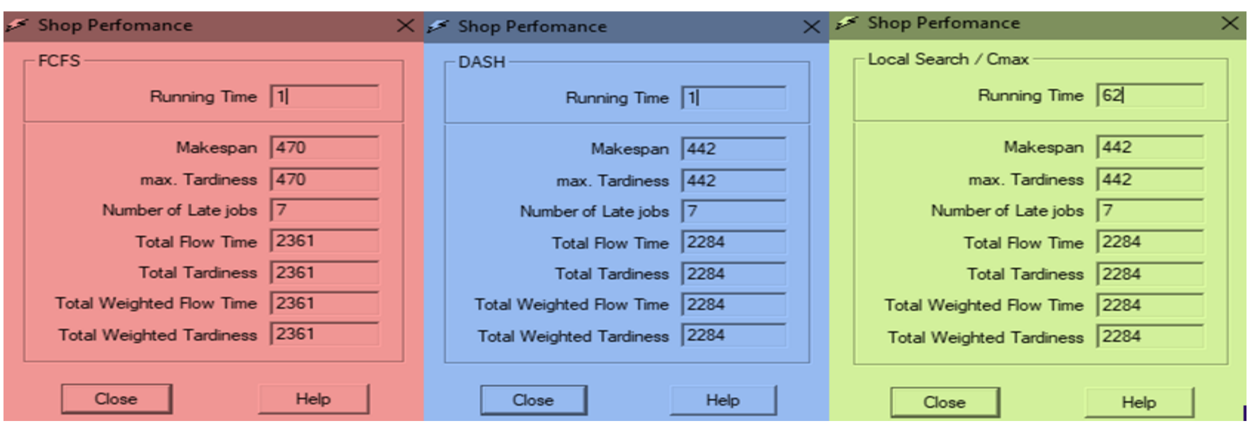
12-number of months in one year

24-number of shifts in one month

442 minutes- total makespan in one shift

Generally, the Akaki Basic Metal Industry uses the First come first service (FCFS) method and the time taken to produce 7624.43 units/machines was 470 minutes/machine in one shift on average. But, by using the Lekin® software scheduler package the time taken to produce the 7624.43 units/machine was 442 minutes/machine in one shift averagely and the gap between around 5units/machine/shift, because of improper scheduling jobs on the given machines. Therefore, when the company applies these methods, productivity will be increased by 7.54% per shift.

Table 12: Shop performance indication of different algorithms built-in Lekin® software



Shop Perfomance	FCFS	DASH	Local Search / Cmax
Running Time	1	1	62
Makespan	470	442	442
max. Tardiness	470	442	442
Number of Late jobs	7	7	7
Total Flow Time	2361	2284	2284
Total Tardiness	2361	2284	2284
Total Weighted Flow Time	2361	2284	2284
Total Weighted Tardiness	2361	2284	2284

Source: (Researcher)

4.9 Simulation model formulation

The simulation model was built using Arena® version 14.0 simulation software for the recorded processing time of operations in machine shops through stopwatch. The objective of the model was to determine which components of the system were included in the model and how the model could flow to imitate a real system (Tolosa, 2018).

Generally, to model and simulate the jobs of a machine shop for optimum make-span or total make-span and resource utilization, by using Arena software package and the researcher classify it into three parts as mentioned below.

Part one: It would be responsible for creating jobs, defining all variables and attributes, releasing jobs, and starting sequencing. It includes the four modules such as;

- ✓ Create module: - from the basic process project bar, the time between arrivals would be constant, the value would be (0), entities per arrival would be (1), and maximum arrivals would be (7).
- ✓ Assign module: - it from the basic process project bar in which define all variables and attributes concerning: part index, entity type, entity sequence, and an attribute to generate random numbers which we would call random.
- ✓ Station module: - it from an advanced transfer project bar which used to release jobs.
- ✓ Route module: - from advanced transfer project bar which used to start sequencing.

Part two: It would be responsible for the machines, the manufacturing process, and the exportation of the information to the Excel file. This part would be done for each machine and the same process repeated for all machines. It includes three modules as mentioned below;

- ✓ Station module: from advanced transfer project bar which used to receive jobs.
- ✓ Process module: from the basic process project bar, it represents the machine and simulating the manufacturing process, in the field action we would select seize delay release, for resources add a resource, and put the quantity for it, in the delay type, choose expression and it would be process time.
- ✓ Route module: from advanced transfer project bar which is used to release the jobs by sequence. In destination type, choose by sequence.

Part three: In this part, jobs would exit the manufacturing system and the system dispose of the parts. It includes the two modules such as,

- ✓ Station module: from advanced transfer project bar which used for the jobs to exit the manufacturing process.
- ✓ Dispose of the module: from the basic process project bar which means that the system disposed of the jobs.

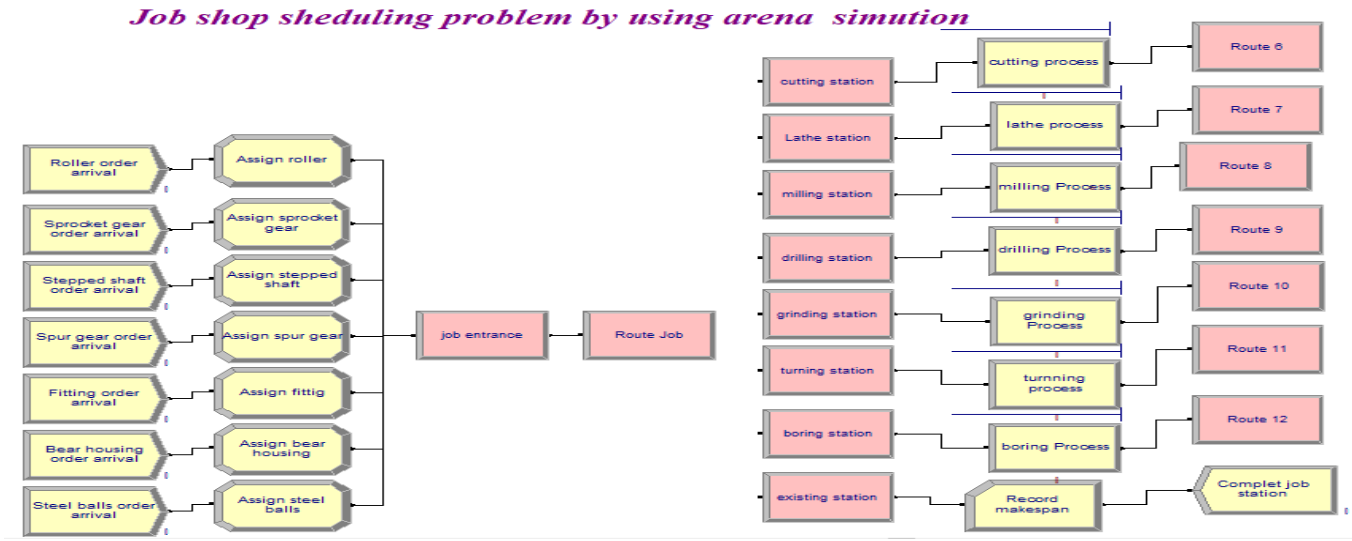


Figure 15.The machine-shop model generated by Arena software, source (Researcher)

4.10 Model Verification and Validation

The most important step in simulation modeling is verification and validation. If the model did not describe the real system, the outputs of the model have bad on quality and reliability of decisions that will be performed. Therefore, in order to properly describe the machine shop scheduling, it should be verified and validated.

Model-Verification

During model translation, it was ensured that the Lekin model run contains the necessary components and checked model operates as needed. The verification process on the Lekin model was performed by various input values and step-by-step execution techniques. The formulation of input values was checked to build the model correctly(Balasundaram, 2018).

Model validation

The arena simulation runs the input parameters and checked the model output findings for their correctness. The model reliability was validated by comparing the output of the real system and the existing system. The test run with ten (10) replications was performed and the output of the real system was 442 minutes. Therefore, the output value according to the model is a realistic value and the test run was operating without problems.

Hence, the make-spans in the model run smoothly without interruptions, and the assumption was made that a model is a realistic approach to the data basis of each operation. It can be said this model represents the real system and is said to be verified and validated. The decision made to use the model as the basis of further analysis and propose a productivity improvement model.

The measurement of make-span and average waiting time for all jobs performed through this model. Make-span is also recorded in the record module from the basic-process template panel. These measurements were recorded in the statistics module, from the advanced-process template panel, for the final results from simulation outputs on the user-specified section.

Table: 13.User-specified output for DASH and Local search algorithms

10:27:17PM User Specified May 19, 2021

Shifting Bottleneck /Tmax (DASH) algorithm or approach Replications:10

Replication:1 Start Time:0:00 Stop Time: 0:30:47 Time Units: Minutes

Tally:

Interval	Average	Half Wide	Minimum	Maximum
Make span	321.5000	(Insufficient)	201.0000	442.0000

9:41:13PM User Specified May 19, 2021

Local Search algorithm or approach Replications:10

Replication:1 Start Time:0:00 Stop Time:1:19:07 Time Units: Minutes

Tally:

Interval	Average	Half Wide	Minimum	Maximum
Make span	321.5000	(Insufficient)	201.0000	442.0000

As studied by Araya, (2018) the status of a machine operating was known as availability and when machines stop operation was known as lose-time. The measurements of lose-time have their factors on productivity, which measured the organizational resources to produce the needed outputs. So, the higher lose-time of resources affects the productivity of the manufacturing industries. Whenever the lose-time was considered as the company loses desired productivity.

4.11 Result and Discussion summary

The job shop scheduling problem formulated for ABMI under sections six were solved using Lekin flexible job shop scheduling software that has eight dispatching rule and five heuristics methods inbuilt with it under the job shop scheduling problem and validated by arena simulation software. The output analysis was the examination of data generated by a Lekin approach and its purpose is to obtain the optimum sequence of the system and report the output results gathered from the Lekin approaches. Based on the Lekin scheduler results /reports with 10 replications the optimum make-span, productivity and cost were achieved. Using these methods, different performances are measured, such as; Make-span (C_{max}), and Tardiness (T_{max}), which are evaluated through this method.

Therefore, the finding of the study has revealed that the shifting bottleneck (DASH) and Local search to minimize maximum tardiness (T_{max}) and make-span yields optimal schedule. The shifting bottleneck (DASH) and Local search have resulted in equal minimum make-span and tardiness of 442 minutes which are determined by the critical job sequence **J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5**. The computational results of the Lekin scheduling software and arena simulation run, the job sequence on each machine (machine loading) are presented in the table below respectively.

Table: 14.Optimum job sequence on each machine (Machine Loading)

Nº	Methods used	Machines	Job-sequences
1	First come first served priority rule	M_1	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
		M_2	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
		M_3	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
		M_4	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
		M_5	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
		M_6	J_1=>J_2=>J_3=>J_4=>J_5=>J_6=>J_7
2	Shifting Bottleneck (DASH) with objectives of minimizing tardiness (T_{max}) and make-span time (C_{max})	M_1	J_7=>J_1=>J_4=>J_6=>J_2=>J_3=>J_5
		M_2	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_3	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_4	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_5	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_6	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
3	Local Search with objectives of minimizing tardiness (T_{max}) and make-span time (C_{max})	M_1	J_7=>J_1=>J_4=>J_6=>J_2=>J_3=>J_5
		M_2	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_3	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_4	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_5	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5
		M_6	J_7=>J_1=>J_4=>J_6=> J_2=>J_3=>J_5

From the above sequencing table, the total make-span of Akaki basic metal industry follow the rule (FCFS) was 470minutes. However, by using the heuristic scheduling rule, the total make-span of the machine shop was reduced to 442 minutes; and when we compare both new and existing sequences, the proposed sequence make-span was less than the existing sequence by 28 minutes/shift. Therefore, the proposed rule Shifting Bottleneck /T_{max} and DASH use less time to produce the spare parts than the company follows the rule.

Chapter Five

Conclusion, Recommendation, and Future Research Area

5.1 Conclusion

Productivity improvement is an important issue in the metal industry in order to stay in the global competitive market. The profit earning of the metal products industry largely depends on productivity improvement. This research is concerned with the productivity improvement of the spare parts manufacturing sector through job shop scheduling problems where the case study took for the Akaki Basic Metal Industry. The objective of this study was to improve the productivity of the Akaki Basic Metal Industry by identifying the factors that affect the productivity of the factory, specifically the machine shop.

According to, statistical data report indicated from 2015 up to 2020; the actual capacity to produce the total productions and delivering time for all customers are less than planned, by different factors. Thus, the researcher identifies these problems through primary and secondary data collection methods and analyzed the collected data through fishbone diagrams, excel, Lekin, and simulation software.

The proposed solution of proper allocation of jobs on the given resources was changed from $\mathbf{J_1 \Rightarrow J_2 \Rightarrow J_3 \Rightarrow J_4 \Rightarrow J_5 \Rightarrow J_6 \Rightarrow J_7}$ into $\mathbf{J_7 \Rightarrow J_1 \Rightarrow J_4 \Rightarrow J_6 \Rightarrow J_2 \Rightarrow J_3 \Rightarrow J_5}$ showed the optimum make-span of the machine shop through job shop scheduling methods by using Liken software scheduler package, becomes 442 minutes from 470 minutes per shift. Additionally, the productivity of the machine shop increased by 7.54% per shift, and the make-span was reduced by 28 minutes/shift or 5.96% per shift. Some others shops or rooms required improvement, which was not addressed due to time limitation and pandemic **COVID-19** issue for this research work.

5.2 Recommendation

Some recommendations were proposed for Akaki Basic Metal Industry and researchers.

- The company has problems with the mismatch of planned make-span and productivity with actual. Therefore, the Akaki Basic Metal Industry will be beneficiary by implementing the proper allocation of jobs on the given machines done by the LEKIN software scheduler and validated by arena simulation software.
- It should be arranging the regular training programs on productivity improvement & analysis for the workers will help the company to improve the productivity of the company.
- To be able to produce metals efficient and competitive way factory needs to adapt to the best manufacturing system practices which help to improve productivity.

5.3 Future Research Area

This study focuses on Akaki Basic Metal Industry, but that it is advantageous to implement to see the impact in other factories. The researchers can identify others productivity lowering factors that are not included in this research, applying the new methods for the factory. And also, this study was limited to scheduling the jobs of a machine shop at a specific time during the research period; reduce the make-span and improve productivity. Other researchers can address the others sections to optimize the make-spans and productivity of the case company through better methods if there.

Reference

Abdolrazzagh-Nezhad, M., & Abdullah, S. (2017). Job Shop Scheduling: Classification, Constraints and Objective Functions. *International Journal of Computer and Information Engineering*, *11*(4), 429–434. https://waset.org/publications/10006691/job-shop-scheduling-classification-constraints-and-objective-functions

Alene, T. (2020). *Productivity Improvement Using Heuristics Algorithm in Scheduling A Flow-Shop Manufacturing, (Case Of Altex)*. http://hdl.handle.net/123456789/10947

Alzahrani, J. S. (2019). *Job Shop Scheduling Considering Makespan , Penalties of Machine Idling , and Job Out of Time*. *7*(January), 73–82. https://doi.org/10.5281/zenodo.2550095

Alzahrani, J. S., Al-qura, U., & Arabia, S. (2019). *Job-Shop Scheduling Optimization with Stochastic*. *6*(January), 73–83. https://doi.org/10.5281/zenodo.2562266

Angerasa, A. (2018). *Labor Productivity Measurement and Improvement: In Case of Ethiopian Medium and Large Footwear Industry*.

Araya, T. (2018). *Efficiency Analysis and Performance Improvement of Bottling Production Line, Case on: East Africa Bottling Share Company*. 131.

Balasundaram, A. K. (2018). A Simulation Modeling Approach for Job Shop Scheduling Problems: Case of Metal Industry. *International Journal of Science and Research (IJSR)*, *7*(10), 421–425. https://doi.org/10.21275/ART20191536

Baskar, A. (2015). *Minimizing the Makespan in Permutation Flow Shop Scheduling Problems using Simulation*. *8*(September).

Bayeh, T. (2019). *Productivity Improvement through Line Balancing: Case Study of Nazareth Garment Share Company*. Addis Abeba Unviversity,School of Mechanical and Industrial Engineering.

Bewoor, L. A. (2016). Application of Genetic Algorithm on Job Shop Scheduling Problem to Minimise Makespan. *International Journal of Science and Research (IJSR)*, *5*(6), 1726–1729. https://doi.org/10.21275/v5i6.nov164660

Biswas, R. (2013). Productivity Improvement in Garments Industry Through Cellular Manufacturing Approach. *Ms Thesis ,IPE BUET, April*, 1–117.

Chang, H., Chen, Y., Liu, T., & Chou, J. (2015). *Solving the Flexible Job Shop Scheduling Problem With Makespan Optimization by Using a Hybrid Taguchi-Genetic Algorithm*. *January 2016*. https://doi.org/10.1109/ACCESS.2015.2481463

Choomlucksana, J., Ongsaranakorn, M., & Suksabai, P. (2015). Improving the Productivity of Sheet Metal Stamping Subassembly Area Using the Application of Lean Manufacturing Principles. *Procedia Manufacturing*, *2*(February), 102–107. https://doi.org/10.1016/j.promfg.2015.07.090

Dave, M. (2016). *Job Shop Scheduling Algorithms- A Shift from Traditional Techniques to Non-Traditional Techniques*. *June*, 1–6.

Duran, C., Cetindere, A., & Aksu, Y. E. (2015). Productivity Improvement by Work and Time Study Technique for Earth Energy-glass Manufacturing Company. *Procedia Economics and Finance*, *26*(15), 109–113. https://doi.org/10.1016/s2212-5671(15)00887-4

Eilon, S., Chowdhury, I. G., Yohannes, H. F., The, I. N., Of, C., Garment, E. M. D., Plc, I., Pongchairerks, P., Jilcha, A. K., Prof, A., Kitaw, D., Jote, A. N., Commerce, O. F., Partial, I. N., Of, F., For, R., Degree, T. H. E., Masters, O. F., Art, O. F., … Eresi, Z. (2019). Job shop scheduling. *Production Engineer*, *54*(7–8), 404. https://doi.org/10.1049/tpe.1975.0197

Eresi, Z. (2019). *Optimization of Inventory through an integrated system Approach for Repairable Spare parts Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering*. *October*.

Eshetu, B. (2017). *Integrated Model for Continuous Productivity Improvement in Footwear Industry : (A Case of Anbessa Shoe S . C .)*.

Ferreira, C. (2020). *Optimizing Dispatching Rules for Stochastic Job Shop Scheduling Optimizing Dispatching Rules for Stochastic Job Shop Scheduling*. *January*. https://doi.org/10.1007/978-3-030-14347-3

Firake, S. T., & Inamdar, K. H. (2014). *Productivity Improvement of Automotive Assembly Line Through Line Balancing*. *2*(3), 124–128.

Gebremedhn, G. (2017). *Road Traffic Congestion Analysis and Traffic Flow Modeling at Meskel Square Signalized Control Intersections*. *June*.

Gujar, S., & Moroliya, M. R. (2018). Increasing the productivity by using work study in a manufacturing industry- Literature review. *International Journal of Mechanical and Production Engineering Research and Development*, *8*(2), 369–374. https://doi.org/10.24247/ijmperdapr201841

Hassanein, W., Nawara, G. M., & Wael Hassanein, E. S. (2014). Solving the Job-Shop Scheduling Problem by Arena Simulation Software Productivity View project Solving the

Job-Shop Scheduling Problem by Arena Simulation Software. In *International Journal of Engineering Innovation & Research* (Vol. 2, Issue 2). https://www.researchgate.net/publication/236631006

Imseitif, J., Tang, H., & Smith, M. (2019). Throughput analysis of manufacturing systems with buffers considering reliability and cycle time using DES and DOE. *Procedia Manufacturing*, *39*(2019), 814–823. https://doi.org/10.1016/j.promfg.2020.01.423

Jadayil, W. A., Khraisat, W., & Shakoor, M. (2017). Different strategies to improve the production to reach the optimum capacity in plastic company Different strategies to improve the production to reach the optimum capacity in plastic company. *Cogent Engineering*, *14*. https://doi.org/10.1080/23311916.2017.1389831

Kassu, J., & Eshetie, B. (2015). *Job Shop Scheduling Problem for Machine*. *15*(1).

Kulkarni, R. G., Kulkarni, V. N., & Gaitonde, V. N. (2018). Productivity improvement in assembly workstation of motor winding unit. *Materials Today: Proceedings*, *5*(11), 23518–23525. https://doi.org/10.1016/j.matpr.2018.10.139

Kumar, P. (2017). *Production Scheduling in a Job Shop Environment with consideration of Transportation Time and Shortest Processing Time Dispatching Criterion Production Scheduling in a Job Shop Environment with consideration of Transportation Time and Shortest Processing . December*.

Kumar, T. V., & Babu, B. G. (2014). Optimizing of Makespan in Job Shop Scheduling Problem: A Combined New Approach. *International Journal of Mechanical Engineering and Robotics Research*, *3*(2), 44–53.

Legesse, D. A., & Singh, A. P. (2014). *Productivity Improvement Through Lean Manufacturing Tools: A Case Study on Ethiopian Garment Industry*. *3*(9), 1037–1045.

Lemma, N. (2019). *International Journal of Engineering Technology and Scientific Innovation Optimizing Make-Span of Job Shop Scheduling Problems Through Dispatching Rules and Heuristic Algorithms (Case Study : Shints Etp Garment Plc .). December*, 285–296.

Leusin, M., Frazzon, E., Uriona Maldonado, M., Kück, M., & Freitag, M. (2018). Solving the Job-Shop Scheduling Problem in the Industry 4.0 Era. *Technologies*, *6*(4), 107. https://doi.org/10.3390/technologies6040107

Mazumder, S. (2014). Productivity Improvement in Readymade Garments Industry -a Case Study. *Ms Thesis ,IPE BUET, January*.

Mentesinot, M. (2017). *Enhancing Productivity through Improved Maintenance System (Case Study in Dashen Brewery Share Company)*.

Mishra, R. (2015). *Productivity improvement in Automobile industry by using method study*. *4*, 361–363.

Moktadir, A. (2017). *Productivity Improvement by Work Study Technique : A Case on Leather Industrial Engineering & Management Productivity Improvement by Work Study Technique : A Case on Leather Products Industry of Bangladesh*. *January*. https://doi.org/10.4172/2169-0316.1000207

Moktadir, M. A., Ahmed, S., Tuj Zohra, F., & Sultana, R. (2017). Productivity Improvement by Work Study Technique: A Case on Leather Products Industry of Bangladesh. *Industrial Engineering & Management*, *06*(01), 1–11. https://doi.org/10.4172/2169-0316.1000207

Naveen, B., & Babu, T. R. (2013). Productivity improvement in manufacturing industry using industrial engineering tools. *Journal of Mechanical and Civil Engineering*, 11–18.

Nawara, P. G. M. (2013). *Solving the Job-Shop Scheduling Problem by Arena Simulation Software*. *2*(2), 161–166.

Nunesca, R. M., & Amorado, A. T. (2015). *Application of Lean Manufacturing Tools in a Garment Industry as a Strategy for Productivity Improvement*. *3*(4), 46–53.

Othman, Z., Rohmah, D., Islam, U., Sunan, N., & Yogyakarta, K. (2012). *Comparison of Dispatching Rules in Job-Shop Scheduling Problem Using Simulation : A Case Study*. *11*(August 2016). https://doi.org/10.2507/IJSIMM11(3)2.201

Ramkumar, R., Tamilarasi, A., & Devi, T. (2011). *Multi Criteria Job Shop Schedule Using Fuzzy Logic Control for Multiple Machines Multiple Jobs*. *3*(2), 282–286.

Rathod, B., Shinde, P., Raut, D., & Waghmare, G. (2016). *Optimization of Cycle Time by Lean Manufacturing Techniques-Line Balancing*. *4*(V), 224–229.

Reddy, K. D., Bhupal, M., & Naidu, G. C. (2018). *Productivity Improvement By Using Line Balancing And Automation Strategies in order To Improve overall Equipment Effectiveness*. *7*(1), 21–27.

Sci, J. C., Biol, S., Jilcha, K., Berhan, E., & Sherif, H. (2015). Workers and Machine Performance Modeling in Manufacturing System Using Arena Simulation. *Journal of Computer Science & Systems Biology*, *8*(4), 185–190. https://doi.org/10.4172/jcsb.1000187

Shah, K., Ripon, N., & Torresen, J. (2014). *Integrated Job Shop Scheduling and Layout*

Planning : A Hybrid Evolutionary Method For Optimizing Multiple Objectives Integrated job shop scheduling and layout planning : a hybrid evolutionary method for optimizing multiple objectives. *June*. https://doi.org/10.1007/s12530-013-9092-7

Sharma, P., & Jain, A. (2016). A review on job shop scheduling with setup times. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *230*(3), 517–533. https://doi.org/10.1177/0954405414560617

Shukla, P., Susheel, P., Prof, M., & Jain, S. (2018). *Improvement of Production Rate by Line Balancing for Small Scale Industry : A Case Study*. *6*(09), 87–92.

Singh, M. D., Singh, S., Keyur, D., Saumil, S., Niki, P., & Harshal, P. (2015). *Overall Productivity Improvement in Casting Industry by Using Various Industrial Engineering Techniques*. 18713–18721. https://doi.org/10.15680/IJIRSET.2015.0401050

Singh, S. P. (2016). Technical Change and Productivity Growth in the Indian Sugar Industry. *Procedia Economics and Finance*, *39*(November 2015), 131–139. https://doi.org/10.1016/S2212-5671(16)30257-X

Soltany, M. R., Sayadi, A. R., Monjezi, M., & Hayati, M. (2013). Productivity Improvement in a Steel Industry using Supply Chain Management Technique. *Int J Min & Geo-Eng (IJMGE)*, *47*(1), 51–60.

Tadiyos, D. (2018). *Productivity Analysisand Improvementin Ethiopian Metal Manufacturing Industries " A C ase of Yesu Metals Manufacturing ." June*.

Tesfaye, H. (2020). *Optimization of Job Shop Scheduling Problem*. *c*, 14–20.

Tilahun, M. (2018). *Enhancing Productivity of Mixed-Model Assembly Line in Tikur Abbay Shoe S.Co*.

Tolosa, T. (2018). *Supply Chain Network Design and Analysis Using Simulation Technique : Case of Kojj Food Complex*. *June*.

Waschneck, B., Altenmüller, T., Bauernhansl, T., & Kyek, A. (2017). Production scheduling in complex job shops from an industrie 4.0 perspective: A review and challenges in the semiconductor industry. *CEUR Workshop Proceedings, 1793*.

Wolde, M. G., Berhan, E., & Jilcha, K. (2018). Production improvement with flow shop scheduling heuristics in Household utensils manufacturing company. *Cogent Engineering*, *13*, 1–11. https://doi.org/10.1080/23311916.2018.1430007

Yemane, Alula. (2013). *Manufacturing System Modeling and Performance Analysis Using*

Simulation Case on Peacock Shoe Factory.

Yemane, Aregawi, Gebremicheal, G., Meraha, T., & Hailemicheal, M. (2020). Productivity Improvement through Line Balancing by Using Simulation Modeling (Case study Almeda Garment Factory). *Journal of Optimization in Industrial Engineering*, *13*(1), 153–165.

Yogesh, D. M. (2018). Productivity Improvement through Kaizen Workshop - A Case Study. *International Journal of Science and Research (IJSR)*, *7*(11), 832–835. https://www.ijsr.net/archive/v7i11/ART20192159.pdf

Addis Ababa University

Institute of Technology

School of Mechanical and Industrial Engineering

Post Graduate Program in Industrial Engineering

Dear Participants:

My name is Negash Lemma, a final year MSc student in Industrial Engineering at Addis Ababa Institute of Technology, Addis Ababa University. I would like to appreciate to your company's staff for their willingness, and cooperation in filling the questionnaire. This questionnaire is developed to conduct scientific research entitled **'Productivity Improvement through Job shop scheduling problem'.** I'm undertaking the research with the guidance of Dr. Gezahegn Tesfaye. The research aims to improve productivity through the job shop scheduling problems approach at Akaki Basic Metal Industry. I would kindly ask the questions for answering truthfully as much as possible, and your response will be kept highly confidential. Thank you in advance for your cooperation.

Sincerely,

Name: Negash Lemma

Email: turalemma23@gmail.com.

Mobile: 0910340320

Appendix-I:-General questions

1. What is your mandate in your company

    Operators [ ]   Supervisors [ ]   Quality control [ ]

    Other: Please specify it…….

2. What is the work experience of workers in your company

    Below 1year 1-2 year [ ] 2-5 year [ ]   5-10 year [ ] more than 10 year [ ]

3. What is sex: male [ ]   female [ ]

4. What are the major problems of your company
    a. Scheduling problem
    b. Customer satisfaction problem
    c. The raw material shortage problem
    d. Skilled manpower problem
    e. Financial problem
    f. Failure of machines

4. What is the major cause of time loss or a waste of the lowering productivity of the company
    a. Raw material cause
    b. Machine cause
    c. Human factor/skilled man-power cause
    d. Other: Please specify if it……..

6. What was the production type of your company
    a. Job shop
    b. Flow shop
    c. Medium size
    d. Large batch size
    e. Other: Please specify if it

7. What was the production strategy following by your company:
    a. Make to Order (MTO)
    b. Make to Stock (MTS)
    c. The mix of MTO & MTS
    d. Other: Please specify if it…….

Appendix-II Factors affecting or lowering the productivity of akaki basic metal industry

Rate the **impact** of the following ***major factors/reasons not to work at high Productivity*** in Akaki Basic Metal Industry**?**

Rate scale: 1=low affecting productivity, 2=medium affecting productivity, and 3=highly affecting productivity

No.	Problems related to low-productivity	3	2	1
1.	Improper allocation of resources			
2.	Machine failure/ breakdowns			
3.	Absenteeism of operators/workers			
4.	Inputs (Raw materials) shortages/problems			
5.	Power Shortage			
6.	Cleaning problems			
7.	Capital or Financial related problems			
8.	Management related problems			
9.	Process related problems			
10.	Workers-skill problems			
11.	PPC- problems			
12.	Market-related problem			
13.	Quality-related problems			
14.	Structure and culture-related problems			
15.	Working condition-related problems			
16.	Infrastructures -related problems			
	Others (Please specify)……………			

Based on the Productivity measurement report please fill in the following information [consider the last six years]

Nº	Productivity Item	Unit	2015	2016	2017	2018	2019	2020
1.	Productivity capacity	Ton						
2.	Productivity volume	Ton						
3.	Level of rejects	%						
4.	Unfinished production	%						
5.	Production cost	Birr						
6.	Sales volume	Ton						
7.	Sales value	Birr						
8.	Export volume	Ton						
9.	Export value	Birr						
10.	Operating profit /profit margin	Birr						
11.	New product models introduced	Qty						

Have you introduced any method productivity improvement program to *improve productivity within* (put ***X*** mark) (consider the 3 years)

No.	*Productivity types*	*Yes*	*No*	*If your answer is "Yes" please specify*
1.	Labor-productivity			
2.	Capital-productivity			
3.	Machinery-productivity			
4.	Energy-productivity			
5.	Material-productivity			
6.	Total-productivity			
7.	Customer satisfaction			
8.	Quality of product			
9.	Supply-productivity			

If your answers are 'No', please describe the reason(s)

Appendix-III <u>Open questionnaires</u>

1. What are the existing productivity and future expansion plan?
2. How do you define, analyze and measure the productivity of your company?
3. What are the factors most significant for your company's productivity?
4. What are the major factors responsible for your company's productivity lowering?
5. What are the major productivity improvement activities taken in your company?
6. What activities are being performed to make the company products, and make competitive in the local and global market?
7. What is your strategy to sell your metal productivity in local and global markets?
8. What are the opportunities your company has in the current business environment?
9. What kinds of supports do the company wants from the Government and none- government to improve their productivity?