



PRODUCTIVITY ENHANCEMENT FOR JOB SHOP
SCHEDULING PROBLEM USING GREY WOLF
OPTIMIZATION (GWO) ALGORITHM:
(CASE STUDY OF AKAKI BASIC METAL INDUSTRY)

MSc. INDUSTRIAL ENGINEERING AND LOGISTICS
MANAGEMENT THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

APRIL, 2023



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DEGREE OF

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Declaration

I hereby declare that this MSc. thesis report is my original work and has not been presented for any degree in any other university and all the sources of material used for this thesis study have been duly acknowledged.

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This is to certify that the thesis entitled “Productivity enhancement for job shop scheduling problem by using grey wolf optimization (GWO) algorithm: Case study of Akaki basic metal industry” submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Industrial Engineering and Logistics management, the Graduate Program of the Department of Industrial engineering, and has been carried out by Bezabih Gebeyehu Yedo Id. No GPIELMW/0003/13, under our supervision. Therefore, we recommend that the student’s thesis can be presented for review and open oral presentation and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Bezabih Gebeyehu Yedo have read and evaluated his thesis entitled “Productivity enhancement for job shop scheduling problem by using grey wolf optimization (GWO) algorithm: Case study of Akaki basic metal industry”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the MSc. Degree. We the examiners’ board approve that this thesis has passed through the defense and review process.

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Acronym

ABMI	Akaki Basic metal industry
BMI	Basic metal industry
EDD	Earliest due date
FCFS	First come first services
GA	Genetic algorithm
GSA	Gravitational search algorithm
GSA	Gravitational search algorithm
GWO	Grey wolf optimization
JSS	Job-shop scheduling
JSSP	Job shop scheduling problem
LPT	Longest processing time
MATLAB	Matrix laboratory
METEC	Metals and Engineering Corporation
MPMJSP	Multi-purpose machines job-shop scheduling problem
PSO	Particle swarm optimization
SPT	Shortest processing time
SSO	Social Spider Optimization

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Abstract

Ethiopian metal manufacturing industries are struggling with a long manufacturing cycle, which results in lower efficiency. Because of issues with improper job allocation on the given machines and machine failure, Akaki BMI has performed significantly worse than other major metal industries in Ethiopia.

The necessary data was gathered from company reports and questionnaires in order to investigate existing issues that impede industry productivity. The sample size considered is 107, of which 98 completed and returned the questionnaires on time, yielding a response rate of approximately 91.6%. It was determined that the major issues affecting Akaki BMI's productivity are related to machinery failure and scheduling. The industry employs a First Come First Serve (FCFS) scheduling method. Thus, the main concern of this research was to pinpoint the causes of the aforementioned problems and to look for different alternative mechanisms/techniques to come up with the best solution.

The solution to scheduling problems is presented and analyzed using the LEKIN and MATLAB software. From the study analysis, GWO based scheduling has better to increase productivity by reducing the makespan, total flow time, total tardiness of the jobs and energy consumption of each machine in the machine shop during both operation time and idle time .

Finally, the findings of the study using FCFS and GWO algorithms showed that the makespan 385 & 225 minutes respectively, which is reduced by a 41.56% improvement, total flow time 5010 & 3840 minutes respectively, which is reduced by a 23.35% improvement, total tardiness 2778 & 1553 minutes respectively, which is reduced by a 44.1% improvement, total energy consumption during operation time of the machines shop 1314.53 & 883.9 kWh respectively, which is reduced by a 32.76% improvement, total energy consumption during idle time of the machines 888.625 & 449 kWh respectively, which is reduced by a 49.47% improvement, and the machine productivity could also be improved by 41.55% per machine/minutes improvement.

Key words: Akaki BMI, First Come First Serve, Flow time, Grey wolf optimization, Local search, Makespan, Scheduling, Tardiness

CHAPTER ONE

1. BACKGROUND AND JUSTIFICATION OF RESEARCH

1.1. Introduction

Productivity is the measure of inputs is converted to outputs in the manufacturing industry (Duran et al, 2015). So, productivity improvement 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).

Production scheduling is essential in achieving optimal performance on a manufacturing shop floor, and it is well known that job shop scheduling problems are computationally challenging. On a manufacturing shop floor, each job is processed on a set of machines in certain sequence according to the job type.

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 makespan 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).

Scheduling is a decision making process that is important in most manufacturing industries. Many scheduling problems are complex and cannot be solved to optimality in polynomial time, such as MPMJSP. The problem normally comes with a given set of jobs where each job consists of a chain of operations. For this entire process, there is a set of multi-purpose machines, which is equipped with different tools that enable it to function for more than one purpose.

The main driving factors to improve the performance of manufacturing systems are the continuous changing demands of customers and the need to deliver better quality and low priced products. To achieve these requirements, the manufacturing system has to have

capability to respond to this changing environment. Because, Productivity is a main factor in which business firm existence is based up on. The main objective of a business firm is providing consumers' satisfaction while making a profit. Business firms always attempt to maximize profit. But in order to maximize profit a business firm has to be efficient where efficiency is measured by the capacity of the business firm to raise the productivity of existing resources so that cost per unit production is reduced. Since cost and productivity are reciprocal of each other, a raise in productivity implies a fall in cost of production which ends in higher profit (Kendrick, J.W. and Daniel Creamer, 1965).

The Ethiopian metal manufacturing sector faces a large makespan 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 makespan and improve the productivity of manufacturing sectors (Kumar, T. V., & Babu, B. G, 2014).

In metal manufacturing factories, assigning the jobs with the given machines is difficult due to many operations done manually. There are many approaches assisting to solve the critical factors of the machine shop scheduling problem. To attain the objective of this study for job shop scheduling problem, grey wolf optimization (GWO) algorithm is utilized. The GWO is a recently developed swarm intelligence algorithm inspired by the social hierarchy and hunting behavior of wolves. It has the advantages of high solution accuracy, and fast convergence speed compared with other classical metaheuristic algorithms such as genetic algorithm, particle swarm optimization, and gravitational search algorithm.

Since the processing times on the machines are fixed and all the machines are switched ON at time zero and switched OFF when the last operation is processed, the idle time for each machine were calculated. Since the processing time for the k^{th} machine is fixed, minimizing the make-span also minimizes the energy consumption caused by the idle time.

In addition, the tardiness of jobs is an important metrics for the classical job shop-scheduling problem. Therefore, for efficient JSSP, the optimization objective is to minimize the sum of individual make-spans, and the total tardiness. Generally, this research focuses on productivity improvement through job shop scheduling problems by identifying the makespan scheduling problems and suggests productivity improvement methods by taking Akaki BMI as a case study.

1.2. Background and Justification of the case study

Akaki Spare Parts and Hand Tools Company is the state-owned firm that are engaged in the production of industrial spare parts, automotive spare parts, boiler electrodes, hand pumps, cutlery and industrial hand tools such as wrenches, pliers, hammers, and so on. It located in the south of Addis Ababa about 25km on the Addis Ababa/Bishoftu main road and about 3km east of the village of Akaki.

Akaki Spare Parts and Hand Tools S.C. were established as the public enterprise in 1989 by the name of Akaki Spare parts and Hand Tools Factory (Negash, 2021). It was established as a national metal processing factory that was intended to produce spare parts (shafts, rollers, sleeves, gears, sprockets, coil springs, sugar mill rollers, ingot moulds, armor plates, and cement balls), industrial hand tools and cutlery.

In October, 1999; the company has been re-established as a share company in according with the proclamation No. 146/98 with a capital of Birr 142,298,000 subscribed by the government and change the name of Akaki Spare parts and Hand Tools Factory in to Akaki Basic Metal Industry by using E.F.D.R state and minister of council No. 183/2002.

Like many industries, Akaki BMI is one of the leader heavy firms in Ethiopia; the company was transferred from the privatization and public enterprises supervising agency, the so-called Metals and Engineering Corporation (METEC) in 2010 (Ethio-engineering, 2020). Nowadays it produces a wide variety of high and low precision assembled and manufactured spare parts and capital items.

The company has an annual melting and production capacity of 4,500 tons of spare parts, 1.6 million pieces of industrial hand tools and 600,000 pieces of cutlery respectively. The company uses its own sales shop in the capital to distribute its product to major customers, such as government owned institutions like sugar factories, electric power companies, cement factories and construction companies and other customers (John & Nebil, 2010). 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 makespan. 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 makespan and lower productivity of Akaki BMI (Ferreira, Figueira, & Amorim, 2020). So, reducing makespan 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. Statement of the problem

As presented in an Ethiopian association of basic metals & engineering report in 2020, Ethiopian metal manufacturing industries are struggling with a high makespan, which could be taken as the one, causing them to be less efficient. As compared with other manufacturing sectors, Ethiopian metal manufacturing firms are performing less than their planned performance percentage with the maximum productivity of 96.27% (Adama steel) and the minimum productivity of 44.74% (Akaki BMI) (Tadiyos, 2018).

The Akaki BMI has performed very less than other major metal industries in Ethiopia. The reason for low performance and longer makespan could be related with improper allocation of jobs on the given machines. (Ferreira, Figueira, & Amorim, 2020). Improper allocation of jobs on machines is one of the main reasons for inefficiencies in job shop scheduling (Negash, 2021). This can lead to increased make span, which is the total time taken to complete all jobs, and irregular work schedules can lead to reduce income generated and reduce the output per planned input. Thus, improving productivity by reducing makespan is becoming the main concerns in metal manufacturing firms (Alene, 2020).

According to Akaki BMI report of 2014 E.C surveyed by the researcher, the firm is engaged in manufacturing the products for the four main sectors, namely: electric power transmission line supporting products, sugar factory spare part products, construction sector spare part and other customer products. Among those main sectors, the other customer products have performed well than other sectors with the 100% performance. But the total planned products and manufactured products were 103,570 spare parts and 27,311 spare parts (26.37%) respectively for all main sectors. The report indicated that the planned and actual productivity were failed to meet.

Table 1-0-1 Performance table of Akaki BMI as of 2014 E.C

1. No	Main activities	Planned (#)	Yield (#)	Performance (%)
1	Power transmission sector	100,539	10,177	10.12
2	Sugar factory sector products	2,217	301	13.58
3	Construction sector products	814	157	19.29
4	Other customer products	0	16,676	100
Grand Total		103,570	27,311	26.37

(Source: Akaki BMI 2014 E.C annual report)

According to the data collected by the researcher, the respondents were prioritized improper allocation of jobs on the given machines as a frequently occurred major problem that are responsible for low productivity in Akaki BMI. So Among the major problems, the improper allocation of jobs on the given machines was the main reason for low productivity, why because the Akaki BMI follows the first come first serve system. Due to these reasons, the longer makespan leading to the lower productivity was showed in the workstation. Thus, the main motivation for conducting this research is to develop efficient and sustainable manufacturing processes and to reduce the makespan and improve machine productivity for the job shop-scheduling problem of the Akaki BMI by using Grey Wolf Optimization algorithms for better competitiveness in the market.

1.4. Objectives

1.4.1. General objective

The main objective of the study was to improve the machine productivity through the JSSP approach by using grey wolf optimization algorithm for Akaki BMI scheduling system.

1.4.2. Specific objective

The specific objectives of the research include:

1. To assess the existing machine productivity level of the industry
2. Identify the factors that lowering the productivity of the Akaki BMI.
3. To assess the existing job-machine sequencing
4. To determine optimal sequencing by using GWO
5. To minimize make-span, total tardiness, and energy consumption.

1.5. Research questions

Based on the background, this study deals about productivity enhancement for Akaki BMI by attempting to answer the following research questions.

1. What is the existing machine productivity level of the Akaki BMI?
2. What are the factors affecting Akaki BMI productivity?
3. What does the existing job-machine sequence of the Industry look like?
4. How will the grey wolf optimization be used in JSSP to obtain optimal job-machine sequence and reduce make span, total tardiness, and energy consumption?

1.6. Significance of the study

Ethiopian metal manufacturing industries are struggling with a high makespan, which could be taken as the one, causing them to be less efficient. Therefore, identifying the problems and suggesting appropriate improvement method to improve the productivity performance will increase their competitiveness level and generally the study could benefit the Akaki BMI as well as other metal manufacturing industries by applying the machine productivity improvement technique like grey wolf optimization for job shop scheduling problems to improve the status of machine productivity factors in machine shops like makespan, tardiness, and energy consumption. It benefits the manufacturing sector involved industries those follows the first come first serve system with job shop scheduling problems to obtain optimal job-machine sequence. Moreover, the research findings could also benefit the researchers and academicians those who are engaged in study and methodology development.

1.7. Scope of the study

Akaki BMI has four sections: Foundry, Machine shop, Forging, and Laboratory sections. Among these sections, the machine shop section was considered as specific focus areas of the study. Since many of the tools and spare parts were manufactured in machine shop section and the Productivity of the industry is becoming highly dependent on machine shop section, this section is taken as a focus section of this research. The reason for low performance and longer makespan could be related with different major problems in the industry. But

improper allocation of jobs on the given machines is the focused problems because the Akaki BMI follows the first come first serve system.

1.8. Organization of the thesis

The paper was organized into five chapters.

Chapter one: presented an introductory part, like introduction, background and justification of the case study, problem statement, objectives, research questions, scope and significance of the study.

Chapter two: presented the theory and literature review about productivity improvement, job shop scheduling problems, review of studies of productivity improvement in manufacturing sectors, and gaps.

Chapter three: presents the research methodology and method for analyzing the data was presented.

Chapter four: presented the results and discussion in a whole.

Chapter five: presented the conclusion, recommendation, and future research area.

CHAPTER TWO

2. THEORY AND LITERATURE REVIEW

2.1. Introduction

In this section literature review on the historical background of basic metal industry, factors affecting productivity in metal industry, productivity measurement and improvement through job shop scheduling problems by different authors, job shop scheduling approaches and grey wolf optimization algorithm for productivity improvement which have been done so far will be presented in detail. Finally, the literature reviews on this area have been undertaken a literature summary, and gaps identified from the literature were presented.

2.2. Historical background of BMI

The steel development can be traced back 4000 years to the beginning of Iron Age. The iron proved to be harder and stronger than bronze. The bronze had previously been the most widely used metal. However, the Iron had begun to replace bronze in weaponry and tools. For the next few thousand years, the quality of the manufactured iron would depend on the ore availability. By the 17th century, properties of Iron were well understood, but increasing urbanization in Europe demanded a more versatile structural metal, and by the 19th century, the amount of iron being consumed has increased remarkably by railroads construction (Solomon, 2018).

The major important development or achievement in steel history came in 1856 when Henry Bessemer developed an effective approach of using oxygen for reducing the content of carbon in the iron. By the late 18th century, iron makers learned how to transform cast pig iron into a low-carbon content wrought iron using puddling furnaces that is developed by Henry Cort in 1784. The furnaces heated molten iron that had to be stirred by paddlers using long, oar-shaped tools, allowing oxygen to combine with and slowly remove carbon (Bell, 2017).

In Ethiopia, industry emerged as a modern economic entity only at the turn of the 20th century. The establishment of a strong central government, expansion of cities associated with the installation of railways and the strengthening of foreign relations increased the demand for importing the manufacturing commodities. In turn, this had encouraged

establishment of the import substituting domestic factories and as a result, modern manufacturing enterprises began to emerge in the 1920s (Gebreeyesus, 2015).

According to some experts in the field, the heavy steel industries in Ethiopia had started some few years before downfall of King Haile Selassie’s regime with Italian investors. Further, the first reinforcement bar factory was owned by an Italian investor, named Mr Risso. That company was founded in 1959, by the name Ethiopian Iron and Steel Factory (EISF) that is located in the south skirt of Addis Ababa, (Akaki Kaliti sub-city). Until recently, EISF was active in operation with a total of annual capacity of 12,000 ton. (Metal and Mining, 2018). In addition to imported billet, the foundry had been using smelting steel scrap for its rebar and wire-rod production (Solomon, 2018).

International Standard for Industrial Classification classified metal industry into basic metal and engineering industry (Demoz, 2014).

Table 2-1: Classification of the metal industry

Industries	Activities
Basic Metal Industries	Engaged in production of metal from ore, scrap and conversion of billet, slabs etc. into primary metal products such as metal sheet, tubes, bars, wires, cables and nails
Engineering Industries	Engaged in conversion of primary metal products into secondary products such as metallic structures, tanks, and pressure vessels, machine parts, machineries, transport equipment, electrical and electronic equipment, measuring and control instruments

There are about 194 metal industries in Ethiopia, from which 155 were engineering industries and 39 basic metal industries, from which 16 (about 41%) were situated in Addis Ababa town and about 26% were situated in Oromia region around Addis Ababa, 20% and 8% in Tigray and Amhara regional state respectively and 5% in Dire Dawa town as (Alemu, Solomon, & Tekeste, 2014). Detail data shown in table 2.2.

Table 2-2: Metals Industries in Ethiopia and Regional Distribution

Types of industries	Tigray	Amhara	Oromia	SNNPR	Harare	AA	Dire	Total
Basic Metal Industry	8	3	10	-	-	16	2	39
Engineering Industry	30	9	33	15	1	63	4	155
Total	38	12	43	15	1	79	6	194

Metal industry could be considered as the engine for industrial development. The progress of metal industry is the key to the economic development. It could be a catalytic in achieving import substitution, export enhancement, value addition, optimal use of mineral, agriculture and other resources and forward and backward integration with economic sectors. Accordingly, basic metal industries are central to build up physical economic base, industrialization and development for any country. However, steel companies have been defined as companies producing steel, from steelworks to processed steel. Hence, excluding the mining industry (raw materials) and the engineering industry (modular production) produce engineering products as shown in figure 2.1 (Dametew, Kitaw, & Ebinger, 2017).

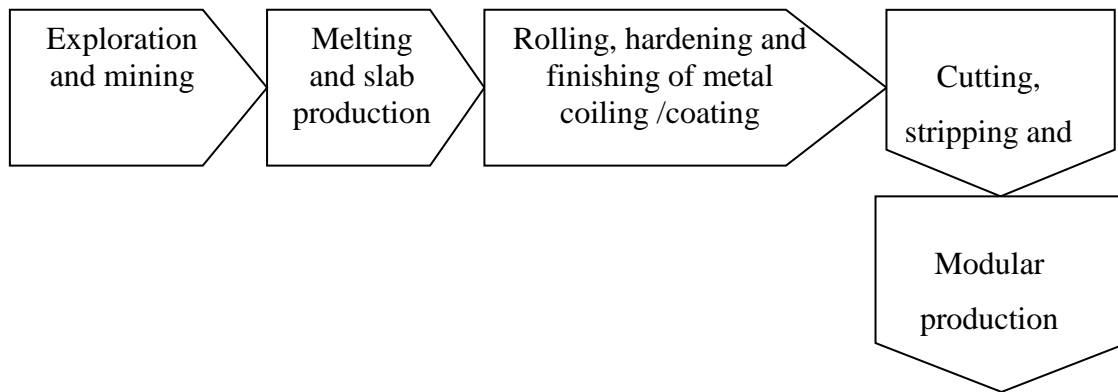


Figure 2-1: Production flow of steel

2.2.1. Background of the Akaki BMI

Basic metal industry groups produce primary raw materials for other manufacturers and they feed other heavy machinery industries, infrastructure and housing projects, etc. Akaki BMI industry has been developed to have a strong industrial base for reducing the progressive dependence on foreign exchange. The overall organizational structure is shown in figure 2.2.

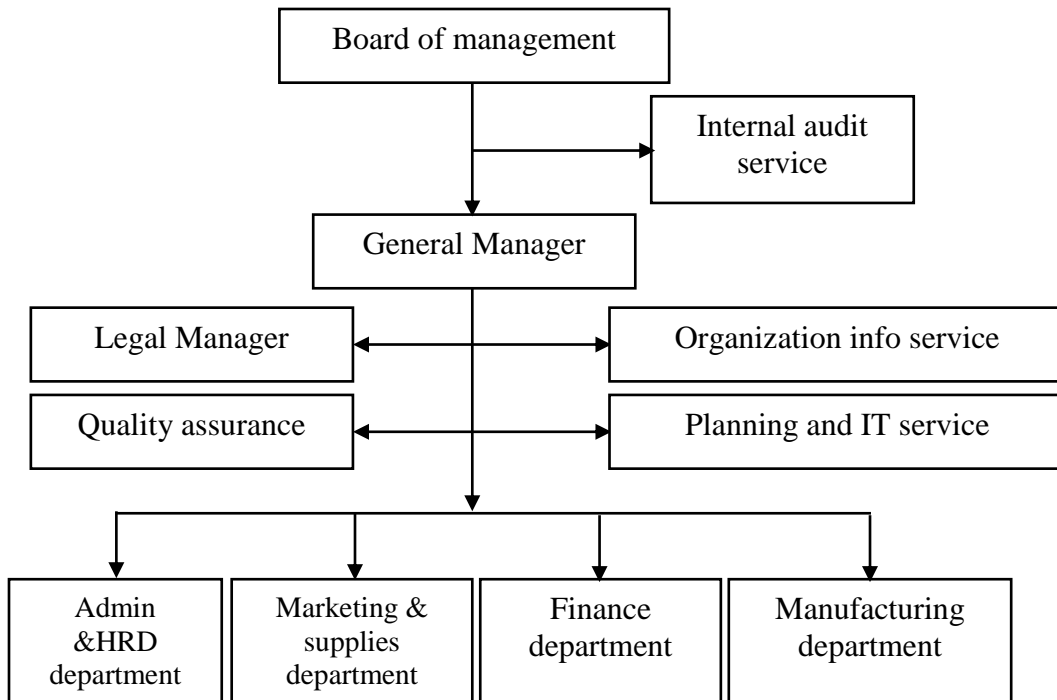


Figure 2-2: Overall organization structure of Akaki BMI

The figure 2.2 shows the general structure of Akaki BMI. However, the manufacturing department is the heart of the company, where the main activities of the company are processed here. Thus, it might be better to show its structure briefly. The manufacturing department overall structure is shown in figure 2.3.

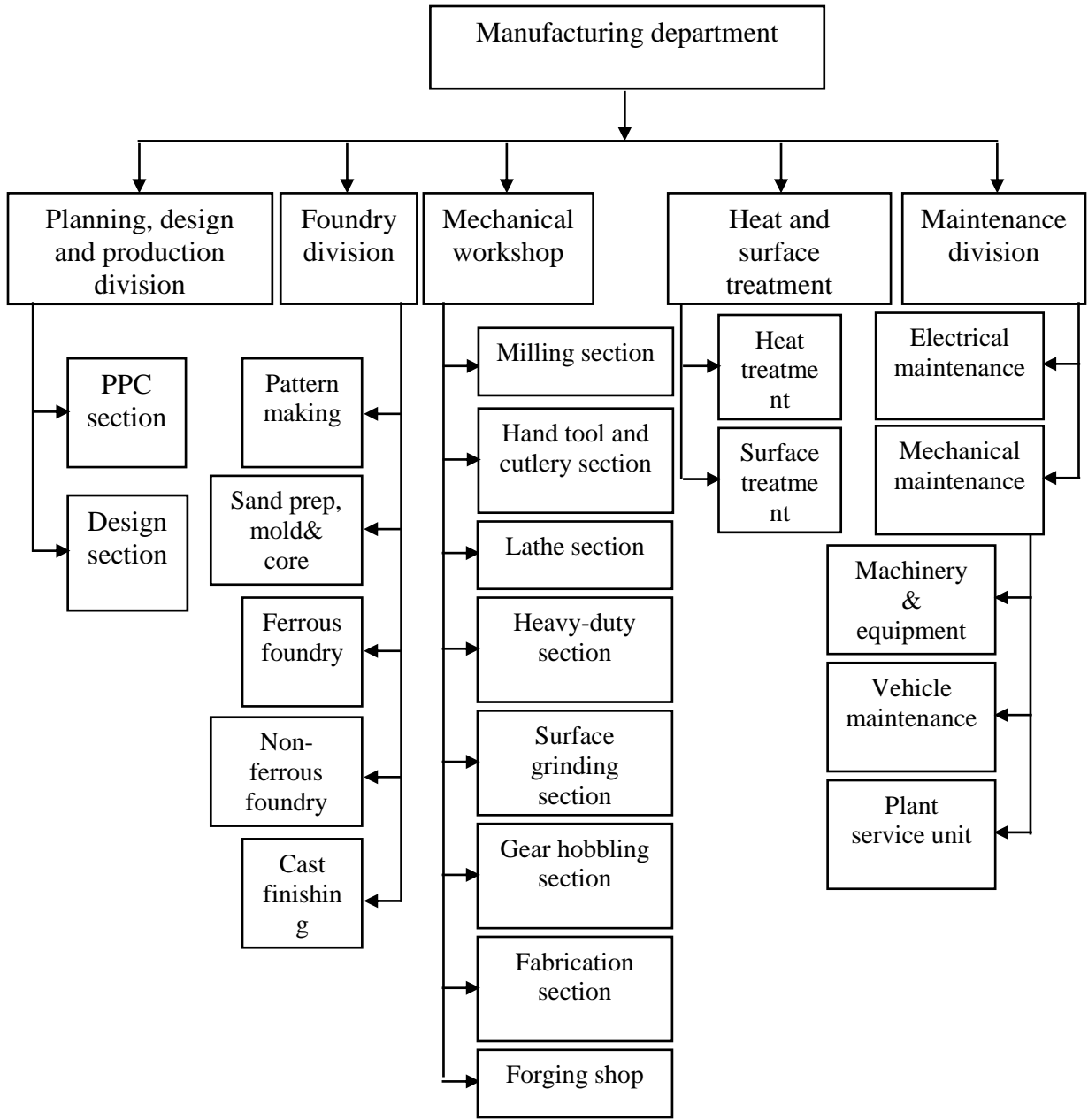


Figure 2-3: Manufacturing department structure of Akaki BMI

The main customers of the Akaki BMI are power sugar, cement and textile industries. In addition, also other customers buy the products of the industry. The main customers are shown in table 2.3.

Table 2-3: Main customers of Akaki BMI

No.	Main sectors	
1	Power industry	<ul style="list-style-type: none"> • Ethiopian electric power
2	Textile Industries	<ul style="list-style-type: none"> • Addis Textile Factory • Akaki Textile Factory • Kombolcha Textile Factory • Dire Dawa Textile Factory
3	Sugar factories	<ul style="list-style-type: none"> • Fincha Sugar Factory • Metehara sugar factory • Wenji sugar factory
4	Cement Factories	<ul style="list-style-type: none"> • Abyssinia cement factory • Mossobo cement factory • Mugar cement factory • National cement factory • Massimo Cement Factory
5	Steel Factories	<ul style="list-style-type: none"> • Ethiopia Iron and Steel • Kolfe House Hold utensils • Ethiopian Fiber
6	Other factories	<ul style="list-style-type: none"> • Elfora Agro Industry • Adei Ababa • Wonji Show S.F • Nardelli Paolo • Midroc Construction • Walya transport, etc.

Some of the Main products and Services of the Akaki BMI manufacture was presented in table 2.4.

Table 2-4: Main products and Services of Akaki BMI

Product name	Customers
Different types id ripper tips, mixer, planet and pinion gear, construction steel bar, etc.	Construction sector
Bend pipe, compressor, water pump parts, etc.	Agricultural sector
Wheel disc, front hub, spoke wheel, liner, U-bolt, etc.	Transport sector
Cement ball, jaw plate, crusher hammer, armor plate, etc	Cement sector
Pinion gear, sprocket gear, sugar cane juice tanker, mill roller, T-Bar, Head stock, etc.	Sugar factories
Flat bar, big and small collar, cross arm, different types of hooks and pins	Ethiopian electric power and Ethiopian electric utility
Pulley, different type of gear, worm gear, kill care wheel, ring gear, male and female coupling, different types of bearing housing, eccentric cover, gear box housing	Different factories

2.3. Factors affecting productivity in metal industry

Capacity utilization is a major indicator in every industrial group that not only helps to determine the utilization level of existing capacity but also helps for defining the required expansion level of the capacity for a targeted output. Specifying the capacity utilization could measure the utilization rate in terms of actual output relative to installed capacity. Full utilization of installed capacity could help to control economy inflation and could make more economical industrialization process (Solomon, 2018).

Productivity can be defined as the ratio of output to input for a typical production system. The output of the production system can be products or services delivered while the input includes various resources such as labor, materials, tools and equipment used for producing the products or services. Productivity can be defined as the efficient use of resources that needs to be considered. In production process, productivity represents the relationship between inputs and outputs (Yogesh, 2018).

The figure 2.2 shows the production process for a system having a set of inputs and output. The input x_1, x_2, \dots, x_n are controllable factors, like temperature, pressure, feed rate and others. The inputs z_1, z_2, \dots, z_n are uncontrollable (difficult to control) inputs, such as environmental factors or/and property of raw materials. The manufacturing process transforms these inputs in to a finished product, which has a several quality characteristics. The output variable, y is measure of the process quality (Tadiyos, 2018).

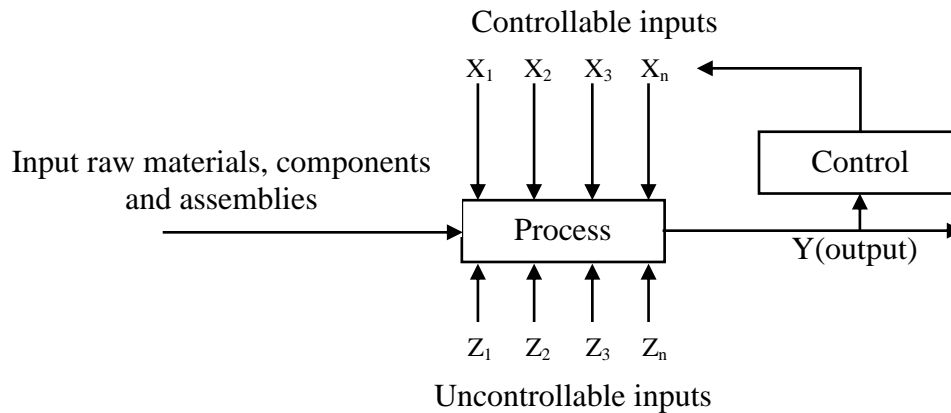


Figure 2-4: Input, output and control elements of productivity (Jain, 1980)

An inefficient scheduling could result in poor utilization of resources, over-loaded/idle capacity, and long production lead time and unreliable due date commitments, which in turn increases production costs and reduces competitiveness in the market place. Furthermore, ineffective scheduling often delays orders, results in unsatisfied customers, and may subject the firm to penalties.

The productivity can also be influenced by both internal and external factors. The internal factors could be production process condition, labor, management firm level investment, structure of the organization and marketing. The external factors could be infrastructure, trade policies, good governance, political stability, demand inflation, national governance system (Tadiyos, 2018).

Even though, productivity were not only be measured by the number of the output the equipment produces per given period, instead the proper use of resources (raw material, man-hour and other resources) makes the company produces the expected amount. Therefore,

productivity incorporates the effective and efficient use of resources throughout the production process (Menbere, 2018).

Identification of the factors affecting the productivity is the major element for productivity enhancement. The productivity factors can either boost or hinder the productivity. The factors influencing the performance of the process are process, control, product and resources. The factors related with process are lead-times, bottlenecks, flow of material, volumes, layout of the losses, cyclic transport. The factors related to control are purchasing, production (less or over), quality of product, location. Factors related to product are assembly design, product variants, standardization and modularization. Factors related to the resources are organization, efficiency, measurement, work methods, capacity, communication, motivation, satisfaction (Tesfaye, 2020).

Generally, the productivity of one factor may be affected by the productivity of another factor. For example, productivity of labor may adversely be affected by poor quality of management, defective tools and machinery, bad quality of materials. In spite of all these difficulties, it is desirable to measure productivity so that action may be taken for correction and improvement may take place (Yitagesu, Daniel, & Amare, 2017).

2.4. Productivity measurement and improvement

Measurement of productivity is a very difficult task because it depends on so many factors. If a concern is engaged in the production of a single product, output can be measured in physical terms, e.g., number of units produced, volume, weight, etc. Nevertheless, it becomes very difficult when a variety of goods is being manufactured. The problem becomes more complicated when an industry produced some by products.

The productivity measurement models availability for measuring the productivity is at the minimal levels. However, the macro level models should be proposed for the manufacturing industry for better productivity measurement. The major possible classification approaches were shown in table 2.5 as presented in (Eilon, Chowdhury, & Yohannes, 2019).

Table 2-5: Productivity measurement models

Production function models	<ul style="list-style-type: none"> • Represents the traditional attempts • Production is considered as a major activity • Production function was perceived as a function of several input factors
Financial ratios models	<ul style="list-style-type: none"> • Evaluate the financial performance of the company • Creditors' turnover, liquidity, profitability, stability, stock, and coverage are concerned for productivity measurement
Production-based models	<ul style="list-style-type: none"> • Output as a value addition • Output as a value of production
Partial productivity models	<ul style="list-style-type: none"> • Used for small set-up in highly affecting factors • Key activities of the total productivity were stated
System approach based models	<ul style="list-style-type: none"> • The productivity measurement activities were reduced to measure the output created concerning input
Productivity accounting model	<ul style="list-style-type: none"> • Used to measure the productivity through total output to total input • Grounded on the basic accounts of industries • Help in areas of improvement • Take into account all outputs and inputs
Economic utility models	<ul style="list-style-type: none"> • Recommended for the use of multi-ratios on the particular economic-utility function • The ratio concept of output into input was not followed • Useful at the macro-level instead of the micro-level

Productivity enhancement can be conducted through various approaches, like through productivity indices, through work-study, through job-shop scheduling. The productivity indices based approaches were labor-based, material based, machine-based and capital-based productivity (Tadiyos, 2018), (Yitagesu, Daniel, & Amare, 2017). The productivity improvement is the result of effectively managing the manufacturing processes. It would cost more when considered as unaware of the benefits for achieving the diligence execution (Tadiyos, 2018). Aspects concerned with the productivity improvement were presented in table 2.6.

Table 2-6: Productivity improvement based on productivity indices

<p>Labor - based</p>	<p>The procedures considered are (Jadayil, Khraisat, & Shakoor, 2017)</p> <ul style="list-style-type: none"> • Allocation of the right labor on the right job • Labor-training • Proper maintenance of machines • Incentive payment • Flow of raw materials • Proper allocation of jobs on a given resource • Working conditions <p>Labor-base productivity = total output/ labor-input</p> <p>Productivity increased by increasing labor efficiency and reducing labor time (Tadiyos, 2018)</p>
<p>Material-based</p>	<ul style="list-style-type: none"> • Increased by designing the suitable minimum material consumption • Increased by preparation of bill of materials • Based on the effective material utilization in the finished products <p>Material-based productivity = total output/ material input (Tadiyos, 2018)</p>
<p>Machine-based</p>	<p>Increased through</p> <ul style="list-style-type: none"> • Proper maintenance of machines • Optimum use of machine time • Proper scheduling of jobs, and loading work <p>Machine-based productivity= total output/ machine input (Jadayil, Khraisat, & Shakoor, 2017)</p>
<p>Capital-based</p>	<ul style="list-style-type: none"> • Capital was required for such assets, like tools, machines, land, etc. • Depends on effective utilization of the assets <p>Capital-based productivity = total output/ capital input (Tadiyos, 2018)</p>

The work-study used as an important tool for obtaining the higher productivity. Manufacturing efficiency improvement requires effective usage of equipment, labor, etc., which can be achieved through work-study (Gujar & Moroliya, 2018). Productivity could be affected by several factors such as land, labor, material, machine and capital (Singh, Singh, Keyur, Saumil, Niki, & Harshal, 2015).

The job shop scheduling is used to determine the optimal order or sequence for processing set of jobs through several machines interface, has received considerable attention. There are

different types of analytical and graphical approaches utilized for productivity enhancement in job shop scheduling problem as presented in (Leusin, Frazzon, Uriona, & Freitag, 2018).

Analytical technique is based on the mathematical approach that assigns jobs to machines for optimizing a certain criterion to have an exact solution. The scheduling technique was used to provide the existing resources with the recorded time to assign the jobs. In manufacturing firms, job shop scheduling problems were applying the priority with a process designed for providing the best solutions for the complex problems (Lemma, 2019). The graphical methods provide approximate optimal or near-optimal solutions (Nawara, 2013).

2.5. Job shop scheduling approaches

Many rules are found in literature for scheduling the jobs based on their due dates, operation criticality, processing time and critical ratio. The ratio of processing time of a job and its due date is known as critical ratio (Blackstone, Phillips, & Hogg, 1982). Based on the processing time, there are two types of rules: (1) shortest processing time (SPT) and (2) longest processing time (LPT). The jobs having shorter time are processed first in SPT, while the jobs having longer time are processed first in the LPT. The jobs having earlier due dates are processed first in due date. The other dispatching rules are first come first serve (FCFS) where the jobs are processed in their incoming order and last come first serve (LCFS) where the last jobs are first processed (Abbas, Abbas, & Khan, 2016).

Analytical approach is the mathematical technique of assigning jobs to machines relations utilized for optimization of certain criteria. To assign jobs-machine interface with the recorded time was provided by the scheduling models. The scheduling techniques were utilized for ordering jobs to the existing machines.

Job shop is a work location where a number of general-purpose workstations exist and for performing a variety of jobs. Scheduling is the allocation of the resources over time for competing activities. Emphasis has been on machine scheduling investigating problems where activities are represented by jobs and resources are represented by machines in which machine processes at most one job at a time.

The $n \times m$ minimum makespan general job-shop scheduling problem can be described by a set of n jobs $\{J_j\}_{1 \leq j \leq n}$, which is to be processed on a set of m machines $\{M_r\}_{1 \leq r \leq m}$. The

processing of job J_j on machine M_r could be called as operation O_{jr} . Operation O_{jr} requires exclusive use of machine, M_r for an uninterrupted processing time, p_{jr} .

A schedule is a set of completion times for each operation $\{c_{jr} \mid 1 \leq j \leq n; 1 \leq r \leq m\}$ that satisfies the typical constraints. The time required for completing all the jobs is called the makespan, L .

Where n is number of jobs

m is number of machines

J_i is job number in matrix

M_r specific machine number in matrix

O_{jr} is specific operation number

P_{ir} is specific processing time

C_{jr} is specific completion time of operation

The objective when optimizing JSSP is to determine the schedule, which can minimize the L .

A typical example of a 3×3 JSSP is given in Table 2.7. The data presented in the table shows three jobs with three machines including the routing of each job-machine interface and the processing time for each operation shown in parentheses.

Table 2-7: A typical 3×3 JSS problem

Job	Operations routing (processing time)		
1	1(3)	2(3)	3(3)
2	1(2)	3(3)	2(4)
3	2(3)	1(2)	3(1)

Gantt chart is mostly used for JSSP, which is simple graphical display technique suitable for only less complex situations. It does not provide any rules for choosing but simply presents a graphical technique for displaying results and schedule for evaluating makespan, idle time, waiting time and machine utilization.

Some of the factors to describe JSSP are arrival pattern, number of machines (workstations), work sequence and performance evaluation criterion. The arrival patterns can be static

arriving of n jobs at idle shop to be scheduled for work and dynamic intermittent arrival (often stochastic). The work sequence can be fixed, repeated sequence flow shop or random sequence possibility of all patterns.

Each job contains the specified number of activities to be performed on the given machines, their setup and processing times. Thus, JSSP deals with the searching mechanism for optimal sequencing of the given operations on the specified machines within the specified orders with typical constraints.

The major approaches for solving the classical JSSPs include exact mathematical algorithms, dispatching rules, metaheuristics, and artificial intelligence methods. These approaches and some of their examples are listed in Fig. 2.5 (Zhou, 2017).

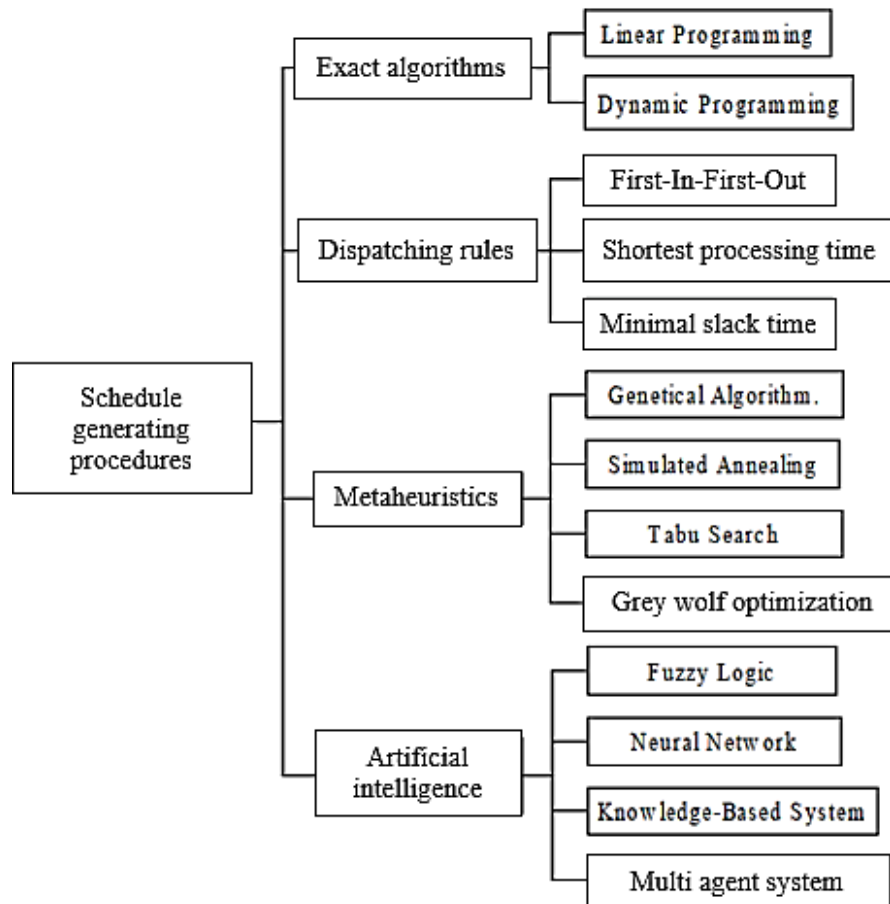


Figure 2-5: Approaches to solve classic JSSP

The modern integer programming was developed by Balas in 1965 and 1967, which allows the JSSPs to be formulated and solved in a manner that would theoretically permit them to be

exact. Another exact mathematical approach reported is dynamic programming, which enumerates in an intelligent manner all the possible solutions by eliminating the schedules that are not optimal. However, the exact algorithms (both integer programming and dynamic programming) are computationally involving a lot of effort (Zhou, 2017).

Some performance evaluation criteria are makespan, which is the most commonly considered as the total completion time for all jobs, average time the typical jobs take in the shop, lateness, average number of jobs in the shop, utilization level of the machines and utilization level of workers.

In the JSSP environment, there are “J” jobs to be processed on “M” machines with a certain objective function to be minimized. Thus, JSSP was used to determine the optimum orders of jobs on the given machines that optimize the makespan through different algorithms.

The nature of variety of products in which the way they are produced gives certain characteristics, which is common to all job shops.

Some of the typical characteristics are: (Nezhad & Abdullah, 2017)

- At any time, there are a large number of orders at having various completion times.
- Orders make conflicting demands on resources.
- Since every order has different completion time, it is difficult to forecast the required exact completion time for each operation.
- Not every operation workflow is continuous but it is intermittent.
- Since there is queue for every work on each machine, it is difficult to determine exact priority for each queue.
- Many changes are resulting from scrap, rework, machine breakdown, material shortages, engineering changes, and rush orders.

2.6. Grey wolf optimization algorithm

Grey Wolf Optimizer (GWO) algorithm is applied to many engineering optimization problems with different typical complexity. The experimental results show that the GWO algorithm is superior in terms of optimal performance, solution stability, applicability and effectiveness; and can better solve the problems in engineering design. The results show that

the GWO algorithm has higher convergence speed, convergence precision and robustness compared with other algorithms (Mohammad, Andrew, & Seyedali, 2014).

Gray wolves follow a strict hierarchy of social dominance. The best solution is marked as α ; the second-best solutions are marked as β , the third-best solutions are marked as δ and the rest of solutions are marked as ω . Its dominant social dominance is shown in Figure 2.6.

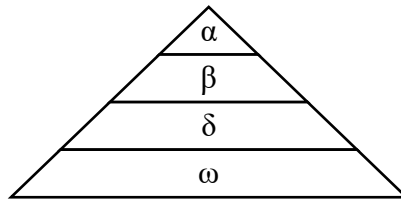


Figure 2-6: Social hierarchy of grey wolves

To obtain the objective of this study, the grey wolf optimization (GWO) algorithm is proposed. GWO is a recently proposed swarm intelligence algorithm inspired by the social hierarchy and hunting behavior of wolves. It has the advantages of high solution accuracy, and fast convergence speed compared with other classical metaheuristic algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), and gravitational search algorithm (GSA).

Grey Wolf Optimizer (GWO) algorithm mimics the hunting pattern of grey wolves in day-to-day life. Grey wolves prefer to live usually in groups of 6 to 12. Their social hierarchy is quite dominant with the top-level wolves are known as alpha wolves. These wolves are the leaders of the group and they are responsible for making decisions within the group.

The second-level wolves are known as Beta wolves, which are subordinate of the alpha wolves. They can also be thought of as the next alpha wolves in case any alpha gets injured or harmed. Their role is to assist alpha in decision making along with other activities of the group.

The third level is of the subordinate wolves called delta. This consists of sentinels, scouts, hunters, caretakers, etc. Their role can range from guaranteeing safety of the pack, observing the boundaries for any danger, helping the alpha and beta wolves in hunting to take care of the weak and wounded wolves. Omega is the lowest category of wolves. They are the

followers of all other dominant wolves in the pack but their presence is equally important as of the other members.

The ability of grey wolves to memorize position of the prey and to encircle them is what is used to develop the so-called algorithm: Grey Wolf Optimizer algorithm. In mathematically designing the hierarchy of grey wolves, the alpha is considered as the best solution followed by beta, as the second and delta as the third. The rest of the candidate solutions are assumed as omega.

Negash L. have conducted study in Akaki BMI to determine the proper jobs -machines allocation in order to optimize the make-span for productivity improvement by using shifting bottleneck and local search algorithms. For proposed purpose, seven jobs (products) with six machines were utilized. The findings revealed that the make-span is reduced with improved percentage productivity (Negash, 2021).

Kulkarni et al. proposed the approach to 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. Moreover, proposed a revised layout to reduce material movement in the shop and improvement methods (Kulkarni & Gaitonde, 2018).

Mentesinot M. proposed the improvement in the ergonomics systems as an important task to enhance the productivity of the manufacturing sector. He presented reducing the total make-span of specific jobs and improving the performance of the manufacturing system through JSS (Mentesinot, 2017).

K. Luchoomun et al. proposed improved genetic operators for enhancing the existing genetic algorithm for getting a shorter makespan in less computational time. Finally, it was investigated that the results shows that the enhanced genetic algorithm produce the optimal makespan in a shorter genetic evolution than existing genetic algorithm (Luchoomun, Auckloo, & Sonah, 2014).

Bayeh T. proposed to improve the productivity of manufacturing sectors by using the line balancing approach. Productivity improvement can also be obtained by various methods, which consists technology, employee, task, process, product, and material-based techniques (Bayeh, 2019).

H. Diaz et al. proposed a genetic algorithm to minimize the makespan that takes into account the uncertainty problem during the search process. The behavior of the algorithm is experimentally evaluated and compared with other state-of-the-art algorithms. Further analysis in terms of solution robustness proves the advantage of taking into account interval uncertainty during the search process with respect to considering only the expected processing times (Diaz, Ines, Juan, & Vela, 2020).

C. Hu et al. proposed the grey wolf optimizer (GWO) algorithm to find the optimal job processing sequence to minimize the total expected cost. The experimental results showed that the GWO algorithm had resulted in higher performance and computational stability than GA and other optimization algorithms (Hu, Qian, Lu, & Liu, 2020).

P. Milica et al. had proposed a methodology based on GWO in order to find the optimal solution of the nondeterministic polynomial hard single mobile robot-scheduling problem. The performance criterion was formulated to minimize total transportation time of the mobile robot while transporting the raw materials, goods and parts in manufacturing system. Experimental results show the applicability and effectiveness of the developed intelligent approach in real world conditions (Milica & Zoran, 2017).

Y. Luo et al. had proposed a multi-objective grey wolf optimizer (MOGWO) to prove the effectiveness of the JSSP. The comparison was conducted with another multi-objective genetic algorithm. The experimental results suggested that the proposed MOGWO outperforms its competitor on JSSP (Luo, Lu, Li, Wang, & Gao, 2019).

B. Gavalil et al. proposed hybrid Social Spider Optimization (SSO) and Grey Wolf Optimization (GWO) conventional optimization technique. Solving job shop scheduling, problem with metaheuristics technique was certainly conserve the time consumption in manipulating. The proposed hybrid optimization technique resulted the minimized makespan time (Gavalil, Bewoor, Barik, & Prabakaran, 2017).

T. Jiang et al. proposed an energy-efficient job-shop scheduling problem by using grey wolf optimization algorithm with double-searching mode (DMGWO) with the objective of minimizing the energy-consumption cost and tardiness. In the proposed DMGWO algorithm, to enhance the global search ability a random seeking mode is added. Finally, from the

simulation, it was demonstrated the effectiveness of the proposed DMGWO algorithm based on 43 benchmarks (Jiang, Zhang, Zhu, & Deng, 2018).

L. Liu et al. presented the job shop-scheduling problem by considering non-identical job sizes with practical constraints of sequence dependent setup times, incompatible job families and job dependent batch processing time consideration. In order to find scheduling strategies that minimize the mean weighted tardiness, they proposed a genetic programming based hyper-heuristic to generate efficient dispatching rules. Then, based on the nested partition framework together with the optimal computing budget allocation technique, a hybrid rule selection algorithm was proposed to search specified rule combinations (Liu & Shi, 2019).

2.7. Summary and research gap

Table 2-8: Summary of the literature review

Author	Proposed algorithm	Objective function
Negash L.	Shifting bottleneck and local search	Minimize makespan
Kulkarni R. et al.	String diagram technique	Flow time
Mentesinot M.	Improved Maintenance System	Reducing total makespan
K. Luchoomun et al.	Enhanced genetic algorithm	Shorter makespan
Bayeh T.	Line balancing approach	Flow time
H. Diaz et al.	Genetic algorithm	Minimize makespan
C. Hu et al.	Grey wolf optimizer (GWO)	Minimize total expected cost
P. Milica et al.	Grey wolf optimizer (GWO)	Minimize transportation time
Y. Luo et al.	Multi - objective GWO	Minimize makespan and total energy consumption
B. Gavali et al.	Hybrid Social Spider Optimization (SSO) and GWO	Minimize makespan
T. Jiang et al.	GWO with double-searching mode (DMGWO)	Minimize energy consumption cost and tardiness
L. Liu et al.	Genetic programming based hyper-heuristic	Mean weighted tardiness

To get enough information and best understand about the subject matter and the field of study many literatures are reviewed and discussed above by different researchers, productivity may improve through different techniques and approaches. However, very little literature is focusing on metal manufacturing industries, and this study will follow the job

shop scheduling approach by using grey wolf optimization algorithm to improve productivity by reducing makespan, energy consumption, and tardiness in the case of a metal manufacturing company.

There are different published and unpublished literature's that are related to productivity improvement for manufacturing industries through different techniques and approaches, like Shifting bottleneck and local search, String diagram technique, line balancing, Improved Maintenance System, 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. Also the number of metal manufacturing industries is small due to this reasons orders come in large numbers from different customers. However, every company has its objectives and way of decision making processes to produce the orders that come to them. Akaki BMI follows the first come first serve system to produce the orders; this means that the orders that came first will be finished first. If there is an urgent order but if it comes in late, to handle it an additional order procedure is needed to handle the job orders. Because, FCFS scheduling has long waiting time, non-pre-emptive, that is, the process will run until it finishes also the system cannot utilize resources parallel and does not consider the priority. Therefore, using different scheduling approaches is necessary to solve these problems and became competitive in the market. In today's highly competitive market manufacturers face the challenge of reducing make-span and productivity improvement.

In the manufacturing firms, the Job shop scheduling problem aims to determine the processing order between jobs on each machine to acquire good production performance, like make-span, total tardiness, total flow time, etc. The Akaki BMI uses job shop work system; however, it faces a lot of problem. Thus, the selected study section was optimized by proper scheduling of jobs on the existing machines using grey wolf optimization (GWO) algorithm by MATLAB software simulation.

CHAPTER THREE

3. METHODOLOGY

3.1. Introduction

Detailed explanations of the procedures proposed for completion of this thesis work were discussed in below. This section covers the approach used to answer the research question and explain the reason why the approach was selected. The main steps of the research are the overall performance assessment of the company, method of data collection, data collection instrument and method of data processing and analysis.

3.2. Data collection

Data collection methods are the fundamental activity that enables to accomplish the study. This research model helps to collect data about the actual problems of the existing situation for explaining the metal manufacturing scheduling process concepts through resources allocation to search alternative potential solution for the JSS problem. The qualitative and quantitative data needed for this study were mainly collected from primary data collection tools such as questionnaires, interviews, direct observation and secondary sources such as documented reports of the production scheduling through in the case company. In addition, the past studies conducted on Akaki BMI were referred as much as possible.

Primary data collection methods: The methods proposed for collecting primary data are questionnaires, direct observation and face to face interviews.

- Direct observation: through observation of proper assigning of job on the workstation machines, machines and operators idle, machine idle and raw materials availability.
- Face to face interviews was conducted on operational management section, PPC section, Supervisors and Machine operators to assess the current working condition of job shop station and factors related to high makespan, incur a high cost, and low productivity. Also about the industry production type, production strategy and Scheduling methods.

- Questionnaires: by distributing questionnaires to several departments in the industry to examine the existing productivity-related problems that hinder the productivity in the case industry

Secondary data collection methods: the sources of the secondary data include the case company annual production reports of the from the production planning and controlling department which helps to identify performance level of the company and state of the art, different websites, different thesis papers, articles and journals related to the study. This helps to identify how other authors improved the productivity. The data sources that others utilized were help to discover how this research is related to other studies for analyzing the total and partial productivity trends of the Akaki BMI.

3.3. Job shop scheduling problem formulation

The n -jobs needed to be processed on m -machines in the workshop with certain processing times and routing. In this study, we concentrate on the effects of production scheduling on the productive and environmental performances in a job shop, i.e., make-span and total tardiness mainly considered for better production scheduling performances.

Since the processing times on the machines are fixed and all the machines are switched ON at time 0 and switched OFF when the last operation is processed, the idle time for each machine were calculated. Since the processing time for the k^{th} machine is fixed, minimizing the make-span also minimizes the energy consumption caused by the idle time.

There are three major constraints for JSSP:

- 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.
- If a task is once started, it must run up to completion.

The performance evaluation criterion for evaluating the performance of the shop having very important role in the scheduling process can be Make-span, Lateness, Utilization of machines, Utilization of energy

3.3.1. Objective function formulation

The terminologies applied for dispatching rules include EDD (earliest-due-date), truncated shortest processing time (TSPT), LPT (longest processing time), SPT (shortest processing time), and CR (critical ratio) rules.

- Processing time (t_j) is sum of both setup and actual processing time. The processing time (t_j) can be taken as the amount of time required to process operation O_{ij} . The setup time refers to the time required by a machine to shift from the status to the next one in order to process the next operation.
- Ready time (r_j) is the time the job J is to be processed.
- Due date (d_j) is the time at which the job J takes up to its completion. The due date of job J is the time by which the last operation of the job should be completed.
- Makespan (C_j) is the time at which the job J is completed in a sequence. Moreover, makespan is an interval between the time at which the schedule begins and the time at which the schedule ends.

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

Flow Time (F_j) 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. It can also be called cycle time, which is the amount of time job J spends in the shop floor.

$$F_j = C_j - r_j \quad (3.1)$$

Lateness (L_j) is the amount of time by which the completion of job J differs from its due date.

$$L_j = C_j - d_j \quad (3.2)$$

Tardiness (T_j): -the non-negative amount of time by which the completion time exceeds the due date or otherwise zero:

$$T_j = \max \{0, [C_j - d_j]\} \quad (3.3)$$

Energy consumption can be given as the product of kW rating of the machine and the processing time, P_i of job j on each machine.

$$\text{Energy consumption} = \min(kW * P_t) \quad (3.4)$$

Consider a typical job shop with n jobs and m machines. Each job was processed through one machine only once. However, it is not necessary that all jobs were processed through all machines. Every job having a particular order of processing. The processing time for each job is fixed and known.

To schedule jobs the following parameters, have to be identified first:

- [1] Available facility on the shop floor
- [2] Total jobs in the system
- [3] Setup and operation time for each job on each machine
- [4] Completion time to complete all jobs

3.3.2. Constraints formulation

After parameter identification, jobs scheduling could be performed based on the following constraints.

- I. Every job was processed through respective machines ($j = 1, 2, 3, \dots, m$).
- II. One machine can process a single job at a given operation time.
- III. The setup time for different operations does not depend on the sequence
- IV. The setup time for different operations is incorporated in the processing time.
- V. The job scheduling was done on priority basis (due dates). Jobs were assigned with three levels of priority. The top priority jobs were scheduled first and the lowest priority at the last.
 - a) Priority 1 being the top priority
 - b) Priority2 being the medium priority
 - c) Priority 3 the lowest priority

The objective functions to be considered under this thesis consist of minimization of the makespan, tardiness and total energy consumption cost.

Given a machine set $M = \{1, 2, \dots, m\}$ and a job set $J = \{1, 2, \dots, n\}$, the objective of JSP is to determine the processing order of operations on machines to minimize the makespan. Every job $j \in J$ is composed of n_j ordered operations $O_{j1}, O_{j2}, \dots, O_{jn}$ each of them has to be processed on a predetermined machine. Every machine can only process at most one

operation at a time. The processing time, P_o of every operation $o \in O$ is fixed. Once the operation processing started, it cannot be interrupted until it is completed.

We represent S_o as the start time of operation $o \in O$, represent p_o as its predecessor operation, and let denote E_h as the set of operations processed on machine $h \in M$. The model of JSP is given as:

$$\text{Minimize } C_{max} = \max\{S_o + P_o\} \quad (3.5)$$

Subject to

$$S_o - S_{p_o} \geq P_{p_o}; o = 0, 1, \dots, n \quad (3.6)$$

$$S_i - S_j \geq P_i \text{ or } S_j - S_i \geq P_j; (i, j) \in E_h, h \in M \quad (3.7)$$

$$S_o \geq 0; o = 0, 1, \dots, n \quad (3.8)$$

The eqn. (3.6) guarantees the precedence order between operations of the same job, the eqn. (3.7) ensures the precedence order between operations on the same machine and the eqn. (3.8) imposes the start time of all operations are non-negative.

3.4. Grey wolf optimization algorithm formulation

The algorithm starts by random generation of an initial population of wolves within the search space. Based on the objective function the positions of the wolves are evaluated. The steps are repeated until the stopping criterion is reached. In each iteration, the position of each wolf is updated with respect to the prey encircling, hunting and attacking. Finally, by repeating the steps, best location of the prey can be located. The process consists of three main steps: encircling, hunting, and attacking the prey.

1. Encircling: encircling the prey by the grey wolves can be modeled as:

$$\left. \begin{aligned} D &= |C * X_p(t) - X(t)| \\ X(t+1) &= X_p(t) - A * D \end{aligned} \right\} \quad (3.9)$$

Where X_p is the prey position, X indicates position vector of a grey wolf, t is the current iteration, C and A are the coefficient vectors calculated as:

$$\left. \begin{aligned} A &= 2 * a * r_1 - a(t) \\ C &= 2r_2 \end{aligned} \right\} \quad (3.10)$$

Where r_1, r_2 are random vectors in $[0, 1]$, and a linearly decrease from 2 to 0 over the course of iterations as:

$$a(t) = 2 - 2 * \frac{t}{Iter_{max}} \quad (3.11)$$

2. Hunting: It is assumed that α, β , and δ have better knowledge about the prey location.

$$\left. \begin{aligned} D_\alpha &= |C_1 * X_\alpha - X(t)| \\ D_\beta &= |C_1 * X_\beta - X(t)| \\ D_\delta &= |C_1 * X_\delta - X(t)| \end{aligned} \right\} \quad (3.12)$$

Where C_1, C_2 and C_3 are calculated by Eq. 2.2.

$$\left. \begin{aligned} X_{i1}(t) &= X_\alpha(t) - A_{i1} * D_\alpha(t) \\ X_{i2}(t) &= X_\beta(t) - A_{i2} * D_\beta(t) \\ X_{i3}(t) &= X_\delta(t) - A_{i3} * D_\delta(t) \end{aligned} \right\} \quad (3.13)$$

Where X_α, X_β and X_δ are the first three best solutions at iteration t

$$X(t + 1) = \frac{X_{i1}(t) + X_{i2}(t) + X_{i3}(t)}{3} \quad (3.14)$$

3. Attacking: The wolves terminate hunting process when the prey stops moving and wolves start an attack. Thus, the final position could be considered as a solution.

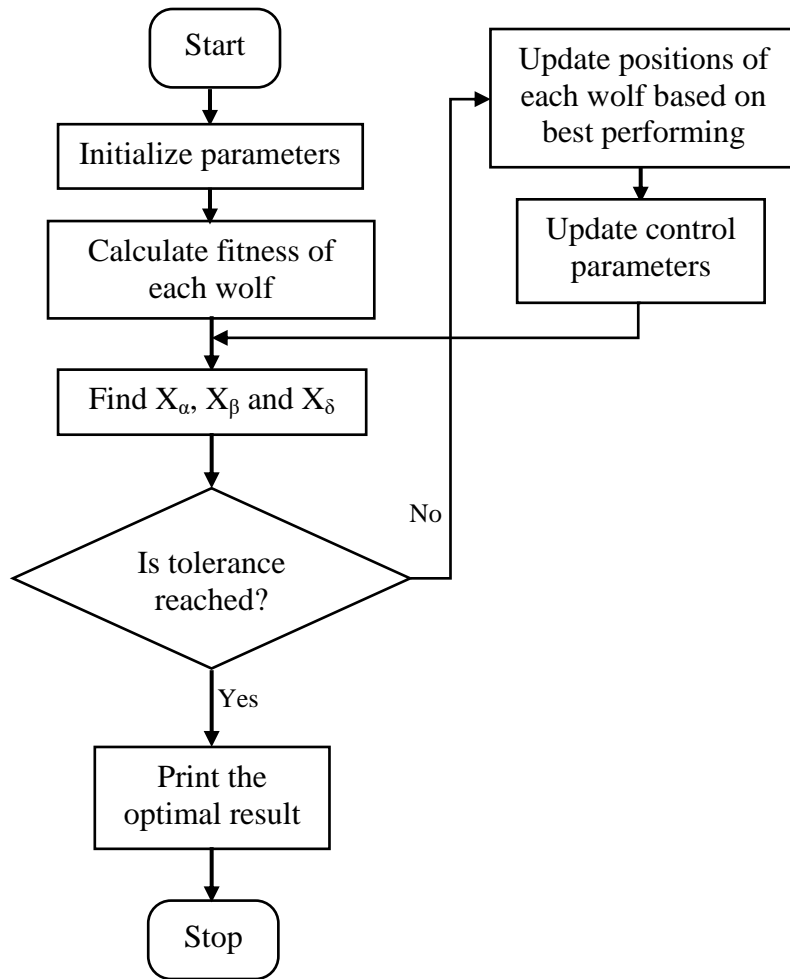


Figure 3-1: GWO algorithm optimization flowchart

Steps to apply the GWO in the job-scheduling problem:

Step 1: Compile all jobs and machines with their operating time on each machine

Step 2: Measure the processing time for each job with the ordered amount of pcs

Step 3: Assign the processing time for each job based on their due date

Step 4: Group all the jobs according to the given priority level

Step 5: Calculate the weight index for each job in the system

Step 6: Arrange each job according to the resulting weight index

Step 7: Apply the GWO algorithm to determine the optimal schedule

Step 8: If all jobs considered, print the optimal schedule. Else, go to the step 5.

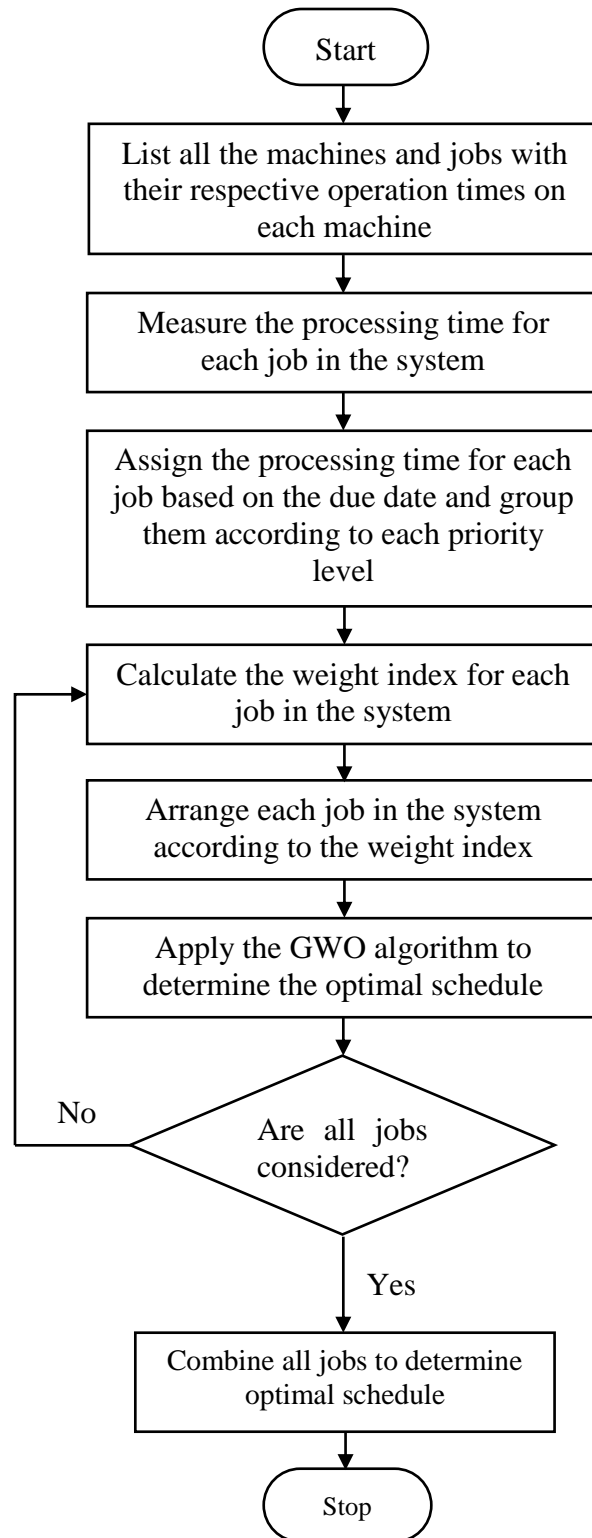


Figure 3-2: Proposed approach for jobs scheduling base on priority

3.5. 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.

3.5.1. 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 is simple 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. As an Akaki BMI human resource manual report of 2022, there is 346 male and 145 female total 491 workers. From this 369 workers are the direct laborers (targeted population) engaged in the manufacturing process. To get a reasonable sample size that supports the research findings, different equations were used as mentioned below (Eshetu, 2017).

$$S_i = \frac{Z^2 * P(1-P)}{C^2} \quad (3.15)$$

$$S_t = \frac{S_i}{1 + \frac{S_i - 1}{N}} \quad (3.16)$$

Where: 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; $0.08 = \pm 8$

p = percentage choice described as decimal 0.5

N = Population = 369 workers

By using the equation (3.15) and considering the 95% confidence level, we could calculate the initial sample size as

$$S_i = \frac{Z^2 * P(1 - P)}{C^2} = \frac{(1.96)^2 * 0.5 * (1 - 0.5)}{(0.08)^2} = 150.0625$$

Then the target sample size can be calculated by using equation (3.16) as

$$S_t = \frac{S_i}{1 + \frac{S_i - 1}{N}} = \frac{150.0625}{1 + \frac{150.0625 - 1}{369}} = 106.885 \approx 107$$

Thus, out of the total populations workers that are the direct laborers engaged in the manufacturing process is about 369 workers, the sample of about 107 respondents were participated during data collection period for obtaining the required data for this study in the case company.

Table 3-1: Target respondents participated for data collection

No	Position of respondents	No of respondents	Sample size
1	Top management & operational department	6	2
2	Maintenance manager & team	34	10
3	Inventory Manager & team	8	2
4	PPC manager & team	11	3
5	Purchasing Department & team	17	5
6	Quality Control Team	13	4
7	Senior Operators from 4 workshops	280	81
Total		369	107

3.6. Data analysis techniques and tool

To achieve the objective of this study, the data was collected through face-to-face interviews, direct observation, Questionnaires, and secondary data was analyzed by using LEKIN and MATLAB software.

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 for grey wolf optimization algorithm MATLAB software was selected for minimizing the sum of individual make-spans and the total tardiness. And productivity improvement, that achieved by Lekin's approaches and finally, a conclusion and recommendation were reached.

3.7. Overall research framework

The research methodology and procedures of this study to be followed are illustrated in the figure 3.3.

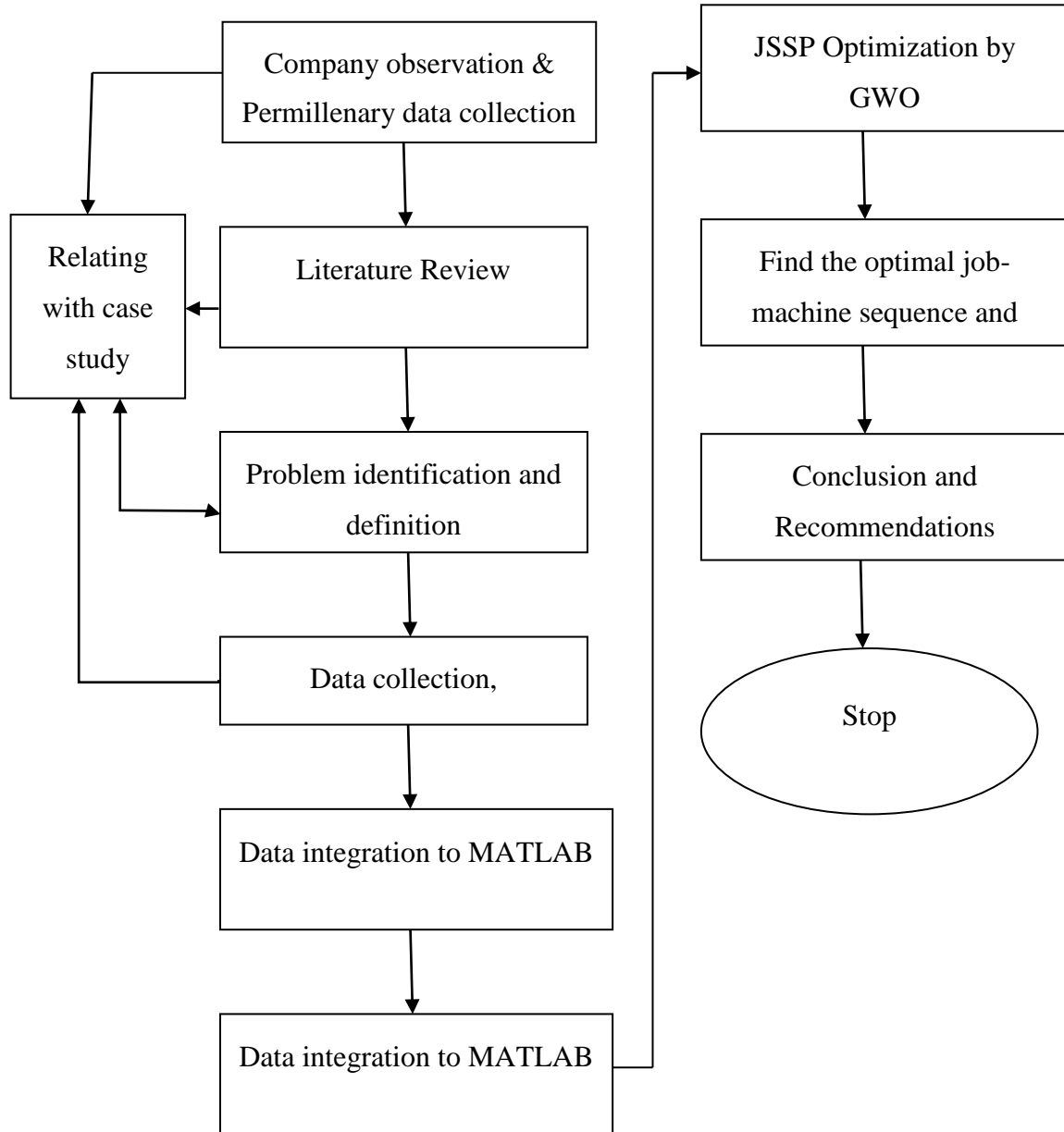


Figure 3-3: Overall proposed methodology of the research

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Data collection and Analysis

The required data was collected from the company by distributed questionnaires to several departments in the industry to examine the existing productivity related problems that hinder the productivity in the case industry, face to face interview with operational management section and production supervisors, observation has been conducted with different shops and surveying literature (explore the various work report documents of the industry).

Data collection starts through observing and identifying different activities done in the machine shop. Then, the numbers of jobs in the shop were determined with their processing time required for single pieces and total required time that it takes for the total ordered pieces with their due date. 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 responses collected from different sections/departments of the company are presented as follows in below sections.

4.1.1. Data collected and identified through questionnaires

The sample size considered for this study is 107 respondents from which 98 filled in and returned the questionnaires in good time giving a response rate of about 91.6%, which represents the sufficient rate to make conclusions for the study.

Table 4-1: Respondents work experience in your company

No	Year	Amount (percent)
1	Below one	0
2	1-to-2	12(12.24%)
3	2-to-5	36(36.73%)
4	5-to-10	40(40.82%)
5	More than 10	10(10.21%)

As shown in Table 4.1, about 40.82% of the respondents have work experience of 5-to-10 years in the industry followed by 36.73% 2-to-5-year work experience respondents. About 10.21% respondents have work experience of more than 10 years. So that, in terms of their

experience the individuals who filled out the questionnaire can provide enough information for the research

Table 4-2: Educational background of the company respondents

No	Qualification	Amount (percent)
1	PhD	0
2	MSc/MA	4(4.08%)
3	BSc/BA	39(39.8%)
4	TVET level	55(56.12%)
5	Other	0

As shown in Table 4.2, about 56.12% respondents have TVET level (from level 1-to-5) educational background followed by 39.8% of first-degree qualification. About 4.08% respondents have second degree qualification. It indicates that their educational background allows them to provide sufficient information.

Case 1: Operational Management (OM) Section

The responses are collected from nine (9) respondents of the OM section. Respondents provided more than one response as shown in Table 4.3 and 4.4.

Table 4-3: Major existing problems of the company

No	Problems	Amount (%)
1	Scheduling problem	6 (67%)
2	Customer satisfaction problem	1 (11%)
3	Raw material shortage problem	0
4	Skilled manpower problem	1 (11%)
5	Financial problem	1 (11%)
6	Failure of machines	1 (11%)

As shown in Table 4.3, the majority of operational management section respondents (6 out of 9 about 67%) agreed that the major existing problem of the industry is scheduling related problem that affects the industry. And according to the information they filled in table 4.3, they said that they did not have problems related to raw material shortage in the industry.

Table 4-4: Major causes of low productivity of the company

No	Problems	Amount (%)
1	Raw material cause	0
2	Human factor/skilled man power cause	1(11%)
3	Improper allocation of job on machine	5 (56%)
4	Machine breakdown	2 (22.22%)

As shown in Table 4.4, the major problem causing the low productivity in the Akaki BMI is improper allocation of job on machine (about 56%). And also about 22.22% OM section responders agreed other major cause of low productivity is machine breakdown.

Thus, from Table 4.3 and 4.4 responses, we could conclude that the major existing problems of the industry that causes low productivity is scheduling problem and the major causes of low productivity of the company is improper allocations of job on the given machines.

Table 4-5: Productivity improvement program introduced in the company

No	Program to improve productivity	Yes	No	If your answer is "Yes", please specify
1	Labor Productivity	7	2	Improving operating system, internal capacity building training and facilitating incentives for employees
2	Capital Productivity	0	9	-
3	Machinery Productivity	8	1	Applying preventive maintenance
4	Energy Productivity	0	9	-
5	Material Productivity	0	9	-
6	Total Productivity	3	6	Measuring productivity apply input to output ratio
7	Customer satisfaction	9	0	By improving quality of products and by collecting survey data from customer and recording customer feedback
8	Quality of product	9	0	Producing products based on quality management system – ISO 9001: 2015 international standards
9	Supply Productivity	9	0	By efficient use of raw materials

As shown in Table 4.5, the labor, machine, customer, quality and supply based productivity improvement programs are highly introduced and conducted in the industry through capacity building trainings, improving operating system, applying preventive maintenance, quality improvement of the products, implementing quality management system ISO 9001: 2015 & efficient usage of raw materials. However, the capital, energy and material based productivity improvement programs are not yet introduced in the company. So, they confirmed that the desired change could not be achieved despite using various reform programs. Therefore, it indicates that they should use another program that increases the productivity of the industry. Figure 4.1 shows the improvement programs conducted in the industry.

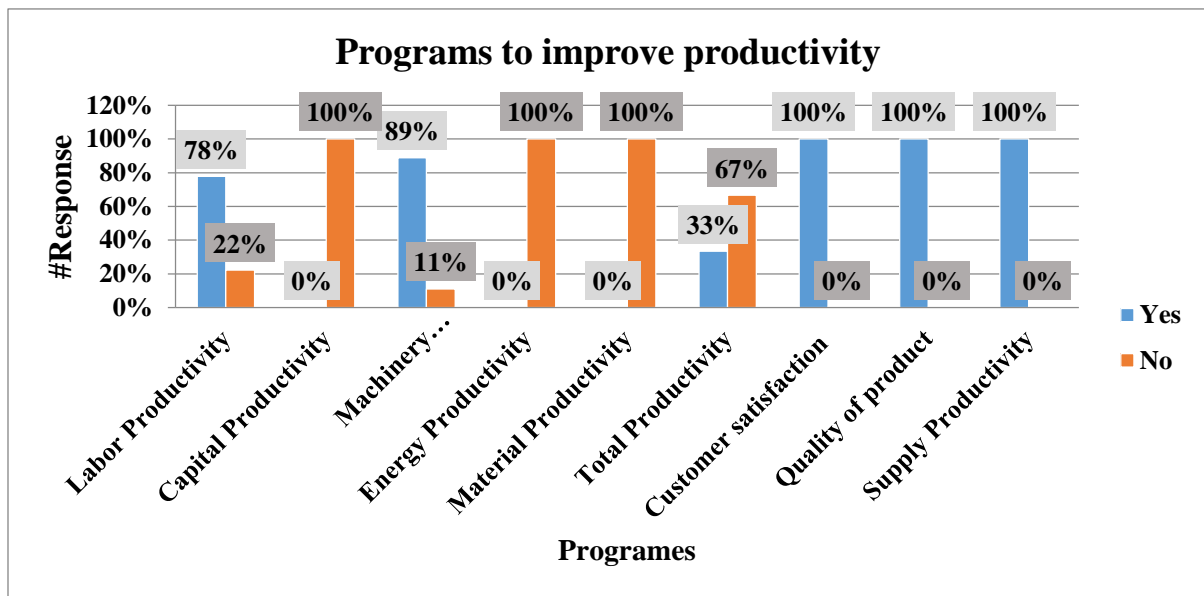


Figure 4-1: Productivity improvement programs introduced in the company

Case 2: Processes planning and control (PPC) Section

The responses are collected from 15 respondents of the PPC section. All the respondents agree that the manual MS-Excel based method is applicable to handle the job orders and to sequence them. The industry applies dispatching rule like first come first serve that is the company were process the order that came first. But when a large number of product orders arrive, sometimes work orders are given verbally command from the head of the department. The large number product orders are processed first and small amount product orders are processed next. Doing so there are pros and cons. The pro is the productivity and revenue of

the company is increased if a large number of orders are prioritized and completed. However, the cons present is when small amount orders for products are delayed, customers complaint and less satisfactions created and came.

Based on the surveyed pieces of questionnaires the PPC section are asked to give a response on the main reasons related to low productivity in Akaki BMI were analyzed. The respondents were asked to prioritize the problem based on the company frequently occurred major problems which are around eleven major problems that are responsible for low productivity in Akaki BMI. And the findings of the respondents are shown in the table 4.6.

The rating scales are (1) for low effect on productivity, (2) for medium effect on productivity and (3) for high effect on productivity.

Table 4-6: Problems resulting low productivity in Akaki BMI

No.	Problems related to low productivity	3	2	1
1	Improper job allocations on machine	12	3	0
2	Machine failure/breakdowns	8	7	0
3	Absenteeism of operators/workers	2	9	4
4	Inputs (Raw material) shortage/ problems	2	9	4
5	Power shortage	0	0	15
6	Capital or financial related problems	9	6	0
7	Process related problems	1	11	3
8	Workers skill related problems	0	10	5
9	PPC problems	2	12	1
10	Market related problems	1	9	5
11	Quality related problems	8	7	0

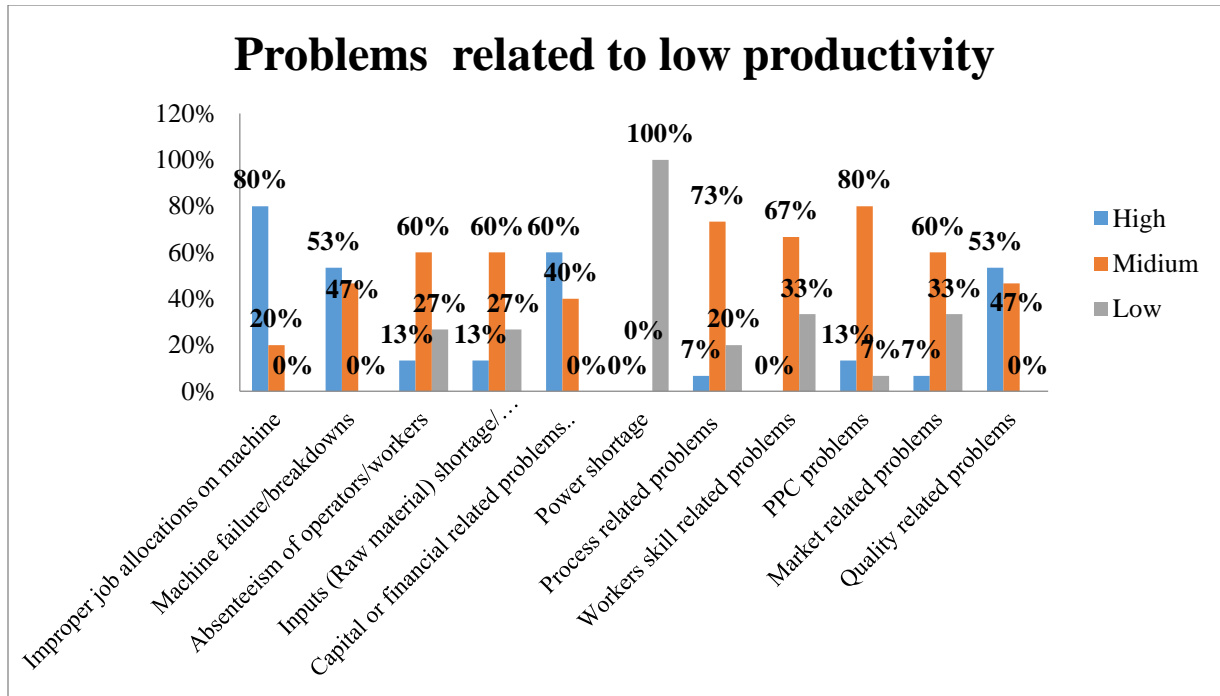


Figure 4-2 Problems of the Akaki BMI for lowering the productivity

From Figure 4.2, the respondents have prioritized the major problems at Akaki BMI; like are the improper job allocations on machines (80%), Capital or financial related problems (60%), machine failure/breakdown (53%), Quality related problems (53%), and so on are the problems that highly affect the productivity of the industry. So among them, the improper allocation of jobs on the given machines was the main reason for low productivity, why because the Akaki BMI follows the first come first serve system.

Case 3: Supervisors and Machine Operators

In this section, a total of 74 supervisors and machine operators in all the workshops were asked to respond to the questionnaire. Based on the surveyed pieces of questionnaires the supervisors and machine operators are asked to give a response on the factors affecting productivity of Akaki BMI were analyzed. The respondents were asked to prioritize the factors from lowest level to the highest level based on the company frequently occurred major factors which are around eight major factors and others that affects the productivity of Akaki BMI. And provided their responses on the factors affecting the productivity of the industry from lowest level to the highest level [1 = low; 2 = high; 3 = Critical] as presented in Table 4.7.

Table 4-7 Factors affecting productivity of Akaki BMI

No	Factors/ Problems	Low (1)	High (2)	Critical (3)
1	Raw material related problems	36	32	6
2	Capital related problems	15	43	16
3	Machineries and equipment related	4	15	55
4	Planning and management problems	11	47	16
5	Process related problems	10	32	32
6	Skill and labor related problems	26	42	6
7	Technology and innovation related	13	28	33
8	Quality and higher production cost related	15	49	10
9	Salary/payment of experts	2	1	6

The problems are depicted in figure 4.3 for better visualization of the major affecting problems.

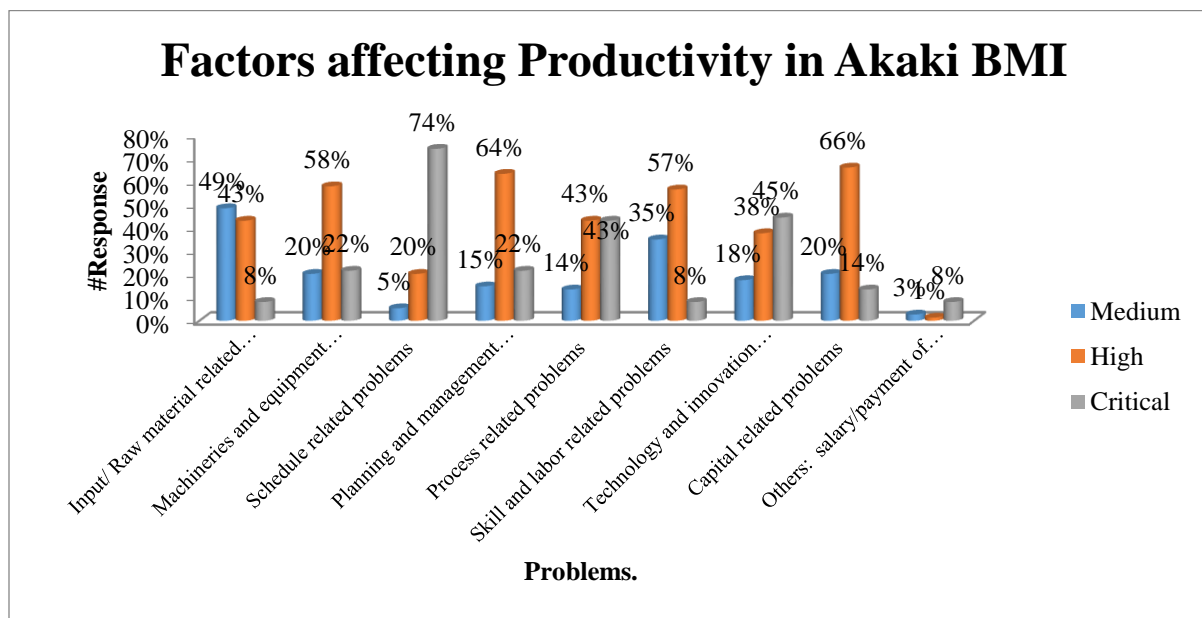


Figure 4-3 Factors affecting productivity at Critical, high and low level

As shown in Figure 4.3, Schedule related problems (74%), Technology and innovation related (45%) and process related problems (43%) are affecting the productivity of Akaki BMI at critical level. Capital related problems (66%), planning and management related problems (64%), machinery and equipment related problems (58%), and Skill and labor related problems (57%) are affecting the productivity of the Akaki BMI at higher level.

Input/Raw material related problems (49%) have medium effect on the productivity of Akaki BMI.

Thus, it is possible to present this conclusion based on the three case questionnaires that the machinery related and scheduling related problems are the major problems affecting the productivity of Akaki BMI and the major causes of low productivity of the company is improper allocations of job on the given machines.

4.1.2. Data collected and identified through interviews

During the interview of the researcher with Operational Management Section, PPC Section, Supervisors and Machine Operators by staying with those who work in different top positions of the Akaki BMI, the researcher understood that the type of production of the industry is in Job shop based production with the Make to Order (MTO) production strategy and obtained the critical factors or problems that responsible for lowering productivity in the case study from the respondents. These problems are:

- Schedule related problems
- Capital related problems
- Machinery and equipment related problems
- Skill and labor related problems because of employee turnover due to salary, etc...

As the interview responses conducted with the top management personnel of the Akaki BMI and senior operators According to them, even though we apply dispatching rule like first come first serve (FCFS) and follow some production improvement programs, the desired results are not forthcoming. This means that the industry has to follow different production improvement methods to increase productivity. Therefore, one of the ways to increase machine productivity is to solve the scheduling related problems is presented in this study.

4.1.3. Data collected and identified through observation

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

- ☞ Improper allocation of jobs on the existing machines
- ☞ Turnover of workers due to Salary and other incentives

☞ Number of failed machines

4.1.4. Data obtained from review literature and company document report

- ☞ Targeted production capacity of company
- ☞ Actual production capacity of company
- ☞ Number of functional machines
- ☞ Job order with their processing and due date time
- ☞ Related information from different thesis and articles, etc....

4.2. Scheduling using LEKIN software

There are 20 jobs to be processed on the 20 machines available in the machine shop in the industry. Thus, the total size of the system going to be considered and analyzed as per the requirement for the performance evaluation is 20x20 matrix size.

The table 4.8 shows the available jobs, the sequence of the machines to be utilized, processing time (minutes) that the job stays on each machine, total processing time of each job, average setup, waiting time and due date (minute) for each job. The assignation of each job and the ordered quantity is presented in table 4.8 as well.

Table 4-8 Job processing time on the available machines

No	Job Name	Machine sequence	Proc. time on each mach.	Total mach. Time	Average setup time	Average waiting time	Due date
1	J1	M8-M12-M19-M1	20-15-20-10	65	30	16.25	95
2	J2	M6-M17-M16	25-10-20	55	25	18.33	80
3	J3	M9-M13-M2-M3	40-25-30-5	100	30	25	130
4	J4	M15-M5	45-10	55	15	27.5	70
5	J5	M4-M7-M18-M11	20-10-25-15	70	25	17.5	95
6	J6	M2-M14-M6-M5	25-15-15-10	65	30	16.25	95
7	J7	M1-M9-M10-M16	40-25-50-20	135	25	33.75	160
8	J8	M6-M17-M20-M12	20-20-25-15	80	30	20	110
9	J9	M2-M14-M15	50-25-15	90	20	30	110
10	J10	M4-M18-M2-M7	30-25-15-10	80	30	20	110
11	J11	M3-M10-M19-M8-M1	45-25-30-25	125	45	31.25	170
12	J12	M8-M12-M19-M15	20-25-15-15	75	35	18.75	110
13	J13	M1-M11-M16-M20	40-25-20-30	115	25	28.75	140
14	J14	M5-M14-M17-M2-M6	50-10-40-10-5	115	40	28.75	155
15	J15	M6-M16-M20	30-25-20	75	25	25	100
16	J16	M1-M11-M12-M9	15-25-15-20	75	30	18.75	105
17	J17	M7-M15-M18-M4	40-25-15-15	95	45	21	140
18	J18	M2-M5-M14-M18	30-20-12-10	72	30	18	120
19	J19	M4-M7-M18-M2	40-25-30-20	115	25	28.75	140
20	J20	M8-M12	40-15	55	15	27.5	70

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 BMI was formulated as shown in the Table 4.9.

Table 4-9 Job-Machine matrix with processing time (minutes) on each machine

M/J	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J17	J18	J19	J20
M1	10						40						40			15				
M2			30			25			50	15				10				30	20	
M3			5								45									
M4					20					30							15		40	
M5				10		10								50				20		
M6		25				15		20						5	15					
M7					10					10							40		25	
M8	20											20								40
M9			40				25									20				
M10							50				25									
M11					15								25			25				
M12	15							15				25				15				15
M13			25																	
M14						15			25					10				12		
M15				45					15		15	15					25			
M16		20					20						20		25					
M17		10						20						40						
M18					25					25							15	10	30	
M19	20										30	15								
M20								25					30		20					

The processing sequence was solved under the following assumptions:

- ☞ All machines are available during the scheduling period
- ☞ All jobs are ready to be processed at a processing time $t_0 = 0$ & Ready time $r_j = 0$
- ☞ Each machine process only one job at a time
- ☞ Each job was visiting each machine only once.
- ☞ No job splitting
- ☞ Processing time is deterministic
- ☞ Transportation times between different machines are neglected

LEKIN scheduler software package for the existing manufacturing process of the industry is used to solve the makespan of the existing system. Therefore, the data fed into the LEKIN scheduler software package, and makespan were obtained through the dispatching and

heuristic approaches. Since the Akaki BMI job allocation or scheduling follows the FCFS method and for this method, the Gantt-chart was developed by using the LEKIN scheduler software package to obtain the total makespan of a manufacturing process of the company.

4.2.1. First Come First Serve (FCFS) scheduling

The Gantt chart that shows the sequences of jobs or machine loading for the existing schedule indicated by LEKIN scheduling system that company using method (FCFS) is presented in the Figure 4.4.

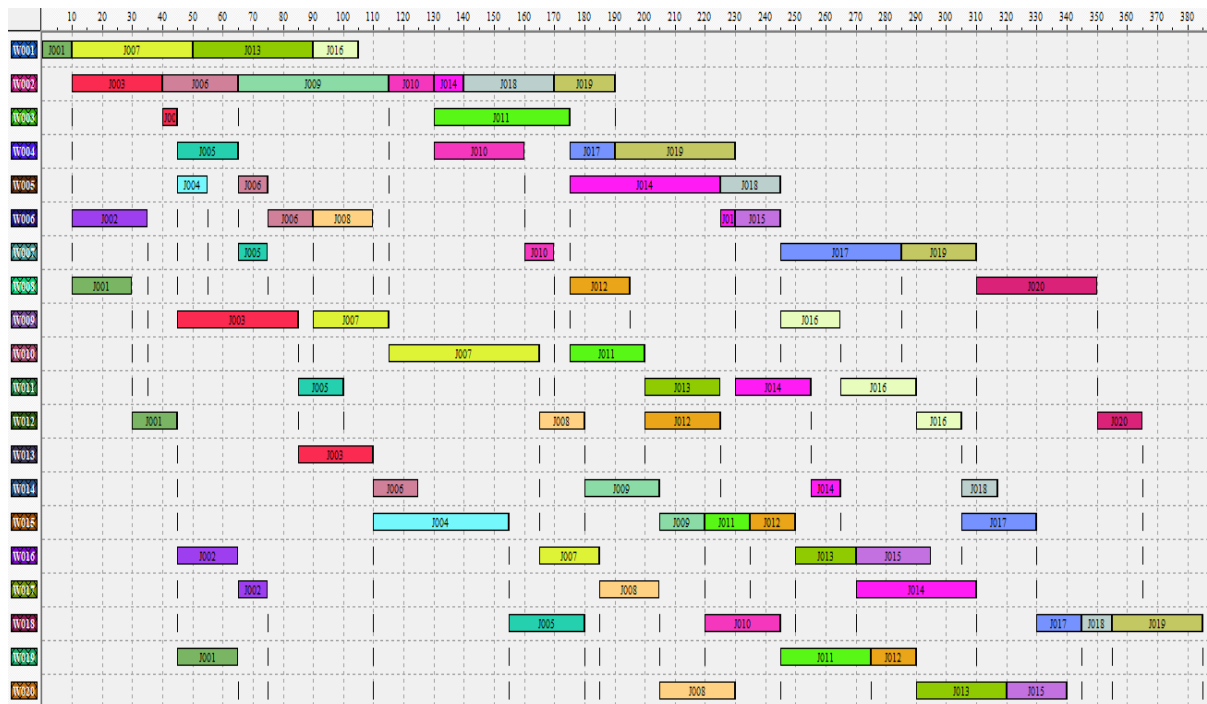


Figure 4-4 Akaki BMI existing scheduling by using FCFS scheduling

Figure 4.4 shows the existing scheduling makespan resulted by LEKIN software by using FCFS scheduling. The makespan by using FCFS approach was found as 385 minutes per shift. The total tardiness of existing scheduling of FCFS is found as about 5010 minutes.

Productivity analysis for FCFS approach

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 (CHOWDHURY, 2007). 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. From the 2014E.C annual reports of the company indicates the company's planned and actual output, make-span, and the number of functional machines in the machine shop of Akaki BMI.

Machine Productivity:

It is one of the techniques used in the Akaki BMI to measure the productivity of the machines by converting the raw inputs into a useful product. In Akaki BMI of spare part manufacture, measure its productivity by considering both the labor and machine productivity (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 functional 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:

$$\text{Machine productivity} = \frac{\text{total number of spare part produced}}{\text{total number of machines used in the machine shop}} \quad (\text{Negash, 2021})$$

To calculate the machine productivity of Akaki BMI for existing FCFS methods:

$$\text{productivity} = \frac{27,311}{80 \cdot 12 \cdot 24} = 1.19 \text{ units/machine/shift or}$$

$$\text{productivity} = \frac{27,311}{80 \cdot 12 \cdot 24 \cdot 385} = 0.00308 \text{ units/machine/minutes}$$

Where, 27,311= number of annually produced spare parts (from company data)

80 = number of functional machines in machine shop (from company data), 12 = number of months in one year, 24 = number of shifts in one month, and 385 minutes = total make span for FCFS method.

The productivity of the Akaki BMI, as the existing data obtained from annual report through mathematical approach is 1.19 units/machine/shift.

Generally, the Akaki BMI was one among the Ethiopian metal & engineering industries with a planned capacity of manufacturing 103,570 units per annum. However, currently, it is performing under the capacity of about 27,311(26.37%) annually due to several reasons.

The tardiness table for each job in the system is presented in Table 4.10. The tardiness was calculated in a way that if the completion time of the particular job is less than that of the due date, it is zero. And if the completion time of a job is greater than the given due date, the tardiness is difference of completion time and the due date.

Since all the jobs in the shop are assumed as ready to be processed on their provided machines, the time for readiness of all jobs is considered as zero. Thus, the flow time of job J was considered as equal with the completion time of each job.

Table 4-10 Tardiness table of each job by using FCFS approach

Jobs	Pro time (min)	Due date (min)	Completion time (min)	Tardiness (min)
J1	65	95	65	0
J2	55	80	75	0
J3	100	130	110	0
J4	55	70	155	85
J5	70	95	180	85
J6	65	95	180	85
J7	135	160	185	25
J8	80	110	230	120
J9	90	110	230	120
J10	80	110	245	135
J11	115	170	275	105
J12	75	110	290	180
J13	115	140	320	180
J14	140	155	320	165
J15	60	100	340	240
J16	75	105	340	235
J17	95	140	345	205
J18	72	102	355	253
J19	115	140	385	245
J20	55	70	385	315
Total			5010	2778

From table 4.10, the maximum tardiness is found as 315minutes for J20. Thus, J20 is so tardy in the system. As shown in figure 4.5, J12 can be processed on M8 after completion of J1. However, M8 was idle from 30th minute up to 175th minute for about 145 minutes. Then J20 can also be processed after completion of J12 at 195th minute. However, J20 started to be processed on M8 at 310th minute leaving the M8 idle for 115 minutes. Thus, tardiness for J20 was found by subtracting its processing time 70 minutes from its completion time 385 minutes, which is found as 315 minutes.

The performance of FCFS scheduling analysis result is summarized as shown in Table 4.11. As shown the maximum makespan and tardiness are found as 385 minutes and 315 minutes respectively. The total flow time and tardiness was found as 5010 minutes and 2778 minutes respectively.

Table 4-11 Performance of the FCFS scheduling analysis

Parameters	Values
Makespan	385
Maximum Tardiness	315
Total flow time	5010
Total Tardiness	2778

The sequence of jobs to be processed on each machine is shown in Table 4.12.

Table 4-12 Sequence of jobs on each machine using FCFS scheduling

No	Machine	Job sequence
1	M1	J1->J7->J13->J16
2	M2	J3->J6->J9->J10->J14->J18->J19
3	M3	J3->J11
4	M4	J5->J10->J17->J19
5	M5	J4->J6->J14->J18
6	M6	J2->J6->J8->J14->J15
7	M7	J5->J10->J17->J19
8	M8	J1->J12->J20
9	M9	J3->J7->J16
10	M10	J7->J11
11	M11	J5->J13->J14->J16
12	M12	J1->J8->J12->J16->J20

13	M13	J3
14	M14	J6->J9->J14->J18
15	M15	J4->J9->J11->J12->J17
16	M16	J2->J7->J13->J15
17	M17	J2->J8->J14
18	M18	J5->J10->J17->J18->J19
19	M19	J1->J11->J12
20	M20	J8->J13->J15

The sequence of jobs to be processed on each machine that could resulted in the best FCFS results is shown in figure 4.4 and table 4.12. Moreover, the total processing time and idle time for each machine is also presented in table 4.13.

Table 4-13 Job sequence, operating and idle time of each machine

No	Machine	Total operating time (min)	Idle time (min)
1	M1	105	0
2	M2	190	10
3	M3	175	125
4	M4	230	125
5	M5	245	155
6	M6	245	165
7	M7	310	225
8	M8	350	270
9	M9	265	180
10	M10	200	125
11	M11	290	200
12	M12	365	280
13	M13	110	85
14	M14	317	255
15	M15	330	215
16	M16	295	210
17	M17	310	240
18	M18	385	280
19	M19	290	225
20	M20	340	265
Total		5347	3635

As shown in the table 4.13, the total processing time of all machines in the shop to produce single pcs of each job is found as about 5347 minutes. The total idle time, in which the

machine stays for nothing waiting for the next job without processing any job is found as 3635 minutes, which could be represented as 67.98%. Thus, the waiting time for all the machines in the shop is very high and thus, the energy consumption would be very high, and thus may cost much. The figure 4.5 shows the operating and idle time for each machine.

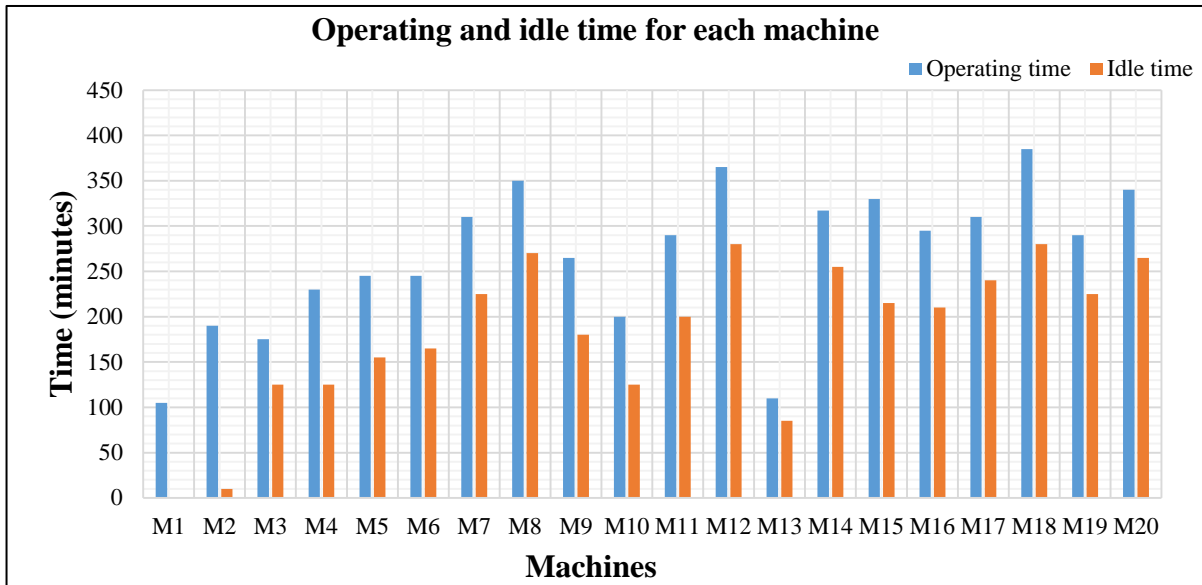


Figure 4-5 Operating and idle time for each machine

4.2.2. Local search scheduling

To optimize the existing makespan, the Local Search heuristic scheduling techniques was employed in comparison with the FCFS scheduling approach. The Gantt chart that shows the sequences of jobs for the existing schedule indicated by LEKIN scheduling system using Heuristic Local Search scheduling is presented in the Figure 4.6.

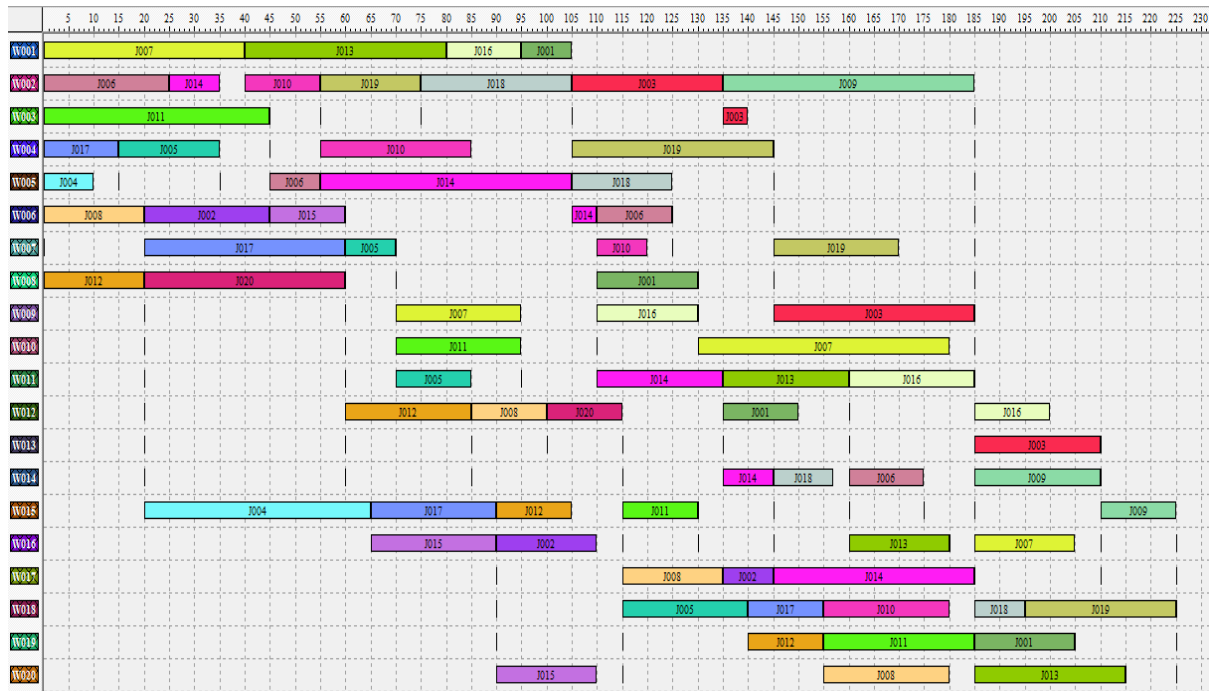


Figure 4-6 Scheduling by using heuristic local search scheduling

Figure 4.6 shows the existing scheduling makespan resulted by LEKIN software by utilizing the Local Search approach. The makespan found during Local Search algorithm-based scheduling was 225 minutes per shift with the total tardiness found as about 1833 minutes. The tardiness table for each job by using local search scheduling approach is shown in Table 4.14.

Table 4-14 Tardiness table for each job by using local search scheduling

Jobs	Pro. time (min)	Due date (min)	Completion time (min)	Tardiness (min)
J1	65	95	215	120
J2	55	80	215	135
J3	100	130	225	95
J4	55	70	115	45
J5	70	95	215	120
J6	65	95	225	130
J7	135	160	225	65
J8	80	110	180	70
J9	90	110	225	115
J10	80	110	225	115
J11	115	170	215	45
J12	75	110	215	105
J13	115	140	215	75
J14	140	155	225	70
J15	60	100	110	10
J16	75	105	225	120
J17	95	140	215	75
J18	72	102	225	123
J19	115	140	225	85
J20	55	70	185	115
Total			4120	1833

The performance of Local search based scheduling analysis result is summarized as shown in Table 4.15. As shown the maximum makespan and tardiness are found as 225 minutes and 135 minutes respectively. The total flow time and tardiness was found as 4120 minutes and 1833 minutes respectively.

Table 4-15 Local search scheduling performance

Parameters	Values
Makespan	225
Maximum Tardiness	135
Total flow time	4120
Total Tardiness	1833

The sequence of jobs to be processed on each machine is shown in Table 4.16.

Table 4-16 Sequence of jobs on each machine by Local search scheduling

No	Machine	Job sequence
1	M1	J7->J13->J16->J1
2	M2	J6->J14->J10->J19->J18->J3->J9
3	M3	J11->J3
4	M4	J17->J5->J10->J19
5	M5	J4->J6->J14->J18
6	M6	J8->J2->J15->J14->J6
7	M7	J17->J5->J10->J19
8	M8	J12->J20->J1
9	M9	J7->J16->J3
10	M10	J11->J7
11	M11	J5->J14->J13->J16
12	M12	J12->J8->J20->J1->J16
13	M13	J3
14	M14	J14->J18->J6->J9
15	M15	J4->J17->J12->J11->J9
16	M16	J15->J2->J13->J7
17	M17	J8->J2->J14
18	M18	J5->J17->J10->J18->J19
19	M19	J12->J11->J1
20	M20	J15->J8->J13

The sequence of jobs to be processed on each machine that could result in the best Local search scheduling results is shown in figure 4.6 and table 4.16. Based on this sequence, the total processing time and idle time for each machine is also presented in table 4.17.

Table 4-17 Operating and idle time of each machine by local search approach

No	Machine	Total operating time (min)	Idle time (min)
1	M1	105	0
2	M2	185	5
3	M3	140	90
4	M4	145	40
5	M5	125	35
6	M6	125	45
7	M7	170	85
8	M8	130	50
9	M9	185	100
10	M10	180	105
11	M11	185	95
12	M12	200	115
13	M13	210	185
14	M14	210	148
15	M15	225	110
16	M16	205	120
17	M17	185	115
18	M18	225	120
19	M19	205	140
20	M20	215	140
Total		3555	1843

As shown in the table 4.17, the total processing time of all machines in the shop to produce single pieces of each job is found as about 3555 minutes. The total idle time, in which the machine stays for nothing waiting for the next job without processing any job, is found as 1843 minutes, which could be represented as 51.84%. Thus, the waiting time for all the machines in the shop is very high and thus, the energy consumption would be very high, and thus may cost much. The figure 4.7 shows the operating and idle time for each machine.

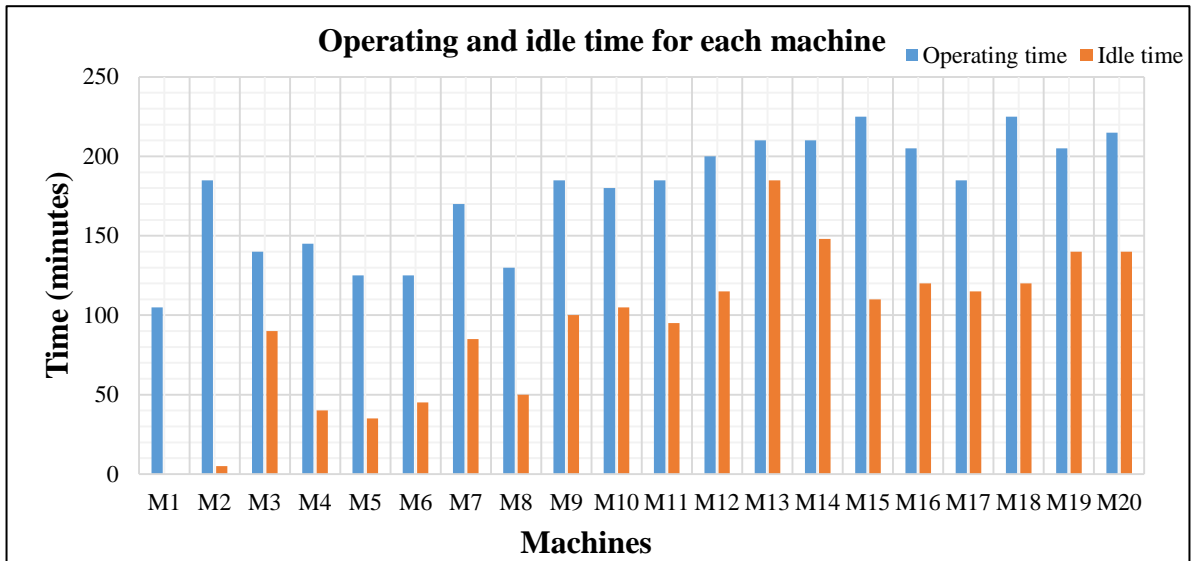


Figure 4-7 Operating and idle time for each machine by local search approach

The comparison of the existing FCFS approach and the local search scheduling approach is compared as shown in Table 4.18. As shown, the makespan during FCFS and heuristic local search-based scheduling is found as 385 minutes and 225 minutes respectively.

Table 4-18 Comparison of FCFS and Local search scheduling

Schedule	Makespan	Tardiness	Total flow time	Total tardiness	Total operation time	Total idle time
FCFS	385	315	5010	2778	5347	3635
Local search	225	135	4120	1833	3555	1843

The total tardiness resulted by using the FCFS and local search scheduling is 2778 minutes and 1833 minutes respectively. The total operation time of all machines in the shop for the same jobs during FCFS and local search case was found as 5247 minutes and 3555 minutes respectively. Thus, the local search scheduling has effectively reduced the makespan and total tardiness of the existing FCFS scheduling approach.

However, there is still some problem related with the job sequencing of the system. For instance, if we look inside the Figure 4.6, J11 is finished its processing at 45th minute on M3. Nevertheless, for nothing it waits until 70th minute to start processing on M10, while the M10

is unloaded. Similarly, J5 is finished its processing at 85th minute on M11. However, for nothing it waits until 115th minute to start processing on M18, while the M18 is unloaded.

Thus, to overcome some other drawbacks and related problems and to reduce the makespan, total tardiness and idle time of the machines as much as possible, the algorithm called grey wolf optimization (GWO) was utilized and coded in MATLAB software package for better productivity of the industry.

4.2.3. Analysis with GWO algorithm

The control parameters utilized for GWO algorithm are presented in Table 4.19 to select the optimal machine sequencing for reducing the makespan and total tardiness.

Table 4-19 Control parameter value of GWO

Total number of wolves: 12
Lower bound: [65]
Upper bound: [385]
Iterations: 100

Table 4.19 shows the control parameters of the GWO algorithm. The number of wolves selected to be 12 are based on the principle that the wolves move in group up to maximum of 12 members per group. The lower and upper bound are selected based on the minimum processing time of jobs 65 minutes and the makespan resulted during FCFS scheduling approach 385 minutes respectively, since FCFS approach is base approach and it is currently applied in the industry.

The Gantt chart that shows the sequences of jobs for the existing schedule indicated for scheduling the given system using GWO scheduling approach is presented in the Figure 4.8.

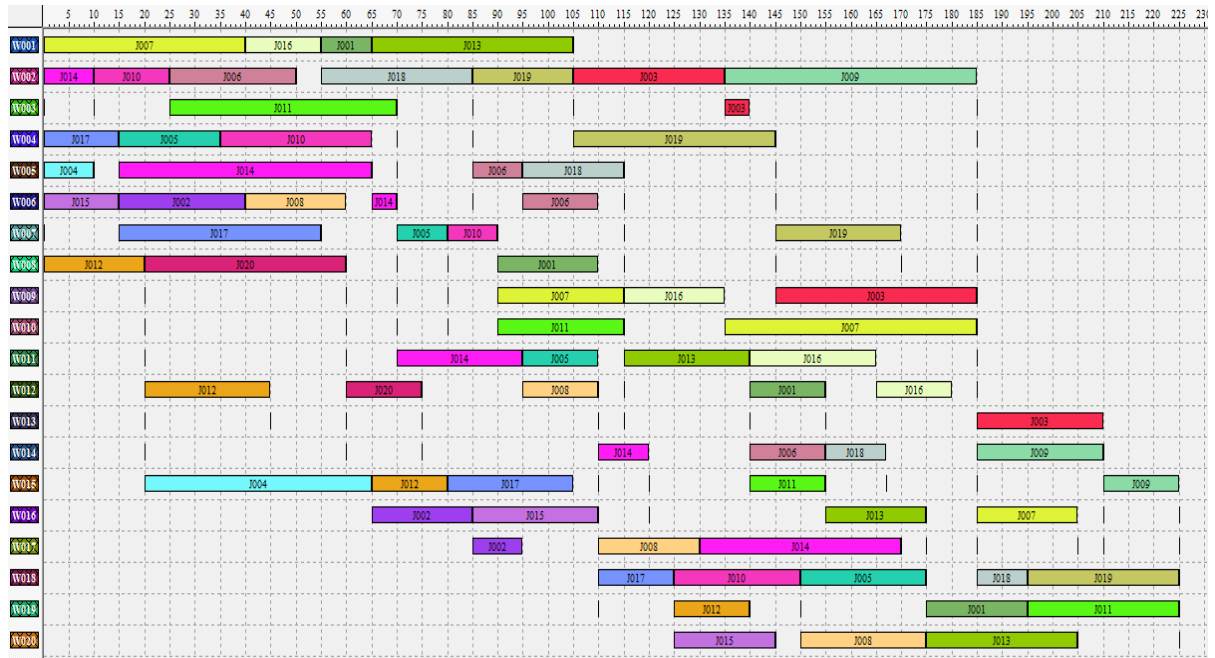


Figure 4-8 Scheduling by using GWO scheduling

Figure 4.8 shows the existing scheduling makespan resulted by utilizing the GWO algorithm approach. The makespan found during Local Search algorithm-based scheduling was 225 minutes per shift with the total tardiness found as about 1553 minutes. The tardiness table for each job by using local search scheduling approach is shown in Table 4.20.

Table 4-20 Tardiness table of each job in the system using GWO

Jobs	Pro. time (min)	Due date (min)	Completion time (min)	Tardiness (min)
J1	65	95	205	110
J2	55	80	145	65
J3	100	130	225	95
J4	55	70	145	75
J5	70	95	175	80
J6	65	95	205	110
J7	135	160	225	65
J8	80	110	175	65
J9	90	110	225	115
J10	80	110	225	115
J11	115	170	225	55
J12	75	110	145	35
J13	115	140	205	65

J14	140	155	225	70
J15	60	100	145	45
J16	75	105	205	100
J17	95	140	145	5
J18	72	102	225	123
J19	115	140	225	85
J20	55	70	145	75
Total			3840	1553

The performance of GWO-based scheduling analysis result is summarized as shown in Table 4.21. As shown the maximum makespan and tardiness are found as 225 minutes and 123 minutes respectively. The total flow time and tardiness was found as 3840 minutes and 1553 minutes respectively.

Table 4-21 Grey wolf optimization-based scheduling performance

Parameters	Values
Makespan	225
Maximum Tardiness	123
Total flow time	3840
Total Tardiness	1553

The sequence of jobs to be processed on each machine is shown in Table 4.22.

Table 4-22 Sequence of jobs on each machine by GWO scheduling

No	Machine	Job sequence
1	M1	J7->J16->J1->J13
2	M2	J14->J10->J6->J18->J19->J3->J9
3	M3	J11->J3
4	M4	J17->J5->J10->J19
5	M5	J4->J14->J6->J18
6	M6	J15->J2->J8->J14->J6
7	M7	J17->J5->J10->J19
8	M8	J12->J20->J1
9	M9	J7->J16->J3
10	M10	J11->J7
11	M11	J14->J5->J13->J16
12	M12	J12->J20->J8->J1->J16

13	M13	J3
14	M14	J14->J6->J18->J9
15	M15	J4->J12->J17->J11->J9
16	M16	J2->J15->J13->J7
17	M17	J2->J8->J14
18	M18	J17->J10->J5->J18->J19
19	M19	J12->J1->J11
20	M20	J15->J8->J13

The sequence of jobs to be processed on each machine that could result in the best GWO scheduling results is shown in figure 4.8 and table 4.22. Based on this sequence, the total processing time and idle time for each machine is also presented in table 4.23. The idle time was calculated as the difference of machine's total operation time and its recorded processing time.

Table 4-23 Operating and idle time of each machine by GWO approach

No	Machine	Total operating time (min)	Idle time (min)
1	M1	105	0
2	M2	185	5
3	M3	140	90
4	M4	145	40
5	M5	115	25
6	M6	110	30
7	M7	170	85
8	M8	110	30
9	M9	185	100
10	M10	185	110
11	M11	165	75
12	M12	180	95
13	M13	210	185
14	M14	210	148
15	M15	225	110
16	M16	205	90
17	M17	170	100
18	M18	225	120
19	M19	225	160
20	M20	205	130
Total		3470	1728

As shown in the table 4.23, the total processing time of all machines in the shop to produce single pieces of each job is found as about 3470 minutes. The total idle time, in which the machine stays for nothing waiting for the next job without processing any job, is found as 1728 minutes, which could be represented as 49.8% of the total operation time. Thus, the waiting time for all the machines in the shop is significantly reduced and thus, the energy consumption would be also reduced accordingly. The figure 4.9 shows the operating and idle time for each machine resulted from GWO scheduling.

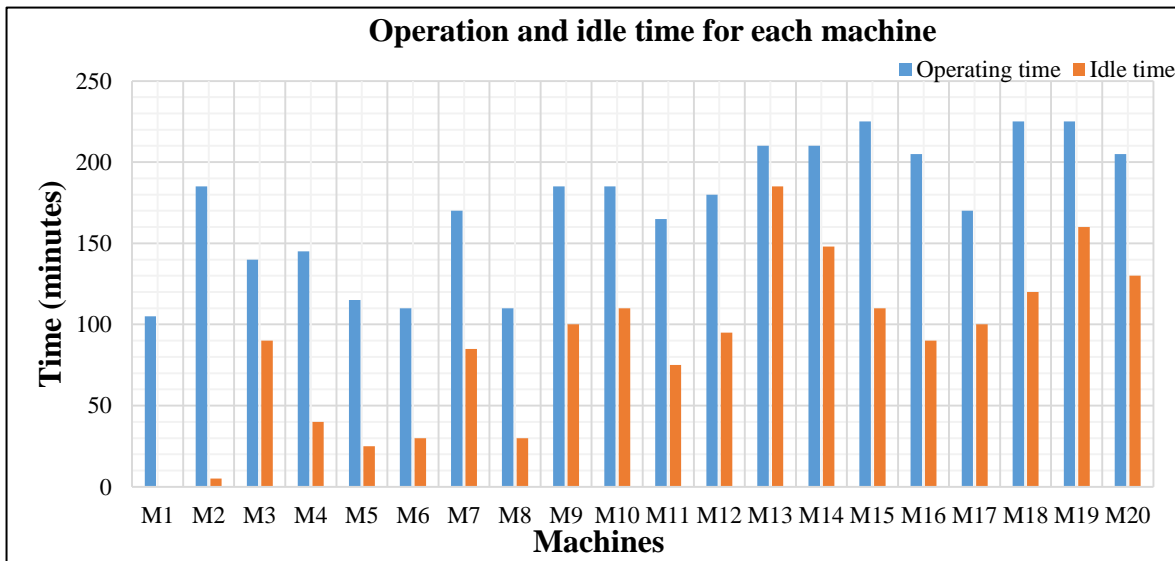


Figure 4-9 Operation and idle time for each machine by GWO approach

4.3. Comparative analysis

The comparisons of each of the approaches considered for this study were presented here for their scheduling abilities. The comparison was made regarding the makespan, tardiness, machine operation time, machine idle time and the energy consumption.

The comparison of the FCFS approach, local search scheduling approach and GWO based approach is shown in Table 4.24. From this comparison, we could say that the GWO-based scheduling have better scheduling capacity to reduce the makespan, tardiness and the idle time of the machines of the system for the same size of jobs than FCFS and local search approaches.

Table 4-24 Comparison of FCFS, Local search and GWO scheduling

Schedule	Makespan	Max. Tardiness	Total flow time	Total tardiness	Total operation time	Total idle time
FCFS	385	315	5010	2778	5347	3635
Local search	225	135	4120	1833	3555	1843
GWO	225	132	3840	1553	3470	1728

The total flow time for FCFS, local search and GWO approaches was found to be 5010 minutes, 4120 minutes and 3840 minutes respectively as shown in Table 4.24. The total tardiness for each of the FCFS, local search and GWO approach is found to be 2778 minutes, 1833 minutes and 1553 minutes respectively.

From this analysis, utilization of GWO based scheduling has better capability to reduce the waiting time of the jobs in the system accordingly. And has better capability to reduce the tardiness of the jobs in the system. Thus, jobs were completed before the due date.

The total operation time for all the machines for each of the FCFS, local search and GWO approach is found to be 5347 minutes, 3555 minutes and 3470 minutes respectively. And the total idle time for all the machines for each of the FCFS, local search and GWO approach is found to be 3635 minutes, 1843 minutes and 1728 minutes respectively.

The energy consumption of each machine to process the proposed jobs for the given processing time is shown in Table 4.25. The consumption was calculated by multiplying the rated kW of the machine by its processing time (which was converted in to hr. for convenience).

Table 4-25 Comparison of energy consumption during operation time

Machine		Operation time (min)			Consumption (kWh)		
No	Rating (kW)	FCFS	Local search	GWO	FCFS	Local search	GWO
M1	330	105	105	105	34.65	34.65	34.65
M2	300	190	185	185	57	55.5	55.5
M3	200	175	140	140	35	28	28
M4	150	230	145	145	34.5	21.75	21.75
M5	150	245	125	115	36.75	18.75	17.25
M6	175	245	125	110	42.875	21.875	19.25
M7	200	310	170	170	62	34	34
M8	100	350	130	110	35	13	11
M9	200	265	185	185	53	37	37
M10	350	200	180	185	70	63	64.75
M11	400	290	185	165	116	74	66
M12	650	365	200	180	237.25	130	117
M13	350	110	210	210	38.5	73.5	73.5
M14	250	317	210	210	79.25	52.5	52.5
M15	150	330	225	225	49.5	33.75	33.75
M16	300	295	205	205	88.5	61.5	61.5
M17	150	310	185	170	46.5	27.75	25.5
M18	150	385	225	225	57.75	33.75	33.75
M19	250	290	205	225	72.5	51.25	56.25
M20	200	340	215	205	68	43	41
Total		5347	3555	3470	1314.53	908.525	883.9

As shown in figure 4.25, the total energy consumption during FCFS, local search and GWO scheduling conditions was found as 1314.53, 908.525 and 883.9 kWh respectively. From the table, we could observe that application of GWO algorithm reduced the total operation time

by about 35.1% than that of FCFS scheduling approach. Moreover, the energy consumption rate is also reduced by about 32.76% by applying GWO algorithm.

The energy consumption of each machine during its idle time (without doing anything and waiting for the incoming job) is shown in Table 4.26.

Table 4-26 Comparison of energy consumption during idle time

Machine		Idle time (min)			Consumption (kWh)		
No	Rating (kW)	FCFS	Local search	GWO	FCFS	Local search	GWO
M1	330	0	0	0	0	0	0
M2	300	10	5	5	3	1.5	1.5
M3	200	125	90	90	25	18	18
M4	150	125	40	40	18.75	6	6
M5	150	155	35	25	23.25	5.25	3.75
M6	175	165	45	30	28.875	7.875	5.25
M7	200	225	85	85	45	17	17
M8	100	270	50	30	27	5	3
M9	200	180	100	100	36	20	20
M10	350	125	105	110	43.75	36.75	38.5
M11	400	200	95	75	80	38	30
M12	650	280	115	95	182	74.75	61.75
M13	350	85	185	185	29.75	64.75	64.75
M14	250	255	148	148	63.75	37	37
M15	150	215	110	110	32.25	16.5	16.5
M16	300	210	120	90	63	36	27
M17	150	240	115	100	36	17.25	15
M18	150	280	120	120	42	18	18
M19	250	225	140	160	56.25	35	40
M20	200	265	140	130	53	28	26
Total		3635	1843	1728	888.625	482.625	449

As shown in table 4.26, the total idle time energy consumption during FCFS, local search and GWO scheduling is found as 888.625, 482.625 and 449 kWh respectively. Application of GWO could reduce the idle time energy consumption of about 49.47% and then convert it to machine processing time, which could also increase machine productivity by reducing the energy that was wasted due to idle time running put it to work.

Productivity analysis for a new scheduled GWO approach

To calculate the machine productivity of Akaki BMI for GWO algorithm method

$$\text{Productivity} = \frac{27,311}{80 \times 12 \times 24 \times 225} = 0.00527 \text{ units/machine/minutes}$$

Where, 27,311= number of annually produced spare parts (from company data)

80 = number of functional machines in machine shop (from company data), 12 = number of months in one year, 24 = number of shifts in one month and 225 minutes = total make span for GWO scheduling method

The productivity of the Akaki BMI was through mathematical approach 0.00527 units/machine/minutes.

Generally, the Akaki BMI uses the First come first service (FCFS) method and the time taken to produce 1.19 units/machines was 385 minutes/machine in one shift. But, by using the LEKIN scheduling system the GWO scheduling the time taken to produce the 1.19 units/machine was 225 minutes/machine in one shift. So there is gap because of improper scheduling jobs on the given machines. Therefore, when the company applies these methods, productivity was increased by 41.55% (0.00147 units/machine/minutes).

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Akaki basic metal industry is Ethiopia's largest and oldest basic metal industry. However, due to scheduling issues as well as other administrative and machine issues, productivity is currently falling short of expectations.

To address these issues, data was gathered from company reports and distributed questionnaires to various departments in the industry to examine the existing productivity related issues that impede productivity in the case industry. The sample size considered for this study is 107 respondents, of whom 98 completed and returned the questionnaires on time, yielding a response rate of approximately 91.6%.

According to the questionnaire results, the major issues affecting Akaki BMI's productivity are machinery failure/breakdowns and scheduling issues. As a result, the better way to solve scheduling problems is presented in this study and analyzed using the LEKIN and MATLAB software.

The job shop scheduling problem formulated for Akaki BMI under machine shop sections were solved using Lekin flexible job shop scheduling software. The output analysis was the examination of data generated by a Lekin approach and MATLAB software. Its purpose is to obtain the optimum sequence of the system and report the output results. Using these methods, different performances are measured, such as; Makespan (C_j max), Total flow time (F_j max), Tardiness (T_j max), and Energy consumption which are evaluated through this method.

Therefore, the finding of the study has revealed that grey wolf optimization minimize maximum tardiness and makespan yields optimal schedule. Using FCFS, local search, and GWO based scheduling, the makespan is found to be 385 minutes, 225 minutes, and 225 minutes, respectively. The total flow time for the FCFS, local search, and GWO approaches is 5010 minutes, 4120 minutes, and 3840 minutes, respectively. The total tardiness for the FCFS, local search, and GWO approaches is 2778 minutes, 1833 minutes, and 1553 minutes, respectively.

The total energy consumption during operation time of the shop machines is found to be approximately 1314.53, 908.5, and 883.9 kWh for FCFS, local search, and GWO based scheduling cases, respectively. The total energy consumption during idle time was also determined to be 888.625, 482.625, and 449 kWh, respectively.

The objective of this study was to improve the productivity of the Akaki BMI by identifying the factors that affect the productivity of the factory, specifically the machine shop. The machine productivity for FCFS and GWO approach was found as 0.00308 units/machine/minutes and 0.00527 units/machine/minutes respectively.

The benefits of using GWO instead of FCFS included a 160 minute reduction in makespan, a 1225 minute reduction in total tardiness, a 1170 minute reduction in total flow time, reduce idle time energy consumption by 49.47% and increase machine productivity by 41.55%.

According to this analysis, using GWO-based scheduling has a better ability to reduce waiting time and tardiness of jobs in the system. As a result, jobs were take less time to process in the shop and were completed ahead of schedule.

5.2. Recommendations

From the findings of this study the following recommendations are drawn for better productivity requirement.

- ☞ The Akaki BMI is using the FCFS scheduling approach. However, the makespan is very large during this approach and the GWO proved that it has a capability to reduce the makespan. Thus, the industry may apply heuristic algorithms, like GWO for reduced makespan with better productivity.
- ☞ During interview session, the operators pointed out that the job orders are handled by manual letter or oral job ordering approach. However, it could be better if the job ordering processes are based on some other database systems for flexible identification and selection of free shops in the industry. Also in their interview, they stated that the turnover of experienced workers is in terms of salary and other benefits so that the company should be arranging various incentives and regular internal capacity building training programs on productivity improvement & analysis for the workers were help the company to improve the productivity of the company.

5.3. Future works

Due to time and other economy related constraints, this study focused on only identification of the problems related to the machine shop activities and reduction of makespan and tardiness that affect the productivity of the industry. However, the future studies should include one or more of the following aspects.

- ↪ Problems that affect the productivity of the industry related to the foundry shop activities like casting processes.
- ↪ Inclusion of the quality testing activities for better satisfaction and acceptance of customers.
- ↪ Operators and customer satisfaction investigation in-and-out of the industry
- ↪ Economic consideration of the productivity enhancement activities.

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Appendix I

GWO MATLAB code

Main-program as sample

```
clear;
clc;
% Objective function
global maxi F
Max_iter = 100;
JSSP_GWO('Job_01.xlsx',Max_iter);

% Initialize alpha position
dim =12; lb = 65; ub = 385;
Alpha_pos=zeros(1,dim);
Alpha_score = inf;

% Initialize beta position
Beta_pos=zeros(1,dim);
Beta_score = inf;

% Initialize delta position
Delta_pos=zeros(1,dim);
Delta_score = inf;
Positions = zeros();

iter=0; % Initial loop counter
% Main loop
while iter<Max_iter
for i=1:size(Positions,1)
% Return back if the search agents go beyond
% the boundaries of the search space
    Flag4ub=Positions(i,:) >ub;
    Flag4lb=Positions(i,:) <lb;
    Positions(i,:)=(Positions(i,:).*(~(Flag4ub+Flag4lb)))+ub.*Flag4ub+lb.*Flag4lb;

% Calculate fitness for each search agent
fitness = processing(Positions,0.5);

% Update alpha
if fitness<Alpha_score
Alpha_score=fitness;
Alpha_pos=Positions(i,:);
end
% Update beta
```

```

if fitness>Alpha_score& fitness<Beta_score
Beta_score=fitness;
Beta_pos=Positions(i,:);
end
% Update delta
if fitness>Alpha_score& fitness>Beta_score& fitness<Delta_score
Delta_score=fitness;
Delta_pos=Positions(i,:);
end
end
% a decreases linearly from 2 to 0
a=2-iter*((2)/Max_iter);

% Update the position of all search agents
fori=1:size(Positions,1)
forj=1:size(Positions,2)
% Update the position of alpha agents
r1=rand(); % r1 is a random number b/n [0,1]
r2=rand(); % r2 is a random number b/n [0,1]

A1=2*a*r1-a;
C1=2*r2;

D_alpha=abs(C1*Alpha_pos(j)-Positions(i,j));
X1=Alpha_pos(j)-A1*D_alpha;
% Update the position of beta agents
r1=rand();
r2=rand();

A2=2*a*r1-a;
C2=2*r2;

D_beta=abs(C2*Beta_pos(j)-Positions(i,j));
X2=Beta_pos(j)-A2*D_beta;
% Update the position of delta agents
r1=rand();
r2=rand();

A3=2*a*r1-a;
C3=2*r2;

D_delta=abs(C3*Delta_pos(j)-Positions(i,j));
X3=Delta_pos(j)-A3*D_delta;

Positions(i,j)=(X1+X2+X3)/3;
end

```

```

end
iter=iter+1;
end
N = 1:length(F);
disp('      Machine-Job sequence matrix')
disp('-----|')
disp(' |Mach|----- Jobs sequence -----|')
disp([N', F])
disp('-----')
fprintf('Smallest optimal makespan is: %d minutes \n',max(maxi));

```

Appendix II

Questionnaires



INSTITUTE OF TECHNOLOGY

FACULTY OF MANUFACTURING ENGINEERING

DEPARTMENT OF INDUSTRIAL ENGINEERING

General Introduction

My Name is Bezabih Gebeyehu and I reside in Hawassa University Institute of technology faculty of Manufacturing Engineering Department of Industrial Engineering Studying my MSc in Industrial Engineering and Logistics Management. Know I am preparing my MSc Thesis on the **Title of productivity enhancement for job shop scheduling problem using grey wolf optimization algorithm.** For the effectiveness of the study your support is very necessary so here is some interview questioner in order to answer.

The study is purely for academic purpose and thus not affects you in any case. So, your genuine, voluntarily and timely response is vital for successfulness of the study. Therefore, I kindly request you to respond to each items of the question very carefully. And give reliable information on the issues.

Thank you in advance for your time and kind cooperation!!

Bezabih Gebeyehu

Phone: 0926406472

Email: bezabih400@gmail.com

1. Interview Questions for Operational Management Section, PPC Section, Supervisors and Machine Operators

1. What is your position in the company?

Operators [] Supervisors [] Quality control []

Other: Please specify it.....

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

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

3. What is your Educational background?

PHD [] MSC/MA [] BSC/BA [] TVET Level 1-4 []

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

g. Other: Please specify if it.....

5. 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. Improper allocations of job on the given machines

e. 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.....

8. Is there any method for to estimate due date, lead time and backlog control method?

2. Questionnaires for Operational Management Section

1. What is your position in the 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 your sex: male [] female []

4. What is your Educational background?

PHD [] MSC/MA [] BSC/BA [] TVET Level 1-4 []

5. Do you have any Scheduling methods in your company?

6. What are the existing machine productivity and future expansion plan?

7. What are the factors most significant for your company's productivity?
8. What are the major factors responsible for your company's productivity lowering?
9. What are the major productivity improvement activities taken in your company?
10. What activities are being performed to make the company products competitive in the local and global market?
11. What is your strategy to sell your metal productivity in local and global markets?
12. What are the opportunities your company has in the current business environment?
13. What kinds of supports do the company wants from the Government and non-government to improve their productivity?
14. Is there any advanced method of scheduling like software supported, developed algorithm or computer aided process planning method in your company?
15. Have you introduced any method productivity improvement program to improve productivity within (put X mark) (consider the 3 years)

Table 0-1 method of productivity improvement program

<i>No.</i>	<i>Productivity types</i>	<i>Yes</i>	<i>No</i>	<i>If your answer is "Yes", please specify it</i>
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)

3. Questionnaires for Processes planning and control Section

1. What is your position in the company?

Operators [] Supervisors [] Quality control []

Other:

Please specify it.....

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

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

3. What is your sex: male female

4. What is your Educational background?

PHD MSC/MA BSC/BA TVET Level 1-4

5. What method is applicable to handle job order and to sequence them? It is manual (paper based) or automated?

6. What type of work ordering method is used between sections and what are its main challenges?

7. Is there any work prioritization method in your company? If so what is its prone and cones of this method in scheduling?

8. How to allocate specific job to specific machine?

9. 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. [Please, put X mark on the number that applies]

Table 0-2 Problems related to low productivity

<i>No.</i>	<i>Problems related to low productivity</i>	<i>3</i>	<i>2</i>	<i>1</i>
1	Improper job allocation on machine			
2	Machine failure			
3	Absenteeism of operators/workers			
4	Raw material shortage			
5	Power shortage			
7	Financial problems			
9	Process problems			
10	Worker's skill problems			
11	PPC problems			
12	Market problems			
13	Quality problems			
	Others please specify -----			

4. Questionnaires for Supervisors and Machine Operators

1. What is your position in the 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 your sex: male female

4. What is your Educational background?

PHD MSC/MA BSC/BA TVET Level 1-4

6. How do you rate the effect of the following factors on the Productivity of your company?

Rate the impact of the following major reasons not to work at high Productivity in Company [1 = medium; 2 = high; 3 = Critical][Please, put X mark on the number that applies]

Table 0-3 Reasons to do not work at high Productivity

<i>No</i>	<i>Reasons to do not work at high Productivity</i>	<i>1</i>	<i>2</i>	<i>3</i>
1	Raw material related problems			
2	Machineries and equipment related			
3	Schedule related problems			
4	Planning and management problems			
5	Process related problems			
6	Skill and labor related problems			
7	Technology and innovation related			
8	Capital related problems			
9	Others please specify -----			

Appendix III

Table 0-4 Available job and their assignments

No	Job names	Assigned symbol	Quantity (pcs)
1	Rail track to gantry cane for 160 ton (J- bolt)	J1	800
2	L.T Insulator hook N-95	J2	50
3	L.T Insulator hook N-96	J3	70
4	L.T Insulator hook N-80	J4	3000
5	H.T Insulator hook 17/5 15kV	J5	500
6	Compact substation enclosure	J6	360
7	Feed table chain assembly 4	J7	3200
8	Chain link 1	J8	400
9	Rack pinion driver segment	J9	50
10	15kV heavy angle cross arm	J10	41
11	Crasher hammer	J11	18
12	Scraper plate	J12	10
13	Mill roller	J13	15
14	Big collar	J14	5
15	Mean shaft 4 th gear B	J15	12
16	Mill #3 trash plate	J16	54
17	Helical gear	J17	23
18	Rotary dryer swing roller	J18	37
19	Spur gear	J19	20
20	Plate with RHS	J20	25

Table 0-5 Machines in the shop with their assignation symbol, job and power rating

No	Machine name	Assigned symbol	Rating (kW)	Assigned job in No.
1	Internal gear cutting	M1	330	4
2	Bevel gear gener.	M2	300	7
3	Univ.G. Hob. M/C	M3	200	2
4	Horz. hobbing m/c	M4	150	4
5	Shaper Machine	M5	150	4
6	Univ.hob.for Spur gears	M6	175	5
7	Slotting.M/C	M7	200	4
8	GH	M8	100	3
9	Univ. hob. for spur gears	M9	200	3
10	Grinder Machine	M10	350	2
11	Center Lathe (medium)	M11	400	4
12	Center Lathe (Big)	M12	650	5
13	Vertical Lathe	M13	350	1
14	Radial Drilling	M14	250	4
15	V.W.F.Boring	M15	150	5
16	Center Lathe	M16	300	4
17	Vertical Milling	M17	150	3
18	Horizontal Milling	M18	150	5
19	Com.Univ Milling	M19	250	3
20	Vertical Milling	M20	200	3

The parts (jobs) per machine matrix are shown in table for 20 jobs to be processed. The first column of the table shows the jobs (parts) and the first row shows the required machines for processing the jobs. The value one (1) represents the J^{th} job is to be processed on the respective M^{th} machine. For instance, the job J1 uses the machines M1, M8, M12 and M19 to be processed in the shop in the given time period.

Table 0-6 Parts (jobs) per machine matrix

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