Investigation of Overall Effect of Production Bottlenecks on Productivity of Soft Drink Industry: A Case Study in East Africa Bottle Share Company (EABSC)

Helen Tadesse Bekele

A Thesis submitted to
Department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering

Presented in partial fulfillment of the Requirement for the Degree of Master's in Manufacturing Engineering

Office of Graduate Studies
Adama Science and Technology University

June, 2022
Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled "**Investigation of overall effect of production bottlenecks on productivity of soft drink industry: A case study in East Africa Bottle Share Company (EABSC)**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of material that are used for this thesis have been duly acknowledged through citations.

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Recommendation of Advisor

I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Investigation of overall effect of production bottlenecks on productivity of soft drink industry: A case study in East Africa Bottle Share Company (EABSC)**" prepared under my guidance by **Helen Tadesse Bekele** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering**.** Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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Advisor approval for M.Sc. Thesis

I, the major advisor of this thesis entitled "**Investigation of overall effect of production bottlenecks on productivity of soft drink industry: A case study in East Africa Bottle Share Company (EABSC)**" and developed by **Helen Tadesse Bekele**, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

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ABBREVIATION

ASTs – Application solution templates

BPM – Bottle per minute

CCBA – Coca Cola Beverages Africa

CIP – Cleaning in place

DIMAC – Define, Identify, Measure, Action, Control

DES – Discrete-event simulation

DTA – Downtime analysis

EABSC – East African Bottling Share Company

EF – Equipment failure

FMG – Food and manufacturing groups

HMI – Human interface

KO – Coca Cola International

KPI – Key performance indicator

ME – Machine efficiency

OEE – Overall equipment efficiency

PET – Polyethylene terephthalate

RGB – Returnable glass bottle

SD – Shut down

SU – Startup

TOC – Theory of constraints

USLE – Unconstrained system line efficiency

ABSTRACT

Nowadays the struggle to survive in global market competition has become threatening. Even though the productivity of a manufacturing industry plays a significant role in enabling the industry to survive in this competition. It can be negatively impacted by the presence of bottlenecks in a production system. Therefore, the main purpose of this project work is to investigate overall effect of production bottlenecks on productivity and determine proper bottleneck identification and controlling approach for soft drink industries to improve production performance and productivity by conducting a case study in East Africa Bottling Share Company. Related works have been reviewed on related subjects like production line, production bottlenecks, line performance, line efficiency, and data analysis methods. Theory of constraint was taken as the main methodology to investigate and eliminate production bottlenecks. Line performance analysis has been done using overall equipment efficiency to understand the current operational condition of the line and then by implementing different bottleneck identification approaches the production bottleneck station has been identified. For the identified production bottleneck, root causes were investigated using the five why analysis method, as a result, focus improvement areas were identified. Then remedy action, countermeasures, and action plans have been suggested as a line improvement strategy. A line simulation model has also been developed by using Arena simulation software to evaluate the line improvement. Finally, the improved line simulation model was developed where productivity can be enhanced by 15% and production loss can be reduced by 4.7% after implementing the proposed line improvement strategy. Therefore, it has been concluded that the identification and elimination of production bottlenecks have a great positive impact on productivity improvement and loss reduction which ultimately ensures a company's profitability.

Keywords: *Bottleneck identification, Productivity, Production performance, Theory of constraint, Soft drink industry*

CHAPTER – 1

INTRODUCTION

1.1 Background of the study

Nowadays the struggle to survive in global market competition has become threatening. To be able to compete in this increasingly tough market, it is vital to determine the primary objective of any business. It is clear that manufacturing companies are established to produce and sell products, but these are nothing but means to help a company meet its ultimate goal which is making money. Productivity is money in business, because a company's profitability depends on its ability to perform operations with a high ratio of output to input. And Productivity, resource efficiency, and flexibility, and production performance will continue to rise in line with continuous productivity improvement. Better production performance can be archived by continuous improvement of a production process. (P.R. Subodh Patil, 2019)

Manufacturing superiority can only be achieved through productivity improvement since it is essential approach to achieving better operational and financial performance. It also guarantees sustainable growth to an organization by preparing it for flexible adaptation to market change and customer requirements. (Xuan Su et.al., 2022)

As continuous improvement has a great significance in boosting production efficiency, it can be obtained by providing a control framework. This improvement can be in the form of optimizing the system, reducing variation, maximizing throughput, reducing cost, improving waste elimination, correcting ineffective processing, simplifying the process, or responsiveness, and reducing set-up time. Therefore, the required steps must be taken to eliminate unproductive activities and meet the main objective as efficiently as possible. If there is no improvement opportunity in the productivity of any individual machine, the overall system throughput of a production line is said unimprovable, which means the production line is said to be well designed or optimally balanced. But such a thing as an optimally balanced production line is ideal because many constraints and obstacles hinder a production process to meet its optimum production performance. These constraints are called bottlenecks, the actual point of a bottle which limits the amount of water flowing in and out. Production bottlenecks are uninventable, however, they are a key ingredient to enhancing productivity and profitability of the entire production system by creating an opportunity to build continuous improvement of production. (Lin Li et al., 2009)

Bottlenecks are the constraint that reduces the capacity of the production system and limits its success. There are many causes of constraints in a production process it can be raw materials, machines, people, process, business policy, etc. Many scholars suggest constraints to be seen from the whole production system perspective like a market constraint, capacity constraint, political constraint, raw material constraint, process constraint, logistics constraint, behavioral constraint, and administrative constraint. But among all these constraints in production flow and machine capacity have a significant effect on production performance. (Nataša Tošanovi´c and Nedeljko Štefani´c, 2022)

To ensure continuous improvement of a production process it is necessary to continuously identify, manage and control bottlenecks in a production system. This research aims to find suitable approaches to identify, manage, and control production bottlenecks in the soft drinks industry and beverage industries as a whole, since a soft drink manufacturing company was chosen as a case study to conduct this research. Line OEE analysis and simulation study has been conducted for investigation of the existing production system to identify production bottleneck, analyzing line efficiency to suggest better bottleneck managing approach for better productivity improvement. The model built has given a deep understanding of the system and to find the best improvement strategies to be implemented on the actual system to increase productivity and the performance of the production line.

1.2 Background of the company

EABSC is a share company and Coca-Cola franchise bottler in Ethiopia bottling Coca-Cola, Sprite, Schweppes, Novida, and Fanta family soft drinks with the permission of Coca-Cola International (KO). Coca-Cola was first bottled in Ethiopia by the Ethiopian Bottle Share Company in Addis Ababa in 1959 and later in Dire Dawa in 1965. On May 19, 1999, South Africa bottling Share Company and Ethiopian Bottle Share Company signed a joint venture agreement and become East Africa Bottling Share Company (EABS.C) as a member of Coca-Cola Sabcon, lately, EABSC become a member of Coca-Cola Beverage Africa (CCBA). Currently, EABSC has four soft drink production plants in Ethiopia located at Addis Ababa, Dire Dawa, Bahir Dar, and Sebeta with an aggressive expansion plan throughout the country. The products of this company are carbonated sweet soft drinks in glass and plastic bottles of different flavors. There are also sugar-free products of all flavors. This research focused on the production bottleneck of one of EABSC production lines in the Addis Ababa plant. The production plant has four production lines, three RGB (returnable glass bottles) and one PET (polyethylene terephthalate) soft drink bottling line. Both types of bottling processes have their production process. This explains the high variety of output products which complicate the production process.

1.3 Research motivation

Productivity, production performance, and production capacity are terms used to explain the profile of any manufacturing company. Thus, one of the elements of a company's profile related to the mentioned factors is profitability. The survival and sustainable growth of any company depend on the profit they make. And as discussed in the introduction section any situation or constraint that holds a company from earning its planned profit is poor production performance which is mainly caused by a production bottleneck. However, bottlenecks are unavoidable, either expected or unexpected situations occur in a production process dragging it from performing at its optimum production capacity. Therefore, bottlenecks should be managed and controlled appropriately for better performance and a good profile of the company.

Since different conclusions can be drawn from different bottleneck identification and detection approach, following proper strategies in bottleneck identification and management as well as the implementation of suggested improving methods are critical. In addition, when one bottleneck is solved it leads to the rise of another one, therefore a continuous improvement towards diminishing the occurrence of bottleneck is necessary. Therefore, the motivation for this research paper is mainly to solve such problems of manufacturing firms by suggesting suitable bottleneck identification, detection, and mitigation approach for continuous improvement of their production lines, especially for soft drink manufacturing companies.

1.4 Problem statement

Nowadays production enterprises are facing common problems of insufficient and limited production capability. Operating at minimum production capacity costs not only the company's profit, but a manufacturing company may also lose fortunes just because of the smallest bottleneck which was not managed properly and on time. Manufacturing and selling products are not the primary objective of any company, rather making money and increasing the profit earned from a unit product is the real objective. That is why operational cost is a burning issue in the manufacturing industry.

The production system of bottling plants is characterized by mass production, complex, automated - high-speed processes, and capital intensive with continuous flow, which involves a huge investment in machines and raw materials. But these investments alone cannot ensure the financial growth of the company. Optimal use of the machines and resources is necessary and it could be achieved only by avoiding bottlenecks through the permanent application of productivity tools. And out of all kinds of bottlenecks, production bottlenecks play a major role in depriving the production capacity of a production line. Therefore, a required step must be taken to operate as efficiently as possible and eliminate unproductive activities in production lines. And by changing factors that constrain the production system a better performance and volume of throughput can be achieved.

The productivity improvement of a manufacturing industry not only benefits the owners of the business but also all the stakeholders including the customers, employees, society, and also the country. The same is true for the failure in a business performance too. The soft drink industries are one of the production industries facing such problems. We can take EABSC, Addis Ababa plant as a practical example, unconstrained system line efficiency(USLE) of the company's production lines is constantly dropping.

Table 1.1 Machine efficiency (ME) of production lines in EABSC (2016 - 2020)

Years / **Line**	2020	2019	2018	2017	2016	Target
1 (RGB)	93.54 %	95.93 %	88.83 %	88.66 %	80.61 %	95 %
3 (RGB)	86.68 %	93.91 %	88.53 %	80.9 %	80.73 %	95 %
4 (PET)	76.24 %	90.31 %	82.4 %	79.44 %	79.65 %	95 %
5 (RGB)	88.81 %	92.99 %	91.68 %	88.49 %	87.08 %	95 %

Table 1.2 USLE of production lines in EABSC (2016 - 2020)

Years / **Line**	2020	2019	2018	2017	2016	Target
1 (RGB)	60.57 %	65.93 %	63.81 %	59.28 %	61.05 %	70 %
3 (RGB)	57.79 %	68.25 %	60.86 %	53.16 %	62.82 %	70 %
4 (PET)	52.77 %	52.77 %	52.77 %	52.77 %	52.77 %	70 %
5 (RGB)	54.15 %	63.57 %	58.26 %	56.05 %	67.99 %	70 %

As shown under Table 1.1 and 1.2, ME and USLE indicating the production performance of the lines proves exitance of uncontrolled bottlenecks. Especially RGB Line five of the Addis Ababa plant operates with two filler machines and yet it is operating with lower efficiency than other lines. This line (RGB Line 5) is not achieving the targeted production plan because it is performing below its production capacity and target performance.This is due to the existence of production bottlenecks and their poor management which has a negative effect on the productivity and financial performance of the organization.

Identifying and mitigating bottleneck is not an easy task; most of the time, determining the true bottleneck of a production system is time-consuming and confusing. Many scholars have studied different approach to identifying the real bottlenecks of a production system but successful implementation of those approaches have been tough. And different conclusions can also be drawn from the application of various approaches. Therefore, because of improper handling of bottlenecks production capacity, production performance and productivity will be negatively impacted which disturbs the financial performance of the company.

Therefore, studying different approaches toward identification and management of production bottlenecks that can be implemented on shopfloors is necessary to improve the efficiency of production lines, and this improvement leads to lower production costs per unit, lower personnel costs, and/or lower equipment and material costs.

1.5 Research question

Based on the above-stated statement of the problem this research will be conducted to answer and put findings for the following research questions.

1- What are the bottlenecks of RGB lines in soft drink industries?
2- Which bottleneck contributes to the significant change in production performance?
3- What is the suitable bottleneck identification approach and why?
4- What bottleneck detection and analysis method should be implemented to eliminate the root cause of production bottlenecks?

1.6 Objective

1.6.1 General objective

The general objective of this research is to investigate overall effect of production bottlenecks of on productivity of soft drink industries by conducting a case study in East Africa Bottling Share Company.

1.6.2 Specific objective

- ✓ Study the effect of the bottlenecks on the overall production process and production performance.
- ✓ Determining a suitable bottlenecks identification approach for RGB bottling production lines.
- ✓ Identify potential production bottlenecks of the RGB production line in EABSC.

- ✓ Investigate and develop a continuous improvement approach towards eliminating production bottlenecks.
- ✓ Build a simulation model to study the improvement of the production line after eliminating the production bottlenecks.

1.7 Significance of the study

This research project aims to identify production bottlenecks and eliminate them to have a significant impact on the efficiency and effectiveness of the production system of the company. Determination of production bottlenecks indicates limitations of the system and gives guidelines and direction on how to improve the production system.

Including the Addis Ababa plant there are around six RGB lines in Ethiopia under EABSC, and detecting and eliminating the bottleneck of one of the production lines will be a bigger milestone for further continuous improvements of other lines. This has a great impact on the overall productivity and profitability of the company, and it also highly affects the market share of the company. The findings of this research are expected to be used as input toward the improvement of production capacity, performance, and productivity of EABSC and other beverage industries. It can also be used as a foundation for further research in related areas.

1.8 Scope and limitation

This research mainly focuses on identifying potential production bottlenecks and studying the effect of the bottleneck on the production lines, production process, production performance, and productivity. In this research, a continuous improvement approach has been investigated and developed toward eliminating production bottlenecks in the soft drinks industry. This research takes one RGB line of East Africa Bottling Share Company as a case study on the investigation of production bottlenecks in the soft drinks industry. In this research only a one and quarter year data of a selected case study line have been analyzed since increasing the amount of data will make the study complex and also difficult. Only one line of one plant has been considered (RGB line five, Addis Ababa plant) because it can be a huge milestone for further improvement of other lines. Besides, there was time and budget limitation to include all the lines. Therefore, the researcher took the one which represents the most.

1.9 Organization of thesis

This thesis work incorporates six main chapters including an introduction, literature review, research methodology, data collection and analysis, line improvement and simulation analysis, and finally conclusion and recommendation. The first chapter is an introduction and it briefly explains the objectives, problem statement, significance of the study, etc., and the second chapter, a literature review, discusses various kinds of literature on related subjects and previous works. The third chapter proposes appropriate research methodology and under the fourth chapter, data collection, and analysis, collected data have been presented and line performance analysis, bottleneck analysis as well as root cause analysis has been conducted and discussed. The fifth chapter is line improvement and simulation analysis, where the line improvement strategy has been investigated and simulation model development and analysis are conducted. In the last chapter, a conclusion and recommendation have been made, and what should be done to ensure continuous improvement of product performance and productivity has been presented.

****

CHAPTER – 2

LITERATURE REVIEW

2.1 Introduction

Previour works have been reviewed on related subjects to capture the basic knowledge and information. In this section core concepts of the subject under study has been discussed.

2.2 Production system and production line

A production process is the transformation of raw materials or components into finished products. In a factory, raw material components are processed to make finished or semi-finished goods by passing through a set of sequential operations visiting many work stations, and the arrangement of these mechanical and manual operations is called a production line. And production system is a part of an organization, where a production product of an organization takes place. In the production line resources flowing within a defined system are combined and transformed in a controlled manner to add value to the policies communicated by management (Teklay Araya, 2018).

There are few characteristics for the production line are; (Kleindorfer et al., 2005)

- ✓ Machines are spatially positioned to form lines;
- ✓ Production might be partially or fully automated;
- ✓ Primary control system integrates and combines work on the production line;
- ✓ Stand-alone machines are integrated for handling and transporting work over a short distance;
- ✓ Uses of protective safety components on the whole line;
- ✓ Use of measuring and controlling devices on workstations, to check the materials, semi-finished products, and finished products.

Depending on the number of parts to be produced, the production line is categorized into four basic types; (Bhasin, 2018)

1- Unit or job production – production line producing one single unit of product.

2- Batch production – production line producing a large variety of products having variable demands.

3- Mass production or flow production – a production line where there is multiple work station installed and the assembly line goes through all the work station turn by turn.

4- Continuous production or process production – is the same as mass production lines except majority of work is done by machines rather than humans. The work is continuous, i.e., once the production starts it cannot be stopped otherwise it will cause a huge loss.

And depending on the nature of the complexity of manufacturing parts, the sensitivity of the product, cost, and production volume. The production or manufacturing lines can be also categorized into three types; (Teklay Araya, 2018)

1- Automated production lines – process line which is designed to operate with fewer workers. In such a production line machines are capable of running for a longer duration with a constant rate of production. When the process line is fully automated it can cut costs for long-run production plans, fulfill mass production output, and is ideally suited to serve large.
2- Semi-automated production lines – process lines where machines are installed to assist workers.
3- manual production lines – labor-intensive production lines, with low production rates and higher long-run production.

2.3 Productivity

The efficiency of transformation of raw materials, both human and material, into useful services and goods is indicated by productivity (S.Singh and S.Singhal, 2016). Productivity is a broad term whose definition is different for different people. (S.Singh and S.Singhal, 2016) defines productivity as a measure of the efficiency with which a company or an enterprise converts its available resources (inputs) into finished goods or services. But it can be also defined as the effectiveness of productive effort, especially in industry, as a measurement of how many outputs are produced from a given amount of input. In general, productivity is a term used to explain both efficiency and effectiveness of processes conducted in an economic business.

Measuring the productivity of a production line allows the managers to have a clear view of the current situation of their company. Productivity is an important input for operational management, since it helps the growth of the organization and enables them to survive in a competitive world.

There are three different views of the productivity concept;

- ✓ Technological concept - describes the relationship between ratios of outputs to the inputs used in its production.
- ✓ Engineering concept - the relationship between the actual and the potential output of a process.

- ✓ Economist concept - the efficiency of resource allocation.

Manufacturing superiority can only be achieved through productivity improvement. And this improvement can be in the form of optimizing the system, reducing variation, maximizing throughput, reducing cost, improving quality, eliminating waste, correcting ineffective processing, simplifying the process, or responsiveness, and reducing set-up time. This continuous improvement has a great significance in boosting production efficiency and it can be obtained by providing a control framework. It also guarantees sustainable growth to an organization by preparing it for flexible adaptation to market change and customer requirements of a production. If any improvement in the productivity of any individual machine cannot improve the overall system throughput a production line is said unimprovable, which means the production line is said to be well designed or optimally balanced (Lin Li et al., 2009).

2.4 Production performance

Most manufacturing firms focus on improving the production performance in terms of productivity output to survive in the competitive market because a high productivity performance has a direct relationship with the equipment efficiency and process control (Amir Aziz, 2015). Production performance is a capacity of a system to meet its productivity goal or its demand. It is mainly evaluated by production throughput. Better production performance can be archived by continuous improvement of a production process.

Throughput, circle time, and average delay are factors affecting the production performance of any production process and the variability of these factors is a key parameter for evaluating product performance. The performance of a production line plays a vital role to control the production line and make a tactical decisions. Therefore, production line manager uses different tools and indicators to evaluate the production performance of their line. This production performance measurement systems measure the inputs and outputs of an operation to determine how good or bad the operation is using them. Continuous improvements in manufacturing systems are necessary for a competitive industry.

Manufacturing firms should pay great attention and track their key performance indicators (KPI) to measure their operational process and create a sustainable manufacturing process. Mostly used KPIs for manufacturing industries are; (Lindsey Andrew, 2019).

1- OEE (Overall Equipment Effectiveness) - is a reliable quantitative metric used in most manufacturing systems for controlling and monitoring the productivity of production equipment. This performance indicator consists of three important components which are availability, productivity, and quality to measure how well (or ill) the line is performing.

2- Total cycle time – measures the time it takes for an order to start and finish the entire production process; it represents the total time it takes to convert raw material into the final product from the starting point of a line to its end. This KPI measures machine efficiency and indicates real-time machine performance.

3- Throughput (total production volume) – is an important parameter to evaluate production performance since it directly indicates the presence of issues that constrain production. It is defined as the time rate of units produced. Throughput can be improved by eliminating downtime losses, calibrating machines, improving machine maintenance strategy, solving the raw material quality issue, and reducing the number of steps in a cycle to reduce shortstops.

4- Capacity utilization – is a ratio of actual and potential output of a production line, which indicates the available capacity and slack of the production system. This KPI is great to understand the line's ability to scale production or institute more flexible job scheduling during production.

5- On-time delivery – measures the percentage of orders delivered on time.

6- Yield – is the ratio of good parts produced to the total unit produced. It is the best KPI to have a clear understanding of production efficiency and profitability since it is a measure of the quality and performance of a production line.

7- Availability – is the basic manufacturing lines performance indicator that measures the uptime and downtime of machines.

2.5 Line efficiency

Production line efficiency is a measurement of the production of good products at the lowest cost possible. Production line efficiency can be calculated by dividing the actual output rate by a standard output rate of the line, where output is the amount of work that can be done per unit of time.

The interrelationship between productivity, profitability, performance, efficiency, and effectiveness has been plotted in a schematic view in a TRIPLE-P model as shown in Figur 2.1. This model captures the main difference between those terms.

The core of the Triple-P model is productivity, which clearly explains the operational definition of productivity as the ratio of output and input of a production process. Then comes profitability which considers the financial status of the production process. And performance is the umbrella term for manufacturing superiority which reflects productivity, profitability as well as factors such as quality, speed, delivery, and flexibility. Effectiveness and efficiency are production-building parameters where effectiveness focuses on the output of the manufacturing transformation process, while efficiency represents how well the input of the transformation process is utilized (Teklay Araya, 2018).

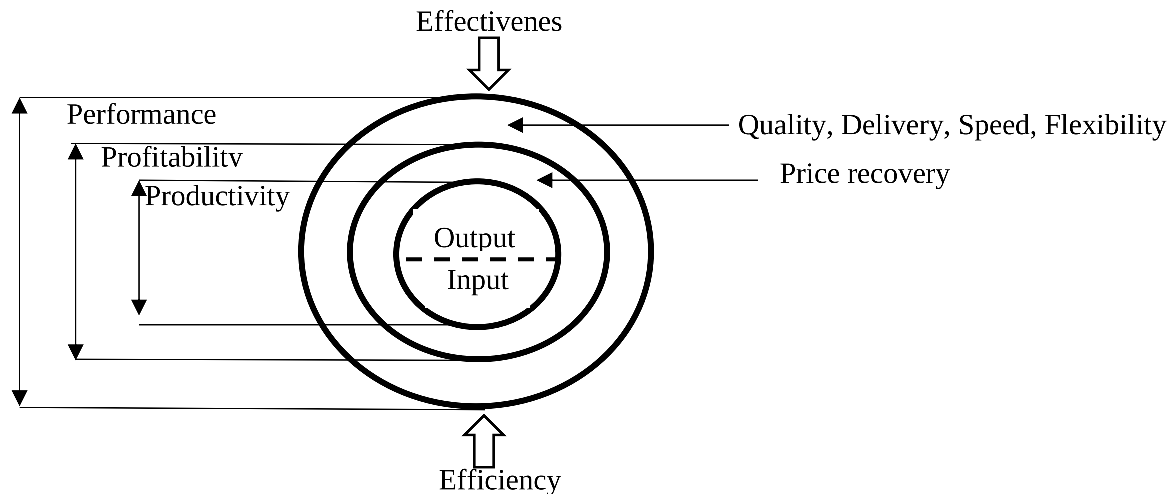

Figure 2..1 Schematic view of the Triple-P model, *(Teklay Araya, 2018)*

2.6 Production bottleneck

Bottlenecks are constraints the resembles actual point of a bottle which limits the amount of water flowing in and out as shown in Figure 2.2.

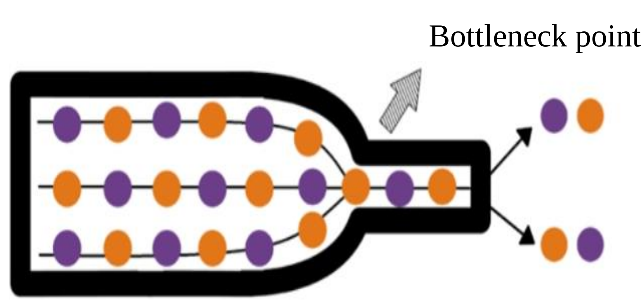

Figure 2.2 Representation of bottleneck *(wikipedia, 2022)*

The bottleneck has been defined by many scholars, and a survey of many research and literature have found various definitions to explain bottlenecks in manufacturing. Some of these definitions are the following:

- ✓ A machine or a process is defined as a throughput bottleneck if its performance is the most sensitive to the overall performance of a manufacturing system (Lin Li et al., 2009).
- ✓ A bottleneck is a constraint that restricts the overall result of the whole process, in manufacturing it is the factor that negatively affects the throughput of a production (bottleneck in production, 2021).
- ✓ Bottlenecks in manufacturing are any situations on a factory floor that diminishes productivity (Tina Jacobs, 2020).
- ✓ A bottleneck is an element of resources with the lowest production capacity marking the capacity of the entire production system (R.Domanski and J.Kolinsaki, 2017).
- ✓ A bottleneck is defined as any resource whose capacity is less than the demand placed upon it (S.R.Lawrence and A. H.Buss, 1995).
- ✓ From the system point of view, bottlenecks are the congestion points of the system, which slow down the whole operation chain (Yong-C.W. et al., 2018).
- ✓ According to TOC, bottlenecks are the weakest link in the chain of the production system which affects the whole production process (Z.T Şimşit et al., 2014).
- ✓ A bottleneck is a stage in a production system that has the largest effect on slowing down or stopping the entire system (Chirstopher Roser et al., 2002).

Production bottleneck marks the capacity of the entire production system which is a crucial element of manufacturing companies' competitive advantage and also has an influence on the company's costs and ecological issues. (S.O. Ongbali et al., 2021)

Production bottlenecks are uninventable, however, they are a key ingredient to enhancing productivity and profitability of the entire production system by creating an opportunity to build continuous improvement of production.

2.6.1 Types of bottlenecks

As it has been discussed bottlenecks are the constraint that reduces the capacity of the production system and limits its success. There are many causes of constraints in a production process it can be raw materials, machines, people, process, Business policy, etc. Many scholars see constraints from the whole production system perspective market constraint, capacity constraint, political constraint, raw material constraint, process constraint, logistics constraint, behavioral constraint, and administrative constraint. But among all these constraints in the production flow, machine capacity has a significant effect on production performance (Prof. W.Urban and P.Rogowska, 2018).

Depending on the location of the occurrence of manufacturing bottleneck in a whole production process, they can be classified into three:

- ✓ Production bottlenecks – are bottlenecks observed in a production line due to build-up accumulation of products before and after certain machines, machines operating at full capacity, and an increase in wait time. Having a full understanding and deep insight into every individual process may help the fast identification of the bottleneck station. Tracking the downtime and waiting time of the machine is an ideal bottleneck identification method.
- ✓ Supply chain bottlenecks – these bottlenecks have mainly resulted from the material, equipment, and transportation constraints. Poor inventory management, inadequate production forecast, incomplete financing, lack of spare parts, and changing the mix of products are mainly observed reasons for such bottleneck. And the remedy action that can be taken to solve these bottlenecks are eliminating unexpected disruptions by creating and sticking to a comprehensive supply chain plan and regular maintenance schedules to keep equipment operational.
- ✓ People bottleneck – these kinds of bottlenecks are caused by poorly trained, low morale, people, lack of proper communication between workers, lack of appropriate working standards, and managerial inefficiency. Creating a proper work environment and facilitating learning platforms for the employee will reduce the occurrence of people bottlenecks and their effect on the overall production process.

Depending on their duration in the production system bottlenecks can be classified into two major categories; short-term and long-term bottlenecks. Short-term bottlenecks are those which are caused by temporary production operation interrupting issues while long-term bottlenecks are caused by frequent problems having a significant impact on the whole production process. Many works of literature studied that managing short-term bottlenecks yield a higher improvement in performance than that of long-term bottlenecks.

Depending on their nature of occurrence, production bottlenecks can be categorized into three;

- ✓ Simple bottleneck - when there is just one bottleneck during the time period considered.

- ✓ Multiple bottlenecks – when there are two or more bottlenecks during the considered time period. Multiple bottlenecks are consistent and they do not change.
- ✓ Shifting bottleneck - the shifting bottleneck distinguishes between a momentary bottleneck, describing the bottleneck at any given time, and an average bottleneck describing rather the bottleneck behavior over a selected period of time.

2.6.2 Production bottleneck identification methods

The very first crucial step towards managing constraints is identifying a bottleneck of the system which involves localizing the system's limitations. But it can sometimes be quite challenging to detect the bottleneck(s) because of the nature of the analyzed production system, the system may change over time or due to random events, and subsequently, the bottleneck may shift from one machine to another machine.

Identification of bottlenecks is the basis for continuous improvement of the production system and production capacity. The concept of bottleneck identification aims to meet managerial needs for clear guidance regarding the practical recognition of a bottleneck location in a manufacturing system. Many scholars have suggested different methods for bottleneck identification; some of the bottleneck identification approaches are discussed below.

1- The process Time method is one way of bottleneck identification method using a measurement of the material flow time in processes. This approach indicates the maximum efficiency of a process in the tested conditions (P.Rogowska and W.Urban, 2020).

2- The average Active Period method measures the time when a machine is active continuously to indicate the production constraints. The main activities of a machine are production, waiting for another machine (starved or blocked), repair, or tool replacement. Therefore, active time of a machine means anytime the machine is working, in repair, changing tools, or is being serviced. Processes with the longest average active time are the so-called bottlenecks in this approach and temporary bottlenecks are processed with the longest instantaneous active periods. These methods use extensive process data (Madeleine Thour, 2014) and it is ideal to detect momentary bottleneck.

3- The Longest Waiting Time method focuses on measuring the machine's utilization in the production process. The highly utilized machine will be considered to be the bottleneck. In this method, accurate results require longer observations and measurements. This method is limited to stationary production processes (P.Rogowska and W.Urban, 2020).

But if production lines have limited or no buffers/waiting times it makes it impossible to detect a bottleneck using this method. This method is also similar to that of Longest Queue method analyses which measure the length of a queue or the waiting time of machines in a production process. A machine with the longest queue or the longest waiting time is considered to be the bottleneck. This method can detect instantaneous bottlenecks.

4- The Utilization method is also known as an effective process time method. It is the best approach to mass production where the number of parts is constant at each station. A bottleneck is detected by calculating the utilization of each resource. A station with the highest degree of utilization is considered to be the bottleneck of the production system (P.Rogowska and W.Urban, 2020).

5- The Bottleneck Walk method – according to this process bottleneck detection is done mainly by observation of the production processes and the level of inter-process resources. Therefore, statistics, measurements, and calculations are not required.

6- The Flow Constraint Analysis method – this method is different from the rest because it evaluates customer demand. The identification of production bottlenecks in this method is done by comparing the takt time and the resource cycle time in a production system. If the machine cycle time of a process is longer than the time required to complete an order, then this machine or station with a higher cycle time is the bottleneck of the production system.

7- Shifting Bottleneck detection method – this method detects and monitors both shifting momentary bottleneck as well as the average bottleneck over a particular period of time. The analysis of this method is based on the active time of a machine without any interruption since the momentary bottleneck is the machine with the longest uninterrupted active period. And after the momentary bottleneck is determined the average bottleneck will be analyzed for a particular period of time by calculating the percentage of time a machine is a sole bottleneck and the percentage of the machine which has part of a shifting bottleneck (P.Rogowska and W.Urban, 2020). And the larger the sum of this percentage, the larger the effect the machine has on the overall system.

8- The Corrected C/T method this method integrates both cycle time and the degree of utilization of each process in the production stream. The actual time required to produce a product can be calculated from C/T and the process utilization, of their product. And corrected C/T indicates the bottleneck machine, process, or station by calculating its efficiency.

9- The SCORE method used simulation-based multi-objective optimization to find the most beneficial improvement for the production improvement. This method finds the most beneficial throughput but even if this method is ideal to detect several bottlenecks and sort them according to their size, it does not assist in the improvement of every constraint. Improvement from the fewest numbers of system changes through setting improved values for parameters such as mean time to repair, availability, and cycle time: and also, by maximizing the throughput while minimizing the number of changes.

From the bottleneck identification methods that were mentioned earlier, some of them seem remarkably similar for instance the longest waiting time, average waiting time, and utilization, but they need different data collection and analysis and also their application area is also unlike. Some methods require long-term data collection and expensive data analysis tools; extensive process data that are not always available; may only detect temporary bottlenecks, or may only apply to certain kinds of production systems (Madeleine Thour, 2014).

The summary of bottleneck identification methods is shown in Table 2.1 with their detailed data requirement and application.

Table 2.1 Bottleneck identification methods in detail *(Prof. Wieslaw Urban and Patrycja Rogowska, 2018)*

Method	**Bottleneck type**	**Data requirement**	**Approach**	**Result**	**Application area**
Process time Method	Historical	Process times	Material flow time in-process measurement	Maximum capacity of the flow line	Serial production lines with constant cycle times
Utilization method	Historical	Net production time or Active and total time	Rate of the utilization of machine measurement	The utilization per machine. The machine with the largest utilization is considered to be the bottleneck	Serial production lines

Average waiting time method	Historical	Waiting times	The waiting time before the process measurement	The machines with the longest average waiting times and thus a ranking of the most likely bottleneck	Systems with infinite buffers
Arrow method	Historical	Blockage and starvation probabilities	Observation of blockage and waiting process	Indicates most likely bottleneck, which has blockage and starvation	Serial production lines
Turning point method	Historical	Blockage and starvation probabilities	Observation of blockage and waiting process	Indicates most likely bottleneck, which has blockage and starvation	Serial production lines and complex serial-manufacturing systems
Average active period or active period method	Momentary/ Real-time and Historical	Machine states (active/ not active)	Measurement of the machine activity continuously	Average uninterrupted active time and with that a ranking of the most likely bottleneck	Serial production lines and complex manufacturing systems
Bottleneck walk method	Bottleneck(s)	Momentary/ Real-time	Observation of processes and the level of inter-process resources	Observed inventory levels and process status	Systems with visible queueing
C/T corrected method	Historical		Cycle time and degree of utilization of	System parameters	Complex manufacturing systems

			each process measurement		
Simulation -based method	Historical or Expected	Multiple performance measures	Building a validated plant simulation model	System parameters	Complex manufacturing systems

For some particular methods which use machine data, their accuracy in detecting bottlenecks may be affected by data variability. And this data variability may lead a researcher to an unreliable or incorrect bottleneck identification. Because they are caused mainly by setting machine parameters and also some other reasons like unplanned machine downtime, repairing, or changing process times.

2.6.3 Theory of constraints

Theory of Constraints (TOC) is a constraint management approach formulated by Israeli physicist Dr. Eliyahu M.Goldratt and introduced to the audience through his book "The Goal: A process of ongoing improvement" in 1984. The very basic concept of TOC is that a continuous improvement of any system can only be guaranteed by identifying, eliminating, and managing the process that limits the output of the system. According to the TOC approach, processes are seen as rings of chain which are interdependent and cannot function on their own to give the required result or output. Therefore, Goldratt defines the bottleneck in his TOC approach as the weakest link in the chain of production system which affects the whole production process (Z.T Şimşit et al., 2014). While the traditional approach to management believes in the reduction and even elimination of system constraints, TOC suggests proper management of constrain is done through the implementation of appropriate tools and methods.

The very core concept of the theory of constraints is that the entire production system capacity of a business depends on the capacity of its constraint and its main purpose is the identification and management of these constraints. It's more effective to utilize the constraint rather than focusing on individual components and processes.

Dr. Eliyahu M.Goldratt proposed a systematic constraint management method called Five Focusing Step for continuous improvement of the production system by ensuring the transformation of the weakest links of the production system into efficient and effective resources.

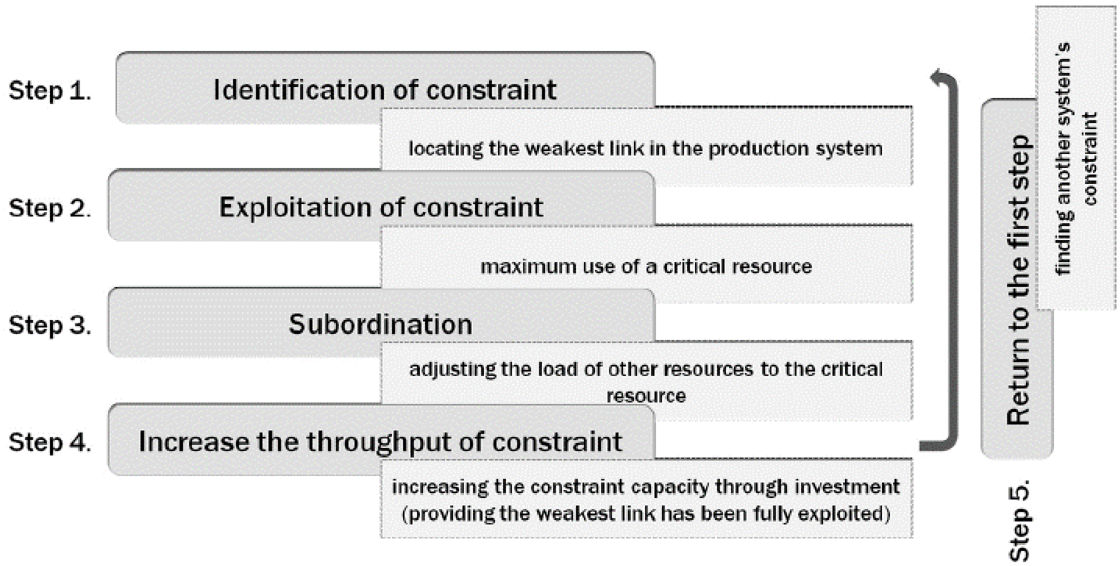

Figure 2.3 Five focusing step (P.Rogowska and W.Urban, 2020)

The five focusing steps of this method shown in figure 2.3 are explained below;

1- The identification of a constraint: Identification of constraints means prioritizing them in order of their effect on the overall operation of the business. Determining the resource that limits the capacity of a production system and finding its exact location is the first and most important step to monitor and manage the bottleneck. And it is necessary to find its root cause because according to the efficiency of the entire system will not upgrade by improving other elements which are not related to constraint (Eliyahu M.Goldratt).

2- The exploitation of the constraint: This stage focuses on the elimination of all the time waste on a resource that results in the occurrence of constraint in a production system. Several tools and methods should be used and remedial action should be taken to improve system efficiency by ensuring a continuous operation of the constraint with no additional cost (P.Rogowska and W.Urban, 2020). Constraints should be managed so that everything that it is consuming will be supplied by the non-constraints (Eliyahu M.Goldratt). This is a step where the constraint is pulled away, and exploit to its full capacity.

3- Subordination: Subordination is the adaptation of non-constraint resources with the working pace of resources that constitute a constraint. Because the resource supplied to the constraint station must match its need. Therefore, the remaining resources should not produce more than the constraint is capable of processing (P.Rogowska and W.Urban, 2020). This step is making the whole system play with the rhythm of the constraint.

4- The increase in the throughput of the constraint: Basically, this step is all about improving the efficiency of the constraint process. This stage is where the action is taken, investment is pushed to improve the functioning of the constraining factor. but full exploitation of the constraint is needed before taking this step.

5- The throughput of the constraint and the return to the first step - elimination of one constraint in one lead to the occurrence of other constraints. Therefore, it is important to constantly monitor a production line and repeat the previous steps to improve the production process by searching for and overcoming constraints.

2.7 Machine downtime

Downtime is a serious issue in manufacturing industries since it is very related to business profitability and productivity. Machine or equipment downtime is the amount of time in which the machine stays idle, not operating for assigned duty due to many reasons like unplanned and planned downtime. Planned events when the operation of a machine intentionally stopped are categorized under planned downtime, breaks, scheduled maintenance, and holidays are under this category. but unplanned events that cause loss of planned production time are called unplanned downtime, events such as mechanical problems, operator error, and lack of oversight are categorized under unplanned downtime (Hechtman T., 2011).

Machine downtime is one of the reasons behind the frequent occurrence of production disturbance leading to poor production efficiency. unplanned downtimes are measured against plant operating time, which is the total available time of the plant for operation. Therefore, plant availability can be calculated by dividing unplanned downtime by planned production time. Calculating plant availability is important to understand and investigate the cause of the downtime and production disruption and take corrective action to solve the root cause problem. Tracking and reducing downtime is the first step toward improving OEE. Tools like fish born, Five-why and DMAIC (i.e., Define, Measure, Analyze, Improve, and Control) can serve as root cause analysis methods. Line operators, maintenance artisans, and also production supervisor affects downtime on their own assigned responsibility.

Tracking machine downtime is important to monitor and secure a healthy production environment. Machine downtime information is vital in operations management systems to precisely adjust the maintenance operations and correct ongoing machinery deficiencies. Maximizing machine uptime has become good action taken towards reducing downtime in various production processes, including Food and Manufacturing Groups (FMG's) (Abafi Jeol and Oka adenkola, 2020).

2.8 Simulation modeling

Simulation modeling is the preparation of a model which imitates the process of a real-time operation or system of a particular time (wikipedia, 2022). The word simulation is derived from the Latin word “Simulate” which means to imitate or imitation, and it can be defined as a set of highly complex mathematical expressions or equations, that are analyzed by modeling to express a complex system or phenomenon, i.e., processes that contain stochastic, nonlinear or time variable (Johannes Göbel et al., 2013).

The main purpose of a simulation is to relate the fictitious creation of the history of the system and its revision to reach some conclusions about the features of real system function, which can be used to investigate solutions behind the various problem of the real system, answer a “What will happen if?” questions, to predict the effects of possible changes on system performance and to compare situations.

The availability of languages that are specific to simulation, extensive computational capabilities together with decreasing costs of any computation, and advances in simulation techniques, have caused this topic to be considered one of the most common and most widely accepted research tools in systems operations and analysis (Teklay Araya, 2018).

In manufacturing simulation can help identify problem areas in production plants and lines, to quantify system performance, and also make a cost-effective decision toward constraint management. The presence of numerous system interactions, discrete and continuous product flow and variability associated with different processing steps in many complex production plants make a simple analytical approach to bottleneck analysis difficult, which makes a plant simulation model a well-suited approach for such analysis, as it captures such complexities with relative ease (Bikram Sharda and Scott J. Bury, 2010).

Simulations of the production process yield an output of numeric measures of performance, such as throughput under a given set of conditions, but the main simulation demands its main advantage of giving insight and understanding regarding system operations.

But a correct and reliable conclusion can be drawn from simulation outputs when the models incorporate an accurate range of experimental conditions and rigorous analysis and, for stochastic simulation models, a proper statistical analysis is needed. visualization through animation and graphics is the major contributor to a model's credibility and also it assures the credibility of the model's numeric outputs.

Simulation models can be classified into many categories depending on various dimensions. Based on the time the model covers it can be classified into two; static and dynamic modeling. Static modeling is when the model concerns the system only at a fixed time while the dynamic model shows how the system evolves. The other classification is based on the induction of randomness in the model, if there is no randomness induced in the model it is called a deterministic model, but in the stochastic model, one or several sources of randomness are modeled. The simulation models can be classified ad continuous and discrete: if the change of the system state is calculated continuously it is a continuous model and if a model is discrete the system state changes at certain intervals.

For the plant simulation model, several models can be used, continuous Simulation, Monte Carlo simulation, discrete-event Simulation, the combination of discrete and continuous simulation, and spreadsheet simulation for minor simple problems.

For the plant simulation model, several models can be used, continuous Simulation, Monte Carlo simulation, discrete-event Simulation, the combination of discrete and continuous simulation, and spreadsheet simulation for minor simple problems.

Specific issues that simulation is used to address in manufacturing are:

- ✓ The need for and the quantity of equipment and personnel – number and type of machines for a particular objective, number, type, and physical arrangement of transporters, conveyors, location and size of inventory buffers, evaluation of a change in product volume or mix, evaluation of the effect of a new piece of equipment on an existing manufacturing system, evaluation of capital investments, labor-requirements planning;
- ✓ Performance evaluation – throughput analysis, time-in-system analysis, bottleneck analysis;
- ✓ Evaluation of operational procedures, production scheduling, inventory policies, control strategies, reliability analysis, and quality-control policies;
- ✓ Performance measures commonly estimated – throughput, time in the system for parts, times parts spend in queues, queue sizes, timeliness of deliveries, utilization of equipment or personnel.

Like every other production performance analysis method, analyzing the production process using simulation modeling also has advantages and limitations. Conducting simulation model-based analysis enables cost reductions by avoiding unwanted costs, reduces ramp-up time of production, creates an overall understanding of relationships, interactions, dependencies of production processes, captures time-dependent behavior, enables replicability of experiments any time and most importantly visual analysis can be done.

In addition, simulation models also allow the use of new strategies and procedures, verify production in revised systems, locate production bottlenecks and evaluate different variants of production and their effectiveness without any cost of implemented changes (Mateusz Kikolski, 2016).

But developing a simulation is not able to give an optimized result and requires:

- ✓ Special training is an art that is learned over time through experience;
- ✓ A significant amount of knowledge of statistical theory and methods is required;
- ✓ May take lots of time and be expensive.

DES is a powerful tool to analyze production performance and improvement of a production system due to the easiness of alterations in a model, and improvement in the system can easily be shown. Today, there are hundreds of commercially available DES software packages; some of the packages under a classification of simulation environment are 2-D animation, Arena, Extend Sim, Flexi Sim, Witness, and Plant Techno-Matrix. From all these software packages Arena software has been selected to conduct the study.

Performing production line analysis comprises many steps and phases; model design, development, and deployment are the three phases involved in arena simulation software. In these phases, there are around nine steps to be followed (Dereje Geleta Oljira et al., 2020).

1. Identify the issues to be addressed.
2. Plan the project.
3. Develop a conceptual model.
4. Choose a modeling approach.
5. Build and test the model.
6. Verify and validate the model.
7. Experiment with the model.
8. Analyze the results.
9. Implement the results for decision-making.

2.9 Data analysis tools

2.9.1 OEE analysis

OEE (Overall Equipment Effectiveness) is a reliable quantitative metric used in most manufacturing systems for controlling and monitoring the productivity of production equipment.

This performance indicator consists of three important components which are availability, productivity, and quality to measure how well (or ill) the line is performing. OEE can be explained as the percent of the time that equipment would need to run at its maximum speed to achieve the actual output of that machine. It is calculated by multiplying the three factors; availability, performance, and quality rate of the equipment. OEE analysis can be implemented at different levels in manufacturing industries and its value can be used as a benchmark for further measurements of production plants (Subba Shree M et al., 2022).

Since production bottlenecks are what constrain a process throughput and hinder a production from becoming effective, bottlenecks should be the first place where OEE is applied.

2.9.2 Pareto analysis

A bar graph where the bars are arranged in descending order of height, starting at the left is called a Pareto chart, it also contains lines to represent the total cumulative values. This chart is a vital tool to perform Pareto analysis. Pareto analysis is a technique that helps the identification of major problems, according to Pareto analysis, 80% of problems can be traced to 20% of the cause. The main advantage of Pareto analysis is that it helps to identify and determine the main cause or root causes of defects or problems by prioritizing them in descending order. It also provides common knowledge based on facts, instead of hunches, which results in gaining the cooperation of all problems involved. Therefore, in this study Pareto chart was chosen to identify the 20% predominant downtimes that caused around 80% of total filler downtime so that it can be easier to study the root cause of major problems causing the highest downtime loss.

2.9.3 Five why analysis

Five why the method is referred to as the ultimate root cause analysis tool which helps a production team to focus on finding the root cause of any problem. This analysis is done in a brainstorming session where team members are sharing ideas to eliminate recurring failures and problems caused in a production line. This method originated in Japan, developed by a Japanese inventor and industrialist Sakichi Toyoda. It has become an integral part of a lean philosophy and was also used in the Toyota production system for the first time and it is suggested by many scholars to be an effective tool taken as a problem elimination step in the complex production system.

The five why the method is structured by an iterative interrogative question to explore the cause-and-effect relationship underlying a particular problem, and the primary goal of this technique is to determine the root cause of a problem by repeating the question “why?”.

There are two primary techniques are used to perform a five why analysis; the fishbone (Ishikawa) diagram and tabular format. These two techniques allow the analysis to be branched so that multiple root causes could be provided. The structure of the five why analysis is shown in the Figure 2.4.

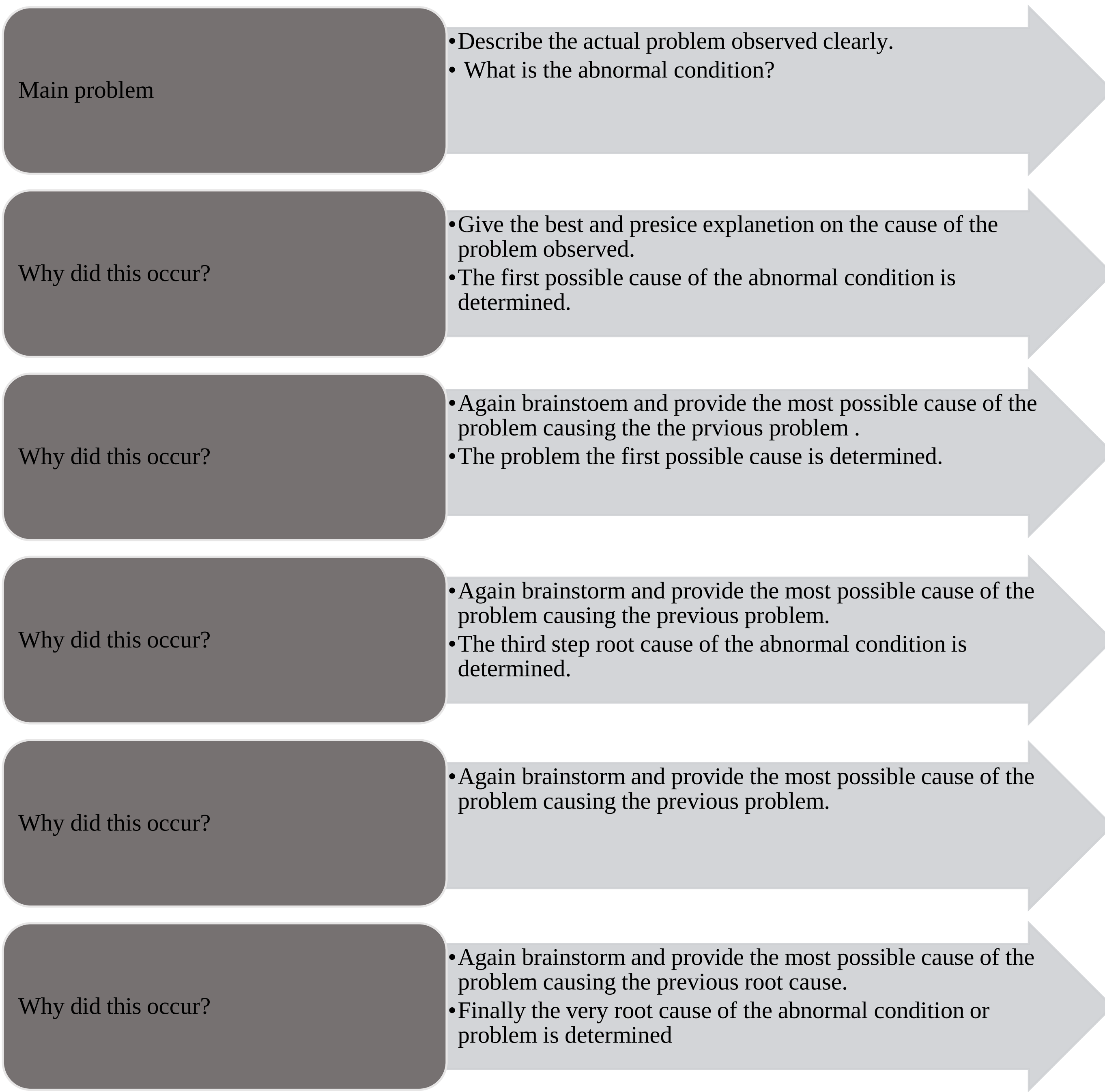

Figure 2.4 Structure of five why analysis (Olivier Serrat , 2017)

2.10 Review of related research

Patrycja Rogowska and Wieslaw Urban (2020) studied a detailed analysis of methods for bottleneck identification based on a comprehensive literature review and the design of a generalized methodology for bottleneck identification in a production system. Different types of bottleneck identification methods were discussed in this paper including their application area, advantage, and disadvantages. And care must be taken while choosing from those methods since they may lead to a wrong result and conclusion. Since identifying a bottleneck has a great impact on the efficiency of the entire production system, analysis of the production flow and division into processes should be the first step to identifying the bottleneck of a production system. (Patrycja Rogowska and Wieslaw Urban, 2020) suggests a direct observation of a process be conducted and focus should not only be given to production processes, a bottleneck can also be found in logistics operations, warehousing operations, and even the information flow. Therefore, accurate and detailed analysis of the production flow and the mutual relationships between the processes should be conducted deeply.

Calculating the distance from the identified bottleneck to the next constraint is important in addition to bottleneck identification and it requires at least measuring the process C/T or the process. The key stage of the proposed method is an in-depth analysis of the production flow and its division into processes. This makes it possible to understand and evaluate the current status of the system. The recommended method does not require the performance of all the suggested steps and it is a flexible tool that can be used for a broad range of production systems.

Prof. Wieslaw Urban and Patrycja Rogowska (2018) categorizes bottleneck into two types based on their utilization level, exceeding the level of utilization of the level of performance limit and 100% utilization. In this research paper theory of constraints has been used to identify, manage and control bottlenecks of a building material manufacturing company.

In this case study company a diverse variety of products are produced passing through the different production processes in three shifts. Identification of flow sequence has been taken to be the first step. Observing the production system and measuring the cycle time in every process were the actions taken to spot the bottleneck. Along with the cycle time quantity of available production resources for parallel processes and the number of pieces of the product in one process cycle were recorded. Then the time needed for each production unit to pass through each of the previously identified processes was examined based on the number of available production resources. The third step in bottleneck identification, management, and mitigation proposed in this research is the investigation of process cycle times regarding production losses due to product quality since production losses are a major factor affecting production performance. Machine change over time also contributes to the unproductive loss of a production system it also affects the bottleneck identification, so recording change over time has been taken as step four. Next, utilization of the operation time for each resource was also examined to calculate the time of unused availability of all resources, (Prof. W.Urban and P.Rogowska, 2018).

Prof. Wieslaw Urban and Patrycja Rogowska (2018) have got three bottlenecks in the production system, and using the theory of constraint they have been solved one after the other. But exploitation of bottlenecks should be preceded by steps to ensure maximum utilization of the production capacity and the last step is working towards the continuous improvement of the production process. (Nataša Tošanovi´c and Nedeljko Štefani´c, 2022) has investigated the influence of bottleneck on productivity of production processes with respect to different pull control mechanisms in different production conditions defined by level of variations, number of pull control cards and processing time. And by using regression functions, productivity was calculated in the study for different control mechanism so one can make a comparison and decide which control mechanism to choose for implementation.

(Lin Li et al., 2009)has developed a real-time bottleneck control method using online measurable data such as production line blockage and starvation information to monitor system performance in real-time and to obtain sustainable production benefits based on continuous product improvement. An automotive assembly line has been taken as a case study to illustrate the benefit of the proposed approach.

The bottleneck control strategy proposed in this study focuses on the amount of downtime. The bottleneck location will change under different operating conditions. The amount of downtime to be reduced directly affects the variation at the bottleneck location. (Lin Li et al., 2009) said that reducing downtime of a bottleneck machine should be performed until the new bottleneck is detected because of bottleneck inertia phenomena. Reducing the downtime which causes the most production loss is a much more meaningful and practical goal. In this study, a calculation of threshold value for downtime reduction has been derived and the real-time bottleneck control algorithm has been developed to consistently improve system performance towards balanced-line status. The method of reactive maintenance task prioritization and different assumptions and conditions were considered for bottleneck control and three bottleneck stations could be observed.

Compared to the original conditions 7.7% production improvement could be achieved using the short-term bottleneck control by the initial buffer.

Yong-Cai Wang et al.(2018) focuses on the causes of bottlenecks in a production system, and how to define, recognize and utilize them. In this study, bottlenecks are classified into two major categories, performance in processing (PIP) based and sensitivity-based definitions depending on application preference. And their detection method is also based on their definition, measurement-based methods, and sensitivity-based indicators. Our conclusion depends on the methods we choose to define and detect the bottlenecks.

PIP-based definition defines the bottleneck based on system performance measurements. In PIP-based definitions, average waiting time and capacity workload (utilization) is measured and utilized to identify the bottleneck, the machine with the longest average waiting time and the machine with the largest busy/idle ratio is considered the bottlenecks of a production process.

Sensitivity-based definition defines the bottleneck based on the effect of the bottleneck on the overall system throughput. Production bottleneck definition considers a machine as a bottleneck if the sensitivity of the system performance index to its production rate in isolation is the largest, as compared to other machines. And under the sensitivity-based definition, a resource limiting profitability is taken as an economic bottleneck taking cost and revenue into account.

B. Naveen and Dr. T. Ramesh Babu (2018) has researched to improve the productivity of brake shoe manufacturing companies. And it was done by identifying, analyzing, and mitigating the bottleneck of a production process. In this study, a cycle time data was collected from every process, and from the data analysis few bottleneck stations were observed and production time is less than the takt time for the case study organization which implies the need for an improvement of a production process to meet the demand by implementing the suitable industrial engineering tools. After the bottleneck was identified the root causes for those bottlenecks were studied by using Pareto analysis and cause and effect fishbone diagram. So remedial measures could be given to the causes to boost the production rate and production performance.

A bottleneck is an element of resources with the lowest production capacity (Roman Domanski and Joanna Kolinsaki, 2017). Joanna and Roman have researched bottleneck identification and management taking the world's leading manufacturer which supplies shock absorbers, batteries, radiators, condensers, evaporators, and air-conditioning systems for various car manufacturers. Data from one production line was analyzed which has 12 stations dedicated to manufacturing one product. Set-up time, cycle time, and machine's unproductive time were collected during each of the three shifts in the form of mass production.

To determine the bottleneck of the production process first the productivity of each operation should be determined according to (Roman Domanski and Joanna Kolinsaki, 2017). From this, the weakest link of the entire production process is the operation or workstation with the lowest productivity and the workstation with the highest utilization. Data from one production line was analyzed which has 12 stations dedicated to manufacturing multiple products has been also analyzed in this study in the same manner, but analyzing bottlenecks will consist in reducing the number of manufactured products to make maximum use of the weakest link.

Teklay Araya researched, efficiency analysis and performance improvement of bottling production line taking EABSC as a case study, (Teklay, 2018). In this study, line analysis and simulation model using Arena simulation were conducted and 22 production disturbances were observed being responsible for production bottleneck stations loss of 3498 production hours throughout the given year of data collection. Excess machine breakdown, frequent component stoppage, and longer setup and adjustment time were the main bottlenecks. Also, higher speed loss and frequent shortstops were the main reasons for the lower performance of the line.

Preform blowing and filling systems were found to be the best line improvement area due to higher availability and performance loss and also for their huge raw material loss as well. And changes and modifications were suggested to the line by developing a simulation model. Blockage and starvation time could be reduced by 11%, preform (raw material), as well as the cost of a unit lost, have been reduced. As a result, about 11% and 21.4% increase in availability and line performance, and Line productivity (OEE) could be achieved from the suggested improved model.

(Bikram Sharda and Scott J. Bury, 2010) investigated a bottleneck for different products in the chemical plant of The Dow Chemical Company by using discrete event simulation to represent the chemical plant operations and to identify individual constraint processes of the plant production. Different bottlenecks were successfully identified for each product. The plant simulation model also serves as a cost and benefit evaluating tool for the remedy action that was suggested for appropriate bottleneck management. The complex system interaction, continuous and discrete flow of different products at various production steps, and variability associated with different processing steps make the bottleneck analysis of chemical plants difficult which cannot be solved with a simple analytical approach. A general approach used for bottleneck identification and analysis was presented in this paper. Using DES simulation software, the chemical plant was modeled, verified, and validated. After successful validation of a model, bottlenecks for different products have been identified and prioritized based on their effect on the overall production system. And further study and analysis of the plant were recommended to eliminate bottlenecks and improve the overall production process (Bikram Sharda and Scott J. Bury, 2010).

(Abafi Jeol and Oka adenkola, 2020) had analyzed downtime in a typical Nigerian multinational bottling company by extracting failure data from the report book. The main reason for this analysis is to observe and improve line efficiency (OEE) by identifying and managing bottleneck workstations by tracking downtime.

OEE is a potent metric of manufacturing performance absorbing measures of the utilization, yield, and efficiency of a given process, machine, or manufacturing line (Abafi Jeol and Oka adenkola, 2020). And one of the parameters of OEE is machine availability, which is calculated by total unplanned downtime divided by planned production time.

Failure data of every system were collected on a report book and semi-automatic data were extracted from A “Human Machine Interface” (HMI) bottling packaging facilities to calculate overall equipment efficiency. Filler, labeler, bottle washer, pasteurizer, empty bottle inspector (ebi), depalletizer, repalletizer, packer ,and unpacker were the machines or facilities.

From the nine bottling packaging facilities four of them, filler, EBI, labeller, and bottle washer (BW) were found unreliability and have the highest percentage of downtimes while the remaining facilities. Downtime analyses like pareto chart analysis, weibull distributions, and reliability/failure time analysis were carried out. Since consequently, a continuous production process of beverage plant facilities depends on the operational efficiency of the filler machine, it was concluded that the installation of a standby filler system is a better solution.

When studying issues of various complexities becomes work-consuming or impossible while using classic analytical methods, computer-assisted simulation can be utilized (Mateusz Kikolski, 2016). The performed study confirms the possibility of applying Plant Simulation software in the analysis of simple production processes. The use of a computer simulation tool allows to predict the work of the production line and provides some of the behavior of systems.

(Dereje Geleta Oljira et al., 2020) developed a simulation model for the successful bottling and packaging of the production line by using Arena simulation software. The model is developed for a mineral water packaging process in a returnable glass bottle Production Line basically to eliminate the bottlenecks in the production line and provides optimal performance.

Actual resource processing time, machine parameters, nominal run speed, capacity, length, width, loss data, reliability data, and cost data were collected to model the simulation. while simulating the line machines which made minor change effects on production losses of the line were neglected to reduce the complexity. The bottlenecks were identified based on machine utilization and machine performance and the bottle washing machine, filling machine and Unpacker Machine was found to be the main bottleneck of the system. And as a remedy action Effective Preventive Maintenance Strategy was suggested because it has the potential to increase the output of the RGB production line from 21.12% to 54.03% and cuts cycle time by 33.33% with the minimum possible capital investment and reduces the costs of corrective and breakdown maintenance. (Dereje Geleta Oljira et al., 2020)

2.11 Research gaps

Many researchers have conducted several studies on production bottleneck identification and elimination methods and various approaches have been recommended for manufacturing companies. As noted in the literature, several researchers have focused their studies on methods for bottleneck identification and elimination of only a production line and machines neglecting the whole production process**.** There are also inadequate studies to refer to bottleneck identification in soft drink industries' production systems and food processing companies in general. Many research works tend to focus only on the production performance and line efficiency analysis but not on the cause of continuous disturbance in production performance and line efficiency of a production line. There is also limited research conducted in food processing and beverage production lines with a case study. Many beverage industries are working in Ethiopia but no one researcher has done research work related to the identification of production bottleneck in beverage industries in the Ethiopian working environment. And the effect of a bottleneck on the overall line performance and efficiency has been neglected and limited research has been conducted on simulation models to investigate the production bottleneck of complex, high speed, and continuous production systems. This research aims to fill the gap in these researches.

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CHAPTER – 3

RESEARCH METHODOLOGY

3.1 Introduction

The methodology is a guideline for a researcher to plan the structure flow of defined procedures, understand and explore activities and process flows of the production system in depth; collect detailed information over some period of time using a variety of methods, and analyze the collected data.

To achieve the objective of the study the systematic bottleneck management method, the theory of constraints (TOC), has been taken as a foundation for the research design of this study. Therefore, a case study line has been used to implement this methodology in a research design and study how to improve production line performance by eliminating production bottlenecks.

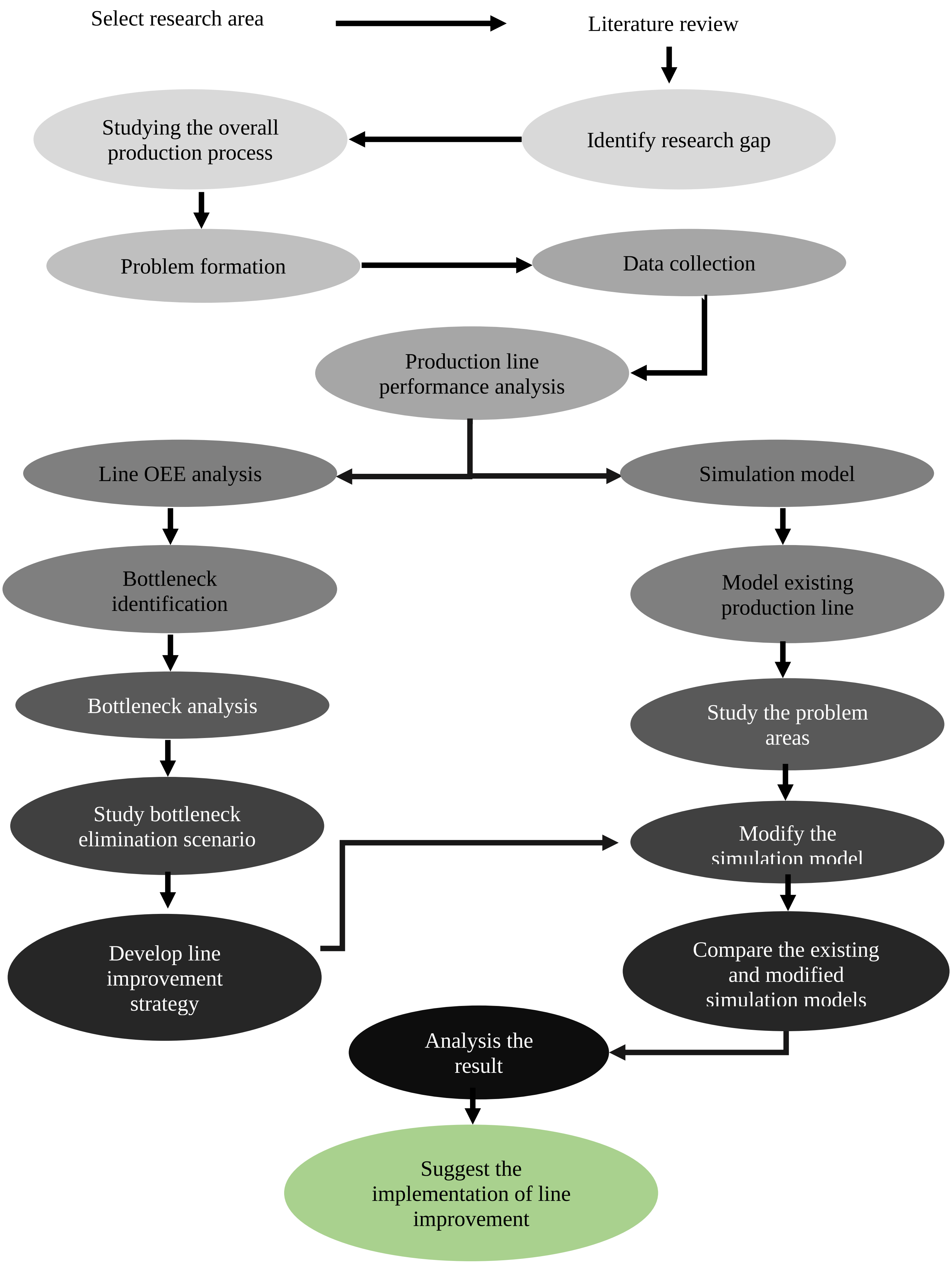
The researcher has developed and followed the research methodology shown in Figure 3.1 while conducting the study.And in this chapter data collection, data presentation and introduction about the analysis method used have been discussed.

3.2 Data collection

Data collection is a critical factor when studying complex production processes, therefore, it is vital to collect recent and long-term precise data from reliable sources. And to do so it is a must to have a better understanding of the overall production process and observe the production performance of the production line. Therefore, it is required to study the process flows of the production, different activities performed in the line, and the working principles of machines in detail. Reading related research works and documents like journal articles, and books concerning production system are also important to acquire a better insight into the general characteristic and new information in the field of productivity.

And after getting a better understanding of the production line, the required data to conduct the research were identified. For this study primary data from the real-time production system and historical data have been collected from every machine HMI, from the SAP (EABS.C internal communication software) system of the company, and from production report books. And literature reviews, machine operating and user manuals, books, and interviews were also used as a source of secondary data for the research.

Figure 3.1 Detail of proposed bottleneck management methodology



Data collection is a very important step to conduct productive research work. The data collection must be conducted properly since inaccurate data collection may impact the results of a study and eventually lead to invalid results. The ultimate use of the collected data is to be an input for both numerical and simulation analysis and to further investigate the root cause of the problem. The collection of input data is often the most difficult process involved in conducting a simulation modeling and different analysis.

The following data have been collected both from the historical database and directly from the production system.

Real-time production data collected through observation are the following;

- ✓ The overall company production system
- ✓ The planned and actual output of the production line
- ✓ Production volume
- ✓ Every machine production data
- ✓ Every machine downtime data
- ✓ Breakdown of every machine and their frequency
- ✓ Time loss for setups and product change over
- ✓ Planned and unplanned downtime
- ✓ Machine speed
- ✓ Production rate
- ✓ Process time

Secondary and historical data collected from the companies SAP system, datasheets, and interviews

- ✓ Working principle of the machine in the production line
- ✓ Production line and machine designed capacity
- ✓ Machine cycle time
- ✓ Company working hour
- ✓ Historical planned and unplanned downtime data
- ✓ Distance and conveyor accumulation between each machine
- ✓ Related information

For better analysis results the data should be analyzed over different production shift teams, time periods, product types, and production parameters of the line. Therefore, to collect real-time production data, the morning and night shift of two weeks period has been taken. And in coincidence during the data collection period, both Sprite and Coca-Cola products have been produced which gives the researcher more insight into overall production scenarios.

3.3 Data presentation

EABSC production lines operate 365 days per year, 7 days per week, and 24 hours per day in three shifts. Except for planned stoppages the line operates without shift handover, lunch, or tea breaks. Once a week there is planned maintenance for 8 hours or one shift period. Even though the production line is in operation 24 hours per day, it may not be always producing goods. The following states explain the condition of machines and conveyors in different states;

- ✓ Production: The machine is producing products; this could be with different speed levels.
- ✓ Maintenance: The machine is not producing due to planned maintenance.
- ✓ CIP (cleaning in place) and change-over: The machine is not producing due to planned cleaning activities and product changeovers.
- ✓ Starvation: The machine is not producing due to a lack of infeed. Mostly caused by failures of preceding machines.
- ✓ Blockage: The machine is not producing due to a backup at discharge. Mostly caused by failures of succeeding machines.
- ✓ Inheritance failure: The machine is not producing due to a component or other failure problem of the machine itself; the failure duration can be for a short or long time.

Actual production and planned production data

Due to different factors, the production plan of every shift may differ, mainly because some activities like flavor change over, CIP (cleaning in place), planned maintenance, set up adjustment, and planned meetings do not occur in every production shift. The planned production data has been extracted from the team leader data record sheet and since the packer machine counts the net actual production of the line, the packer counter has been taken as the source of actual production data of the line. Under table 3.1 the actual production, planned production, and their variance is presented.

Table 3.1 Actual and planned production of 28 shift

Shift		**Actual production (Case)**	**Planned production (Case)**	**Variance (Case)**
6/03/2022	Morning	8,874.000	9,860.237	986.237
	Afternoon	7,853.000	9,680.804	1,827.804

07/03/2022	Morning	4,930.000	6,519.240	1,589.240
	Afternoon	8,040.000	10,070.720	2,030.720
08/03/2022	Morning	8,437.000	10,574.116	2,137.116
	Afternoon	9,000.000	11,288.000	2,288.000
09/03/2022	Morning	0	0	0
	Afternoon	8,030.000	10,986.040	2,956.040
10/03/2022	Morning	7,190.000	9,920.000	2,730.000
	Afternoon	8,050.000	10,083.400	4,033.400
11/03/2022	Morning	7,266.000	9,357.288	2,091.288
	Afternoon	7,888.000	9,867.840	1,979.840
12/03/2022	Morning	5,068.000	7,230.224	2,162.224
	Afternoon	6,133.000	8,848.644	2,715.644
13/03/2022	Morning	7,000.000	9,680,804	2,680.804
	Afternoon	8,480.000	10,460.230	3,980.230
14/03/2022	Morning	4,000.000	5,419.240	1,419.240
	Afternoon	8,940.000	10,570.982	1,630.982
15/03/2022	Morning	8,986.000	10,574.206	1,588.206
	Afternoon	8,406.000	10,985.000	2,579.000
16/03/2022	Morning	0	0	0
	Afternoon	7,789.000	10,900.040	3,111.040
17/03/2022	Morning	6,190.000	8,348.060	2,158.060
	Afternoon	9,120.000	13,683.809	4,563.809
18/03/2022	Morning	8,266.000	10,357.288	2,091.288
	Afternoon	7,030.000	9,867.840	2,837.840
19/03/2022	Morning	7,986.000	10,330.205	2,344.205
	Afternoon	7,103.000	9,808.704	2,705.704
Total		196,355.000	259,561.387	63,226.387

Gross and net production data

The product which does not meet the standard requirement of the production process is rejected and they are not considered a net production output. Bottle burst (breakage) in a filler machine, underfilled bottle, overfilled bottle, and product filled in a dirty bottle are considered as the main cause of product rejection. While under-fill and overfill are checked by a check mat, sighters check the cleanness of the full bottle. The actual gross production, net production, and their difference which is the number of rejected products are presented under Table 3.2.

Table 3.2 Gross and net production of 28 shift

Shift		**Actual gross production (Case)**	**Actual net production (Case)**	**Rejected (Case)**
6/03/2022	Morning	9395.000	8,874.000	521.000
	Afternoon	8,163.000	7,853.000	310.000
07/03/2022	Morning	5,150.000	4,930.000	220.000
	Afternoon	8,480.000	8,040.000	542.000
08/03/2022	Morning	8,927.000	8,437.000	490.000
	Afternoon	9,620.000	9,000.000	620.000
09/03/2022	Morning	0	0	0
	Afternoon	8,317.000	8,030.000	287.000
10/03/2022	Morning	7,435.000	7,190.000	245.000
	Afternoon	8,482.000	8,050.000	432.000
11/03/2022	Morning	7,752.000	7,266.000	486.000
	Afternoon	8,768.000	7,888.000	380.000
12/03/2022	Morning	5,304.000	5,068.000	236.000
	Afternoon	6,433.000	6,133.000	300.000
13/03/2022	Morning	7,320.000	7,000.000	320.000
	Afternoon	8,547.000	8,480.000	367.000
14/03/2022	Morning	4,200.000	4,000.000	200.000
	Afternoon	9,296.000	8,940.000	356.000
15/03/2022	Morning	9,672.000	8,986.000	486.000
	Afternoon	9,018.000	8,406.000	612.000
16/03/2022	Morning	0	0	0
	Afternoon	8,265.000	7,789.000	476.000
17/03/2022	Morning	6,427.000	6,190.000	237.000
	Afternoon	9,532.000	9,120.000	412.000
18/03/2022	Morning	8,616.000	8,266.000	350.000
	Afternoon	7,320.000	7,030.000	290.000

19/03/2022	Morning	8,186.000	7,986.000	200.000
	Afternoon	7,313.000	7,103.000	210.000
Total		205,920.000	196,335.000	9,585.000

The difference between net and gross production quantity is loss. And Table 3.3 presents the type of this losses and their quantity.

Table 3.3 Types of quality losses and their quantity

Type of reject	Bottle burst (breakage in filler)	underfill	Over fill	Uncleaned bottle
Quantity of bottle (Case)	1917.000	5,368.000	1,534.000	766.000

Time loss due to unplanned and planned downtime of machines

Table 3.4 shows the company's actual working hours, planned stoppages, unplanned stoppages (downtime loss), planned working time, and actual operating time in the two shifts of two weeks production period.

Table 3.4 Total planned and unplanned stoppage and planned working time of 28 shifts

Day		**Working hour(min)**	**Planned stoppage(min)**	**Unplanned stoppage(min)**	**Planned working time(min)**	**Actual working time(min)**
6/03/2022		960	0	215	960	745
07/03/2022		960	180	251	960	529
08/03/2022		960	0	145	960	815
09/03/2022		960	480	45	950	425
10/03/2022		960	120	80	945	745
11/03/2022		960	0	80	960	880
12/03/2022		960	180	210	943.8	553.5
13/03/2022		960	0	265	960	695
14/03/2022		960	180	193	943.8	570.5
15/03/2022		960	0	223	960	737
16/03/2022		960	480	20	960	460
17/03/2022		960	120	100	960	740
18/03/2022		960	0	94	928.8	866
19/03/2022		960	180	50	950	720
Total	14 days	13,440	2100	1971	13341.4	9481

The data under Table 3.5 is collected directly from the machine HMI and real-time production observation using a stopwatch. Fourteen days of morning and afternoon production shift producing two variety of products (Coke and Sprite) has been observed and downtime of every machine has been recorded by the researcher and machine operators.

Table 3.5 Unplanned and planned downtime duration of machines

Weeks	**Station**	**Unplanned down time (min)**				**Planned downtime (min)**	
		Due to machine failure	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over
Week one	Unpacker	88 min	61 min	191 min	21 min	480 min	480 min
	Washer	100 min	137 min	325 min	47 min	480 min	480 min
	KRONES Filler	636 min	150 min	120 min	110 min	480 min	480 min
	KHS Filler	549 min	174 min	85 min	74 min	480 min	480 min
	Packer	153 min	131 min	18 min	30 min	480 min	480 min
Week two	Unpacker	88 min	44 min	191 min	21 min	480 min	480 min
	Washer	87 min	90 min	365 min	35 min	480 min	480 min
	KRONES Filler	651 min	165 min	102 min	98 min	480 min	480 min
	KHS Filler	565 min	180 min	73 min	80 min	480 min	480 min
	Packer	123 min	159 min	10 min	23 min	480 min	480 min

Collected downtime and shutdown data one year and quarter (1 ¼ year) duration

Downtime and shutdown data is one historical data collected to support the line bottleneck analysis for the virtuous result. The downtime, production rate, and production capacity of any production line in beverage industries depend on the filler machine. Therefore, the downtime of the filler machine is taken as production line downtime, and as a standard operating practice filler operator always records any filler machine stoppage that longs more than 3 minutes on the breakdown sheet. And the team leader takes this breakdown data and fills it in SAP software

(EABS.C internal communication software) for future use. Both downtime and shutdown loss of the production over 1 ¼ year duration are presented under Table 3.6 and Table 3.7 respectively.

Table 3.6 Downtime data (Jan 1,2021– Mar 30, 2022)

Downtime type	**Component**	**Duration (min)**	**Case lost (cases)**
EF	Depalletizer	110	2,932.80
EF	Empty crate conveyor	536	14,027.20
EF	Uncaser	2,861	76,294.4
EF	Empty bottle conveyor	2,223	59,281.60
EF	Bottle washer	2925	77,998.4
EF	EBI	390	10,667.20
EF	Filler	12,854	342,774.4
EF	Capper	5021	133,905.6
EF	Blender	3291	87,758.400
EF	FBI	53	1,412.80
EF	Date coder	4096	109,227.2
EF	Full bottle conveyor	440	11,732.80
EF	Packer	1,755	46,796.8
EF	Full caret conveyor	51	1,360
EF	Labor shortage	35	932.8
OT	Glass quality	4214	112,366.4
OT	Syrup room	1,143	30,488.00
OT	Lab test	1,592	42,536.00
OT	Glass shortage	34,984	552,115.20
OT	Crown quality	869	31,172.8
SU	Start-up	2,330	62,052.80
CO	CIP Rinse	350	9,339.20
CO	5 Step CIP	14,181	378102.4
CO	3 Step CIP	655	17,467.20
CO	Size Change	130	3,470.40
SD	Shut down	425	11,355.20

Table 3.7 Shutdown data (Jan 1,2021– Mar 30, 2022)

Shut down reason	**Duration (min)**	**Case lost(cases)**
Fire drills	10	267.2
Boiler	30	800
Water treatment	1,364	23,569.6
CO_2 lab test	10	267.2
Refrigeration plant	530	14,132.80
Insufficient storage space	10,100	269,331.2
Line commissioning	9,395	250,528
Utility	2,211	58,979.2
Fork lift problem	8,637	230,329.6
LP compressor	354	9,438.4
No production schedule	5,277	102,326.4
Planned meeting	568	15,145.6
Planned maintenance	23,045	233,731.2
Planned cycle count	5,113	14,745.6
Autonomous Maintenance	3,418	91,145.6

In general, the machine's function and the number of operators, processing time, machines capacity, production loss, conveyor area, accumulation, and other data summary for EABSC, Addis Ababa plant line 5 RGB production line were presented under the following tables. Conveyor accumulation capacity shown under Table 3.8 is required for simulation analysis.

Table 3.8 Conveyor accumulation capacity

Location	**Area (m^2)**	**Accumulation capacity**
Conveyer from depalletizer to packer (if required)	15.552	4,320 bottles
Conveyer from unpacker to washer	20.736	5,760 bottles
Washer discharge conveyor	12.96	3,600 bottles
Conveyor from washer discharge conveyor to KRONES Filler	10.08	2,800 bottles
Conveyor from washer discharge conveyor to KHS Filler	4.752	1,320 bottles
Conveyor from KRONES Filler to pack infeed conveyor	4.68	1,300 bottles
Conveyor from KHS Filler to pack infeed conveyor	3.24	9,00 bottles
Pack infeed conveyor	12.6	3,500 bottles

Station parameter

In any beverage industry, the Filler machine is the most critical one when studying line performance and efficiency, because it determines the line operating speed. The upstream and downstream machines for filler machines operate according to the filler speed for smooth flow of production, i.e., to eliminate starvation and blockage in the line the speed of the upstream and downstream machines of filler machines are designed in a V shape, where the flow of production process starts at high speed (at 120%, 110% of the filler machine) and decrease to the speed of the filler and the rise again with 10% speed increment. The production line under study also follows the same principle as presented in Table 3.9.

Table 3.9 Machine parameters

Station	Design capacity (BPH)	Actual output (BPH)	Machine speed (BPM)	Machine head (bottle per cycle)	Cycle per minute
Unpacker	72000	65000	1200	240	0.2
Washer	67000	55200	1116	482	0.43
EBI (1)	36000	31500	600	1	0.00167
EBI (2)	24000	20000	400	1	0.0025
KRONES filler	36000	32000	600	91	0.15167
KHS Filler	24000	20500	400	72	0.18
Packer	57600	57000	960	240	0.25

Processing time of conveyors and machine

Processing time in production line is the time required to work on the conversion of input to output. The processing time of every station and handling systems of inputs and outputs of every machine has to be recorded and presented in Table 3.10 below for the simulation analysis of the study.

Table 3.10 Processing time of conveyors and machines

No	Data type	Average processing time(min)
1	Delaying time of 240 bottles in unpacker machine	0.26
2	Conveying time of bottles after unpacker machine	0.15
3	Delaying time of 492 bottles in bottle washer machine	0.523
4	Conveying time of bottles after bottle washer machine	0.25

5	Delaying time of 1 bottle in EBI (1) machine	0.00193
6	Delaying time of 1 bottle in EBI (2) machine	0.00333
7	Conveying time of bottles after EBI (1) machine	0.002
8	Delaying time of 91 bottle in KRONES Filler machine	0.1761
9	Conveying time of bottles after EBI (2) machine	0.15
10	Delaying time of 72 bottle in KHS Filler machine	0.24
11	Conveying time of bottles after KRONES Filler machine	0.1
12	Conveying time of bottles after KHS Filler machine	0.15
13	Delaying time of 240 bottle in Packer machine	0.25

Number of machines and respective operators

Even though the production line is automatic some of the machines in the production line need continuous human observation and control during production. And there are sighters and casual workers to assist the operators to facilitate smooth production, they would control falling bottles on the conveyor, help the operator while troubleshooting a problem, manage and handle rejected products. The number of main stations and their respective operator excluding the casuals and sighter is listed in Table 3.11.

Table 3.11 Number of machines and respective operators

No	Station	No of machines	Number of operators on the machine
1	Un-packer	1	1
2	Washer	1	1
3	EBI	2	0
4	Filler with capper	2	2
5	Check mat	2	0
7	Date coder	2	0
8	Caret washer	1	0
9	Packer	1	1

3.4 Data analysis

All collected data have been analyzed using different tools and software; tables, graphs, and charts have also been used to present the results on various variables in the study. To achieve the objective of this study three major analyses conducted are line performance analysis, bottleneck analysis and line simulation analysis.

3.4.1 Production line performance analysis

To perform the line performance analysis required and relevant data were isolated and presented clearly so that appropriate performance indicators can be calculated and result figures have been interpreted. Line analysis is carried out to identify the current operational performance of the production line and understand the reason behind such performance. After production performance and efficiency losses were analyzed, major bottlenecks of the production line causing performance losses were identified and root causes of those production bottlenecks have been studied and their elimination method for continuous performance improvement of the production line was investigated according to TOC bottleneck management.

After studying the bottleneck elimination method line improvement strategies have been suggested and findings were provided on optimal line improvement opportunities using simulation model analysis. Detail of this analysis has been covered on the next chapter under section 4.3.1.

3.4.2 Line simulation analysis

The real-time behavior of the production system is imitated by developing a simulation model, which requires a better understanding of the system, collection of adequate and accurate input data from reliable sources, and use of the analysis of the input data in the simulation model. The production line simulation enables the analysis of current production performance and indicates the presence of production constraints in existing production system. Then after conducting line and bottleneck analysis, the line simulation model has been modified by considering the suggested line improvement strategy which enables the researcher to measure the line productivity and performance improvement.

The following steps are involved in developing a production line simulation model but to achieve the ultimate objective of the simulation iteration at various sub-stages may be required.

Step 1- Identify and formulate the problem,

Step 2- Collect and process real system data

Step 3- Formulate and develop a model

Step 4- Validate and verify the model

Step 5- Establish experimental conditions for runs

Step 6- Perform simulation runs

Step 7- Interpret and present results

3.4.3 Selection of simulation software

Arena simulation software has been used to build a simulation model. Because Arena uses an entity-based and flowcharting methodology for modeling dynamic processes. Most other commercial simulation products are code-based and require programming in proprietary scripting languages, and many simulation products primarily requires a concentration on animating a process rather than documenting it. The arena is a Visio-compatible, flowcharting tool. Entities in an Arena model proceed through a flow chart of the process and size control of resource capacity as they are processed. The flow chart approach to the model building makes the most sense to engineers and process designers who must be able to carefully document a process to accurately model it and analyze it. This results in models that become highly detailed documents of the processes being studied. Arena's flowcharting methodology makes Arena software to be :

- ✓ Easier to learn than other simulation tools
- ✓ Easier to validate, verify, and debug
- ✓ Easier to communicate the intricacies of complex processes to others

Arena packaging edition has been used from arena toolbars to build the model. Arena Packaging Template is one of a family of application solution templates (ASTs) built on the Arena simulation system It is designed specifically for performing accurate and efficient simulations of high-speed, high-volume manufacturing systems, where the processing rates take place at hundreds, even thousands, of entities per minute. The packaging template enables users to build and run simulation models of high-speed processing lines quickly and easily, and to analyze the results that these models produce. Arena packaging edition templates contain machine module, conveyor module, simulate, machine link and conveyor link, operator, operator group, and operator schedule and label.

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CHAPTER – 4

OVERVIEW OF CASE STUDY COMPANY AND DATA ANALYSIS

4.1 Introduction

In this section real bottling line production process and operation overview, workflow, plant layout and detail data analysis have been discussed.

4.2 Overview of production lines in EABSC

As discussed in the introduction section EABSC is a share company as a Coca-Cola franchise bottler in Ethiopia bottling Coca-Cola, Sprite, Schweppes, Novida, and Fanta family soft drinks in Ethiopia with the permission of Coca-Cola International (KO).

The products of this company are carbonated sweet soft drinks in glass and plastic bottles of different flavors. There are also sugar-free products of all flavors. This explains the high variety of output products which complicate the production process.

The case study production plant has four production lines, three RGB (returnable glass bottles), and one PET (polyethylene terephthalate) soft drink bottling line. Both bottling lines have their production process. The PET line is the only line producing PET products; therefore, it produces all varieties of Coca-Cola brands. But the three RGB lines are designated to a specific brand, line one only produces Fanta families, Schweppes, and Novida while line 3 and line 1 produce Coca-Cola and Sprite respectively.

The manufacturing of carbonated soft drinks involves several distinct stages. One of the two basic methods is a premix system where all ingredients for the beverage are mixed, chilled, and carbonated (R.Ashurst, 2016). This production approach is used by all the plants and lines in EABSC regardless of their bottling type. The major and basic difference between RGB and PET lines is their bottling raw materials and machines used.

The main ingredients are concentrate, sugar (artificial sweetener for sugar-free products), water, and carbon dioxide. Besides, glass bottles, crowns, PET preforms, caps, labels, ink, shrink and stretch film are the main raw materials of both RGB and PET products. Production lines cannot stand alone because they need supporting departments like utility, process, quality checks, logistics, and human resource departments working hand in hand.

The utility department under the manufacturing department supports the production line by managing a sustainable supply of electricity, steam, compressed air, and chilled water; while treated water and syrup are provided with the help of the process department. Transportation of raw materials and resources as well as the finished product is managed by a logistic department. One of the major resources or inputs of production is people, suitable personnel for any operation in the production line or other supporting departments are hired and developed by the human resource department. The quality department also helps the system by working towards the quality of a product, health, and safety of the environment and society to meet required operating standards.

This can be better explained by the organizational structure shown in the Figure 4.1, it is designed in such a way that duties and responsibilities are clearly stated and each department contributes its share to the meaningful accomplishment of the company's mission and manufacturing quality.

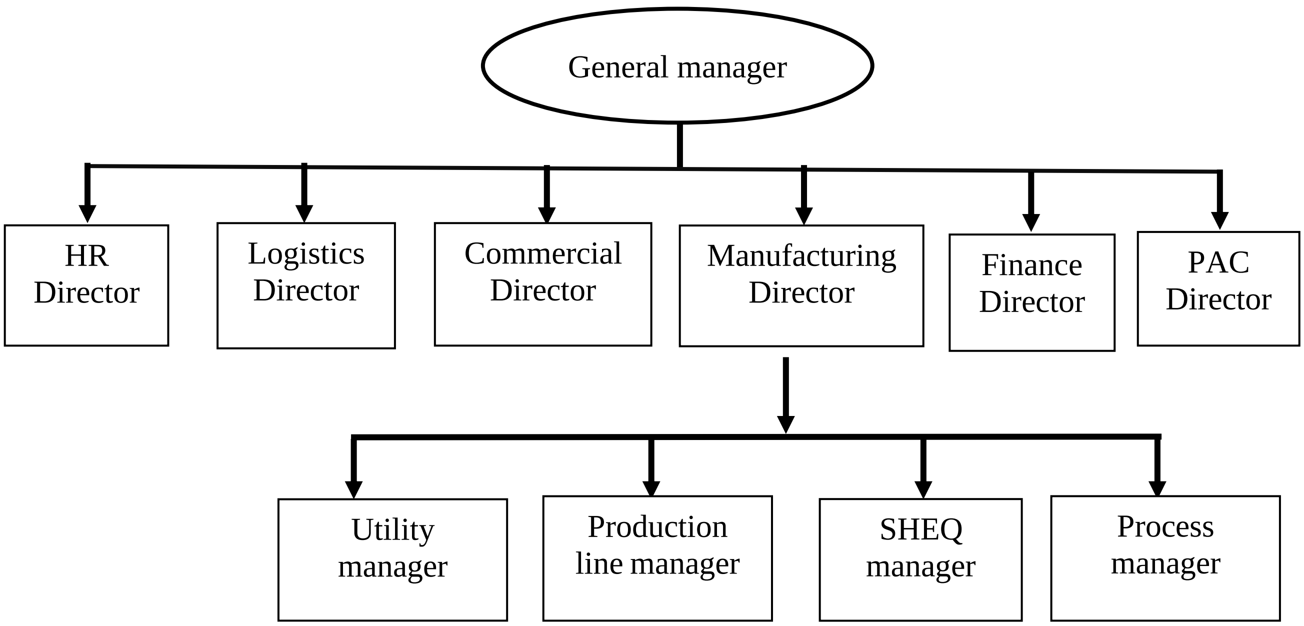

Figure 4.1 Organizational structure of EABSC

Types of products

There are two major product lines in the factory; these are Returnable Glass Bottles (RGB) and Polyethylene Terephthalate (PET) Production Lines.

In Returnable Glass Bottles (RGB) production line: 300 ml

- ✓ Coca-Cola
- ✓ Coca-Cola sugar-free
- ✓ Sprite
- ✓ Fanta orange
- ✓ Fanta orange sugar-free

- ✓ Fanta pineapple
- ✓ Fanta red apple
- ✓ Schweppes
- ✓ Novida

In Terephthalate (PET) Production Line: 500 ml

- ✓ Coca-Cola
- ✓ Coca-Cola sugar-free
- ✓ Sprite
- ✓ Fanta orange
- ✓ Fanta orange sugar-free
- ✓ Fanta pineapple
- ✓ Fanta red apple

4.2.1 Production process

All RGB lines have the same production process consisting of various machines and bottle handling mechanisms.

Empty bottle handling

Operation of RGB production lines highly depends on the returned glass bottles therefore logistic department should facilitate the collection of distributed bottles and transport them to the company and ensure its fast delivery.

The production process starts by transporting case pallets from an empty glass store to the depalletizing station of the line and unloading bottle carrying cases from the pallet, the case study company does not have a depalletizing machine for the RGB lines, thus this operation is done manually. Plastic bottle carriers (caret or case) are then transported from pallets to the unpacker infeed case conveyors. And from the case, conveyor unpacker machines unpack bottles from their cases. This may also be done manually, but there is one unpacker machine for this operation in the case study line. The unpacked bottles and the empty carets then take their way to the bottle washer and caret washer machines respectively. In the bottle washer, the bottle got cleaned using caustic soda, hot and cold water in different stages and compartments. The bottle washing process takes a longer time than the whole bottling process, around 30 to 40 minutes since the bottle had to be soaked in caustic and the caustic should be cleared out.

Empty bottle inspection comes right after the washing process, the inspection can be done either by inspector personnel or an EBI machine. In the case study line, both inspectors and EBI machines do the inspection. During the inspection broken bottles, uncleaned bottles and scratched bottles will be rejected. The physically good empty bottles then be transferred to the filler machine on one lane conveyor.

In the filler machine, the bottles is filled with the beverage and crowned with crock. The quality of the filling and crowning process is checked by check-mat at the discharge conveyor of the filler machine by using PE and capacitive proximity sensors. And there is a rejector to reject products that don't meet the product quality like underfill, overfill, and uncrowned bottles. And on the good finished products the production date, production line, and expiry date informations are printed by the date coder. After the date coders, there are full bottle inspectors (sighters) checking the quality of finished good products. And finally, the packer machine packs the finished products into cleaned cases (caret boxes) and which is then transported to the palletizing station to be layered on case pallets and then to the finished product warehouse using forklifts. Similar to depalletizing, palletizing is also done manually in all RGB lines of EABSC, Addis Ababa plant.

Product handling

A bottling company (bottler) is a company that mixes ingredients and bottle the beverage and distribute the final product to wholesalers. They don't prepare the ingredients and they are mostly franchisees of corporations. And EABSC as a bottler company imports concentrates (ingredients) for its products. These ingredients mix up with treated water and sugar (artificial sweetener for sugar-free products) in the syrup room and sent to a blender machine for carbonation and proportion. The blender machine executes carbonation and proportion of the product as per the quality requirement and sent the final beverage to the filler machine through pipes.

These are the main machines and processes of RGB production line. The production line is fully automatic and PLC controlled, which enables different stations and different types of conveyors to communicate with each other. The conveying line controller provides the logic and instructions to each of the conveyor drives based on data received from line sensors, together with the data collected from the individual machines. Photocell sensors on the conveyor system control the speed and state of their respective machine. Accordingly, the signal received from respective sensor machines changes their speed from low to medium and high speed or even stoppage depending.

The flow of the production process in RGB line is shown in Figure 4.2.

Station	Description
Unpacker	• Empity glass bottles are collected from the customer and transported to the production line. • And by using unpacker machine or human labor it is unpacked from the caser.
Washer	• After unpacking the empity glass they will be reused by removing the residual drinks and dirts by using a washer machine. • The cleanness of the empity bottle is checked every 45 min to assure the quality of the produt .
EBI	• EBI (empity bottle inspection) ,machine or an inspector personeel checks the precence of impurities and apperance of the bottle.
Filler	• The bottle is filled with the beverage using filler macine , the production line efficiency is mainly indicated by the performance of this macine, it operates with the lowest speed than the upstream and downstream machines. • The ingridients are mixed in a mixer and the final beverage is transported to filler using pumps and pipe.
Crowner	• This station is where the bottle get closed. • Crowner will be supplied to this machine in a proper position using diffrrent mechanisms.
Checkmat	• Checkmat is where the full bottle or the product is inspected under fill , over fill or unclosed bottle can not pass after this stage.
Date coder	• Manufacturing date , expire date and production line is printed on the bottle in this station to give information about the product for the coustomer .
Packer	• In this station the procuct is packed in a case and palatized in a bulk to get it ready for a distribution .

Figure 4.2 Production process flow of RGB lines

4.2.2 Plant layout of the production line

As shown in Figure 4.3, the production line understudy has a complex plant layout and comprises many buffer conveyor systems because of the presence of two filler machines with their own EBI, blender, check-mat, and date coder while sharing an unpacker, washer, and unpacker machines.

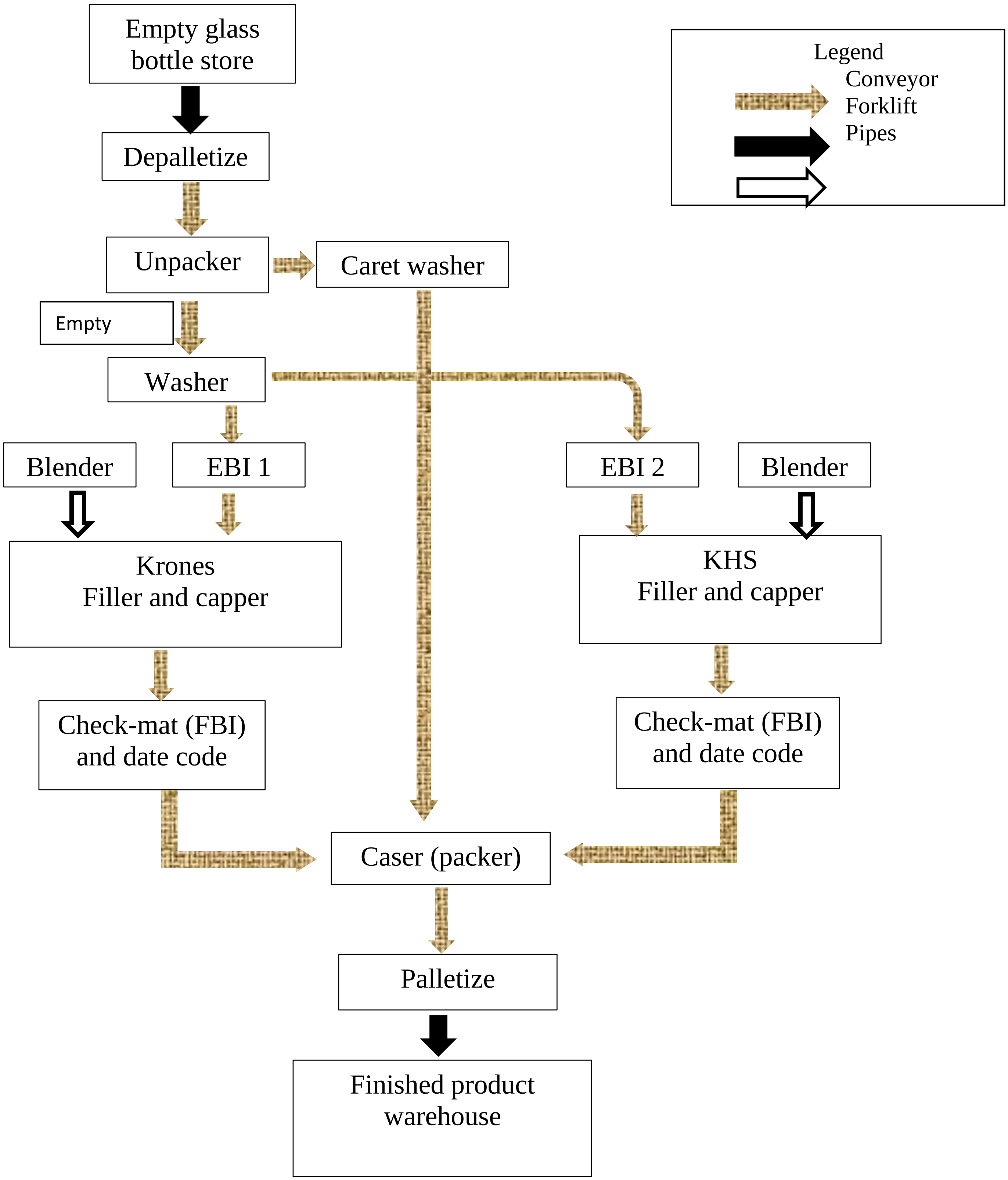

Figure 4.3 Plant layout of the case study line

4.3 Data analysis

4.3.1 Production line analysis

The analysis of this research work starts by studying the current production performance of the case study RGB production line. Since it is one of the reliable quantitative metrics which is used in most manufacturing systems for controlling and monitoring the productivity of production equipment, OEE (Overall Equipment Effectiveness) analysis has been implemented to perform line performance analysis. It's mainly used to indicate the current performance of the production line. This quantitative metric consists of three important components which are availability, performance, and quality to measure how well (or ill) the line is performing.

But in addition, the OEE analysis also helps the researcher to understand the major factors and causes that affect the production efficiency more and enable to narrow the focus area of the study. To calculate the OEE of the production line the following information is required:

- ✓ Calendar Time (Ct)-is the total time that the machine is available to manufacture based on the calendar, which includes weekends, public holidays, etc.
- ✓ Working Time (Wt)-is the actual time that the plant is expected to run, excluding public holidays and shifts not planned.
- ✓ Loading Time (Lt) – is a panned working time, the time that the line is planned to run.
- ✓ Shut down loss (SDL) – time losses that are caused by planned activities related to repairing, maintaining, and cleaning or activities which does not directly fall within the control of a production line.

$$Lt = Wt - SDL \tag{EQ 1}$$

- ✓ Operating Time (Ot) – the actual working time used for production, net operating time excluding both planned stoppages and unplanned stoppages.
- ✓ Down time loss (DTL) – time losses that are caused by unplanned or sudden activities which directly fall within the control of a production line.

$$Ot = Lt - DTL \tag{EQ 2}$$

- ✓ Net Operating Time (Nt) – the time in which the production is at the standard production rate including minor stoppages.

$$Nt = \frac{Gross\ production}{Base\ quantity} \tag{EQ 3}$$

- ✓ Performance Loss (PL) – is total time loss caused by short stops and speed losses of machines mainly affecting the gross throughput of the line.
- ✓ Value Adding operating Time (Vt)- is the actual time in which the line produces a good product in the total shift time.

The line loss structure in Figure 4.4 further elaborates the relationship between the different production time frames.

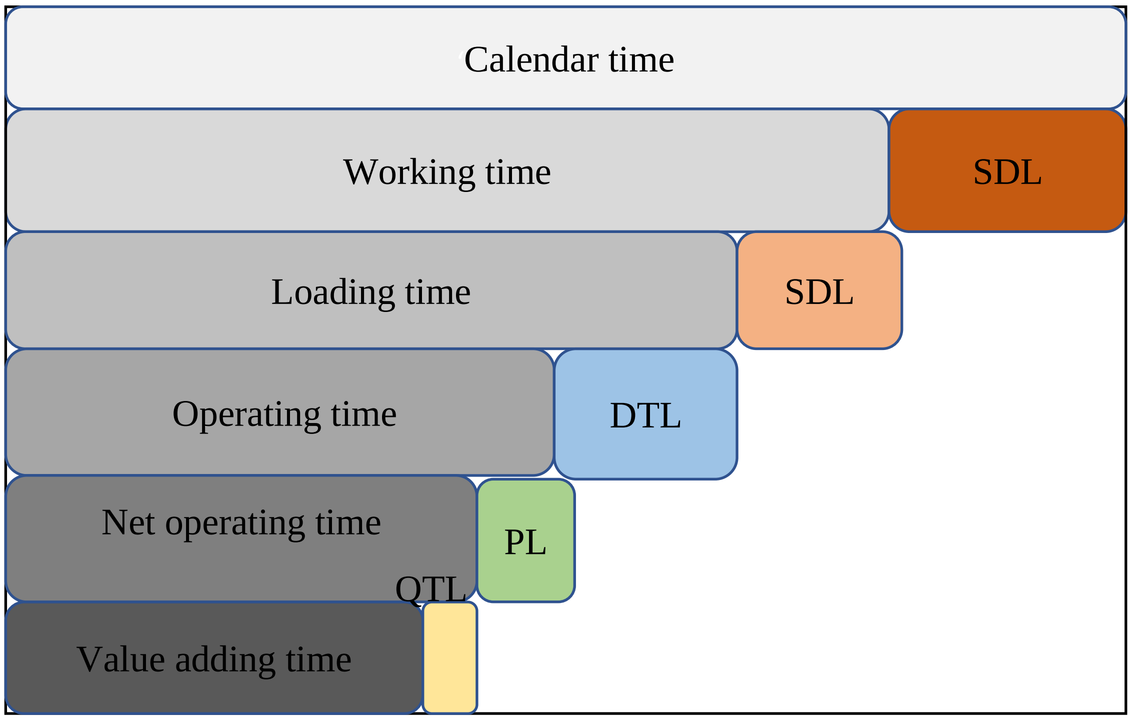

Figure 4.4 Loss analysis structure

In EABSC Addis Ababa plant RGB production line, a raw production data of a total 28 shifts have been used to calculate OEE and analyze the recent production performance from the data collected:

- ✓ One shift operates for 8 hours, therefore,

$$\text{Calendar Time (Ct)} = 28 * 8hrs = 224\ hrs = \mathbf{13,440}\ \boldsymbol{min}$$

- ✓ Due to many factors sometimes, there is a loss of a few minutes of production time, therefore,

$$\text{Working Time (Wt)} = 222.567\ hrs = \mathbf{13,341.4}\ \boldsymbol{min}$$

- ✓ Once a week there is scheduled maintenance for eight hours (one shift), planned cleaning activity (CIP) every 48 hours, and flavor change when needed. And since flavor changes are always followed by CIP, the shutdown loss for two shifts of two weeks is due to scheduled maintenance, CIP, and flavor change.

Planned maintenance – 16 hours (960 min)

CIP and flavor changes – 16 hours (960 min)

$$\text{SDT} = 32\ hrs = 1{,}920\ min$$

$$Lt = Wt - SDL = 13{,}341.4 - 1{,}920\ min = \mathbf{11{,}421.4\ min}$$

- ✓ In any beverage industry, the Filler machine is the most critical one to studying line performance and efficiency, because it determines the line operating speed and directly affects the production throughput. Therefore, any stoppage at filler due to starvation, blockage, or even filler machine inheritance failure is taken as downtime of the line because it is the only time the actual production is stopped. Thus, the downtime loss of the line for the case study production period is the summation of time loss of filler machine due to starvation, blockage, and equipment failure.

Down time loss (DTL) – 2032 min

$$Ot = Lt - DTL = 11{,}421.4 - 2{,}032 = \mathbf{9{,}389.4\ min}$$

- ✓ The base quantity or production capacity of the line is calculated from the actual avarage production capacity of filler machine and since the line under study has two filler machines it has a capacity of producing 44,000 bottles per hour which is equal to 1833.33 packs per hour and 30.55 packs per minute which gives us a net operating time of

$$Net\ operating\ time(Nt) = \frac{Gross\ production}{Base\ quantity}$$

$$= \frac{205{,}920\ Pack}{30.55\ PPM} = \mathbf{6739.19}$$

- ✓ During the studied production period, there were 324,055 rejected products due to underfill, overfill, crown problems, and dirt. From this the net value-added operating time is;

$$Value - adddes\ operating\ time(Vt) = \frac{Net\ production}{Base\ quantity}$$

$$= \frac{196{,}335\ pack}{30.55\ PPM} = \mathbf{6425.5\ min}$$

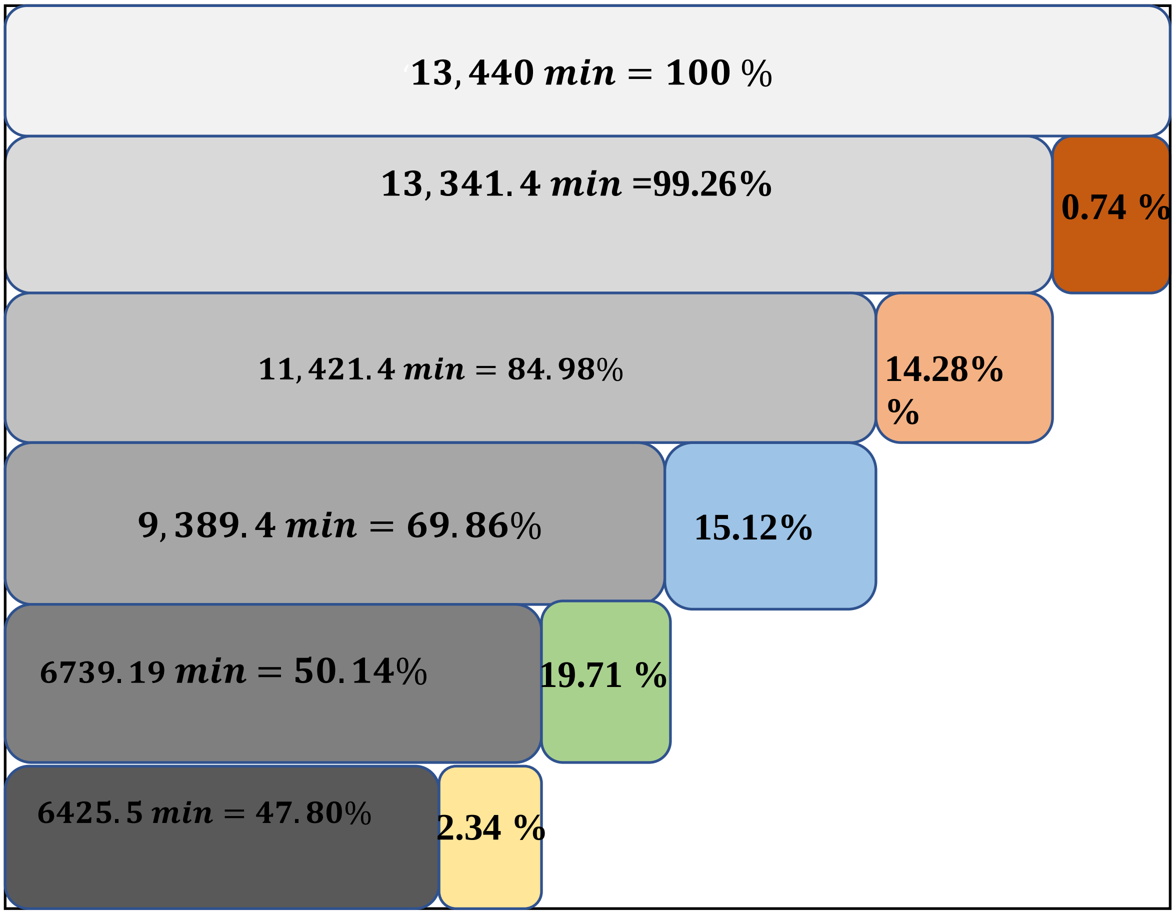

Figure 4.5 Line loss analysis structure of the studied production duration

OEE calculation

OEE is calculated by multiplying availability, performance, and quality rate of production for a certain period of the production line.

$$OEE = Availability * Performance * Quality$$

The availability rate is a ratio of total operating time to planned production time which takes both planned stoppages like setting up time, adjustment time , time for cleaning, and unplanned stoppage into account. If there is neither planned nor unplanned stoppage it can be said that the line is operating at a 100% availability rate which means its producing products full-time.

$$Availability\ rate = \frac{Net\ operating\ time}{Loading\ time} * 100\%$$

$$= \mathbf{59}\ \%$$

Performance rate measures how effective the production equipment is used. It is a ratio of net operating time and operating time by considering the idle time of the machines, minor stoppage, and speed losses.

$$Performance\ rate = \frac{Net\ operating\ time}{Operating\ time} * 100\%$$

$$= \mathbf{71.77}\ \%$$

Quality rate calculates the production lost due to rejected products that do not meet the quality standard of sealable products. It is a ratio of value-added production time and total operating time or a ratio of net good product and gross product.

$$Quality = \frac{Actual\ output - Number\ of\ reject}{Actual\ output} * 100\%$$

or $$Quality\ rate = \frac{\text{value−added operating time}}{Net\ operating\ time} * 100\%$$

$$= \mathbf{95.34}\ \%$$

And finally, the OEE value can be found by multiplying the rate of the three components; availability rate, rate of performance, and quality rate.

$$OEE = Availability * Performance * Quality$$

OEE =59 % * 71.77 %* 95.34%= **40.37%**

From the above OEE calculation and OEE factors, it is observed that there is an excessive downtime loss that is beyond the target downtime, this is due to both planned and unplanned activities. Since planned downtime (shut down) losses are for the necessary actions or events that are required for a smooth, continuous, and quality production process, they are not included in line OEE analysis.

As one of the manufacturing industries which is building a better company profile, EABSC is also striving to become a world-class organization (WCO). But as far as production bottlenecks are hindering the production performance and lowering the OEE value of the production line it gets tougher to even fulfill the production performance target of the company itself. Figure 4.6 compares the OEE result of the current production line with OEE value company’s target and world-class organization which confirms the need for production line improvement.

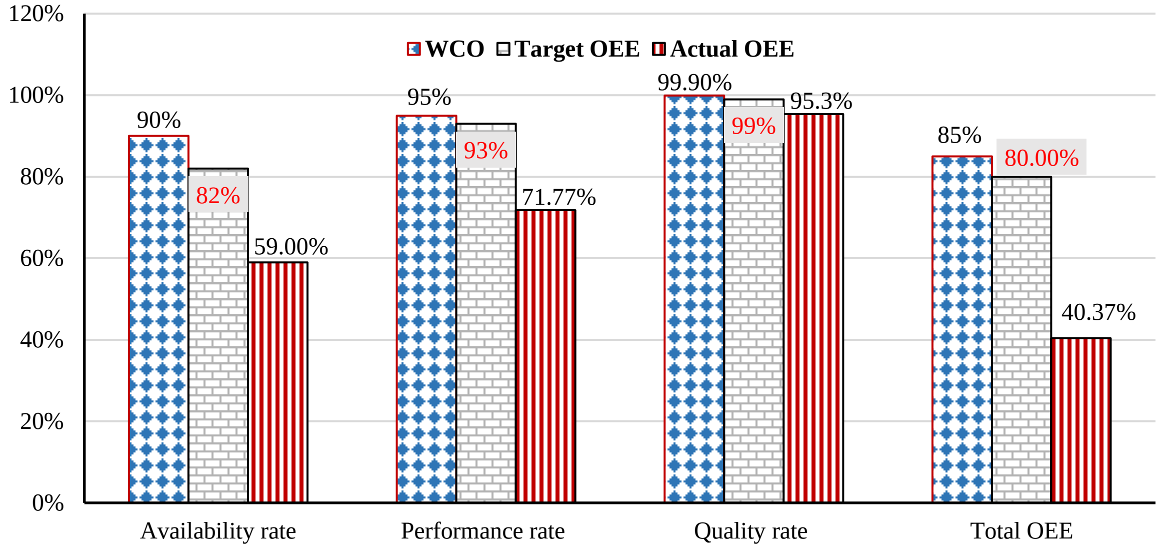

Figure 4.6 OEE value comparison between actual, planned, and world-class

This OEE analysis provides necessary information for further bottleneck analysis and narrows the focus area for tackling the problems, improving line efficiency and performance to drive down the operational costs and improve the profitability of the company. Mainly losses that OEE analysis takes into consideration are unplanned downtime loss (availability rate), the time loss due to short stoppage or speed reduction (performance rate), and time loss due to rejecting a product (quality rate).

Comparing the effect of the three factors on the overall equipment efficiency, the availability rate is shown to be responsible for the higher time loss of the line.

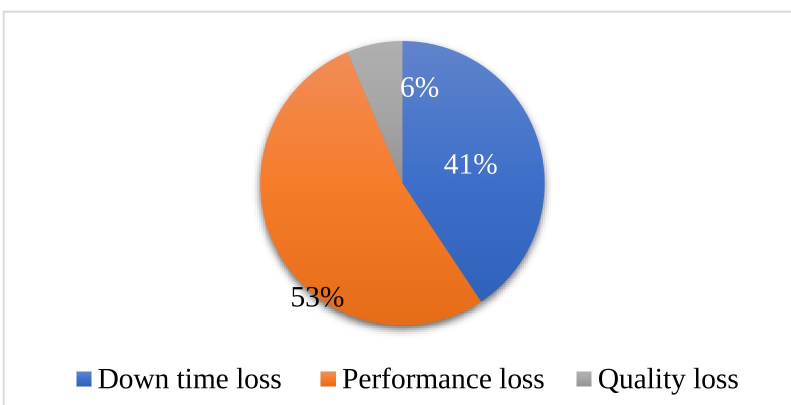

Figure 4.7 Loss comparison between OEE factors

From Figure 4.7, it is clear that unplanned downtime like equipment failure and other unplanned activities and short stops are contributing morethan 90% of total time loss of the production line while loss is contributing only 6 % of the total unplanned time loss. From the pie chart in Figure

4.7 presenting the result of the production time loss analysis, it is observed that potential production bottlenecks are the result of time loss due to unplanned downtimes and shortstops in the production line. There higher downtime loss and lower availability rate indicate that there is huge room for production performance improvement if the cause of machine downtime is identified and eliminated.

4.3.2 Bottleneck analysis

Bottleneck identification

The main objective of this research paper is to identify and eliminate production bottlenecks of a production system and to investigate better methodology for continuous improvement of productivity and production performance.

Bottleneck analysis of a production line is necessary because bottleneck machine or process is due to which productivity is diminished and one RGB line of EABSC Addis Ababa plant was selected as a case study for line OEE calculation and other analysis. The OEE analysis done earlier helps the researcher to select the focus area of production loss to find the real and potential production bottleneck of the production process.

Production lines in beverage industries are complex and continuous production system producing thousands of products per hour, the machines are designed to operate at high speed, they are fully automatic and PLC controlled. Hence the type of production line, data availability (reliability and accuracy of data), and the desired result have to be taken into consideration while choosing the bottleneck identification method. Choosing a bottleneck identification method is a critical step toward bottleneck management. since it is a cornerstone in determining the real production bottlenecks, failing to have the right bottleneck identification method may lead a researcher to the wrong conclusion.

As the OEE analysis done earlier shows, the performance of the production line under study is mainly affected by the availability rate, thus analyzing the availability rate of every station has been taken as one of the bottleneck identifications. Availability analysis also guides the measurement of machine utilization. In addition to determining the momentary and real-time bottleneck of the production line active period bottleneck identification method was utilized because it is the best approach suggested for the continuous production lines with the complex production system in the previous research works. And to consider the presence of starvation and blockage arrow method has been used and the results of all this analysis were further evaluated by production line simulation analysis. Using different bottleneck identification methods might take time and be difficult to conduct but it increases the reliability and accuracy of the result.

A. Availability analysis

Availability rate analysis is studied with the main objective of finding the station with major breakdowns causing production losses to the company. From the result of the analysis, it is possible to determine the bottleneck station so that countermeasures can be executed to reduce the root cause of the problems and improve the station performance.

Working time, planned stoppage, unplanned stoppage, planned working time, and actual working time of every station(machine) for 28 shifts of the production line needed for availability analysis has been collected by the machine operators using stopwatch and machine HMI's and presented in data collection section of the study. The availability rate analysis of a machine mainly uses machine downtime to measure productivity losses. Any event causing stoppage of planned production for a certain period are lead from machine downtime, thus downtime is the biggest factor that directly affects the availability and utilization of a machine. Even though planned downtimes are also parts of downtime, since they are a necessary planned event their occurrence doesn't affect the OEE of the production line. So, in this availability analysis only unplanned downtime is considered machine downtime.

According to availability analysis in the bottleneck identification process, a station that exhibits the least availability rate of all is taken as the one that is hindering the productivity and production performsnce of the line, the bottleneck station.

Machine downtime can result from three major stoppages at a particular station:

- ✓ Starvation – stoppage due to a lack at the infeed of a particular machine, mainly caused by lack of raw material of a particular machine , failure or stoppage its preceding machines.
- ✓ Machine failure – stoppage due to long- or short-term equipment failure at the particular station.
- ✓ Blockage - stoppage due to a backup at the discharge of a particular machine, mainly caused by failures or stoppage of succeeding machines.

Machine downtime analysis (DTA)

The major factor affecting machine availability is downtime, that is why it is essential to consider DTA when availability analysis is conducted. For any plant, operational management downtime analysis (DTA) is an important tool used to have an understanding of the underlying issue affecting plant availability and rate loss.

The downtime of a machine is measured by recording the total time in which the machine (equipment) has broken down during a certain specific time of the study. Besides providing input data for availability analysis this analysis can be also used to indicate the bottleneck station of the production line. But in this study its main objective is to support the availability analysis.

A station with a higher number of downtimes affects the productivity of a production line by blocking and starving the preceding and succeeding machines respectively. Therefore, a machine with the highest downtime has a high probability of being a bottleneck station of the production line especially if the downtime due to inheritance failure is greater.

Table 4.1 Downtime loss due to starvation, blockage and inheritance failure

Station	**Downtime due to starvation(min)**	**Downtime due to machine failure (min)**	**Downtime due to blockage (min)**	**Total downtime (min)**
Unpacker	105	176	382	663
Washer	227	187	82	496
Krones Filler	315	1,287	208	1,810
KHS Filler	354	1,114	152	1,620
Packer	290	276	53	619

The total downtime of every station in the production line due to starvation, blockage, and inheritance machine failure has been analyzed under Table 4.1, and the chart in Figure 4.8 compares the downtime loss of every station.

From the down time loss analysis KRONES and KHS filler machines are observed to have the highest down time of all the stations mainly because of machine failure. But for the unpacker and washer, the machine time loss due to blockage affects the total down time more than the other two while starvation provides the highest down time loss for the unpacker machine. Even though the downtime analysis result identifies the two filler machines to be the bottleneck station of the line further study is needed for the exact answer.

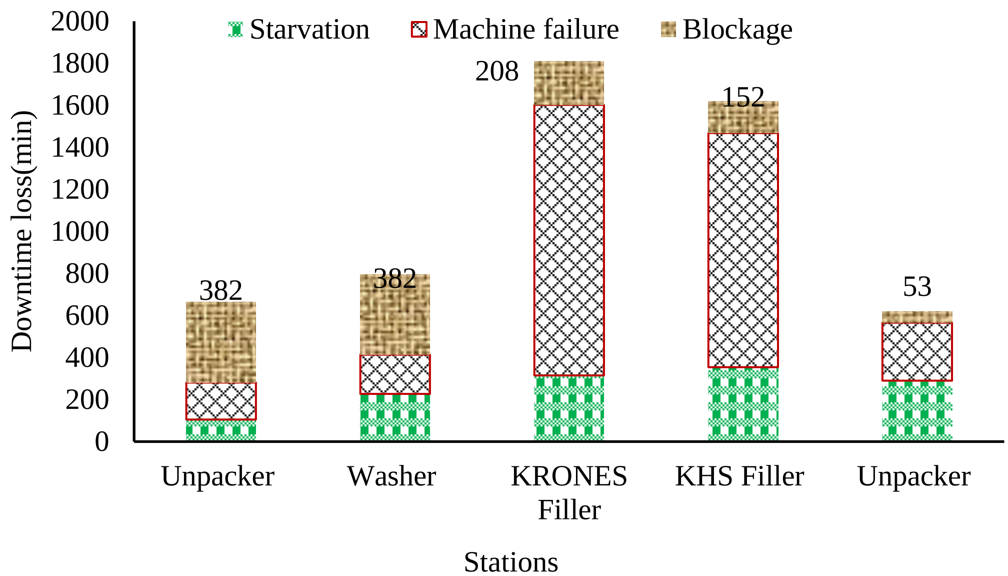

Figure 4.8 Comparison downtime loss analysis

When coming to machine availability calculation, the working time of the production line is taken as the working time of all stations because to say the production line is running then all stations must be in operation.

$$\text{Working Time (Wt)} = 222.567\ hrs = \mathbf{13,341.4}\ \boldsymbol{min}$$

But when calculating availability analysis unplanned downtime considers time loss due to supply chain way, which means time loss due to problems caused outside of production line or in other support departments like utility, logistics, sales, and others. Because they bring sudden and unplanned stoppages and directly affect the performance of the production line.

The availability rate of the unpacker machine has been calculated in detail underneath as an example.

Availability calculation on unpacker machine;

$$Downtime\ loss(DTL) = \text{Starv} + \text{MF} + \text{blkg} + \text{SCW} = 705\ min$$

Where; Starv – Starvation , MF – machine failure ,blkg – blockage and SCW – supply chai way.

$$\text{Actual working Time} = Planned\ working\ time - Downtime\ loss(DTL)$$

$$= 13{,}341.4\ min - 705\ min = 12{,}636.4\ min$$

$$Availability\ rate = \frac{Actual\ working\ time}{Planned\ working\ time} * 100\%$$

$$= \frac{12636.4}{13341.4} * 100\% = \mathbf{94.71}\%$$

By using the same procedure availability rate of every station has been calculated and presented under Table 4.2.

Table 4.2 Availability rate of every station

Station	Total downtime loss	Actual working time	Availability rate
Unpacker	705 min	12636.4 min	91.71 %
Washer	1186 min	12155.4 min	88.11 %
KRONES Filler	2032 min	11309.4 min	74.77 %
KHS Filler	1780 min	11561.4 min	76.77 %
Packer	647 min	12694.4 min	93.15 %

From the conducted machine availability analysis, both filler machine exhibits the least availability rate with 74.77% and 76.77 % while the unpacker has the highest availability rate of 93.15 %. This shows the stoppage of the filler machine due to unplanned downtime affects the low OEE value and ill performance of the production line. Hence according to availability analysis both filler machines are identified as bottleneck stations of a production line.

B. Active period bottleneck identification method

Active period bottleneck identification method is also utilized in this study since it indicates both real-time and historical bottlenecks of the line. Besides, active time period, average active time period, and average waiting time bottleneck identification method has been exploited in many other types of research works alternatively depending on the characteristics of production lines and type of data available yielding parallel result. For the production line under study out of the three approaches, the active time period is suitable because of the serial and complex manufacturing system of the production line, and the real-time and historical data was available to be collected. But mainly this method has been suggested by many scholars as an appropriate bottleneck identification method to detect real-time production bottlenecks of continuous production lines like production lines of beverage industries.

The active period measures the time in which a machine is active continuously without any interruption. The main activities of a machine are production, waiting for another machine, repair, or tool replacement. But the active time of a machine is only the time that the machine is producing, in repair, changing tools, or is being serviced but not either waiting for infeed or blocked at its discharge. Processes or stations with the longest average active time are the so-called bottlenecks in this approach and temporary bottlenecks are stations with the longest instantaneous active periods. These methods use extensive process data but it’s ideal to detect momentary and real-time production bottlenecks because the production bottleneck is the machine with the longest uninterrupted active period at a given time.

The active period of every station is different since the activities performed in every machine are different. For unpacker, washer, and packer machines the active period includes the time duration that the machines are in production and maintenance since there is no setup, adjustment, and cleaning performed on these machines, but filler machines are required to execute cleaning every 48 hours and whenever there is a flavor change this cleaning is what is referred as CIP (cleaning in place). Therefore, the active period of a filler machine includes the time duration that the machines are in production, maintenance, and also in CIP operation.

Active period calculation of stations in production line;

$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$

Machine idle time can be the time the machine stays unproductive resulting from time loss due to starvation, blockage, problems in other supportive departments, and activities in other machines, like cleaning (filler CIP).

Calculating the active period of every station in a production line,

Strv – downtime due to starvstion

Blkg – downtime due to blockage

SCW – downtime due to supply chainway

CIP – time taken for filler cleaning activity

- ✓ unpacker machine

$$Machine\ idle\ time(It) = Starv + Blkg + SCW + CIP$$
$$= 105 + 382 + 42 + 960 = 1489\ min$$
$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$
$$= 13{,}341.4\ min - 1489\ min = \mathbf{11{,}852.4\ min}$$

- ✓ Washer machine

$$Machine\ idle\ time(It) = Starv + BLkg + SCW + filler\ CIP$$
$$= 227 + 690 + 82 + 960 = 1959\ min$$
$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$
$$= 13{,}341.4\ min - 1959\ min = \mathbf{11{,}382.4\ min}$$

- ✓ KRONES Filler machine

$$Machine\ idle\ time(It) = Starv + Blkg + SCW$$
$$= 315 + 222 + 208 = 745\ min$$

$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$

$$= 13{,}341.4\ min - 745\ min = \mathbf{12,596.4\ min}$$

✓ KHS Filler machine

$$Machine\ idle\ time(It) = Starv + Blkg + SCW$$

$$= 354 + 158 + 154 = 666\ min$$

$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$

$$= 13{,}341.4\ min - 666\ min = \mathbf{12,675.4\ min}$$

✓ Packer machine

$$Machine\ idle\ time(It) = Starv + Blkg + SCW + filler\ CIP$$

$$= 290 + 28 + 53 + 960 = 1775\ min$$

$$\text{Machine active time(At)} = \text{Working Time (Wt)} - Machine\ idle\ time(It)$$

$$= 13{,}341.4\ min - 1775\ mnin = \mathbf{11,566.4\ min}$$

Table 4.3 compares the active period of every station and Figure 4.9 present result of the analysis graphically.

Table 4.3 Total active period of every station

Station	Machine idle time	Machine active time	Active period percentage
Unpacker	1489 min	11,832.4 min	88.81 %
Washer	1959 min	11,382.4 min	85.31 %
KRONES Filler	745 min	12,596.4 min	94.4 %
KHS Filler	666 min	12,675.4 min	95 %
Packer	1775 min	11,566.4 min	86.69 %

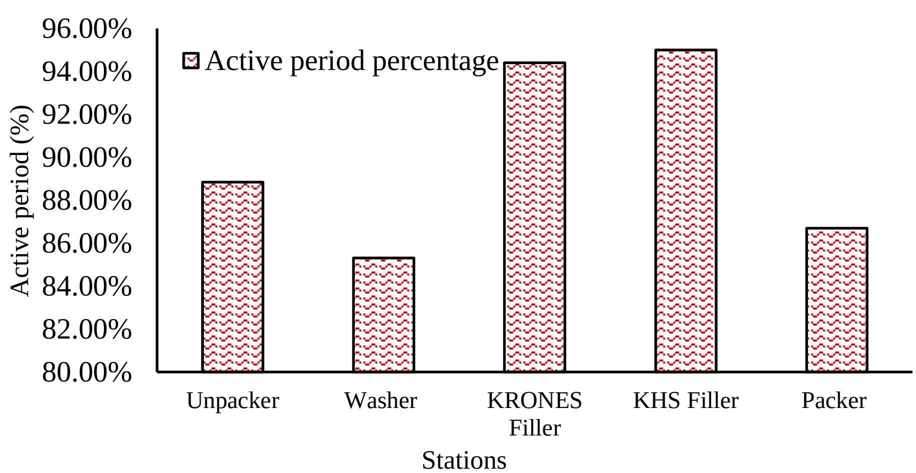

Figure 4.9 Comparison of the active period of stations

From the above figure, the duration of the active period of KHS and KRONES filler shows the highest percentage of 95 % and 94.4 % respectively where the washer and packer are stations with the least active period percentage. According to the active period bottleneck identification method, the result implies both filler machines are the bottleneck stations of the line.

C. Arrow or turning point bottleneck identification method

Identifying production bottlenecks using blockage and starvation analysis lets the researcher to considering the buffer capacity of the line which helps to indicate the bottlenecks caused by starvation and blockage of a serial production line like the case study production line.

The arrow method or turning point method is a method of bottleneck identification through observation of mutual blocking and waiting of processes. A process or a station whose share of the work time is the largest of all the neighboring processes is a turning point. Longer process waiting time than blocking time indicates the absence of a turning point, in such case the bottleneck is considered to be the first process. Otherwise, the last process will be the bottleneck. But in the presence of a turning point, a station preceded and followed by a station with the highest blockage and starvation time respectively can be taken as a bottleneck of the production line.

However, this method cannot be used alone to indicate the real-time production bottleneck for the reason that it only indicates the most likely bottlenecks but for any sequential production system which comprises buffer accumulation in between stations, observing starvation and blockage leads to accurate identification of production bottleneck.

To perform this analysis the percentage of time loss due to starvation and blockage of every station has to be calculated by using production time loss (unplanned downtime) data. For this analysis both KHS and KRONES filler are considered as a single station since they share downstream and upstream machines causing a lack of infeed and back up at discharge. Thus, filler starvation and blockage percentage will be calculated by using their average and total starvation and blockage time of the stations are presented in Table 4.4.

Table 4.4 Total starvation and blockage time of stations

Station	**Starvation percentage**	**Blockage percentage**
Unpacker	4.4 %	10.77 %
Washer	11.7 %	29.20 %
Filler	12.2 %	10.4 %
Packer	20.15 %	1.18 %

The bottleneck identification using the arrow method is based on the frequency of a process or a station being starved or blocked. According to this method, if the time loss due to production blockage of the machine (m_i) is larger than the time loss due to production starvation of the next machine (m_{i+1}), then the downstream of the machine (m_i) is said to be the production bottleneck. Meanwhile, if the time loss due to production starvation of machine (m_i) is larger than the time loss due to production blockage of the next machine (m_{i+1}), then the upstream of the machine (m_i) is said to be the production bottleneck.

Figure 4.10 explains the arrow bottleneck identification method for dynamic manufacturing systems like RGB bottling lines using the case study production line as an example. Therefore, according to the arrow method concept, it can be concluded that filler is the primary bottleneck in the production line since it is the downstream machine for the washer and upstream for the packer by considering the unpacker, washer, and packer to be non-bottleneck stations.

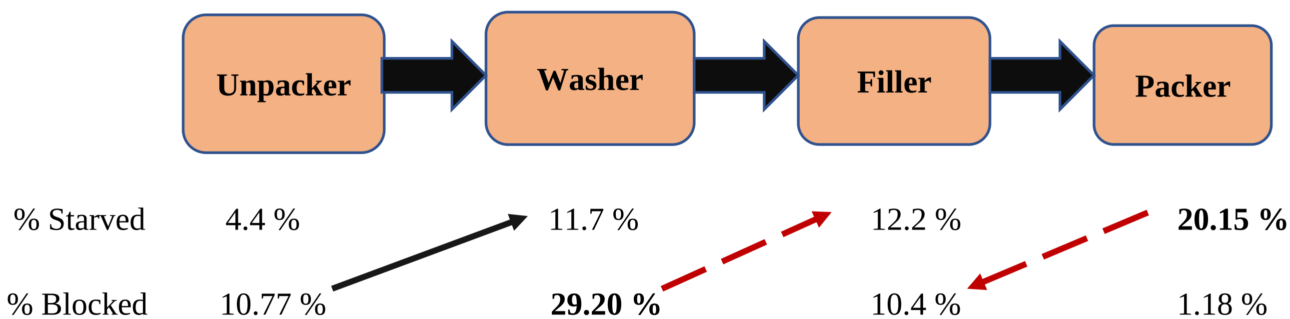

Figure 4.10 Turning point bottleneck analysis result

Bottleneck elimination

Now that the potential bottleneck is identified and some of the events that contribute to the losses due to this station have been studied further by focusing on ways to monitor and correct them with the necessary steps. From the start, the researcher has taken the TOC bottleneck management approach as a basic foundation of the study. The very fundamental notion of the theory of constraints (TOC) is that the entire production system capacity of a business depends on the capacity of its constraint. Thus identification and management of this constraint is its main purpose because it is more effective to utilize the constraint rather than focusing on individual components and processes.

To do so Dr. Eliyahu M. Goldratt proposed a systematic constraint management method called Five Focusing Step for continuous improvement of the production system by ensuring the transformation of the weakest links of the production system into efficient and effective resources.

The basic step of TOC is the identification of production bottlenecks, exploitation (elimination) of those bottlenecks, subordination, maximizing throughput, and return to the first step.

The first step which is production bottleneck identification has been covered in the previous section using different approaches and analysis tools to obtain an accurate result. According to the bottleneck identification method utilized, both filler machine of the production line has been detected as real-time bottleneck station affecting the overall productivity and performance of the filler machine.

And in this section reasons behind the production bottleneck and their elimination method has been studied. This stage also focuses on the elimination of all the time and resource loss that results from the occurrence of constraints in a production system. Several tools and methods have been utilized to come up with proper remedial action that should be taken to improve system efficiency by ensuring a continuous operation of the constraint with no additional cost.

A production system comprises a complex mix of processes, equipment, people, configuration, and coordination. Dealing with a bottleneck station, therefore, needs the identification of certain parameters which turn the station into a production constraint. If the causes and consequences of production constraints can be identified and studied, the productivity of the line could be improved easily. That is why the researcher utilizes different analysis tools to study the bottleneck station of the production line. To have a better perspective and improvement opportunities filler downtime data for fifteen months (1 1/4year) has been analyzed to find disturbance of the bottleneck station and its root cause.

This study identifies many production disturbances resulting in filler stations to constrain the performance of the production line and associated contribution in general lost time. Pareto analysis has been used to assess and arrange the disturbances according to their contribution to the total time and production loss.

Here under the Table 4.5, total filler downtime data of one year and a quarter is presented. Under this table causes for the downtime loss, the total downtime loss, and production loss are listed. For the sake of bottleneck analysis, the causes of downtime are classified according to their effect on the bottleneck machine which is filler. Based on this, since all the upstream machines lead to starvation on the bottleneck machine their downtime loss is under starvation loss and similarly, the downstream machines lead to the blockage of the fillers so their loss is categorized under blockage. But production time lost due to the failure of the filler itself is under the inheritance failure category. And downtime loss where the production line does not have direct control over is supply chain way downtime.

Table 4.5 Total downtime loss of filler machine over 1 1/4-year production duration

Loss type	**Duration (min)**	**Downtime %**	**Case lost (Pack)**
Depalletizer	150	10.83	4,000.00
Empty crate conveyor	536	6.66	14,294.40
Uncaser	3,136	11.92	83,627.20
Closure/crown feed	50	5.29	1,332.80
Empty bottle handling	2,466	9.03	65,760.00
Unscrambler	114	8.09	3,040.00
Filler	15,677	13.63	418054.40
Bottle washer	3,102	11.80	82,718.40
EBI	546	6.84	14,560.00
Blender/carbonator	3,303	20.25	88,078.40
Crowner	5,931	11.86	158,172.80
Full bottle inspection	53	3.84	1,412.80
Date coder	4,606	7.78	122,825.60
Case packer	1,795	9.32	47,862.40
Full bottle/can/ box	993	9.15	26,478.40
Full crate/case/box	46	3.20	1,227.20
Labor shortage/late (palletizer)	35	7.29	932.80
Component quality	5,083	32.24	135,539.20
Syrup room	1,143	5.91	30,488.00
Lab test	1,592	2.34	42,536.00
Glass bottle shortage	34,984	40.33	552,115.20
Start-up	2,330	3.23	62,052.80
CIP rinse	350	3.52	9,339.20
CIP 5 step	14,181	24.49	378,102.40
CIP 3 step	655	19.04	17,467.20
Size change	130	2.978	3470.70
External service supply	4,499	43.31	107,187.20

New line commissioning	9,395	21.14	250,528.00
Ware house	18,737	22.51	499,660.80
Planned stoppage	37,733	15.90	383,147.20

Total time loss due to starvation, blockage, inheritance failure of the filler as well as downtime due to supply chain way problems is calculated and presented in Table 4.6 for further bottleneck analysis.

Table 4.6 Comparing downtime loss due to starvation, inheritsnce failure, blockade and supply chain way problems

Loss type	**Duration (min)**	**Downtime %**	**Case lost (Pack)**
Starvation	9,916	57.07	261,330.0
Inheritance failure	25,075	59.12	668,678.4
Blockage	7,528	68.79	200,739.2
Supply chain way	130,812	79.61	2,474,633.9

Pareto analysis

A bar graph where the bars are arranged in descending order of height, starting at the left is called a Pareto chart, it also contains lines to represent the total cumulative values. This chart is a vital tool to perform Pareto analysis. Pareto analysis is a technique that helps the identification of major problems. According to pareto's analysis, 80% of problems can be traced to 20% of the cause. The main advantage of pareto analysis is that it helps to identify and determine the main cause or root causes of defects or problems by prioritizing them in descending order. It also provides common knowledge based on facts, instead of hunches, which results in gaining the cooperation of all problems involved. Therefore, in this study pareto chart was chosen to identify the 20% predominant downtimes that causes around 80% of total filler downtime so that it can be easier to study the root cause of major problems causing the highest downtime loss.

When it comes to bottleneck management in a beverage industry the existence of buffer accumulation in-between stations necessitates attention to be given to starvation, inheritance failure, and blockage occurrence due to the bottleneck station. Eventhough, downtime loss due to supply chain way problem is out of production control line, it also includes time loss due to necessary events and activities,thus its pareto analysis has been done to eliminate a biased result. With this fact in mind, the following tables and graphs presents the pareto analysis for the causes of filler downtime.

A. Starvation

Starvation is a condition occurring when a machine stays idled while waiting for infeed (product) from the preceding station, this can be induced by the stoppage of the preceding machine. In the case study line stations causing starvation on filler machine can be filler infeed conveyor, EBI, washer, washer infeed conveyor, packer and packer conveyor. A failure or any stoppage of that equipment may cause the filler machine to stop waiting for products. From Table 4.5, the total time lost because of these stations was isolated and calculated and it has been found that starvation contributes to 165.60 hours of downtime loss of filler machine which is 23.42 % of the total downtime.

Table 4.7 Filler downtime loss due to starvation

Cause	Downtime duration (min)
Depalletizer	150
Empty crate conveyor	536
Uncaser	3,136
Empty bottle handling	2,466
Bottle washer	3,102
EBI	546

Using the information under Table 4.7, pareto analysis has been conducted and the pareto chart in Figure 4.11 shows that unpacker, EBI, and bottle washer machines are the cause of 80% of the total downtime loss.

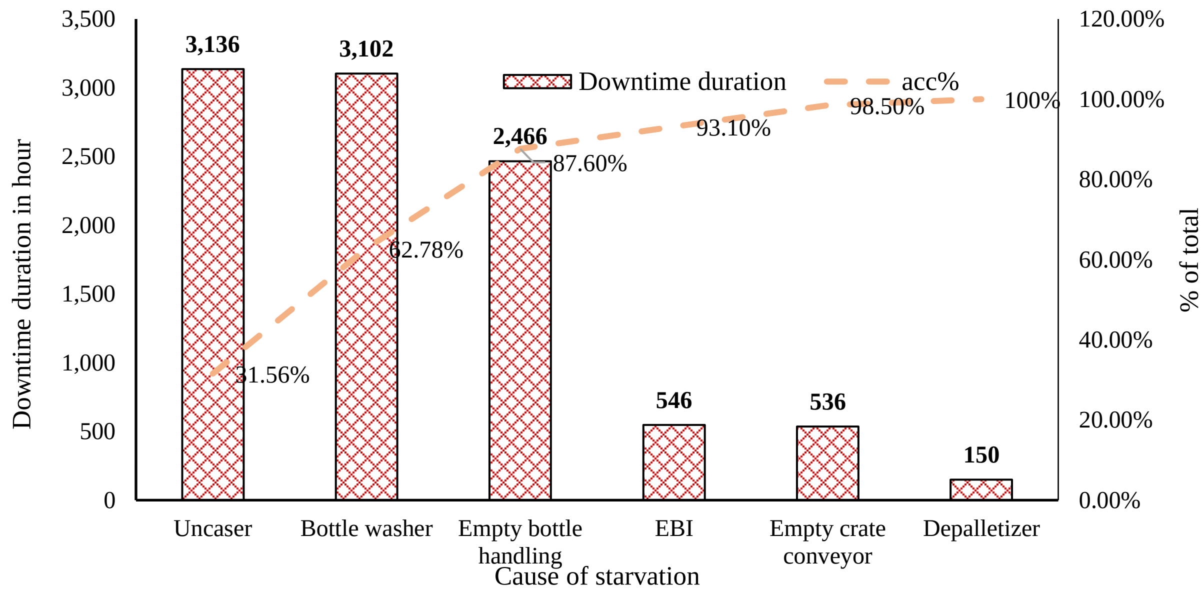

Figure 4.11 Pareto analysis of downtime due to starvation

This analysis implies that solving the root cause for problem occurring in unpacker, EBI, and bottle washer stations ensures a better and more effective productivity improvement. Therefore, the result of this analysis has been taken as an input for the bottleneck elimination step of bottleneck management.

B. Inheritance failure

Inheritance failure of equipment is a failure or problem that occurred in the machine itself, it is neither caused by the preceding nor the following machine. For making the analysis easier and complete and for the major reason that mixer and crowner are controlled by filler operator and HMI; they were considered as a subsystem of one parent machine which is filler. Thus, failure or stoppage of mixer, crowner, or filler machine creates an inheritance failure of filler machine. As it has been done for the starvation the total time lost due to these subsystems of the filler machine was isolated and calculated and it has been found that starvation contributes to 412.02 hours of downtime loss of the filler machine which is 58.83% of the total downtime.

Table 4.8 Filler downtime loss due to inheritance failure

Cause	**Downtime duration (min)**
Closure/crown feed	50
Unscrambler	114
Filler	15,677
Blender/carbonator	3,303
Crowner	5,931

Figure 4.12 shows that the total downtime loss due to inheritance failure of filler machine the filler and crowner machines were responsible for the 80% downtime loss.

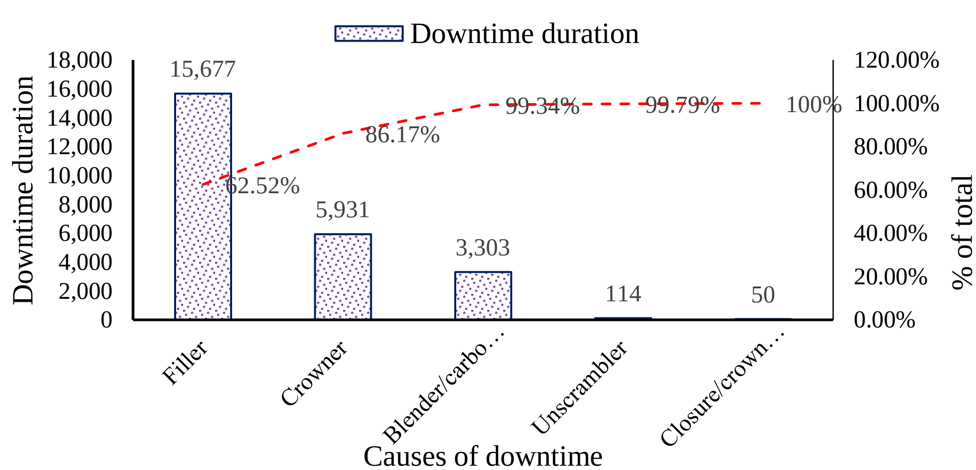

Figure 4.12 Pareto analysis of downtime due to inheritance failure

The Pareto analysis indicates that solving the root cause problem of filler and crowner breakdown ensures a better and more effective productivity improvement. And the ultimate use of the result of this analysis is to be taken as an input for the bottleneck elimination step of bottleneck management.

C. Blockage

Blockage in production is a state of a machine or station being blocked or restricted to produce goods due to a problem occurring in the station in front of the blocked one. In the line under study FBI, date coder, packer, full bottle, case conveyor, and palletizers are stations that could block the filler machine. From a year and quarter filler downtime data taken 17.75 % of filler, downtime is caused by blockage and the station responsible for it is listed in the table 4.9.

Table 4.9 Filler downtime loss due to blockage

Cause	**Downtime duration (min)**
Full bottle inspection	53
Date coder	3,606
Case packer	2,795
Full bottle conveyor	993
Full crate conveyor	46
Labor shortage/late (palletizer)	35

Using the above table Pareto analysis has been conducted and the Pareto chart of Figure 4.13 that the date coder and case packer are causing 80% loss of the total downtime loss.

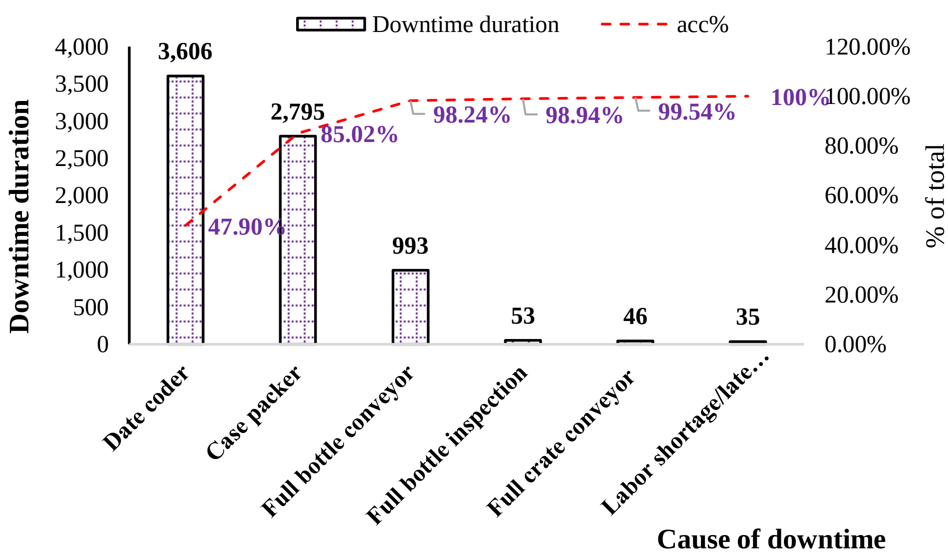

Figure 4.13 Pareto analysis of downtime due to blockage

The result of this analysis suggests solving the root cause problem of date coder and packer machines eventually leads to effective productivity improvement. And the ultimate use of the result of this analysis is also to be taken as an input for the bottleneck elimination step of bottleneck management.

Supply chain way factors shown in the Table 4.5 are classified as planned shutdown, planned downtime is the time used by the packaging line without production, according to the standards used in the production plan and they have not been included in line OEE calculation. Besides, external unplanned downtime is also excluded from OEE since this downtime is not caused by the operation of the packaging line itself. But if the efficiency of the organization itself were understudied it would have been necessary to take extremal unplanned downtime into account. Therefore, downtime loss due to the supply chain way includes all events that should be excluded from efficiency analysis because there was no intention of running production (e.g. problems in other departments' operations, scheduled maintenance, or periods where there is nothing to produce). In this study general thirteen supply chain way factors were identified, and from these factors major determinant contributors were isolated. Even if OEE line analysis calculation does not include these shutdown losses they have to be studied and ways to reduce these losses should be investigated.

Table 4.10 Filler downtime loss due to supply chain way problems

Reason	**Duration (min)**	**Downtime %**	**Case lost (pack)**
Glass bottle shortage	34,984	40.33	552,115.2
Planned maintenance	23,045	20.248	233731.2
CIP 5 step	14,181	24.482	378,102.40
No storage space	10,100	13.672	269,331.20
New line commissioning	9,395	21.143	250,528.00
Forklift – warehouse	8,637	8.839	230,329.60
No production scheduled	5,277	29.075	102326.4
Planned cycle counting	5,113	13.029	14745.6
Component quality	5,083	32.246	135,539.2
Planned autonomous maintenance	3,418	3.336	91145.6
Start-up	2,330	3.233	62,052.8
Utility supply (power interruption)	2,211	11.186	58,979.20

Lab test	1,592	2.339	42,536.00
Water treatment	1,364	13.693	23,569.60
Syrup room	1,143	5.91	30,488.00
CIP 3 step	655	19.042	17,467.20
Planned meetings	578	34.145	15,145.60
Refrigeration plant	530	5.142	14,132.80
LP compressor	354	4.833	9438.4
CIP rinse	350	3.518	9,339.20
Early shift end	302	18.661	8052.8
Size change	130	2.978	3470.7
Boiler (hot and steam)	30	3.125	800
CO_2 equipment / supply	10	5.335	267.2

Using the information in table 4.10, pareto analysis has been performed and glass bottle shortage, higher planned maintenance, CIP requirement, and warehousing (storage space insufficiency and forklift malfunction) were the identified major planned production disturbance, so they are considered to be the most important loss to reduce. Planned line commissioning is also one of the major factors in shut down losses but since it was a very critical improvement for the line and took only the time that was planned for it, it was not considered as a loss.

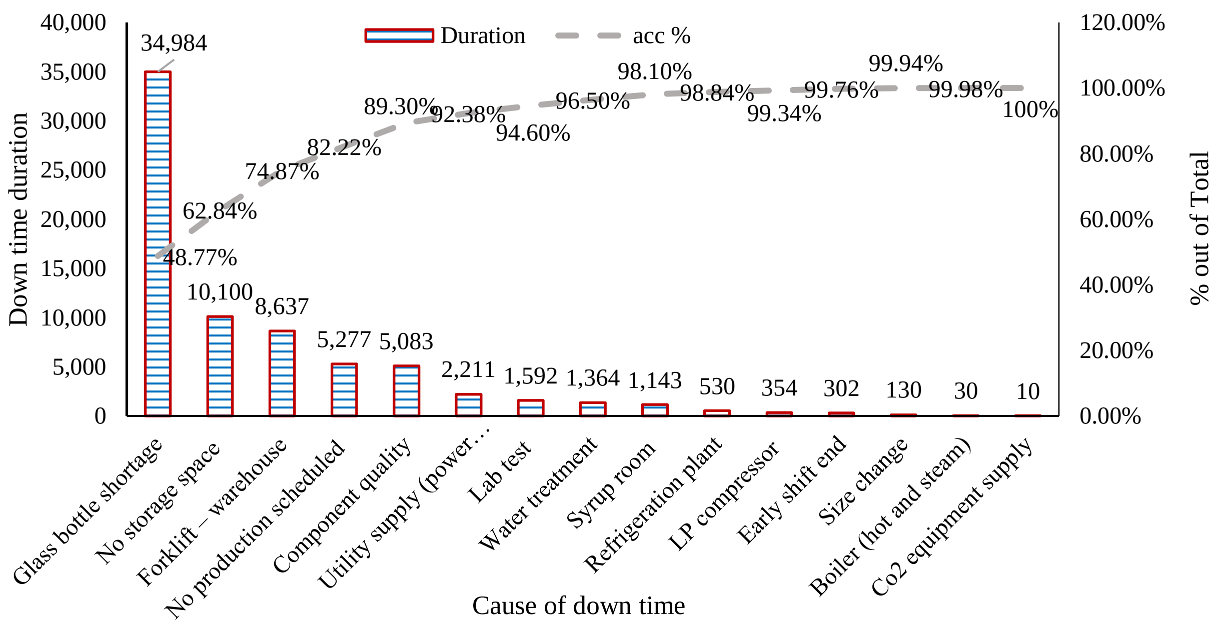

Figure 4.14 Pareto analysis of filler downtime due to supply chain way

Therefore, addressing the root cause of major time loss due to problems caused by factors outside of the production line also ensures better productivity improvement of the production line.

Root causes analysis

Once a major stations contributing heavy downtime loss to the filler machine were identified (disscused under bottleneck analysis section), the frequent problems or breaks downs of those stations should be explored (data extracted from SAP) , thus the result of the pareto analysis needs to be analyzed for determination of possible root causes of the breakdowns**.** Thus, the next step is to find out the root causes for the major concerning areas. For this, the brainstorming session was held and root cause analysis (five why the analysis) was utilized for this bottleneck elimination step.

Five why analysis

Five why the method is referred as the ultimate root cause analysis tool which helps a production team to focus on finding the root cause of any problem. This analysis is done in a brainstorming session where team members are sharing ideas to eliminate recurring failures and problems caused in a production line. The five why the method is structured by an iterative interrogative question to explore the cause-and-effect relationship underlying a particular problem, and the primary goal of this technique is to determine the root cause of a problem by repeating the question “why?”.

The researcher used this analysis tool to investigate the root cause problem so that countermeasures and remedial action can be suggested and improved production line performance can be achieved.

The root cause of problems causing filler machines to starve, fail, and the block is studied by using both historical (1 ¼ years) downtime data and two weeks of real-time production data taken from the production line. This enables the study to consider the historical and current issues that arise in the production line allowing a researcher to propose a well-organized and applicable countermeasure.

An example for five why analysis is given in Figure 4.15 and a root cause of all major problems have been studied using the same procedure.

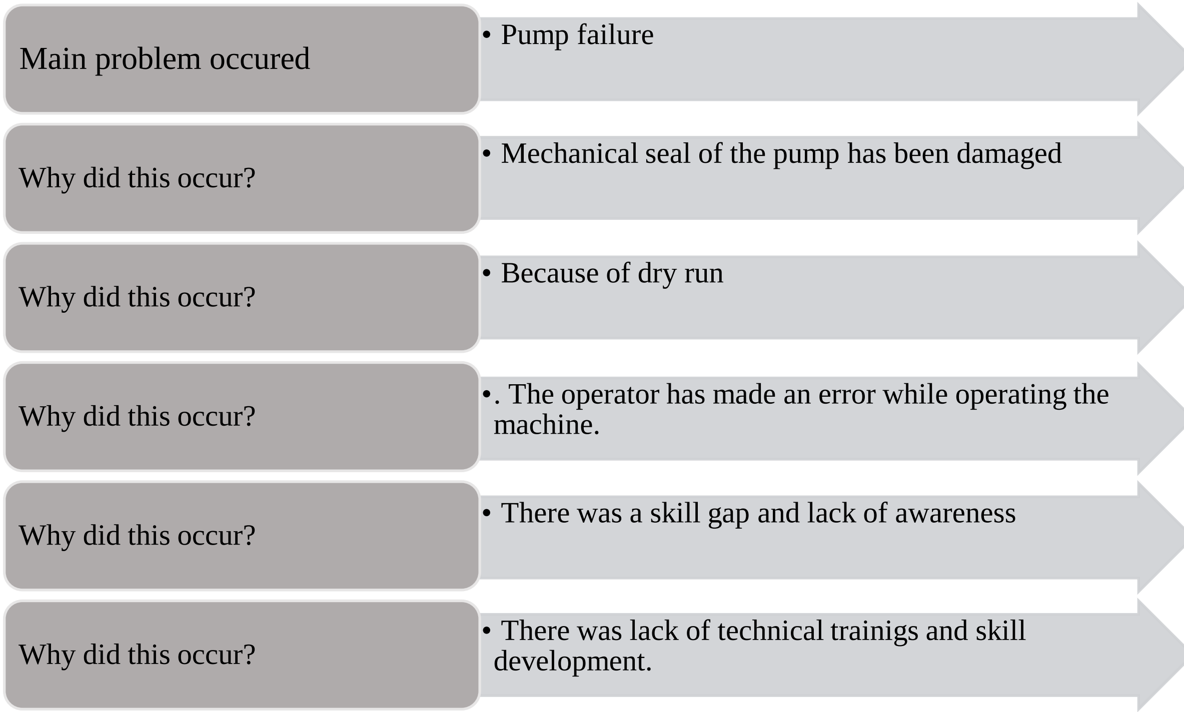

Figure 4.15 Five why analysis of pump failure *(Olivier Serrat , 2017)*

Frequent problems causing major downtime loss of filler machine were recorded in the stations and their root cause has been investigated using the five why technique and it is summarized under the following tables (from Table 4.11 to Table 4.19) along with their remedy actions.

Table 4.11 Root cause analysis of major problems of unpacker machine

Frequent problems	**Root cause**	**Remedy action**
✓ Unpacker transfer plate malfunction	✓ Used over its designed lifetime	✓ Replace by the new one on time ✓ Conduct proper preventive maintenance
✓ Electrical malfunction	✓ Lack of proper overhaul	✓ Plan periodic overhaul maintenance
✓ Unpacker conveyor malfunction (bearing adjustment)	✓ Infeed drive is under the required capacity	✓ Change the drive system from chain drive to direct the drive system
✓ Unpacker gripper adjustment fault	✓ Due to deformed carets	✓ Check the quality of caret used ✓ Dispose carets under quality

		✓ Have spare for gripper
✓ Case conveyor malfunction (case stack)	✓ Due to deformed carets	✓ Check the quality of caret used ✓ Dispose carets under quality ✓ Have spare for gripper

Table 4.12 Root cause analysis of major problems of the washer machine

Frequent problems	Root causes	Remedy Action
✓ Washer electrical problem	✓ Lack of proper overhaul	✓ Plan periodic overhaul maintenance
✓ Infeed time malfunction	✓ Due to unsorted bottle entering to infeed carrier	✓ Give awareness to operators to attentively follow the movement of every bottle to the infeed
✓ Washer water level	✓ Automatic regulator valve damaged	✓ Replace by new one on time
✓ Caustic temperature too low	✓ Due to problem of boiler under utility	✓ Create a better communication with utility department
✓ Infeed bottle guide problem	✓ Lack of proper overhaul	✓ Plan periodic overhaul maintenance ✓ Do proper guide adjustment
✓ Pump failure	✓ Bearing or mechanical seal used over its designed life time	✓ Always conduct proper autonomous maintenance every shift

Table 4.13 Root cause analysis of major problems of empty bottle conveyor

Frequent problem	Root cause	Remedy action
✓ Empty bottles conveyors worn & stacked	✓ Lack of proper maintenance and cleaning	✓ Perform appropriate preventive maintenance and cleaning.
✓ Conveyor bearing problem	✓ Used over its designed life time	✓ Replace by new one on time

		✓ Conduct proper preventive maintenance
✓ Bottle falling on infeed and discharge conveyor	✓ Lack of lubrication and guide adjustment problem	✓ Always check conveyer has sufficient lubrication. ✓ Always check if foreign objects (bottle,closure) has stacked in conveyer lanes and guides. ✓ Always check the guide is adjusted correctly.
✓ Synchronization problem	✓ Lack of experience	✓ Work on technical skill development of employees
✓ Chain and sprocket problem	✓ Aging, quality and lack of lubrication	✓ Perform quality inspection of incoming materials for every spare ✓ Always check conveyer has sufficient lubrication. ✓ Replace aged parts by new one on time
✓ Electrical problem	✓ Lack of proper overhaul	✓ Plan periodic overhaul maintenance

Table 4.14 Root cause analysis of major problems of filler machine

Frequent problem	Root cause	Remedy action
✓ Filler discharge bottle falling	✓ KHS filler - due to vibration ✓ Krones filler -due to discharge guide adjustment	✓ Perform appropriate preventive maintenance and condition-based maintenance (CBM) ✓ Do proper mechanical adjustment
✓ Star wheel and guide adjustment problem	✓ Used over its designed life time	✓ Replace by new one on time

		✓ Conduct proper preventive maintenance
✓ Under fill correction (why does it take more time to correct underfill?)	✓ Low CO_2 pressure from CO_2 plant	✓ Create a better communication with utility department
✓ Centering bell adjustment problem	✓ Infeed star adjustment problem	✓ Perform proper inspection during CIP and maintenance activities
✓ Filler infeed worm gear and stoper malfunction	✓ Used over its designed life time	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock
✓ Filler timing problem	✓ Damaged bottle handling inside the machine and operational negligence	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock ✓ Follow the operation of the machine attentively
✓ Filling malfunction (underfill and 0foaming)	✓ Low sterilize air pressure ✓ Low product temperature ✓ Carbonation problem	✓ Create a better communicating system with utility department
✓ Filler sensor problem	✓ Due to water ingress during cleaning	✓ Follow appropriate step while performing cleaning
✓ Worn snifter cam	✓ Bottle burst	✓ Inspect quality of incoming bottles
✓ Filler opener problem	✓ Bottle burst	✓ Inspect quality of incoming bottles

Table 4.15 Root cause analysis of major problems of crowner machine

Frequent problem	Root causes	Remedy action
✓ Crown crimping adjustment problem	✓ Due to worn out bottle sit pad and neck adjustment	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock
✓ Bottle seat pad belt loses	✓ Seat pad worn out	✓ Replace by new one on time ✓ Conduct proper preventive maintenance
✓ Cork clamp malfunction	✓ Used over its designed life time	✓ Replace by new one on time
✓ Crown turner problem	✓ Due to deformed crown	✓ Inspect quality of incoming bottles
✓ Bottle breakage	✓ Improper crowner height adjustment	✓ Inspect quality of incoming crowns
✓ Cork stoper problem	✓ Stoper worn out and it frequently loss	✓ Perform proper preventive and autonomous maintenance
✓ Crowner plunger bolt problem	✓ Lack of proper preventive maintenance	✓ Proper inspection of checklist

Table 4.16 Root cause analysis of major problems of blender

Frequent problem	Root cause	Remedy action
✓ Syrup pump rectification	✓ Used over its designed lifetime	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock
✓ Pump leakage	✓ Mechanical seal quality	✓ Perform quality inspection of incoming materials for every spare

✓ Air leakage	✓ Air house and pipe line quality	✓ Perform quality inspection of incoming materials for every spare
✓ Pump failure	✓ There was lack of technical trainigs and skill development.	✓ Facilitate proper technical and soft skill development programs
✓ Pump motor bearing failure	✓ Used over its designed life time	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock
✓ Mixing ratio problem	✓ Mixing pump used over its designed life time	✓ Replace by new one on time ✓ Conduct proper preventive maintenance ✓ Prepare enough stock

Table 4.17 Root cause analysis of major problems of date coder

Frequent problem	Root cause	Remedy action
✓ Poor date code printing	✓ Ink quality, moisture of the room and lack of proper follow up	✓ Perform quality inspection of incoming materials ✓ Attentively follow up the operation of the date code
✓ Poor ink quality	✓ Incoming inspection problem	✓ Perform quality inspection of incoming materials
✓ Date code adjustment problem	✓ Lack of proper follow up	✓ Attentively follow up the operation of the date code and prepare appropriate inspection of checklist
✓ Date code gutter fault	✓ lack of proper autonomous	✓ Attentively follow up the operation of the date code and prepare appropriate inspection

	maintenance and follow up	of checklist and assign a responsible operator
✓ Ink leakage	✓ lack of proper autonomous maintenance and follow up	Attentively follow up the operation of the date code and prepare appropriate inspection of checklist and assign a responsible operator

Table 4.18 Root cause analysis of major problems of packer machine

Frequent problem	Possible root cause	Remedy action
✓ Electrical problem	✓ Due to high vibration	✓ Tighten machine during autonomous maintenance
✓ Centering frame malfunction	✓ Lack of proper autonomous and preventive maintenance	✓ Proper inspection of checklist
✓ Packer leading frame problem	✓ Lack of proper autonomous and preventive maintenance	✓ Proper inspection of checklist
✓ Gripper misalignment	✓ Caret conveyor stacking and jamming	✓ Perform appropriate cleaning, lubrication and maintenance for the conveyors

Table 4.19 Root cause analysis of major supply chain way problems

Station	Frequent problem	Root cause	Remed`y action
Glass bottle shortage	✓ Lack of glass bottle	✓ Poor production planning (flexibility)	✓ Develop flexible production planning system
No storage space	✓ Lack of space for full goods	✓ Poor production planning (flexibility)	✓ Develop flexible production planning system

Forklift problem	✓ Forklift way blocked ✓ Forklift breakdown ✓ Forklift delay ✓ Electrical problem	✓ Poor forklift trafficking system ✓ Lack of proper forklift maintenance	✓ Develop better forklift trafficking system ✓ Schedule forklift maintenance time and execute proper maintenance activity
Utility power supply	✓ Power interruption	✓ Absence of UPS (uninterrupted power supply)	✓ Install UPS system ✓ Create a better communication with utility department

4.3.3 Simulation analysis of current production system

The study used OEE and simulation modeling tools to analyze the existing performances of the RGB production line. OEE was calculated and the results were below the OEE world class based on the existing data collected for 26 days as discussed earlier. The next step is to analyze the real system or production performance through simulation modeling, this step can be taken as a subordination stage of TOC bottleneck management strategy where the adaptation of the non-bottleneck station with the working pace of resources that constitute the bottleneck station. Simulation modeling used arena simulation modeling software to build and analyze the real system which helps as a comparison with OEE results.

The necessary data were collected from the company. The machine's function and the number of operators, processing time, machine capacity, production loss, conveyor length, and other data summary for RGB production line have presented in tables under the data presenetation section (refer section 3.3). Input, output data or performance indicators, and assumptions were considered.

The input data used for the simulation model are:

- ✓ Machine cycle/processing times;

- ✓ Machine set up time production plan (types of product, quantity of product to be produced);
- ✓ Machine and conveyor speed;
- ✓ Conveyor length;
- ✓ Machine /component failures;
- ✓ Production loss (reject and rework).

Output data/ performance indicators: To measure output data use the following performance indicators were used:

- ✓ Production/ Output quantity
- ✓ Amount of production lost
- ✓ Availability rate and yield

Loss is one of the equipment behaviors that occur as units are processed or transferred. This wastage can be expensive and dramatically impact system throughput and performance. The loss dialog in the machine/conveyor module allows the specification of the amount of product that is lost (wasted) during the operation of the machine. This lost product shows up in the production statistics and the yield statics. Loss can be specified in two different categories. Event-Based Loss only occurs when a specific event occurs. Production-Based Loss occurs whenever the device is producing the product. Table 4.20 shows the existing production base loss obtained from the company's RGB production line.

Table 4.20 Loss data of machines for RGB Line

Machines	Un-packer	Washer machine	Krones Filler machine	KHS filler machine	Date coder machine (1)	Date coder machine (2)	Packer machine
Production based loss (%)	0	0.002	5	4	0.002	0.002	0

Formulation and developing the model

The returnable glass bottle (RGB) production line is operating based on the market need for products. The glass bottle was returned to the company after being distributed to its customer. Areas taken for the modeling and simulation were the production section which contains an un-packer machine, bottle washer machine, two filler machines (Krones filler and KHS filler), two date coder machines, and a packer machine on the same line. The modeled system under consideration is a discrete parts manufacturing system. Parts used as raw materials for the manufactured product such as glass empty bottle and crowning corks). To optimize the system efficiency, all potential problems should be determined before developing the model. RGB Empty Glass Bottle was taken as an entity for simulation modeling. The working hour for the factory is divided into three shifts (8hrs per shift). The day shift ranges from 7:00 AM to 3:00 PM, the evening shift ranges from 9:00 PM to 11:00 PM, and the night shift range from 11:00 PM to 7:00 AM. This is the planned working schedule of the factory and the production time of the line for the three shifts 24hours. The line starts at 7:00 AM (morning) and the next day ends production at 7:00 AM (morning) without any break. But there were unplanned stoppages as shown in the tables from collected data which should be considered in the simulation model during the model development. The necessary parameter that should have to be fulfilled in arena package templates when building the model was;

- ✓ Machine type
- ✓ Percent of production-based loss
- ✓ Processing time (cycle/min, unit/cycle, unit/min)
- ✓ Capacity
- ✓ Scheduled stop
- ✓ Time to repair machine (unplanned downtime)
- ✓ Conveyor length, width, nominal velocity, unit density, and sensor position

Once the module has been built replication number, replication length, time unit, and base time unit are set from setup. Replication is a repetition of the arena simulation run.

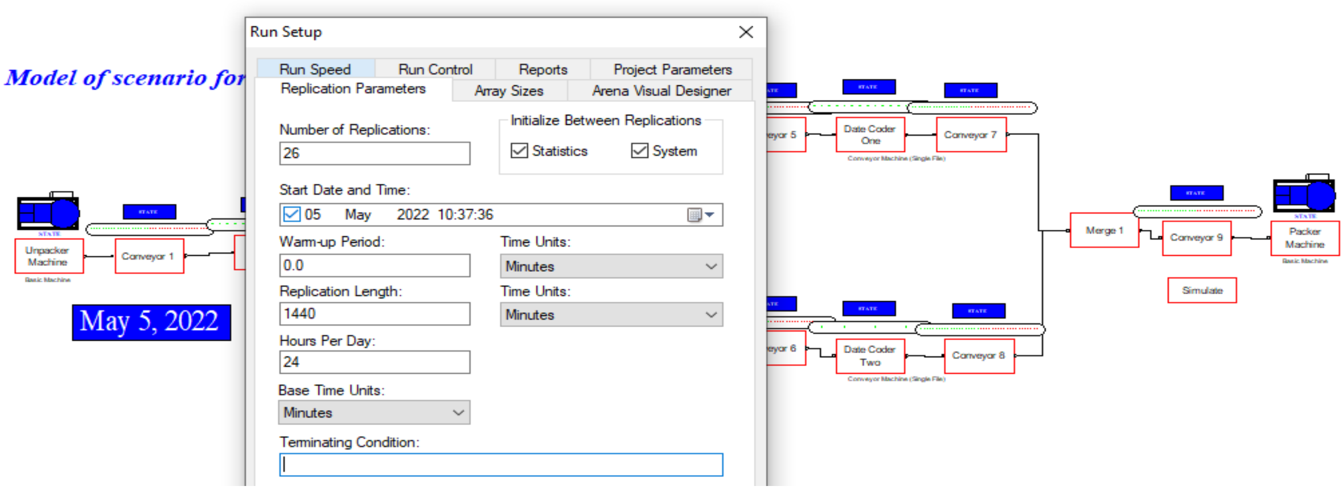

Figure 4.16 Run setup of the existing model

When the replication number increase, the accuracy of the simulation analysis results increases and becomes very approximate to the real output. Therefore, twenty-six (26) replications has been considered (which is equal to daily production collected for 26 days to calculate OEE) in the arena simulation model and the simulation finishs when the time to produce is finished. The replication length shows the terminating point of the running model. It also shows working hours per day which is equal to 1440 minutes. The maximum arena simulation model result shows the output of the production line per day. Since the company works three-shift or 24 hours per day, the arena simulation software shows a result of 24 hours (1440minutes). The base time unit is selected as minutes and it is shown in Figure 4.16.

Logic of Flow

Logic flow describes the way by which the entity acts during its journey in the simulation model. Many model developments were done before it reached the final model shown in the Figure 4.17, which has the same layout as the real production line (shown in figure 4.3).

The production process (sequence) of the product in the model is described as follows:

First empty bottles with crates are transported from the unloading station and loaded to the un-packer machine by chain conveyor. Each crate contains 24 bottles and the conveyor can hold and transport a double crate and goes sequentially to the un-packer machine. Then the un-packer machine separates the empty bottle from the crates by picking the bottles from the crate. The picking capacity of the machine is 240 bottles per one picking cycle. The un-packer machine then puts the empty bottles on the bottle washer machine feeding conveyor. Unclean empty bottles are then transferred to a bottle washer machine and cleaning is done by using different chemicals and distilled water and the dirty crate is also transported to the crate washing machine. After the crate is washed it is transferred to the packer machine via chain conveyor machine and waiting for the filled bottle at the packer machine. The washing process of empty bottles takes place in four consecutive stages to attain clean bottles before filling in the washer machine. The bottle washer machine has the capacity(designed) to wash 67000 bottles per hrs. But, the company most of the time adjusts 55200 bottles per hour by reducing the machine speed. Then filling operations followed. Two fillers machines are there on the production line. After the washing process is finished the cleaned bottle goes to two filler machines by two separate conveyors. Those filler machines are KHS and Krones filler machines. The KHS filler machine fills the 72 bottles per cycle (24000 bottles (designed) per hrs.) and the Krones can fill 91 bottles per cycle and 36000 bottles (designed) per hrs. After the bottles have filled the crowner machine caps the bottles. After that, the product manufacturing date and the expiration date are coded on the bottle around its neck by two separated date coding machines. Then the filled and decoded product is conveyed to the packer machine to put the product in the crate. The packer machine also picks 240 bottle products and puts them in the crate and then transported them to the palletizing via chain conveyor machine and then to the warehouse. The washed empty bottles are inspected and separated by manpower through the help of an empty bottle inspector before it arrives the filling operations and different inspection operations are done after filling and date coding to remove the dirty, unfilled bottle, overfilled, and an empty bottle.

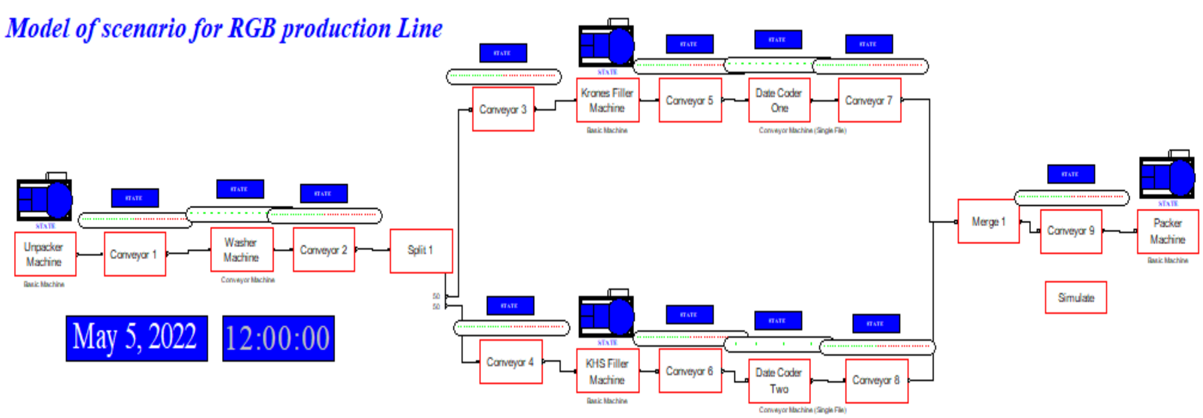

Figure 4.17 Simulation model of the existing production line

Modeling assumptions

1. The number of empty glass bottles is equal to the filled glass bottles (output of filler machine) for RGB production line.
2. For the modeling, machines such as; the capper machine and crate washing machine were neglected for RGB line; this is because those machines do not contribute much to the production losses of the line. The capper machine is inside the filler machine so it was considered a filler machine.
3. The modeling for RGB line includes stations from the unpacker machine to the packer machine which includes seven machines connected by a conveyor.
4. The beverage (syrup) comes from the process department (syrup room) to the blender machine, blender machine hasn't been considered in the simulation model also because its contribution to the production loss is negligible.

Model Verification and Validation

The model is built based on the existing configuration of the system so that its overall appearance resembles the actual system. One should be able to draw valid and acceptable conclusions from results by running the simulation models. Verification is the process to check that the model is running according to the modeling assumptions and answers the question: how do we build the model right? And validation is making sure that the behaviors of the model match the behaviors of the real system. According to W. David Kelton, the validity of modeled simulation is evaluated by comparing the actual production out put of the line and the simulation model of existing model. If the output of the real system and arena simulation model is approximate, the built model can be said valid. (W.D.Kelton, 1993)

Hence, when comparing the throughput of the actual production rates and the simulation model run results; it is observed that the actual daily production rate ranges from 500,000 to 600,000 bottles/ day (an average production of 543,752.307 bottles per day, refer table 3.1). The total daily production of the virtual model is 525,674 bottles/day: which is the total unit processed by the packer machine because it is the end machine of the production line. Therefore, since the result of the production rate for the virtual model approximates the rates for the production line or the company the simulation model is valid.

Multi Run Statistical Analysis

Although the single run reports indicate roughly the results of activities in the system, the result is not as reliable as that of the multi-run reports for statistical analysis, therefore a large number of runs are needed for the analysis of the purpose. The number of runs (replications) is 26 instead of one so that the system will reach the steady-state as stated above. The length of replication is defined as 24 hours per day each (and a total of 26 working days). Initialization of the system and statistics is needed since the work re-continues day after day.

As stated above, the system has one station modeled from an un-packer machine to a packer machine as shown in figure 4.17. The output (total good units produced) by this modeled is counted by on the packer machine output because it is the end machine of the production line. Therefore, the total good unit obtained on the packer machine is considered to be the total production line output. Hence, from the arena simulation model, the total good unit produced was 525,674 bottles per day.

4.4 Proposed production line improvement strategy

From the above discussion on the line OEE and bottleneck analysis production bottleneck station was determined, frequent problems causing larger downtime losses of production bottleneck station and their root cause in the packaging line have been identified and categorized. In this section a better line improvement strategy has been developed by investigating countermeasures from suggested remedy actions for the root cause of problems. To come up with those remedy actions and to further suggest an improvement strategy the researcher conducted discussion and brainstorming sessions with machine operators, specialists, and maintenance planners. Since the remedy actions has been already stated in the root cause analysis section, the following table, Table 4.21, summerizes the line improvement strategy proposed after undertaking many deep discussions.

Table 4.21 Line improvement strategy

Strategy		**Action**
Challenge and related losses	*Objective*	
Machine equipment failure (Availability loss)	Reduce cause frequent unwanted breakdowns and unplanned maintenance stoppages	✓ Revise and update overhaul, preventive and autonomous maintenance standard, strategy, and procedures continuously depending on the machines operating condition. ✓ Keep the spare part of critical machine components in stock. ✓ Develop standard procedures for guide adjustments depending on the current situation. ✓ Keep track of components' lifetime ✓ Assign an appropriate responsible person for every operation and activities
Quality failure	Improve the quality of incoming materials	✓ Create strong partnerships, relationships, and communication with

(Availability and performance loss)		the suppliers. For example, advance the involvement of input materials consumers (bottling line experts) in the production process of the supplier as well as input material producers (suppliers' experts) involvement in bottling line processes to prevent quality and other issues at the source in the first time. ✓ Improve inventory system, and keep spare parts safe. ✓ Implement FIFO (First in first out) principle ✓ Evaluate the implementation of incoming materials inspection and their standards and if necessary, revise and update its incoming inspection standards and procedures.
Operational failure (Performance loss)	Minimize shortstop of the machines and speed reduction	✓ Keep optimal operating condition of machines ✓ Always clean the machine according to the specified standard and keep them neat. ✓ Carry appropriate setups and adjustments before any start-up and always perform maintenance once per shift. ✓ Perform all autonomous, preventive, and overhaul maintenance activities at the right time and interval. ✓ Check the quality of material to be used and consumed before operation.

		✓ Identify, standardize, develop and document the best process recipes for each type of product to be used as a reference.
Human failure (Availability, performance, and quality loss)	To practice following the right operational standard and procedures of the company, material supplier and machine manufacturer for quality, operational, and maintenance tasks.	✓ Communicate all necessary standards and procedures for cleaning, maintenance, lubricating, operating, and quality inspecting in the right way with the right personnel. ✓ Develop a habit of following the standard and procedures ✓ Introduce team-based continuous improvement activities or projects ✓ Give continuous soft and technical skill training for employers
Quality loss	To reduce underfill, overfill products, and uncleaned bottles	✓ Maintain operating standards of product ingredients ✓ Perform all autonomous, preventive, and overhaul maintenance activities at the right time and interval. ✓ Check the quality of material to be used and consumed before operation. ✓ Evaluate the implementation of quality control and their standards and if necessary, revise and update its incoming inspection standards and procedures

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CHAPTER – 5

RESULT AND DISCUSSION

5.1 Simulation modeling

After developing the production line simulation model using Arena software and the result was analyzed. Then the result was compared with the real system production line output which ranges from 500,000 to 600,000 bottles per day (an average production of 543,752.307 bottles per day) according to collected data above for 26 days and it was approximate (525,674botles per day) as seen in the table and graph shown under Figure 5.1.

08:59:35 **Category Overview** May 3, 2022

Values Across All Replications

Analysis of RGB Production Line

Replications: 26 Time Units: Minutes

Packaging Machine

Unit Summary

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	274611.38	29,861.22	100154.0000	324759.0000
Date Coder Two	275972.00	29,953.02	101632.0000	326156.0000
KHS Filler Machine	289079.00	31,368.59	106424.0000	341531.0000
Krones Filler Machine	289148.19	31,432.64	105744.0000	341859.0000
Packer Machine	525674.96	56,911.53	185071.0000	619600.0000
Unpacker Machine	587788.58	63,695.51	216859.0000	694770.0000
Washer Machine	587479.08	63,741.96	216275.0000	694170.0000

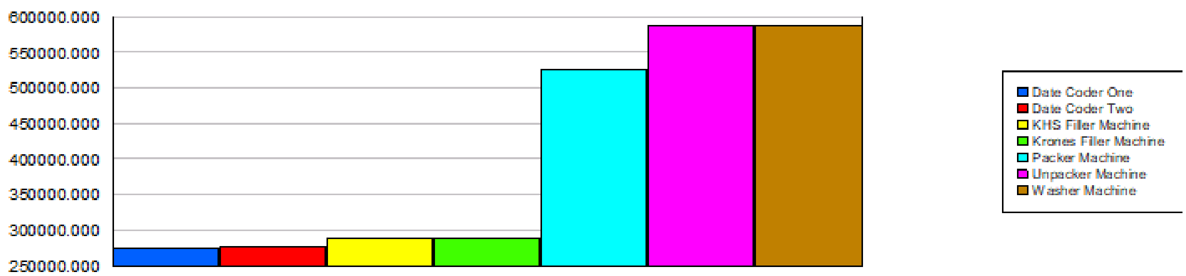

Figure 5.1 Simulation analysis result of the existing production line

The result shows that the collected data for 26 days production date to calculate OEE and the simulation model result were matched and the model was validated.

But the calculated OEE of the real machines production line were below world-class standards and also from the existing arena simulation model result the value of total good unit, yield, performance index, and utilization were very samll when compared with the production line planned capacity (720,000 bottles per day). The result shows that there were production bottlenecks that causes variation between the actual output and the planned or designed capacity on the RGB production line similar to the OEE result. Most of the production loss was due to unplanned stoppage (downtime loss), setup and adjustment time loss, minor stoppages, and lack of material.

5.2 Improvements and modifications

As discussed above, both OEE and arena simulation model results realize that the company production line needs improvement in order to to drive the actual production capacity to at least get closer to its designed or planned capacity by reducing production bottlenecks from the RGB production line. This is the fourth step of TOC, where the action is taken, and investment is pushed to improve the functioning of the constraining factor. The actions that have to be taken to reduce the filler downtime have also been discussed. The study aims to increase the actual production capacity of the company by eliminating the production bottleneck which is filler.

The scenario has been proposed as below to improve, and increase actual production capacity and selected as the proposed solution by comparing with the existing one.

Downtime loss was the major problem that affects the actual production capacity of the production line. As seen in table 4.5, high unplanned stoppages were there due to machine failures. Hence, the availability and performance rate of each machine was below the OEE world-class standard and it is very low when seen from the arena simulation result (refer APPENDEX:C). The root causes of machine downtime have been also discussed under the five why analysis. After identifying the root causes remedy actions based on those action line improvement strategy has been developed and proposed. Generally, the study discussed the reduction method of downtime loss to increase production line output to its designed capacity.

The quality loss includes both reject and reworking products. As discussed above, the quality rate of both the filler machine and the two date coder machine was below the world-class standard and the arena simulation yield was also less and needs improvement (refer APPENDEX:C). The types of quality losses on the production line were dirty (un-cleaned bottle), underfill, overfill, empty bottle leaves from filler machine, bottle breakages and problem with date coding. These losses affect the company's actual production capacity and cost the company. The elimination or reduction of these quality losses increases the actual output of the company. The elimination method was proposed to increase product quality by reducing quality loss.

By considering the reduction of downtime and quality loss, the arena simulation model was modified and the production loss and time to repair machine results are presented under Table 5.1 and Table 5.2 respectively. (refer APPENDEX:D also)

Table 5.1 Comparing production loss of existing and modified line model

Machines	Un-packer machine	washer machine	Krones filler machine	KHS filler machine	Date coder machine (1)	Date coder machine (2)	Packer machine
Existing production loss (%)	0	1.5	5	4	0.002	0.002	0
Modified production loss (%)	0	0.002	0.3	0.3	0.0001	0.0001	0

Table 5.2 Comparing time to repair the machine for existing and modified line model

Machine		Un-packer machine	Washer machine	Krones Filler machine	KHS filler machine	Date coder machine (1)	Date coder machine (2)	Packer machine
Existing	Time to repair(min)	15	20	60	50	5	5	15
Modified	Time to repair	3	4	15	13	2	2	4

After the arena was built depending on modified downtime (time to repair of each machine) and production-based loss (%), the total good units produced by the production line were increased from the existing result and the lost unit produced was reduced, i.e. the total good units obtained at the end of the production line's machine (Packer machine) were **640637bottles** per day as sho3wn from the figure below, Figure 5.4.

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	321992.69	29,153.66	120013.0000	364930.0000
Date Coder Two	318718.81	29,693.41	100601.0000	363188.0000
KHS Filler Machine	336373.85	31,300.07	119811.0000	381644.0000
Krones Filler Machine	336512.62	31,328.43	120013.0000	381699.0000
Packer Machine	640637.73	58,819.80	220614.0000	728085.0000
Unpacker Machine	675919.27	62,816.72	241322.0000	766477.0000
Washer Machine	675219.65	62,806.65	240767.0000	765640.0000

Utilization	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	41.5048	3.75	15.4806	47.1930
Date Coder Two	59.8197	5.57	18.8816	68.1660
KHS Filler Machine	54.2351	5.05	19.3177	61.5343
Krones Filler Machine	43.1063	4.01	15.3503	48.9952
Packer Machine	69.4474	6.38	24.5545	77.3210
Unpacker Machine	32.5964	3.03	11.6378	36.9636
Washer Machine	19.1619	1.77	6.7880	21.7358

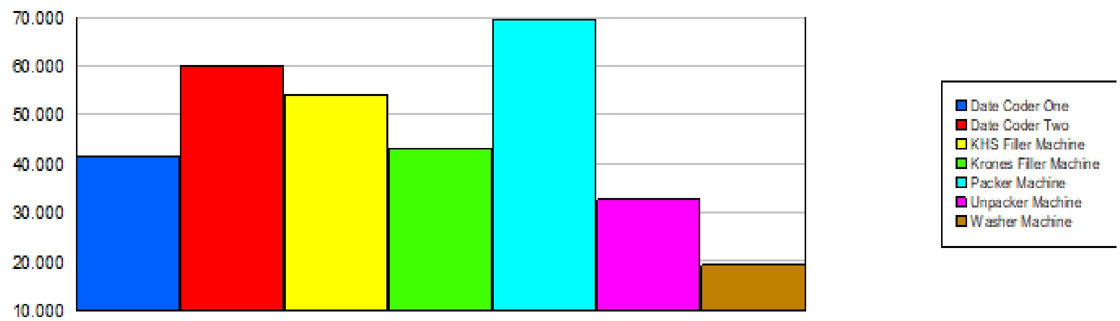

Figure 5.2 Simulation analysis result of the modified production line

From the above comparison table, the comparison concern between the current system and the modified system clearly shows that the production line has improved in different aspects. The simulation analysis, therefore, confirms the significance of line improvement through production bottleneck elimination.

According to the suggested line improvement strategy filler downtime has been decreased by more than 75% since it only 80% of the cause were investigated and by considering implementation gap. In terms of line output, in the current situation, the amount of average actual production is 543,752.307 bottles per day (and according to the line simulation analysis 525674 bottles per day. And after the line improvement, the modified model shows that 640,367.73 bottles can be produced per day if the cause of production bottlenecks can be eliminated successfully.

And in terms of loss 0.3 % loss can be achieved instead of 4% and 5% production loss of filler. Generally, in the modified arena simulation model Krones and KHS filler machines produces total good unit of 336373 and 336512 bottles per day respectively with 99.7 % yield. The result shows if the production bottleneck is eliminated from the production line, the company's actual output should be increased. The existing actual output was 73% and the modified result was 88.98%, taking the actual output of the line 30,000 bottles/hour.

Thus, by OEE and simulation analysis of the RGB production line, the study confirms that when the production bottleneck is eliminated from the production line, the productivity increases, and better production performance can be achieved. Figure 5.5, 5.6 and 5.7 presents the result of the study by comparing productivity and performance of the existing and modified line simulation models.

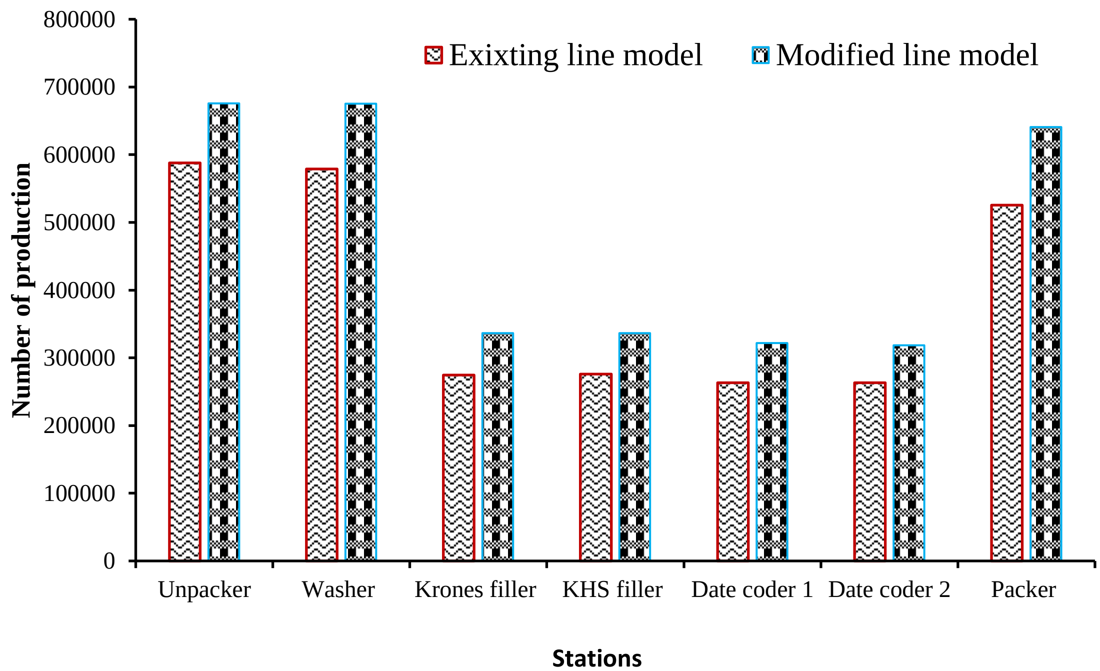

Figure 5.3 Comparison of total good unit produced in existing and modified production line

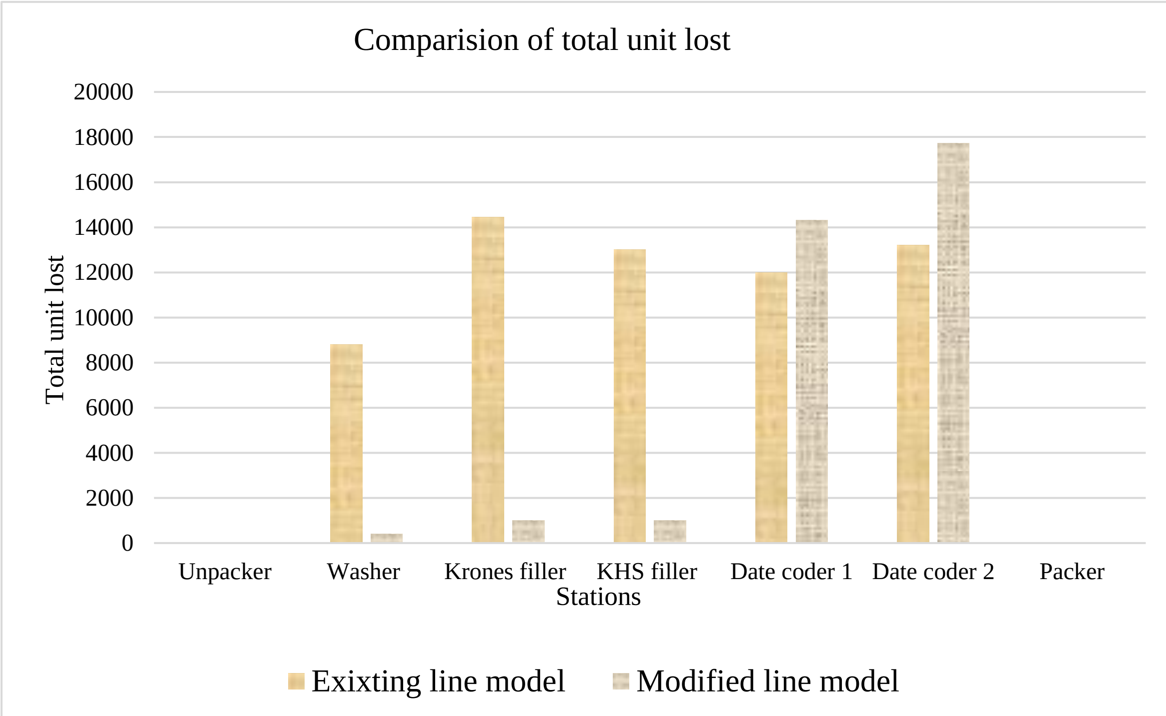

Figure 5.4 Comparison of a total units lost in the existing and modified production line

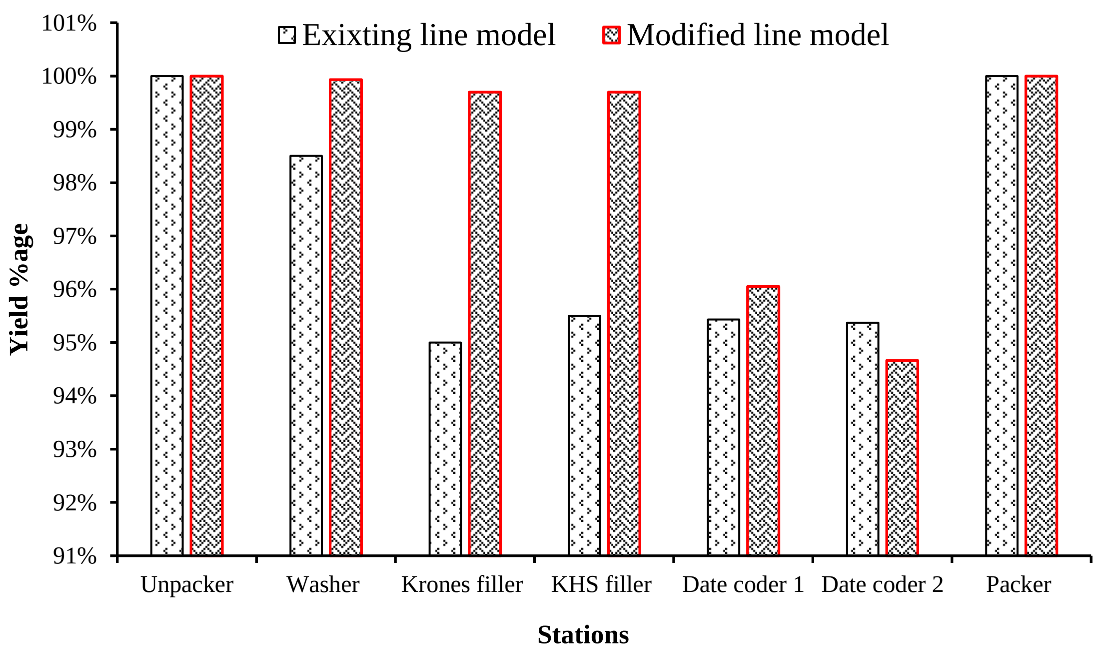

Figure 5.5 Comparison of yield in the existing and modified production line

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CHAPTER – 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this study production bottleneck analysis and production line improvement through elimination of production bottlenecks has been performed on RGB soft drink bottling production line through line performance analysis, production bottleneck analysis, and simulation analysis respectively.

After collecting all the necessary data required for the analysis, existing line performance has been analyzed by using one of the best production line performance analysis tool, OEE analysis. From the line performance analysis (OEE analysis) it has been observed that the availability rate of the production line under study is below the standard of a world-class organization, which indicates that downtime loss contributinh the most to the poor performance of the line.

And according to TOC, the bottleneck station of the production line was investigated by using availability (downtime) analysis, active period, and arrow or turning point bottleneck identification methods. From these analysis both filler machines has been found to be the bottleneck station of the RGB production line in the case study company. Blockage, starvation as well as inheritance failure of the filler machines were contributing for filler machine downtime loss.

And after studying the root cause of frequent problems of the bottleneck station, a line improvement strategy has been suggested based on remedy actions and countermeasures. By developing a simulation model for the production line, it has been proved that the productivity can be improved from 73% to 88.89% after implementing the proposed line improvement strategy. Therefore, from the study, it can be concluded that identifying and eliminating production bottlenecks is necessary to improve the production performance and productivity of any manufacturing industry. And also employing the TOC approach enables continuous improvement of the company.

It can also be concluded that the proposed line improvement strategy is beneficial to the company. And by continuously practicing the TOC production bottleneck management approach, many additional opportunities can be found for improving the performance and productivity of the production line. And developing a line simulation model can be a cost-effective method to check proposed line improvement strategies.

6.2 Recommendation

The recommendations of this study to enhance the productivity of EABSC and other soft drink industries are:

- ✓ Companies should give attention to eliminating production bottlenecks in order to boost the productivity and performance of their production lines.
- ✓ From the study, it is recommended to use the TOC bottleneck management approach to identify and eliminate the true production bottleneck, and for continuous management of production bottlenecks as well. Since the last step of the TOC approach is going back to the first step to identify another bottleneck, it is always necessary to start all over again after the successful elimination of the existing bottleneck.
- ✓ The company should also measure the line improvement and to do so this study recommend a simulation model for better productivity and performance improvement analysis.
- ✓ And also, to enhance productivity and performance effective implementation of the line improvement strategy proposed in this study is essential, and performing continuous bottleneck analysis is necessary for sustainable continuous improvement.

This research can be done or include more than what it has already covered, some recommendations are given to be considered in future work on related topics.

- ✓ The productivity will be better improved if the bottleneck analysis could be done on the overall company's operation.
- ✓ Since the accuracy of the OEE analysis result depends on the relevance of the data used, it is recommended to automate data collection in the manufacturing system.
- ✓ The simulation model can also be better utilized by collecting more information; therefore, it is recommended to exploit the simulation model to perform cost and other analysis.

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APPENDIX

APPENDIX A: Time loss unplanned and planned downtime data of every machine

One-week downtime data of unpacker machine

Day		Unplanned downtime				Planned downtime	
		Due to machine failure(inheritance)	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over
Morning shift	6	7 min	7 min	2 min	5 min		
	7	5 min	0 min	1 min	4 min		180 min
	8	8	0	1	2		
	9					8 hrs	120 min
	10	7	3	10	0		
	11	7	2	4	0		
	12	5	0	3	0		180
Afternoon shift	6	9	5	14	1		
	7	5	16	61	4		
	8	7	5	10	0		
	9	7	2	4	0		
	10	7	0	6	0		
	11	9	5	14	1		
	12	5	16	61	4		
Total	14st	88 min	61	191	21	8 hrs	8 hrs

One-week downtime data of washer machine

Day	Unplanned downtime				Planned downtime	
	Due to machine failure	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over

Morning Shift	6	6	6	27	9		
	7	6	0	35	4		180
	8	4	7	19	7		
	9	0	0	0	0	8 hrs	0
	10	1	13	23	0		120
	11	1	3	8	0		
	12	2	0	32	0		180
Afternoon Shift	6	12	19	60	0		
	7	15	0	35	9		
	8	13	0	27	0		
	9	1	58	22	0		
	10	19	21	15	0		
	11	12	7	19	6		
	12	8	3	30	12		
Total	14 sh	100	137	325	47	8 hrs	8 hrs

One-week down time data of Krones filler machine

Day		Unplanned down time				Planned downtime	
		Due to machine failure	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over
Morning Shift	6	25	15	15	35		
	7	65	25	25	10		180
	8	20	10	25	20		
	9					8 hrs	
	10	30	10	0	0		120
	11	15	10	5	0		
	12	105	15	0	0		180
Afternoon Shift	6	95	10	10	10		
	7	76	20	15	15		

	8	35	10	15	10		
	9	25	10	0	10		
	10	25	10	5	0		
	11	40	5	5	0		
	12	80	10	0	0		
Total	14 sh	636	150	120	110	8 hrs	8 hrs

One-week downtime data of KHS filler machine

Day		Unplanned downtime				Planned downtime	
		Due to machine failure	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over
Morning Shift	6	50	0	15	20		
	7	30	0	0	5		180
	8	20	10	25	0		
	9					8 hrs	
	10	30	15	0	0		120
	11	25	5	25	0		
	12	120	20	0	0		180
Afternoon shift	6	129	10	5	25		
	7	5	16	0	5		
	8	22	10	0	0		
	9	81	40	0	14		
	10	23	29	0	0		
	11	3	9	0	0		
	12	56	10	15	10		
Total	14 sh	549	174	85	74	8 hrs	

One-week downtime data of packer machine

Day		Unplanned downtime				Planned downtime	
		Due to machine failure	Due to starvation	Due to blockage	Due to supply chain way	Maintenance	CIP and flavor change over
Morning shift	6	20	8	0	10		
	7	22	12	2	15		180
	8	32	1	4	5		
	9					8 hrs	
	10	10	11	0	0		120
	11	13	12	0	0		
	12	9	6	0	0		180
Afternoon shift	6	11	2	0	0		
	7	5	20	3	0		
	8	4	6	0	0		
	9	3	5	0	0		
	10	7	16	4	0		
	11	13	12	0	0		
	12	4	20	5	0		
Total	14 sh	153	131	18	30	8 hrs	8 hrs

APPENDEX B: Conveyor data

No	Conveyor	From	Speed (feet/min)	Length	Width	Unit/sq.feet
1	Conveyor one	Unpaker to washer	70	15	3	10
2	Conveyor two	From washer to conveyor three and four	70	2	4	15
3	Conveyor three	Conveyor two to Krones filler	70	15	4	10
4	Conveyor four	Conveyor two to KHS filler	70	5	4	10
5	Conveyor five	Krones to date coder one	70	7	3	10
6	Conveyor six	KHS to date coder two	70	7	3	10
7	Conveyor seven	Date coder one to conveyor nine	70	5	3	10
8	Conveyor eight	Date coder two to conveyor nine	70	5	3	10
9	Conveyor nine	From conveyor seven and eight to packer machine	70	4	3	10

APPENDIX C: Simulation model machine statistic and result report of existing line model

The category overview statistics for machines of the existing system are described and also for clarity of the statistics some logic and terms of the report are explained here below.

Note: All times and rates are reported in base time units. Here for this modeling system, the model base time unit is 'minute'.

I. Description

A. Nominal Run speed--- reports the machine's nominal run speed (Units/minute).

Type--- reports the machine type (i.e. Basic, Conveyor, Assembly, or Filling) see table

08:59:35 **Category Overview** May 3, 2022

Values Across All Replications

Analysis of RGB Production Line

Replications: 26 Time Units: Minutes

Packaging Machine

Description

Nominal Run Speed	
Date Coder One	600.00
Date Coder Two	367.00
KHS Filler Machine	360.00
Krones Filler Machine	546.00
Packer Machine	1200.00
Unpacker Machine	1200.00
Washer Machine	920.00

B. Unit Summary

Total Units processed- This statistic reports the total number of units, assemblies, or containers that have entered the machine and completed or at least started processing. The following expression holds:

Total Units Processed = Total Good Units Processed + Total Units lost + Current Units Inside

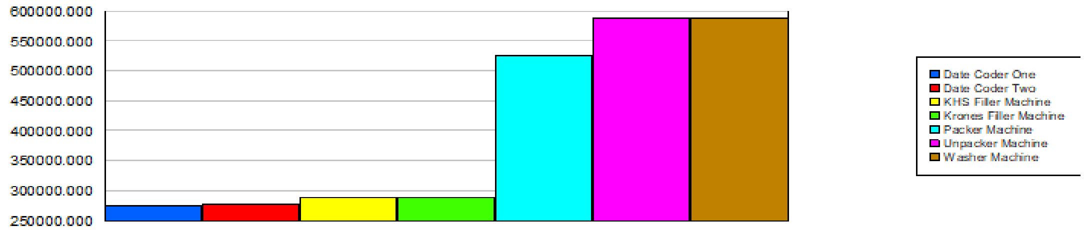
Analysis of RGB Production Line

Replications: 26 Time Units: Minutes

Packaging Machine

Unit Summary

Total Units Processed	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	274611.38	29,861.22	100154.0000	324759.0000
Date Coder Two	275972.00	29,953.02	101632.0000	326156.0000
KHS Filler Machine	289079.00	31,368.59	106424.0000	341531.0000
Krones Filler Machine	289148.19	31,432.64	105744.0000	341859.0000
Packer Machine	525674.96	56,911.53	185071.0000	619600.0000
Unpacker Machine	587788.58	63,695.51	216859.0000	694770.0000
Washer Machine	587479.08	63,741.96	216275.0000	694170.0000



Total Good Units produced-reports the total number of units, assemblies, or containers that completed processing and were produced as good output by the machine see table

Total Good Units Produced	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	263306.15	28,620.12	84128.0000	310585.0000
Date Coder Two	262972.46	28,316.30	98025.0000	309515.0000
KHS Filler Machine	276070.46	29,957.02	101634.0000	326162.0000
Krones Filler Machine	274690.73	29,861.04	100456.0000	324766.0000
Packer Machine	525674.96	56,911.53	185071.0000	619600.0000
Unpacker Machine	587788.58	63,695.51	216859.0000	694770.0000
Washer Machine	578666.88	62,785.84	213031.0000	683757.0000

Total Units Lost - reports the total number of units, assemblies, or containers that completed processing but were produced as loss or scrap by the machine.

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	11990.81	1,627.12	22.0000	18594.0000
Date Coder Two	13211.46	2,143.03	20.0000	20017.0000
KHS Filler Machine	13008.54	1,411.61	4789.0000	15369.0000
Krones Filler Machine	14457.42	1,571.62	5287.0000	17093.0000
Packer Machine	0.00	0.00	0.0000	0.0000
Unpacker Machine	0.00	0.00	0.0000	0.0000
Washer Machine	8812.19	956.11	3244.0000	10413.0000

C. Quality rate

Yield - this statistic reports the efficiency of the machine for producing a good product (quality rate). This statistic is calculated as follows:

Yield = ((Total Good Units Produced)/ (Total Good Units Produced + Total Units Lost)) *100

Yield	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	95.4315	1.06	83.9986	99.9798
Date Coder Two	95.3791	0.98	87.0042	99.9803
KHS Filler Machine	95.5000	0.00	95.4999	95.5004
Krones Filler Machine	95.0000	0.00	94.9996	95.0001
Packer Machine	100.00	0.00	100.0000	100.0000
Unpacker Machine	100.00	0.00	100.0000	100.0000
Washer Machine	98.5000	0.00	98.4998	98.5001

D. Availability rate

Utilization

Utilization	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	41.6324	4.51	13.5238	49.1822
Date Coder Two	52.6138	5.67	19.5711	62.0639
KHS Filler Machine	55.7637	6.05	20.5292	65.8818
Krones Filler Machine	44.7831	4.86	16.6056	53.0926
Packer Machine	64.6228	6.93	24.2191	75.2400
Unpacker Machine	34.0155	3.69	12.5497	40.2066
Washer Machine	44.3447	4.81	16.3251	52.3981

APPENDEX D: Simulation analysis result for modified line model

Packaging Machine

Performance

Yield	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	96.0530	0.60	94.7766	100.0000
Date Coder Two	94.6629	1.00	84.1138	100.0000
KHS Filler Machine	99.70	0.00	99.6996	99.7004
Krones Filler Machine	99.70	0.00	99.6999	99.7002
Packer Machine	100.00	0.00	100.0000	100.0000
Unpacker Machine	100.00	0.00	100.0000	100.0000
Washer Machine	99.93	0.01	99.8267	99.9900

Total Units Lost	Average	Half Width	Minimum Average	Maximum Average
Date Coder One	14328.65	2,252.63	0.0000	18887.0000
Date Coder Two	17724.08	1,983.64	0.0000	20767.0000
KHS Filler Machine	1012.12	94.18	361.0000	1148.0000
Krones Filler Machine	1012.54	94.29	361.0000	1149.0000
Packer Machine	0.00	0.00	0.0000	0.0000
Unpacker Machine	0.00	0.00	0.0000	0.0000
Washer Machine	415.88	43.69	75.0000	526.0000

APPENDEX E: Downtime recording data sheet

DATA SHEET

Machine -_____________ **Product type -** _____________ **Date and shift -** _____________

Panned production -__________ **Total product produced -** __________

Total good product produced - __________

Actual time	Area/component	Breakdown description	Time loss

Glass bottle rejected after check mat – Glass bottle rejected after date code –

APPENDEX F: Root cause analysis format used in brainstorming and disscution session

Description about the session	
Details	Participants in the disscution session
Production line :	Maintenance controller :
Station :	Maintenance planner :
Component :	Technician :
Date:	Operator :

Understanding the problem	
What happened?	
Where did it happened?	
When did it happened?	
Why was is it a problem?	
Who was involved?	
How big was the problem?	

Root cause analysis using Why 5 method		
	Possible causes	High probable cause
Why 1		
Why 2		
Why 3		
Why 4		
Why 5		
Main root cause		

Solution strategy		
Root cause problem	Remedy action	Further improvement strategy

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