Investigation on Packaging Process Using Method of OEE and Arena Software to Improve Beer Productivity

(United Beverages S.C in Ethiopia)

Abel Ashebir Tefera

A Thesis Submitted To The 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 Mechanical Engineering (Manufacturing Engineering)

Office of Graduate Studies

Adama Science and Technology University

May -2024

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DECLARATION

I declare that this thesis proposal entitled **"Investigation on Packaging Process Using Method of OEE and Arena Software to Improve Beer Productivity in United Beverages S.C in Ethiopia"** is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Abel Ashebir Tefera	______________	_____________
Name of student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "**Investigation on Packaging Process Using Method of OEE and Arena Software to Improve Beer Productivity in United Beverages S.C in Ethiopia**" prepared under my/our guidance by Abel Ashebir submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Mechanical Engineering.

Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

____________________	______________________	________________
Main Advisor	Signature	Date
______________________	____________________	________________
Co-advisor	Signature	Date

APPROVAL SHEET

I/we, the advisors of the thesis entitled "**Investigation on Packaging Process Using Method of OEE and Arena Software to Improve Beer Productivity in United Beverages S.C in Ethiopia**" and developed by Abel Ashebir, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________________ ______________________ ______________

Main Advisor **Signature** **Date**

We, the undersigned, members of the Board of Examiners of the thesis by Abel Ashebir have read and evaluated the thesis entitled "**Investigation on Packaging Process Using Method of OEE and Arena Software to Improve Beer Productivity in United Beverages S.C in Ethiopia**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Mechanical Engineering.

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Chairperson Signature Date

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Internal Examiner Signature Date

Solomon Bayue Huluka(PhD) ______________________ 19/07/2024

External Examiner Signature Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head Signature Date

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School Dean Signature Date

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Office of Postgraduate Studies, Dean Signature Date

Acknowledgement

First, I would like to thank Almighty God. Then I would like to really express my deepest gratitude to Dr. Moera Gutu who is my advisor on this thesis work for all of his untapped support and his knowledge investment on me to know the basic knowledge on thesis preparation, guidelines and important requirement. I am also most indebted to thank UB Team (operators, line technicians, packaging engineers, and section heads). I would also like to thank all Managers and workers of the company for their support while doing this thesis work. And I don't want to pass without thanking my colleagues and great bosses Teka Lema and Theodros Alebel for giving me a best and constructive suggestion and support throughout my thesis work. Finally, I also thank all of person involved directly or indirectly for their helpful and supportive discussion.

Abstract

Now a days competition in business industries is forcing companies to constantly analyze and improve their manufacturing systems. even though productivity of manufacturing industry plays significant role in enabling an industry to survive in this competition, it can be negatively impacted by the presence of production disturbances that hinder the production system efficiency, performance and reduce profitability. The major problems of the case company packaging line are related to low throughput, efficiency losses, higher production cost and others. As a result, overall equipment efficiency of the packaging line and planned production volume do not meet the pre-seated target. Therefore, The aim of this study is to evaluate line efficiency and identify possible improvements to their existing manufacturing system by minimizing packaging efficiency losses due to disturbances that affect the packaging line operation, and performance. As a case study, United Beverages S.C (UB) was used. In relation to Packaging line, efficiency losses, OEE analysis, and simulation modelling are conducted, primary and secondary data are collected from the case company through direct observation, documentation, and company reports. Also, the past one production year data are presented, calculated, and analyzed by one of the total quality management tools, which is over all equipment effectiveness (OEE). Also, different tools such as OEE, pareto chart, fish bone diagram, Arena simulation software are used to analysis and improvement process. As a result, the disturbances that causes production and efficiency losses are identified, focus of improvement areas associated with their challenges and their root causes are investigated, then corrective action plans are suggested as strategy for improvement. After analyzing the packaging line model through Arena simulation software, the cause of efficiency losses under varies condition were studied and performance measures are recorded. Also, several problems including performance losses starvation and blockage are identified as problems. Then changes and modifications on the actual system simulation model are suggested. Finally, an improved model was proposed where packaging line value added time increases by reducing short stops, starvation and blockage time by 4.46%. Therefore, it has been concluded that identification and elimination of production bottlenecks has great positive impact on productivity improvement and loss reduction which ultimately ensures a company's profitability.

Keywords: *performance, efficiency loses, productivity, packaging line, OEE*

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ABBREVIATION

Acronym	Nomenclature
ACUTW	Accumulated conveyor from unpacker to washer
ACWTE	Accumulated conveyor from washer to EBI
ACFTP	Accumulated conveyor from filler to pasteurizer
ACPTL	Accumulated conveyor from pasteurizer to labeler
BD	Break Down
BDA	Break Down Analysis
Bpm	Bottle per minute
Bps	Bottle per second
DT	Down Time
EBI	Empty Bottles Inspector
FBI	Full Bottles Inspector
Gp	Gross Product
Rs	Rated Speed
HL	Hectoliter
HL	Information System
KPI	Key Performance Indicator
LU	Line Utilizations
LME	Line Mechanical Efficiency
OPI	Organizational Performance Index
OT	Operating Time
OEE	Overall Equipment Effectiveness
PD	Production Disturbances
SAP	System Analysis Program Development
SCUTW	Single conveyor from EBI to filler
SCPTL	Single conveyor from pasteurizer to labeler
TPM	Total Productive Maintenance
UB	United Beverages
VAT	Value Adding Operating Time
YTD	Year to Date

CHAPTER-1

INTRODUCTION

1.1 Background of the factory

This study has conducted in United Beverages S.C. Mojo plant on bottling line, which produces Anbessa and Waliin beers in returnable bottles. The speed of bottling line is 40000 bottles per hour or 1666 creates of beer per hour. Production runs 24 hours a day, nearly seven days a week. There are three 8 hour shifts every day. The line runs constantly throughout lunch, breaks, and shift changes.

In the beer production every bottling industry must be able to find the way in producing good quality product. Quality products are supported by machines that can increase productivity and minimize production costs. Nowadays companies around the world are producing high quality products for sale at the lowest price possible. Company operators do not just want to earn more money only through the sales of those products; but they also want to gain by minimizing their production costs, minimizing raw material loses, and minimizing overhead cost (re-work) by increasing their production efficiency to lead in this sector of economy. It is because they are facing challenges due to high continual raw material cost and increasing their participation in the market where competitors are also selling their products with high quality at the lowest price possible. To meet their cost of production, the mass production line must operate continually through continuous improvement drive (Yuniawan et al., 2013).

Productivity improvement is one of the main goals for bottling companies and it is also necessary to enhance financial and operational performance of the organization. Improvement can be attain through elimination of unnecessary or ineffective processes, by applying adequate planned and corrective maintenance, simplifying the process, reducing product and raw material losses, by optimizing the process, reducing idle time, maximizing throughput, reducing production cost, improving quality, improving performance and others (Yuniawan et al., 2013).

There exist various factors that may impact the production process, primarily associated with the manufacturing system in use, culture throughout the plant, operational and technical faults. Obstacles that prevent the production process from reaching the predetermined goals may lead to significant production losses, which may have an impact on quality, safety, and the organization's overall performance (Uday Kumar, August 2013).

Production disturbance can be categorized into 6 losses of efficiency. These are: Equipment failure, set up& adjustment, Idling and minor stoppages, reduced speed, defects in operation or process and Start up & reduced yield. These losses are measured by OEE, which is a combined measurement of equipment availability, performance, and quality. Managing production difficulties effectively is essential for achieving high system reliability, improving productivity, reducing losses, raising output, and boosting profitability. Therefore, one strategy to increase productivity is to identify the source of disruptions in the manufacturing system and remove them. Even tiny system performance improvements can have a big impact (Nagdiya, 2013).

With competition in the current competitive market, many technologies currently exist and are utilized by large breweries that allow for improved efficiency concerning resource use, many are cost prohibitive to smaller breweries. So that it’s important to design and implement methods to improve production efficiency and to adapt new competitive strategy. One such strategy is how to minimize production loss due to process loss and breakdown. Creating disturbance-free line is the goal of any manufacturing plant in ensuring its operating costs kept as minimum as possible.

1.2 Machine Operations

All returnable bottles need pre-treatment in terms of washing and rinsing followed by some filling process with beer then contents volume checking, pasteurizing, labelling, date coding, final packing and palletization for warehouse storage and dispatch.

United Beverages' packaging operation is as follows: Empty bottles are transported by conveyor from the depalletize and de-crater to the bottle washer, where they are soaked in and jetted with detergent (caustic soda) and then rinsed. Empty bottles are then transported to the filler, where they are evacuated to remove any air and counter-pressured with CO_2 to exclude air and manage the filling rate. After the bottles are filled with beer, they are immediately sealed with a crown cork. Finally, the full bottles are examined for their contents level, and after pasteurization and labeling, they are carried to the crater, palletizer, and warehouse (IBD et al, 2023).

1.2.1 Packaging machine operations

United Beverage (UB) is using bottles for packaging process and packaging line is designed to fill bottles with beer and to present those packages to the warehouse or customer suitably assembled in the most efficient way while preserving the quality of the beer. In United Beverages there are different types of machines used for packaging. Those are: -De-palletizer, Unpacker, Bottle washer, Empty bottles Inspector (EBI), Filler, Full Bottles Inspector (FBI), Pasteurizer, Labeler, Full Bottle Inspector, Packer, palletizer (beverage, 2022).

- **De-palletizer:** It has a purpose to remove new bottles from pallets and to present them to a conveyor for transport the line. Its feature is mechanical operation using pneumatic/hydraulic rams and electric motors. Sensing of positions by microswitches and light beams (Ying HE, 2016).

Figure 1. 1 Depalletizer machine

- **Unpacker:** It has a purpose to remove empty bottles from the crates and to present them to a conveyor for transport to the line. Its feature is mechanical operation uses pneumatic or mechanical grips to lift the bottles from crates (Parveen Kumar, 2017).

Figure 1. 2 Unpacker machine

➢ **Bottle Washer:** In this machine bottles are clean both the inside and outside of the bottle and to present a commercially sterile empty package to the filler. Label removal will dissolve the glue while leaving the label intact otherwise paper fibers will contaminate the cleaning liquids. The bottles are conveyed through the washer in pockets. They are rinsed with water, soaked in detergent, sprayed inside and out with detergent, and then rinsed with water to remove all detergent traces. A final freshwater rinse is used before bottles are leaving from the machine (Tewari, 2014).

Figure 1. 3Bottle washer machine

➢ **Empty Bottle inspection (EBI):** In which bottles leaving the bottle washer meet the requirements of cleaning and undamaged. Empty bottle inspectors throw a beam of light or radiation through the empty bottle. Damaged and not properly cleaned bottles are rejected (SHUBHI SHARMA, et al, 2015).

Figure 1. 4 EBI machine

➢ **Filler and Crowner:** Filling machines consist of a rotating circular tank which houses a number of filling heads. The bottles are filled as they travel around the system. There are several stations on the filler that are designed to ensure that the bottles are filled meeting the specified parameters. Bottles are fed onto the filler by a crown wheel which picks them up from the conveyor, separates them and spaces them so that they fit onto the bottle lifts which raise them up to seal on the filling head. Beer is supplied from the bright beer tank. Crowner is used to seal the bottle so that beer cannot leak out air, cannot get in, the bottle is tamper proof and can be opened easily when required for consumption (IBD et al, 2023).

Figure 1. 5 Filler machine

- **Pasteurizer:** the purpose of pasteurizer machine is to produce a microbiologically stable beer (IBD et al, 2023). In the pasteurizer the bottles are heated to deactivate all microorganisms and enzymes that can influence the quality of the beer, and to increase the shelf life. The cycle time of the pasteurizer is the largest of the whole line, with an average of 43.2 minutes. After the bottles are pasteurized, they will move to the labelers.

Figure 1. 6 Pasturizor machine

- **Full Bottle inspection (FBI):** is used to check that the bottles leaving the filler/crowner meet the requirements of Filled with the right volume of beer and undamaged. Full bottle inspectors throw a beam of light or radiation through the bottle at the ‘target’ beer level. Incorrectly filled bottles are rejected (IBD et al, 2023).

Figure 1. 7 FBI

- **Labeler:** is used to put a label or labels onto the bottle that Informs the customer about the product giving details about name (Anbessa or Waliin), alcohol content, volume, best before date etc. Advertises the product by presenting an attractive appearance when displayed. Provides information for the manufacturer giving details about the date code, bottling line, bright beer tank etc (IBD et al, 2023). The labelers stick three labels (front, back and the neck of the bottle). Again, the bottles are inspected and, if necessary, removed from the line. The quality checks at this stage are strict, with a single deviation, the bottle will be removed. Perfectly labeled bottles move to the packer.

Figure 1. 8 Labeler machine

- **Packer:** is used to put full bottles into crates or cardboard boxes and to present them to a conveyor for transport to the pelletizer. It has a mechanical operation using pneumatic or mechanical grips for lifting the bottles into the boxes or forming the boxes around the bottles (Parveen Kumar, 2017).

Figure 1. 9 Packer machine

- **Palletizer:** is used to stack full packs onto pallets so that they are stable and to present them to a conveyor for transport the warehouse. Mechanical operation using pneumatic/hydraulic rams and electric motors. Sensing of positions by microswitches and light beams (Ying HE, 2016).

Figure 1. 10 Palatalized machine.

1.2.2 Packaging Plant layout

The schematic representation of packaging plant layout in UB is shown below.

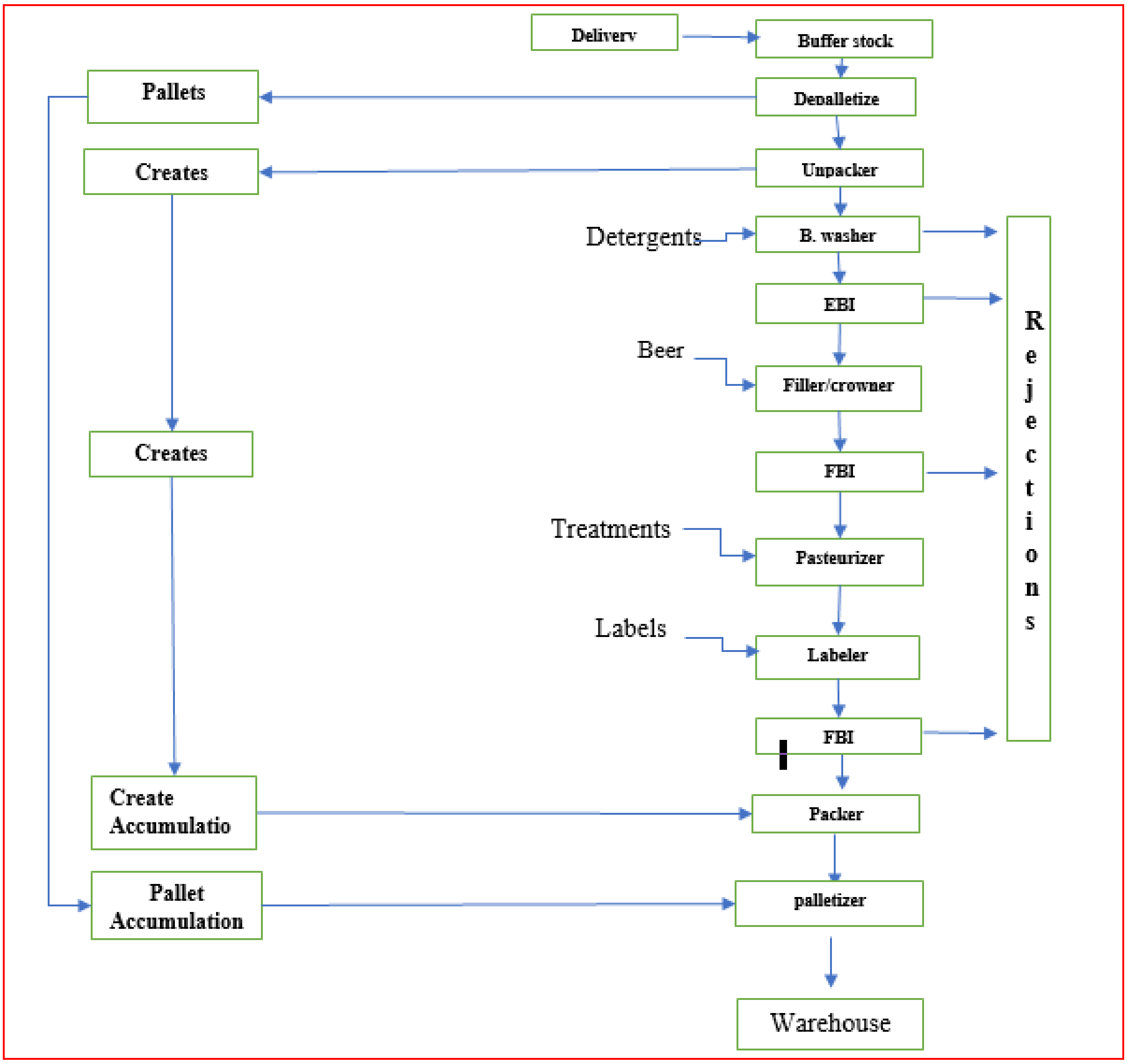


Figure 1. 11 Schematic representation of packaging plant layout in UB

1.3 Statement of the problem

United Beverage (UB) had produced 58% of its production capacity in the production years of 2023 (Source, company data, 2024). In these production years the bottling line experienced breakdowns (BD) and short stop times of 858.2 hours from total operating 4176.2 hours. As a result, in these past production years the company has lost 1,430,333 creates of beers, only by those breakdowns and short stops time. Based on the figure the company has lost an average of 954,437,782 ETB on this production year (Source, company data, 2024). So that, one method to increase the efficiency is identifying and removing or minimizing those disturbance from packaging process. Apart from that, throughout this year of production on the packaging line, there were also losses related work in process raw materials and other unspecified losses. These uncontrolled losses make its production cost bigger than ever. Therefore, united beverages need to decrease its production cost per hectoliter, to become productive, competitive, and profitable on the market.

1.4 Objective of the study

The general objective of this thesis case study is to investigate, analyze and enhance performance of packaging line to improve beer productivity in bottling plant of United Beverages S.C.

1.5.1 Specific objective

1. To identify the bottleneck of packaging line and evaluate past year performance.
2. To develop simulation model and analysis performance factor using Arena Software.
3. To minimizing efficiency losses and to come into world best practice standard.
4. To recommend line efficiency and performance through OEE.

1.6 Significance of the study

The relevance of the study in terms of bottling factory and practical use is very high. In beverage industry one of the big challenges is how to minimize the raw material losses, reduce production cost, increase performance, and increase throughput. This research focuses on identifying the most common operational challenges faced by machines and developing solutions to address them. Both the actual records are taken from the company recording formats (documentation). In addition, simulation model had developed to measure efficiency, identify areas that needs improvement, discovering bottleneck of the machines and prioritizing problems areas. So that, this research is conducted by analyzing and grouping production system data to find the existing problems and area of focus in addressing the current problems. Therefore, enhancing those machines' performance has significantly increase cost saving and financial benefit. Simultaneously, it can decrease manufacturing cost per hectoliter (HL) and help the company to achieve their goal as per the standard.

Lastly, this research is used as a reference base for improvements on this company.

1.8 Expected outcome of the study.

After end of research, study will:

1. Identifying the real challenge of packaging line and Improve production performance.
2. Measure the line efficiency (OEE), performance and understand challenges.
3. Lowering raw material losses.
4. Improve productivity(volume), line utilization and adherence to the standard.

1.9 Scope of the study

The scope of the study is to perform efficiency and performance evaluation of the machine by means of OEE and Arena simulation software. In this study I used numerical approach and parametric validation. This thesis case study aims to test and validate the performance of a packaging machine and to identify disturbances or constraints affecting the packaging line. In addition, to optimize the process parameters using response methodology. Inhibition of production activities can lead to downtime, therefore by applying mimic simulation software and measuring line OEE, and taking the needful corrective action, can improve productivity and machine performance. A variety of operation execution system and performance analysis system like OEE had conducted.

1.9 Motivation of the study

UB is the youngest beer factory among the existing beer factories in Ethiopia. The reduction of productivity and profit due to different reasons of machinery, human, and operational factors this company has been losing lot of money in terms of time, raw material, and product. In addition, the bottling line production costs are gradually increasing. So, this motivates me to plan in depth to investigate and analyze those different losses related to packaging line in this MSc thesis work.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction

Several studies were conducted to gain a better understanding of the packaging system, best practices, and methods for optimizing the packaging process and increasing beer production. In the production industry, the importance of maintenance equipment and machinery is emphasized in situations involving unknown types of machine failures, where the cause of the failure cannot be identified during production. The management of raw materials and spare parts is also incorporated, as it impacts production capacities. Investigation using industrial system as a case study, how manufacturers are being affected by unplanned failures such as machine defects, failure and breakdown; which reduced the annual percentage profit of the industry are important to identify and to take the corrective action (JOSIAH, U., UZORH, et,al., 2023).

2.2 Production System and productivity

The production function is the part of an organization that is concerned with transforming a variety of inputs into the appropriate outputs (products) with the required quality level. Production can be defined as "the step-by-step conversion of one form of material into another form using chemical or mechanical processes to create or improve the utility of the product to the user." Thus, production is a value-added process (General & Operations Management).

A production system is the organization and operation of machines, equipment, materials, people, and information to create a value-added physical, informational, or service product, the success and cost of which are measured. In a manufacturing process, the items to be processed go through a set of processes or operations that are shared by the majority of other products being produced. Since, high throughput is required, specially designed equipment and processes are frequently used to achieve lower production costs. (Area, & Dr. Hemant Sharma Professor)

Frequently, the tasks handled by workers are divided into relatively small segments that can be quickly mastered and efficiently performed. Production technology is the application of engineering and manufacturing technology to increase the speed, ease of use, and efficiency of production. Production technologies, related services, procedures, facilities, and machinery, such as automation, robotics, measurement systems, cognitive information processing, signal processing, and production control via high-speed information and communication networks, are all included in manufacturing systems. Process automation makes highly productive production systems possible. Higher production rates, more effective material utilization that results in less scrap, greater product quality, increased safety, shortened labor workweeks, and shorter lead times for factories are some of the benefits that are frequently linked to automation. Increased productivity and higher output have been two of the primary reasons in favor of using automation (Usubamatov, 2018).

The productivity rate of manufacturing systems is the primary area of any industry in the world. Macro and microeconomics consider two types of productivity. In macroeconomics, the term productivity is the ratio of output to input, which is the efficiency of the economic system according to the fundamental science. Microeconomics considers physical productivity as the number of products fabricated per given time as accepted by The American Society of Mechanical Engineers (ASME). Productivity rate is one important indicator criteria for an industry engineer to improve the manufacturing system and provide a good sustainable output of production processes. Productivity may be conceived of as a metric of the technical or engineering efficiency of production and might be measured based on the number of hours it takes to produce a good. Economists provide the definition of the efficiency of production as the ability to accomplish a job with minimum expenditure of time and effort (Usubamatov, 2018).

$$\text{Productivity} = \frac{\text{Output}}{\text{Labor * Production time per day (hour)}} \qquad (2.1)$$

Factors influencing productivity can be broadly classified into two categories: controllable or internal factors and un-controllable or external factors. Under the controllable factors Product factor, plant and equipment, technology, material and energy, human factors, work methods and management style are mentioned. From the abovementioned controllable factors technology is one of the considered factors in this study. The various aspects of technology factors to be considered are size and capacity of the plant, control, repairs and maintenance, waste reduction, and efficient material handling system. Factors that are classified under the uncontrollable are: Structural adjustments, Natural resources and Government and infrastructure (Parveen Kumar, 2017).

2.3 Production constraint

In any industry, there is always room to improve overall performance. Identifying and solving "bottlenecks," or obstacles that are preventing the company from moving forward, is an excellent method to improve overall performance. The theory of constraints (TOC) is one method that assists in locating bottlenecks in systems and processes. The core principle of the TOC was that every system or organization had one or a few restrictions that affect the system as a whole. To get the most out of the entire system, controlling these limitations and how the system interacts with them is the key to success. The primary goals of the company are to maintain high levels of productivity, improve the quality of the products, raise customer satisfaction, and reduce organizational costs. On the other hand, a production disturbance (PD) directly impairs production performance, and lower PDs mean reliable production systems (Ingemansson, 2004). Originally, OEE was developed to reveal the losses from PDs and has been widely used to measure equipment performance in industry (Uday Kumar, August 2013). However, the handling of PDs must focus on individual factors and their underlying causes, not merely on addressing the symptoms of poor performance (Bokrantz, 2016). By measuring individual PDs and the different components of the OEE figure, a production system's OEE can be increased (Ingemansson, 2004). OEE is a commonly used metric in industry that has been proposed as a means of quantifying the losses due to production disturbance.

2.4 Over all equipment effectiveness (OEE)

The main objective of the production plant to improve the performance of their present equipment for that purpose Overall Equipment Effectiveness (OEE) tool is used. OEE is an effective tool to analyses and improve your production process. Overall Equipment Effectiveness is a way to monitor and improve the efficiency of the manufacturing process. OEE has become a widely acknowledged management technique for measuring and assessing plant floor productivity. OEE is divided into three measurement metrics: availability, performance, and quality. In the industrial sector, production businesses typically use methodologies and tools to assess production performance. The fundamental reason is the necessity to measure the achievement of the company's objectives and, as a result, identify areas for improvement. The major goals of these tools of measuring production performance are to free up capacity and therefore to create more value from existing resources with fewer additional costs (Roessler, 2015). According to the original definition by (Nagdiya, 2013) OEE is a bottom-up approach where an integrated workforce strives to achieve OEE by eliminating the six big losses: equipment failures/breakdowns, set-up/adjustments, idling and minor stoppages, reduced speed, reduced yield, and quality defects. These losses are measured in terms of OEE, which is a function of the three components availability, performance, and quality. The OEE Foundation has proposed an "OEE Industry Standard" that outlines how to describe OEE in order to identify all potential losses. They emphasize that all losses must be specified and visualized, and that set-ups, breaks, and maintenance are all potential losses to be eliminate (Chalmers, 2016).

OEE is a set of measures that assesses how efficiently a manufacturing activity is run. The findings are presented in a generic format that enables comparisons between manufacturing units in various departments, companies, machines, and industries.

In essence:

- OEE is a measure that identifies equipment potential.
- OEE identifies and tracks loss.
- OEE discover potential opportunity.

The main objective of OEE is:

- To Increase productivity
- Decrease cost.
- Increase awareness of the need of machine productivity
- Extend equipment life.

The results of these objectives are to

- Increase profits.
- Gain (or sustain) a competitive edge.
- Identify equipment ownership.
- Reduce expenditure.

As a result, OEE is a measure that assesses how well capital equipment is used by identifying constraints and how they affect OEE. Effectiveness is calculated by multiplying availability and performance efficiency by the rate of quality product produced.

Availability: The time the equipment is actually running versus the time it was expected to run.

Performance: This measures how well the line performed in the available time against the rated speed and minor stoppages.

Quality: This measures the percentage of good sellable product manufactured

OEE is a hierarchy of metrics proposed by Seiichi Nakajima in 1988 to measure the performance of the equipment in a factory. These metrics help gauge the plant's efficiency and effectiveness and categorize the key productivity losses that occur within the manufacturing process (Stamatis, 2011).

2.4.1 OEE comprises six key metrics and production losses.

The six big losses in equipment or machines generally are thought to be:

1. Breakdowns
2. Setup/adjustment (performance loss)
3. Idle/stops
4. Reduced speed
5. Scrap
6. Start-up yield

1. Machine Breakdowns

Stoppages due to machine failure that results in loss of production (Filler Stoppage) during scheduled production hours. Should not be confused with time taken to fix the breakdown. This is the time that will be reported in the production reports. Agreement on this time is vital between the technician & the production personnel. This time will be booked as an EPL against the machine that caused the downtime. It is important to capture actual times of not manufacturing. The time that the Filler starts producing again after repairs – The time that the Filler stopped producing because of the failure.

2. Performance Losses

These are losses which are caused by short stops and speed losses only, which affect the gross output of the filler. This will be automatically accumulated as unrecorded downtime in the production report. Short stops and Speed losses may not be accumulated during the shift or part of a shift. Performance loss is a stoppage on any equipment on the packaging line that directly causes a filler stoppage for a time.

3. Idle/Short Stop or Minor Stop

This is a stoppage on any equipment on the production line that directly causes a filler stoppage for less than 5 minutes at a time. This must not be accumulated during the shift or part of a shift.

4. **Reduced speed**

This is when the filler, due to its own inability or any up or down stream equipment influences, runs consistently slower than line rated speed. This must not be accumulated during the shift or part of a shift and booked as an Equipment performance loss.

5. **Scrap**: **-** This is all the cases (Accumulation Table Rejects and Scrapped Quantity) lost on the line due to quality defects
6. **Yields:** - Shows how efficiently and effectively raw materials are used during the production process. Measures the loss (in quantity & monetary value), theoretical vs actual against the actual usage. or difference between actual Quantity (or cost) & Theoretical quantity (or cost)

- ✓ Primary Yields: -This yield reflects all the materials that are directly in contact with the product such as Beer, Labels, Bottles, Cork, Glue etc.
- ✓ Secondary Yields: -This yield reflects all the materials that are indirectly in contact with the product such as creates, pallets etc.

In addition to the above some other key metrics of OEE loses are listed below

1.Unused Time

Unused time are time in a week, month, period, or year that is planned shutdown where production or maintenance activities did not schedule such as public holiday, weekends, shift not planned etc.

2.Shut down losses

Are losses which are caused by planned activities related to equipment or activities which are not directly falling within controls a production line. e.g., unplanned meetings, utility(external)supply failure, CIP, early shift end, planned inventory counts, paid/unpaid breaks.

3.Down time losses

Are losses which are caused by unplanned activities by equipment or activities which are directly related to the production line e.g. Depalletize / palletizer ,empty bottle and create conveyor, uncase /caser, bottle washer, EBI, filler, date coder, FBI, labeler, pasteurizer, full bottle &create conveyor, boiler utility machines equipment failure, operators error, quality or lab test, start-ups end ups, adjustment, change over, materials package change.

4. performance losses

Are losses caused by short stops, idling and speed losses only which affects the gross output of the filler. This is a stoppage on any equipment on the production line that directly causes a filler stoppage for less than 5 minutes at a time.

5. quality losses: - Are losses which are caused as a result of rejections of products due to quality reasons such as underfill, overfill, beer OG, carbonation, stock destroyed, accumulation table reject which includes lab test.

6. Operational and technical Losses

Some of the reason for Loss in occurred in packaging is due to manpower error (operator/maintenance personal), incoming material error (e.g. Labels and cork printing fault), machines fault (programming, missing of timing), machine breakdown, products (beer) quality fault etc. are some of the reasons of waste/loses.

2.5 The six major losses

Are the loss of a production plant which is the difference between a 100% OPI and the real OPI. By minimizing losses, the actual OPI grows. These losses are categorizing into "six big losses": equipment failure, setup, and adjustment, idling and minor stoppage, reduced speed, defects in process and reduces yield. As one can see in figure 2.1 losses are used to compute the OEE.

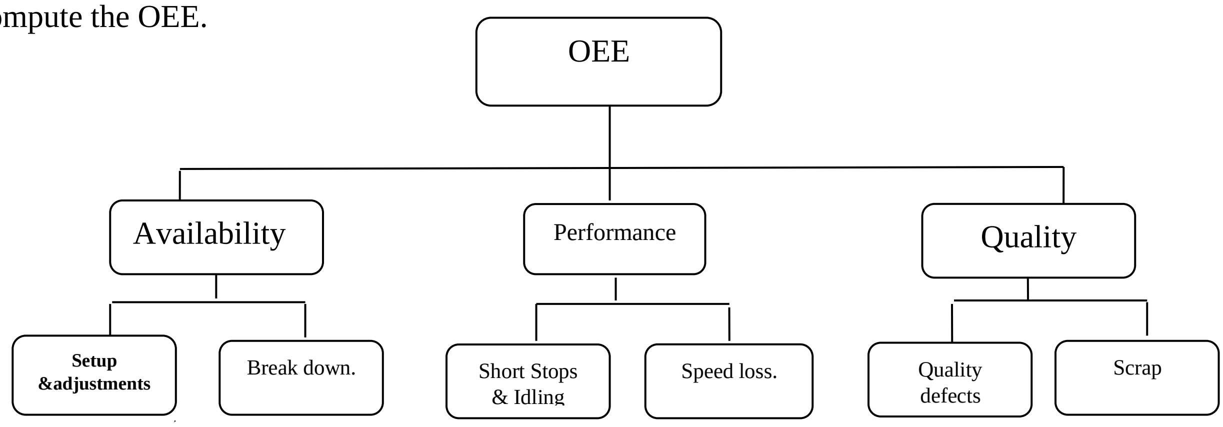


Figure 2. 1 OEE flow chart.

An organization uses OEE to examine available time as well as downtime, speed, defect, and loss of availability. These three categories of losses are represented as performance, quality, and availability. The OEE is calculated using the performance of the fillers. The OEE is calculated using the product of Availability, Performance, and Quality. OEE identifies (hidden) losses caused by any change in performance by analyzing each component. Eliminating these losses provides improved performance, where zero losses will result in an OEE of 100%.

The Overall Equipment Effectiveness is calculated as follows:

$$OPI = Availability * Performance * Quality \qquad (2.2)$$

Where these three indicators have their own equations which are stated below:

$$Quality = \frac{\text{Good product}}{\text{Good product + Reject \& rework}} \qquad (2.3)$$

$$Performance = \frac{\text{Production time}}{\text{Operating time}} \qquad (2.4)$$

$$Availability = \frac{\text{Operating time}}{\text{Manned time}} \qquad (2.5)$$

These indicators are calculated in order to measure the line performance of a production line. As stated above, these indicators are multiplied which means that the weight of these indicators are the same. The quality measures the ratio of good products, which are the products that exit the production line in order to enter the market. The performance measures the efficient production time of all operating time.

The Operating time = total time- unused time – nonteam maintenance – No order No Activity changeover time –planned downtime–breakdown time (2.6)

This means that only the blockage and starvation times are the difference between operating time and production time. These times are used in order to calculate the performance.

The availability is the operating time (described above) divided by the manned time. The manned time is the time that operators are working on the production line.

2.6 Production line

A production line consists of a series of workstations arranged so that the product moves from one station to the next, and at each location a portion of the total work is performed on it. The production rate of the line is limited by its slowest station. Workstations whose pace is faster than the slowest will ultimately be limited by that bottleneck station. Transfer of the product along the line is usually accomplished by a conveyor system or mechanical transfer device, although some manual lines simply pass the product from worker to worker by hand. Production lines are associated with mass production. If the product quantities are high and the work can be divided into separate tasks that can be assigned to individual workstations, then a production line is the most appropriate manufacturing system (Groover, 2010).

A production line is a set of machines connected by a transport system; the machines and the transport system are controlled by a central computer. In recent years, increased competition in global markets has pushed industries to adopt innovative production systems, targeting improved production quality at reduced cost; in particular, high-volume production demands a highly automated and organized production line. The conveyor provides work to the machines on pallets so that work-machine registration is accurate, fast, and automatic (Law, 2000).
production lines have two basic types: manual assembly lines and automated production lines. However, hybrid lines consisting of both manual and automated operations are not uncommon.

There are various ways of moving work units from one workstation to the next. The Three major types of work transfer systems are used on production lines:

1. Continuous transfer
2. Synchronous transfer
3. Asynchronous transfer

1. Continuous transfer: -systems consist of a continuously moving conveyor that operates at a constant velocity. The continuous transfer system is most common on manual assembly lines. Two cases are distinguished:

1. parts are fixed to the conveyor and
2. parts can be removed from the conveyor.

In the first situation, the items are typically huge and heavy (for example, an automobile or a washing machine) and cannot be taken from the line. To execute the assigned duty for that unit while it is at the station, the worker must walk alongside the moving conveyor. In the second situation, the product is tiny enough to be removed from the conveyor, making it easier to work at each station. Some of the pacing benefits are lost in this approach since each worker is not compelled to complete allocated duties within a specific time frame. On the other hand, in this approach, each worker has greater flexibility in dealing with any technical issues that may arise on a specific work unit.

2. In synchronous: - Work units move from one station to another in a fast, discontinuous motion using transfer systems. These systems are also known as intermittent transfer, which refers to the type of motion that the work units encounter. Synchronous transfer involves workstation location, which is required for automated lines that use this type of transfer. Synchronous transfer is uncommon for manual lines since the task at each station must be completed within the cycle time, or the product will leave the station incomplete. Human workers find this strict pace of discipline stressful. This form of pacing, on the other hand, is ideal for automated operation.

3. Asynchronous transfer: - allows each work unit to leave its present station once processing is complete. Each unit travels separately rather than simultaneously. As a result, at any given time, some units on the line are in motion, while others remain stationary. The tactical usage of queues between stations is associated with asynchronous transfer system operation. Small lineups of work units are allowed to form in front of each station, averaging fluctuations in worker task times and ensuring that stations always have work waiting for them. Asynchronous transfer is utilized in both manual and automated production operations (Groover, 2010).

2.6.1 Characteristics of transfer system in production line

2.6.1.2 Conveyors

Conveyors are used to transfer bottles from one machine to the next. Conveyors are vary in both width and length. Conveyors can also serve as buffers. A buffer is supplied to cope with unforeseen failures of the installation (machines), which may create stops in the production processes (Van der Duyn Schouten, 1995). The speed (level) of a conveyor is preset and programmed into the information system (IS). Generally, conveyors have varying speed levels to accommodate the requirements of the afterwards conveyor/machine. The number of bottles on the conveyor determines the occupation of the buffer, which is measured through the use of sensors. Each conveyor has one or more sensors, which are located on the conveyor. The sensor is the metal ‘arm’ at the left/right side of the conveyor fence. The presence of the bottles triggers these sensors, and the bottles push the metal arm in the direction of the left and right fence. Mostly the sensors are located in such a way that bottles will not directly trigger these sensors when arriving at the buffer. This happens when bottles stagnate and enumerate, due to the fact that machines further in the line are already stopped producing or when the machine is in failure. In most cases, sensors (yellow sensors) are only activated when the buffers are filled up to the point where the sensor is activated. Therefore, in the event that the machine after it stops producing, the bottles in front of it will multiply, disperse, and collide with the sensor. Switches and photocells are the two types of sensors that are available online. A switch must be triggered physically with a bottle. A photocell beams a laser to a reflector and is triggered when the beam is interrupted by a bottle.

2.6.1.3 Dry and Wet sides

On a packaging line there are two areas, namely the dry side and the wet side.

The dry side is the area before the washer discharge, and the section after the filler where the packing takes place.

The wet side is from the washer discharge to a point after the bottles have been through filler.

Conveyors on the dry side are subject to higher wear due to the fact that the bottles normally dusty on the outside. With the movement of the bottles, this dust falls on to the slat band chain which acts as an abrasive which causes this high wear to the chain, wear strips and bottle guides.

In the packing area, the bottles are clean, but the weight of the full bottles (638.9gm) is the factor that causes high wear.

Figure 2. 2 Weight of full goods and empty bottles

It is for this reason that chain lube in these areas must always be working 100%, and the conveyor CIP in here is so critical. On the wet side, the bottles are clean and empty, thus the wear is reduced considerably, but there is still a wear factor but not as high as the dry side. Even though the wear is less, the chain lubrication still a critical factor to ensure the smooth operation of the bottles moving through the inspectors (EBI) through the combining sections and the bottle filler.

2.6.1.4 Production line performance

UB uses the Overall Equipment Effectiveness as measure for its packaging performance per production line. In figure 2.3 one can find the calculation of OEE which is explained below. OEE exists of three main components and its formula is given below:

$$\text{OPI} = \text{Availablity} * \text{Performance} * \text{Quality}$$

The Availability is calculated with the following formula:

$$\text{Availability} = \frac{\text{Operating time}}{\text{Manned time}} \tag{2.7}$$

The performance is calculated with the following formula:

$$\text{Performance} = \frac{\text{Production time}}{\text{Operating time}} \tag{2.8}$$

The production time is the time needed for producing the total number of products (good product + reject and rework). The operating time is the production time + the speed losses and minor stoppages. Where the minor stoppages are the failures of a machine less than 5 minutes. The quality is defined as the fraction needed to produce the 'good product.' This is the time needed to produce the actual output divided by the production time (= good product + reject & rework). The formula is shown below:

$$\text{Quality} = \frac{\text{Theoretical production time}}{\text{production time}} \tag{2.9}$$

- ✓ **OEE time waterfall**

The OEE waterfall consists of: -

1. Callender Time: -Are a total time in a week, month, period, or year.
2. Working Time: - Are the total shift patter times per week, month, period, or year.

Is calculated by working time= Calander time-unused time

3. Loading Time: -Are the expected time the equipment must operates in one day, totaled for a week, month, or year.

Are calculated by Loading Time=Working time- shutdown losses

4. Operating Time: -Are the amount of time the equipment actually runs, totaled for a week, Month or year.

Are calculated by Operating Time=Loading Time-Downtime Losses

5. Net operating Time: - Are the amount of time the equipment operates at rated speed also accounting for minor stopes.

Are calculated by Net Operating Time=Operating Time-Performance Losses

Or Net Operating Time= Gross production/Rated speed

6. Value Added Operating Time: -Are the amount of time the equipment operates producing sellable products.
7. Quality Loses= Total Rejects/Rated Speed

Or Value-Added Time=Net Production/Rated Speed

Are calculated by Value Added Operating Time=Net Operating Time-Quality Losses

The below OEE water flow figure is designed to easily understand and analyze OEE measure.

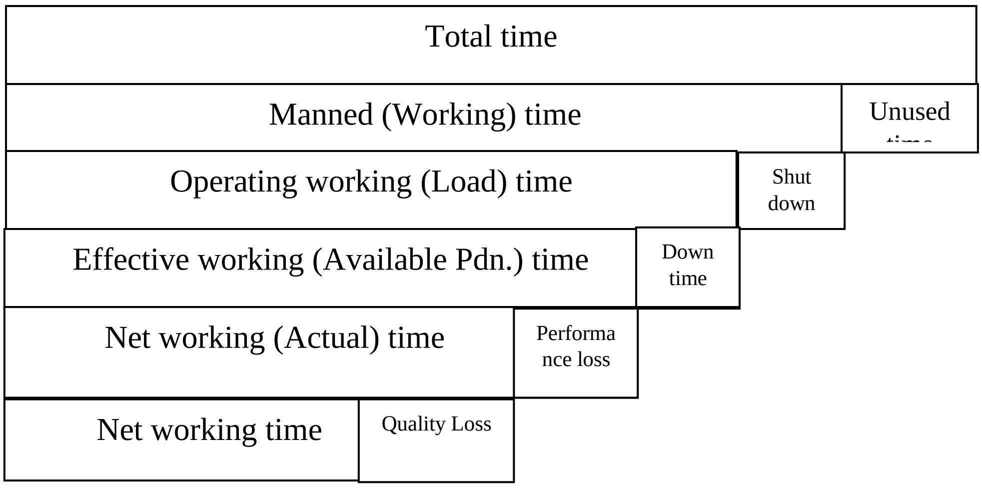


Figure 2. 3 OEE waterflow

UB uses the OEE to evaluate line performance. As seen in figure 2.3, it comprises external stops, unused time, and planned downtime. As previously stated, these parameters have no direct effect on machine efficiency or line restrictions. Take, for example, the Customer Services & Logistics department. A forklift, which is controlled by operators and stores pallets in warehouses, fails. Then this failure is for line an external failure because the palletizer (last machine in line) is in blockage. It therefore decreases the OEE, even when all machines operate perfectly. For that reason, these external stops are neglected in this research. Even the changeover time is neglected because line produces just one product (Anbessa beer), so no changeovers take place. Finally, the planned downtime (e.g., maintenance) will be neglected because it will not influence the machine efficiency during production. This is not to say that planned downtime is not important; without maintenance, production performance suffers greatly. This study focuses on enhancing line performance. As a result, the attention is on the performance aspect. As a result, undetermined losses, short stops, and speed losses are the primary focus for improving current performance. To focus on performance measurement, consider production time. Therefore, the line performance should examine the output of the machines and compare these numbers with the production time. Line performance is therefore measured as:

$$\text{Line performance} = \frac{\text{Production quantity}}{\text{Operating quantity}} \tag{2.10}$$

Where operating quantity is the number of products that could be produced in a certain period. Production quantity is the number of 'good products' that are produced.

2.6.1.5 Continuous improvement strategy

Continuous improvement is a technique in which a production system is considered as a chain, with the goal of constantly reinforcing the chain by identifying and strengthening its weakest link. The theory of constraints pushes for a continual improvement strategy that allows companies to focus on bottlenecks of the process. The metrics are designed to determine whether the company is on the correct track, whereas the core of the improvement process that limitations advise consists of five basic elements. The five focusing phases were established to ensure that management focuses its attention on what is critical to good system performance, namely, improving the performance of the system constraints. It assists firms via a process of continual improvement and is suggested by (Pretorius, 2014). The steps are generic in that they can be applied to any system, including service businesses. The steps are generic, meaning they may be used to any system, including service businesses. This series of phases is comparable to the Deming (or Shewhart) Plan-Do-Check/Study-Act Cycle. In that they represent an iterative method to managing continuous improvement, whereas the five-why process, fishbone diagram, and Pareto analysis are connected with process improvement.

2.7 Simulation Model

(Kumar, 2006) highlights how simulation can help to build a better overall understanding of a system and gives awareness about the impact of increasing a specific variable on the performance of the entire system.

Two types of models are typically used to estimate performance measures:

- ✓ Simulation models
- ✓ Analytical models.

1. Simulation models: The process of creating a model of a system and running experiments with it to either understand how the system behaves or assess different approaches (within the limits set by a criterion or set of criteria) for how the system operates is known as simulation. Discrete-event simulation models mimic the real system by constructing a list of events that occurs in the real life. New events are planned and added to the event list whenever an event occurs, such as a process completion or a breakdown. By selecting random integers from predefined distributions, the randomness in the intervals between two events (arrivals or breakdowns) is captured. These distributions can be derived from data of the production system; both empirical and fitted distributions can be used. The production system's data can be used to construct these distributions; fitted and empirical distributions can both be used. Stochastic variables can be derived from these distributions. "One major advantage of simulation is its capacity to incorporate stochastic variables, such as machine breakdowns and product arrival times." (Wein, 1992). A simulation model is a simplified model of reality and is used to test out different production rules.

2. Analytical models: Try to express the system in terms of sets of equations and then solve them. In many circumstances, the solutions to these equations are numerical. Since most systems in practice are too complicated to study accurately, heuristic methods must be developed to achieve approximate results. According to (Tino, 2013) simulation method takes a lot of time to use. In order to produce solutions in a much shorter amount of time, analytical models are frequently used. Still, generating these models is a tedious and complex process. An analytical analysis is just a collection of formulas, while a simulation is an analysis tool that is graphical.

2.7.1 Types of Simulation

1. **Static vs. Dynamic Simulation Models:** A static simulation model is a representation of a system at a specific time. In contrast, a dynamic simulation model shows a system as it grows over time, such as a manufacturing conveyor system.
2. **Deterministic vs. Stochastic Simulation Models**: A simulation model is referred to as deterministic if it lacks any probabilistic (i.e., random) components; an example of such a model is a complex (and analytically intractable) system of differential equations representing a chemical reaction. In deterministic models, the output is "determined" once the model's set of input quantities and relationships is stated, even if evaluating it may take a significant amount of computer time. Stochastic simulation models create random output, which must be taken as an estimate of the model's underlying features.
3. **Continuous vs. Discrete Simulation Models:** Discrete-event simulation is the modeling of a system's evolution across time using a representation in which the state variables change instantly at different points in time. When a model is continuous, the change in the system's state is calculated continually (Averill M. Law & Associates, 2015).

Simulation enables us to analyze the impact of, e.g., breakdowns and inter arrival times. At the production line of UB these events should be considered to mimic real life situations. This would be too hard to solve with an analytical model due to the dynamic production environment.

2.7.2 Advantages of simulation

- ✓ Complex real-world systems with stochastic aspects cannot be accurately captured by a mathematical model for analytical evaluation. As a result, simulations are the only available investigative methods.
- ✓ Simulation estimates the performance of an existing system under expected operating conditions.
- ✓ Simulation can compare different system designs or operating strategies to determine the best fit for a specific demand.
- ✓ Simulation can investigate a system in compressed time, such as an economic system, or in expanded time, allowing for extensive analysis of its operations.

2.7.3 Drawback of simulation

- ✓ Each run of a simulation model gives only estimations of the model's true features for a specific set of input variables. As a result, multiple independent runs of the model will likely be required for each set of input parameters to be investigated. As a result, simulation models are often less effective at optimization than they are at evaluating a fixed number of various system designs. On the other hand, if an analytic model is acceptable, it can frequently generate true properties of the model for a range of sets of input parameters. Thus, if a "valid" analytic model is available or quickly built, it is often preferred over a simulation model.
- ✓ Developing simulation models can be costly and time consuming.
- ✓ Simulation studies and realistic animations might lead to overestimation of outcomes. If a model is not a "valid" representation of the system being studied, the simulation findings, no matter how impressive they appear, will provide little meaningful information about the real system. When deciding on whether or not to do a simulation study in a given case, we can only recommend that these benefits and drawbacks be considered, as well as all other relevant data about one's own situation. Finally, in some research, both simulation and analytic models may be relevant. Simulation, in particular, can be used to validate analytic model assumptions. In contrast, an analytic model might provide plausible options to investigate in simulation research.

2.8 Research Gap

There is no research conducted in this company on packaging line to improve productivity, efficiency, and performance. As a result of the focus on productivity, efficiency and performance improvement, there is a scarcity of data on packaging line. This research aims to fill the gap and improve the efficiency, productivity, and performance of bottling line by using OEE, and Arena simulation software technique.

CHAPTER-3

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter data collection tools and analysis methods are discussed in detail. To achieve the study's goal, the research design of this study was built on the reduction of downtime and performance losses by collecting detailed information using a variety of procedures and tools. Therefore, the case study line was used to implement this methodology in research design and study how to improve production line performance and productivity by eliminating down time and performance losses.

This chapter discusses data collection tools and analysis methods in detail. To achieve the study's goal of reducing downtime and improving performance, a research design was developed that utilizes various procedures and tools to collect detailed information. A case study production line was then chosen to implement this methodology. By examining this line, the researchers aimed to identify ways to reduce downtime and performance losses, ultimately leading to enhanced production line performance and productivity.

3.2 Methods

In this research, identifying undetermined efficiency loss, productivity, and machine performance are the main objectives. Primary and secondary data from historical database and the actual machines and buffer capacity are used for this investigation. Simulation software is used for performance analysis and improvement modeling. OEE metrics are used to evaluate and assess all of the data that has been collected. To establish probability distributions and assess the present parameters of the raw data, machines had placed mimic software. Finally, the results on each factor in the study are presented using tables, equations, and graphs. Generally, a methodology is proposed to be followed to achieve the objective of this study.

3.2.1. Data Collection

Data collection can be classified into two, namely: primary and secondary data. Primary data are fresh and collected for the first time. Secondary data are data that were previously collected and analyzed. The method used for data collection in this paper are primary and secondary data from the real production systems those are: company raw material usage and performance recording data history, planned and actual output of total production, machine downtime data, failure of every machine and their frequency, planned and unplanned down time and others are included. In addition, collection of recent data from reliable sources, observation and understanding of the overall packaging process conducted.

Figure 3.1 shows a flow chart of research methodology. This research work will follow the following methodologies to accomplish the entire work of the thesis.

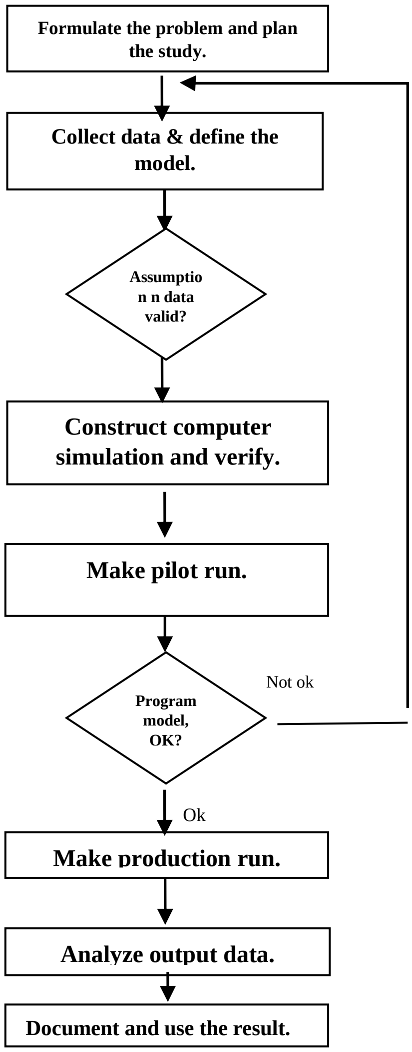


Figure 3. 1 Flow chart of research methodology

3.2.2 Data analysis

The gathered data are analyzed by charts, graphs, and evaluated by using different tools and software. In this research thesis one year data are collected by different techniques including structural meetings are conducted with workers to get information on different topics.

The data collected from the UB packaging department was reviewed, compared, and summarized to find areas for improvement applying OEE and simulation model analysis.

3.2.3 Simulation modeling and analysis

In a simulation, the ultimate use of input data is to drive the simulation model. This process involves the collection of input data, analysis of the input data, and use of the analysis of the input data in the simulation model using computer software for the process verification and validation.

After the line OEE analysis conducted the major performance losses, efficiency losses, focus area for improvement and their root cause are determined. Then, corrective action plan is suggested. Using of simulation software enables to identify the existing constraints and disturbance of the line and helps to suggest the improvement area for enhancing the output.

3.2.4 Steps in simulation modeling

1.Formulate the problem and plan the study.

2. Collect data and define a model.

- ✓ Collect information on the system structure and operating procedures.
- ✓ No single document is sufficient.

3. Is the assumptions document valid?

- ✓ Take place before programming begins, to avoid significant reprogramming later.

4. Construct a computer program and verify.

- ✓ Program the model in simulation software (Arena)
- ✓ Verify the simulation computer program.

5. Make pilot runs.

- ✓ Make pilot runs for validation purposes.

7.Is the programmed model valid?

If the model is Go to the next sext. If not back to step 2 and start again

8. Make production runs.

9. Analyze output data. Two major objectives in analyzing output data are to

- ✓ Determine the absolute performance of certain system configurations.
- ✓ Compare alternative system configurations in a relative sense.

9.Document, present, and use results.

3.2.5 Flow chart of simulation modeling and research methodology

The below line are shows steps on developing simulation model as shown in Fig.3.2.

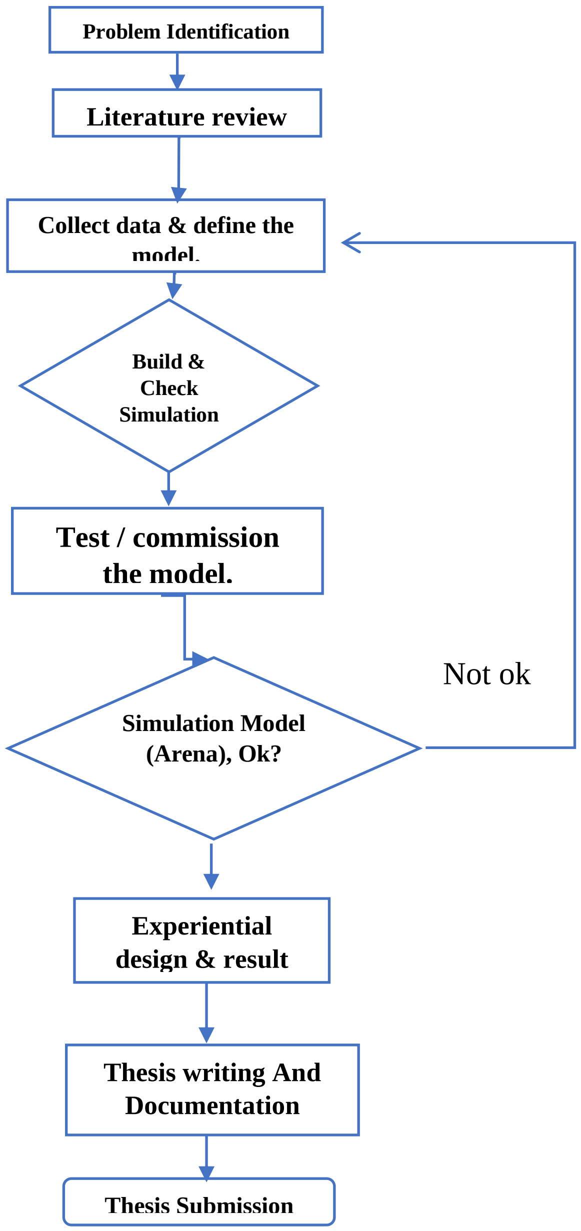


Figure 3. 2 Flow chart of steps in simulation modeling

3.3 Line process overview

According to UB, all bottles used in production are returnable. These bottles are collected and accumulated at the warehouse. Initially, empty bottles with their creates and pallets are fed into the depalletizer using forklifts, and full items with their contents are removed from the palletizer using a forklift; these are the first and last machines in the packaging hall. Forklifts are vehicles that transfer pallets, containers, and bottles to and from the packing process. All of these machines are connected by conveyors, as discussed in Chapter 2.6.1. Figure 1.11 shows the layout of a packaging line, including all machinery. At first, the de-palletizer removes creates from pallets and transports them to the un-caser, while empty pallets are transferred to the pallet magazine to be reloaded with full items. When creates with empty bottles arrive at the un-caser, the bottles are removed by an un-packer gripper and presented to a conveyor for transport to the washer machine, while the remaining empty creates are sent to the washer machine to be cleaned with caustic and hot water before being packed again with full bottles. When the bottles reach the bottle washer machine by conveyor and are properly aligned in the various pockets, they begin feeding into the machine. The machine washes the bottles in full automation mode. The bottles are fed to the loading deck (pockets) by its pusher to the conveyor belt, from where they pass into the conveyor system to perform the washing cycle, which consists of three stages: prerinse and gradual heating with internal and external sprays, washing in a high-temperature caustic (80, 85, and 80ºC) in caustic bath 1, bath 2, and bath 3 detergent solution, respectively. The process of removing labels, alternating immersion, and internal sprays, washing, and gradually chilling with internal and exterior sprays is repeated until the microbiological properties of the final rinse water match those of the mains water. When they reach the end of the system, the bottles are transported to the unloading deck and sent to the conveyor belt, where they are dispatched to be inspected and checked by an EBI machine. The quality specifications of each bottle are examined at the EBI machine, and if the bottle meets the quality criteria, it is transferred to the filler machine for the filling process. If the bottle's quality is not confirmed, it is sent to the rejection line. Following the completion of the filling procedure in the filler machine. Immediately, corks sealed the bottles. The filled bottle is next subjected to full bottle inspection; if the bottles pass all of the inspection standards (which include meeting the over and underfill pre-seated parameters), it is transferred to the pasteurizer machine to produce a microbiologically stable beer. The bottles are heated in the pasteurizer to destroy any microbes or enzymes that could affect the beer's quality and extend its shelf life. The pasteurizer has the longest cycle time of the entire line, lasting 43.2 minutes on average. After pasteurization, the bottles will be sent to the labelers. In a labeler machine, labels are applied to the bottle to inform the customers about the product, including the name (Anbessa), alcohol content, volume, best before date, and so on. Following that, The bottles are reviewed and, if necessary, removed from the line, while perfectly labeled bottles are sent to the packer. When the packer machine reaches full capacity, it immediately peaks and loads the bottles into crates before transporting them to the palletizer via a conveyor. Finally, the packed goods are placed into pallets to ensure stability before being delivered to a roller conveyor for delivery to the warehouse by forklift.

3.4 Line regulation

Line regulation on packaging line used to ensure that the machines and conveyors work together. Line regulation uses a logic of machine speed level control, KRONES uses conveyor sensors to regulate line speed. A single sensor before and after a machine can also be used to monitor its start or stop condition. When the sensor before the machine is triggered and the sensor after the machine is not activated production begins, and when the sensor after the machine is triggered or before the machine is not triggered stops production.

3.4.1 V-graph

The V-graph theory is based on the bottleneck machine, which has additional capacity to restore the accumulation following a breakdown. It comprises the bottom of the machines on each side of the core machine. An overview of the machine event summary for the machines in the line is provided by this V graph. The V graphs can help to identify the bottleneck machine, as this is the machine which has many internal failures, and the preceding machine has a lot of blockages, and the succeeding machine has a lot of starvation.

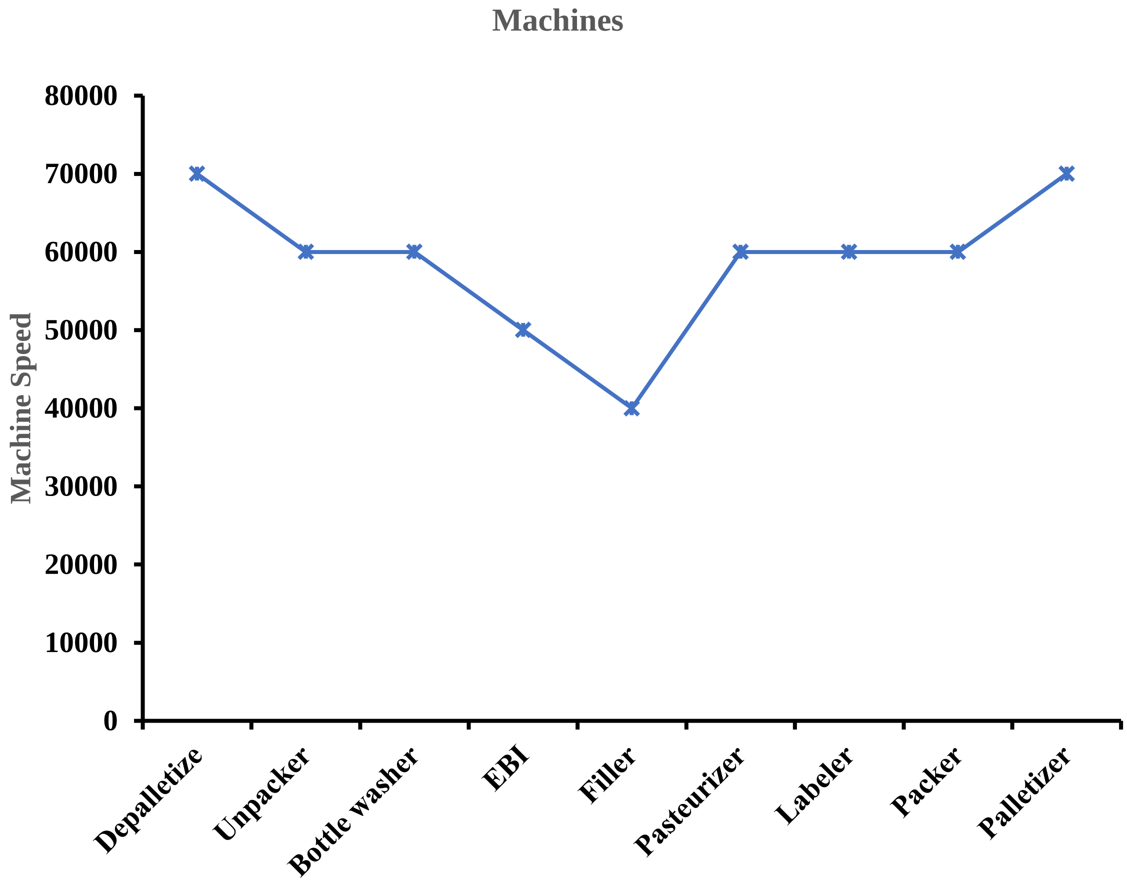


Figure 3. 3 V-graph of machine capacity

3.5 Data Collection

Data collection was a critical factor when studying complex packaging processes. Therefore, it was vital to collect recent data from reliable sources. To do so, it was necessary to have better understanding of the overall packaging process and observe the packaging process. Therefore, it was necessary to study the packaging flow of the process, different activities performed in the process, and the working principles of machines in detail. Reading related research works and documents related to this packaging system, such as journal articles and books, where also important for gaining better understanding of the general characteristics and new information in the field of productivity.

After gaining deeper comprehension of the packaging process, the tools needed to carry out the research were determined. For this study, primary data where from real-time production systems, and historical data are collected.

The below data's are collected from historical share dive database and directly from the packaging department recording database. These are: -

1. Planned and Actual production
2. Standard and actual consumption for material usage
3. Time loss due to machines downtime (CM).
4. Time loss due to CIP, CILT, startup and end up production, and NONA.

Table 3. 1 Collected planned and actual production per month in one-year duration.

Month	Planned Production (HL)	Filler Production (HL)	Net Production (HL)	Variance from plan (HL)	Production Loss
January	55000	52487	52166	2834	321
February	50000	44218	43860	6140	358
March	65000	54353	53827	11173	526
April	45000	35727	35366	9634	361
May	45000	39768	39312	5688	456
June	45000	34809	34426	10574	383
July	55000	45802	45321	9679	481
August	45000	31920	31651	13349	269
September	45000	32629	32305	12695	324
October	50000	30694	30387	19613	307
November	50000	32883	32566	17434	317
December	50000	29348	29045	20955	303
Total	**600000**	**464638**	**460232**	**139768**	**4406**

Table 3. 2 Collected standard and actual material usage consumption per month in one-year duration.

Overall Labels			
Month	Actual (Pics.)	Standard (Pics.)	Variance (Pics.)
January	47,545,807	47,424,240	121,567
February	39,994,384	39,873,240	121,144
March	48,996,927	48,920,472	76,455

April	32,712,520	32,707,584	4,936
May	35,669,952	35,681,616	-11,664
June	31,296,816	31,296,816	0
July	41,348,506	41,201,064	147,442
August	28,830,228	28,772,712	57,516
September	29,378,342	29,368,080	10,262
October	27,625,032	27,625,032	0
November	29,844,660.00	29,606,040	238,620
December	26,520,712.00	26,405,496	115,216
Total	**419,763,886**	**418,882,392**	**881,494**

Glue			
Month	Actual (Pics.)	Standard (Pics.)	Variance (Pics.)
January	3774	3,754	20
February	3736	3,157	579
March	4658	3,873	785
April	3038.73	2,589	449
May	3057	2,825	232
June	2394	2,478	-84
July	3292	3,262	30
August	2284	2,279	5
September	2,333	2,326	7
October	2,370	2,188	182
November	2,388	2,345	43
December	2,106	2,094	12
Total	35430.73	33,170	2261

Corks			
Month	Actual (Pics.)	Standard (Pics.)	Variance (Pics.)
January	15937970	15,808,080	153,932
February	13398030	13,291,080	109,558
March	16445000	16,306,824	138,176

April	11008000	10,902,528	339,501
May	12036000	11,893,872	198,552
June	10524000	10,432,272	91,728
July	13863000	13,733,688	129,312
August	9653000	9,590,904	62,096
September	9870000	9,789,360	80,640
October	9272000	9,208,344	63,656
November	9928288	9,868,680	59,608
December	8871712	8,801,832	69,880
Total	**140807000**	**139,627,464**	**1,179,536**

Table 3. 3 Collected Down Time Loss (EPL)

Machines	January	February	March	April	May	June	July	August	September	October	November	December	Sum
	Time (Hr.)												
Dipal	0.25	0.73	0.62	0.55	1.9	4.17	1.05	0.97	0.37	0.1	0.23	2.32	13.26
Unpacker	0.83	0.28	1.72	0.38	0.32	0.75	0.18	0.32	0.08	1.43	0.72	0.18	7.19
Bottle washer	2.2	0.8	3.5	1.15	2.22	3.15	3.37	2.08	2.93	1.32	0.87	1.37	24.96
EBI	0.4	0.65	0.27	0.87	0.62	0.15	1.05	0.33	1.45	0.53	1.95	1.58	9.85
Filler	1.5	1.35	17.93	10.55	3.39	2.08	11.62	3.28	4.65	11.15	3.33	2.58	73.41
Pasteurizer	0.62	0.07	0.47	0.22	0.77	0.38	0	0	0.7	0	0.8	0.42	4.45
Labeler	2.73	3.48	4.07	7.33	2.67	1.07	6.8	4.08	2.22	4.23	3.75	6.87	49.3
Packer	0.08	0.35	6.3	0.33	1.38	0.68	1.03	0.33	0.73	0.58	0.77	0.33	12.89
Pal	0	0.08	1.33	0.23	0.57	0.95	0.3	1.73	0	0.17	1.33	0	6.69
Total	8.61	7.79	36.21	21.61	13.84	13.38	25.4	13.12	13.13	19.51	13.75	15.65	202

Table 3. 4 Collected performance loss (Short stops/ Minor stops and Speed loss)

Machines	January	February	March	April	May	June	July	August	September	October	November	December	Sum
	Time (Hr.)												
Short Stops	21.5	26.5	23.3	22.6	25.3	24.7	18.2	17.7	29.8	34.2	31.5	21.5	296.8
Speed Loss	12.3	13.2	13.7	15.7	11.8	12.9	12.7	10.5	13.5	25.7	28.8	12.6	183.4
Undetermined Loss	10	12	13	12	18	15	20	12	24	18	12	10	176
Total	43.8	51.7	50	50.3	55.1	52.6	50.9	40.2	67.3	77.9	72.3	44.1	656.2

Table 3. 5 Collected Time loss due to Planned down time (External, CIP, CILT, startup and end up) production per month in one-year duration.

Issues	January	February	March	April	May	June	July	August	September	October	November	December	Sum
	Time (Hr.)												
CIP	7.9	10.9	11.8	2.4	8.4	2.6	7.3	3	1.1	0.8	1.6	0.8	58.6
Start-up & End-up	8.4	14.9	62.4	45.7	28	28.7	28.3	41.6	49.3	39.2	48.1	65	459.6
External	5.65	29.7	2.23	2.5	9.07	2	23	0.5	0.75	2.35	3.12	2.7	83.57
NONA	7	10	-	2	2	8	2	98	46	10	42	92	319
CILT	13	30	8	20	18	50	14	30	30	26	24	26	289
BH	10	24	54	40	20	30	-	40	20	20	30	40	328
PM	32	32	8	32	32	32	32	48	48	48	48	48	440
WH	24	48	8	24	48	48	144	96	72	112	96	192	912
Total	107.95	199.5	154.43	168.6	165.47	201.3	250.6	357.1	267.15	258.35	292.82	466.5	2890

In addition, the below packaging machine's actual capacity and its design are evaluated.

1. Conveyer accumulation (buffer capacity)
2. Machine speed or parameter

Table 3.6 shows that, the conveyor accumulation capacity of accumulated conveyor from unpacker to washer (ACUTW), accumulated conveyor from washer to EBI(ACWTE),single conveyor from EBI to filler(SCFETW), accumulated conveyor from filler to pasteurizer(ACFTP), accumulated conveyor from pasteurizer to labeler(ACPTL),single conveyor from pasteurizer to labeler(SCPTL), accumulated conveyor from labeler to packer(ACLTP).

Table 3. 6 Conveyer accumulation (buffer capacity)

Conveyor Name	Average accumulation
ACUTW	7680
ACWTE	7392
SCETF	288
ACFTP	7680
ACPTL	7680
SCPTL	280
ACLTP	7680

Table 3.7 Shows that, the machine speed of depalletize, unpacker, bottle washer, EBI, filler, pasteurizer, labeler, Packer and palletizer and they have a capacity to process 70k,60k,60k,50k,40k,60k,60k,60k and 60k bottles per hour (B.Ph.) respectively.

Table 3. 7 Machines speed

Machine	Speed (bhp)	Speed (Bps)
Depalletize	70000	0.0008
Unpacker	60000	0.001
Bottle washer	60000	0.001
EBI	50000	0.0012
Filler	40000	0.0015
Pasteurizer	60000	0.001
Labeler	60000	0.001
Packer	60000	0.001
Palletizer	70000	0.0008

Table 3. 8 Collected 30 hours of packaging performance.

Shift	Time of Production	Filler counter (bttls.)	Rejection counter(bttls.)	Net production (bttls.)	DT/BD (min.)
1	07:00-08:00	39000	350	38650	2
	08:00-09:00	78000	730	38620	2
	09:00-10:00	118000	1095	39635	0
	10:00-11:00	156000	1440	37655	2
	11:00-12:00	196000	1795	39645	0
	12:00-13:00	236000	2167	39628	0
	13:00-14:00	275000	2489	38628	2
	14:00-15:00	314000	2823	38666	2
2	15:00-16:00	354000	3103	39720	0
	16:00-17:00	393000	3415	38688	2
	17:00-18:00	432000	3753	38662	2
	18:00-19:00	472000	4030	39723	0
	19:00-20:00	511000	4348	38682	2
	20:00-21:00	551000	4695	39653	0
	21:00-22:00	590000	4988	38707	2
	22:00-23:00	629000	5202	38786	2
3	23:00-00:00	669000	5457	39745	0
	00:00-01:00	709000	5790	39667	0
	01:00-02:00	748000	6119	38671	2
	02:00-03:00	786000	6466	37653	2
	03:00-04:00	826000	6822	39644	0
	04:00-05:00	866000	7133	39686	0
	05:00-06:00	905000	7478	38655	2
	06:00-07:00	945000	7853	39625	0
1	07:00-08:00	984000	8194	38659	2
	08:00-09:00	1024000	8652	39542	0
	09:00-10:00	1064000	9124	39528	0
	10:00-11:00	1104000	9557	39567	0
	11:00-12:00	1143000	10026	38531	2
	12:00-13:00	1181000	10483	37543	2
	13:00-14:00	1181000	0	0	60
	14:00-15:00	1181000	0	0	60
Total production		1181000	10483	1170517	

All collected data is analyzed over different production months and time periods using the OEE and Simulation models. Simulation software will use these data to indicate areas for improvement, and this will help to improve productivity and OEE.

3.6 Packaging Line Analysis

The data taken from Table 4.1 shows that the planned and actual produced beer in 2023 production year. Based on this data, the below graph Figure 3.4 was drawn. As the graph shown, there was difference between the plan and the actual beer packed. However, for the variation between beer planned to be produced and on actual production there are different reason such as shortage of returnable bottles, lack of filtered beers, machine equipment failure, operation loss, planned and unplanned loss, no production schedule due to holidays and weekends, external(utility) failures and others are the main reasons.

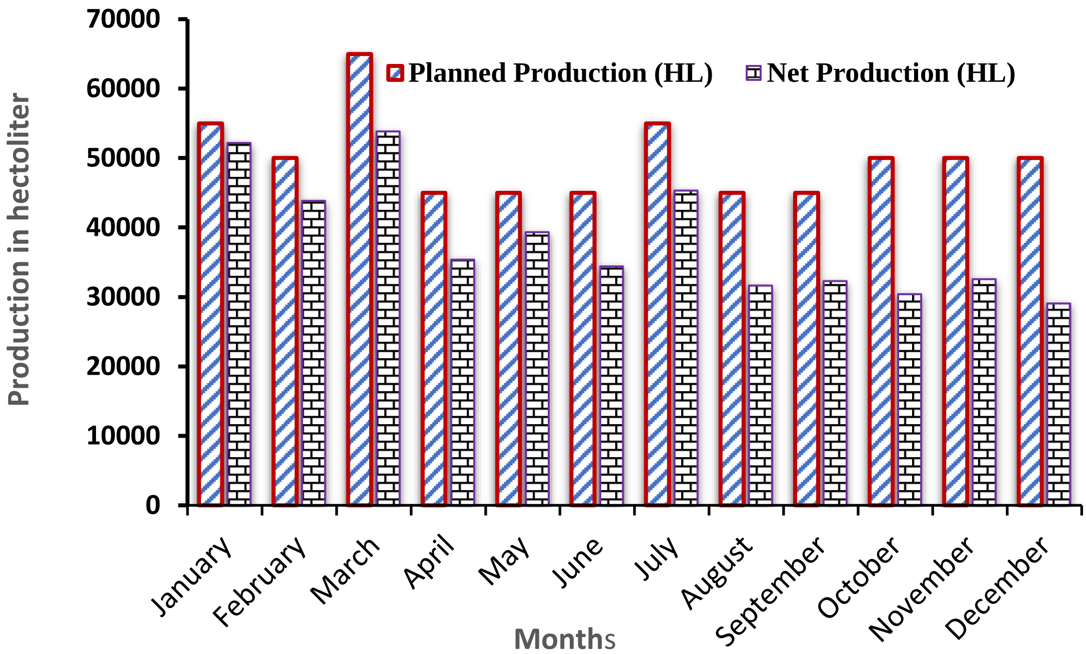


Figure 3. 4 Planned and Actual production in 2023 GC

The following efficiency analysis of the packaging machines, as well as study the line capacity in terms of OEE and simulation are used to understand which are the potential factors that causes to lower production efficiency. Also, it helps to investigate losses, to track issues and events that contribute to these losses, to identify the bottle necks with their root causes and focus on corrective action plan to correct them will be next step that aim to improve the efficiency of the packaging lines.

On the below topic yearly packaging analysis of OEE structure are presented

Ct	**8760 Hrs.** **100%**	
Wt.	**7296 Hrs.** **83.2%**	**UTL 1464 Hrs.**
Lt	**4406 Hrs.** **50.2 %**	**SDL 2890 Hrs.**
Ot	**4176.2 Hrs.** **47.6%**	**DTL 229.8 Hrs.**
Nt	**3519.9 Hrs. 40.18%**	**PL 656.2 Hrs.**
Vt	**3486.7 Hrs.** **40.1%**	**QL 33.3Hrs**

Figure 3. 5 Yearly OEE

Figure 3.5 shows that the one-year production performance about 1464 hours was unused time loss (UTL), 2890 hours was shutdown losses (SDL), 229.8 hours was down time losses (DTL), 656.6 hours was performance loss (PL) the about 33.3 hours was the quality loss. Also, these UTL, SDL, DTL, PL and QL are contributes 27.76%,54.8%,4.35%,12.4% and 0.63% of the total line efficiency loss respectively.

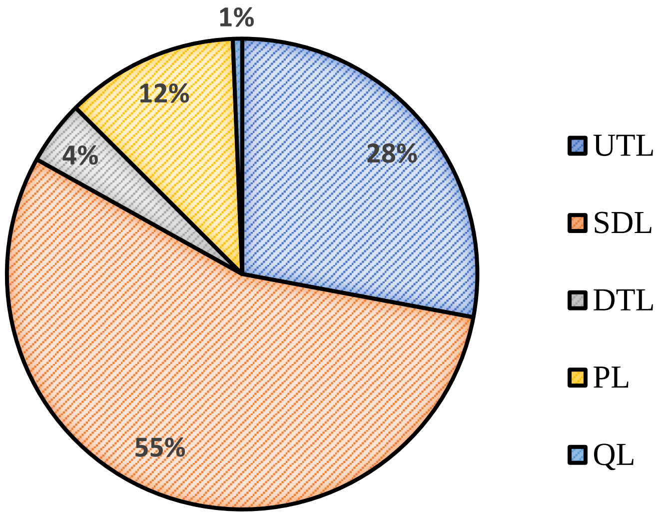
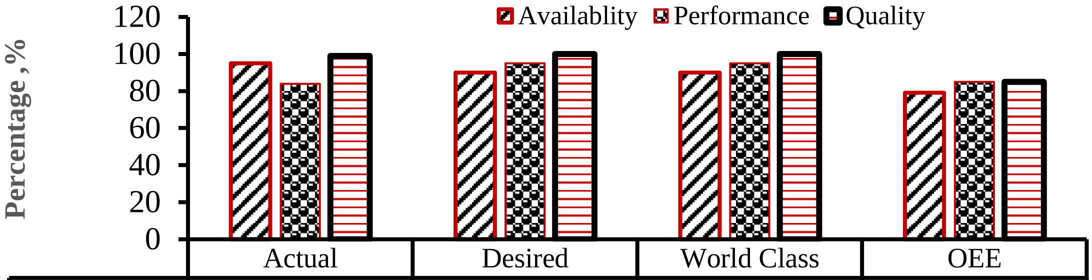


Figure 3. 6 Loss contribution.

Figure 3.6 show that the quality of product meets the company standard and world class specification about loss, which has contributed around 33.3 hours and below 1% (around 0.63%) loss and which is negligible. Shut down loss, unused down time loss, performance loss, and down time loss contribute 55%,28%,12% and 4% of loss respectively. Planned down time (SDL and UTL) was not include inn OEE and has no affect the line performance. However, PL and unplanned down time loss are part of the OEE, and our focus will be minimizing these two losses to enhance the performance.

As we see on the above chapter OEE is a multiplication of availability, performance, and quality. Figure 3.7 shows the details analysis of line availability, performance, and quality rate. Moreover, Availability is the time, the equipment is actually running versus the time it was expected to run and it is calculated by dividing the effective working (Available production) time by operating working (load) time and which come 95%. Performance measures how well the line performed in the available time against the rated speed and minor stoppages it is calculated by dividing the networking (Actual) time by operating working(load)time which comes 84%. Quality rate also measures the percentage of good sellable product produced, and it is calculated by value added networking time by networking (Actual) time which comes 99%. As a result, our OEE is become 79% which is far below the target and the world class standard. From the above one-year OEE analysis the production line is below the target by about 6% from target and world class. Improving toward the target and a world class OEE rating will give a great improvement in productivity. The below figure 3.7 represents OEE performance of 2023.



	Actual	Desired	World Class	OEE
Availablity	95	90	90	79
Performance	84	95	95	85
Quality	99	99.9	99.9	85

Figure 3. 7 OEE calculation

3.7 Identification of production losses

In the above topic 3.5 the packaging line analysis was done to determine the production loses in terms of UTL, SDL, DTL, PL and QL now their sources and the main reason are assessed in the below topics.

Table 3. 9 Unused Time Loss

No.	UTL factor	Loss (Hr.)	Percentage
1.	Weekends	1152	79%
2.	Holiday's	312	21%
	Total	1464	

Table 3.9 shows that the total hour of unused times, during production year of 2023 there were no production activities due to weekends and holidays. From these unused time events weekends and holidays are shares 79% and 21%, respectively. The below figure 3.8 are shows unused time contribution of weekends and holidays.

Figure 3. 8 Unused time

Table 3.10 shows that the total hour of shutdown loss during production year of 2023 was caused by cleaning into parts (CIP), start up and end up, external utility stops, no operation no activity (NONA), cleaning, inspection, lubricating and tightening (CILT), lack of beer, planned maintenance and lack of bottles events which result in 2%,16%,3%,11%,10%,11%,15% and 32% efficiency loss respectively. The below table 3.10 and figure 3.9 are shows shutdown contribution of various incidents.

Table 3. 10 Shutdown loss

No.	SDL factor	Loss (Hr.)	Percentage
1.	CIP	58.6	2%
2.	Start-up & End-up	459.6	16%
3.	External (Utility Stops)	83.57	3%
4.	NONA (Cleaning, descaling, Meeting)	319	11%
5.	CILT	289	10%
6.	Brewhouse Lack of Filtered beer	328	11%
7.	Planned Maintenance	440	15%
8.	Warehouse Lack of bottles	912	32%
	Total	2890	

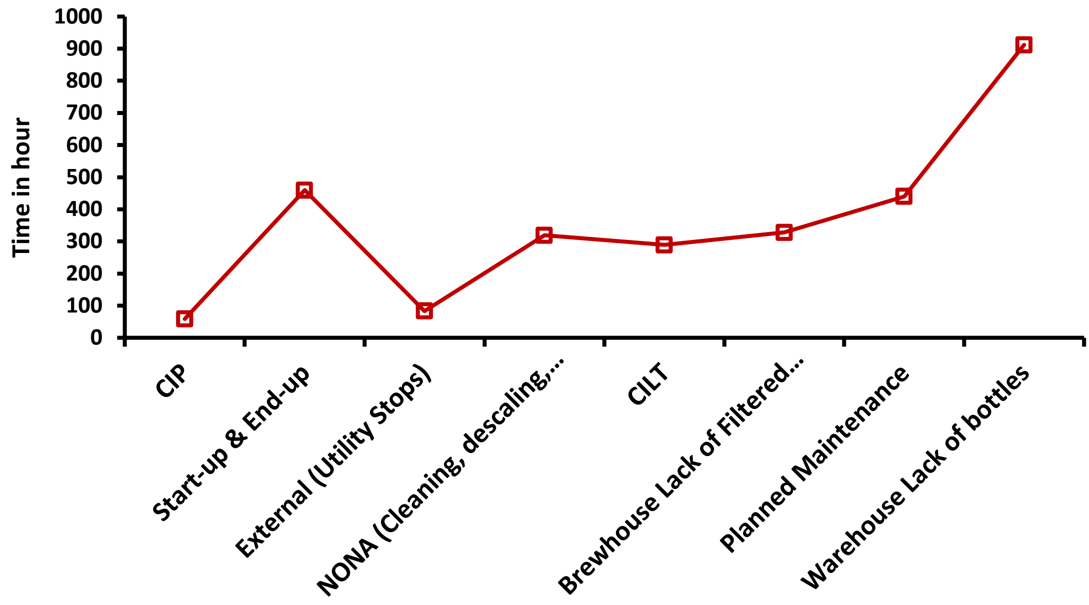


Figure 3. 9 Shutdown loss factor

Table 3.11 shows that the total unplanned down time loss, during production year of 2023. There were machine breakdown, setup and adjustment, and operational and technical errors and these events are contributing down time losses of 88%, 11% and 1%, respectively.

Table 3. 11 Unplanned down time loss

No.	DL factor	Loss (Hr.)	Percentage
1.	Machine Break down	202	88%
2.	Set up and adjustment	25	11%
3.	Operator and Technician error	2.5	1%
	Total	229.5	

Table 3.12 shows that the total performance loss, for production year of 2023. There were short stops or minor stops, speed loss, and undetermined loss. These occurrences are contributing 45%, 28% and 27% of performance loss respectively.

Table 3. 12 Performance Loss

No.	PL factor	Loss (Hr.)	Percentage
1.	Short Stops/ Minor Stops	296.8	45%
2.	Speed Loss	183.4	28%
3.	Undetermined Loss	176	27%
	Total	656.2	

Tabel 3.12 shows that, the performance loss of production year 2023

3.7.1 Unused time and shut down loss factors.

As we seen from the above figure 3.8 and figure 3.9 unused and shutdown loss factors are categorized separately. These are the time used by the packaging line without production, which do not count on the OEE; typically include not scheduled to run, weekend and holiday, CIP, start up and end up, external utility stops, NONA (cleaning, descaling, meeting), CILT, brewhouse lack of filtered beer, planned maintenance and warehouse lack of bottles. In this study, general 10 factors are identified out of the 10, four major contributors are isolated, normally they are not part of the OEE calculation. Weekends, Warehouse lack of bottles, higher planned maintenance, and start up and end up times have been identified as major planned production disturbance, are considered to be the most important to be reduced. Additionally, to increase the line performance our focus would be improving the availability and performance of the line by identifying the reason for lowering performance rate and increasing the availability rate.

3.7.2 Line Availability factors

Depend on the analyzed data the main big losses are identified as the availability and performance loss. Therefore, the detailed analysis on these factors will be analyzed in the below topics.

- ✓ Line Availability factors.

Availability is the portion of the OEE metric represents the percentage of scheduled time that the operation is available to operate. In addition, it’s a percentage of time a machine is available to produce beer. The Availability metric is a pure measurement of uptime that is designed to exclude the effects of Quality, Performance, and Scheduled downtime events.

Availability is the actual time left for production after you subtract all planned down time. Planned downtime occurs in a form of breaks, meetings, T.P.M activities. It measures the result of loss due to unplanned down time. Unplanned down time occurs in the form of breakdowns, idle time, set up and adjustments. So that, availability is killed by unplanned downtime or breakdown, idle time, and setup and adjustments. Also, it improved by reducing break down time, idle time and set up and adjustment time.

In the below topic the collection of one year data is used to analysis the availability in order to understand, investigate the cause of the downtime, and to find their root cause.

First, we use the table 3.3 of one year equipment break down time (EPL). Second, yearly total of unplanned down time is put in table 3.11 to determine the cumulative effect in the given year. Third, major problematic machines of the line in terms of break down factor are identified in figure 3.10. Finally, major causes of problem of the three machines are identified.

Table 3.13 shows that about 202 hours of production time were lost in packaging line due to down time loss of filler machine which shares 36% of the total down time, with the remaining 24%,12%, and 7%, in Labeler, Bottle washer, and Dipal, respectively. These machines are the source of around 80% of the equipment down time that kills the availability of line.

Table 3. 13 Collected yearly machine down time.

Machines	Sum	Percentage
Time (Hr.)		
Dipal	13.26	7%
Unpacker	7.19	4%
Bottle washer	24.96	12%
EBI	9.85	5%
Filler	73.41	36%
Pasteurizer	4.45	2%
Labeler	49.3	24%
Packer	12.89	6%
Pal	6.69	3%
Total	202	

3.7.3 Down time analysis with pareto chart

On the below topic break down time analysis of packaging line is presented.

Figure 3.10 shows that, downtime analysis of Filler, Labeler, Bottle washer and Dipal has caused around 80% of down time in the packaging line due to different reasons of machine break down and other reasons. As indicated in the figure below, these machines are the source of around 80% of the equipment down time that kills the availability of line.

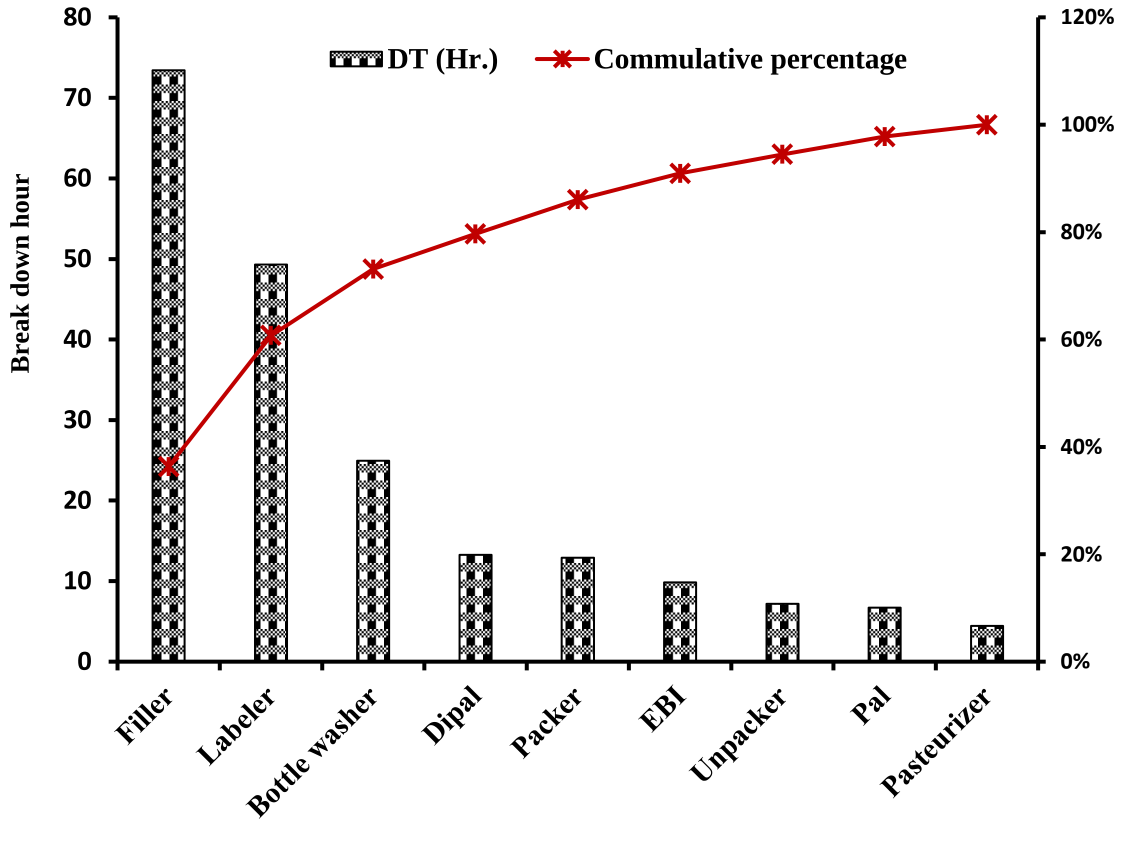


Figure 3. 10 Breakdown analysis of packaging line

To identify and prioritize what needs to be done in these significant problematic machine regions, will conduct a pareto analysis on each problematic machine independently.

Figure 3.11 shows that the main sources of problems on the filler machine are recognized as emptying bottles, HPI, and Star timing fault, which account for approximately 80% of total filler machine downtime

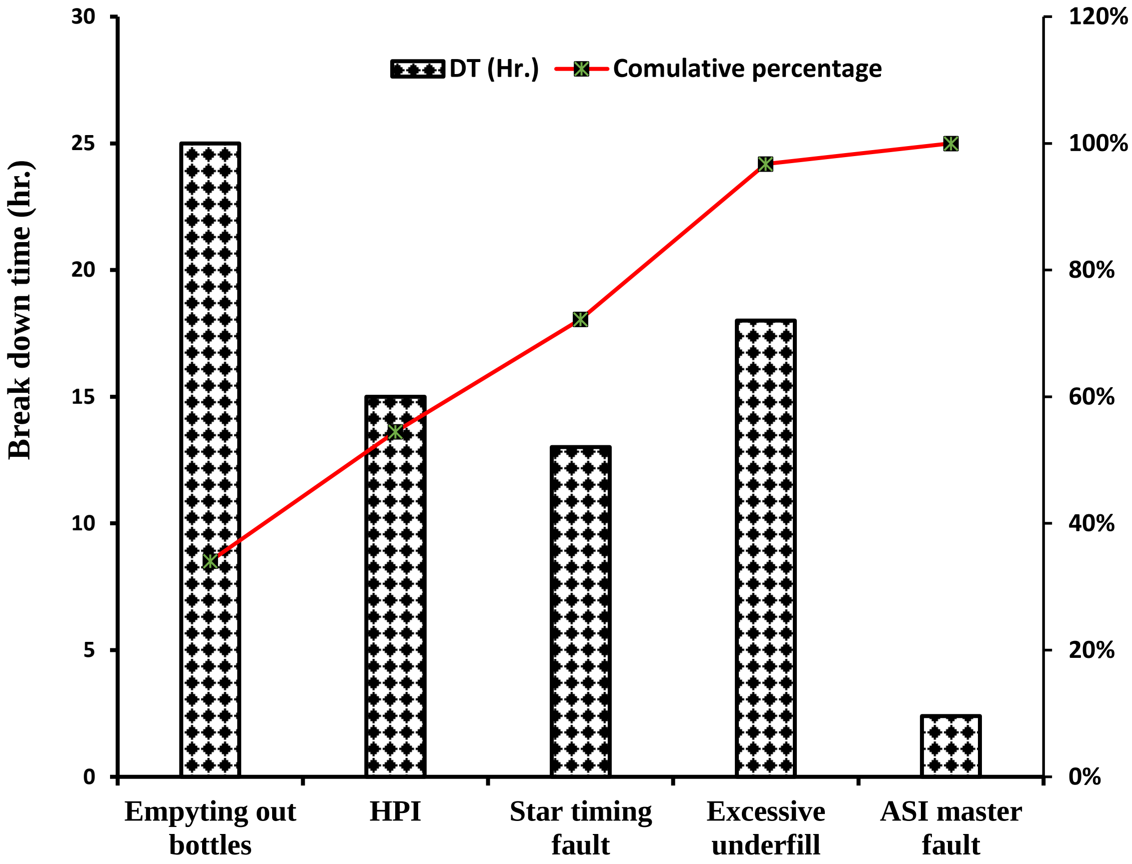


Figure 3. 11 Filler machine problem area

Figure 3.12 shows that the main causes of problems on Labeler machines include label flagging and scattering, as well as worm timing, label magazine timing, and an ASI master failure. These sectors accounted for approximately 81% of total downtime in labeler machines.

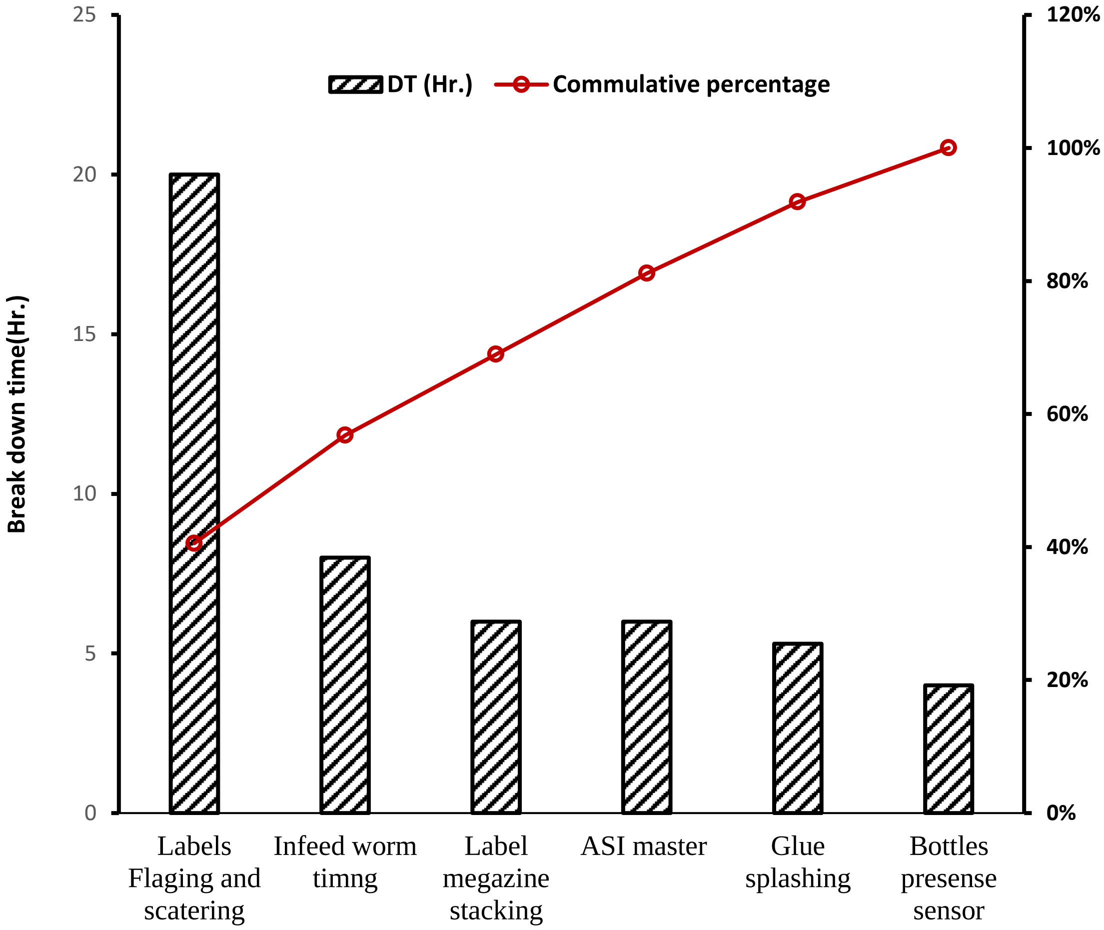


Figure 3. 12 Labeler machine problem area

Figure 3.13 shows that, the major causes of problems on bottle washer machine are identified as label carry over, Label removal conveyor motor trip, and caustic con. reading sensor. these areas accounted for approximately 80% of total downtime in bottle washer machine.

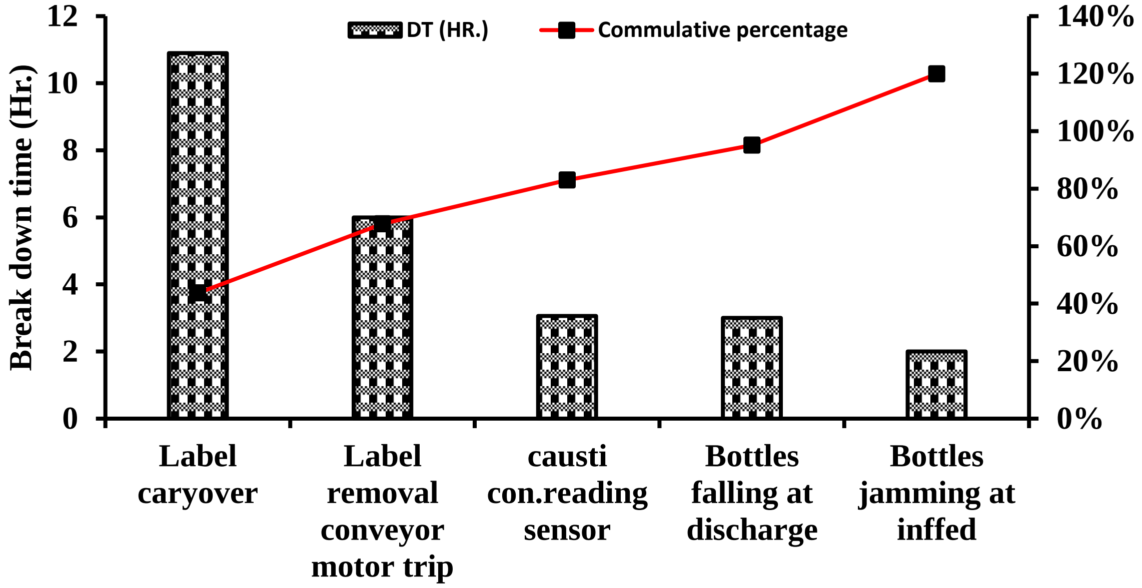


Figure 3. 13 Bottle washer problem area

Figure 3.14 shows that the most common causes of issues on dipal machines are gripper faults, moving units (belts), and deformed pallets. These locations accounted for approximately 80% of overall downtime in dipal machine.

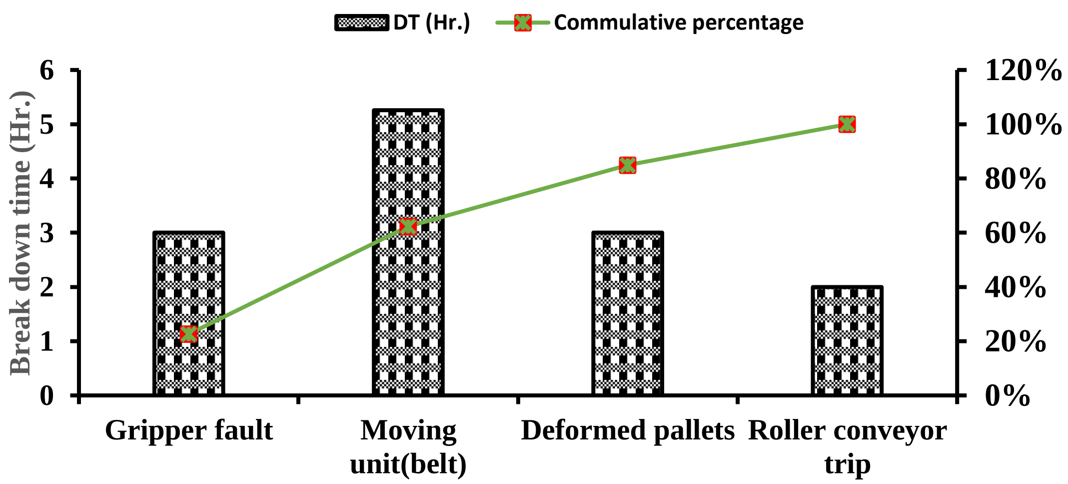


Figure 3. 14 Dipal problem area.

Finally, based on a one-year downtime analysis, 20 areas of the machined components were identified throughout the four key DT contributor machines. Based on their increased downtime contribution, three machine areas have been identified as critical problem areas of the line for further research to investigate the cause and implement a corrective action plan.

3.7.4 Major breakdown problems identified in machines.

From the data analysis of the above-mentioned areas, one key problematic area from each machine is selected and grouped into three sections depending on their DT contribution, as shown in the Table 3.14

3.7.5 Identified general problems of key machine areas.

On the below topic table 3.14 shows that the general problem of key machine areas is presented.

Table 3. 14 Identified general problems of key machine areas.

Machine Areas	Possible problem
Filler Empty out bottles	Bottles presence sensor fault
	Communication fault along power line
	Filling solenoid valve not opening
	Low Co2 pressure on bowl counter pressure
	Communication cable broken
	Loose connection
Label Carry over	Lack of surfactants (Additive)
	Label quality fault
	Glue quality fault
	Labels removal brush fault
	Low contact time
	Temperature not reached at set point
	Low caustic concentration

Gripper Fault	Missing software reference
	Gripper holder crashed due to timing fault
	Misalignment of create and gripper
	Tightening of slider belt too high or too low
	Running time of belt
	Wrong adjustment of tension belt

Once major problematic areas of the machine are selected, and the key problems are identified the next step will be to analyze their root causes based on the analysis of pareto chart. The machine downtime and performance loss are regrouped into three parts to analyze the effect of each component on the production loss and production line inefficiency. Lastly, will find out the root cause of these major problem areas in the below topic and fish bone diagram is used to analysis the cause and effect of these machine areas.

3.8 Key machine problems

Table 3.15 shows that, the key machine problem is presented.

Table 3. 15 Key machine problems

Machines	Problems
Filler	ASI Master Fault
	Empty bottles out
	Under fill
	HPI fault
	Star timing fault
	Flushing
Bottle washer	Bottles falling at discharge
	Bottles jamming at infeed
	Uncleaned bottles
	Label carryover

	Label removal conveyor motor trip
	Caustic concentration reading sensor fault
Labeler	Labels Flagging and scattering
	Infeed worm timing fault
	ASI master fault
	Label magazine stacking
	Glue pump fault
	Bottle presence sensor fault

3.9 Cause and effect analysis

On the below topics cause and effect of filler, washer and labeler machine are presented:

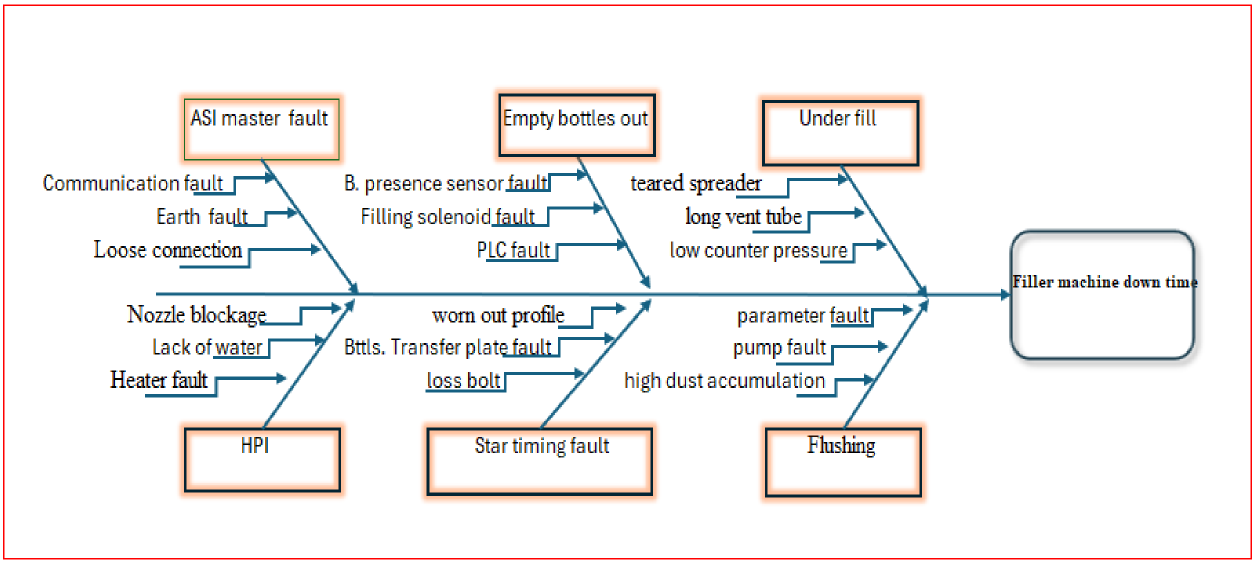


Figure 3. 15 Filler machine down time

Figure 3.15 shows that, the cause-and-effect diagram and the relationships between various causes and their effects on filler machine downtime.

Cause and effect of bottle washer machine are presented below:

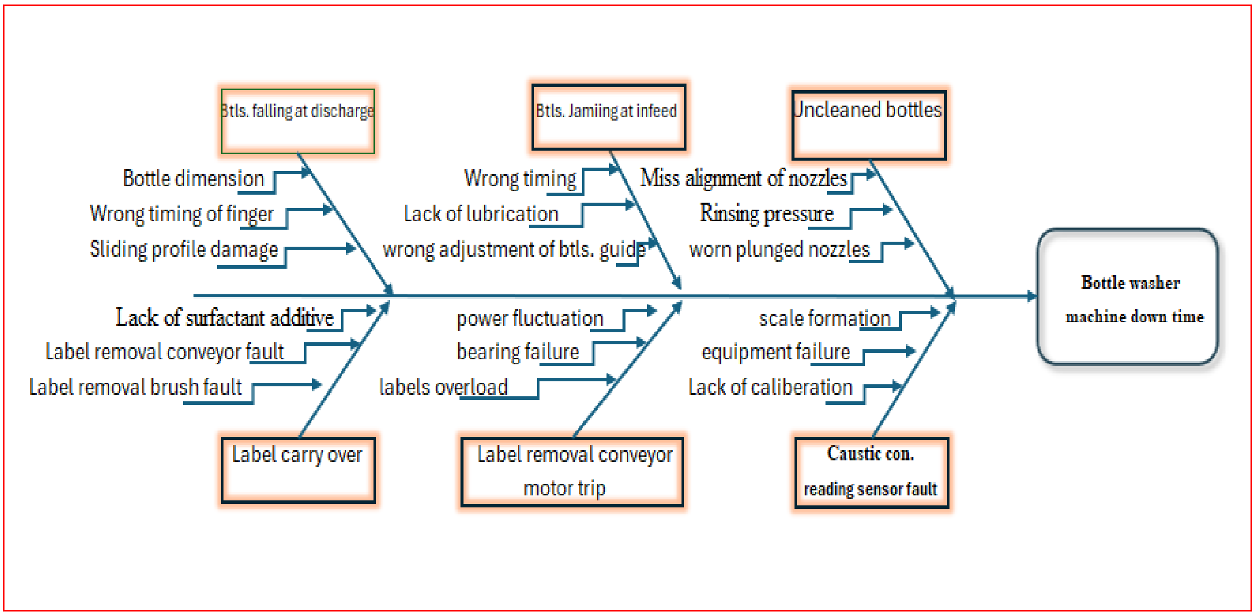


Figure 3. 16 Bottle washer machine down time

Figure 3.16 shows that the cause-and-effect diagram and the relationships between various causes and their effects on bottle washer machine downtime.

Cause and effect of labeler machine are presented below.

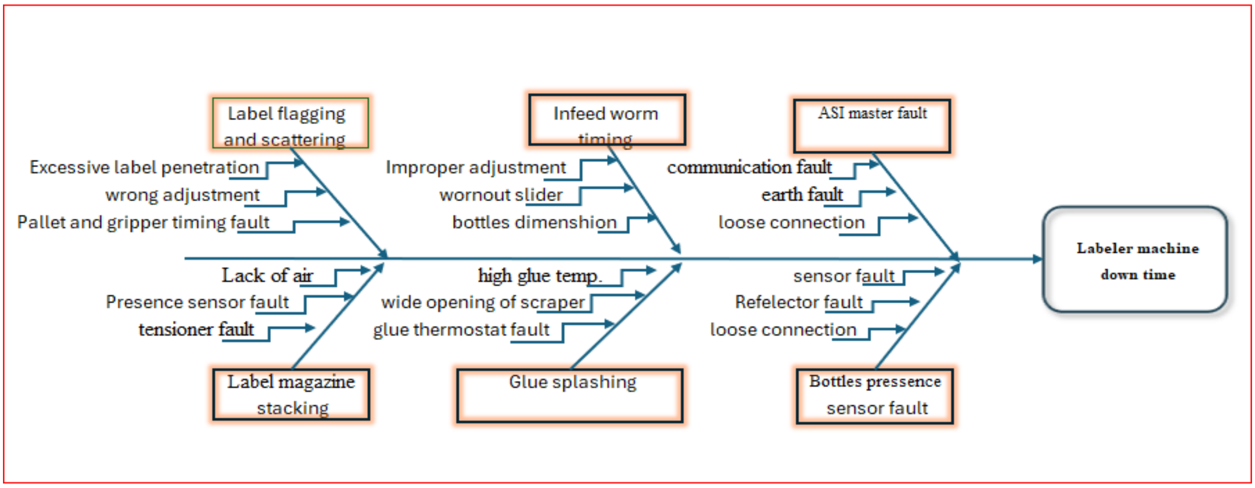


Figure 3. 17 Labeler machine down time

Figure 3.17 shows the cause-and-effect diagram and the relationships between various causes and their effects on Labeler machine downtime.

3.9.1 Line performance factors and root cause analysis

Performance is the portion of the OEE metric measures how well the line performed in the available time against the rated speed and minor stoppages.

Performance losses are caused by short stops and speed loss only which affect the gross output of the filler. This stoppage is any equipment on the production line that directly causes a filler stoppage for less than 5 minutes. When you divide the networking (Actual) time by effective working (Available production) time the result is the performance ratio.

From the previous analysis in table 3.12 short stops and speed loss are shares 73% of the line performance. Now, in the below topic performance loss areas and their cause are presented in order to understand, investigate the cause of performance loss, and to find their root cause.

Table 3. 16 Performance loss areas

Performance loss factors	
1.	Crown Jamming
2.	Caper flushing
3.	Starvation at lower side of the filler
4.	Blockage from upper side of the filler
5.	Adjustments
6.	Fallen bottles at infeed and discharge
7.	Utility supply interruption
8.	Brewhouse product interruption
9.	Raw material quality
10.	Emergency stops

Table 3.16 shows that, the performance loss areas of the packaging line

The problems for performance losses of the line are identified. As a result, on figure 3.18 it will be analyzed by fish bone diagram to determine the possible causes.

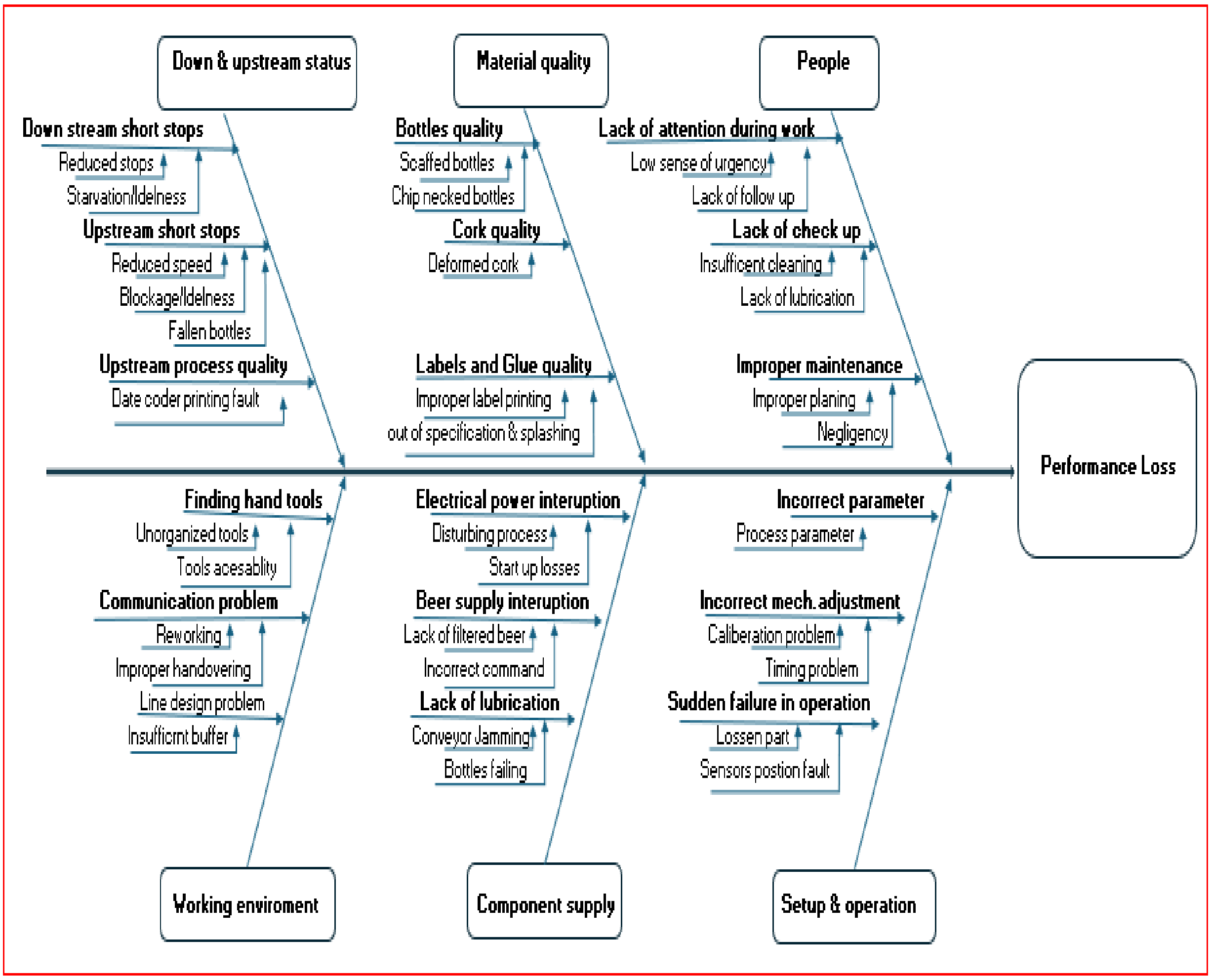


Figure 3. 18 performance loss

Figure 3.18 shows that the cause-and-effect diagram and the relationships between different causes and their effect on performance loss has been shown.

3.9.2 Root Cause Analyses

In order to make RCA the below minimum requirements have been used.

1. 5 why questions have raised.

- ✓ What happened?
- ✓ Where did it happen?
- ✓ When did it happen?
- ✓ Why was it a problem?
- ✓ Why was it a problem?

2. Description of incident or failure
3. Solution Category

Based on the below identified RCA corrective action plan suggestion has been made to reduce loss due to Equipment breakdown. On the below topic RCA of filler, bottle washer, labeler and depalletize machine are presented.

Table 3. 17 RCA of filler, bottle washer, labeler and depalletize machine

<table>
<tr><td colspan="5">Filler</td></tr>
<tr><td>No.</td><td colspan="4">Major problems: - Filler Empty out bottles</td></tr>
<tr><td>1</td><td colspan="2" rowspan="7">5W 1H</td><td>Questions</td><td>Answers</td></tr>
<tr><td rowspan="15"></td><td>What happened?</td><td>Sometimes Filler unable to fill some bottles from Station 11 to 37</td></tr>
<tr><td>Where did it happen?</td><td>On Filler machine Filling Stations</td></tr>
<tr><td>When did it happen?</td><td>It happens randomly any time.</td></tr>
<tr><td>Why was it a problem?</td><td>Affects line efficiency and causes crown loss.</td></tr>
<tr><td>Who was involved to fix?</td><td>Artesian and Automation engineers</td></tr>
<tr><td>How big was the problem</td><td>It costs about 5 to 10 minutes of breakdown when it happens every time and crown loss on empty bottles.</td></tr>
<tr><td colspan="4">Root Cause Analysis</td></tr>
<tr><td>Why 1</td><td>Q</td><td colspan="2">Why Communication between FVC controller and these stations interrupted / corrupted.</td></tr>
<tr><td></td><td>A</td><td colspan="2">Because there is CRC fault on this specific Stations</td></tr>
<tr><td>Why 2</td><td>Q</td><td colspan="2">Why CRC fault on this specific Stations</td></tr>
<tr><td></td><td>A</td><td colspan="2"></td></tr>
<tr><td>Why 3</td><td>Q</td><td colspan="2"></td></tr>
<tr><td></td><td>A</td><td colspan="2"></td></tr>
<tr><td>Why 4</td><td>Q</td><td colspan="2"></td></tr>
</table>

		A	
	Why 5	Q	
		A	

Description of incident failure	
Before	All Stations (96) fills all bottles properly
	1. For Communication errors We Corrected all poor wiring connections like clean and
During this	tight ground/shield connection points, replaced Powerlink cables which connects
	stations on the E tower
	2. For Hardware issues: we changed defective Modules that are the cause for interference (due to earth fault), Exchanged FVC Cards from affected stations to normal stations
	3. Software or firmware issues: checked compatibility issues in the software or firmware of the network devices
After	*After* performing this task, the problem not happened, but we have to wait to confirm or perform other tasks again.
Root Cause	
Communication b/n filling valve controller and its station data exchanging was corrupted	
CAP Suggestion	
Inspect the condition and position of cams and limit switches on time-based PM tasks.	

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication,	Operating pressure,	Condition and time-based PM	Improvement to increase life	Technician and operator

	Inspection & Tightening	temperature, speed, etc.	tasks	span or improve weak design	training

Filler				
No.	Major problems: - HPI fault			
2	5W 1H		Questions	Answers
			What happened?	*HPI temperature not reached at set point (90^{o}c)*
			Where did it happen?	*At filler machine*
			When did it happen?	*Any time during startup of production*
			Why was it a problem?	*It stops the line for prolonged time and affect efficiency*
			Who was involved to fix?	*Artesian, mechanical specialist and packaging engineer*
			How big was the problem	*It costs 20 to 30 min. every time it happens*
	Root Cause Analysis			
	Why 1	Q	Why HPI temperature did not reach its pre seated temperature	
		A	B/c heater is not sufficiently heated the water	
	Why 2	Q	Why the heater not heater the water properly	
		A	B/c the heating resistor covered by scale	
	Why 3	Q	Why heating resistor covered by scale	
		A	B/c HPI heater not descaled for prolonged time	
	Why 4	Q		
		A		
	Why 5	Q		
		A		
	Description of incident failure			
	Before	HPI is working properly		
	During current	to start up production and to resume production operators has increased the		

	After removing the heater from machine and descaled it properly
	Root Cause
	Lack of proper cleaning or descaling
	CAP Suggestion
	Plan and execute descaling as per the standard descaling procedure
	Solution Category

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

	Filler		
No.	Major problems: - Star timing fault		
3	5W 1H	Questions	Answers
		What happened?	*Filler infeed star miss timing*
		Where did it happen?	*At filler*
		When did it happen?	*Any time during production*
		Why was it a problem?	*It affects production efficiency*
		Who was involved to fix?	*Technicians and mechanical specialist*
		How big was the problem	*It costs about 15 to 20 minutes of breakdown when it happens every time*
	Root Cause Analysis		
	Why 1	Q	Why infeed star misses its timing

		A	B/c the star wheels locking unit bolt has lost its bolts
	Why 2	Q	Why locking unit losses its bolt
		A	B/c of vibrations
	Why 3	Q	Why vibration happened
		A	B/c of there was the star holder was not tightened properly
	Why 4	Q	
		A	
	Why 5	Q	
		A	

Description of incident failure	
Before	Filler star wheels was working properly
During	tightened the star holder, its stand and fixture
After	After performing this task, the problem not happened again

Root Cause
Lack of proper follow up and doing autonomous maintenance

CAP Suggestion
Proper follow up and executing autonomous maintenance based on the standard

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

Filler				
No.	Major problems: - underfill			
4	5W 1H		Questions	*Answers*
			What happened?	*Underfill on bottles*
			Where did it happen?	*On filler machine*
			When did it happen?	*Any time during production*
			Why was it a problem?	*It affects production loses*
			Who was involved to fix?	*Technicians and packaging engineers*
			How big was the problem	*It costs liquid loss and affect production*
	Root Cause Analysis			
	Why 1	Q	Why underfill happened	
		A	Because of teared speeders	
	Why 2	Q	Why spreaders are teared	
		A	Because of bottle burst	
	Why 3	Q	Why bottles are burst	
		A	Because it can't resist the bowl counters pressure	
	Why 4	Q		
		A		
	Why 5	Q		
		A		
	Description of incident failure			
	Before	Filler are working smoothly		
	During	Inspect spreaders and mouth pieces		
		Changing longer vents tubes		
	After	Started running smoothly		

	Root Cause
	Process fault
	CAP Suggestion
	Follow and change failed parts
	Solution Category

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

Labeler			
No.	**Major problems: - Label flagging and scattering**		
5	5W 1H	Questions	Answers
		What happened?	*Label flagging and scattering*
		Where did it happen?	*On Labeler machine*
		When did it happen?	*Any time during production*
		Why was it a problem?	*Due to high label and glue loss and incur DT*
		How was involved to fix?	*Technicians and mechanical specialist*
		How big was the problem	*It costs about 15 to 30 min. when it happens every time*
	Root Cause Analysis		
	Why 1	Q	Why labels are flagging and scattering
		A	Because labels are not on position
	Why 2	Q	Why labels are not on position
		A	Because label tensioner bolt not functional
	Why 3	Q	Why label tensioner bolt not functional

		A	Because bolt have damaged threads	
	Why 4	Q	Why bolt have damaged threads	
		A	Because overtight during adjustment	
	Why 5	Q		
		A		
	Description of incident failure			
	Before	Machine run smoothly at the mid of production		
	During	Flagging and scattering happened		
		Inspection		
	After	Magazine and brush adjustment		
		Changed tensioner bolt and roller		
		Run smoothly		
	Root Cause			
	Improper way of tightening and adjustment			
	CAP Suggestion			
	Train technicians for proper adjustment			
	Solution Category			

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

	Labeler		
No.	Major problems: - Label magazine stacking		
6		Questions	Answers
		What happened?	*Label magazine stacked*

5W 1H	Where did it happen?	*On labeler machine*
	When did it happen?	*Any time during production*
	Why was it a problem?	*Incurs down time*
	Who was involved to fix?	*Technicians, Mechanical specialist*
	How big was the problem	*It costs about 15-20min when it happened*

Root Cause Analysis

Why 1	Q	Why label magazine stack
	A	Because oscillator drive not functional
Why 2	Q	Why oscillator drive not functional
	A	Because of lack of air
Why 3	Q	Why lack of air
	A	Because of leakage on in air supply
Why 4	Q	
	A	
Why 5	Q	
	A	

Description of incident failure

Before	machine run smoothly
	Inspected on oscillator drive Festo
During	corrected leaked Festo
After	machine run smoothly

Root Cause

Aging

CAP Suggestion

Follow and change all the equipment parts as per the manufacturer recommendation

Solution Category

A	B	C	D	E
Sustain basic	Observe &	Restore	Make	Raise skill

	condition	correct operating condition	deteriorated equipment	improvements to design	levels
	Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

Bottle washer			
No.	Major problems: -Label carryover		
7	5W 1H	Questions	Answers
		What happened?	*Label carry over*
		Where did it happen?	*On bottle washer*
		When did it happen?	*Any time during production*
		Why was it a problem?	*Quality defect on bottles and incur DT*
		Who was involve to fix?	*Technicians, Mechanical specialist, and packaging engineers*
		How big was the problem	*It causes high bottles rejection on EBI*
	Root Cause Analysis		
	Why 1	Q	Why label carry over happened
		A	Because the label stick on bottles
	Why 2	Q	Why labels stick on the bottles
		A	Because label removal brush malfunction
	Why 3	Q	Why label removal brush malfunction
		A	Because of aging
	Why 4	Q	
		A	
	Why 5	Q	
		A	
	Description of incident failure		
	Before	labels was removing properly	

	During	Inspection on label removal brush and change by the new one
	After	labels starts removing properly
	Root Cause	
	Aging	
	CAP Suggestion	
	Follow and change all equipment parts as per the manufacturer recommendation	
	Solution Category	

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

Bottle Washer			
No.	Major problems: - Label removal conveyor motor trip		
8	5W 1H	Questions	Answers
		What happened?	*Label removal motor trip*
		Where did it happen?	*On bottle washer*
		When did it happen?	*Any time during production*
		Why was it a problem?	*The machine stops till restarting*
		Who was involved to fix?	*Electricians and Automation engineers*
		How big was the problem	*It incurs 10-20 min DT when it happened*
	Root Cause Analysis		
	Why 1	Q	Why label removal motor trip
		A	Because of overload or over current

Why 2	Q	Why over current happened
	A	Because of over label accumulated on removal sieve conveyor
Why 3	Q	Why labels accumulated on removal sieve conveyor
	A	Because of label removal brush malfunction
Why 4	Q	Why label removal brush malfunction
	A	Because of it was damaged and waiting for spare
Why 5	Q	
	A	

Description of incident failure	
Before	It was working properly
During changed	label removal conveyor motor trip at least two times per shift and the brush
	By the new one
After	running smoothly

Root Cause
Aging

CAP Suggestion
Follow and change all equipment parts as per the manufacturer recommendation

Solution Category				
A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

<table>
<tr><td colspan="5">Depalletize</td></tr>
<tr><td>No.</td><td colspan="4">Major problems: - Gripper fault</td></tr>
<tr><td>9</td><td colspan="2" rowspan="7">5W 1H</td><td>Questions</td><td>Answers</td></tr>
<tr><td></td><td>What happened?</td><td>Gripper head crash</td></tr>
<tr><td></td><td>Where did it happen?</td><td>On depalletizer machine</td></tr>
<tr><td></td><td>When did it happen?</td><td>Any time during production</td></tr>
<tr><td></td><td>Why was it a problem?</td><td>Incurs break down</td></tr>
<tr><td></td><td>Who was involve to fix?</td><td>Technicians, mechanical specialist, and packaging engineers</td></tr>
<tr><td></td><td>How big was the problem</td><td>It incurs 10-15min when it happened</td></tr>
<tr><td></td><td colspan="4">Root Cause Analysis</td></tr>
<tr><td></td><td>Why 1</td><td>Q</td><td colspan="2">Why gripper head crush</td></tr>
<tr><td></td><td></td><td>A</td><td colspan="2">Because create are not on position</td></tr>
<tr><td></td><td>Why 2</td><td>Q</td><td colspan="2">Why creates are not on position</td></tr>
<tr><td></td><td></td><td>A</td><td colspan="2">Because pallet stopper not working properly</td></tr>
<tr><td></td><td>Why 3</td><td>Q</td><td colspan="2">Why pallets stopper not working properly</td></tr>
<tr><td></td><td></td><td>A</td><td colspan="2">Because of sensors that control the stopper not working</td></tr>
<tr><td></td><td>Why 4</td><td>Q</td><td colspan="2">Why sensors not working</td></tr>
<tr><td></td><td></td><td>A</td><td colspan="2">Because it damages during operation</td></tr>
<tr><td></td><td>Why 5</td><td>Q</td><td colspan="2"></td></tr>
<tr><td></td><td></td><td>A</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="4">Description of incident failure</td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td>Before</td><td colspan="3">machine running smoothly</td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td>During</td><td colspan="3">Inspect the sensors and changed the failed one</td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td>After</td><td colspan="3">machine run smoothly</td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td colspan="4">Root Cause</td></tr>
<tr><td></td><td colspan="4">Lack of attention and controlling during operation</td></tr>
</table>

	CAP Suggestion
	Train operators to properly follow operation and take needful action before failure has happened
	Solution Category

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

Depalletize				
No.	Major problems: - Moving unit (belt) fault			
10	5W 1H		Questions	Answers
			What happened?	*Linear belt miss positioned*
			Where did it happen?	*On palletizer machine*
			When did it happen?	*Any time during production*
			Why was it a problem?	*Incurs down time*
			Who was involve to fix?	*Technicians, mechanical specialist, and packaging engineers*
			How big was the problem	*It costs 15-20min.DT when it happened*
	Root Cause Analysis			
	Why 1	Q	Why linear belt miss positioned	
		A	Because excessive grease used around sprocket	
	Why 2	Q	Why excessive grease used around the sprocket	
		A	Technicians' skill gap	
	Why 3	Q		
		A		
	Why 4	Q		

		A	
Why 5		Q	
		A	
Description of incident failure			
Before	Machine run smoothly		
During	Adjusted linear belt position		
	Clean over greased		
	Tighten loosen parts		
After	Problem solved and machine started running		
Root Cause			
Skill gap			
CAP Suggestion			
Train technicians to properly grease their machine			
Solution Category			

A	B	C	D	E
Sustain basic condition	Observe & correct operating condition	Restore deteriorated equipment	Make improvements to design	Raise skill levels
Cleaning, Lubrication, Inspection & Tightening	Operating pressure, temperature, speed, etc.	Condition and time-based PM tasks	Improvement to increase life span or improve weak design	Technician and operator training

CHAPTER- 4

Result and Discussions

4.1 Root cause analysis and corrective action plan

After finding the general and key problems occurred in each machine as shown in the above table 3.14 & 3.15 In order to came up in to common understanding the nature of problems and their relation to each machine, risk assessment and effect on machine performance is studied before finding the root causes of the problems.

In addition to data collection and analysis using the pareto chart, the key problems of four machines were summarized into 12 problems, and the RCA process was used to identify potential factors that constraints machine efficiency, to determine the most likely incident or failure cause, and to generate solution categories, which helps in clearly identifying the problem.

Finally, the brainstorming session was conducted by including line process engineers, mechanical specialists, electrical specialists, packaging engineers, and automation engineers. During these brainstorming sessions, the most basic problem areas were updated based on the collected data and its analysis. Following that, a corrective action plan for all of the identified problems was suggested. Furthermore, based on these RCA and identified problems, an improvement action plan has been proposed to reduce the causes contributing to the loss due to equipment breakdown.

Table 4.1, Table, 4.2 and Tabel 4.3 shows that, the potential root causes and solutions based on the overall issues encountered in these three critical machines in tables 3.14 and 3.15.

4.2 Suggested solution for filler machine

Table 4.1 presents different possible root causes and possible solutions for filler machine.

Table 4. 1 Suggested solution for filler machine.

Major problem	Possible root cause	Possible solution
Frequent bottle falling at filler infeed	Low lubrication viscosity	Check conveyer lubrication ad water ratio has to be on the standard
	Vibration on conveyor	check conveyors stand and its water level to be the standard
	Lack of lubrication on conveyer	check conveyor has sufficient lubrication
	Conveyer guide adjustment	check bottles guide has adjusted correctly
	Worn-out conveyer	check and replace worn ot conveyors
	Worn out sprocket on conveyor	check and replace worn out sprocket
	Irregular bottle base shape	check the bottles quality and remover the irregular one
	Bottles fragment on conveyor	check if there is stacked foreign object on bottles conveyor
Frequent bottle falling at filler discharge	Improper timing of discharge star wheel	Check and adjust star timing with its conveyor
	Worn out (wide tooth) star wheel	check and change worn out star wheel
	Low lubrication viscosity	Check conveyer lubrication ad water ratio has to be on the standard
	Calibration on conveyor	check conveyors stand and its water level to be the standard
	Lack of lubrication on conveyer	check conveyor has sufficient lubrication

	Conveyer guide adjustment	check bottles guide has adjusted correctly
	Worn-out conveyer	check and replace worn ot conveyors
	Worn out sprocket on conveyor	check and replace worn out sprocket
	Irregular bottle base shape	check the bottles quality and remove the irregular one
	Bottles fragment on conveyor	check and correct if there are stacked foreign object on bottles conveyor.
Cork stacking at chute	Quality of cork	Check if there is deformed cork inserting on chute
	Insertion of inverted cork on chute	check and remove inverted cork from twister
	Dust accumulating on chute	check and clean the dust on chut and hopper
	Failure of vibrator on chute	check and correct the functionality of vibrator,
	Low air pressure on chute	check and correct the air pressure on chute
Under filling	Long vent tubes	Check and correct vent tube length,
	teared spreaders on vent tube	check and replace teared spreaders on vent tubes
	Teared moth seal	Check and replace teared/damaged mouth seal
	Low Pressure on product bowl	check and adjust pressure on product bowl
	Wrong parameter setting	check and correct recipe parameter

Over filling	Short vent tubes	Check and correct vent tubes length
	Teared mouth seal	Check and change damaged mouth seal
	High pressure on product bowl	check and adjust pressure on product bowl
	Wrong parameter setting	Check and correct recipe parameter

4.3 Suggested solution for labeler machine

Table 4.2 presents different possible root causes and possible solutions for labeler machine.

Table 4. 2 Suggested solution for labeler machine.

Major problem	Possible root cause	Possible solution
Safety clutch tripped at infeed worm	damaged/ loosen universal joint	Check and correct the mechanical condition of universal joint
	Failure or false reading of PE sensor/reflector	Check and correct PE sensor or clean the PE sensor reflector for proper reading
	Wrong guide adjustment	Check and correct guide adjustment
	overload due to incorrect gap	Check and correct the gap b/n bottles
	damaged/ faulty clutch	Check and correct the mechanical condition of safety clutch
	faulty safety clutch sensor	Check and correct the sensor position on safety clutch
	damaged/ loosen universal joint	Check and correct the mechanical condition of universal joint
infeed star wheel timing problem	Elongated conveyor	Check and reduce the conveyor length
	Incorrect timing of worm wheel and infeed star wheel	Check and correct timing of infeed worm star wheel

	Lack of lubrication	Check conveyor has sufficient lubrication
	Loosen bolt infeed worm wheel	Check and tight the loosen parts
Label scattering	Wrong timing of finger	Check and correct of fingers and label magazine
	Lack of proper lubrication	Check and correct lubrication
	Insufficient glue on paper	Check papers has supposed to have sufficient glue
	Irregular bottles dimension	Check and remove irregular bottles
	Over tension of label magazine	Check and correct tension of label magazine
	Wrong timing of labels grippers and bottles	Check and correct timing b/n labels gripper and bottles
Bottles presence sensor detection fault	Sensor damage	Check and replace the failed sensor
	Dirt covers the reflector	Check and clean reflector
	Loose connection on sensor connectors	Check and correct the loosen connection
Glue splashing.	Wide opening of scraper	Check and correct the gap b/n scrapper and glue roller
	Bearing failure on glue roller	Check and replace bearing
	high glue temperature	Check and correct heater thermostat
Glue pump malfunction	Glue bowl is at low level	Check the level of glue bowl
	No or low air pressure	Check there is sufficient air supply for the pump
	Faulty of solenoid valve	check and correct the functionality of solenoid valve
	Teared mechanical seals and hose	Check and correct leakage on mechanical seal and hose

4.4 Suggested solution for Bottle washer machine

Table 4.3 presents different possible root causes and possible solutions for bottle washer machine.

Table 4. 3 Suggested solution for bottle washer machine.

Major problem	Possible root cause	Possible solution
Jetting nozzles misalignment	Incorrect timing of bottles pocket head with jetting	Check and correct timing b/n pocket head and nozzles
Sieving conveyor stacking	Bearing failure	Check and replace bearing on sieving conveyor motor
	Labels overload on sieve conveyor	Check and remove labels from seeing conveyor
Conductivity sensor fault	Equipment failure	Check and replace the failed sensor
	Sensors covered by scale	Check and descale the sensor
	Wrong measurement	Check and calibrate with proper solution
Pockets blocking	Broken bottles insertion	Check the incoming bottles before inserting to the washer
	Lack of awareness	Provie training for operators

4.5 Productivity Improvement Strategy

The key production losses in the packing line and the reasons behind them are identified, categorized, and areas for line improvement are identified based on the line OEE analysis, fish bone diagrams, and root cause analyses. In addition, possible solutions to general problems are proposed, as well as a corrective action plan also provided.

4.6 Suggested solutions for line improvement strategy

Table 4. 4 Suggested solutions for line improvement.

Table 4.4 shows that, the possible method for improving packaging line efficiency.

Challenge & related losses	Objectives	Action	Result measures	Expected outcome
Shut down loss				
Start-up & End-up	Minimize production startup & end up	Improve communication with supporting department (brewhouse & warehouse) to reduce stops due to lack of beer and shortage of bottles	Communicate and get updates first	Reduce effect of production start and stops
Utility stops	Minimizing power supply interruption	1. Prepare standby UPS for all machine to prevent sudden stoppage. 2. Improve PM execution for utility machines	Recording utility stops and communicate timely	Reduce effect of sudden power failure
NONA (Cleaning, descaling, Meeting)	Minimizing cleaning, descaling, and meeting times	Plan a head and use opportunity stops for line cleaning, descaling, and meeting	Record and communicate all NONA activities	Reduce effect of NONA activities

Availability loss				
Machine break down	Reduce cause of breakdown and unplanned maintenance activities	1. Develop standard preventive maintenance procedures based on the operating conditions of machineries. 2. Start to implement predicative maintenance and identify critical components which need priority to fail based on their operating hour and keep their spare parts in stock.	Weekly machine audit	Reduce breakdown and unplanned maintenance
Set up and adjustments	Reduce frequent timing correction and adjustments needed during operation time	1. Use standard tools and procedure for timing correction. 2. Keep recording of real time incident, corrective action taken, and operating condition as it helps to know the history of machine events and it uses as input for prior planning of maintenance. 3. Create a hand overing mechanism and keep recording the details of maintenance activities that doing in every shift	Weekly Line machine audit	Reduce mechanical and operational adjustments
Operator and Technician error	Reduce human error	1. Develop necessary SOP for maintenance and machine operation.	Build teamwork coulter and	Culture of continuous improvement,

		2. Develop standard CILT procedures. 3. Create awareness to follow the standard operating procedures and maintenance manuals. 4. Document good practice. 5. Implement continuous improvement activities like TPM activities. 6. Use 5s procedures throughout the packaging hall. 7. Train employees to fill skill gaps. 8. Coach them to understand the process and to improve their trouble shooting capacity. 9. Create awareness on process improvement and minimization of loss	provide training on continuous improvement	Self-driving culture, higher employ motivation and engagement and improved performance

Performance loss				
Short Stops/ Minor Stops, Speed Loss & Undetermined Loss	Reduce minor stops, speed loss and undetermined loss	1. Keep optimal operating condition of machines. 2. Keep machine neat and clean all time to avoid sensors covering by dusts. 3. Do necessary tightening and lubricating before start-up of production. 4. Ensure execution of preventive maintenance activities as per the standard 5. Check and commission every equipment’s after maintenance activities. 6. Check the quality of raw material to be consumed before operation and use FIFO method. 7. Identify all unrecorded down time	Weekly machine audit and performance measurement	Reduced minor and speed loss, undetermined loss

Quality Loss				
Quality failure	Improve quality of incoming materials (Labels, Glue, Cork, Lubrication, and additives).	1. Implement quality specification, standard measurement of standards and frequently update procedure. 2. Create strong partnership, relationship, and communication with the suppliers. 3. Give feedback for suppliers timely. 4. Improve storage condition of raw material. 5. Use FIFO principles. 6. Implement common understanding on what are the acceptable quality problem and follow the rule for no quality compromise.	FIFO, Daily raw material quality audit, Daily packaging line quality audit,	Reduced raw materials loss and process rejection. Reduced short stops

4.7 Line simulation modeling and analysis

There are many kinds of simulation models on the market, including Arena software, which is a mimic software designed for doing accurate and efficient simulations with high-speed, high-volume production, with processing speeds of thousands of entities per minute. Arena Software from Rockwell Automation, Inc. was chosen to construct and evaluate a model for this real production line because of its capacity to analyze high-speed, high-volume production systems in a highly accurate and effective manner.

4.8 Simulation model development

By using the above collected data as input in table 3.6 and 3.7 for each processing machine of the line, the existing system model is developed by Arena software and the design built is similar to the real process system as shown in the below figure 4.1.

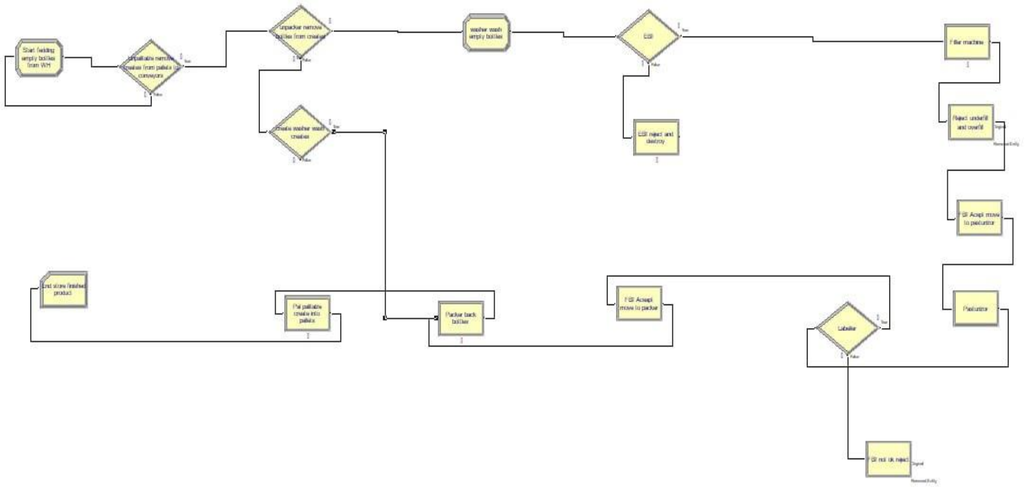


Figure 4. 1 line simulation model of the existing system

Figure 4.1 shows that, the proposed methodology that used for built line simulation model and performance analysis of packaging line are presented. This process involves the collection of input data, analysis of the input data, and using of the analysis of the input data in the simulation model for performing and analyzing the result these are:

- ✓ Identify the problem.
- ✓ Formulate the problem.
- ✓ Collect and process real system data.
- ✓ Formulate and develop a model.
- ✓ Validate the model.
- ✓ Perform simulation runs.
- ✓ Interpret and present results.
- ✓ Document model for use.

4.8.1 Input data

The input data we use for our model is:

1. Process times: - The time it takes for a machine to perform an activity (e.g., depalletize, unpacking, bottle washing, filling, pasteurizing, labeling, packing, and palatalizing).

2. Buffer capacity per zone: - The conveyor accumulation capacity
3. Machine speed and parameters

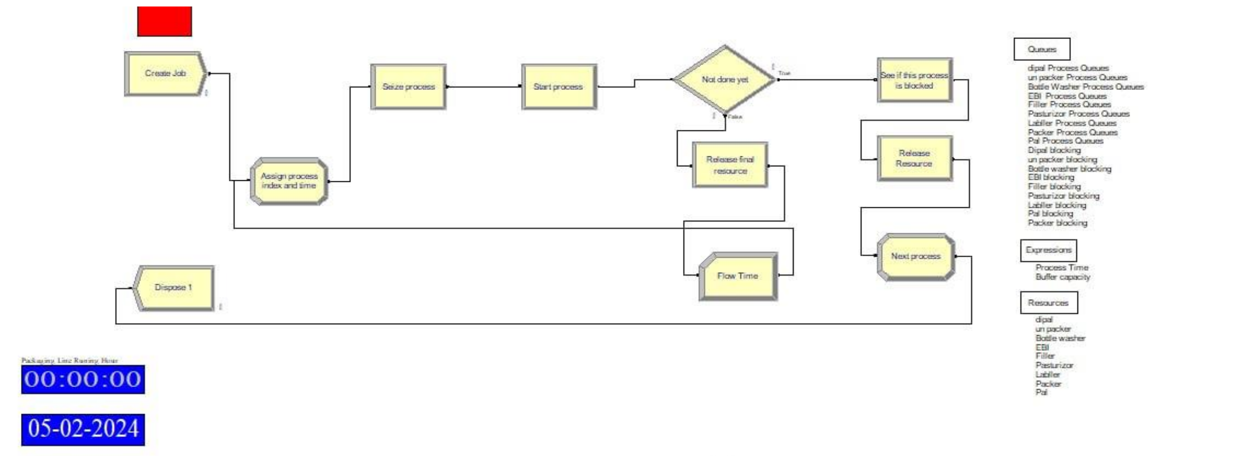


Figure 4. 2 running line simulation model of the existing system.

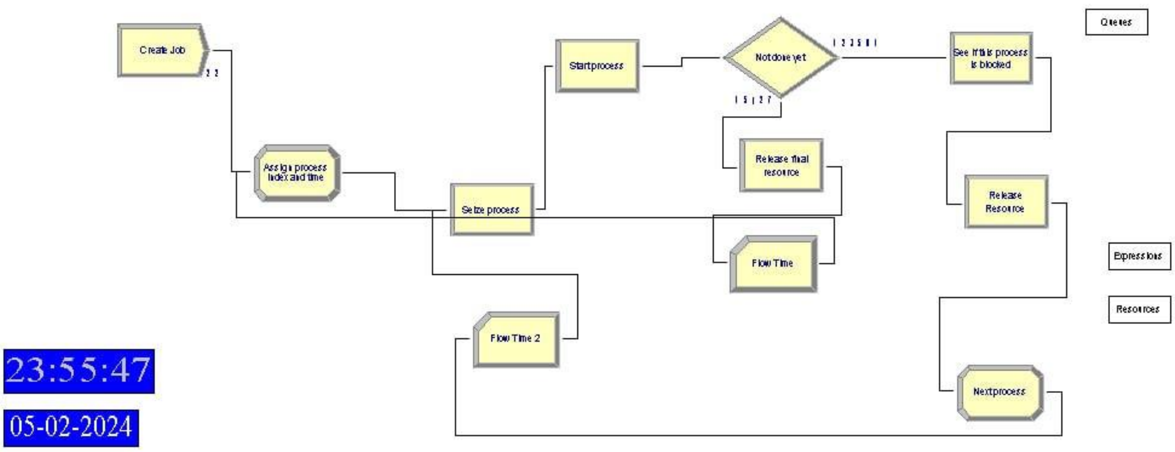


Figure 4. 3 running line simulation model of the improved system.

4.8.2 Simulation Model Verification

In this case study, packaging line model verification and validation steps has accomplished. For verification, the animation method was used to show the entities movement inside the model and to ensure that the movement is similar to what it should be, and it is in accordance with the flow of bottles in the real production line and this verifies the model.

4.8.3 Pilot run of developed model, results, and summary

After developing the line simulation model, considered assumptions are made based on the data collected, all essential input parameters are provided, and a pilot run is conducted. A simulation for 30 hours of production run with 30 replications was performed. Finally, the results of the simulation were used to calculate and measure line productivity and associated losses. The simulation model was analyzed using the result values of the produced line model. For this investigation, the number of seized productions, maximum flow duration, simulation run length, and total entity created total unit produced of line simulation were all important factors.

The following data are collected from developed line simulation model of packaging line and has been used for OEE analysis on the developed model and these data are attached on APPENDIX section.

On the below section the real packaging running data result and simulation model results are presented.

1. Real system running results:
- ✓ Total goods produced =1181000 bottles
- ✓ Net goods produced =1170517 bottles
- ✓ Rejections = 10483 bottles
- ✓ Loading time=30.26 hours
- ✓ Operating time = 30 hours
- ✓ Net OT=GP/Rs=1181000/40000=29.5 hours
- ✓ VAT=Net Pdn. /Rs=1170517/40000=29.2 hours

2. Simulation model results
- ✓ Total units processed (TUP) =1199463 bottles
- ✓ Total units good processed (TGUP) =1184336 bottles
- ✓ Total units lost = 15127 bottles
- ✓ Flow time (Total entities production time) = 33.48 hours
- ✓ Flow time 2 (Net entities production time) =30.28 hours
- ✓ Simulation run length (SRL) =40158014 hours
- ✓ Net OT=GP/Rs=1199463/40000=29.9 hours
- ✓ VAT=Net Pdn. /Rs=1184336/40000=29.6 hours

Before conducting OEE analysis on simulation result some terms from simulation result and OEE model terms are related as follow:

- ✓ The value of working time is equivalent to value of simulation run length.

- ✓ The value of loading time is equivalent to value of simulation run length or working time minus shutdown loss.
- ✓ The value of operating time is equivalent to flow time 2 or Loading time minus downtime loss.
- ✓ The net operating time is equivalent total unit produced divided by rated speed or operating time minus performance loss.
- ✓ The value-added time is equivalent to total good units produced divided by rated speed.
- ✓ Availability is operation time divided by load time.
- ✓ Performance is net operating time divided by operating time.
- ✓ Quality is value added time divided by net operating time.

Finally, for collected 30-hour packaging running performance based on table 3.8. OEE analyses are conducted on real production system as well as simulation model and results are summarized and presented in tabular form as shown in the below table 4.5 to facilitate easy comparison with the actual line values.

Table 4. 5 OEE analysis for simulation model and real system

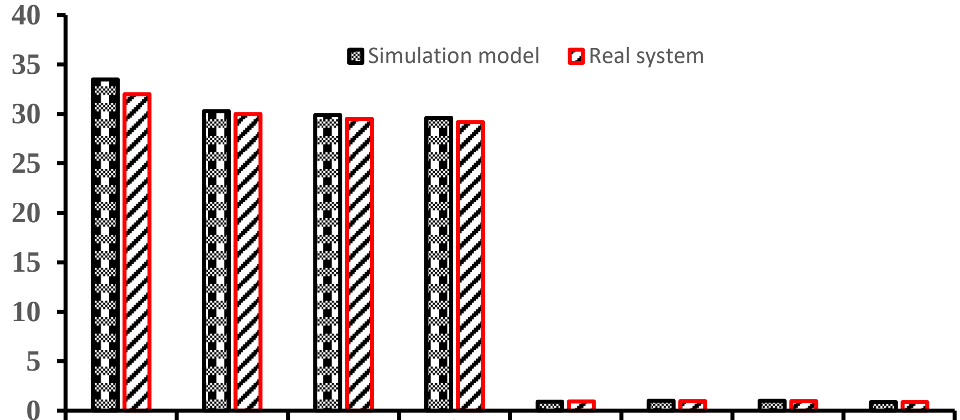
	Parameter Time (Min.)	Simulation Model	Real system
		Simulation model	Packaging line
A	working time	34	34
B	load time	33.48	32
C	operating time	30.28	30
D	net operating time	29.9	29.5
E	value added time	29.6	29.2
C/B	Availability	90.4%	93.7%
D/C	Performance	98.70%	98.3%
E/D	Quality	98.9%	96.3%
	OEE	**88.2%**	88.6%

Tabel 4.5 shows that, the analysis of the average value of OEE factors (availability, performance, and quality) and for 4 production shifts from the real system and the

simulation model is compared. As a result, that there is no significant difference in between actual real system and simulation model OEE analysis.

4.8.4 Validation of the simulation model

Validation of the Arena model was done by comparing the results of OEE from model output with the real system output as revealed in the figure below:



	load time	operating time	net operating time	value added time	Availability	Performance	Quality	OEE
Simulation model	33.48	30.28	29.9	29.6	90.40%	98.70%	98.90%	88.20%
Real system	32	30	29.5	29.2	93.70%	98.30%	96.30%	88.60%

Figure 4. 4 comparison of real system and simulation model

Figure 4.4 shows the validity of the model, the average value of OEE factors (availability, performance, and quality) and for 4 production shifts from the real system and the model is compared. As a result, that there is no significant difference in between actual data and model result data which is considered to be valid.

4.9 Loss propagation on packaging line

Filler machine is the core machine, which determines the line efficiency. Production time of the filler machine determines the output of the line and loss of production time on this machine cannot be recovered. Form the collected data on table 4.6 the buffer capacity of the line between Filler and EBI machine can only hold 288 bottles. If the short stops or break down on EBI machine for a duration of 1 and more minutes have occurred immediately loss starts to propagates to within the entire production line, because the accumulated bottles in buffer conveyor before filler are processed within less than 1 minutes, at this moment no bottle flow from filler is available for processing in pasteurizer machine so this areas becomes starved. In this condition immediately short stops on the rest of downside of the filler machine have occurred. This is because of buffer between filler and EBI machines can accumulate only 288 bottles.

Generally, the production time loss longer than 1 minute propagates to entire production system due to whatever reason of sort stops, down time and break down of the EBI machine.

4.9.1 Improvements Strategies

The current production line has been producing below the planned target and at higher production cost due to start/stop situation in EBI machine as well as the block system (between filler and EBI buffer) which are identified as a cause. To improve the productivity of the existing line, three possible solutions have been identified for each problem areas and selected based on blockage and starvation time and that give possible maximum up time with higher output.

In this study, three modifications are proposed to achieve line improvement in the current situation are:

1. Adding a buffer conveyer between Filler and EBI.

The first solution is supposed to absorb the start/stop condition of Filler by reducing machine to machine stops and adding buffer system on these block zone.

2.Operational error correction

UB packaging machines are designed by engineers to be balanced in very particular ways. Equipment is bought to give maximum performance with minimum disruptions. The most critical part of a bottling line is the filler, which should never be stopped due to build up after the filler (downstream) or be starved of product, bottles, corks, etc. (upstream of the filler). Most of these occurrences are preventable and should not happen by design.

Generally, during production time I had observed an opportunity and a gap during operation which is first, the production flow in such a way that after the filler, processes are more efficient by a factor of 15 to 20 percent in each consecutive process. Capper has slightly faster than the filler. Conveyers must move the bottles away from the filler slightly faster than the capper. The bottle crating operation must again be slightly faster. In other words, if any of these systems go too slow, a backlog will build up eventually affecting the filler which will have to stop, having to wait for the build-up to recede. This is the downstream side. What about the upstream side?

The upstream side is where the bottle washer is located. Here the equipment is designed to supply the next stage 15 to 20% faster again. Here we include the depalletizer, unpacker, bottle washer, and EBI machines.

Let’s summarize my finding and clarify the bottlenecks with some realistic numbers to highlight this point.

Assume the filler capacity is 666 bpm.

According to design the washer should therefore supply bottles at a speed of about 765 bpm (16% up from the filler).

Next assume the bottle washer has 40 pockets running through it.

Again, assume some of these pockets are problematic for whatever reason (it normally occurs on the end or side pockets), and the engineers struggle to sort out the problem. Often these pockets are blocked off leaving that line to run through the washer empty, thus the problem is not experienced anymore.

Next let us assume 8 pocket rows are blocked off.

This means the washer is running at an output reduced by: - 8/40 x 100 = 20% With the washer designed to supply 765 bpm, it is now supplying bottle at 765 – 20% = 612 bpm.

We are now starving the filler (optimal speed of 666 bpm) of 54 bottles every minute, and often see empty filler heads.

54 bottles less per minute equates to a drop of 8.1% in efficiency for the whole line.

The lines OEE (overall equipment effectiveness), a measure of efficiency often used in production is 8.1% down no matter how well the rest of the line runs.

Problematic pockets should therefore be reported, investigated and corrected/fixed and not just be blocked off (a common practice), as that is profit down the drain due to either lost sales or higher production costs.

3.Technical error correction

The very first question needs to address on this point is: - Does the bottlewasher receive adequate maintenance?

Keep in mind the importance the rinse section has on overall bottle washing performance. If the wash section functions well but performance in the rinse section is deficient, then overall bottle washing performance will be poor.

As discussed in the above performance loss topics one of the causes for line performance is due to bottle washer which happens due to its poor mechanical performance, and delays solving of the problem. Also, while it is possible to compensate for mechanical deficiencies to some extent by increasing chemical concentrations, this approach increases bottle washing costs.

As per the detailed analysis of the line, EBI machine has been running by continues rejection of washed bottles and this become the cause for the line to not run in the most efficient manner. For this reason, it is important to learn as much as possible about mechanical aspects of bottle washing machines.

On bottle washer one aspect that needs to be consideration is the spray nozzles used in the bottle washer. In UB washers use spray nozzles to assist with the cleaning and for rinsing. This has the effect of causing a turbulent scouring action which helps to remove stubborn dirt. Although needed in the process, it has its own associated problems that need to be considered, though mainly from an engineering aspect. One aspect is that the bottle mouth must be properly aligned with the nozzle. It would be of no use to have a spray that does not reach all parts of the bottle.

Another is the strength of the spray which must reach high enough to reach the ceiling of the upside-down bottle (the base of the bottle) to run down the sides and out again. Neither can it be too strong with too much liquid sprayed into the bottle, as this would cause caustic solution to run down the sides too fast and create a liquid “plug” in the neck area. This plug would render the wash ineffective. Nor can it be too weak and not reach the ceiling of the bottle.

The same goes for the rinses. As a result, nozzle sizes and pressures are specified in order to give the correct spray. These sizes and pressures differ from one section in the washer to the next, as well as between the top and bottom sprays at the rinses.

This is also one of the reasons to have an empty bottle inspector after the washer, to take off any bottles that may still contain any form of dirt not removed by the washer or dirt not washed out due to different reasons.

In conclusion, to get properly cleaned bottles from washer and to prevent bottles from being rejected by EBI machine the below points should operate properly on bottle washer machine.

These are critical parts needs to check as per the standard: -

- ✓ Misalignment of nozzles
- ✓ Rinsing pressure
- ✓ worn, plugged, or enlarged nozzles.

Below are presented suggestions of operational follow up and checks.

Table 4. 6 Suggested operational follow up checks.

Equipment	Activity	Frequency
Pressure gauges	Make sure they operate and conform to the manufacturer’s recommended operating pressures. Water pressure is normally maintained between 2.8kg/cm2 to 4.2 kg/cm2	Daily
Caustic and rinse jets for each bottle size	Make sure that they are clean, operating, and aligned with bottles in place	Daily
Bottle Carrier Chain	Check for slack and for proper alignment of the header and jets, adjust if needed	Daily
Screens and strainers	Check for cleanliness, repair or replace if damaged	Daily
Washer interior chain, pockets, carriers, headers, jets, screens, strainers piping heating coils and pumps	Check for scale or rust, correct if necessary	Daily

Recirculating pumps	Take apart, check for wear, and replace worn parts. If this action is not practical because of the equipment's position or construction, routinely check discharge pressure gauges to ensure proper performance.	Weekly

4.9.1 Improved simulation model

After improving the buffer capacity between filler and EBI the simulation model runs for 7 shift (7*480min) with 3 replications, the results from the existing and improved models are collected and analysis on the output measures is done to relate the results from both systems. To study the propagation of loss on these bottleneck areas it is assumed that the effect of labeler, pasteurizer, unpacker, pal and dipal is not considered because of the presence of buffer (accumulation conveyer) in between that can absorbs disturbance. This conveyer minimizes the effect of failures from both streams. As wee seen from APPENDIX G the same input parameters have been used in existing line model and the improved parameter also used in simulation model to compare and analyze their results.

Table 4. 7 Collected and summarized result of buffer capacity existing system and improved system

Buffer capacity between Filler and EBI machine existing and improved model performance			
Result	Existing model	Improved model	Improvement
Blockage (minutes)	50	0	-50
Starvation (minutes)	400	0	-400
Running (minutes)	9630	10080	450

Table 4.7 shows that, the analysis of both systems, the existing and the proposed, a comparison between the model in terms of time blockage and starvation is presented.

4.9.1 Improvement results and Discussion

From the previous comparison table of simulation and existing model the performance on proposed model has a considerable improvement by making zero the blockage and starvation time. From these improved models of simulation, the reduction in total blockage time is become 50 minutes and from the starving time also reduced by 400 minutes from the total running time. As a result, the operating time of the filler is increased by 450 minutes. In addition, the line output also increased by 300000 bottles. This result is achieved by increasing the buffer capacity of the blocked system. Generally, due to the above benefits from the modified (improved line model), an improvement in line productivity (OEE) has been made from the improved (proposed line simulation model) system. beside improving the performance of the line, the company will be benefited by minimizing energy cost and improving line productivity by these enhanced line OEE performance.

CHAPTER-5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research case study focused on the analysis of packing line efficiency and performance improvement using OEE and simulation techniques. The OEE approach is used to measure, analyze, and determine line efficiency losses while also indicating areas for improvement. The root cause analysis approach is used to analyze equipment failures and recommend corrective action plans, the fish bone diagram is used to figure out the true cause and impact of efficiency loss, and the pareto chart is used to prioritize improvement areas.

According to the results of the study, identifying and eliminating packaging bottlenecks are required to increase production performance and efficiency of the packaging line. Also, simulation models were built for the packaging line to provide a deep understanding of the system to find improvements opportunities to analyze the performance, and this approach enables to know and understand the strengths and weaknesses before implementing on the actual system to increase the efficiency and performance of the production system.

It can also be concluded that the proposed suggestion was beneficial to the company to improve their performance and productivity of the company.
As per the results of the study, the following conclusions are presented:

1. In this study, total 13 Operational disturbances are investigated, and out of the 13 factors, 8 are external disturbances, 5 are internal disturbance and totally they are responsible for total time lost about 3775 hours throughout the given year of data collection.
2. OEE of the production line is below target by about 6% and the world class standard. The identified reason for lower OEE is due to lower line availability and line performance by 5% and 16%, respectively. The main reasons for lower availability are due to machine breakdown, longer set up and adjustment and frequent equipment stoppage due to operational and technical error. The main reasons for lower performance are due to higher short stops, speed loss and undetermined loss.
3. The line block system between EBI and filler is identified as one source of source of undetermined loss which is considered as a design fault. In addition to that,

operation and technical follow up error has the other contributor for undetermined loss. So that, these areas are focus of improvement area and found as the reason for availability and performance losses which in return affects the line OEE and clearly shown that, they are reasons for starvation and lower productivity.

4. Simulation model for the current production line has been developed using Arena simulation software. By putting the line under varying set of circumstances the real cause of disturbance and its reduction, line performance analysis in the improvement area has been studied in detail, as a result, high starvation situation has been identified as reasons for lower efficiency and performance. Therefore, capturing the propagation of starvation from the block system (filler-EBI) were basic areas to start improvements.

Finally, the below strategies are suggested to improve the line performance: -

Production time increases as a result of a number of changes and modifications to the improved (modified) model, which improves the buffer capacity of the developed model and reduces starvation and blockage time by 4.46%. As a result, the company will be able to reach its predetermined performance target, reduce production costs, and enhance production capacity, all of which will improve operational and performance efficiency. As a result, it can be concluded that the line efficiency analysis and proposed model benefit the company.

5.2 Recommendations

Following the findings in this study the below are suggested as recommendation:

- The company should pay attention to minimize operational and performance error by giving awareness and training for operators and technicians. Also, should clearly put the follow up mechanism for adherence of adequate maintenance in all machines.
- According to the result analysis on block system (Filler to EBI) the company should work to increase or change the existing design by increasing the buffer capacity of these areas.
- As per the detail data collection and analysis on labeler raw material usage the company should find a way to minimize its over processing trend specially by removing its back label.
- This study covers only the internal production losses of 16%. But by analyzing the planned efficiency losses which is 84% of total time loss. The company can get great improvement in productivity.

References

Area, D. H. (n.d.). *General & Operations Management.* Dr. Hemant Sharma Professor & AAmity University Valley, Panchgaon, Manesar, Gurgaon- 122413 (Haryana).

Averill M. Law & Associates, I. (2015). *Simulation Modeling and Analysis.* Tucson, Arizona, USA: Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

beverage, U. (2022). *Packaging-standard operating procedure.* Mojo: packaging department.

Bokrantz, J. e. (2016). Handling of production disturbances in the manufacturing industry. *Journal of Manufacturing Technology Management* , 1054-1075.

C. U. (2016). Handling of production disturbances in the manufacturing industry Jon Bokrantz, Anders Skoogh, Torbjörn Ylipää and Johan Stahre Department of Product and Production Development. *Journal of Manufacturing Technology Management Emerald Group Publishing Limited* , 1057.

Chrissoleon T. Papadopoulos, Michael E. J. O'Kelly, Michael J. Vidalis, and Diomidis Spinellis . (2009). *Analysis and design of discrete part production lines. Springer Optimization and Its Applications.* New York, NY: Springer., doi: 10.1007/978-0-387-89494.

Food Buissness Africa. (2019). United Beverages launches Anbessa Beer in Ethiopia as operations commence. *Food Buissness Africa*.

Groover, M. P. (2010). *FUNDAMENTALS OF MODERN MANUFACTURING Materials,Processes,andSystems 4th ed.* United State of America: John Wiley & Sons, Inc.

Härte, F. (1997). Efficiency Analysis of Packaging Lines, Delft University .

IBD et al. (2023). *Packaging Technology – Packaging Operations.* Institute of brewery and distillation.

Ingemansson, A. a. (2004). Improved efficiency with production disturbance reduction in manufacturing systems based on discrete-event simulation. *Journal of manufacturing technology management*, 267-269.

JOSIAH, U., UZORH, et,al. (2023). Experimental And Simulation of Failure Analysis of Machinery in Ab Breweries.

Kumar, S. a. (2006). Improving a manufacturing process by mapping and simulation of critical operations. *Journal of Manufacturing Technology Management 17.1*, 104-132.

Law, &. K. (2000). *Simulation Modeling and Analysis. McGraw-Hill.*

M.C. Prieto-avalos, C.R. Navarro-gonzález, A. González-angeles and S.V. Medina-león . (2014). Reduction Waste by Combining Lean Manufacturing and Six Sigma in an Electronics Industry. *Research Journal of Applied Sciences, Engineering and Technology*.

Meerkov, Jingshan Li and S.M. (2009). *Production Systems Engineering. Springer,.*

Nagdiya, M. N. (2013). Performance Analysis using OEE. *Acadamia*.

Parveen Kumar, P. T. (2017). Performance analysis and optimization for CSDGB filling system of a beverage plant using particle swarm optimization. *International Journal of Industrial Engineering Computations*.

Pretorius, P. (2014). Introducing in-between decision points to TOC’s five focusing steps. . *International Journal of Production Research*, 496-506.

Pun, R. a. (2015).

Roessler, M. P. (2015). Enhancement of the overall equipment effectiveness measure: a contribution for handling uncertainty in shop floor optimisation and production planning. *International Journal of Industrial and Systems Engineering 20.2*, 141-154.

SHUBHI SHARMA, et al. (2015). EMPTY AND FILLED BOTTLE INSPECTION SYSTEM. *Journal on image and video processing*.

Stamatis, D. (2011). *The OEE Primer Understanding Overall Equipment Effectiveness, Reliability, and Maintainability.* New York: CRC Press Taylor & Francis Group.

Tewari, P. K. (2014). Performance Modeling and Analysis of the bottling system of beverage industry. *IUP Journal of Mechanical Engineering*.

Tino, A. a. (2013). High performance NoC synthesis using analytical modeling and simulation with optimal power and minimal IC area. *Journal of Systems Architecture*, 1348-1363.

Uday Kumar, D. G. (August 2013). Maintenance performancemetrics: a state-of-the-art review. *research gate*, 19(3):233-277.

Ujam, C. J. (2018). Optimization of Packaging Line Performance: ACase Study of AB Breweries in Nigeria. *Acadamia*.

Usubamatov, R. (2018). *Productivity Theory for Industrial Engineering.* New York : CRC Press Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton.

Van der Duyn Schouten, F. A. (1995). Maintenance optimization of a production system with buffer capacity. *European journal of operational research*, 323-338.

Wein, L. a. (1992). A broader view of the job-shop scheduling problem. *Management science*, 1018-1033.

Ying HE, J. M. (2016). Lightweight Design of a Machine Base for a Robot Palletizer. *Google scholar*.

Yuniawan et al. (2013). Calculation of overall equipment effectiveness weight by Taguchi method with simulation. *Concurrent Engineering: Research and Applications*.

APPENDIX A

20:47:00 **Resources** May 12, 20

United Beverages S.c Packaging Line Performance Replications: 1

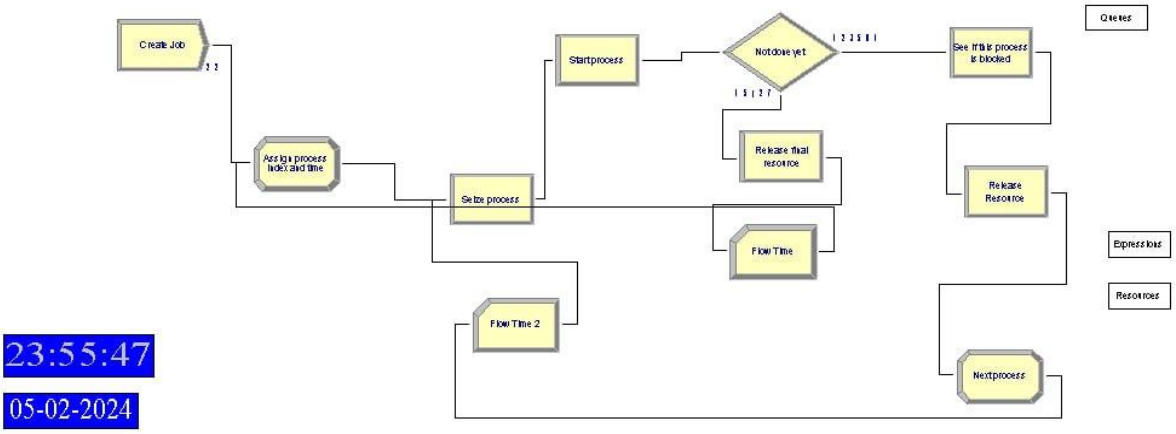
Replication 1 Start Time: 0.00 Stop Time: 40,158,014.76 Time Units: Seconds

Resource Detail Summary

Usage

	Inst Util	Num Busy	Num Sched	Num Seized	Sched Util
Bottle washer	0.11	0.11	1.00	1,199,463.00	0.11
dipal	0.09	0.09	1.00	1,199,463.00	0.09
EBI	0.13	0.13	1.00	1,199,463.00	0.13
Filler	0.16	0.16	1.00	1,199,463.00	0.16
Labller	0.11	0.11	1.00	1,199,463.00	0.11
Packer	0.11	0.11	1.00	1,199,462.00	0.11
Pal	0.09	0.09	1.00	1,199,462.00	0.09
Pasturizor	0.11	0.11	1.00	1,199,463.00	0.11
un packer	0.11	0.11	1.00	1,199,463.00	0.11

APPENDIX **B**



APPENDIX C

20:47:53 **User Specified** May 12, 20

United Beverages S.c Packaging Line Performance Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 40,158,014.76 Time Units: Seconds

Tally

Interval	Average	Half Width	Minimum	Maximum
Flow Time	33.4800	(Correlated)	33.4800	33.4800
Flow Time 2	16.8300	(Correlated)	2.8800	30.6000

Unnamed Project Replications: 1

APPENDIX D

United Beverages S.c Packaging Line Performance Replications: 1

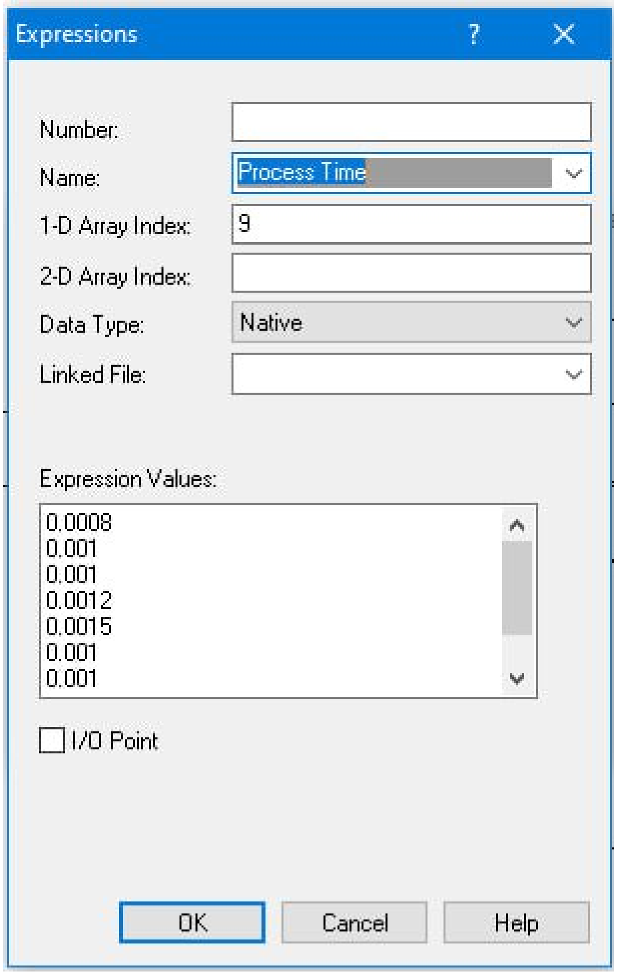
Replication 1 Start Time: 0.00 Stop Time: 40,158,014.76 Time Units: Seconds

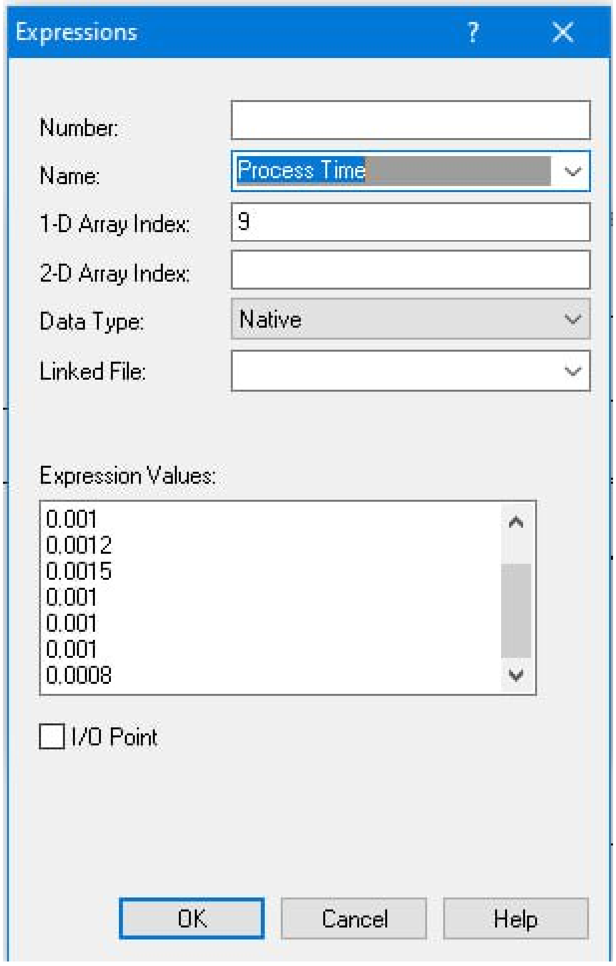
Queue Detail Summary

Time

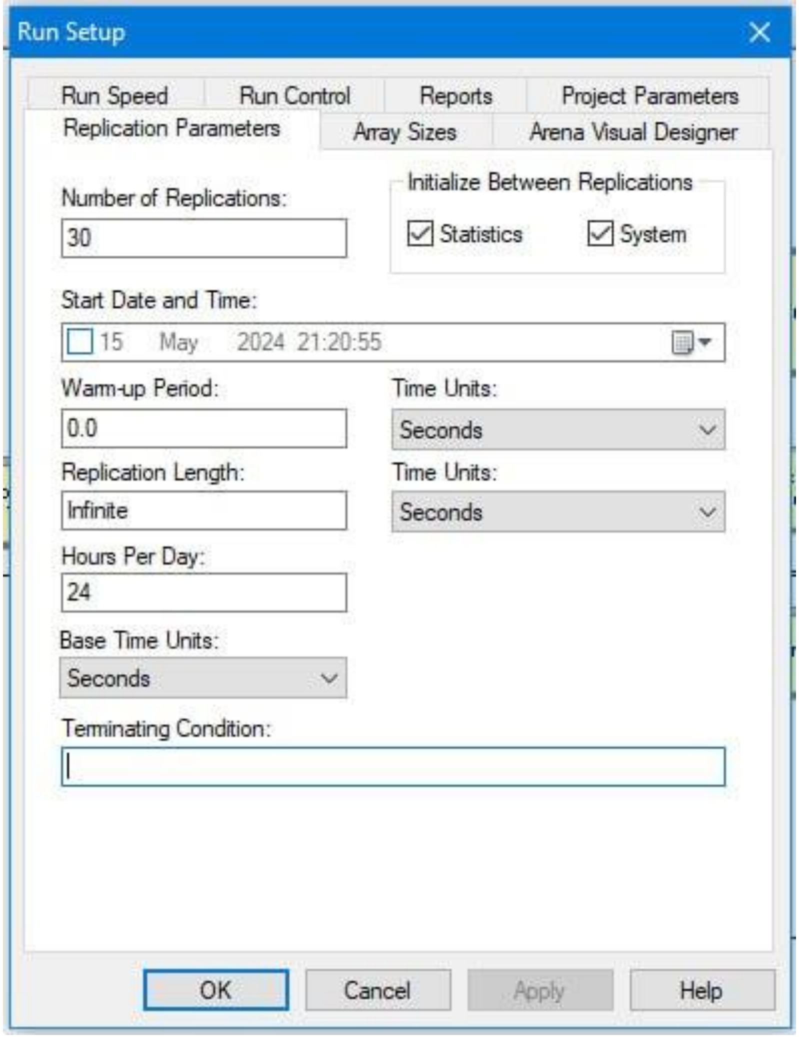
	Waiting Time
Bottle washer blocking	0.00
Bottle Washer Process Queues	0.00
Dipal blocking	0.00
dipal Process Queues	0.00
EBI Process Queues	0.00
EBI blocking	0.00
Filler blocking	0.00
Filler Process Queues	0.00
Labller blocking	0.00
Labller Process Queues	0.00
Packer blocking	0.00
Packer Process Queues	0.00
Pal Process Queues	0.00
Pasturizor blocking	0.00
Pasturizor Process Queues	0.00
un packer blocking	0.00
un packer Process Queues	0.00

APPENDIX E

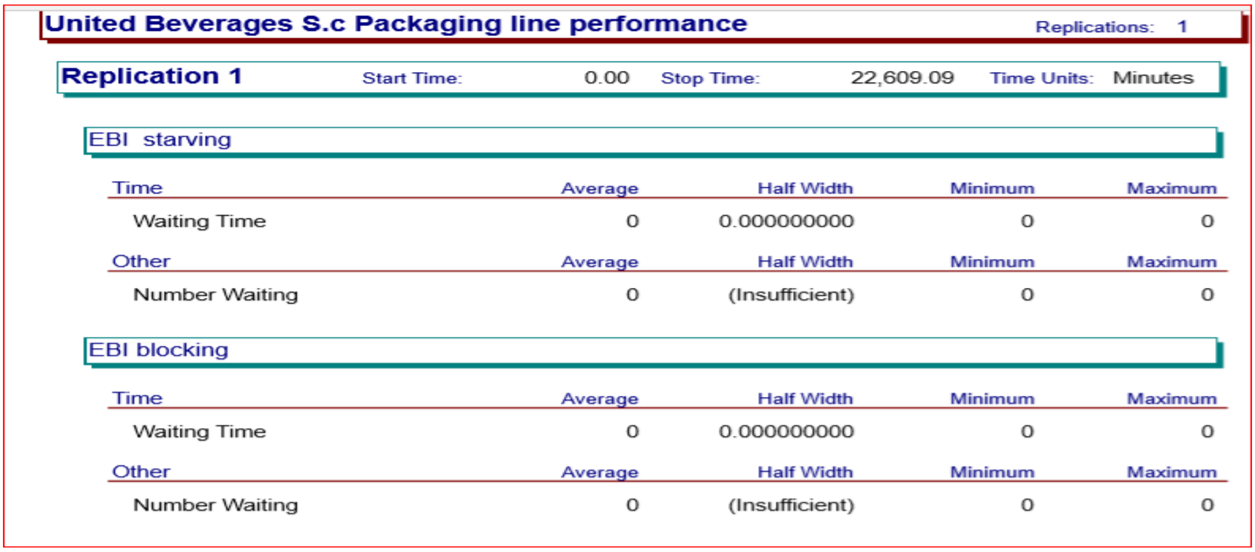

Expressions
Number:
Name:
Process Time
1-D Array Index:
9
2-D Array Index:
Data Type:
Native
Linked File:
Expression Values:
0.0008
0.001
0.001
0.0012
0.0015
0.001
0.001
I/O Point
OK
Cancel
Help


Expressions
Number:
Name:
Process Time
1-D Array Index:
9
2-D Array Index:
Data Type:
Native
Linked File:
Expression Values:
0.001
0.0012
0.0015
0.001
0.001
0.001
0.0008
I/O Point
OK
Cancel
Help

APPENDEIX F



APPENDEIX G



United Beverages S.c Packaging line performance — Replications: 1

Replication 1 — Start Time: 0.00 — Stop Time: 22,609.09 — Time Units: Minutes

EBI starving

Time	Average	Half Width	Minimum	Maximum
Waiting Time	0	0.000000000	0	0

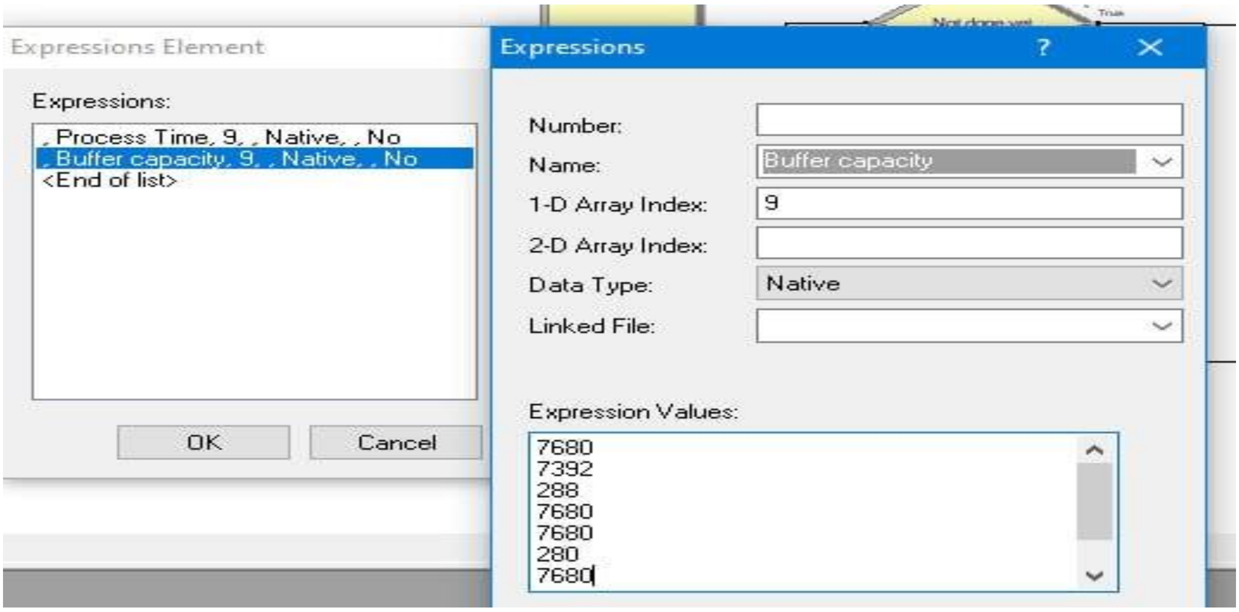
Other	Average	Half Width	Minimum	Maximum
Number Waiting	0	(Insufficient)	0	0

EBI blocking

Time	Average	Half Width	Minimum	Maximum
Waiting Time	0	0.000000000	0	0

Other	Average	Half Width	Minimum	Maximum
Number Waiting	0	(Insufficient)	0	0

APPENDEIX H



APPENDEIX I