KYAMBOGO UNIVERSITY

GRADUATE SCHOOL

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

MASTER THESIS

OPTIMIZATION OF PACKAGING OPERATIONS FOR BEER PRODUCTION LINE EFFICIENCY

CASE STUDY: PACKAGING LINE 1, NILE BREWERIES LIMITED

By

MATENDE NKWOLEKE RICHARD

A Master's Thesis submitted to the Graduate School in Partial Fulfillment of the Requirements for the Award of the Master of Science Degree in Advanced Manufacturing Systems Engineering of Kyambogo University

NOVEMBER 2018

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ABSTRACT

In light of the need for beer production plants to foster competitiveness in today's beer market, Nile Breweries Limited packaging beer line 1 factory efficiency dropped from 83.25% in January 2015 to 56.8% in January 2018 due to availability losses, performance losses and quality losses. Through optimization of packaging operations to improve line efficiency above 83.25%, by identifying bottlenecks, determining efficiency loss caused by bottlenecks and optimizing line 1 using lean manufacturing tools, a sample survey research design was carried out. Through observations, qualitative and quantitative data was collected to identify bottleneck machines using stop watch and data gathering worksheet. Data was analysed using fishbone method, graphs and tables. Depalletizer and palletizer machines were identified as bottleneck machines with efficiency drop from 135% V-profile efficiency to 109% and 120% respectively and general line efficiency loss of 18.8%, hence causing a total financial loss of USD 1,174,378.377 by January 2018. Through detailed implementation of unified theory for lean manufacturing tools, line balancing and adopting new preventive maintenance strategy, waste reduction measures are proposed in order to improve machine performance and factory efficiency above 89% and 83.25% respectively.

DECLARATION

I, Matende Nkwoleke Richard, Reg. No. 16/U/13441/GMEM/PE, do hereby declare to the best of my knowledge that the information in this thesis research report is my own work and has not been presented to any institution of learning for any academic award.

Signature…………………………………………. Date …………………………...

Matende Nkwoleke Richard

APPROVAL

This research proposal has been written under my supervision and is solely work of a student pursuing a Master's of Science in Advanced Manufacturing Systems Engineering. It is now ready for submission to the board of examiners of Mechanical and Production Engineering, Faculty of Engineering, Kyambogo University with my due approval.

Supervisor (1)

Dr. Batte George

Signed... Date.............................

Supervisor (2)

Dr. Kizito Mubiru Paul

Signed... Date.............................

DEDICATION

I dedicate this thesis research report to the staff of Mechanical and Production Engineering of Kyambogo University, more especially to Dr. Catherine Wandera, Dr. Titus Watmon Bitek, Dr. Olwa Joseph, Dr. Batte George, Dr. Ssengonzi Bagenda, Dr. Kizito Paul Mubiru, Dr. Saeed Bagoth, Prof. Jo Song Nam, Prof. Jo Song Pak, and Prof. RI Kyong Sok, my colleagues Ms. Atima Rose, Mr. Mafabi Peter, Mr. Omalla Walter Louis, Mr. Batia Stephen, and Mr. Apora James, to my children, Namatende Ruth Knowel, Matende Venekent Humphrey, Namatende Egulance Mildred, Matende Tibagheka Harry and to my beloved wife Mrs. Kirabira Justine.

ACKNOWLEDGEMENT

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ABBREVIATIONS/ ACRONYMS

ABC   - Anheuser-Busch Companies or Alcoholic Beverage Control or Activity Based

               Costing

ABInBev - Anheuser-Busch International Beverages

ABPG   - Anheuser-Busch Packaging Group

ABV   - Alcohol by Volume

ABW   - Alcohols by Weight

Bph   - bottles per hour

Btls   - Bottles

ERP   - Enterprise Resource Planning.

FE   -Factory Efficiency

GLY   - Gross Line Yield

GMEM   - Graduate of Mechanical Engineering and Manufacturing

Hrs   - Hours

Hl   - Hectoliter

KYU   - Kyambogo University

LEF   - Line Efficiency

LTD   - Limited

ME   - Machine Efficiency

MTBF   - Mean time before failure

MTTR   - Mean time to repair

NBL   - Nile Breweries Limited

OPL   - One Point Lesson

PKG   - Packaging

PSA   - Producibility, Supportability and Affordability

PPE   - Personal protective equipment

TOC   - Theory of constraints

UIA   - Uganda Investment Authority

UGX   - Uganda Shillings

USD   - United States Dollars

CHAPTER ONE

INTRODUCTION

This chapter introduces the subject of optimization of packaging operations for beer production line factory efficiency. First, a background to how this project came to existence is given. Following background is the focus of thesis translated into purpose (problem statement) and objectives. How the objectives have been reached is further explained by the method section. Finally, the introduction chapter is concluded with the delimitations of the research thesis

1.1 Background

Beers are based on the substrates which are locally available and drunk in all societies in the world (Okafor, 2015). Founded sixty-seven (67) years ago, Nile Breweries Limited (NBL) is the leading brewery in Uganda by market share of 59% by end of 2017 (Khisa, 2017), other competing beer producing companies in Uganda include; Uganda Breweries Limited, Paramboti distillers, etc. Nile Breweries Limited is a subsidiary of Anheuser-Busch International Beverages (ABInBev), located on Yusuf Lule Road, Njeru in Buikwe district, approximately 6 kilometers north east of the central business district of Jinja Uganda (Nbl, 2016). Other plants in East African business unit include; Nile breweries Mbarara, Tanzania Breweries Limited with four plants in different places, that is to say. Mwanza brewery, Mbeya Brewery, Arusha Brewery and Dar-es-salam Brewery. Dar-es-salam Brewery is the best performing brewery in Anheuser-Busch International Beverages (ABInBev) East Africa business unit with factory efficiency of 88.4% and machine efficiency of 99%. Several alcoholic brands produced at Nile Breweries Limited include Nile special, Club Beer, Eagle Extra, Eagle Lager, Eagle Dark Lager, Castle Milk Stout, Castle Lite, Nile Gold, Club Twist, Redds Premium Original, Redds Lemon Vodka, Chibuku, Chairman etc (NBL N. b., 2013). Nile Breweries Limited products are facing a lot of competition from many other companies producing related products, alternative beers and imported beers into Uganda (Afunadula, 2017).

Packaging beer is an extremely important process in the production and sale of beer. Beer can be packaged inside bottles, cans or kegs, each with its pros and cons (Karl, 2014). Packaging of beers is both economically and ecologically sensible for better transportation of beer from the

brewery to warehouses, restaurants, inn, etc (Treeze, 2013). NBL packaging section has got three production lines, two glass bottles packaging lines and one stainless keg packaging line.

Nile Breweries Limited Packaging line 1 was installed in 1951, with current capacity of 36000 bottles per hour and runs one type of bottle, the 500mls (Euro bottle) pack. This line runs seven days a week and 24 hours per day. Each day consists of three shifts of 8 hours and for every shift, the line is ran by a team of operators, process operators, process artisan under a team leader. Packaging line 1 is semi-automated mixed-technology line with different machines from different manufacturers like KHS, Krones and other technologies respectively (NBL-not published). Product packaging plays several important functions which enable commerce and trade. The functions of modern-day packaging go beyond containing, protecting and preserving products. It also includes functions to communicate, promote and transact products. Packaging provides products designed with strong feelings to affect consumer's perception of the product and influence their behavior (Gopinathar, 2016). Several machine types are integrated into a single packaging line and transportation between machines is achieved via conveyors (Premchand, 2014).

Traditionally packaging beer lines practice relied on extrapolation of past experiences (Durgin, 2015). It is easy to predict and explain packaging beer line performance and identify the influence of key line parameters e.g, machine capacities, machine speed, conveyor speed and sequence, failure behavior, etc, that may affect line performance (Dingley, 2017).

Nile breweries packaging line 1 is planned to run at factory efficiency of 80% and machine efficiency of 89% including allowed service stops. From January 2012 to January 2015, the factory efficiency and machine efficiency for beer packaging line 1 increased from 73% and 81.7% to 83.25% and 96% respectively. An increase of 10% factory efficiency and 15.2% machine efficiency in a period of only 3 years. From January 2015 to January 2018, factory efficiency dropped from 83.25% to 56.8% and machine efficiency dropped from 96.90% to 82.1% respectively (nbl, 2015). The factors affecting line performance include availability losses which includes equipment failures, material shortages, and changeover time, production loss or speed losses like machine wear, substandard materials and operator inefficiency, and   quality or

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rework losses. The purpose of this study is to restore factory and machine efficiencies back to the 2015 level and better.

1.2 STATEMENT OF THE PROBLEM

GRAPH OF PACKAGING LINE ONE FACTORY AND MEACHINE EFFICIENCIES DROP OVER YEARS
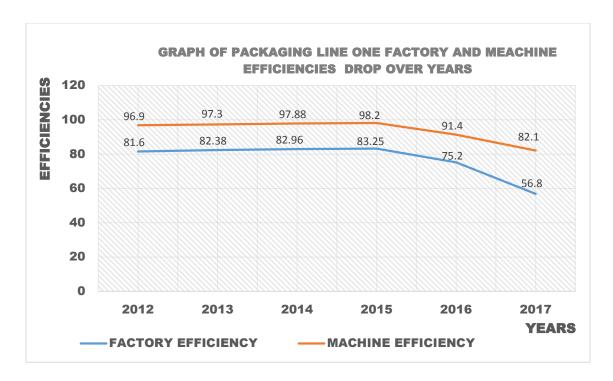
Figure 1.1 : Nile Breweries Limited packaging line 1 FE & ME from 2012 to January 2018

Nile Breweries Limited packaging beer line 1 factory efficiency has been steadily dropping from 83.25 % in 2015 to 56.8% in January 2018. This has led to loss of production, sales and profits to the business. There is an urgent need to restore packaging line 1 factory efficiency to or above the 2015 level. The drop-in factory efficiency is graphically depicted in fig 1.1

1.3 Objective of the study

1.3.1 Main objective

To optimize packaging operations so that beer line one factory efficiency exceeds 83.25% by December 2018.

1.3.2 Specific Objectives

1. To identify bottlenecks on packaging beer line one at Nile Breweries Limited.
2. To determine the efficiency loss caused by the bottlenecks.
3. To optimize packaging beer line one using lean manufacturing tools and practices.

1.4 Research Questions

1. What are the current bottlenecks on packaging beer line 1 at Nile Breweries Limited?
2. What is the percentage of efficiency loss caused by bottlenecks?
3. How can lean manufacturing tools be used to optimize packaging beer line?

1.5 Significance/ contribution of the study

The optimization of packaging operations for beer production line efficiency through lean manufacturing results to implementation of best maintenance practices to eliminate/ reduce machine failures during production process, increasing on machine performance, availability and good quality products, resulting to increase in production volumes and hence automatic increase of packaging beer line 1 efficiency. Continuous supply of good quality products in time to meet market demands increases sales and profits to Nile Breweries Limited, hence increasing employment opportunities, improving standards of living, increasing government revenue through tax collection and high economic development in the country.

1.6 Justification/rationale of the study
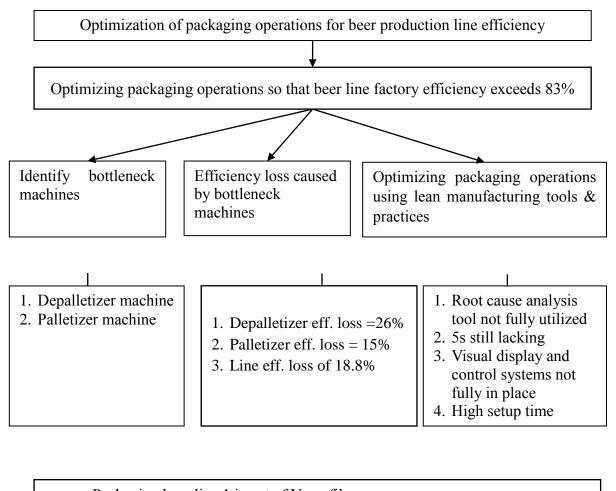
Nile Breweries Limited is one of the largest producers of beers in the food and beverages sector of Uganda with the highest market share. Failure to supply quality beer to customers in time due to poor production run means loss of sales (money) to business. In effect, customers opt for alternative brands from sister companies and hence, decline in market share for Nile Breweries Limited products. Packaging beer line 1 frequent unplanned stoppages makes it difficult to meet target line factory efficiency of 80% and machine efficiency of 89% or volume of 3330 hectoliters per day resulting to increased cost of production due to high levels of water, power, compressed air and steam usages caused by prolonged machine breakdowns, frequent start-ups and shut downs generating many defects and reworks. Due to poor production runs on packaging beer line 1, Nile Breweries Limited management is forced to cut down fixed costs to maximize

profits by reducing on the head count, hence creating unemployment, low standards of leaving, less taxes paid to government and hence less economic development in the country.

1.7 Scope

The study of optimization of packaging operations for beer production line efficiency was conducted on packaging beer Line 1, packaging department of Nile Breweries Limited, located at Yusuf Lule Road, Njeru, Buikwe district, Uganda. The study focused on packaging beer line 1 machine performance. Primary and secondary (Qualitative and quantitative) data related to line performance was collected, guided by objectives. Observation method of data collection was used to identify bottleneck machines using stop watch and data gathering worksheet. Data was analysed using fishbone method, graphs and tables. This research covered a period of four (4) month (August to November 2018)

1.8 Conceptual framework

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┌─────────────────────────────────────────────────────────────────────┐
│      Optimization of packaging operations for beer production line efficiency │
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                                    │
                                    ▼
┌─────────────────────────────────────────────────────────────────────┐
│   Optimizing packaging operations so that beer line factory efficiency exceeds 83% │
└─────────────────────────────────────────────────────────────────────┘
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Identify bottleneck machines	Efficiency loss caused by bottleneck machines	Optimizing packaging operations using lean manufacturing tools & practices

1. Depalletizer machine 2. Palletizer machine	1. Depalletizer eff. loss = 26% 2. Palletizer eff. loss = 15% 3. Line eff. loss of 18.8%	1. Root cause analysis tool not fully utilized 2. 5s still lacking 3. Visual display and control systems not fully in place 4. High setup time

- Packaging beer line 1 is out of V-profile,
- Efficiency loss of 18.8%
- High setup time during brand changes
- Lean manufacturing tools & practices not fully utilized to improve

- Do line balancing.
- Implement unified theory of lean manufacturing tools.
- Recruit technical operators to operate critical machines.
- Adopt new preventive maintenance model to reduce wastes & improve efficiency

Figure 1.2 : Conceptual framework network

The optimization of packaging operations for beer line efficiency focused on restoring packaging beer line 1 factory efficiency to 83.25 and above. Through identifying bottleneck machines, determining efficiency losses caused by bottleneck machines, and optimizing packaging operations using lean manufacturing tools, depalletizer and palletizer machines were identified as bottleneck machines with efficiency loss of 26% and 15% respectively causing general beer line efficiency loss of 18.8%. The lean manufacturing tools currently employed but not fully utilized to improve line performance include root cause analysis, 5s, visual display and control systems, and high setup times. In conclusion, packaging beer line 1 is out of V-profile resulting to general beer line factory efficiency drop of 18.8%. Restoring packaging beer line 1 V-profile through line balancing, full implementation of lean manufacturing tools to improve line performance, adopting new preventive maintenance model, recruiting technical operators to operate critical machines to reduce on high setup times are some of the recommendations to be employed in order to improve on packaging beer line 1 efficiencies. This is depicted in fig 1.2.

1.9 Limitations of Research

The study of optimization of packaging operations for beer production line efficiency was conducted on packaging line 1 at Nile Breweries Limited. During data collection, Nile Breweries Limited being a private business treated company data as confidential and not available to researchers, limited access to plant premises and packaging production line 1 in particular, Nile Breweries Limited packaging management did not allow any machine adjustment to be done on packaging beer line 1 during production process, and lack of special safety personal protective equipment's limited the researcher from accessing critical areas of packaging production line 1 making data collection difficult.

1.10 Delimitations

During the study of optimization of packaging operations for production beer line efficiency on packaging line 1, Nile Breweries Limited provided some information about packaging beer line 1 performance for the previous three years, the researcher was granted access to observe production process on packaging beer line 1, and also Nile Breweries Limited provided breakfast and lunch throughout the entire period of data collection at their premises.

CHAPTER TWO

LITERATURE REVIEW

In chapter two, a review of literature related to optimization of packaging operations for beer line efficiency was conducted and discussed. Detailed topics included in this chapter are packaging beer line, bringing packaging beer line machinery together, bottlenecks affecting beer line efficiency, efficiency losses caused by bottlenecks, effective waste elimination, optimizing packaging beer line using lean manufacturing tools and conclusion.

2.1 Packaging beer line

A packaging line is a coordinated system formed by single or multiple equipment, that performs packaging of goods or products for transport, warehousing, logistics and sale (Lee, 2014). In a beer factory, a packaging line is also defined as 'the aggregate of distinct machines working together in a sequence to fill beverage containers (bottles, cans, or kegs), including the preceding and succeeding machines and equipment, usually from depalletized empty crates until the output of full packaged beer is palletized (Seminer, 2012). The packaging line is set up in order to meet the speed and overall quantities of the product to be packed and may range from manual operation up to high speed fully automatic operation. The machines are put in a sequence and connected by conveyors, which can also serve as buffers (Ferguson, 2004).

There are many different types of packaging lines (Bussinessvibes, 2014), all having their own design characteristics (Mahalik, 2014). Some lines are designed for short and flexible production runs (different product sizes and product packages), other lines are designed for mass production (dedicated to just one product). Some lines have many parallel machines and/or large buffers to meet space and capital constraints (Jialu liu, 2011). However, most bottle and can filling lines have similar machinery for the different stages and follow a similar design rule for bringing the machinery together. Specific packaging line decisions are made regarding the individual machines, conveyors and other line equipment (Branch, 2016). The selected equipment is configured in the line layout and the controls are chosen (Cancar, 2015). Each of these factors affects the overall design of the line, and thus the performance of the line. It is important to keep the objective and history of a packaging line in mind when its performance is being analyzed, because the inherent limitations of the line determine the maximum line efficiency (Ho, 1997).

2.1.1Types of Packaging beer line

Basically, there are two types of bottle filling lines, bottle filling lines for one-way bottles and bottles filling lines for returnable bottles (Morris, 1951). Some filling lines can handle both types of bottles and are called multi-purpose lines.

One-way bottle filling line is for non-returnable or so-called one-way bottle, there are several packaging options (Harte, 1997). One-way bottle filling lines produce mainly for export (krones, 2008). At Nile Breweries limited, all bottle filling lines are for returnable bottles.

Returnable-bottle filling line (Dario Cancar, 2015) runs bottles recovered from the domestic market. The empty returnable bottles are packed in crates and then on pallets. Returnable bottle filling lines produce mainly for the domestic market.

2.1.2 Packaging beer line process

Packaging beer line production process in breweries starts at the depalletizer and ends at palletizer. Pallets full of crates of empty bottle are received from market (returnable bottles) or manufacturer, and are brought to depalletizer (Leer D. v., 2014).

The depalletizer removes the crates from the pallets, layer by layer, and drops it on the conveyor to the unpacker machine. The unpacker machine removes empty bottles from crates to conveyors. The bottles are transported to the bottle washing machine by a bottle conveyor, the crates are transported to crate washing machine by a crate conveyor and both the crates and bottles are then washed. The bottles go on to empty bottle inspection (EBI) for inspection and are removed from the line if quality is not met and the crates go to the crate store. At the filling machine, bottles are filled with beer, closed with a crown and then moved through full bottle inspection (FBI) machine to the pasteurizer. The bottles are pasteurized to kill microorganisms, to make the beer keep longer. Then the bottles are transported to a labelling machine which applies the labels onto the bottles. Bottles are then conveyed through full final bottle inspection, and to packer machine, where they are put back into the crates. The full crates are conveyed to full crate inspector (FCI), then to palletizer, which palletizes crates to pallets. Finally, the pallets are taken from the line and dispatched to the warehouse using forklift (Härte, 1997). This is depicted in fig 2.1.
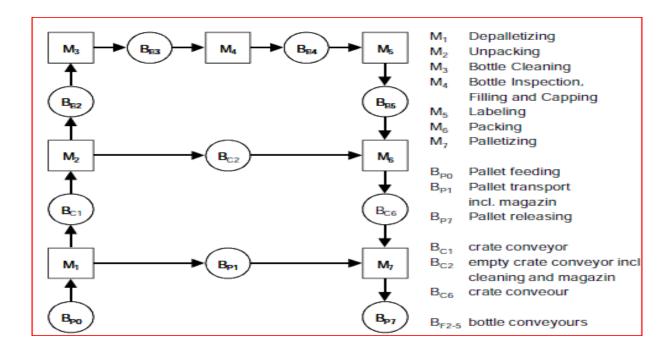
Figure 2.1 : Generic structure of a bottling plant for returnable bottles

2.1.3 Principles of packaging line design

A packaging line is made up of individual machines performing specific operations to deliver the final packed product. Rather than just considering the line as the sum of its parts, it is important to ensure that individual machines are correctly specified so that they work together as part of an efficient overall design.

Each machine has a design speed, but the overall speed of the line cannot exceed the speed of the slowest machine called the bottleneck machine for obvious reasons. The bottleneck machine should be the one considered for reasons of production, quality, cost, etc, to be the most important to keep running as close to its maximum capacity as possible. To make sure the desired machine is the bottleneck, you need to deliberately specify a higher design speed for all the others. You also need to design the rest of the line to service the bottleneck machine and keep it running as constantly as possible ideally it should never be starved infeed and never be stopped because of build-back. This means specifying the design speeds of each machine on the packaging beer line in a 'V-profile' and building in their appropriate buffer capacity.

The V-profile means that the conveyors between upstream machines have a tendency to fill up with bottles at infeed of bottleneck machine and the downstream machines after bottleneck

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machine have a tendency to be relatively empty. Conveyors provide a limited amount of buffer capacity to help keep the bottleneck machine running if a breakdown or stoppage occurs elsewhere on the line. Some packaging lines are designed with storage areas for bottles known as accumulators between machines to give additional buffer capacity. However, accumulators will only keep the bottleneck machine supplied if the packaging line has the correct V-profile, ie the upstream machine can run faster than the bottleneck machine.
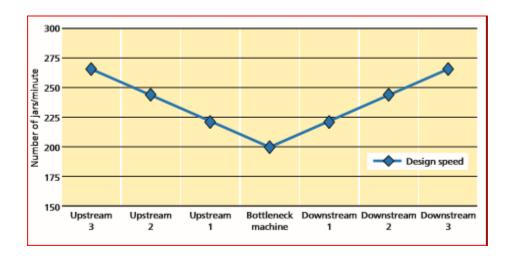
Figure 2.2 : example of designed packaging line V-profile (Enviros, 2000)

2.1.4 Bottle and crate conveyors

Bottle conveyors transport the bottles from one machine to the other and consists of segments of chains (Gribbins, 2014). Most conveyor also serve as buffers (Miller, 2017), because of some extra chains (Voigt, 2013). Case conveyors transport crates from one machine to the other. The buffer function of these conveyors is created by the distance between the cases (Malopolski, 2017). The speed of the machines and the conveyors is adapted on the basis of sensor signal, which indicate whether a conveyor segment is full or empty (Oladapo, 2016). Most machines have several speeds. Often parallel machines are used for a stage, where each machine has extra capacity, so if one of more of the parallel machines fail, the other machine(s) can run at a higher speed to compensate for the failed machine(s) (Nieberg, 2014).
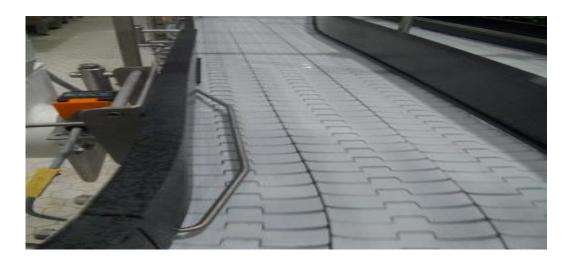
Figure 2.3 : sensor swing arm which indicate whether a conveyor segment is full or empty

2.2 Bringing packaging beer line machinery together

The filling machine is the most important machine on bottle filling line, because filler is critical quality wise and performs the primary function of the packaging line by putting the product into the container. Therefore, on most packaging lines, the filling machine is called the core machine, and the rest of the line is designed around it. It determines the v-profile of the entire line and it's where efficiencies are calculated from. Usually the line efficiency is based on the capacity of the filling machine and other equipment is sized to ensure, as far as possible, that the filler does not stop because of failures on the other equipment (Leer D. , 2014). This is done for both efficiency and quality reasons.

2.2.1 Design principle and buffer strategy

The design principle for packaging lines amounts to a buffer strategy, which makes sure that the buffers before the core machine are almost full and the buffers after the core machine are partly empty. This allows the core machine to continue in the case of a failure somewhere else on the line. In other words, the core machine should have products at the infeed and space at the discharge.

2.2.2 Buffer strategy

The buffer strategy consists of two complementary elements (Miller, 2017). The first element is formed by the buffers which provide accumulation. Static accumulation is achieved by putting a

real buffer between machines (e.g. an accumulation table or a crate store). Dynamic accumulation is accomplished by the conveyors between the machines (Grimes, 2007).

The second element is formed by production speeds of the machines. The machines on either side of filler machine have extra capacity or overcapacity. This overcapacity ensures that the filler machine has products at the in feed and space at the discharge. This enables these machines to catch up after a failure has occurred. After a machine has had a failure and a part of the accumulation is used, then the overcapacity of the machine is used to restore the system back to the situation before the failure. The machine before and after the core machine have extra capacity with respect to the core machine. The machines upstream of the core machine (filler) each have extra capacity with respect to the next machine, and the machines downstream of the core machine each have extra capacity with respect to the previous machine. The results in the V-Profile capacity graph for the line stages, with the filling machine at the lowest point.

A bottling package lines design usually revolves around the V-profile or curve principle. A V-profile ensures that the bottleneck asset, typically the filler is neither starved nor blocked due to issues up or downstream. The filler is fed at a higher rate than it can accept, thus product is accumulated and the filler will never be starved even if the upstream machines breaks down for less than 5 minutes. Similarly, downstream machines runs at a higher speed than the filler, hence bottles are pulled away faster than they are processed to prevent blockage. The V-graph plays a central role in the buffer strategy of a packaging line. Essentially the V-profile of a packaging line is a graph of the machine capacities in the sequence of the packaging line. In keeping with the packaging line design principle, the machines on either side of the core machine have extra capacity.
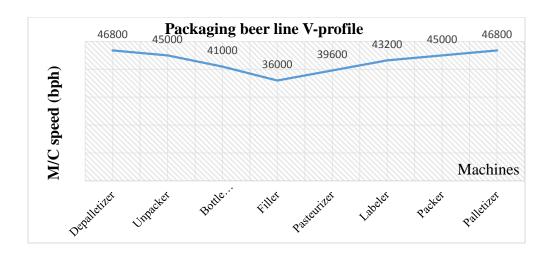
Figure 2. 4 : V profile

The V-graph is developed to cope with machine failures thus when there is no machine failure, the graph will be flattening. The theory of the V-graph ensures that the core machine has enough bottles at input to prevent the lack of bottles at infeed, and the machines after the core machine will have a higher capacity in order to prevent backup at discharge. A core machine can also be called the bottleneck machine, if it has in reality also the lowest capacity. The situation can occur that the core machine (filler) is not the bottleneck machine. For example, if the bottle washer has a high failure rate and therefore produces less than the 36,000 bottles/hour of the filler (fig 2.4), then the bottle washer is the bottleneck machine and the filler is the core machine. So the core machine is theoretically the machine with the lowest production capacity and the bottleneck machine is operationally the machine with the lowest capacity. Losses made by the bottleneck machine cannot be corrected by other machines. Thus a loss on the bottleneck machine is a direct loss on total line performance. In order to determine the bottleneck machine, Machine Efficiency Rate (MER) is introduced or used. The machine efficiency rate is calculated with the following formula (Daan, 2014):

$$\text{Machine efficiency} = \frac{\text{Production time}}{\text{Production time} + \text{internal stoppage time}} \text{ x } 100\%$$

$$\text{Machine efficiency rate} = \frac{\text{Production time}}{\text{production time} + \text{internal failure rate}} \text{X machine capacity}$$

Therefore, availability takes into account all events that stop planned production long enough where it makes sense to track a reason for being down (typically several minutes). Availability is calculated as the ratio of Run Time to Planned Production Time:

Availability = Run Time / Planned Production Time

Run Time is simply planned production time less stop time, where stop time is defined as all-time where the manufacturing process was intended to be running but was not due to unplanned stops (e.g., breakdowns) or planned stops (e.g., Changeovers).

Run Time = Planned Production Time − Stop Time

This proves that the core machine (filler) is not the same as the bottleneck machine. Every machine could be the bottleneck machine, dependent on the internal failure time. The machine with the lowest Machine Efficiency Rate is called the bottleneck machine.

2.3 Bottlenecks affecting production line

The process of packaging is one that happens in a pre-defined sequence of events. When any sort of automation is involved, an additional factor comes into play, success will depend on just how well the equipment in the process is integrated and that means each of the machines on packaging line does its job at the right time and at a right speed. A bottleneck in the manufacturing process can be difficult to identify in a complex system. The bottleneck can be found by looking at each sequence of the process individually and measuring the production level at each step. If a particular sequence has a low production level, then it is the source of the bottleneck. It should be noted that there can be multiple bottlenecks within a complex system (Clark, 2017).

Since packaging beer line machines are not producing all the time during production, there are several states that indicate the condition of the machine stoppage. A core machine (filler) can be stopped during production under the following states;

- Producing - the machine is producing products. This could be with different speed levels.
- Planned production stop - the machine is not producing due to planned maintenance.

- Starvation - the machine is not producing due to a lack at the infeed mostly caused by failures of preceding machines.

- Blockage - the machine is not producing due to a backup at discharge. Mostly caused by failures of succeeding machines.

- Short failure - the machine has an internal or external failure with a duration **less** than 5 minutes.

- Long failure - the machine has an internal or external failure with a duration **longer** than 5 minutes.

- Unknown - the cause of the machine downtime is not registered. This state will be neglected in this research because the unknown time is nil. If this time arises it will be often a downtime due to a test.

The bottlenecks that affect the overall equipment effectiveness (OEE) are essential in affecting the line efficiency and increase in costs (Egan, 2014). Over-production, rejects & rework, waiting-time waste, inventory waste and motion waste are the most deadly wastes on a packaging production line (Domingo, 2017). Other types of waste include: Untapped human potential, inappropriate systems, wasted energy and water, wasted materials, service and office waste and waste of customer time (Smith, 2006).

The factors that contributes to high production loss are, availability (manufacturing time) loss, performance (manufacturing speed) loss and quality (scrap or rework) loss. The step-by-step approach is used to identify the root causes of packaging beer line bottlenecks in order to:

1. Measure the performance of the packaging beer lines machines
2. Recognize the symptoms of poor packaging beer line performance
3. Identify where problems occur on packaging beer line
4. Focus efforts to improve efficiency in the right areas
5. Reduce product and packaging waste.

2.3.1 The step-by-step approach of identifying bottlenecks

The following are the steps followed during step-by-step approach of identifying bottle necks on packaging beer lines and they include;

- Regular measurements of the performance of the line as a whole. The key performance indicators are used show when the line is not performing well and highlight the need to take a detailed look at individual machines. Example of key performance indicators include machine performance, factory efficiency, water usage, etc.
- Specific investigation of the performance of individual machines, identify the real causes of poor line performance and to investigate appropriate solutions. The core of this investigation is the V-profile. This includes three elements which indicate problems in specific areas of the packaging beer line (Enviros, 2000), i.e.
    1. The design values curve shows whether individual machines have been specified correctly
    2. The observed values curve shows whether individual machines are operating at specification
    3. The effective values curve shows whether individual machines are operating reliably and how this affects overall line performance.
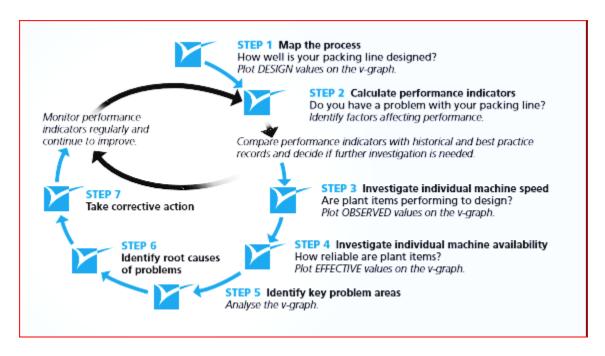
Figure 2.5 : Step-by-step approach of identifying bottlenecks

The step-by-step approach of identifying bottlenecks is further explained in details below

Step 1

To identify the packaging production line bottleneck, first review the packaging line designed V-profile or graph during installation, identify the core (slowest) machine and other different individual machine speeds.

Step 2

Identify the packaging production beer line performance indicators. Compare the current performance indicators to historical records of the same performance indicators to justify the existence of bottlenecks on packaging beer line.

Step 3

Investigate individual machine speed and performance in comparison with packaging line designed V-graph machine speeds. Any machine speed below the v-graph designed speed is registered as a bottleneck.

Step 4

Investigate the individual machine availability by carrying out capability study and plot to check the effectiveness of the V-graph or profile. This helps to identify areas on packaging line which are performing poorly.

Step 5

Identify the key problem areas on packaging line with comparison to V-graph and mark out the most problematic machines and other components.

Step 6

Use problem solving tools to identify the root cause affecting line performance. Forexample use 5 why, DMAIC and abnormality reports, etc.

Step 7

Take corrective actions or measures to solve the problems. Then, monitor the performance indicators regularly and repeat the cycle to improve.

2.3.2 Availability/ manufacturing loss

Availability or manufacturing losses are unplanned or unexpected stoppages that arise during a routine manufacturing process, causing additional time to process, less products produced, increases in cost of production, etc. The availability/ manufacturing losses include the following:

1. Prolonged setup time- is the excess/extra time taken from the set (planned) time to change a machine from the last part of production lot to the next production lot, hence causing loss of production.
2. Breakdowns- is a failure of an equipment that prevents it from working properly. The most causes of breakdowns in manufacturing are not rea6ding operator's manual, improper maintenance, poor electrical connections, overrunning machines, not replacing worn parts, misaligned tighteners, improper equipment storages, weather related, ignoring warning signals, and untrained operators (Wehrspann, June 2018).
3. Short stops-these are idling and minor stops where the equipment stops for a short period of time typically a minute or two, with the stop resolved by the operator. And this is a performance loss. Some example of short stops include material jams, incorrect settings, misaligned or blocked sensors, periodic quick cleaning, obstructed product flow, etc. Short stops are usually below five minutes and does not require maintenance personnel.

2.3.3 Performance losses (Speed losses/ reduced speed)

Performance takes into account Performance Loss (Chidoko, 2015), which accounts for anything that causes the manufacturing process to run at less than the maximum possible speed when it is running (including both Slow Cycles and Small Stops) (Lichtenberg, 1996-2011). Examples of things that create Performance Loss include machine wear, substandard materials, misfeeds, and jams. The remaining time after Performance Loss is subtracted is called Net Run Time.

$$\text{Performance} = \frac{\frac{\text{Total count}}{\text{Run time}}}{\text{Ideal run rate time}} = \frac{\text{Net run time}}{\text{ideal run rate time}}$$

2.3.4 Quality losses (scrap and rework)

Rework is defined as the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time (Okechukwu, 2015). Scrap and rework costs are a manufacturing reality impacting organizations across all industries and product lines (McMahon, 2013). Scrap and rework costs are caused by many things when the wrong parts are ordered, when engineering changes are not effectively communicated or when designs are not properly executed on the manufacturing line.

$$\text{Quality} = \frac{\text{Good count}}{\text{Total count}}$$

This is the same as taking the ratio of Fully Productive Time (only Good Parts manufactured as fast as possible with no Stop Time) to Net Run Time (all parts manufactured as fast as possible with no stop time). High startup rejects is partially as a result of defective parts that are produced until stable production run is reached.

2.4 Efficiency losses caused by bottlenecks

A bottleneck has a terrible effect on the efficiency of production beer line. The stages following the bottleneck must function below their capacity because they do not receive enough input to operate at full capacity (Clark, 2017). The stages before the bottleneck need to slow down production because the subsequent stages cannot handle the capacity. As a result, the overall efficiency of the system is significantly reduced. Excessive durations for various events are indicators of bottlenecks that can be tuned (Milener, 2017).

2.4.1 The Theory of Constraints

The Theory of Constraints (TOC) provides a powerful set of tools for helping to achieve high line performance (Goldratt, 1984), including:

- The Five Focusing Steps (a methodology for identifying and eliminating constraints)

- The Thinking Processes (tools for analyzing and resolving problems)

- Throughput accounting (a method for measuring performance and guiding management decisions).

Hence TOC offers the above to improve line performance once implemented.

The top priority is always the current constraint. In environments where there is an urgent need to improve, TOC offers a highly focused methodology for creating rapid improvement.

Theory of Constraints implementation will have the following benefits:

- Increased profit (the primary goal of TOC for most companies)

- Fast improvement (a result of focusing all attention on one critical area – the system constraint)

- Improved capacity (optimizing the constraint enables more product to be manufactured)

- Reduced lead times (optimizing the constraint results in smoother and faster product flow)

- Reduced inventory (eliminating bottlenecks means there will be less work-in-process)

The Theory of Constraints provides a specific methodology for identifying and eliminating constraints, referred to as the Five Focusing Steps (Vorne, Theory of Constraints, 2018).
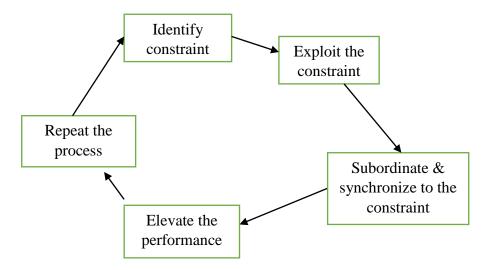
Figure 2.6 : the five focusing steps to identify and eliminate constraints

The Thinking Process is a set of tools; graphical trees which enable us to drill down into our intuition to verbalize the cause and effect relationships that is observed on day-to-day production line process, but which are difficult to captured on line stoppage sheet and project plans. It allows us to capture those non-obvious leverage points which are separated in time space and to portray their relationships in a simple and straightforward manner. Thinking Process is absolutely integral to Theory of Constraints. The Thinking Process allows us to work through the sequence of;

(1) What to change.

(2) What to change to.

(3) How to cause the change.

The Thinking Process performs a number of functions often simultaneously. It allows to interrogate the situation in a systematic and logically rigorous way, analyze and synthesize, communicate the situation, and to generate organizational knowledge. The thinking Process enables to work through the sequential layers of agreement to obtain an implementable solution. We do this using the intuition of the people involved in cause and effect relationships. In general, the thinking process is integral to the systemic nature of Theory of Constraints and allows not

only analysis of problems, but also the construction of solutions and the communication and effective implementation of those solutions.

2.5 Effective waste elimination

Before one can stop waste, he should able to see it, recognize it as waste, identify who is responsible, and finally appreciate its size and magnitude (Domingo, 2017). Waste that is not seen cannot be eliminated. When something is denied as waste, it cannot be stopped. When one refuses to accept responsibility for the waste, then she/he will not eliminate it. Finally, when the waste is not measured, people may think it is small or trivial and therefore will not be motivated to stop it. As the saying goes "What is not measured, is not improved" (Hunter, 2015).

These steps of waste elimination are:

1. Make waste visible.

2. Be conscious of the waste.

3. Be accountable for the waste.

4. Measure the waste.

5. Eliminate or reduce the waste

2.6 Optimizing packaging beer line using lean manufacturing tools

Optimization is obviously a quantitative procedure that requires application of discipline and serious multivariable mathematical models. The bottom line is that most production processes are underutilized and the use of mature, accessible mathematical technology unlocks the latent capacity, which is of significant value. The best possible performance is "Optimal Operations," called "Process Optimization" in the process industry. In manufacturing it is the extreme of Lean Operations, one of the components of "Lean Manufacturing" success. Other components that qualify for "lean" in the sense of avoiding waste (non-value-added), and not missing opportunities for improvements are: Lean Design (the most common emphasis today), Lean Logistics and Supply Chain, Lean Maintenance, Lean Scheduling, Lean Safety and Lean Scheduling. Some share interests with Six Sigma as well (quality and costs).

Some line parameters can be changed (e.g. the machine speeds, the conveyor speeds, and the location of the sensors), other parameters vary (e.g. the failure behavior of the machines). Most line parameters are limited by the line design. Within these limits there is some room to tune the line parameters to improve the line efficiency. Ideally, in the line design the slope of the V-profile and the buffer capacities between the machines are determined by the failure behavior of the machines. The accumulation is adjusted to the MTTR and the recovery time is adjusted to the MTBF. However the exact failure behavior of the machine is of course not known in advance. So, data of comparable machines must be used and a sensitivity analysis should be done. Once the line is installed, a true value of the line parameters becomes known. Then efficiency analysis should give an indication which line parameters should be changed to improve the line efficiency

Many manufacturing companies have been measuring the efficiency of their lines and work cells in such a way as to mask many causes of efficiency loss (Scott, 2005). Over the years, management focus has shifted to reporting high efficiency numbers, instead of considering how the numbers are arrived at. Lean concepts are mostly evolved from Japanese industries especially from Toyota (Sundar, 2014). Lean manufacturing aims to reduce total amount of waste in a system to promote efficiency and conserve resources. By reducing waste, industrial companies are able to increase product output and profit (Christopher, 2016). According to Arfmann et al, (2014), Lean is a production practice that aims to minimize waste along entire production line and create more value for customers (Arfmann, 2014). Lean manufacturing is a philosophy that targets the identification and elimination of any waste in production process especially to reduce waste in human effort, inventory, time to produce and production space (Yerasi, 2011). Lean manufacturing is also the systematic elimination of waste to increase productivity (Hosseini, 2015). The key lean manufacturing principles are perfect first-time quality, waste minimization by removing all activities that do not add value, continuous improvement and flexibility (Anvari, 2011). Lean manufacturing is a Japanese method focused on 3M's. These M`s are: muda, the Japanese word for waste, Mura, the Japanese word for inconsistency, and Muri, the Japanese word for unreasonableness (Clever, 2015). Muda specifically focuses on waste activities to be eliminated. Within manufacturing, there are categories of waste. Waste is broadly defined as anything that adds cost to the product without adding value to it. Lean manufacturing battles waste and concentrates on how to create a greater value by removing all barriers to accomplishing manufacturers' objectives. There are seven types of waste in which lean

manufacturing can assist in alleviating and will result in more efficient production lines. Suzaki 2009 reports seven types of waste identified at Toyota: waste from overproduction, waste of waiting time, transportation waste, processing waste, inventory waste, waste of motion, and waste from product defects. Japanese automobile manufacturers achieved high quality and low costs by removing buffers and impediments from the system, hence the term "lean." Eliminating excess inventory, for example, drives closer linkages between assemblers and suppliers, reshapes the factory floor, forces greater attention to first-time quality, and so on. Excess inventory means manufacturing mistakes or broken equipment will not halt production because downstream processes draw on inventories to keep going while the mistakes are remedied or fixed. However, excess inventory costs money and can hide production problems that lead to greater problems later on. Mass production allows for excess inventory to provide a buffer against mistakes, while lean manufacturing aims to eliminate mistakes and hence the need for costly buffers. Removing inventory buffers requires very tightly coupled processes that closely link different functions within the organization. The lean system must be adopted wholesale to see improvements (jones, 2003). The synergies from applying lean to different areas of the manufacturing process are so significant that new processes cannot be properly understood alone or adopted singly. Such piecemeal efforts could only result in small improvements at best, a fraction of what full-scale implementation would offer

In their second book on the topic "Lean Thinking" (Womack, 1996), depart from a specifically functional approach and offer a more general way of understanding lean manufacturing. They outline the five principles of the system as follows:

> (1) Defining value for each product
> (2) Eliminating all unnecessary steps in every value stream
> (3) Making value flow
> (4) Knowing that the customer pulls all activity
> (5) Pursuing perfection continuously.

The five principles are laid out in some detail here because they contribute to the understanding of lean manufacturing throughout the plant. Taken together, these principles may offer powerful performance enhancements. However, while companies can incorporate these principles in their

business practices, they often do not correspond to the functional divisions within companies, which may be separately managed. These principles are explained in details below.

1. Defining value for each product

To better understand the first principle of defining customer value, it is important to understand what a value is. Value is what the customer is willing to pay for. It is paramount to discover the actual or latent needs of the customer. Sometimes customers may not know what they want or are unable to articulate it. There are many techniques such as interviews, surveys, demographic information, and web analytics that can help manufacturers decipher and discover what customers find valuable. By using these qualitative and quantitative techniques you can uncover what customers want, how they want the product or service to be delivered, and the price that they afford.

2. Eliminating all unnecessary steps in every value stream

In this step, the goal is to use the customer's value as a reference point and identify all the activities that contribute to these values. Activities that do not add value to the end customer are considered waste. The waste can be broken into two categories, non-valued added but necessary and non-value & unnecessary. The latter is pure waste and should be eliminated while the former should be reduced as much as possible. By reducing and eliminating unnecessary processes or steps, you can ensure that customers are getting exactly what they want while at the same time reducing the cost of producing that product or service.

3. Making value flow

After removing the wastes from the value stream, the following action is to ensure that the flow of the remaining steps run smoothly without interruptions or delays. Some strategies for ensuring that value-adding activities flow smoothly include: breaking down steps, reconfiguring the production steps, leveling out the workload, creating cross-functional departments, and training employees to be multi-skilled and adaptive.

4. Knowing that the customer pulls all activity

Inventory is considered one of the biggest wastes in any production system. The goal of a pull-based system is to limit inventory and work in process (WIP) items while ensuring that the requisite materials and information are available for a smooth flow of work. In other words, a pull-based system allows for Just-in-time delivery and manufacturing where products are created at the time that they are needed and in just the quantities needed. Pull-based systems are always created from the needs of the end customers. By following the value stream and working backwards through the production system, you can ensure that the products produced will be able to satisfy the needs of customers.

5. Pursuing perfection continuously

Wastes are prevented through the achievement of the first four steps. However, the fifth step of pursuing perfection is the most important among them all. It makes Lean thinking and continuous process improvement a part of the organizational culture. Every employee should strive towards perfection while delivering products based on the customer needs. The company should be a learning organization and always find ways to get a little better each and every day.

The five Lean principles provide a framework for creating an efficient and effective organization. Lean allows managers to discover inefficiencies in their organization and deliver better value to customers. The principles encourage creating better flow in work processes and developing a continuous improvement culture. By practicing all 5 principles, an organization can remain competitive, increase the value delivered to the customers, decrease the cost of doing business, and increase their profitability.

Lean Manufacturing has endeavored to rationalize production by:

I.   Completely eliminating waste in the production process
II.   To build quality into the process
III. To reduce costs - productivity improvements
IV.   To develop its own unique approach toward corporate management
V.   To create and develop integrated techniques that will contribute to corporate operation.

Many concepts of lean manufacturing such as Just in Time (JIT), Kanban, Production smoothing, Total Productive Maintenance (TPM) and Total Quality Management (TQM) have been implemented in more than one process industry and resulted in huge benefits (Ward, 2007). A series of simulation experiments in a steel mill suggested that Value Stream Mapping (VSM), Kanban, JIT, Production smoothing, TPM, Setup reduction, 5S and Visual Control resulted in a decrease of production lead time from 48 days to 15 days and a reduction of work in progress inventory from 96 to 10 coils for a particular portion of the process (Abdulmalek, 2006).

2.6.1 Improving manufacturing processes through Lean Implementation

Reducing waste, implementing efficiency-promoting practices, and continuously improving operations are the main goals of lean manufacturing ideology. Simplifying manufacturing tasks, increasing spatial and workflow organization, reducing errors and listening to employees on the manufacturing floor, results into reduced waste, improved employee morale, improved efficiency, and a greater ability to manufacture products on a predictable timetable. The lean manufacturing principles for production line improvement include: elimination of waste, continuous improvement (kaizen), respecting human elements, leveling production, Just in time (JIT) production, one piece flow, quality built-in and mistake proofing (Mulholland, 2018).

Lean Maintenance for Lean Manufacturing using Six Sigma DMAIC is the best methodology of reducing downtime (Cooper, 2014). The benefits of pairing autonomous and preventive maintenance strategies are an increase in planned maintenance over unplanned, maximized equipment availability, and the ability to forecast production capacities and maintenance budgets with greater precision (Brum, 2016), this includes utilizing preventative maintenance strategies, autonomous maintenance strategies, plan to replace wear components and critical spare parts, choose a manufacturer or supplier who can help in a pinch and plan for upgrades (Hiroshige, 2004). And do total plant maintenance after a specified period of time (annually).

2.6.2 Lean manufacturing tools to be used to optimise packaging beer lines

The lean manufacturing tools to be used include the following

(1) **Total productive maintenance, TPM** - A holistic approach to maintenance that focuses on proactive and preventative maintenance to maximize the operational time of equipment. TPM blurs the distinction between maintenance and production by placing a strong emphasis on empowering operators to help maintain their equipment. This reduces on wastes on production beer line.

(2) **5 s** - Organize the work area where Sort (eliminate that which is not needed), Set In Order (organize remaining items), Shine (clean and inspect work area), Standardize (write standards for above), Sustain (regularly apply the standards). Eliminates waste that results from a poorly organized work area (e.g. wasting time looking for a tool).

(3) **Andon** – is the Visual feedback system for the plant floor that indicates production status, alerts when assistance is needed, and empowers operators to stop the production process. Andon acts as a real-time communication tool for the plant floor that brings immediate attention to problems as they occur, so they can be instantly addressed

(4) **Bottleneck Analysis** – it's a tool used to identify which part of the manufacturing process limits the overall throughput and improve the performance of that part of the process. Improves throughput by strengthening the weakest link in the manufacturing process.

(5) **Continuous flow** – this is where production work-in-progress smoothly flows through production with minimal (or no) buffers between steps of the manufacturing process. Continuous flow eliminate many forms of waste (e.g inventory, waste time and transport).

(6) Gemba – is a philosophy that reminds us to get out of our offices and spend time on the production floor where real action occurs. Gemba promotes a deep and thorough understanding of real-world manufacturing issues by first-hand observation and by talking with plant floor employees.

(7) **Policy deployment** – this aligns the goals of the company, with the plans of middle management (tactics) and the work performed on the production line (action). It ensures that progress towards strategic goals is consistent and through eliminating the waste that comes from the poor communication and inconsistent direction.

(8) Automation - Design equipment to partially automate the manufacturing process (partial automation is typically much less expensive than full automation) and to automatically

stop when defects are detected. After Jidoka, workers can frequently monitor multiple stations (reducing labor costs) and many quality issues can be detected immediately (improving quality).

(9) **Just-In-Time (JIT)** - Pull parts through production based on customer demand instead of pushing parts through production based on projected demand. Relies on many lean tools, such as Continuous Flow, Heijunka, Kanban, Standardized Work and Takt Time (the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand). JIT is highly effective in reducing inventory levels. Improves cash flow and reduces space requirements.

(10)   **Kaizen (Continuous Improvement)** – it is a strategy where employees work together proactively to achieve regular, incremental improvements in the manufacturing process. Combines the collective talents of a company to create an engine for continually eliminating waste from manufacturing processes.

(11)   **Kanban (Pull System)** - A method of regulating the flow of goods both within the factory and with outside suppliers and customers. Based on automatic replenishment through signal cards that indicate when more goods are needed. Kanban eliminates waste from inventory and overproduction. Can eliminate the need for physical inventories (instead relying on signal cards to indicate when more goods need to be ordered).

(12)   **KPIs (Key Performance Indicators)** - are metrices designed to track and encourage progress towards critical goals of the organization. Stronline efficiency promoted KPIs can be extremely powerful drivers of behavior, so it is important to carefully select KPIs that will drive desired behavior. The best manufacturing KPIs are aligned with top-level strategic goals, effective at exposing and quantifying waste and readily influenced by plant floor employees (so they can drive results)

(13)   **Muda (Waste)** – is anything on the production process line that does not add value from the product. Muda means waste. The elimination of muda (waste) is the primary focus of lean manufacturing.

(14)   **Overall Equipment Effectiveness (OEE)** – is a framework for measuring productivity loss for a given manufacturing process. Three categories of loss are tracked: Availability (e.g. downtime), Performance (e.g. slow cycles) and Quality (e.g. rejects).

OEE provides a benchmark/baseline and a means to track progress in eliminating waste from a manufacturing process. 100% OEE means perfect production (manufacturing only good parts, as fast as possible, with no downtime).

(15)   **PDCA** (Plan, Do, Check, Act) – is an iterative methodology for implementing improvements. Plan (establish plan and expected results), do (implement plan), check (verify expected results achieved) and act (review and assess; do it again). Applies a scientific approach to making improvements.

(16)   **Poka-Yoke (Error Proofing)** – is the design error detection and prevention into production processes with the goal of achieving zero defects. It is difficult (and expensive) to find all defects through inspection, and correcting defects typically gets significantly more expensive at each stage of production.

(17)   Root Cause Analysis – is a problem solving tool that focuses on resolving the underlying problem instead of applying quick fixes that only treat immediate symptoms of the problem. A common approach is to ask why five times each time moving a step closer to discovering the true underlying problem. Root cause analysis elps to ensure that a problem is truly eliminated by applying corrective action to the root cause of the problem.

(18)   Single-Minute Exchange of Dies (SMED) **-** reduce setup (changeover) time to less than 10 minutes. Techniques include convert setup steps to be external (performed while the process is running), simplify internal setup (e.g. replace bolts with knobs and levers), Eliminate non-essential operations and create Standardized Work instructions. This enables manufacturing in smaller lots, reduces inventory, and improves customer responsiveness.

(19)   Six Big Losses - Six categories of productivity loss that are almost universally experienced on production lines include; breakdowns, setup/adjustments, small Stops, reduced Speed, startup rejects and production. Rejects provides a framework for attacking the most common causes of waste in manufacturing.

(20)   Standardized work – standard documented procedures for manufacturing that capture best practices (including the time to complete each task). Must be a living documentation that is easy to change. This eliminates waste by consistently applying best practices. Standardized work forms a baseline for future improvement activities.

(21) **Value stream mapping** – it is a tool used to visually map the flow of production. Shows the current and future state of processes in a way that highlights opportunities for improvement. Value stream mapping exposes waste in the current processes and provides a roadmap for improvement through the future state.

(22) **Visual factory** – these are visual indicators, displays and controls used throughout production line to improve communication of information. Visual factory makes the state and condition of production line easily accessible and very clear to everyone.

2.6.3 Benefits of lean manufacturing

Lean manufacturing improves efficiency, reduces waste, and increases productivity (Tonny, 2016). The benefits, therefore, are manifold:

i. **Increased product quality**: Improved efficiency frees up employees and resources for innovation and quality control that would have previously been wasted.

ii. **Improved lead times**: As manufacturing processes are streamlined, businesses can better respond to fluctuations in demand and other market variables, resulting in fewer delays and better lead times.

iii. **Sustainability**: Less waste and better adaptability makes for a business that's better equipped to thrive well into the future.

iv. **Employee satisfaction**: Workers know when their daily routine is bloated or packed with unnecessary work, and it negatively affects morale. Lean manufacturing boosts not only productivity, but employee satisfaction.

v. **Increased profits**: and, of course, more productivity with less waste and better quality ultimately makes for a more profitable company.

Since application of lean pays big dividends, it also generates some challenges (Sigma, 2016). The following possible hurdles experienced during lean manufacturing implementation and they include:

- **Expense** – It costs money to acquire the right equipment or update the production line, and these costs have to be covered before your company can begin seeing the benefits of Lean. It takes time to reap the payoff.

- **More outlays for labor** – Making the changes dictated by Lean also requires an up-front commitment to temporary labor. This increases labor costs briefly while improvements are being put into place, but ultimately, labor cost reductions will follow.

- **Opposition** – People fear innovations – even the ones that bring improvement. Setting aside old practices and processes can be difficult for some employees. Assure them with proper training and education.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter describes the methods, formulas and procedures used to optimize packaging operations for beer production line efficiency on packaging line 1 at Nile Breweries Limited. This chapter therefore looks at the research design, research tools/ instruments, data collection and data analysis.

3.1 Research Design

In order to optimize packaging beer operations for production line efficiency at Nile Breweries Limited, a sample survey research design was used where information was collected by participation. Furthermore, the research was qualitative and quantitative in nature where a systematic subjective approach was used to gain insight.

3.1.1 Sources of data

Primary and secondary data (both qualitative and quantitative) were used in this research study.

3.1.1.1 Primary data

Primary data was collected through observation. Capability study were carried to examine beer line machine availability losses, performance losses and quality losses that directly affects packaging beer line efficiencies.

3.1.1.2 Secondary data

Secondary data was obtained by reviewing the available records on packaging beer line performance, availability and quality issues at Nile Breweries Limited while comparing it with related publication by other scholars on beer line performance guided by objectives.

3.2 Research tools/ instruments

During observations, stop watch (timer) and data gathering work sheets (capability study form) were used to collect data.

Stop watch was used to measure the amount of time elapsed from a particular time when it is activated to the time when it is deactivated in seconds. It was used to measure time taken to complete a defined number of revolutions.

Data gathering work sheets were used to note readings taken from stop watch after counting a defined number of revolutions or rounds. Then the information was used to calculate total downtime per shift, production time, machine speed, machine efficiencies, etc.

3.4 Data collection

Data was collected and complied through observation and active planned participation.

Beer packaging process on packaging assembly line were examined to understand the process of packaging beer into bottles and their movement time on the assembly line. The function of packaging beer line is to pack the right beer brand into bottles at right time in the right amount in sequence at minimum production cost. The number of worker stations were identified to determine the number of workers required.

3.4.1 Identifying bottlenecks on packaging beer line one.

During research, bottlenecks on packaging beer line one at Nile Breweries Limited were identified through observation by carrying out beer line machine capability study to establish the problematic machines/area and review of operational practices.

Historical data on beer line performance was retrieved from performance records available at Nile Breweries Limited and publications on packaging beer line efficiency by other scholars.

3.4.1.1 Observations

Through observation, the following instruments and procedures were used to establish the bottleneck machine on packaging beer line in comparison with original desired beer line V-profile through carrying out capability study.

1. **Instruments**
   (1) Stop watch (timer)

(2) Data gathering work sheets.

2. **Procedure**

(1) One machine at a time was selected during production time, e.g depalletizer.

(2) Standard V-profile machine speed, Y_1 bph (bottles per hour) and time taken to depalletize one pallet, T_1 seconds for the selected machine were written down (noted).

(3) The number of bottles in one pallet was calculated as, (C_p x Z_b) bottles

    a. Where

        i. C_p = No of crates on a pallet

        ii. Z_b = No of bottles in a crate

        iii. 3600 Seconds = One hour

(4) Observed time taken to depalletize a full pallet, t seconds

(5) Repeated step (4) three times and calculated the average time taken to depalletize a pallet of empty crates.

        i. Average time, $T_2 = (\frac{t_1 + t_2 + t_3}{3})\ seconds$.

(6) Calculated machine speed using formula

        i. Machine speed, $Y_2 = (\frac{3600\ x\ (C_p\ x\ Z_b)}{T_2})$ bph

(7) Calculated machine efficiency using formula

        i. Machine efficiency, $Y_e = (\frac{Y_2}{Y_1}$ X V-profile machine efficiency) %

(8) Repeated the above steps for all other machines on packaging beer line 1 to establish their machine speeds and efficiencies.

(9) Compared machine speed and efficiencies with the V-profile machine speed and efficiencies to establish the slowest or fastest machine above or below V-profile set points respectively.

3. **Recording issues causing machine stoppage**

(1) The machine stoppage causes was classified into three categories;

    a. Inherent stoppage (I) - which is internal machine failure

    b. Upstream stoppage (U) - failure before machine or starvation

    c. Downstream stoppage (D) - failure after machine (build back)

(2) Summed up the total machine stoppage time in categories of inherent stoppages, upstream stoppages and downstream stoppages.

(3) Repeated steps (1) & (2) above while examining the remaining machines on packaging beer lines.

(4) Compared the above results with packaging beer line V-profile machine ratings to establish the most problematic machine on the packaging beer line

4.   Additional critical areas observed include

   i.   Production process operators operating machines and their skills

   ii.   Quality of input raw materials

   iii. Operating practices and documentations at work stations on individual machines

3.4.1.2 Machine records review

Secondary data about bottleneck (down time) machines were retrieved from available records at Nile Breweries Limited. This data was extracted from Coswin software archives and their downtime effect on production, maintenance cost and efficiency losses caused by breakdowns.

Data extracted included;

   (1) Major breakdowns and time taken to restore machine for production

   (2) Probable causes of the major breakdowns

   (3) Packaging beer line designed manpower allocation and skill level per machine.

3.4.1.3 Determining the efficiency losses caused by bottlenecks.

During the determination of efficiency losses caused by bottlenecks, examined line efficiency drop from 83.6 % to 56.8% for the previous three years from January 2015 to January 2018.

(1) One machine was Selected at a time, its machine V-profile speed Y_2 and designed V-profile machine efficiency E_e was noted.

(2) Calculated individual machine speeds, using formula

   Machine speed $Y_1 = (\dfrac{3600\ X\ (C_p\ x\ Z_b)}{T_2})$ bph

(3) Calculated machine efficiency using the following formula

Machine efficiency, $Y_e = (\frac{Y_2}{Y_1} X E_e)$ %

Note:

➤ Machine efficiency is a measure for the availability of the machine. It is defined as the percentage of time that the machine is ready to operate, for the period specified:

Machine efficiency $= \dfrac{Total\ running\ time}{Total\ running\ time + total\ time\ internal\ failure}\ X\ 100\%$

➤ Line efficiency is a measure of the efficiency of a packaging beer line during the period specified, and is calculated as follows:

Line efficiency $= \dfrac{Net\ production\ time}{Actual\ production\ time}\ X\ 100\%$

Line efficiency $= \dfrac{Net\ production\ time}{Net\ production\ time + unplanned\ downtime}\ X\ 100\%$

(1) Calculated speed loss for slower machines running below designed speed and speed gain for machines running above desired speed.

    ➤ For slow speed machines

    Machines lost speed = designed V-profile machine speed – current machine speed

    Efficiency loss = designed V-profile machine efficiency – current machine efficiency

    ➤ For high speed machines

    Machine gained speed = current machine speed – designed V-profile machine speed.

    Efficiency gain = current machine efficiency – designed V-profile machine efficiency

(2) External lost time- this indicator shows the impact on the packaging beer line of external factors such as meetings, lunch breaks and supply failures from outside the production time due to manufacturing problems.

External lost time indicator $= \dfrac{Potential\ production\ time - external\ lost\ time}{Potential\ production\ time}$

External lost time indicator $= \dfrac{Potential\ run\ time}{Potential\ production\ time}$

$$\text{Machine downtime} = \frac{\text{Potential production time} - \text{Downtime}}{\text{Potential production time}} = \frac{\text{Run time}}{\text{Potential production time}}$$

$$\text{Reduced speed indicator} = \frac{\text{Average line speed}}{\text{Designed line speed}} = \frac{\text{Quantity produced}}{\text{Designed line speed x Run time}}$$

But since run time excludes external lost time and downtime, then

$$\text{Run time} = \frac{\text{Potential production time} - \text{external lost time} - \text{downtime}}{\text{Potential production time}}$$

3.4.2 Optimizing packaging beer line using lean manufacturing tools.

Machine parameters states, that is to say, failure behavior, machine efficiency and machine production rates were tested. An important tool in controlling the packaging line machines is to check if the configured machine speeds correspond with the V-profile desired machine speeds. Often machine speeds are shifted down when frequent failures occur to necessitate continuous slow run than total line stoppage; or this create a more even flow. However, from a line efficiency point of view this may not be desired.

Secondly, designing a new preventive maintenance model involving maintenance team, packaging management and production process teams to start executing the best preventive maintenance methods at all levels to reduce or eliminate machine failures, poor quality products and guarantying continuous production (machine availability, good quality and high performance) during production process.

3.5 Data analysis

Data were analysed using graphs, tables and fishbone analysis to establish failure modes and effect analysis to establish the root cause of machine failures. Data was edited for errors and misinterpretations to ensure accuracy, uniformity, completeness and consistency.
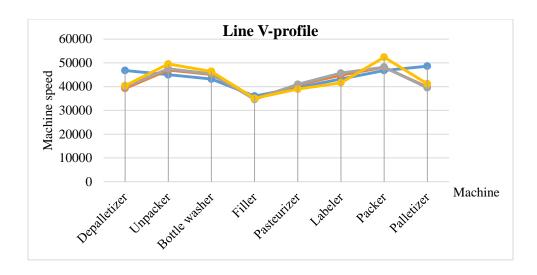
Figure 3. 1 : Example of a graph used to analyze data

The V-graph generated after capability study is used as a measure to check whether the packaging line is still running at the designed V-graph during installation.

Man

Method

Machine
-worn top guide
-misaligned bottom guide
-misaligned suspension shafts frame
-by passed over load sensor
-missing bolt securing plates
-malfunctioning overload sensor

Suspension shaft securing bolt got broken.

Measureme

Material
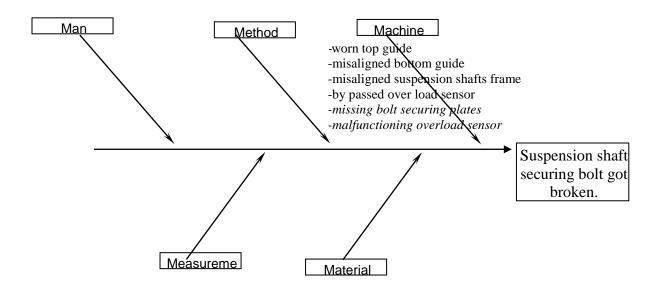
Figure 3. 2 : Example of fishbone diagram applied on depalletizer broken bolt

Fishbone is the most common root cause analysis tool used by shop flow staff to establish root cause of any problem and do action log from the investigation to solve the problem.

Table 3.1 : Summary of all the details on how this research were conducted

Specific objective	Methodology design	Procedure	Expected findings
Identifying bottlenecks on packaging beer line one.	Observation following observation guidelines	Participatory observation by taking measurements through capability study.	Identifying bottleneck machines on packaging beer line one
	Review records	Reviewing available literature on packaging beer line performances (breakdowns).	The common bottlenecks that affects packaging beer line efficiencies.
Determining the efficiency losses caused by bottlenecks	Data analyzing tools(graphs, tables & fishbone)	Use excel sheets to compare and contrast data.	Bottleneck machines on beer line that affects line performance and efficiency
Optimizing packaging beer line using lean manufacturing tools	Applying line balancing, total productive maintenance and best preventive maintenance model	Implementation of lean manufacturing tools to eliminate wastes	Improved line performance and reduced/ no unplanned stoppages (breakdowns) on packaging beer line.

CHAPTER FOUR

PRESENTATION AND DISCUSSION OF RESULTS

This chapter presents findings and discussions of the findings that were discovered during data collection on the study of optimization of packaging operations for beer production line efficiency at Nile Breweries Limited packaging beer line one Jinja plant. These are presented by first identifying bottleneck machines, determining efficiency loss caused by bottlenecks and lean manufacturing tools and practices which are not fully utilized to improve line efficiency. Describes various methods used during efficiency analysis based on process data collected, the efficiency analysis serves to transform the process data into information on efficiency loss by representing data in graphs. The interpretation of graphs is based on history of the packaging beer line performance.

4.1 Identifying bottleneck machines on packaging beer line 1

In identifying bottlenecks that affects efficiencies during production process of packaging beer line 1, beer line capability study was carried out on individual machines, and machine performance records for the last three years (January 2015 to January 2018) were retrieved from COSWIN.

 Note: Coswin is a maintenance planning and scheduling software used to keep and track maintenance records, machine failure records (downtime per machine) when to maintain and which spare is required for each job.

4.1.1 Beer line capability study

During data collection, the following data was collected through capability study to identify bottleneck areas on beer line resulting to poor performance and low efficiencies during production. Tools used include stop watch, pen and data sheet. The study were four hours (**14400 seconds).** Below are the findings per machine on packaging beer line in relation to V-profile. Calculations used to generate data table are presented in appendix 4.

 V-profile line speed (filler capacity) = 36000 bph

1. **Depalletizer**

Table 4.1 : Time taken to palletize one pallet

Pallet	1st	2nd	3rd	Average time
Watched time (Seconds)	130	127	131	129

Pallet = 54 x 25 = 1350 bottles

Current Machine speed = $\frac{3600 \; x \; 1350}{129}$ = 37674 bph

V-profile machine speed = 46800 bph

V-profile efficiency = 135%

Current machine efficiency = $\frac{37674}{46800}$ x 135 = 109%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 2014 seconds (30:34 minutes)
   a. Machine head-jams
   b. Pallet jams
   c. Crates dropping on table
2. Upstream and downstream stoppages = 1326 seconds (22.6 minutes)
   a. Crate build back
   b. Stuck pallet

2. **Unpacker**

Table 4. 2 : Unpacker time taken to complete 10 revolutions

10 revolutions	1st	2nd	3rd	Average time
Watched time (seconds)	132	130	133	132

Each revolution = 7 x 25 = 175 bottles

10 revolutions = 175 x 10 = 1750 bottle

V-profile machine speed = 45000 bph

Current machine speed = $\frac{3600 \; x \; 1750}{132}$ = 47727 bph

V-profile efficiency = 130%

Current machine efficiency = $\frac{47727}{45000}$ x130 = 138%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 1140 seconds (19 minutes)
   a. Crate stopper failure
   b. Bottle transfer plate went out of position
2. Upstream stoppages = 1988 seconds (33.13 minutes)
   a. Lack of crates at infeed
3. Downstream stoppages = 1211 seconds (20.18 minutes)
   a. Bottle build back discharge

3. **Bottle washer**

Time taken for 10 bottle dumps

Table 4. 3 : Time taken for Bottle washer to complete 10 bottle dumps

10 bottle dumps	1st	2nd	3rd	Average time
Watched time (seconds)	35	36	35	35

Each dump = 43 bottles

10 dumps = 430 bottles

Current machine speed $= \frac{3600 \; x \; 430}{35} = 44229$ bph

V-profile machine speed = 43200 bph

V-profile efficiency = 120%

Current machine efficiency $= \frac{44229}{43200}$ x 120 = 123%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 479 seconds (8 minutes)
    a. Infeed light barrier
    b. Infeed bottle jams
2. Upstream stoppages = 1258 seconds (21 minutes)
    a. Lack of bottles
3. Downstream stoppages = 565 seconds (9 minutes)
    a. Bottle build back
4. **Filler**

Table 4.4 : Time taken to run one complete revolution

One revolution	1st	2nd	3rd	Average time
Watched time (seconds)	9.3	9.4	9.2	9.3

Each round = 90 bottles

Machine speed $= \frac{3600 \; x \; 90}{9.3} = 34839$ bph

V-profile speed = 36000 bph

V-profile machine efficiency = 100%

Machine efficiency $= \frac{34839}{36000}$ x100 = 96.8%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 505 seconds (8.4 minutes)
    a. Discharge star wheel breaking bottles
    b. Crown jams
2. Upstream stoppages = 1306 seconds (22 minutes)
    a. Fallen bottles at infeed
    b. Lack of bottles
3. Downstream stoppages = 645 seconds (11 minutes)
    a. Bottle build back

5. **Pasteurizer**

Table 4.5 : Time taken to complete one dump of bottles

Round of bottles	1st	2nd	3rd	Average time
Watched time (seconds)	12.1	12.4	13	12.5

Dump for each deck = 69 bottles

Dumps for both (top & bottom) decks = 138 bottles

Pasteurizer speed $= \frac{3600 \, x \, 138}{12.5} = 39744$ bph

V-profile machine speed = 39600 bph

V-profile machine efficiency = 110%

Current Machine efficiency $= \frac{39744}{39600}$ x110 = 110.4%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 120 seconds (2 minutes)
    a. Bottle jams inside machine

2. Upstream stoppages = 1380 seconds (23 minutes)

    a. Lack of bottles

3. Downstream stoppages = 360 seconds (6 minutes)

    a. Bottle build back

6. Labelers

There two labelers (Solomatic and Prontomatic)

    i.   Solomatic labeler

Table 4.6 : Time taken to complete 8 rounds of bottles

8 Round of bottles	1st	2nd	3rd	Average time
Watched time (seconds)	34	33	36	34

Each round = 30 bottles

8 rounds = 30 x 8 = 240 bottles

Solomatic machine speed $= \frac{3600 \, x \, 240}{34} = 25412$ bph

V-profile machine speed = 25000 bph

V-profile machine Efficiency = 120 %

Current Machine efficiency $= \frac{25412}{25000}$ x 120 = 122%

Captured issues during capability study include the following;

1. Inherent issues (internal machine failures) = 28 seconds

    a. Broken bottle at infeed worn

2. Upstream stoppages = 1262 seconds (21 minutes)

    a. Lack of bottles

3. Downstream stoppages = 296 seconds (5 minutes)

   a. Bottle build back

  ii. Prontomatic labeler

Time taken to run 8 round of bottles

Table 4.7 : Time taken to complete 8 rounds of bottles

8 Round of bottles	1st	2nd	3rd	Average time
Watched time (seconds)	27	27	28	26

One complete round = 18 bottles

8 complete rounds = 8 x 18 = 144 bottles

Machine speed $= \frac{3600 \; x \; 144}{26} = 19200$ bph

V-profile machine speed = 18000 bph

V-profile machine Efficiency = 120 %

Current Machine efficiency $= \frac{19200}{18000}$ x 120 = 128%

Captured issues during capability study include the following;

  1. Inherent issues (internal machine failures) = 0 seconds
  2. Upstream stoppages 1262 seconds (21 minutes)
   a. Lack of bottles
   b. Uncrowned bottles
  3. Downstream stoppages = 152 seconds (2.5)
   a. Bottle build back

Both labelers

V-profile labeler speed = 43200 bph

V-profile machine efficiency = 120 %

Machine speed = 25412 + 19200 = 44612 bph

Machine efficiency = $\frac{122+128}{2}$ = 125%

7. Packer machine

Time taken to packer 10 rounds

Table 4.8 : Packer time taken to complete 10 revolutions

Packer 10 revolutions	1st	2nd	3rd	Average time
Watched time (seconds)	95	92	93	93

Each revolution = 5 x 25 = 125 bottles

10 revolutions = 125 x 10 = 1250 bottle

V-profile machine speed = 45000 bph

Current machine speed = $\frac{3600 \ x \ 1250}{93}$ = 48387 bph

V-profile efficiency = 130%

Current machine efficiency = $\frac{48387}{45000}$ x130 = 139%

Captured issues during capability study include the following;

      1. Inherent issues (internal machine failures) = 898 seconds (15 minutes)

          a. Packer head jams

        b.   Fallen bottles inside machine

   2. Upstream stoppages = 1505 seconds (25 minutes)

        a.   Lack of bottles

   3. Downstream stoppages = 1619 seconds (27 minutes)

        a.   Bottle build back discharge

8. Palletizer

Table 4.9 : Time taken to palletize one pallet

Pallet	1st	2nd	3rd	Average time
Watched time (Seconds)	114	120	118	117

Pallet = 54 x 25 = 1350 bottles

Current Machine speed = $\frac{3600 \ x \ 1350}{117}$ = 41538 bph

V-profile machine speed = 46800 bph

V-profile efficiency = 135%

Current machine efficiency = $\frac{41538}{46800}$ x 135 = 120%

Captured issues during capability study include the following;

   1. Inherent issues (internal machine failures) = 2160 seconds (36 minutes)

        a.   Machine head-jams

        b.   Pallet chain slipping

        c.   Pallet jams on track 5

   2. Upstream stoppages = 0 seconds

   3. Downstream stoppages = 1858 seconds (31 minutes)

        a.   Pallet build back

Table 4.10 : Summary of capability study calculated results of machines speed & efficiencies

Machines	V-profile machines speed (bph)	Current machine speed (bph)	V-profile machine efficiencies (%)	Current machine speed (%)
Depalletizer	46800	37674	135	109
Unpacker	45000	47727	130	138
Bottle washer	43200	44229	120	123
Filler	36000	34839	100	96.8
Pasteurizer	39600	39744	110	110.4
Labeler	43200	44612	120	125
Packer	45000	48387	130	139
Palletizer	46800	41538	135	120
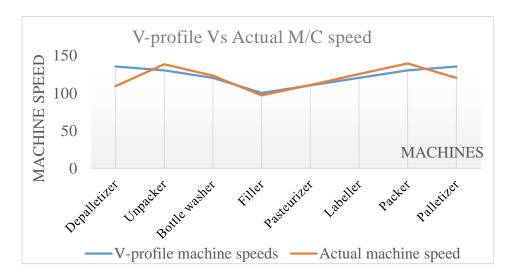
Figure 4.1 : A graph of V-profile vs actual machine speeds

Table 4.11 : Summary of machine stoppages (minutes) captured during 4hr capability study

Machine	Stoppages			
	Upstream (mins)	Inherent (mins)	Downstream (mins)	Time (mins)
Depalletizer	22.6	30.34	0	52.92
Unpacker	33.13	19	20.18	72.31
Bottle washer	21	8	9	38
Filler	22	8.4	11	41.4
Pasteurizer	23	2	6	31
Labelers	25	21	3.8	49.8
Packer	25	15	27	67
Palletizer	0	36	31	67
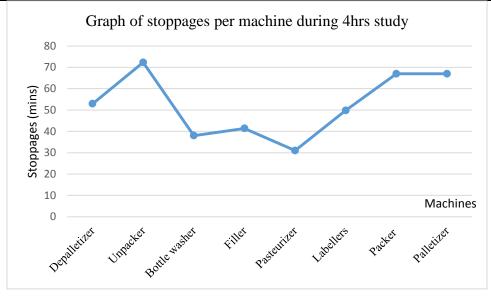
Figure 4. 2 : Graph of stoppages per machine during 4hrs study

4.1.2 Depalletizer and palletizer machines downtime for last three years

By reviewing available records on depalletizer and palletizer machine failures for the last three years since 01st January 2015 to 31st December 2017 are given below.

Table 4.12 : Depalletizer downtime for the last three years in hours

Depalletizer Machine			
Month	**Downtime (hrs)**		
Year	**2015**	**2016**	**2017**
Jan	0.92	0.88	0.53
Feb	0	6.79	1.47
March	0.73	0.95	0.35
April	0.75	0.75	5.19
May	1.58	0	4.3
June	0.58	0.17	2.74
July	0.3	0	2.05
Aug	0	0	11.07
Sep	0.6	0	1.93
Oct	0.17	1.83	8.39
Nov	2.63	0.85	2.61
Dec	2.78	0.59	2.81
Total downtime	11.04	12.81	43.44
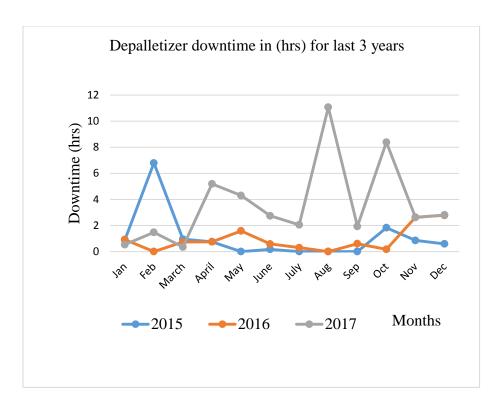
Figure 4. 3 : A graph of depalletizer downtime per month for three years in hours

Table 4.13 : Palletizer downtime for the last three years in hours

Palletizer Machine			
Month	Downtime (hrs)		
Year	2015	2016	2017
Jan	0.9	0.8	0.4
Feb	0.12	0.31	0.71
March	1.2	0.81	1.1
April	0.59	1.12	1.59
May	0.87	1.41	0.87
June	0.41	1.9	1
July	0.4	0.98	1.04
Aug	0.21	1.33	0
Sep	0.2	1.9	0.2
Oct	1.49	2.8	4.49
Nov	0.78	0.9	2.31
Dec	0.9	1.3	3.2
Total downtime	8.07	15.56	16.91
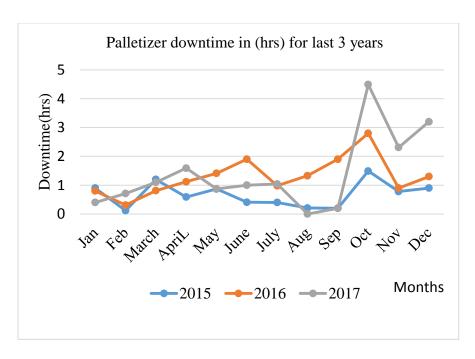
Figure 4. 4 : A graph of palletizer downtime per month for three years in hours

Table 4.14: Top three most repeated downtime (hrs) on depalletizer and palletizer machines

Machine	Issues
Palletizer	- Frequent head jams - Pallet track failures - Machine lost sequence
Depalletizer	-Pallet track failures -Head jams - Gripper failure

4.1.3 Bottleneck machines and root causes

The bottleneck machines are depalletizer and palletizer as presented above from records. This is because depalletizer and palletizer are running below the V-profile speed, hence depalletizer

creates a lot of gaps to the following machines while palletizer builds-back increasing waiting time for machines supplying palletizer, e.g packer and labelers.

4.1.3.1 Depalletizer

Depalletizer machine removes empty bottle crates from pallets to conveyors at a predetermined speed of beer line V-profile to avoid crate starvation at discharge or pallet accumulation at infeed. From table 4.10, depalletizer is running at speed of 37674 bph (bottles per hour) which is much lower than V-profile speed of 46800 bph with a difference of 9126 bph. Hence, depalletizer machine efficiency dropped from 135 % to 109% which directly contributes to general beer line poor performance and efficiency drop. During four hour capability study, depalletizer lost 0.6 hrs (2014 seconds) due to inherent machine stoppages causing the following machines to lack bottles up to the critical machine (filler) hence, ending up affecting general line performance and efficiency. Further investigation were carried out to establish depalletizer machine performance for the last three years, and it was identified that annual downtime went on increasing from 11.4hrs in 2015 to 12.81hrs in 2016 and 43,44hrs in 2017 respectively. Table 5.1 below shows depalletizer downtime financial impact after converting downtime into beer in htls and then into money in Uganda shillings.

Table 4.15 : Depalletizer downtime financial impact

Year	Downtime(hrs)	Missed volume(hl)	Money (UGX)	Money (USD)
2015	11.4	2052	820,800,000	221,837.837
2016	12.81	2305.8	922,320,000	249,275.675
2017	43.44	7819.2	3,127,680,000	845,318.918

4.1.3.2 Palletizer

Palletizer machine palletizes full bottles crates to pallets at a predetermined speed of beer line V-profile to avoid crate accumulation at infeed or pallet accumulation in the palletizing zone respectively. Currently palletizer is running at speed of 41538 bph which is much lower than V-profile speed of 46800 bph with a difference of 5262 bph. Hence, palletizer machine efficiency
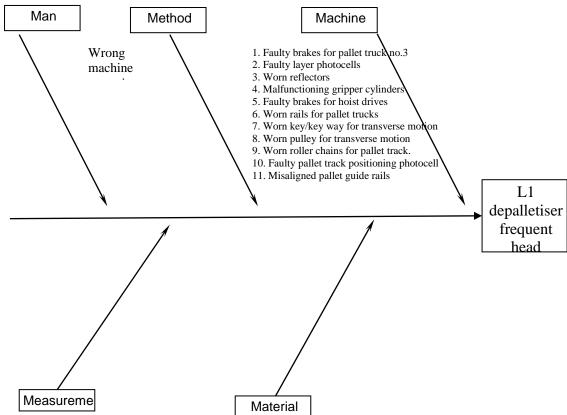
dropped from 135 % to 120%, efficiency difference of 15% which directly contributes to general beer line poor performance and efficiency drop. During four hour capability study, palletizer lost 0.6 hrs (2160 seconds) due to inherent machine stoppages causing full beer crate build-back at machine infeed conveyors, increasing waiting time for machines feeding palletizer, e.g packer and labelers, affecting general line performance and efficiency drop. Further investigation were carried out by reviewing available beer line performance records for the last three years from January 2015 to went January 2018 to establish palletizer machine performance, identified that annual palletizer downtime went on increasing from 0.87hrs in 2015 to 15.5hrs in 2016 and 16.91hrs in 2017 respectively. Table 5.2 below shows palletizer downtime financial impact after converting downtime into beer in hls and then into money in Uganda shillings.

Table 4.16 : Palletizer downtime financial impact

Year	Downtime(hrs)	Missed volume(hl)	Money (UGX)	Money (USD)
2015	8.07	1,452.6	581,040,000	157,037.837
2016	15.56	2,800.8	1,120,320,000	302,789.189
2017	16.91	3,043.8	1,217,520,000	329,059.459

4.1.4 Analyzing depalletizer and palletizer top most failure causes

The other issues causing machine failures during production process are further discussed, the probable root cause and prevention measures are analysed in the table below using fishbone analysis.

Example of fishbone cause and effect analysis of depalletizer frequent head crushes

Figure 4.5 : fishbone cause and effect analysis of depalletizer frequent head crushes

Table 4.17 : Failure root causes and prevention measures using fishbone analysis

Machine	Problem	Cause	Root Cause	Preventive measures
Palletizer	Frequent head jams	Misaligned head sensors and reflectors	Daily ATM tasks not done	Develop ATM schedule to ensure daily cleaning and inspection of all sensors.
	Pallet track failures	Accelerated wear of track chains	Track chains running dry.	Develop daily ATM schedule to ensure lubrication and cleaning of track chains.
			Accumulated dirt and foreign materials	
	Machine lost sequence	Malfunctioning head sensors	Daily ATM tasks not done	Develop ATM schedule to ensure daily cleaning and inspection of all sensors.
Depalletizer	Pallet track failures	Accelerated wear of track chains	Track chains running dry.	Develop daily ATM schedule to ensure lubrication and cleaning of track chains.
			Accumulated dirt and foreign materials	
	Frequent head jams	Misaligned head sensors and reflectors	Daily ATM tasks not done	Develop ATM schedule to ensure daily cleaning and inspection of all sensors.

These failures have caused packaging department and Nile Breweries Limited at large a huge loss of money. Efficiency losses caused by bottlenecks as indicated in tables 5.1 & 5.2 respectively. Generally, depalletizer and palletizer machine failures are a sign of lacking maintenance practices forexample, autonomous and predictive (condition monitoring) on the two equipment.

It's further seen in table 4.2 that during capability study of 4hrs, unpacker machine had the longest stoppage time of 72.31 minutes mostly waiting for crates full of empty bottles from

depalletizer which was running below its V-profile speed with a production speed loss of 9126 bottles per hour as depicted in table 4.1 causing gaps at unpacker infeed These stoppages further affect the following machine up to the critical machine (filler) causing line stoppage resulting to poor performance and lower line efficiencies.

Palletizer and packer machine are following machines with the highest stoppage time of 67 minutes. Packer stoppage time is the same as palletizer stoppage time because of palletizer is running below its V-profile with a production speed loss of 5262 bottles per hour and efficiency loss of 15%. Poor maintenance practices, using unskilled manpower to operate machines, are some of the core reasons as to why packaging beer line 1 performance has deteriorated resulting to poor efficiencies as depicted in table 5.3 and appendix v.

This trend can only be solved to achieve continuous production run after carrying out line balancing, allocating technical operators on critical machines to facilitate proper autonomous and total productive maintenance to detect machine failures before they happen. This will enable packaging beer line 1 to achieve daily production targeted volume of 330htls or above 83% beer line efficiency. Hence continuous supply of beer to market increasing sales, profits and more taxes to government fostering country wide development. This also creates more employment opportunities.

4.2 Efficiency losses caused by bottlenecks

Packaging beer line 1 efficiency is below the desired efficiency according to the capability study machine speeds. Attached below is a table of recommended V-profile machine efficiency versus current machine efficiency.

Table 4.18 : Efficiency losses caused by bottlenecks

Machines	V-profile machine efficiencies (±2%)	Current line machines efficiency (%)	Efficiency losses (%)
Depalletizer	135	109	-26
Unpacker	130	138	+8
Bottle washer	120	123	+3
Filler	100	96.8	-3.2
Pasteurizer	110	110.4	+0.4
Labeler	120	125	+5
Packer	130	139	+9
Palletizer	135	120	-15
Total line efficiency	**980**	**961.2**	18.8%
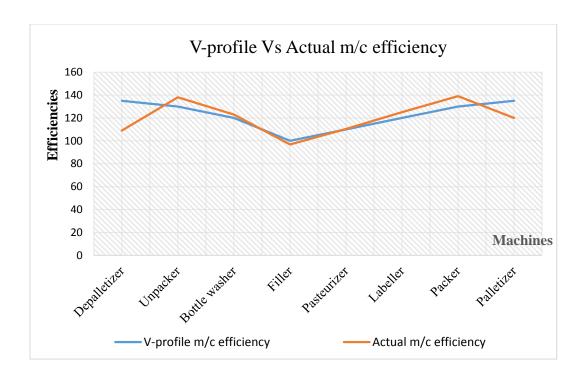
Figure 4.6 : A graph of V-profile Vs actual machine efficiency

Efficiency losses are evidently seen in table 4.2.1 and figure 4.2.1. Depalletizer and palletizer machines are running at efficiencies of 26% and 15% respectively much lower than the desired beer line V-profile efficiencies, hence both machine efficiencies slows down production beer line one speed affecting the overall line efficiency.

4.2.1 Depalletizer

Machine speed loss = (46800 − 37674) bph = 9126 bph

Efficiency loss = (135 − 109) % = 26%

4.2.2 Palletizer

Machine speed loss = (46800 − 41538) bph = 5262 bph

Efficiency loss = (135 − 120) % = 15%

4.3 Lean manufacturing observed but not fully in practice

Through observation during data collection, the following lean tools were observed and they are currently not fully utilized to improve packaging beer line 1 machine performance. These lean tools include the following;

I. Root cause analysis tool e.g 5-Why as a problem solving tool used during machine failure to establish the root cause, but the process operators lacks knowledge using the tool correctly, they don't use all the 5-Why`s to clearly establish the root cause.

II. Standardized work as most job cards/ worker orders for machine inspection or maintenance does not include instructions to guide the execution process and tools to be used during task execution. Poor planning and no baseline instructions to execute a task hence, some jobs end up not fully attended to as it would have been if all tools and guidelines were included on the job card.

III. Visual factory is lacking as visual indictors, displays and controls used on production beer line are not distributed in key areas of the beer line to improve on communication of production information to all operators at their respective work stations. These visual displays and controls are seen at only filler machine making it difficult for other operators access any slight change in production plans.

IV. High setup time, as seen in appendix 4, during brand changes, time taken to change from one brand to another brand and attain full production speed is high for the last one year due to many fine tunings done. This is mostly attributed to unskilled and non-appointed staff with less accountability as in appendix 5, resulting to production time loss and poor quality products.

V. Work standardization not fully in place as there some operations that do not have standard work instructions (SWI) like for repetitive jobs e.g lubrication and standard operating practices (SOP) for jobs that are done once in a while e.g replacing vertical label extraction belt at bottle washer. Also maintenance work orders are not fully enriched with full information to execute maintenance jobs as seen in appendix 2.

VI. Maintenance practices in place not fully utilized as it's evidently seen with a number of repetitive big breakdowns on different machines on packaging beer line. 60% of the work

orders observed for the last five month has missing work instructions and does not bear detailed feedback, appendix 2.

VII. Visual display and control systems not fully in place for quick recognition of production information being communicated and those few available are not strategically placed in areas where they are most importantly needed.

VIII. 5s still lacking as it's not visually fully seen on line. Some items on the line have no home, not labelled, etc resulting to a lot of wastes during production. Improved 5S visual workplace is a tool that assures the continuous improvement by improving the cleaning performance. 5S steps are sorting (to eliminate useless items), shining (to keep workplace clean), setting in order (to keep everything in place), standardizing and sustaining (to assure continuity).

IX. Gemba not at its best most maintenance team members spend most of the time in meetings and less time on production line that makes it difficult sometimes to establish root cause of a failure.

During the study, it was seen that bottleneck machines (depalletizer and palletirser) are running below desired V-profile efficiencies. Other machines like unpacker, bottle washer and packer are running at efficiencies extremely higher than desired V-profile individual machine efficiencies.

4.3.1 Adjusting machine speed to recommended V-profile speed

To restore individual machine efficiencies, must put packaging beer line design into consideration before carrying out line balancing (Stewart, 2018). The following are steps taken to optimize low speed packaging beer line machines back to desired line designed V-profile curve to improve on individual machine speeds and efficiencies (Catherine, 2015). The theoretical steps carrying out production line balancing include;

1. **Requirements**
   (1) Qualified maintenance personnel to do in-depth preferably instrumentation personnel capable of adjusting system speed machine main drive parameters.
   (2) Stop watch
   (3) Data gathering worksheet

2. **Procedure**

    (1) Select one bottleneck machine at a time, note its current machine speed from variable speed detector (VSD) or human interface (HMI0

    (2) Note the current machine main drive speed from variable speed detector (VSD).

    (3) Adjust the machine speed to reduce time taken to complete a full revolution while increasing machine speed.

    (4) Record the parameter readings.

    (5) Do machine watching, and calculate machine speed and efficiency while in comparison with the desired machine speed and efficiency using formula

    a. Machine speed= ($\dfrac{Number\ of\ bottles\ per\ revolution\ X\ \left(\frac{t_1+\ t_2+\ t_3}{3}\right)}{60\ X\ 60}$) Bottles per hour

    b. Machine efficiency = ($\dfrac{Calculated\ machine\ speed}{V-profile\ machine\ speed}$ X 100) %

    (6) Repeat step (3) up to (5) until the desired machine speed is attained.

    (7) Lock the new VSD parameters to avoid further adjustments, document and populate to all levels.

4.3.2 Adopt new maintenance practices
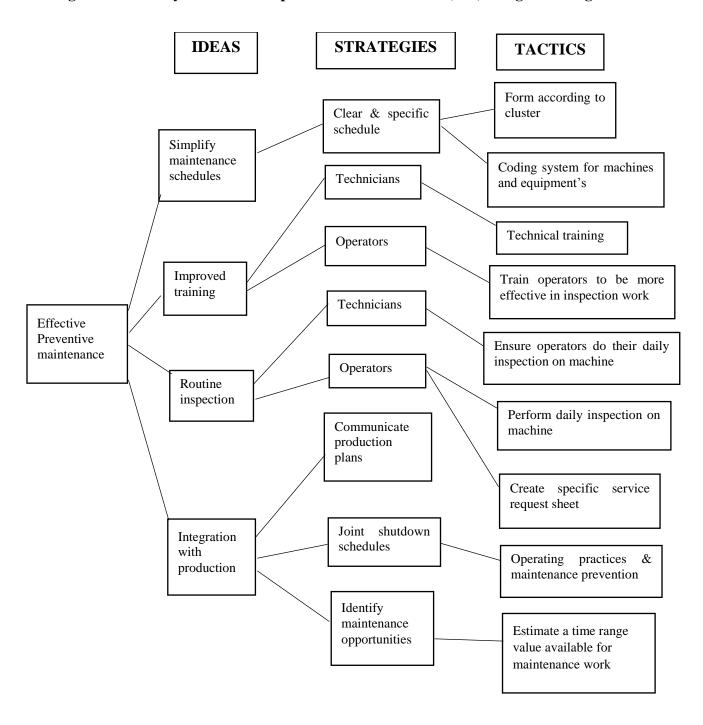
As already seen by a number of machine failures during production time, new maintenance practices must be adopted to guarantee machine availability during production process (Zhu, 2015). The type maintenance system should be able to predict any failure before it happens, when to replace a component of a machine and regular inspection and cleaning of the equipment. The best type of maintenance to be employed is preventive maintenance (periodic servicing of equipment's) and total productive maintenance (TPM) which involves all employees at all levels of the organization, effective utilization of all resources and keeping man-machine-material system in optimum condition. This is achieved in the preventive maintenance model.

4.3.2.1 Preventive maintenance model

The main problem faced in this case study is the downtime still occurs even though after maintenance activities are carried out. Therefore, the available schedule of preventive

maintenance (PM) needs to be simplified to improve on machine availability during production. Based on data gathered, the pattern of the failures based on the previous three years downtime, more attention is needed on critical downtime machines in the cluster. This should help to reduce downtime from recurring in packaging beer line machines. Below is the best preventive maintenance model (PM model) based on the collected data in achieving effective preventive maintenance in a company.

Strategies and tactics are evaluated from the proposed ideas in implementing effective preventive maintenance. The main ideas generated for this preventive maintenance model is to have simple maintenance schedule, do training for technicians and operators in maintaining machines to be in good conditions, do routine inspections and also integrations with production. In terms of integrating with productions, packaging maintenance team must integrate with production teams in doing preventive maintenance periodically. Maintenance planner should communicate with production team leaders to stop operations for a while to do preventive maintenance and joint shutdown schedule. By doing this, machine can be maintained without or with less breakdown. Operators will learn during the process how to repair their machines, not only to depend on machine specialists or technicians.

Figure 4.7 : Analysis of effective preventive maintenance (PM) using Tree diagram

IDEAS	STRATEGIES	TACTICS

Effective Preventive maintenance

Simplify maintenance schedules

Improved training

Routine inspection

Integration with production

Clear & specific schedule

Technicians

Operators

Technicians

Operators

Communicate production plans

Joint shutdown schedules

Identify maintenance opportunities

Form according to cluster

Coding system for machines and equipment's

Technical training

Train operators to be more effective in inspection work

Ensure operators do their daily inspection on machine

Perform daily inspection on machine

Create specific service request sheet

Operating practices & maintenance prevention

Estimate a time range value available for maintenance work

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

During the study of optimization of packaging operations for beer line efficiency, below is the summary, conclusions in relation to objectives and recommendations.

5.1 Summary

Packaging beer lines are challenged with many wastes that affects beer line general performance and line efficiency. This wastes are attributed to performance losses, availability losses and quality losses. From research findings, depalletizer and palletizer machines are identified as bottleneck machines with total downtime of 67.65hrs and 40.54 hrs respectively, and efficiency drop from 135% to 109 109 and 120% respectively. Depalletizer and palletizer individual machine production dropped by 9126 bph and 5262 bph respectively contributing to individual machine efficiency of 26% and 15% respectively and general line efficiency loss of 18.8 %. Generally, packaging beer line 1 is out of V-profile as seen in fig 4.1.1, with general line factory efficiency loss of 18.8% and lean manufacturing tools not fully utilized resulting to poor line performance and efficiency drop.

5.2 Conclusion

Study of optimization of packaging operations for beer production line efficiency at Nile Breweries Limited packaging beer line one Jinja plant, the following are the conclusions as per the objectives.

Depalletizer and palletizer machines were identified as bottleneck machines on packaging beer line 1 at Nile Breweries Limited with total downtime of 67.65hrs and 40.54hrs respectively, and efficiency drop from 135% to 109% and 120% respectively.

In determining the efficiency loss caused by bottlenecks, depalletizer and palletizer machines speeds dropped by 9126 bph and 5262 bottles per hour respectively contributing to individual machine efficiency drop by 26% and 15 % respectively and general packaging beer line factory efficiency loss of 16.1%.

Some of lean manufacturing tools like 5S, Visual factory, Plan Do Check Act (PDCA), etc, are employed on beer line but not fully utilized, making problem solving difficult hence, resulting to poor line performance and efficiency drop.

In general, packaging beer line 1 is out of V-profile, general line efficiency loss of 16.1% and lean manufacturing tools not fully utilized to improve efficiency. Through packaging beer line 1 balancing back to design V-profile, allocation of technical operators on machines, application of total productive maintenance, condition based maintenance and new preventive maintenance model will completely eliminate frequent machine failures during production process hence completely eliminating depalletizer 26%, palletizer 15%, and general line 18.8 % efficiency availability losses. Hence contributing to packaging beer line 1 machine availability and reliability, high line performance, factory efficiency above 83.25%, and gain in profits of USD 1,174,378.377 by January 2018.

5.3 Recommendations

The following recommendations are the result of research carried out at Nile Breweries Limited, packaging department on packaging beer line 1. The study examined optimization of packaging operations for beer production line efficiency through lean manufacturing. This was evaluated through capability study, available data.

Each production person should be part of a Kaizen event not only to learn the tools of lean manufacturing but also to provide their input and expertise to the area in which they work. This will help all production personnel understand the concepts of lean and recognize areas of waste that can be eliminated through continuous improvement. This will create an enthusiastic environment as the Company continues down the path of eliminating any waste that is found on packaging beer line to improve line efficiency.

Continuous improvement needs to be a mindset within packaging department staff to improve packaging beer line efficiency. Each individual on beer line needs to recognize that each lean event is a small step towards a large goal of improving packaging beer line efficiency.

Implement packaging beer line V-profile to ensure streamlined flow right from depalletizer to palletizer, hence stopping machine suffocation, unbalanced machine and conveyor speeds which increase inefficiency. This calls for line balancing as per manufacturer's machine speeds.

Machines that do not need too much attention like crate washer, pasteurizer and those that can be merged should be relocated to provide ample space and operator support so that other areas ensure continuity during process.

Proper implementation of root cause analysis tools on all levels of packaging section, e.g 5-Why problem solving tool for process teams to establish machine failure root causes, abnormality reports (ABR) or final failure reports (FFA) for technicians and lower level management and profit improvement projects (PIP`s) problem solving tools for middle and top management to improve on equipment performances. This should be followed by trainings and refreshers after a given period of time to ensure quality usage of these problem solving tools to address machine performances. 85% of machine failures can be resolved with the application of basic root cause analysis techniques such as 5-Why, as long as it is applied within a suitable framework.

Standardizing job cards by enriching work orders with instructions/guidelines, procedures, pictures and tools required to execute a given job. This will make machine inspection or maintenance jobs easier even to new employees, good planning before maintenance to save time and abrupt departure of any employ will not affect performance.

Improvement on visual factory at all work stations on packaging beer line to populate performance indicators, displays and controls used on production beer line. This will also improve communication of production information to all operators at their respective work stations about any change in plan to reduce on defects and wastes.

Introduction of basic maintenance practices like total productive maintenance, autonomous maintenance, conditions monitoring and preventive maintenance. Train process and maintenance team on how to implement, benefits and involve top management to ensure smooth implementation to improve on machine availability and reliability. The reason is to introduce effective operator cleaning and maintenance, and how operator ownership can play a key role in the life extension of our assets

Visualization of inefficiencies for operators. At the moment every machine has its own bacon light that visualizes the machine state. Nevertheless, not everything is visualized. For example, when on the bottle washer a couple of fallen bottles block the entrance, no light is shown. Sometimes these fallen bottles cause a machine infeed jams and stoppage. Therefore an operator should know if fallen bottles are present at the entrance of the bottle washer. This can be done with another light/ sensors for fallen bottles at infeed conveyor feeding every machine in order to prevent machine shot stops.

Implementation of Gemba in packaging section. This is where maintenance teams, lower level and middle level managers will spend most of their working time on production beer line process and less time in offices or meetings. Gemba involves everybody at all levels on line performance and as result will improve on performances, machine availability and good quality product.

General improvement on 5s to ensure proper workplace organization, cleanness, order and discipline in work areas. 5s necessitates defect identification and reduces on wastes. Good 5s makes employees to be proud of the workplace, work more efficient, increase productivity, reduce waste and cost, maintain quality standards, identify problem area and make improvement and make workplace safe.

Recruit, train and allocate technical operators to critical machines that are currently being operated by support non appointed staff (casuals) to improve on machine ownership and accountability. Technical operators owns and takes accountability of the machine his operating carrying out autonomous maintenance, do quick fixes, predict probable failures and the same time ensures good quality products are produced at machine discharge.

In general, restore packaging beer line 1 V-profile through beer line balancing, implement unified theory of lean manufacturing tools and adopt new preventive maintenance model.

5.4 Suggestions for further study

This research covered mainly machine availability losses on packaging beer line1, for further studies, work measurement and assembly line balancing should be carried out to establish other losses as practical line balancing was not done as indicated in limitations. Heuristic techniques

for production line balancing should also be used for further studies. Further investigation on performance losses and quality losses must be done in future to completely eliminate all wastes to improve on beer line machine performance and efficiencies.

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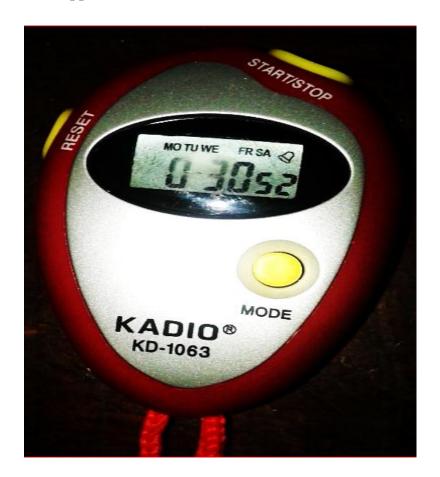
APPENDICES

Appendix i

EQUIPMENT DESCRIPTION	TOTAL DOWNTIME(HRS)	TOTAL COST (shs)
Palletizer	67.65	4,870,800,000
Depalletizer	40.54	2,918,880,000
Bottle washer KHS	33.97	1,087,040,000

Appendix **ii**

Appendix iii

Appendix iv

Other areas were a lot of time is lost is during brand change overs. It was observed that a lot of time is lost during brand changes due to setup time/ adjustments done by unskilled operators on packaging beer line one. In table below is the summary of average time taken to complete brand changes from one brand to another for the last one year.

Shifts	Standard time (seconds)	Brands			Average time per every brand change in a shift (seconds)
		ELX-ELO (seconds)	ELX-NLS (seconds)	ELX-CLUB (seconds)	
Neon	15	21	23	22	22
Trendsetters	15	25	27	26	26
Dream crushers	15	16	18	15	16

Manpower distribution and allocation on different machines in different shifts as it was observed during data collection. Some critical machines are being operated by casuals having no/less skills to operate machines leading to frequents machine stops, high setup times during brand changes, high response time in case of breakdown and poor quality products. Table below shows manpower distribution among packaging line one process teams.

Machines	Standard allocation	Manpower allocation in different shifts		
		Neon	**Trendsetters**	**Dream crushers**
Depalletizer	Operator	Operator	Casual	Casual
Unpacker	Operator	Casual	Operator	Casual
Crate washer	Process Operator	Casual	Casual	Casual
Bottle washer	Process Artisan	Operator	Operator	Process Artisan
Filler	Process Artisan	Process Artisan	Process Artisan	Process Artisan
Pasteurizer	Process Operator	Operator	Casual	Casual
Labelers	Process Artisan	Process Artisan	Process Artisan	Process Artisan
Packer	Process Artisan	Casual	Casual	Operator
Palletizer	Operator	Operator	Operator	Operator

Glossary

Actual run time - time the packaging line actually runs once external lost time and downtime have been subtracted.

Actual run time = Working period − External lost time − Downtime

Availability – it is a measure of the time an individual machine runs at capacity as a proportion of the time it could have run at capacity.

$$\text{Availability} = \frac{Time\ a\ machine\ actually\ ran\ at\ capacity}{Time\ a\ machine\ could\ have\ run\ at\ capacity}$$

$$\text{Availability} = \frac{Study\ time - build - Back\ time - Starvation\ time - Unkknown\ time - Inherent\ time}{Study\ time - Build - back\ time - Starvation\ time - Unknown\ time}$$

Build-back time – is an event when a machine runs below capacity, ie it stops or runs at slow speed, due to lack of space on the out-feed taking away product.

Capacity – is the best observed speed at which the machine can run.

Downtime indicator – is a key performance indicator for the line as a whole which shows the impact of stoppages within the line such as breakdowns, blockages and product changeovers.

$$\text{Downtime indicator} = \frac{Potential\ run\ time - Downtime}{Potential\ run\ time}$$

Effectiveness indicator – is a key performance indicator for the line as a whole, equal to net production divided by potential production.

Effective indicator = Downtime indicator x Reduced speed indicator x Quality indicator

Event study = is period during which all events on a machine that affect speed, output, quality, etc, are recorded and timed.

External lost time indicator – is a key performance indicator for the line as a whole that shows the impact of factors external to the line such as meetings, breaks and problems in processes outside the packaging line.

$$\text{External lost time} = \frac{\text{Working day} - \text{External ost time}}{\text{Working day}} = \frac{\text{Potential run time}}{\text{Working day}}$$

Inherent time – is an event when a machine runs below capacity, ie it stops or runs at slow speed, due to a problem local to the machine itself.

Key performance indicator – is a measurement over a representative period of the performance of the line as a whole. Usually expressed as a percentage.

Mean effective rate (MER) – is a measure of the real time performance of an individual machine

MER = Best observed speed x Availability

Net production – is a number of units coming off the end of the packaging line during normal operation which are within specification and saleable.

Potential production – is the total number of units the line could produce if it was producing at its design capacity for all the potential run time.

Potential run time – is the time that the packaging line could have run after external lost time is subtracted.

Potential run time = Working period – External lost time during that period

Quality indicator – is a key performance indicator for the line as a whole that shows the proportion of units coming off the packaging line during actual run time that are within specification and saleable.

$$\text{Quality indicator} = \frac{\text{Net production}}{\text{Net production} + \text{Rejects}}$$

Where

Rejects are the number of units rejected for quality reasons during run time, ie excluding unsalable units produced during downtime.

Reduced speed indicator – is a key performance indicator for the line as a whole that shows the impact on the line of instances when the line is working, but at reduced speed.

$$\text{Reduced speed indicator} = \frac{\text{Average line speed}}{\text{Line designed speed}} = \frac{(\text{Quantity produced/Runtime})}{\text{Line designed speed}}$$

$$\text{Reduced speed indicator} = \frac{\text{Quantity produced}}{\text{Line desired speed x Run time}}$$

Where

Run time excludes external lost time and downtime:

Run time = Working day – External lost time – Downtime

Starvation time – is an event when a machine stops or runs at slow speed because of a failure in the supply of materials to the machine.

Unknown time – is an event when a machine runs below capacity, ie it stops or runs at slow speed, but the reason is not known or not observed.