CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In today's highly competitive beer and beverage market, AB Brewery needs to stay ahead of its competitors. Heineken(2011) states that in competitive market more product brands will enter the market as customer demand is changing, volume of product demand is decreasing, new product is being introduced, fixed costs as well as variable costs are increasing, and customers expect the same service and quality at reduced price. Therefore, AB Breweries must strive for optimization and continuous improvement of her production system performance and maintenance strategies in order to maximize the utilization of existing production line capacities, reduce operational cost, reduce production wastages and improve on quality to stay ahead of competitors. The main goal is to optimize the efficiency of production lines so as to increase its existing production capacities currently underutilized. To achieve this, regulated lines and preventive maintenance strategy must be optimized and downtimes minimized to gain higher line performance and increased productivity, while maintaining quality to achieve production target and customers' satisfaction.

According to the study done by Subramaniam, Husin, Yusop and Hamidon (2007), the efficiency of industrial production lines is crucial as it results in an improved production and utilization of available resources. Manpower utilization and machine efficiency contribute to production line efficiencies. Management should be able to look for relevant machine data and/or production data and accurately interpret the data in order to identify the various faults at production level and take step to improve efficiency.

The current situation of production lines at AB Breweries appeared to re quire a careful study in order to improve the production capacities, which currently could not meet up the demands. In process analysis, different machine condition and effect were considered as follows; *Machine Producing*, which could be with different speed levels for regulated lines; *Planned production stop*: machine is scheduled on planned maintenance;*Starvation***:** machine is not producing due to a lack of processing material at the in-feed, caused mostly by failures of preceding machines; *Blockage*: There is backup at discharge caused by mostly failure of succeeding machines; *Short failure* is when internal or external failure occurs in less than 5 minutes while *Long failure* is when machine has an internal or external failure occurs longer than 5 minutes. In *Unknown***,**the causes of failure are not registered. These machines states can result to inefficiency and low production performance, which further reduces the existing production capacities. The causes of different machine states includes the following; Improper regulated lines, line imbalance, conveyor/buffer strategy and sensors speed problems, production viability problem, operator's inefficiencies, machine running below the nominal speed, losses, machine breakdown, lack of efficient maintenance and CILT implementation strategies. All these problems are the constraints that limit the existing production capacity of core machine and other machines. Just as Rahman (1998) stated in theory of constraint that every system must have at least one constraint and that the existing constraints represent opportunities for improvement and that positive constraints determine the performance of a system. There is a need to see constraints as an opportunity for improvement especially in the area of improving the existing production capacities. The theory also encourages researchers to discover hidden bottlenecks, which will be an opportunity for improvement. Again, Ramdeen and Pun (2005) emphasized the need for the maintenance of production machineries and equipment and complete assurance of spare parts and raw material availability to the utilization of existing production capacities. Godwin and Achara (2013) carried out industrial based research showing how manufacturers are feeling the heat to hit their production targets in an increasingly competitive global market with heavy industries losing 30 to 40 percent of profits annually due to unplanned downtime occasioned by machine breakdown, failure and defect.

1.2 Problem Statement

AB Breweries has current challenges of sudden increase in product demands and introduction of new product brands to the market, which the current production capacities could not meet the daily demands of her customers and investing in new production line to meet up demand require huge capital expenditure. The problem is how to increase effectively the production capacity of the system, which is the best option and cost effective in increasing production output.

1.3 Aim and Objectives of the Research

The aim and objectives of this research are as stated below.

1.3.1 Aim:

The aim of this research is to evaluatethe production system performance in AB Breweries in order to provide a basis for enhanced competitiveness.

1.3.2 Objectives

The objectives of this research included to:

1. To carry out a work study on the production lines of AB Breweries with a view to understand system behaviors, problems and get relevant data.
2. To build a conceptual model of real life performance of the production line to further reveals the hidden bottleneck of the system.

3. To run animated simulation to verify and validate developed conceptual model.
4. To determine the optimal sensors speeds that will improve labeller outputs, reduce machine idle and stopping time, balance the two labellers, and minimize failure rates.
5. To apply Cleaning, Inspection, Lubrication and Tightening (CILT) and Kaizen to critical components of bottleneck machines to minimize machine downtime and ensure smooth production flow.
6. To build Excel Spreadsheet interface for easy data analysis and performance Tracking.

1.4 Research scope and limitation

The research was carried out in the three production lines of AB breweries. Work studies were performed from January 2014 to January 2017 to observe system behaviors, study system problems and collect data for analysis.

The research was carried out on the identified bottleneck machines (Filler and Labellers).

Due to time constraint, the researcher could not consider all the sensors but only focused on the sensors that link the bottleneck machines.

1.5 Significance of Study

Considering the current pressure in brewery industries, trying to cope with numerous products demands with limited production capacities and huge capital expenditure in the construction of new production lines, this research is intended to evaluate the production performance and preventive maintenance of production lines to increase production output from the existing underutilized capacities.

Production line design engineers will utilize this research to optimize regulated lines with two labellers at the initial stage of design, using plant simulation software before embarking on the construction and installations.

The knowledge from this research will enable operators and maintenance engineers adopt this preventive maintenance strategy to avoid core machine breakdown that will affect the utilization of existing capacities.

In conclusion, the research will be a wakeup call to the brewery industries to understand the essence of continuous improvement of existing system and the overall impact in efficiency, and quick response to product demands from the customers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Process Analysis of Production System

2.1.1 Production Lines Analysis

DIN 8782 (1984) defined production lines as the aggregate of distinct machines working together in sequence to fill beverage containers (bottles, cans, or kegs). It includes preceding and succeeding machines and equipment, usually from the input of palletized empty goods until the output of packaged and palletized full goods. A packaging line is a series system of the packaging process. For each stage one or more (parallel/Series) machines are used. These machines frequently have to deal with failures. Härte (1997) emphasized that the machines are put in a sequence and connected by conveyors, which can also serve as buffers.

Härte (1997) defined different types of packaging lines, all having their own design characteristics, some lines are designed for short and flexible production runs (i.e. they can handle different product sizes and product packages), other lines are designed for mass production (i.e. they are dedicated to just one product). Some lines have many parallel machines and/or large buffers, other lines are strictly series and/or have small buffers. Also, designs have to meet space and capital constraints. 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. For a specific packaging line, decisions are made regarding the individual machines, conveyors and other line equipment. The selected equipment is configured in the line layout and the controls are chosen. Härte (1997) investigated each of these constraints, with result that these constraints affect 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. Rikard (2009) investigated why other industries have been shortening conveyors, reducing buffers, and closing gaps between processes but the canners, brewers, bottlers, and packaging industries have not and came up with the result that inserted long conveyors between workstations and stuffed them with buffer stocks serves as a protection to avoid full line stoppages for minor failures occasioned by increasing line speeds and complex equipment hence the need for failure accumulation, which long buffer provides. Still, major problems do stop the line and cause line downtime of 30-50% of the time. Rikard (2009) suggested that making lines run faster will reduce poor line performance, but can cause even more jam-ups hence the need for optimization of regulated lines of AB breweries to increase the speed level. Haines (1995) carried out research to determine the core machine in packaging line, with the result that most packaging lines has filling machine as the core machine and the rest of the machines are designed around it. 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. This is done for both efficiency and quality reasons.

2.1.2 **Machinery Analysis**

The packaging process starts with the input of empty bottles or cans. Then these bottles or cans are washed or rinsed, filled with beer, closed, pasteurized, and labeled (bottles only). Finally thebottles or cans are put into their final packaging (boxes, six-packs, etc.) and gathered on pallets. At several points on the packaging line inspection machines are used. Härte (1997) carried out research to find the most important machines of bottle and can filling lines. The result shows that Filler and Pasteurizer were often the Core machines, which determines the output of production line, hence the most important machines of the production process. Labeller is also very important machine in production process. Basically, there are two types of bottle filling lines: bottle filling lines for one-way bottles and bottle filling lines for returnable bottles. Some filling lines can handle both types of bottles and are called multi-purpose lines. AB breweries have bottle filling lines for returnable bottles. Usually returnable bottles are filled and packed in crates. Returnable bottle filling lines produce mainly for the domestic market. First, pallets with crates of empty retuned bottles are placed on the line. The crates are taken from the pallets by the de-palletizer and the bottles are taken out of the crates by the un-packer machine; the bottles are transported to the bottle washing machine by a bottle conveyor, and the crates are transported to crate washing machine by a crate conveyor. There the crates and bottles are washed. The bottles go on to the filling machine and the crates go to the crate store. At the filling machine the bottles are filled with beer, closed with a crown and then moved to the pasteurizer. There is a need to optimize the filling process at the Filler to ensure the optimum performance of the Filler and quality of the filled beers before moving to pasteurizer. The pasteurizer pasteurizes the full bottles to make the beer keep longer. Then the bottles are transported to label machine, which applies the labels onto the bottles. Next the bottles are transported to the packer, where they are put back into the crates from the crate store. The full crates are transported by a crate conveyor to the palletizer, which gathers the crates on pallets. Finally the pallets are taken from the line and dispatched to the warehouse.

2.1.2.1 Core Machine (Filler)

It is important to ensure that the filled bottle is free from contamination. Filler machines can potentially induce product re-contamination when biofilm build-up on air-exposed surfaces harbors anaerobic, beer-spoiling microorganisms. Due to specific technology requirements and the high speed circular motion of bottles that are filled but still open, product splashing occurs that will serve as nutrient source for microorganisms attached to surfaces. This will induce biofilm formation which can, in turn, lead to product contamination when beer-spoiling microorganisms in the biofilm are transferred from the surface to the product. It is, therefore, routine practice to employ time-consuming mechanical and chemical cleaning measures, but with real-time biofilm monitoring of critical surfaces, a more pro-active approach to hygiene and sanitation practices can be gained. Dewa, Naicker, and Sigh (2013) carried out Root Cause Analysis to reduce waste at Filler Operations during Filling and Crowning. Process was first mapped to outline the key inputs, outputs and all the possible wastes. Historical and current data for the filling and crowning operations were gathered so that the facts about the problem were accurately described. Ishikawa diagrams were then used to present the key problems and recommended solutions were implemented. SPSS software was used for statistical analysis to compare the before- and-after scenarios with the view to verify and validate the improvements made. A typical bottle filling production line generally includes arranging the bottle, cleaning the bottles, filling, crowning, labeling, detection of the foreign bodies, and packing. Waste during these operations has become problematic since it increases the production costs. With this in mind it became imperative to conduct a study on such line to establish the root causes of waste during the bottle filling and packaging operationsand thereafter put in place the right cost-effective measures to eliminate these losses and optimize the system.

2.1.3 Buffer/Conveyor

Conveyor Theory

Conveyor systems can most of the time be built from basic units as linear conveyor systems. Yeung and Moore (1996) explained that Conveyor systems are typically installed as simple straight assembly lines and a number of workplaces are set on each side of the conveyor for manual and/or automated operations. For simple configurations the design and implementation of conveyor system is relative easily. Yeung and Moore (1996) also explained that the control programs of machines and conveyors are easily developed and executed by PLCs and that the demand for multi-product mixes and flexibility can require more complex conveyor systems. Conveyor systems which support the multi-product mixes and variable product routing need high control requirements. Bastani (1988) unit length of products was accounted in the analysis of multiple homogeneous closed-loop conveyor system with discrete and deterministic flow of material, while three fundamental principles that govern the satisfactory operation of conveyor systems, also known as the Conveyor Theory was established by Kwo (1958) and are as follows: - 1. The speed of the conveyor must be within the permissible range (Speed Principle). 2. The conveyor must have enough capacity (Capacity Principle). 3. The number of items loaded onto the conveyor must equal the number of items unloaded (Uniformity Principle). Additionally, according to Belzer, Holzman and Kent (1978), waiting line analysis and simulation to the field of conveyor systems have been applied by several authors.

Conveyor systems in simulation

Banks (1998) classified conveyor systems in simulation by the type of conveyor as well as the size of the load moving on the conveyor. Difference is made between a non-accumulating conveyor, where a load stops when the entire conveyor stops and an accumulating conveyor. Banks (1998) considered different load sizes as pallet conveyors, case conveyors and power-and-free conveyors. Banks (1998) explained that power-and-free conveyors have carriers that attach to the load being transported and are often seen in automotive paint applications. Since the core machine is the slowest machine of the line it is automatically the bottleneck of the line, other machine can be bottleneck depending on the internal breakdown of the machine. It is important that this machine is never starved or blocked by bottles either up or downstream of this machine. The design principle for packaging lines takes care of it by amounts to a buffer strategy, which makes sure that the buffers before the core machine are almost full and the buffers after the coremachine 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. This buffer strategy consists of two complementary elements. 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. The second element is formed by production speeds of the machines. The machines on either side of the core machine have extra capacity or overcapacity. This overcapacity ensures that the core machine has products at the infeed 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 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.

2.2.1 Line Efficiency

The line efficiency η_{line} is a measure of the efficiency of the packaging lineduring the period specified (Härte, 1997, p. 18) and is calculated as follows:

$$\eta\text{line} = \frac{Net\ Production\ \ time}{Actual\ \ Production\ \ Time} * \frac{100\%}{1} \tag{2.1}$$

$$\eta\text{line} = \frac{Net\ Production\ \ time}{Net\ Production\ \ time + Unplanned\ \ Downtime} * \frac{100\%}{1} \tag{2.2}$$

External unplanned downtime is excluded because this downtime is not caused by the operation of the packaging line itself; taking external unplanned downtime into account would result in an indicator for the efficiency of the organization instead of just the packaging line·. Also external unplanned downtime is hard to measure. As the net production time is equal to the output in production units divided by the nominal line capacity, the Line Efficiency specified in production units is:

$$\eta\text{line} = \frac{Output\ \ in\ Production\ \ units}{Actual\ \ Production\ \ time * Norminal\ \ Line\ Capacity} * \frac{100\%}{1} \tag{2.3}$$

Where the actual production time t on the core machine (group) is taken as the actual production time and the nominal line capacity is the nominal capacity of the core machine (group). If the filler is the core machine, then the filler determines the line efficiency except for a time difference between the time of production at the filler and the time of output at the end of the line (which includes the pasteurization time of 46-60min) and the rejects and breakage after the filler (which is usually less than 1%). Therefore, in the efficiency analysis of packaging lines the focus is on the loss of production time of the filler (or core machine), which is almost equal to the difference between the actual production time and the net production time (i.e. the internal unplanned downtime at filler). Note that loss of production on the core machine cannot be recovered, so the production time of the core machine determines the (maximum) output of the line. Although the line efficiency is the main performance indicator for packaging lines, the utilization (defined as the net production time versus the total time), and the effectively (defined as the available production time versus the manned time), are also important in analyzing the performance of a packaging line. In other words whereas efficiency analysis focuses on the reduction of internal unplanned downtime, the reduction of unused time, planned downtime, and external unplanned downtime, can obviously also improve the line performance. Finally, the output of a packaging line is a very important, simple and useful performance indicator.

2.2.2 **Machine Efficiency Analysis**

The machine efficiency $\eta_{machine}$ is a measure for the availability of the machine (Harte, 1997, p. 22). It is defined as the percentage of time that the machine is ready to operate, for the period specified:

$$\eta\text{machine} = \frac{Total\ \ Running\ \ Time}{Total\ \ Running\ \ Time + Total\ \ Time\ \ Internal\ \ Failure} * \frac{100\%}{1} \qquad (2.4)$$

The machine efficiency is the time the machine produced versus the time the machine could have produced. Obviously, the total planned downtime, external failure time, starved time and blocked time are not taken into account for measuring the machines availability. Also the machine speed is not considered. The machine efficiency is equal to:

$$\eta\text{machine} = \frac{MTBF}{MTBF + MTTR} * \frac{100\%}{1} \qquad (2.5)$$

2.2.3 **Theory of Constraint**

Rahman (1998) formulated the principle of the Theory of Constraint into two statements: Every system must have at least one constraint (no constraints means unlimited profit). The existence of constraints represents opportunities for improvements (positive constraints determine the performance of a system).

Therefore these constraints form the focus of improving the production processes within a company. The main focus lies on the throughput. The theory also involves the research to hidden bottlenecks. The critique on the theory is aimed at the lack of involvement of operating employees. The theory focuses on the whole system and therefore, employees working at part of this process can contribute a very limited way.

2.2.4 **Performance Analysis**

Neely, Gregory and Platss (1995) defined performance measures (PMs) and metrics as the process of quantifying the efficiency and effectiveness of an action. The term metric refers to the definition of the measure, how it will be calculated, who will be carrying out the calculation, and from where the data will be obtained. Fitzgerald et al. (1991) defined two basic PMs in any organization as those that relate results (competitiveness and financial performance) and those that focus on the determinants of the results (quality, flexibility, resource utilization and innovation).

According to Neely (1999), two features are necessary for a business performance measurement system; performance measures and a supporting infrastructure. Although the existence of measures is often taken as a given, there is no such agreement on the nature and design of those measures. Neely (1999) also said that a supporting infrastructure can vary from very simplistic manual methods or recording data to sophisticated information systems and supporting procedures which might include data acquisition, collation, sorting, analysis, interpretation and dissemination.

2.2.5 **OEE/OPI Analysis**

Nakajima (1991), the different between an OPI of 100% and the actual OPI is the loss of production and reducing the losses increases the actual OPI. Nakajima (1991) categorizes these losses into “six big losses”: equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in process and reduces yield. As one can see in Figure 2.1, these losses are used to compute the OEE.

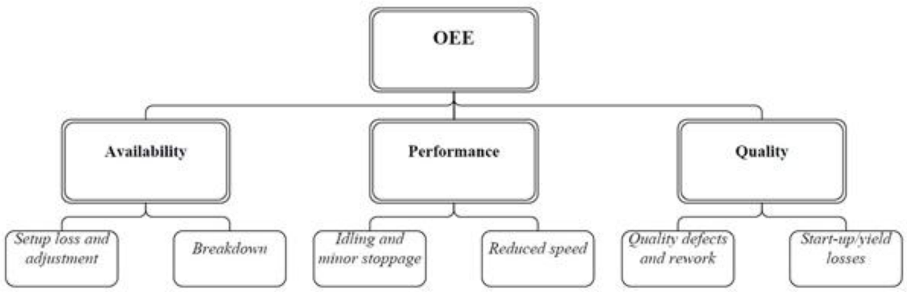


Figure 2.1: Relation Between OEE and Six Big Losses - (Chan, 2005)

With OEE, an organization looks at the total time that is available, down time losses, speed losses and defect losses (De Ron and Rooda, 2006). These three types of losses are translated into Availability, Performance and Quality. Parmenter (2010) explained the difference between performance indicators (PI) and key performance indicators (KPIs), the last one indicates which actions are needed to dramatically increase performance. To measure the performance, company uses a variant of Nakajima’s overall equipment effectiveness (OEE), as a KPI. This variant is the Overall Performance Indicator (OPI). Operational Performance Indicator (OPI) is measured over the performance of each machine in the production lines and it is determined by the product of Availability, Performance and Quality, like the OEE. According to Nakajima (1991), OEE identifies (hidden) losses related to any decrease in performance by evaluating each component and eliminating these losses results in a higher performance, where according to Nakajima (1991), zero losses will result in an OEE of 100%.

The equation of Operational Performance Indicator (Nakajima, 1991) is calculated as follows

$$\text{OPI} = \text{Availability} * \text{Performance} * \text{Quality} \qquad (2.6)$$

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

$$\text{Quality} = \frac{\text{No .of Good Product}}{\text{No of Good Product} + \text{No .of Rework } \& \, reject} \tag{2.7}$$

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

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Manned Time}} \tag{2.9}$$

Table 2.1 shows different activities that affect Overall Equipment Effectiveness (OEE) and Operational Performance Indicator (OPI). Different activities are described, the time taken to achieve the said activities are taken to calculate OPI. All the unused time is calculated and equates it to P.

Table 2.1: Detailed Description of OEE/OPI Calculation

Unused Time	Non-operator maintenance	No Order No activity	Changeover Time	Planned downtime	Breakdown time
P	Q	R	S	T	U
shift system, nights and weekends, unmanned, holidays, no operation	3rd party maintenance, non-operator maintenance	No order, no activity, idle time, extra cleaning, training and meeting	set up and equipment adjustment	Maintenance by team, cleaning, training, meeting, start up, run out, meals and test run	breakdown >5minutes

Starvation Time	Blockage Time	External stop	Speed losses and Minor stops	Reject and Rework
V	W	X	Y	Z
time conveyor fail to feed the	Time last machine is blocked from	External caused stop (no beer, no utility, no	speed less than nominal	

C	D	E	F	**G**
Total Time	Manned Time	Operating working time	Effective Working Time	**Available Production time**
=P+Q+R+S+T+U+V+W+X+Y+Z	=C-P	=D-Q	=E-R	=F-S-T

H	**I**	**J**	K
Actual Production time	**Operating Time**	**Production Time**	**Good products or theoretical production time**
=G-X	=H-U	=I-Y	=J-Z
L	M	N	O
Availability	**Performance**	**Quality**	**OPI**
=I/D	**=J/I**	**=K/J**	**=L*M*N**

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

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

The availability is the operating time (described above) divided by the manned time. The manned time is the time that operators are working on the production line, which is in total 9600 minutes per week.

2.3 Parameter Analysis

Kegg (1990), said in 1970s, companies with transfer lines started studying the productivity of their lines and each discovered that the actual number of parts produced per year was about half of the theoretical maximum, which was widely discussed and published, but the causes of these production losses were kept classified. This led to the conclusion that sensors were needed in order to measure inefficiencies on different places on the production line and the sensors are called the Programmable Logic Controllers (PLCs). PLCs were the first major milestones in the use of electronics to extract information from sensors in manufacturing. Kegg (1990) carried out research on the importance of PLCs and found out that PLCs were reliable measure to collect data from the production line, which supports technicians to detect problems earlier and therefore amount to productivity increased. In the 80s the combination of PLCs and use of measurement systems allows to detect trends on machine failures and other inefficiencies, therefore the PLCs play in important role in the automation of production lines. Mahalik and Lee (2001) investigated another importance of sensors on a production line, with result that it helped to cope with high flexibility and productivity. Sensors do not only register information about machine breakdowns but also about starvation and blockage at the production line. Sensors are linked with conveyors, but also with machines. PLCs are usually positioned on the conveyors to collect information of the number of products.

2.3.1 Line Parameter

A packaging line consists of the different stages of the packaging process, and for each stage one or more machine are used. In other words a packaging line is a series system, with the machines or machine groups as components, and these machines are connected by conveyors/buffers. This is depicted in figure 2.2, in which the buffers upstream of the core machine are full and the buffers downstream are partly empty. The line efficiency is then determined by the line parameters, which are formed by the machine parameters and the buffer parameters.

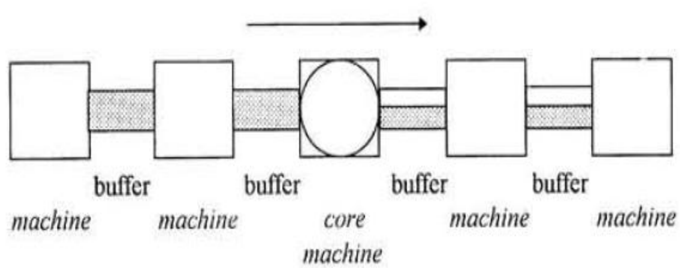


Figure 2.2: Packaging Line as series system (Härte (1997)

2.3.2 **Machine Parameter according to** Härte (1997)

Machine parameter comprises of machine state, the failure behavior, machine efficiency and machine production rate.

Machine state:

Running: A machine is running when it is producing, this can be different speeds and with different reject rates.

Planned downtime: A machine is planned down in the case the machine is stopped for planned maintenance, changeovers, not in use, etc.

Machine internal failure: A machine has an internal failure when the machine stop is caused by a machine inherent failure. There are often many different failures causes depending on the complexity of the machine.

Machine external failure: A machine has an external failure when the machine stop is caused by external factor, either caused by another part of the organization (e.g. no supply of empties, no beer, no electricity, etc.), or by the operator(s) of the line (e.g. lack of material such as labels, cartons, glue, etc.) and waiting time.

Starved: A machine is starved (or idle) when the machine stop is due to a lack of cans or bottles or cases. The machine has no input, i.e. the conveyor preceding the machine is empty, because of a reason upstream on the line. Note that some machines can be starved for more than one reasons, e.g. a packer can be starved for bottles and for boxes.

Blocked: A machine is blocked when the machine stop is due to a backup of cans or bottles or cases. The machine has no room for output, i.e. the conveyor succeeding the machine is full, because of a reason downstream on the line. Note that some machines can be blocked for more than one reason, e.g. a de-palletizer can be blocked by pallets and by crates.

Hence, a machine is either running, or a machine is not running for one of five reasons. The state 'planned down' and part of the state 'machine external failure ' are not included in the calculation. Therefore the loss of production time on the core machine (i.e. the internal unplanned downtime) consists of the total time the core machine has an internal failure or an external failure due to the operation of the packaging line, and the total time the core machine is starved or blocked. This means that efficiency loss can be caused in three ways: either stops (of lower speed) due to the core machine itself, or due to stops upstream of the core machine, or due to stops downstream of the core machine. Sometimes it is hard to differentiate between machine internal failures and machine external failure (e.g. poor quality material), or between machine external failures and starvation /backup (e.g. material). F.L. Härte, (1997) made an assumption that failures due to the machine internal failures are related to the machine external failures or due to other machines of the line (starved and blocked). This results in external unplanned downtime.

Machine Failure Behaviors:

The internal failure behavior of a machine is usually described by the means of two (unknown) probability distribution functions: a distribution function for the internal failure or repair times and a distribution function for the running times. The expectation of the failure or repair time distribution is called “Mean Time To Repair” (MTTR). The expectation of the running time is called “Mean Time Between Failures” (MTBF). According to Härte (1997), these equations are defined as follows for the period specified:

$$\text{MTTR} = Mean\ Time\ to\ Repair = \frac{Total\ Time\ Internal\ Failures}{Number\ of\ Internal\ Failures} \tag{2.10}$$

$$\text{MTBF} = Mean\ Time\ Between\ Failures = \frac{Total\ Running\ Time}{Number\ of\ Internal\ Failures} \tag{2.11}$$

The total time of internal failures is simply the sum of the intern al failures during the period specified, and the running time is the total time the machine is in the state 'running'.

Machine Efficiency:

The machine efficiency $\eta_{machine}$ 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:

$$\eta\text{machine} = \frac{Total\ Running\ Time}{Total\ Running\ Time + Total\ Time\ Internal\ Failure} * \frac{100\%}{1} \tag{2.12}$$

The machine efficiency is the time the machine produced versus the time the machine could have produced. Obviously, the total planned downtime, external failure time, starved time and blocked time are not taken into account for measuring the machines availability. Also the machine speed is not considered. The machine efficiency according to Härte (1997):

$$\eta\text{machine} = \frac{MTBF}{MTBF + MTTR} * \frac{100\%}{1} \tag{2.13}$$

Often these distribution functions are assumed to be exponential distribution functions. Alternatively the failure rate can be specified in terms of numbers per million, e.g. 200 stoppages per one million produced bottles or cans. This means that no matter how fast the machine is running the failure rate will be the same. This might be more in keeping with the quality specifications of the material which is also in unitsper million (or rather a percentage), and it might also explain why machines often show more failures at higher speeds (i.e. because of the constant failure rate the mean time between failures is shorter at higher speeds. On the other side, however, at higher speeds also the circumstances (e.g. temperature, trembling, etc.) are often different. Härte (1997) classified MTBF as based on running time and not on clock time, which implicitly assumes that a machine cannot fail while being forced down by either being starved or blocked.

Machine Production Rate

Machine speed (V_{mach}): The machine speed is the number of products the machine produces per unit of time. Machines can have fixed, pre-selected, or continuously variable speeds. Usually machines have an over speed, a low speed and one or more speeds around the nominal machine capacity. Machines can have different speeds for different product types. Machine capacity (C_{mach}): The machine capacity is the maximum machine speed as set in the machine control. Machines can have different machine capacities for different product types. Group capacity

(C_{group}): The group capacity is the total maximum production speed of the parallel machines that form the group, as set in the control. This can be lower than the sum of the machine capacities. Nominal machine capacity (C_{nom}): The nominal machine capacity is the speed of the machine for which the group to which the machine belongs runs at the same speed as the core machine (group); it is determined by the nominal line capacity divided by the number of machines of the group. Machine overcapacity: ($O_{mach}=C_{mach} – C_{nom}$); the machine overcapacity is the difference between the machine capacity and the nominal machine capacity. Group overcapacity ($O_{group}=C_{group}$- C_{line}.) The group overcapacity is the group capacity minus the nominal line capacity. Core machine (group), One of the machines (or groups) of a line will be thecore machine (group) or critical machine (group). The core machine (group) is defined as the machine (group) on which all the line equipment and conveying system parameters are dimensioned. The capacity of the core machine (group) determines the maximum output of the line. Therefore the nominal line capacity is equal to the capacity of the core machine (group). Nominal/line capacity (C_{line}.): The nominal line capacity is the smallest machine (group) capacity for the specific product, i.e. the capacity of the core machine (group) for the specific product.

2.3.3 **Buffer Parameters:**

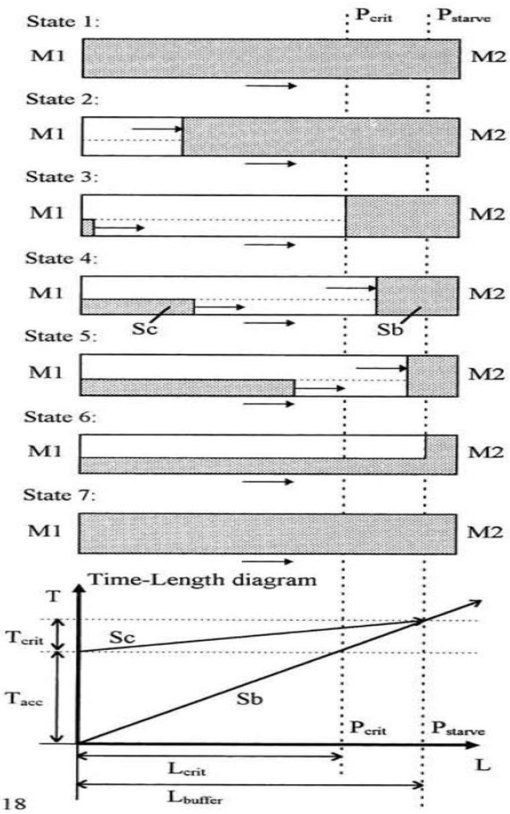
The goal of the buffer strategy is to minimize the influence of the different machines on each other and especially on the core machine (most often the filler), by accumulating additional supply before the core machine and creating space after the core machine. In other words the buffers for bottles/cans and crates/cases/trays between the machines provide accumulation. There are two types of accumulation: dynamic accumulation and static accumulation. **Dynamic accumulation** is accomplished by the conveyors between the machines. Static accumulation is achieved by putting a real buffer between machines. Buffers which are used to avoid starvation of the preceding machine are called anti-starve buffers (these are found upstream of the core machine); buffers which are used to avoid backup of the succeeding machine, are called anti-block buffers (these are founddownstream of the core machine). Accumulation is referred to as the time a machine is allowed to stop without disturbing the operation of the machines around it. There are two types of accumulation: dynamic and static accumulation.

Dynamic Accumulation:Dynamic accumulation is accomplished by the conveyors between the machines. For bottles and cans these conveyors consist of parallel chains, of which some chains are used for transport, and the other chains are used for accumulation. For cases, crates and trays these conveyors are usually one unit wide and the accumulation is achieved by the spacing of the units. The functioning of dynamic accumulation differs for anti-starve and anti-block buffers.

Anti-Starve Buffer

The purpose of anti-starve buffers is to prevent the starvation of the core machine. These buffers are therefore found upstream of the core machine. The idea1 state is when the buffer is full; the machine after the buffer is constantly supplied with bottles. When failure occurs before the buffer, the machine after the buffer can continue to run and drains the accumulated containers from the buffer. This lasts for a certain period of time, the so-called accumulation time. At the end of this time period the machine that stopped, has to start running again, otherwise the machine after the buffer stops because it is starved. Because of the overcapacities the ideal state is recovered.

State 1:
The buffer is fully filled and working. The machines MI and M2 are both running. This situation is called the ideal state.
State 2:
Machine MI has a failure or is starved by a failure further upstream. The buffer content is decreased by M2 with speed Sb. A gap is created in the bottle or can flow, because MI is no longer producing.
State 3:
The bottle/can flow reaches the 'critical point' Pcrit by the critical time Tcrit=Lbuffer/Sc. No later than this point MI has to start running, such that with speed Sc the overtaking container flow can fill up the created space, before it reached the starve point P-starve of machine M2 (i.e. the sensor that signals the lack of bottles and stops machine M2).
State 4 and 5:
The overtaking flow approaches the end ofthe production flow, because of the speed difference. The production flow disappears with the machine production speed and the overtaking flow draws near with the speed of the conveyor.
State 6:
The overtaking flow reaches the production flow, before it has reached the starve point. M2 can continue running, without noticingthe failure of machine MI
State 7:
Because M2 runs at a lower speed than MI (i.e. MI has overcapacity with respect to M2), the buffer has filled up again. The ideal state is recovered



18

Anti-Block Buffer

The purpose of anti-block buffers is to prevent the blockage of core machine. These buffers are found downstream of the core machine. The ideal state is when the buffer is empty, i.e. only the part of the conveyor used for transport is full. When failure occurs after the buffer, the machine before the buffer can continue running and fills the buffer with bottles. This lasts for a certain period of time, the so-called accumulation time. At the end of this time period the machine that stopped, has to start running again, otherwise the machine before the buffer stops because it is blocked. Because ofthe overcapacities the ideal state is recovered.

State 1:
The transport part of the conveyor is filled; the buffer part of the conveyor is empty. Machine M2 is running. This situation is called the ideal state.
State 2 and 3:
Machine M2 has a failure or is blocked by a failure further downstream. The backup of containers builds in the direction of machine M1.
State 4:
The backup reaches the ' critical point', M2 has to start running now, otherwise M1 gets blocked (i.e. the sensor that signals the backup of bottles stops machine M1).
State 5 and 6:
Machine M2 has started running again.
Because of the overcapacity of M2 with respect to MI the container flow decreases. The buffer part of the conveyor is drained.
State 7:
The ideal state is recovered.

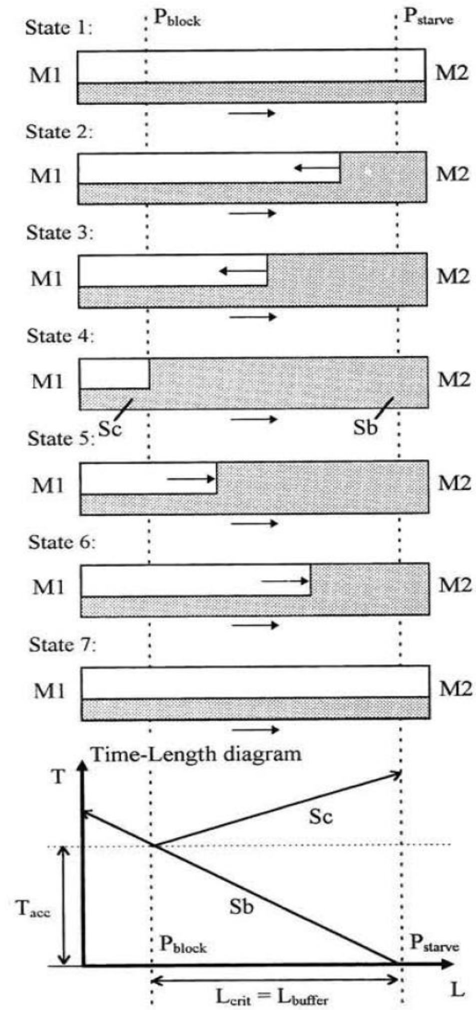


Figure 2.4: Anti-Block Buffer

Bottles and Can Conveyors

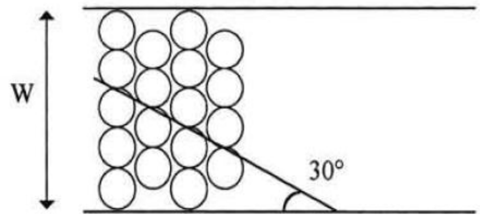


Figure 2.5: Bottles and Can Conveyors

For a given bottle or can conveyor (Härte, 1997, p. 27):

W =width (in mm)

Ø = bottle or can diameter (in mm)

C_{line} = line capacity (in bottles/min or cans/min)

Nb = number of rows of bottles or cans standing on the width of the conveyor

$$= \quad A = ROUND\left[\frac{W-\emptyset}{\emptyset - COS30°} + 1\right] \tag{2.14}$$

Nm = number of bottles or cans per meter conveyor = Nb*$\frac{100}{\emptyset}$

Sb =speed of bottles in translation (in m/min) when the conveyor is filled with bottles on its whole width.

$$= \frac{\text{Cline}}{Nm}$$

Sc= chain speed of the conveyor

L_{buffer} = length of the buffer, taken as the distance between the block and the starve sensors.

ρ = population of bottles or can on buffer chain of the conveyor over the length of the buffer as a percentage of the maximum number of bottles on the buffer chains of the conveyor over the length of the buffer

Of course the machine failure need not to occur when the buffer is full or empty; this means that an optimal accumulation is only possible when the buffer is full or empty. This leads to two buffer times, a nominal accumulation, i.e. the accumulation in the ideal state and the (actual) accumulation that depends on the present population of the buffer, i.e. the fill level. Sb width (in mm) bottle or can diameter (in mm) line capacity (in bottles/min or cans/min) number of rows of bottles or cans standing on the width of the conveyor

Φ = fill level of conveyor as the percentage of the number of the containers on the buffer versus the possible number of bottles on the conveyor.

Φ^{nom} = nominal fill level, defined as the fill level of the conveyor in the ideal state as set in the control.

If a conveyor consists of different segments, with either different widths and/or different speeds, the accumulation is calculated for each segment separately and these are then added together. The maximum number of bottles on the buffer can be even higher, but because of machine control and quality reasons (bottle/can damage, label damage, etc.) extra space between the bottles is achieved in the control. This is called the unused buffer capacity (Härte, 1997)..

Nominal Accumulation

The nominal accumulation is the accumulation when the bufferis in the ideal or nominal state, i.e. the state when the line is producing without failures (Härte, 1997). The nominal Accumulation is equal to:

$$T_{acc}^{nom} = L_{buffer} * [\frac{1}{Sb} - \frac{1}{Sc}] \tag{2.15}$$

For anti-starve buffers this means that the nominal accumulation is equal to the time it takes to empty the full conveyor over the length of the buffer minus the time is takes for bottles to travel the length of the buffer, For anti-block buffer this means that the nominal accumulation is equal to the time is takes to fill the conveyor over the length of the buffer minus the time is takes to fill the transportation part of the buffer.

Actual Accumulation

The actual accumulation is the accumulation that the buffer provides when the conveyor is in a given state. The state is described by the population of bottles on the length of the buffer (Härte, 1997).

$T_{acc} = L_{buffer} * [\frac{\rho}{Sb} - \frac{1}{Sc}]$ for anti-starve buffers (2.16)

$T_{acc} = L_{buffer} * [\frac{1-\rho}{Sb} - \frac{1}{Sc}]$ for anti-block buffers (2.17)

For anti-starve buffers this means that the actual accumulation is equal to the time it takes to empty the conveyor over the filled length of the buffer minus the time is takes for bottles to travel the length of the buffer. For anti-block buffer this means that the actual accumulation is equal to the time is takes to fill the conveyor over the free length of the buffer minus the time is takes to fill the transportation part of the buffer. From this follows that the nominal population of anti-starve buffer is 100% and of anti-block buffers 0%. This does not mean that the whole conveyor is filled or empty, just the conveyor over the length of the buffer. The nominal fill level of the conveyor is then around 90% of the maximum number of bottles on the conveyor for anti-starve buffers and around 50% for anti-block buffers. When the chains and bottles are moving at the same speed (Sb=Sc), there is no accumulation (Tacc=O), because there is no possibility to catch up a gap in the flow in accumulation sections upstream of the core machine, or to empty the overfilled accumulation sections downstream of the core machine. When the chain speed goes to infinity ($Sc \rightarrow \infty$) the accumulation goes to the quantity of bottles the conveyor can accept

(=Lbuffer/Sb), so the higher the chain speed, the higher the accumulation (tending towards the maximum).

Because the line capacity is used in calculating the accumulation, these accumulations can be added to get the total accumulation of each machine with respect to the core machine (FilIer); in reality, however a machine may be forced down in a shorter time than the accumulation, because of the machine overcapacity, or in a longer time than the accumulation, because of the machinelow speed. The accumulation should therefore be regarded as the effective accumulation, with respect to the line capacity, i.e. the core machine.

After the accumulation has been used the buffer has to be restored to its nominal state, this is achieved by the speed difference between the machine before the buffer and the machine after the buffer.

T_{stop} = accumulation to be regenerated, i.e. the duration of machine stop (in min)

C_M = capacity of the machine that has had a stop

Nominal recovery time

The nominal recovery time is the time needed to regenerate the nominal accumulation, in other words the time needed to restore the buffer to its nominal state after a machine stop as long as the nominal accumulation (Härte, 1997).

$$T_{rec}^{nom} = \left[\frac{T_{Acc}^{nom} * C_{line}}{C_M - C_{line}}\right] \tag{2.19}$$

This means that the number of bottles or cans that were removed from or put on the conveyor during the nominal accumulation (=the numerator) is recovered with the speed difference between the machine that has had a stop (and now running at its maximum speed) and the line capacity (= denominator).

Actual recovery time

The actual recovery time is the time needed to regenerate the accumulation that has been used by the machine stop(s). Stated differently it is the time the machine that has had a stop, has to run at its maximumspeed (Härte, 1997).

$$T_{rec} = [\frac{T_{Stop} * C_{line}}{C_M - C_{line}}] \qquad (2.20)$$

This means that the number of bottles or cans that were removed from or put on the conveyor during the stop (=the numerator) is recovered with the speed difference between the machine that has had a stop (and now running at its maximum speed) and the line capacity. Again, because the line capacity is used in ca1culating the recovery time, these times can be added to get the total recovery time of each machine with respect to the core machine; in reality, the recovery time of a buffer may be shorter because of a bigger speed difference or longer because of a smaller speed difference. The recovery time should therefore be regarded as the effective recovery time, with respect to the line capacity, i.e. the core machine. Härte (1997) stated that the bigger the speed difference (or how steeper the V -shape of the V -graph) the faster machine stops can be recovered.

Case, Crate and Tray Conveyor

For case/crate/tray conveyors the accumulation is generated by the space between the cases. For a given case/crate/tray conveyor according to Härte (1997), the equation is stated as follows:

C_{line} = line capacity (in bottles/min or cans/min)

L_c= length of a case (short side leading) or width of case (long side leading)

S_b= speed of case in translation (in m/min), with either a case population ρ or a distance d between two consecutive cases

S_c= chain speed of the conveyor

N = number of bottles or cans in a case= $\left[\frac{C_{line} * L_c}{N*\rho}\right]$ or $\left[\frac{C_{line} *(L_c+d)}{N}\right]$

L_{buffer} = length of the buffer, taken as the distance between the block and the starve sensors.

ρ = population of cases on the conveyor over the length of the buffer as a percentage of the maximum number of cases on the conveyor over the length of the buffer.

Statics Accumulation

Static accumulation is accomplished by accumulation tables between the machines. Such a table (or stack) is placed next to the conveyor and is often called an ebb and flow table. When the conveyor is full the table start to fill, when the conveyor is no longer full the table starts to empty.

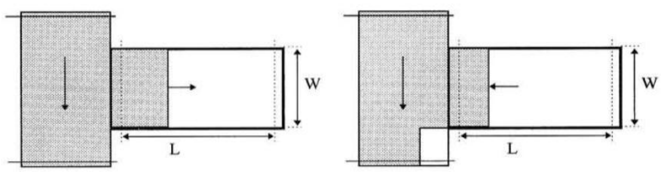


Figure 2.6: Static Accumulation (Nakajima (1991)

2.3.4 Setting the Parameter

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: the machine capacity, the length of the conveyor. 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-graph 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.

2.4Line Regulation

2.4.1 Losses Identification

Nakajima (1991) stated that a loss of a production facility is the difference between an OPI of 100% and the actual OPI. By reducing the losses, the actual OPI increases. Nakajima (1991) categorizes losses into “six big losses”. Nakajima (1991) categorizes these losses into “six big losses”: equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in process and reduces yield.

With OEE, an organization looks at the total time that is available, down time losses, speed losses and defect losses. These three types of losses are translated into Availability, Performance and Quality.

Speed Losses

Nakajima (1991) considered speed loss and defined it as reduced speed of machine during operations. It resulted because machine has different speed levels. Machines produce dichotomously or continuously which means that a machine has only two speed levels, not producing (0%) or producing (100%). Speed levels between the 0 and100% is when machine is in continuous production. To clarify, dichotomous machine or up (0-100%) has no speed levels and speed losses but has blockage, starvation, failures or planned downtime. Speed losses occur with machines of different speed levels when it produces on a lower speed. A machine with different speed levels can create speed losses when it produces on a lower speed than the nominal speed.

Technology

Information systems, MES, do not recognize different speed levels in MES-DNA Strand with the technological needs. Looking at the DNA strand in the IS in Figure 2.7, it cannot be perceived if a machine is producing continuously or dichotomous.

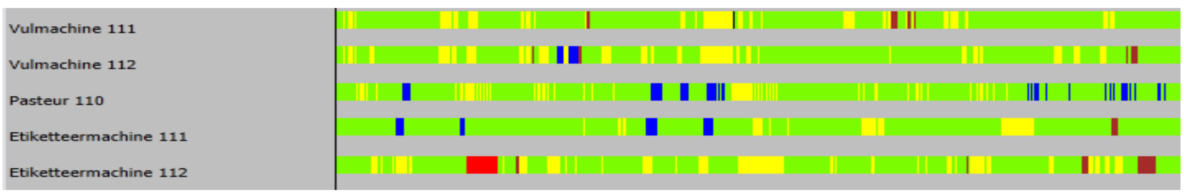


Figure 2.7: MES – DNA Strand (AB Breweries)

The problem of MES-DNA Strand is that a machine which runs for 10 minutes on 10,000 bottles/hour is preferred to machine that runs for 1 minute on 110, 000 bottles/hour and have a failure of 9 minutes because option1 the strand is all green while option 2 is almost fully red. Option 2 is better because the output is higher compared to option

2.5 **Simulation Model and Validation Methods**

Two types of models are typically used to estimate performance measures: simulation models and analytical models. Shannon (1975) defined simulation as a process of designing a model of a system and conducting experiments with this model for the purpose either to understand the behavior of the system or to evaluate various strategies within the limits imposed by a criterion or set of criteria for the operation of the system. Discrete-event simulation models mimic the real system by constructing a list of events that occurs in the real life. At each event occurrence, such as a process completion or a breakdown, new events are scheduled and added to the event list.

The randomness in times between two events (arrival or breakdowns) is captured by drawing random numbers from pre- specified distributions. These distributions can be derived from data of the production system; both empirical and fitted distributions can be used and translated into stochastic variables. Wein and Chevalier (1992) stated the benefit of simulation as the ability to include stochastic variables, for example the inter arrival time of products and the breakdowns of machines. A simulation model is a simplified model of reality and is used to test out different production rules.

Discrete event simulation (DES) techniques cover a broad collection of methods and applications that allows imitating, assessing, predicting and enhancing the behavior of large and complex real-world processes. This work introduces a modern Tecnomatix Plant Simulation, developed with simulation software, to optimize both the design and operation of a complex beer packaging system. The proposed simulation model provides a 3D user-friendly graphical interface which allows evaluating the dynamic operation of the system over time. In turn, the simulation model has been used to perform a comprehensive sensitive analysis over the main process variables. In this way, several alternative scenarios have been assessed in order to achieve remarkable performance improvements. Alternative heuristics and optimizationby simulation can be easily embedded into the proposed simulation environment. Tolk et.al (2014) noted that numerical results generated by the Tecnomatrix Plant Simulation model clearly show that production and efficiency can be significantly enhanced when the packaging line is properly set up

The challenges in engineering for food and beverages production plans are seasonal demands, high product turnover, high flexibility for new products and multi-variety packs, as well as quality and freshness. With highly automated sophisticated technologies and expensive equipment, it is particularly important to ensure that manufacturing processes meet current and future needs. Simulation tool implement fully validated new processes to get it right the first time in other to manage the challenges. Using simulation, you can determine the most cost effective and future-proof planning solution. Alternate planning scenarios can be compared to select the best balance between performance, flexibility and investment. By using Tecnomatrix simulation for food and beverage, it is easy to identify bottlenecks and to plan the best strategy for increasing plant output. Benefits include;Identify and fix bottlenecks, Develop optimal cleaning Strategies, Define quantified measures to optimize output up to 30 percent, Invest in the right equipment, Determine feasible and robustproduction plans, Secure product quality by a stable and harmonizes production flow and Minimize discarded materials.

Analytical models try to capture the system in terms of sets of equations and then solve these equations. In many cases, the solution of these equations is numerical. Most complex systems require heuristic method to be constructed to obtain approximate results.

According to Tino and Khan (2013) states that Simulation techniques are often time consuming. Therefore, analytical models are often used to generate solutions in a fraction of the time but the models are complicated and take effort to derive.

In analytical analysis, simulation is a graphical tool for analysis and enables us to analyze the impact of breakdowns and inter arrival times. At the production lines of Company these events should be considered to mimic real life situations, which will be too hard to solve with an analytical model due to the dynamic production environment

Simulation type

Law (2006) distinguishes several types of simulation models. First we determine which dimensions are applicable to this research. There are three dimensions, which are:

1. Dynamic or static simulation models: A dynamic model shows how a system evolves over time while a static simulation model represents the system at a certain time.
2. Stochastic vs. deterministic simulation models: A stochastic simulation model exists of random input components while a deterministic model does not contain any probabilistic components.
3. Discrete vs. continuous simulation models: In a discrete simulation model the state variable changes at different points in time while a continuous model has continuous state changes.

Furthermore there is a distinction between terminating and non-terminating simulations. In terminating simulation there is a natural event that specifies the end of the run. This can be for example, the end of a shift or end of a day. Non-terminating simulations consider a steady state performance measure. The performance depends on initial conditions, and after time t the simulation can turn into steady state behavior but sometime parameters might be changing over time which results in a continued transient system behavior. Considering steady state parameters, the time it takes until the system turns in a steady state has to be determined in order to measure performance. Other subdivisions of simulations discussed by Law (2006) are:

1. Monte Carlo simulation. This contains a static discrete simulation model and can be stochastic or deterministic.
2. Spreadsheet simulation uses spreadsheet as a platform for representing simulation models and performing simulation experiments.
3. Continuous simulation

4. Discrete-event simulation

5. Combined discrete-continuous simulation

The discrete-event simulation, models the operation of a system as a discrete sequence of state changes in time.

2.6 Total Productive Management (TPM) and Performance Measurement

Nakajima (1988) defined Total Productive Management (TPM) as an equipment management philosophy, focused on maximizing performance and the ultimate goal is to reach zero losses. Rolfsen and Langeland (2012) investigated TPM, TQM and Six Sigma, and emphasized that TPM is preferred because of its strong focus on equipment and maintenance and its usefulness in organizations that have a high level of equipment automation (Chan, Lau, IP and Kong, 2005). Ahuja, Khamba (2008) TPM philosophy eliminate all losses to continuously manage, optimize and improve a supply chain involving all employees. By systematically eliminating losses, TPM improves the performance of a production. In order to know what performance is improved, the performance measure should be clear. Every performance is measured by different kinds of Performance Indicators (PIs) in most business. Also departments in a company have their own PIs. In Beer and Beverage companies, sales department measures its performance on number of pallets sold and number of customers satisfied with the products while production department measures its performance by the number of beer and beverages produced and rejected by lack of quality per day. In literature it is a highly debated topic. According to Neely (2002), the definition of performance measurement is: “The process of quantifying the performance of actions”. De Ron and Rooda (2006) stated that measuring the performance is important in order to be able to perform improvement activities based upon these measures and to keep track of previous results. In addition, only aspects, that have been measured, are actively improved by the stakeholders. Therefore it is important for businesses to identify the correct performance measurement and corresponding PIs for each process. The problem will not be measured correctly and therefore it is unclear when incorrect performance indicators are used and you won't know whether the problem is solved ornot.

2.6.1 Continuous improvementstrategies and Performance Measure

There are multiple improvement strategies and it is hard to separate them from each other while Total Quality Management, Just in Time (Cua, McKone, and Schroeder, 2001)., Lean (Arlbørn and Freytag, 2013), Theory of Constraints (Rahman, 1998), and Six Sigma (De Mast and Lokkerbol, 2012; Schroeder, Linderman, Liedtke and Choo, 2008) are closely related programs. These improvement strategies have grown to comprehensive management strategies. Farris et al., (2009) stated that implementing continuous improvement requires a change in working culture, which can prove to be difficult and have an impact on involved personnel. The four improvement strategies are discussed in details as follows:

Lean management

Arlbørn and Freytag (2013) stated that there is no commonly accepted definition of lean management, and therefore there are a number of views on lean: "Ranging from a focus on waste elimination, utilizing operational tools and implementing specific production-related principles, to identifying conditions that are linked to the product and/or the service and the predictability of demand and its stability." Nevertheless, the basic principle of lean management is *eliminating waste*. Wastes are all activities that add no value to the end product. Shah and Ward (2003) stated the principle of lean in eliminating waste will increase the business performance. The focus lies on the improvement of small improvements, where the overall flow time can be reduced, the variation can be reduced and the quality will increase. However, critiques against lean management involve a decrease in operator autonomy and multi-skilled labor qualities.

Variability Reduction

Adler (1993a)Adler and Borys (1996) Edelson and Bennett (1998) Fujimoto (1999) Imai (1986) Klein(1991) stated that Lean production variability reduction begins with standardization and documentation of processes, along with the requirement that workers perform processes according to the documents. Lean production and standard operating procedure (SOP) theory call for the involvement of workers (usually operating in teams) in the development of procedures for two reasons: (a) only the people actually running the process have access to many key types of knowledge concerning how the process operates in practice, and (b) it is generally believed that participation in development of procedures will give workers a sense of ownership, increasing their willingness to run the process as documented.

Flynn, Sakakibara and Schroeder (1995)stated that **Process standardization and documentation** lays a foundation for statistical process control (SPC), a second lean production practice dedicated to the reduction of variability. Edelson and Bennett, (1998) analysis of SPC is concerned with statistical analysis of process data to distinguish between random and nonrandom variation. For example, process data can be collected, aggregated, and charted to determine whether a process is running under statistical control (i.e., nothing has changed) or whether there is some factor causing the process variability. Edelson and Bennett (1998) stated that in a situation where a process is not standardized, or workers do not run the process according to the documents, it is impossible for a process to run under statistical control.

Use of Equipment: Variability also is reduced in lean production through use of equipment and parts that reduce the probability of operator error. Fujimoto (1999 stated that a machine can be designed so that it is impossible to insert a part in the wrong direction, or so that a buzzer sounds if the machine detects an abnormality. A common term for such machine design is jidoka or poke-a-yoke, long with equipment (such as andon cords that makes it visually clear that an error or problem is occurring, Hopp and Spearman (1996); Schonberger (1982) emphasized that lean production must have visual display of quality-related data.

Incoming raw materials: Dyer, (1996) emphasized the elimination of variability in incoming raw materials through a variety of supplier management tools and practices, ranging from the formation of alliances and asset specificity to better exchange of information with fewer suppliers. Handfield, (1993) stated organization should ensure that parts of consistent quality be delivered on time. Monden (1983) stated that the production line is protected from arrival rate variability through demand-smoothing practices, so that the production schedule does not change from day to day sometimes even from hour to hour.

Keeping the plant clean and orderly is a lean production practice that has been observed to play a key role in variability reduction. Collins and Schmenner, (2003); Hayes, (1981) stated that disorder and dirt encourage quality problems and hinder problem solving.

Hackman and Wageman (1995); Kenney and Florida,(1993) emphasized that **respect for workers** also is encouraged by the lean production/TQM practice of grouping workers into teams according to their production line or cell. It calls for the transfer of certain types of authority and responsibility (including inspection, trouble-shooting, statistical quality control, and equipment maintenance) to lower levels of the organization. Whereas Rinehart, Huxley and Robertson (1997) stated that production tasks under lean production usually are carried out by individuals teams of workers collaborate to attack quality problems and carry out lateral tasks.

Teams take responsibility for quality and discipline members who do not perform tasks correctly and teams reallocate tasks when a member is injured or absent. Boyer (1996) MacDuffie (1995a) McLachlin (1997)Sakakibara, Flynn, Morris and Schroeder (1997) discovered that team membership has been observed in lean production implementations to be a source of both supports. Rinehart et al. (1997) noted that the practice of decentralization of authority as discussed in the lean production literature consists primarily of the transfer of technical tasks rather than a true shifting of power.

Setup time reduction: Continuously try to reduce the setup time on a machine.

Total Quality Management (TQM): A system of continuous improvement employing participative management that is centered on the needs of customers. Training, problem-solving teams, statistical methods and long-term goals are key components to recognize inefficiencies produced by the system, not people while **5S** focuses on effective work place organization and standardized work procedures.

Six Sigma

Pepper and Spedding (2010) stated that Six Sigma tries to solve problems from a data driven point of view. It focuses on process variation reduction. Projects are addressed from start to finish, and each project is controlled by a certified project leader. Bendell (2006) classified Critique on Six Sigma aims on three main aspects. The first one is the lack of taking into account the system interaction. The second one is that it is a cost driven approach instead of focusing on the customers. Thirdly, tools that are innovative and creative are neglected and only the (statistical) data analysis is taken into account.

2.7 Maintenance Analysis

2.7.1 Total Productive Maintenance(TPM)

TPM is mostly known from Japanese car manufacturers like Toyota, and was introduced in the early 1970s. The section ‘TPM philosophy’ will discuss this concept in more detail. This philosophy consists of several “pillars” that represents together the framework of TPM. The explanation of TPM is relevant because Company uses TPM.

TPM is founded by Nakajima (1988) and is a continuous improvement philosophy. Ahuja and Khamba (2008) define Total Productive Maintenance as a methodology to continuously mange, optimize and improve a supply chain by eliminating all losses, and involving all employees of the organization. The methodology aims to “increase the availability and effectiveness of existing equipment in a given situation, through the effort of minimizing input and the investment in human resources which results in better hardware utilization. TPM is applied through the entire organization and involves directors, management, support and operators. By training employees, a working culture can be created in which losses are not accepted and processes are structurally improved. Ahuja(2011) stated that the cooperation between maintenance and operations is very important, since operators shift from pure operational tasks to a more all-round shop floor management role. Tsarouhas(2007) classified TPM as an aggressive maintenance strategy that focuses on actually improving the functioning of the production equipment. Rolfsen and Langeland(2012) noted that TPM is especially used in organizations with a high level of equipment automation.

TPM pillars

According Nakajim (1988), TPM has eight different pillars. Rolfsen&Langeland (2012) stated that within an organization these pillars together form the framework for TPM. These pillars have their own direction regarding losses. Ahuja&Khamba (2008) defined each pillar in relation with operational skills. These combinations are shown in Table 2.2.

Table 2.2: TPM Pillars (AhujaandKhamba,2008)

Pillar	Operational skills
Autonomous maintenance (AM)	Carry out CILT, adjustment and readjustment of production equipment to fostering operator ownership
Focused improvement (FI)	Systematic identification and elimination of losses.
	Working out loss structure and loss mitigation through structured why-why, failure mode and effects analysis. Achieve improved system efficiency. Improved OEE on production systems
Planned maintenance (PM)	Planning efficient and effective PM, predictive maintenance and time base maintenance systems over equipment life cycle. Establishing PM check sheets. Improving mean time before failure, mean time to repair and mean time between assists.
Quality maintenance (QM)	Achieving zero defects Tracking and addressing equipment problems and root causes Setting 4M (machine/man/material/Method) conditions
Training and Education (T&E)	Imparting technological, quality control, interpersonal skills Multi-skilling of employees Aligning employees to organizational goals Periodic skill evaluation and updating
Safety, health and environment (SHE)	Ensure safe working environment. Provide appropriate work environment. Eliminate incidents of injuries and accidents. Provide standard operating procedures
TPM office	Improve synergy between various business functions Remove procedural hassles Focus on addressing cost-related issues Apply 5S in office and working areas Measurement of TPM performance

Table 2.2: TPM Pillars (AhujaandKhamba,2008)

Development management (DM)	Minimal problems and running in time on new equipment Utilize learning from existing systems to new systems Maintenance improvement initiatives, Early equipment management

CILT

An important part of TPM for production is the use of CILT-activities, which comprise of Cleaning, Inspection, Lubrication and Tightening that play an important role in order to maintain the machines and reduce its downtimes. To achieve effective CILT, every operator on the production line has its own responsibility. These activities of CILT should prevent machine breakdowns and improve the line performance.

2.7.2 Optimum Maintenance Strategy

Ramdeen and Pun, (2005) stated that the maintenance of production machinery and equipment and assurance of availability of spare parts are becoming increasingly important while manufacturers are finding it extremely difficult to hit their production targets in an increasingly competitive global market, to enable them maintain their edge and maximize their profits; they consider operational efficiency a top most priority. From research carried out by Godwin and Achara (2013), some heavy industrial segments loss as much as 30 to 40 percent of profits annually due to unplanned downtime occasioned by machine breakdowns, failure and defects. The result of the Analysis of findings from the maintenance assessment throughout 2012 reveals a significant progressive increase in the cumulative equipment downtime hours which impacted on rising maintenance cost and drop in plant output across three paint industries. In Breweries industries, adopting maintenance strategy is a key to reduce frequent stoppage, breakdown, failure and longtime changeover, set up and adjustment; which is currently affecting production performance and output. The need for an optimum maintenance strategy cannot be over-emphasized as it offers a proactive and holistic approach to maintenance towards creating additional value in maintenance system for improved maintenance productivity. Kelly and Harris (1998) noted that optimum maintenance strategy entails ensuring the plant functions (availability, reliability, product quality etc); ensuring the plant reaches its design life; ensuring plant and environmental safety; ensuring cost effectiveness in maintenance and the efficient use of resources (energy and raw materials).

2.7.3 Problem identification techniques

Look out for Six Big Losses

Overall Equipment Effectiveness (OEE) reduces and/or eliminates Six Big Losses – the most common causes of efficiency loss in manufacturing and process industries.

Table 2.3: Six Big Losses and Relationship with OEE ((Ahuja&Khamba,2008)

Six Big Loss Category	OEE Loss Category	Event Examples	Comment
Breakdowns	Down Time Loss	▪ Tooling Failures ▪ Unplanned Maintenance ▪ General Breakdowns ▪ Equipment Failure	There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss) or minor stoppages.
Chang over, Setup and Adjustments	Down Time Loss	▪ Setup/Changeover ▪ Material Shortages ▪ Operator Shortages ▪ Major Adjustments ▪ Warm-Up Time	This loss is often addressed through setup time reduction programs.
Small Stops (Minor Stoppages)	Speed Loss	▪ Obstructed Product Flow ▪ Component Jams ▪ Misfeeds Sensor Blocked, Delivery Blocked, Cleaning and Checking	Stops that are under five minutes and that do not require maintenance personnel are minor stoppages, which the root causes of this type of stops can be found.
Reduced Speed	Speed Loss	▪ Rough Running ▪ Under Nameplate Capacity ▪ Under Design Capacity ▪ Equipment Wear ▪ Operator Inefficiency	Anything that keeps the process from running at its theoretical maximum speed (a.k.a. Ideal Run Rate or Nameplate Capacity).

Table 2.3: Six Big Losses and Relationship with OEE

Startup Rejects	Quality Loss	▪ Scrap ▪ Rework ▪ In-Process Damage ▪ In-Process Expiration ▪ Incorrect Assembly	Rejects during warm-up, startup or other early production. May be due to improper setup, warm-up period, etc.
Production Rejects	Quality Loss	▪ Scrap, incorrect assembly ▪ Rework ▪ In-Process Damage ▪	Rejects during steady-state production. Check out the root causes.

Changeover (C/O) Time

Activities that results in unavailability of manufacturing equipment includes the following; tooling changes, material changes, part changes, program changes, or any other changes. These activities must be performed when equipment is stopped; they are collectively referred as machine changeovers or setup, make ready or planned down time. Creating clearly defined standard and consistently apply that standard to measure change over accurately (over time and across equipment) is very important. For changeover time reduction, we recommend step in Fig 2.8

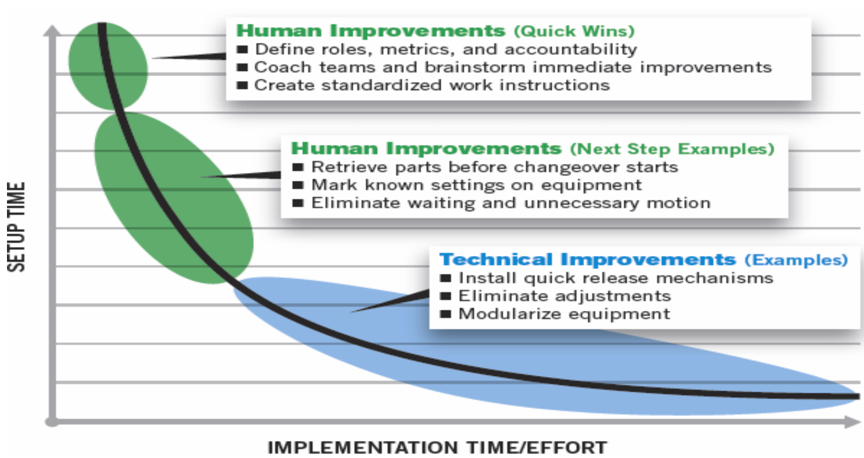


Figure 2.8: Step to Achieve Single Minute Exchange of Die (SMED)

Why?

5-“Why” method of finding root cause analysis requires to question how the sequential causes of a failure event occurs to identify the cause-effect failure path. “Why” question is ask continuously to find each preceding trigger until root causes of the incident is found, but sometimes arriving at the wrong conclusion is easy when asking “why”. “Why” question can result in multiple answers, and unless an evidence is found that indicates which answer is right, you will most likely to have the wrong failure path. To improve your odds of using the 5-Why method correctly, a simple rules and practices must be adopted. Figure 2.9 is example of sequence to achieve 5 “why” without having a wrong failure path.

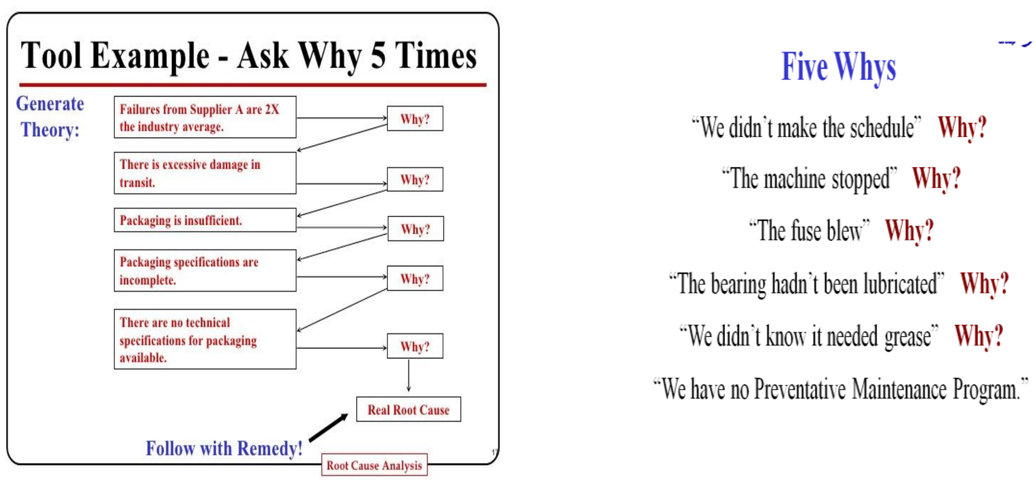


Figure 2.9: Example of Steps to Achieve 5 Why

Waiting; (A) Waiting for design sign and approval (B). Waiting for parts to be delivered. (D). Waiting for quality checks. Either the machine or operator is inactive during the process. (E). Waiting for previous jobs to finish. 2. **Defects and Rejects**; (A). Re-working errors. (B). Re-inspection and sorting, recalls, cost of scrap and reject. (C). Overtime to make production shortfalls due to poor quality. (E). Extra transportation to remove and store reject. (F); Delays in process due to rejects produced. (G); Information incorrectly recorded on job sheets, incorrect specifications and information sheets. 3. **Inventory**; (A); High level of consumables and raw materials. (B). Large amounts of racking and warehousing (C); Batching process rather than single flow. (E). Products made but not sold (F). The final sign is holding production progress or expediting meetings. 4. **Overproduction;** (A); Making in large batches that don't match daily, weekly and monthly demand. (B). Making more products or units than you can sell immediately. (C). Making products or units before they are required by the internal and external customer. (A). 5. **Over Processing**; Too many inspections or quality checks. (B). Product features not requested by the customer. (C). Large machine set-up or maintenance down time. (D). Bottlenecks in the manufacturing process. 6. **Motion**; Searching for tools and materials to complete work. (B). Handling the units more than once. (C). Turning, stretching, bending, reaching to do the work. (D). Visiting other workstations or central location to get stock, tools, consumables etc. (E). Visiting other areas for paperwork, quality checks, photo copying etc. 7. **Transportation;** (A).Unnecessary moving or handling of parts. (B). Handling equipment moving with no parts. (C). Raw materials batch sizes not matching production batch size. (D). Materials, parts, stored a long way from point of use.

Fish Bone Diagram or Cause and Effect Diagram:

Ishikawa or "fishbone" diagram (Cause and Effect Diagram) use graphical tool to expose the possible causes of a certain effect. Classic fishbone diagram is applied when causes group naturally under the categories of Materials, Methods, Machine, Environment, and Man. The benefit of Ishikawa Diagram includes but not limited to the following; It helps teams understand that there are many causes that contribute to an effect by graphically displaying the relationship of the causes to the effect and to each other. It also helps to identify areas for improvement in a production system with inherent problems. Figure 2.10 is the graphical representation of Fish Bone Diagram

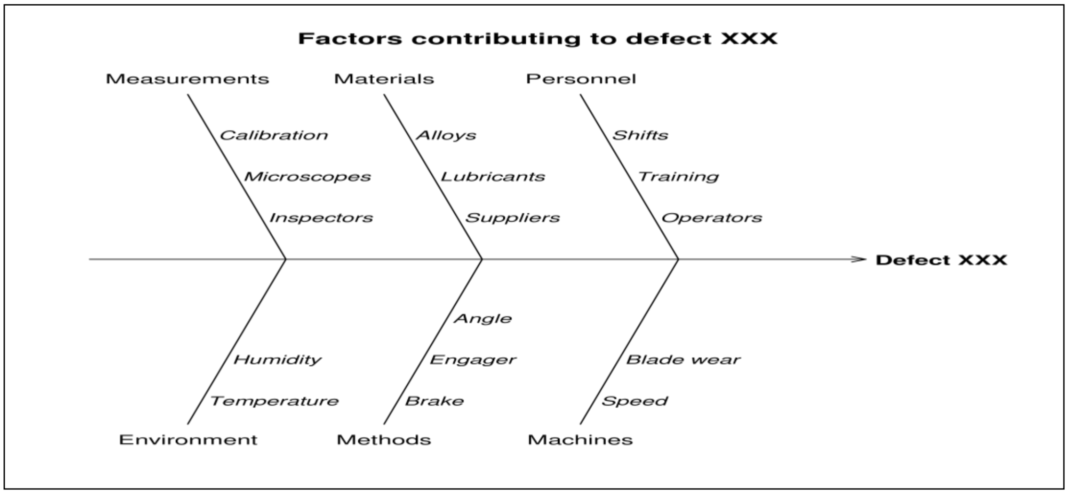


Figure 2.10: Fish Bone Diagram. Source: https://whatis.techtarget.com

2.7.4 Problem Analysis Techniques

Pareto Analysis

Using the 80:20 Rule to Prioritize

As a new manager in a newly established company, you inherited a whole host of problems that need your attention and solving the whole problem might require huge capital expenditure, you then focused your attention on fixing the most important problems. How then would you know which problems you need to deal with first? Which problems that caused by the same underlying issues? Pareto Analysis is a simple technique for prioritizing possible changes by identifying the problems that will be resolved by making these changes. Pareto approach can help you to prioritize the individual changes that will most improve the situation. Pareto Analysis uses the Pareto Principle called "80/20 Rule" with an idea that 20% of causes generate 80% results. Solving all the problems will give you almost the same result as solving the 20% of the entire problems. Figure 2.11 is illustrative – the Pareto Principle illustrates the lack of symmetry that often appears between work input and results achieved. How to Use the Tool

Step 1: Problems Identification and listing–List of all of the problems that requires your attention. Where possible, communicate to clients and team members to get their input, and draw on surveys, helpdesk logs and such like, where these are available.

Step 2: Root Cause Identification of Each Problem –Fundamental causes of each problem are identified with the following tools and techniques such as; Brainstorming, the 5 Whys, Cause and Effect Analysis, and Root Cause Analysis.

Step 3: Problems Scoring – Score each problem based on the gravity or impact. The scoring method you use depends on the sort of problem you're trying to solve. If you are trying to improve on profits, you might score problems on the basis of how much they are costing you. Alternatively, customer satisfaction improvement can be scored on the basis of number of complaints eliminated by solving the problem.

Step 4: Problems are group together by Root Cause –problems should be grouped together by cause. If three of your problems are caused by lack of material input, put these in the same group

Step 5: Sum up the Scores for Each Group – Sum up the scores for each cause group. The group with the top score becomes your highest priority, and the group with the lowest score becomes your lowest priority. Then focus on the group with highest score.

Step 6: Action Required – Causes of the problems can be tackled but deal with your top-priority problem or group of problems first and keep in mind that low scoring problems may not be worth bothering with; solving these problems may cost you more than the solutions are worth.

Figure 2.10 below shows the graphical representation of Pareto Analysis of Missed Deadline is an organization.

1. Office distractions (parties, chatting, etc.) – 6 hours/week = 36 hours.
2. Software glitches – 4 hours/week = 24 hours.
3. Communication delays between departments – 10 hours/week = 62 hours.
4. Delay in Approval – takes 3 hours/week = 18 hours.
5. Production delays-takes two weeks = 80 hours

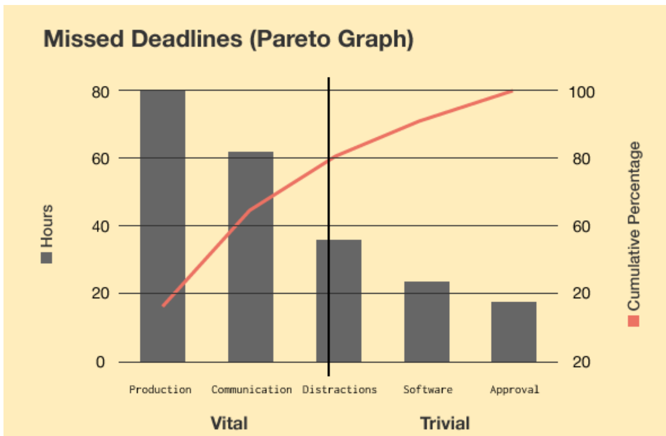


Figure 2.11: Pareto Analysis of Missed Deadline in Organization

2.8 Knowledge gapfrom the reviewed literature

Efficiency was extensively discussed in the literature review especially in the theory of constrain, conveyors, lean manufacturing, production performance optimization, machine efficiency and line efficiency as a way of increasing OEE and OPI but these critical areas which has a greater impact on the OEE and OPI were not discussed. The following areas are;

1. Optimizationof sensor speed to reduce speed losses of conveyor and increase in efficiency of in-feed and discharge of core machine.
2. Regulation of production system as a way of improving the OPI and production capacity.
3. The need to effectively design efficient quality check in the automated production system where poor quality material input can drastically reduce an optimized system. The literature consider the quality of the production output (good products, re-work and rejected products) as an input in the quality calculation of OPI, without considering the effect of poor raw material input on the production system's OPI

CHAPTER THREE

METHODOLOGY

3.1 Research Design

The research work is on the evaluation of production performance and preventive maintenance strategy in AB breweries. The research procedures/method includes:

1. Production System Analysis: Conduct work-study; process overview and data analysis of the production system of AB breweries, to understand the system problems and area of focus in solving the existing problems.
2. Application of Tecnomatrix Plant Simulation software to build a conceptual model to understand the dynamic behavior of the production systems to further discover bottlenecks in the system.
3. Verification and Validation of developed model with Simulation Software; to be sure the experiments have high degree of confidence and reliability.
4. Application of Design of Experiment to select best results or alternatives from the list of possible results of 12 experiments carried out.
5. Application of Cleaning, Inspection, Lubrication and Tightening (CILT) and Kaizen to optimize Preventive Maintenance Strategies to ensure evaluated system robustness.
6. Developing of Excel Spreadsheet Infer-face for easy data analysis and performance tracking.

Figure 3.1 shows the schematic diagram of the research design and structure

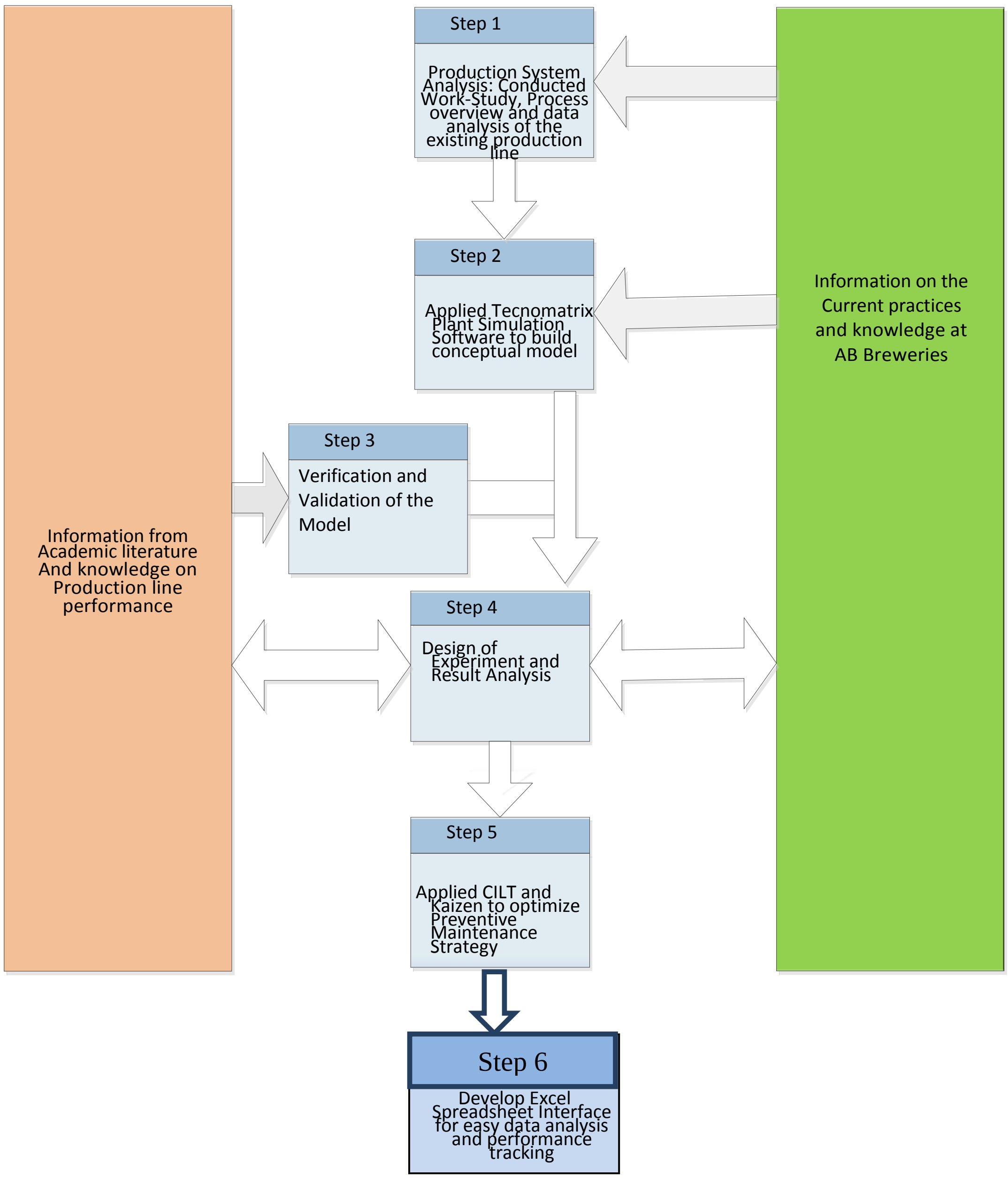


Figure 3.1: Research Design

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3.1.1 Production System Analysis

The research work was carried out in AB Brewery Industries. A work study was carried out from January 2014 to January 2017 to study the production system and obtain necessary data for evaluation. The brief overview of the production system was shown below:

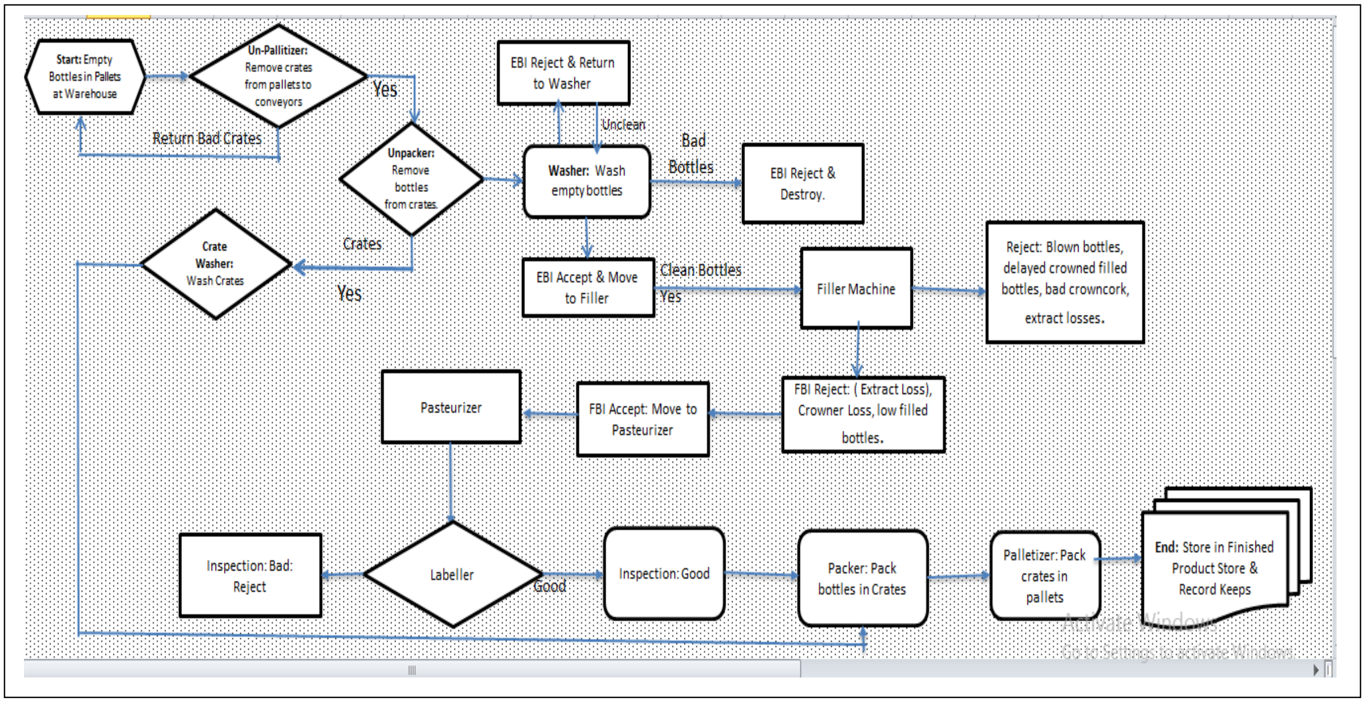


Figure 3.2: Overview of Flow Process of Packaging Line

Packaging Lines consists of returnable bottles, which means that they are recovered from the domestic market. The functioning of lines depends on the quality of the returned material. The Lines consists of several machines. A brief description of the function critical machine is given below, in sequence from start to end. Thus the production process starts at the de-palletizer and ends at the Palletizer.

Bottle Filler

Principle of filling machine

1st Operation

Construction: Ring tank consist of filling tube or vent tube, filling channel, vacuum channel and sniffing channel The Ring Tank which is rotated by electric motor consist of consist of a bowl with product, and lift cylinders around it that carries the bottle has some channels that makes filling technology work well; vacuum channel, sniffing channel, filling channel.

Operations: Bottle coming from EBI or infeed bottle conveyor passes through the bottle gap sensor which make sure that there is gap in-between the bottle (a sort of protection to infeed star wheel) and enters into the infeed star wheel, the lift cylinder pick up the bottle and lift it up, the bottle passes through the bottle present sensor, which initiate the electrical signals.

1. Initial evacuation takes place; 2. Pre-rinsing with Co2 ;3. Second evacuation ;4. Pressurizing ;5.Filling ; 6.Settling ; 7. Sniffing.

After those operations, the bottles comes out and pass through the high pressure injection to make sure it cause the bottle to foam up to displace air from the unfilled side of the bottle, the bottle now enter the crowner. The crowner crowns it and crown sensor check that there is crown in all the bottles, then it discharge through the discharge star wheel.

Filler problems

Under fill or Low filling

Low fill; causes by bad spreader rubber on the vent tube

Bad filling bellow;

Broken bottle detector is not set well

Long vent tube

When the CO_2 counter pressure in the ring tank decreases, it will cause excess foam

Crown Cork problem

Bad Crown

Crown sensor malfunctioning

Bottle Jam at the infeed or bottle jam at the discharge

Bad transfer adjustment or don’t set the height well.

The lift cylinder takes the bottle up into the ring tank

1-3 Operations is to remove air from the bottle because air will reduce the sheff life of beer (Foreign Gas)

De-palletizer:

The de-palletizer removes the crates (returned from the domestic market) from the pallets, layer by layer, and drops it on the conveyor to the de-packer.

De-packing machine (Decrater):

The depacker picks the empty bottles out of the crates. The bottles move to the bottle washer and the crates to the crate washer.

Bottle washer:

The bottle washer cleans the bottles. When the bottles are cleaned they move to the empty bottle inspection.

Crate washer:

The crate washer cleans the crates.

Empty Bottle Inspector (EBI):

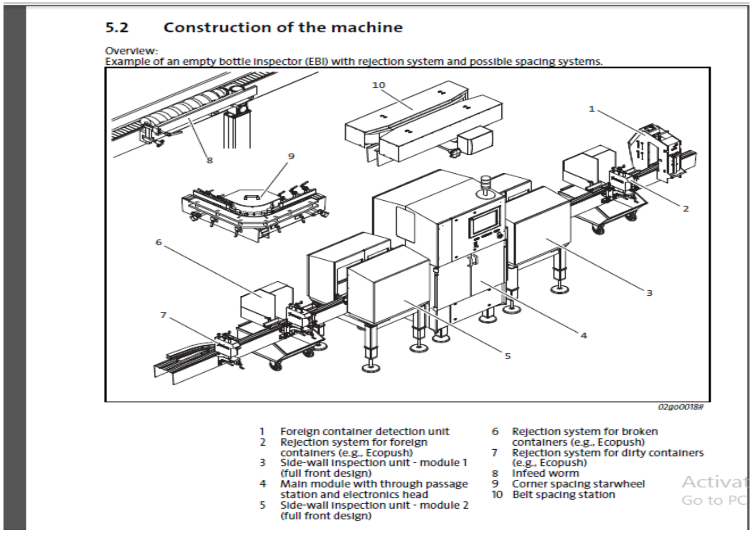


Figure 3.3: Empty Bottle Inspector -EBI (AB Breweries)

Figure 3.3 shows how EBI works. EBI is empty bottles all surface inspection machine. It has the following parts. Sorter uses line scan camera to check the shape of bottles so as to remove foreign bottles from production line to filler. It also has side wall cameras that check the side walls of bottles for dirty. There are other cameras for bottles base, bottles neck, and inner side wall. It has sensors that check for oil and residual liquid like water and caustic. Any bottle with defect is being pushed out of conveyor line that moves to the filling machine so that dirty or foreign bottles or crack bottles or one with liquid are not filled with product.

No. 1 is **Foreign Container detection unit or Sorter or contour** is a machine that uses colour camera to check the colour and shape to know if it is what you are using.

No. 2 **is Rejection System for foreign containers** or pusher or rejector is a unit that pushes out foreign or bad bottle

No 3 is Side Wall 1 and 2 inspection unit- module 1 (full front design); detect anything on the bottle side wall; label on the bottle. Infeed side wall

No. 4 is **Side Main module** with through passage station and electronic head; Belt area inspection unit it contains the base camera, neck camera and internal wall side camera, Infra-red detection, lateral neck. Base and neck inspection; Base inspection is done first before neck inspection.

No. 5 **Side –wall inspection unit-module 2** (full front design); Discharge Side wall;

No. 6 is **Rejection system for broken containers** (Ecopush); Pusher no 2 for neck or chip mouth.

No. 7 is **Rejection system for dirty containers** (E.gecopush); dirty bottles

No. 8 Infeed worm;

No. 9 Corner spacing star wheel;

No. 10 Belt spacing station;

Full Bottle Inspector (FBI):

The bottles are inspected again and are removed from the line if quality is not met. If the bottle passes the inspection they will move to the pasteurizer

Pasteurizer:

In the pasteurizer the bottles are heated to deactivate all microorganisms and enzymes that can influence the quality of the beer, and to increase the shelf life. Pasteurizer has the highest cycle time compared to the whole machine in the production line, with an average of 43.2 minutes. After the bottles are pasteurized, they will move to the labelers

Labeller:

The labelers stick three labels (front, back and the neck of the bottle). Label stands for Cold glue Plastic Label. These bottles are inspected and, if necessary there is wrong labeling, it will be removed from the line. The quality checks at this stage are strict, with a single deviation, the bottle will be removed. Perfectly labeled bottles move to the packer.

Packer (Crater):

The packer puts full and labeled bottles into a clean crate.

Crate cover:

The crate cover will put cardboard sheet on the upper side of the crate, covering the bottles (mostly with attractive marketing promotion). After this, the crates move to the palletizer.

Sorter:

Before the crates move to the palletizer, this machine spins the crates to optimize the way there are stacked on a pallet.

Palletizer:

The palletizer puts the crates on a pallet, layer by layer.

Sticker:

The sticker puts a foil and a label on the pallet. This label will be scanned and linked to an order in the information system. The system contains specific data of each pallet, such as the date of production and destination of delivery. When a batch needs to be retrieved from the market for some reason, the company can easily detect the specific batch. At the end the pallet is ready to enter the market.All these machines are connected with conveyors.

Figure 3.4 shows the complete layout of a packaging line where all the machines are exhibited. At the right side show the de-palletizer and sticker, these are the first and last machines. There are pallets returned from the market, placed in front of the Palletizer, which pack the crates in pallets.

3.1.3 Dynamic Data Collection

From week 41 to 51, the dynamic data of a production lines, data which is changing, were collected and such data were as follows; Production Output, Production Running Time, Machine breakdown, External downtimes, Planned Downtimes, Machine speed change, Buffer fill grade. These data are collected automatically with Line Monitor System (LMS) and manually by researchers and operators.

Automatic data collection

The layers of the Line Monitor System (LMS) in Figure 3.4 for automatic data collection on production lines gave insight into the functioning of the line and to improve its performance. An LMS has three tasks: monitoring, visualizing, and recording the line performance. The process of registration can consist of a host of counts, timers, signals etc. The machines and conveyors of a production line are each controlled by a so-called Programmable Logic Controller (PLC), a computer using a program code for the process tasks. The PLC's give signals or instructions to the machines. These PLC's are connected by a network. The signals of the PLC's are collected by the Supervisory Control And Data Acquisition (SCADA) system. This system visualizes the machine and line information on monitors for the operators. The operator also receives signals directly from the machines from different colour light bulbs or text displays. From the SCADA system the data is stored in a database. Dynamic data information can be collected through links with other computer systems or databases.

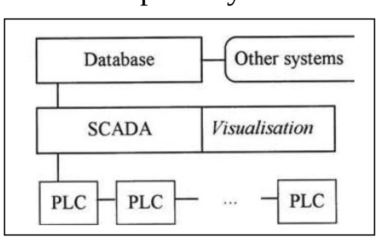


Figure 3.4: Layer of Data Monitor System

Manual data collection

The operator and researcher log production events on an event list or log book, events were also typed directly into a computer system or by pushing touch buttons on a computer screen when an event occurs.

3.1.4 Line Parameter

Production line is a series system, with the machines or machine groups connected by conveyors/buffers. This was earlier depicted in Figure 2.2, in which the buffers upstream of the core machine were full and the buffers downstream were partly empty. The line efficiency was determined by the line parameters, which were formed by the machine parameters and the buffer parameters. In these series machines, production capacities increases upstream and downstream of core machine. These were designed for each machine to cope with failures when blockage, starvation and minor machine failures occur. With the design, the smooth production flow is guaranteed especially when blockage, starvation and machine failure occur in less than 5 minutes.

Line Efficiency

The line efficiency η_{line} is a measure of the efficiency of the packaging lineduring the

period specified, and is calculated as follows:

$$\eta\text{line} = \frac{Net\ Production\ \ time}{Actual\ \ Production\ \ Time} * \frac{100\%}{1} \tag{3.1}$$

$$\eta\text{line} = \frac{Net\ Production\ \ time}{Net\ Production\ \ time + External\ \ Unplanned\ \ \ Downtime} * \frac{100\%}{1} \tag{3.2}$$

External unplanned downtime is excluded because this downtime is not caused by the operation of the packaging line itself; taking external unplanned downtime into account would be applied in OPI calculation. As the net production time is equal to the output in production units divided by the nominal line capacity, the Line Efficiency specified in production units is:

$$\eta\text{line} = \frac{Output\ \ in\ Production\ \ units}{Actual\ \ Production\ \ time * Norminal\ \ Line\ Capacity} * \frac{100\%}{1} \tag{3.3}$$

Where the actual production time (t) on the core machine (group) is taken as the actual production time and the nominal line capacity is the nominal capacity of the core machine (group). If the filler is the core machine, then the filler determines the line efficiency except for a time difference between the time of production at the filler and the time of output at the end of the line (which includes the pasteurization time of 46-60 min and the rejects and breakage after the filler (which is usually less than 1%. Therefore, in the efficiency analysis of packaging lines the focus is on the loss of production time of the filler (or core machine), which is almost equal to the difference between the actual production time and the net production time (i.e. the internal unplanned downtime at filler). Note that loss of production on the core machine cannot be recovered, so the production time of the core machine determines the (maximum) output of the line. In other words whereas efficiency analysis focuses on the reduction of internal unplanned downtime, the reduction of unused time, planned downtime, and external unplanned downtime, can obviously also improve the line performance. Finally, the output of a packaging line is a very important, simple and useful performance indicator.

3.1.5 Machine Parameter

Machine parameter comprised of machine states, the failure behavior, machine efficiency and machine production rate, which were collected during work study.

Machine states are as follows:

Running time: A machine is running when it is producing, this can be different speeds and with different reject rates. **Planned downtime**: A machine is planned down in the case the machine is stopped for planned maintenance, changeovers, not in use, etc. **Machine internal failure or breakdown**: A machine has an internal failure when the machine stop is caused by a machine inherent failure. There are often many different failures causes depending on the complexity of the machine. **Machine external failure or External downtime:** A machine has an external failure when the machine stop is caused by external factor, either caused by another part of the organization (e.g. no supply of empties, no beer, no electricity, etc.), or by the operator(s) of the line (e.g. lack of material such as labels, cartons, glue, etc.) and waiting time. **Machine Starved:** A machine is starved (or idle) when the machine stop is due to a lack of cans or bottles or cases. The machine has no input. **Machine Blocked:** A machine is blocked if the machine stopped due to a backup of cans or bottles or cases. The machine cannot output.

Machine Failure Behaviors:

The internal failure behavior of a machine, was applied in modeling and simulation, was described with two exponential probability distribution functions: a distribution function for the internal failure or repair times and a distribution function for the running times. The expectation of the failure or repair time distribution is called Mean Time To Repair (MTTR). The expectation of the running time is called Mean Time Between Failures (MTBF). These are defined as follows for the period specified:

$$\text{MTTR} = Mean\,Time\;to\;Repair = \frac{Total\;Time\;Internal\;\;Failures}{Number\;\;of\;Internal\;\;Failures} \tag{3.4}$$

$$\text{MTBF} = Mean\,Time\;Between\;Failures = \frac{Total\;\;Running\;\;Time}{Number\;\;of\;Internal\;\;Failures} \tag{3.5}$$

The total time of internal failures is simply the sum of the intern al failures during the period specified, and the running time is the total time the machine is in the state 'running'.

Machine Efficiency:

Machine efficiency was determined, which was used to calculate Overall Equipment Efficiency (OEE) of the production system. The machine efficiency $\eta_{machine}$ 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:

$$\eta\text{machine} = \frac{Total\ \ Running\ \ Time}{Total\ \ Running\ \ Time + Total\ \ Time\ \ Internal\ \ Failure} * \frac{100\%}{1} \quad (3.6)$$

The total planned downtime, external failure time, starved time, machine speed and blocked time are not taken into account for measuring the machines availability, but were used to determine the Operational Performance Index (OPI) of the production lines. The machine efficiency is equal to:

$$\eta\text{machine} = \frac{MTBF}{MTBF + MTTR} * \frac{100\%}{1} \quad (3.7)$$

Machine Production Rate

$$\text{Machine speed } (V_{mach}) = \frac{Production\ \ Output}{Production\ \ Running\ \ Time} \quad (3.8)$$

The production lines machines had continuously variable speeds, hence the need to optimal line regulation; over-speed, a low speed and one or more speeds around the nominal or core machine capacity.

Machine capacity (C_{mach}): Machine capacity, maximum machine speed for beer production was set in machine control. Machines can have different machine capacities for different product types. It was used in plotting of V-graph to determine core machine.

Nominal machine capacity (C_{nom}): The nominal machine capacity is the speed of the machine for which the group to which the machine belongs runs at the same speed as the core machine (group); it is determined by the nominal line capacity divided by the number of machines of the group.

Machine overcapacity: ($O_{mach}=C_{mach} – C_{nom}$); the machine overcapacity is the difference between the machine capacity and the nominal machine capacity.

Group overcapacity ($O_{group}=C_{group}$- C_{line}.); the group overcapacity is the group capacity minus the nominal line capacity.

Nominal/line capacity (C_{line}.): The nominal line capacity is the smallest machine (group) capacity for the specific product, i.e. the capacity of the core machine (group) for the specific product. These production rate parameters are very important in the optimization problem. It is used to plot V-graphs to determine the preceding and succeeding machines around core machine.

3.1.6 Setting the Parameter

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: the machine capacity, the length of the conveyor. Within these limits there is some room to tune the line parameters to improve the line performance.

Ideally, in the line design the slope of the V-graph 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.

3.2 Method of Analysis of production line, machine andbuffers

3.2.1 Buffer Performance Strategy

Machine capacity is the percentage with respect to core machine of 80,000 bottles per hour. It is the nominal capacity of core machine, which is 100%

According to Harte (2007) buffer performance strategy, line efficiency, lower limit efficiency and upper limit efficiency of the production line are calculated as follows;

Buffer Performance Strategy ß $= \frac{\eta_{line} - \eta_{line}^{0}}{\eta_{line}^{\infty} - \eta_{line}^{0}} * 100\%$ (3.9)

The lower limit of the line efficiency η_{line}^{0} for a series system without buffers is assumed to be the production rate of the line, which is the minimum of the machine capacities of the machines and the line availability is the product of the machine efficiencies.

Then the line efficiency lower limit or zero-buffer limit is the product of the line production rate and the line availability.

Lower Limit=$\eta_{line}^{0} = \boldsymbol{R^{low}} * \boldsymbol{A^{low}}$ (3.10)

where

Line production rate $\boldsymbol{R^{low}} = Machines\ of\ minimum\ C^{mac\,h}$ (3.11)

Line Availability =$\boldsymbol{A^{low}} = \prod_{mac\,hine} \eta_{line}$ (3.12)

Where Machine Efficiency=94% and Line Efficiency=77% from table 3.3

The upper limit of the line efficiency $\eta_{\text{line}}^{\infty}$ for a series system with infinite buffers, it is assumed that the line efficiency is the minimum of the Mean Effective Rates of the different machines. This results in the line efficiency upper limit or infinite-buffer limit.

Upper limit = $\eta_{\text{line}}^{\infty}$ = Machines of minimum $MER_{mac\,h}$ (3.13)

Where

Mean Effective Ratio $(MER_{mach}) = \eta_{machine} * C^{mach}$ (3.14)

Line Efficiency $=\eta line = \frac{Net\ \ Production\ \ time}{Actual\ \ Production\ \ Time} * \frac{100\%}{1}$ (3.15)

Line Efficiency $=\eta line = \frac{Net\ Production\ \ time}{Net\ Production\ \ Time + Internal\ \ Unplanned\ \ \ downtime} * \frac{100\%}{1}$ (3.16)

Where Actual production time and nominal line capacity are of the core machine

Machine Efficiency $=\eta mach = \frac{MTBF}{MTBF+MTTR} * \frac{100\%}{1}$ (3.17)

Machine Efficiency $=\eta mach = \frac{Total\ \ Running\ \ Time}{Total\ \ Running\ \ Time + Total\ Internal\ \ Failure} * \frac{100\%}{1}$ (3.18)

The buffer strategy performance is calculated as the difference between the actual line efficiency η_{line} and the line efficiency lower limit as percentage of the difference between the line efficiency upper limit and theline efficiency lower limit:

Buffer Performance Strategy ß $= \frac{\eta_{line} - \eta_{line}^{0}}{\eta_{line}^{\infty} - \eta_{line}^{0}} * 100\%$ (3.19)

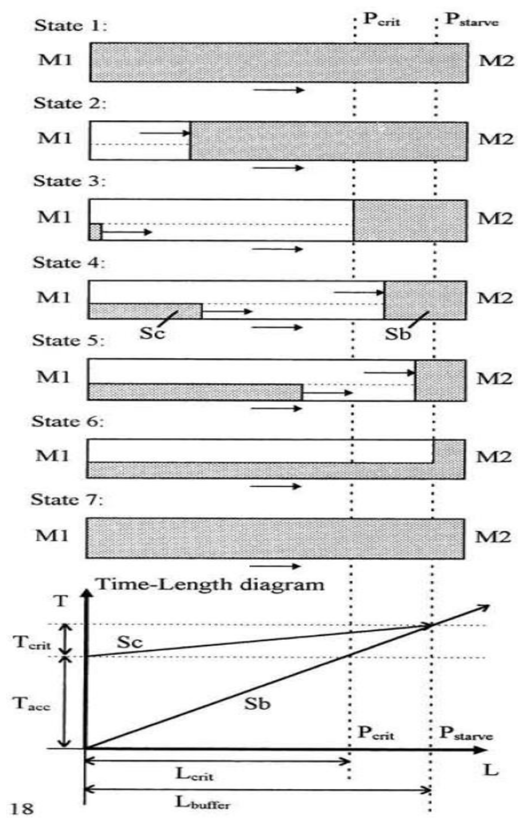
Figure 3.5 shows the seven machines of a (series system) packaging line. The Pasteurizer and Filler are considered as the core machines. The buffer upstream of this machine is full and the buffers downstream are partly empty.

Figure 3.5: Component of Packaging Line

Table 3.1 shows the data from the calculation of the machine capacities as a percentage with respect to the core machine (Filler), Machine Efficiencies and Machine MER.

Anti-Starve Buffer

The purpose of anti-starve buffers is to prevent the starvation of the core machine. These buffers are therefore found upstream of the core machine. The idea1 state is when the buffer is full; the machine after the buffer is constantly supplied with bottles. When failure occurs before the buffer, the machine after the buffer can continue to run and drains the accumulated containers from the buffer. This lasts for a certain period of time, the so-called accumulation time. At the end of this time period the machine that stopped, has to start running again, otherwise the machine after the buffer stops because it is starved. Because of the overcapacities the ideal state is recovered.



State 1:
The buffer is fully filled and working. The machines MI and M2 are both running. This situation is called the ideal state.

State 2:
Machine MI has a failure or is starved by a failure further upstream. The buffer content is decreased by M2 with speed Sb. A gap is created in the bottle or can flow, because MI is no longer producing.

State 3:
The bottle/can flow reaches the 'critical point' Pcrit by the critical time Tcrit=Lbuffer/Sc. No later than this point MI has to start running, such that with speed Sc the overtaking container flow can fill up the created space, before it reached the starve point P-starve of machine M2 (i.e. the sensor that signals the lack of bottles and stops machine M2).

State 4 and 5:
The overtaking flow approaches the end ofthe production flow, because of the speed difference. The production flow disappears with the machine production speed and the overtaking flow draws near with the speed of the conveyor.

State 6:
The overtaking flow reaches the production flow, before it has reached the starve point. M2 can continue running, without noticingthe failure of machine MI

State 7:
Because M2 runs at a lower speed than MI (i.e. MI has overcapacity with respect to M2), the buffer has filled up again. The ideal state is recovered

Let machine A and machine B be the machines before and after the buffer as shown in figure, the flow is from A to B. The core machine is B or one of the following machines. The objective of the buffer between machine A and B is to prevent machine B from becoming starved. Machine A has a higher machine capacity than machine B to catch up when machine A has had a failure.

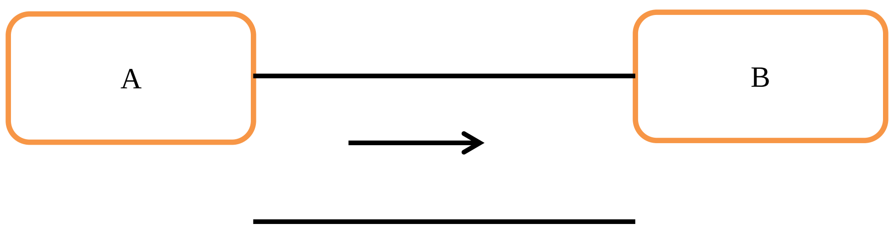


Figure 3.7: Two Machines connected by buffer

The accumulation rate is equal to the rate of the accumulation of the buffer and the MTTR of machine A:

$$\text{Accumulation rate}=\frac{T_{acc}^{nom}}{MTTR_A} = \frac{Accumulation\ \ Capacity\ \ in\ bottles}{C_B^{nom} * MTTR_A} \tag{3.21}$$

The accumulation rate is also equal to the maximum buffer content divided by the average decrease of the buffer content by machine B during the average failure time of machine A. For instance, an accumulation rate of 1.5 means that the buffer provides an accumulation of 1.5 times the average failure time of machine A. The higher the accumulation rate the less influence the failures of machine A have on machine B. The recovery rate is equal to the increase of the buffer content during the average run time of machine A because of the speed difference between machine A and B, divided by the average decrease of the buffer content by machine B during either the nominal accumulation time or the average failure time of machine A.

$$\text{Nominal recovery rate}=\frac{MTBF_A*(C_A-C_B^{nom})}{C_B^{nom}*T_{acc}^{nom}} \tag{3.22}$$

$$\text{Mean recovery rate}=\frac{MTBF_A*(C_A-C_B^{nom})}{C_B^{nom}*MTTR_A} \tag{3.23}$$

The higher the recovery rate the more failures of machine A will be covered. The recovery rate is a measure for the ability of a machine to catch up its own failures. For instance a recovery rate of 2 means that the average run time of machine A is 2 times as long as the time needed to recover the average stop of machine A. Note that the mean recovery rate is equal to the nominal recovery rate multiplied by the accumulation rate.

$$\text{Buffer Efficiency }\ \eta_{Buffer}^{AB}=\frac{(T_{Stop}^{A}-T_{Starve}^{B})}{T_{Stop}^{A}} \tag{3.24}$$

For instance a buffer efficiency of 60% means that on average a stop time of one minute on machine A would result in 24 seconds of starve time on machine B, i.e. 36 seconds are covered by the buffer. If there would be no buffer the starve time of machine B would be equal to the stop time of machine A.

If the buffer efficiency is negative then either every stop of machine A stops machine B, the buffer itself is causing problems, there is a delay before machine B starts after a stop, or machine B has an higher capacity than machine A.

The value of this buffer efficiency can be distorted by macro-stops which are longer that the accumulation time of the buffer and therefore cannot be covered by the buffer (for instance a machine failure of an hour will cause a stop of almost an hour on the other machines). Then it is better to use the buffer efficiency for the number of occurrences:

$$\eta\#_{Buffer}^{AB}=\frac{\text{Number of stops of machine A}-\text{Number times Machine B is starved}}{\text{Number of stops of machine A}} \tag{3.25}$$

A buffer efficiency of 60% means that six out of ten stops on machine A do not result in a stop of machine B, i.e. four out of ten stops of machine A do result in a starvation of machine B.

Again only the stops of machine A not caused by machine B should be counted. If there would be no buffer the number of stops of machine A would be equal to the number of times machine B is starved.

Anti-Block Buffer

The purpose of anti-block buffers is to prevent the blockage of core machine. These buffers are found downstream of the core machine. The ideal state is when the buffer is empty, i.e. only the part of the conveyor used for transport is full. When failure occurs after the buffer, the machine before the buffer can continue running and fills the buffer with bottles. This lasts for a certain period of time, the so-called accumulation time. At the end of this time period the machine that stopped, has to start running again, otherwise the machine before the buffer stops because it is blocked. Because ofthe overcapacities the ideal state is recovered.

State 1:
The transport part of the conveyor is filled; the buffer part of the conveyor is empty. Machine M2 is running. This situation is called the ideal state.
State 2 and 3:
Machine M2 has a failure or is blocked by a failure further downstream. The backup of containers builds in the direction of machine M1.
State 4:
The backup reaches the ' critical point', M2 has to start running now, otherwise M1 gets blocked (i.e. the sensor that signals the backup of bottles stops machine M1).
State 5 and 6:
Machine M2 has started running again.
Because of the overcapacity of M2 with respect to MI the container flow decreases. The buffer part of the conveyor is drained.
State 7:
The ideal state is recovered.

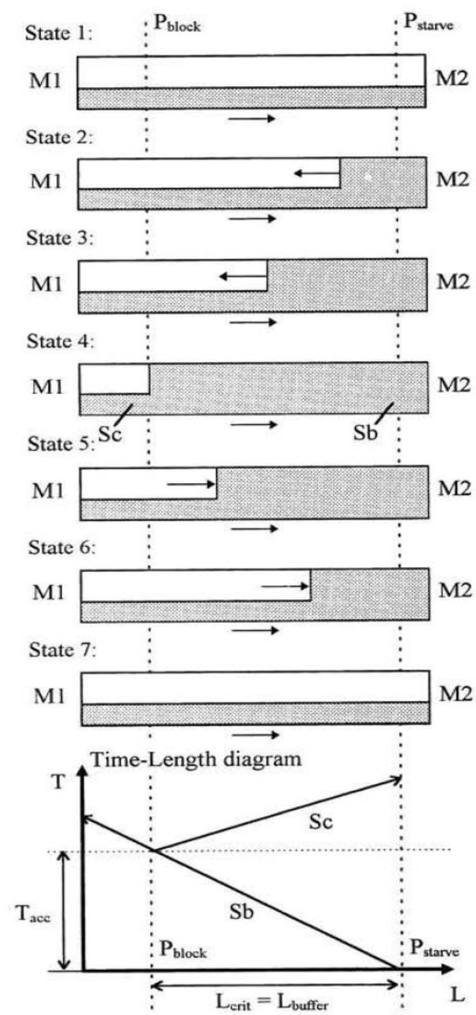


Figure 3.8: Anti-Block Buffer

Anti-block buffers

Let machine A and machine B be the machines before and after the buffer as shown in figure, the flow again is from A to B. Now, however, the core machine is machine A or one of the previous machines. The objective of the buffer between machine A and B is to prevent machine A from becoming blocked. Machine B has a higher machine capacity than machine A, to catch up when machine B has had a failure. The accumulation rate is equal to the rate of the accumulation of the buffer and the MTTR of machine B:

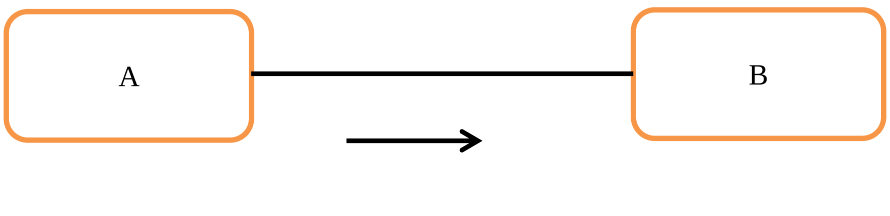


Figure 3.9: Two Machines connected by buffer for Block Analysis

The accumulation rate is equal to the rate of the accumulation of the buffer and the MTTR of machine A:

$$\text{Accumulation rate} = \frac{T_{acc}^{nom}}{MTTR_A} = \frac{Accumulation\ \ Capacity\ \ in\ bottles}{C_B^{nom} * MTTR_A} \tag{3.26}$$

The accumulation rate is also equal to the maximum buffer content divided by the average decrease of the buffer content by machine B during the average failure time of machine A. For instance, an accumulation rate of 1.5 means that the buffer provides an accumulation of 1.5 times the average failure time of machine A. The higher the accumulation rate the less influence the failures of machine A have on machine B. The recovery rate is equal to the increase of the buffer content during the average run time of machine A because of the speed difference between machine A and B, divided by the average decrease of the buffer content by machine B during either the nominal accumulation time or the average failure time of machine A

$$\text{Nominal recovery rate}=\frac{MTBF_A*(C_A-C_B^{nom})}{C_B^{nom}*T_{acc}^{nom}} \tag{3.27}$$

$$\text{Mean recovery rate}=\frac{MTBF_A*(C_A-C_B^{nom})}{C_B^{nom}*MTTR_A} \tag{3.28}$$

The higher the recovery rate the more failures of machine A will be covered. The recovery rate is a measure for the ability of a machine to catch up its own failures. For instance a recovery rate of 2 means that the average run time of machine A is 2 times as long as the time needed to recover the average stop of machine A. Note that the mean recovery rate is equal to the nominal recovery rate multiplied by the accumulation rate.

$$\text{Buffer Efficiency } \eta_{Buffer}^{AB} = \frac{(T_{Stop}^{A}-T_{Starve}^{B})}{T_{Stop}^{A}} \tag{3.29}$$

For instance a buffer efficiency of 60% means that on average a stop time of one minute on machine A would result in 24 seconds of starve time on machine B, i.e. 36 seconds are covered by the buffer. If there would be no buffer the starve time of machine B would be equal to the stop time of machine A.

If the buffer efficiency is negative then either every stop of machine A stops machine B, the buffer itself is causing problems, there is a delay before machine B starts after a stop, or machine B has an higher capacity than machine A.

The value of this buffer efficiency can be distorted by macro stops which are longer that the accumulation time of the buffer and therefore cannot be covered by the buffer (for instance a machine failure of an hour will cause a stop of almost an hour on the other machines). Then it is better to use the buffer efficiency for the number of occurrences:

$$\eta\#_{Buffer}^{AB} = \frac{\text{Number of stops of machine A}-\text{Number times Machine B is starved}}{\text{Number of stops of machine A}} \tag{3.30}$$

A buffer efficiency of 60% means that six out of ten stops on machine A do not result in a stop of machine B, i.e. four out of ten stops of machine A do result in a starvation of machine B. Again only the stops of machine A not caused by machine B should be counted. If there would be no buffer the number of stops of machine A would be equal to the number of times machine B is starved.

3.2.2 Machine Efficiency Analysis

The core machine is of importance; because the production time lost on this machine cannot be recovered (i.e. it results in line efficiency loss). The part of the line causing the most core machine stops can be located; this is either the core machine itself (i.e. core machine failures), upstream of the core machine (core machine starvation), or downstream of the core machine (core machine backup). The analysis then focuses to that part of the line.

Goal

The machine event summary, pie chart and machine efficiency give a quick overview of the performance of each machine during the period specified, and especially the coremachine.

Data

The data needed for the machine event summary table are:

1. Total time that a machine was in each of its possible machine states,
2. Number of occurrences of each machine state,
3. Minimum, average and maximum event duration for each machine state
4. Standard error of the event duration

The data needed for the machine pie chart are:

1. Total time that a machine was in each of its possible machine states.
2. Time period specified which ought to be equal to the sum over the total time that the machine was in each of its possible states.

The data needed for the machine efficiency are:

1. Total time that the machine was running
2. Total time that the machine had an internal failure

The following machine event states for Filler were developed for machine analysis. On each row the total time of the state, the number of state occurrences, the minimum, average, and maximum event duration of the machine state, and the standard error of the event duration.

Table 3.3: Machine event states for Filler in seconds

Machine State	**Sum(s)**	**Number**	**Mean**	**Min**	**Max**	**Std Error**
Running	22163	112	198	12	554	16
Internal Failure	1354	32	41	7	223	15
Starved for bottle	1742	27	65	53	242	24
Blocked by bottles	3117	59	53	23	139	19
Lack of Material	424	12	35	19	77	34
Total	28,800					

$$\text{Machine Efficiency} = \frac{Running\ \ Time}{Running\ \ Time + Internal\ \ machine\ \ failure} = \frac{22163}{22163+1354} = 94\%. \qquad (3.31)$$

$$\text{Line Efficiency} = \eta\text{line} = \frac{Net\ \ Production\ \ time}{Net\ \ Production\ \ Time + Internal\ \ Unplanned\ \ downtime} * \frac{100\%}{1} \qquad (3.16)$$

$$\textbf{Line Availability} = \boldsymbol{A^{low}} = \prod_{machine} \eta_{line} \qquad (3.12)$$

Where Machine Efficiency=94% and Line Efficiency=77% from table 3.3

The starved for bottle, blocked by bottles and lack of material are very important in the calculation of line efficiency. This is because production loss at Filler, which is the core machine, is the production loss of the production lines.

From the table, a total 28,800 seconds were lost at the core machine due to the above machine states.

3.2.3 V-graph Analysis

Core machine has machines on either side with extra capacity to restore the accumulation after a failure has occurred and the overcapacity increases for each machine going upstream or downstream from the core machine. The graph of the machine capacities has a 'V' -shape with the core machine at the base. The V -graph of a packaging line is basically a graph of the machine capacities in the sequence of the line. The V -graph can be expanded with the Mean Effective Rate of the machine, which gives the effective V-graph (using machine efficiencies). The actual line efficiency can also be shown. A more detailed V -graph shows a bar for each machine and the machine state totals are shown as bar segments of each machine bar. This V-graph gives an overview of the machine event summary for the machines of the line. The V -graphs can help identify the bottleneck machine, as this is the machine which has many internal failures, and the preceding machine has a lot of block time and the succeeding machine has a lot of starve time.

Goal

The V -graph creates a line view instead of viewing the machines and buffers separately; this means that machine interaction can be seen on a global level. It also helps to identify the bottleneck machine of the packaging line.

Data

The data needed to create the V-graph are:

1. Line component system, i.e. a description of the machines of the line and where they are connected.
2. Machine capacities for each machine
3. Mean Effective Rate (MER) of each machine, or machine efficiency of each machine to calculate the MERs

$$\text{Mean Effective Rate } MER_{mac\,h} = \eta_{mac\,h} * C^{mac\,h} \tag{3.32}$$

Where $\eta_{mac\,h}$ is machine efficiency

$C^{mac\,h}$=machine capacities

The machine with the lowest M.E.R. is called the bottleneck machine, i.e. the machine with the lowest effective production capacity. In keeping with the design this should be the core machine. The mean effective rate of the bottleneck machine gives the upper limit of the efficiency

$$\text{Machine state bar segment} = \frac{Total\ Time\ of\ Machine\ State}{Total\ Time\ of\ Period\ Specified} * Machine\ Capacity \tag{3.33}$$

The bottleneck machine is then identified as the machine which transforms backup into starvation, i.e. the previous machine is blocked and the next machine is idle, whereas the machine itself has few starvation and backup, but a lot of failures (or loss of speed). Filler is the core machine.

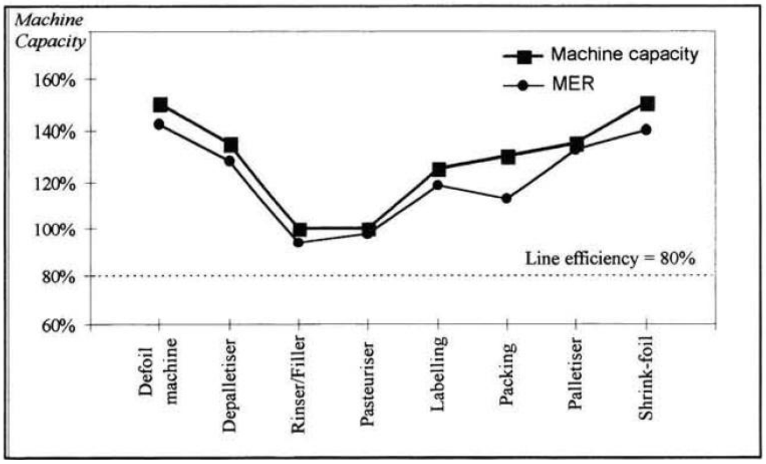


Figure 3.9: V-graph: Machine capacities, MER and Line efficiency

The main use of the V -graph is the overview it gives of the machines and buffers of the line. It is a tool to detect exceptions and bottlenecks. The V-graph is useful in comparing different packaging lines.

3.3 Statistical Analysis

In general statistical analysis is used to confirm impact of certain observed quantities on the production line performance. Pareto, Cause and Effect Analysis were used identify the distribution of the machine behavior, external and planned downtime.

Pareto Analysis

Machine Breakdown, Planned and External downtimes were collected from production line 1, 2 & 4 from week 38 to week 52. The raw data were grouped in external, machine and planned downtimes. Again, it was grouped in 4M (Machine, Method, Material and Man) after which Pareto graph was plotted to know the area of focus in tackling the problems of downtimes.

Cause and Effect Analysis

The machine breakdown, external downtime and planned downtimes were re-grouped into 4M (Machine, Method, Man and Materials) to analyze the effect of each component on the production loss and production line inefficiency. Week 38 to Week 52 of machine breakdown, planned downtime and external downtime were used.

Correlation Analysis

Correlation analysis of the running time against production output is calculated to establish worthiness to consider the impact of running time, which is independent variable on the production output. The coefficient of determination is also calculated to establish the percentage of output problems known and that of unknown. Equation (i) is for a single variable because running time is compared with production output at a constant nominal speed.

The correlation t in equation (i) is used to find the relationships between independent variables and dependent variable.

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \tag{3.34}$$

<u>Coefficient of Determination r^2</u>

Coefficient of determination enables us to identify the percentage of the problems known and the percentage of the problems unknown.

<u>Performance Measurement</u>

OEE was used in this research to measure machines efficiency for productivity improvements. Machine inefficiencies were grouped into three categories for analysis and better understanding of the manufacturing process.

OEE/OPI Calculation

OEE = Availability x Performance x Quality (3.35)

$$\text{Availability} = \frac{Running\ \ Time}{Total\ Time} * 100\% \quad (3.36)$$

$$\text{Performance} = \frac{Total\ Count}{Target\ \ Count} * 100\% \quad (3.37)$$

$$\text{Quality} = \frac{Good\ Count}{Total\ Count} * 100\% \quad (3.38)$$

$$\text{OEE} = \frac{Final\ \ Machine\ Run\ Time}{Planned\ \ Machine\ Run\ Time} * 100\% \quad (3.39)$$

OPI Analysis

OPI was used to measure the performance of the production lines and the entire organization relating to the production output and set production targets.

3.4 Development of Conceptual Model from real life of conveyor and sensors

Figure 3.10: Sensor on Conveyor

Conceptual module was developed with the model overview of beer bottle movement.

Conveyors are used to transport the beer from one machine to another. The conveyors have different sizes in width as well as in length. A conveyor can also be used a as buffer. Van der Duyn Schouten, Vanneste (1995) stated that buffer is provided in order to cope with unexpected failures of the machines. Buffer may equally cause interruptions of the production process. This is in line with the current situation at the company where some conveyors are used as buffers. The speed (level) of a conveyor is predetermined and programmed into the Information System. The conveyors have different speed levels in order to comply with the needs of the next conveyor/machine and timing of switching speed levels is dependent of the occupation of the buffer (number of bottles on the conveyor). Sensor measures the occupation of the buffer. In Figure 3.10 is a picture of regular sensor at the line. On each conveyor one (or sometimes more) sensor is (are) located. The sensor is the metal ‘arm’ at the left side of the picture. These sensors are triggered with the presence of the bottles; the bottles will push the metal arm towards the left fence. Sensors are located in such a way that bottles will not directly trigger these sensors when they arrive at the buffer. Sensors are triggered only when bottles stagnate and enumerate, due to the fact that machines further in the line are already stopped producing or when the machine is in failure as shown in figure 3.10. Sensors are mostly triggered (yellow sensors) when the buffers are full till the corresponding sensor. When succeeding machine is not producing, the bottles before this machine will enumerate and accumulate, spread out and hit the sensor. Two sensors are present on the line: switches and photocells. A switch must be triggered physically with a bottle while photocell beams a laser to a reflector and is triggered when the beam is interrupted by beer bottle.

1. Ideal situation: Machine produces

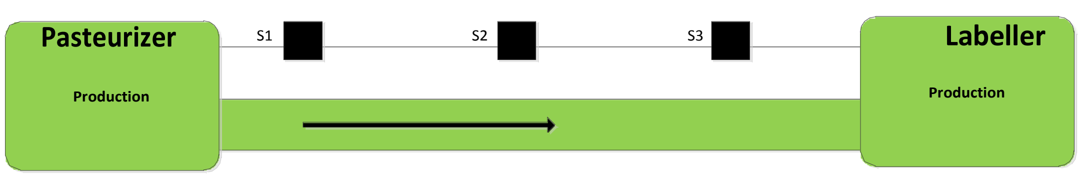
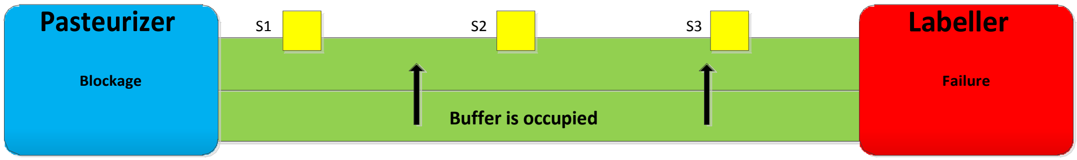


Figure 3.11: Machine is producing



2. Third sensor is triggered due to machine failure

Figure 3.12: Machine in failure mode and third sensor triggered

Figure 3.11 show the ideal state of machine when it is producing, without failure, blockage and starvation, while Figure 3.12 shows an example of how the sensors are located and triggered as failures and accumulation of bottles on conveyor. In reality there are more sensors and conveyors placed between the pasteurizer and Labeller. Furthermore the figure gives only a situation of blockage where the buffer is completely filled. As this occur, the buffer between Labeller and Pasteurizer will be completely filled and Pasteurizer will have a blockage (no sensor is triggered) as a result of blockage as shown in figure 3.12

Manufacturing Execution System (MES)

The company uses information system called MES to register all the different machine states and create visibility among the machine conditions. A print screen of the machine status of 8-hour shift

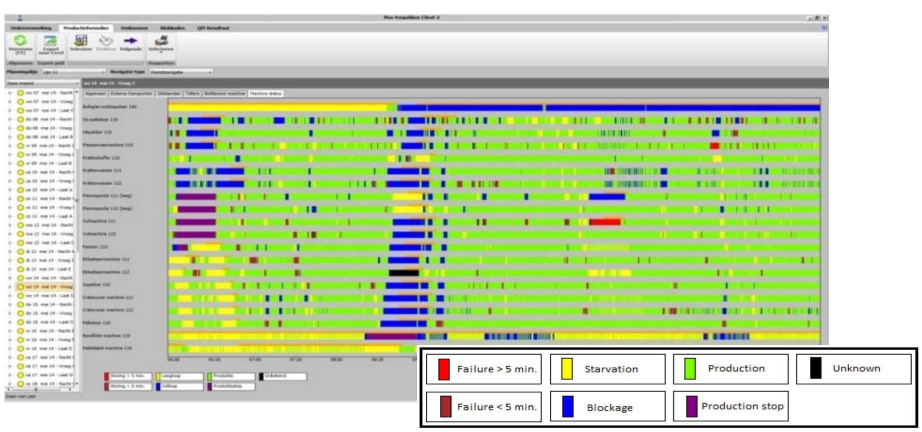


Figure 3.13: MES DNA Strand-8 Hours Work Schedule

3.4.1 Conceptual Simulation Modeling of Beer Bottles

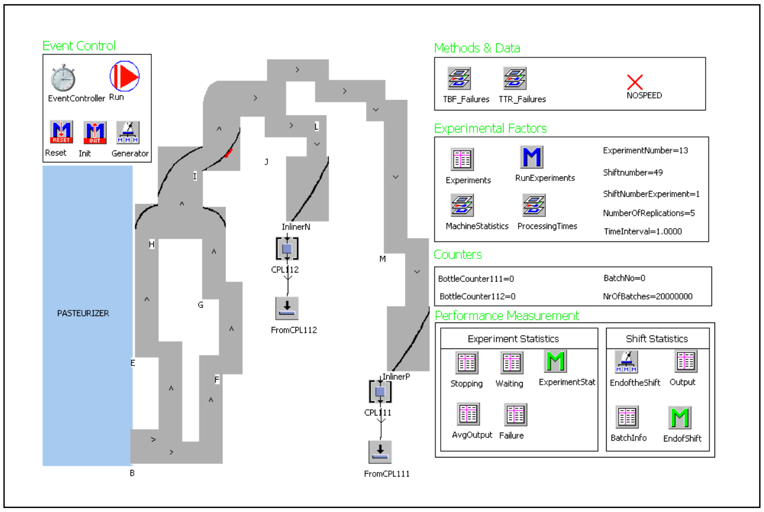


Figure 3.14: Built Simulation Model

In Figure 3.14, the simulation model developed considered Star bottles in bend and straight line and also the processing time, waiting time, stopping time and the outputs during simulation. Simulation model is used in this experiment to simplify the real-life situation of the Star Bottles (SBs) production line and it is divided into three lines that depict the conveyors. The length and width of the lines were developed on scale to transport beer bottles to Labeller Machines. This model focused on the behavior of the bottles when changing from conveyor part. In real life the SBs are positioned in multiple rows next to each other. This makes it different compared to an assembly line, where products are positioned in a single line.

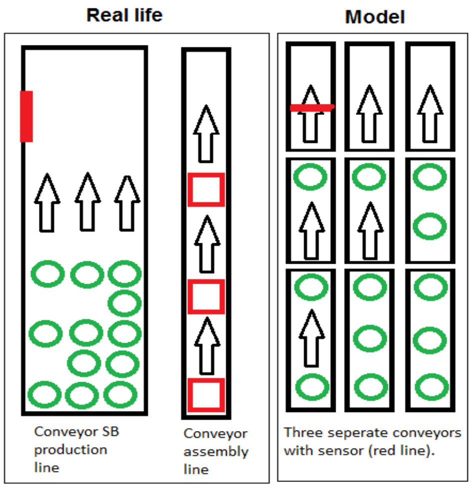


Figure 3.15: Conveyor Belt - Differences In Real Life And Simulation

Figure 3.15 showed the Real life difference between the SB line and an assembly line. The green circles are SBs and the red squares are example products in assembly line, situations are compared. These are generally large products and transferring in single rows. SBs cannot be modeled in multiple rows next to each other. To simulate the movement of each different SBs across the line, the lines were split into three conveyors.

Sensors are triggered when bottles hit the sensor in real life and it can only occur when a conveyor is occupied. In real life, the sensor is placed vertically at one side of the conveyor while in model, a sensor could only be placed horizontally confiscating a total line, shown in Figure 3.21 'Model' with the red line. In model, sensor is triggered every time when a single bottle passes through it and the sensor is denoted by the horizontal red line. In order to prevent that a sensor is triggered by every bottle, first the conveyors were divided into multiple parts. When a SB enters a conveyor with red line, a sensor is triggered which can determine how much SBs currently on the conveyor. The occupancy can be determined when capacity is known and when this conveyor in the model is occupied; the sensor is triggered, just like in real life.

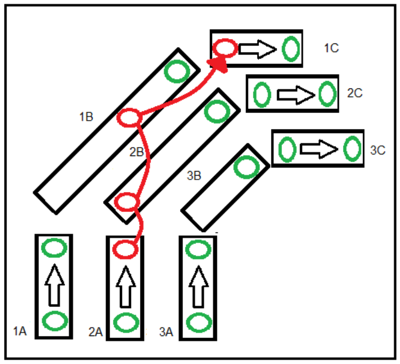


Figure 3.16: Behavior of aSBIn a bend

The model is used to determine the production balance between the LABELLERs, if you consider Figure 3.16, the movement of Star Bottles (SBs) is shown in the conceptual model. This conveyor consists of a bend and SB will move in a centrifugal force towards the outside of the bend as it is done in real life.

Figure 3.22 consists of three line conveyors 1, 2 and 3 and these conveyors were separated into three parts, A, B and C. Bottles on the conveyor are drawn with green and red circles, in conceptual model a red SB must moves from 2A to 2B to 1B to1C towards the outside of the bend, which equally happens in real life. Therefore the conceptual model takes into account the distribution of the SBs between conveyors. From the movement, the possible successor of a SB is easily determined because it is not possible for a SB to move from 1A to 3B, if a bend 'turns' right.

The destination table determines the behavior of a SB. A distinction was made between straight lines and bended lines. Bottles on a bended line have a tendency to movecentrifugally towards the outer of the bend. This is deterministic process, which is modeled with priorities. Figure 3.20 explains the behavior of a bottle in a bend. A SB actually wants to movecentrifugally towards the outside of the bend.

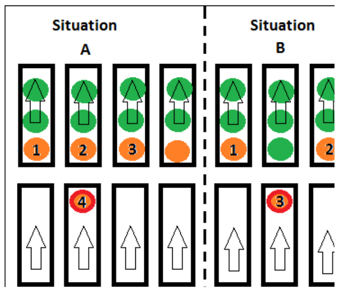


Figure 3.17: SB Bottles in straight lines

There are four possibilities in conceptual model where the SB can flow after triggering a sensor at the ‘end of the line’ in Figure 3.17. There are situation A and B with different possibilities shown with numbers. Consider the red SB with number 4 in it. There are four succeeding options for the SB, which includes; number 1, 2, 3 and 4. The SB can move to three positions: 1, 2 or 3 while Number 4 means that the SB stays on the same position. For SB to remain in its original position, the position of 1, 2, and 3 must not be available. A space is at the right side of number 3, but it is not a possible successor. Because the distance is too large, it is not possible for SB to move from position 4 to space after 3. Therefore determining the possible successors is the first step in this conceptual model, which has been determined.

The second step is to determine the occupancy of the first position from the three positions with orange circles, which is done by determining the capacity of the line and counting the number of SBs on this line. In situation B, the middle conveyor is occupied, and that it is not a possible successor anymore. If after counting, the capacity is equal to the counted SB on the line, then the succeeding conveyor is occupied and the second step is determined.

Prioritizing the possible successors is the third step and it is down by considering two different scenarios, a straight line and a bended line. In a straight line the SB will possibly move in a straight line. In Figure 3.17 this means that the red SB (with #4) will move to number 2 with priority 1. SB will move to position 1 or 2 in situation B with equal priority in a straight line and therefore the chance of moving to these positions is random and equal. Considering a bent line the chances are deterministic because SBs must move toward the curved side of the bend. As explained in Figure 3.20, the SBs will move to the outside of the bend. Therefore considering SB in Figure 3.16, it will from current position to position 1C with priority 1, to 2C with priority 2 and to 3C with priority 3. These priorities are determined beforehand, and are input data to this conceptual model. The SB will always move to the first position if there is a possible successor. Option 4 is chosen when there is no possible successor, which makes the SB remain in its original position and is therefore on blocking list. All the blocked SBs will be in a blocking list waiting to move to a possible successor.

The sensor that triggers the blocking list was on the succeeding production line when the first position becomes empty, a sensor checks whether there are Star Bottles (SBs) on the blocking list. When there are Star Bottles (SBs) on the blocking list and check if the SB in the list is allowed to fill the first position, as described in Figure 3.18. Then, it will pick the SB which is ranked highest in the blocking list (longest waiting), and deleted it from the blocking list. Star Bottle on the blockings list has preference above a part that triggers at the end of the line, and would want to move directly from a conveyor.

Consider Figure 3.18 the red SB (4) is located in the blocking list.

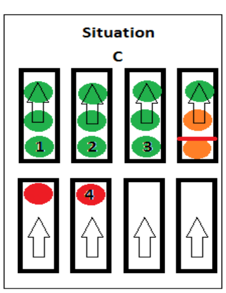


Figure 3.18: SBs in Blocking

However, the orange (first) position is not a possible successor of the red Star Bottles (SBs). SB with number 3 will eventually moves to the orange position since the conveyors will be in constant flowing as obtained in real life, and it is taken into consideration in the conceptual model.

FLOW CHART FOR ANALYSIS

In order to summarize the previous steps, two flowcharts are created. Figure 3.19 describe the flow chart of a moving a SB over the lines.

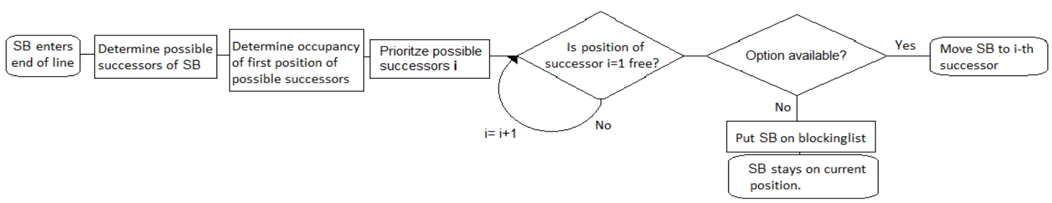


Figure 3.19: Flowchart Conceptual Model 1A - Moving SB Forward

In Figure 3.20 describe how another blocking list is triggered.

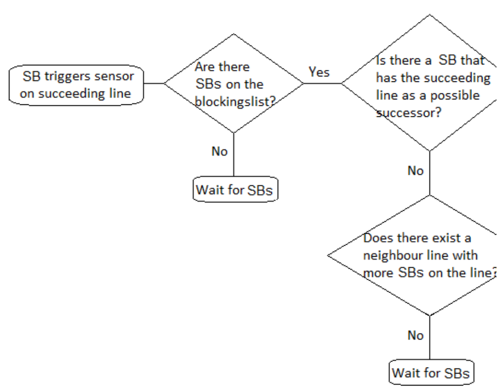


Figure 3.20: Flowchart Conceptual Model 1B - Take SB from Blocking List

3.4.2 Model Overview of Line Regulation in conceptual model

There is a sensor (sensor 10) located at part H/I. The sensor ensures that Labeler (CPL 112) will start producing when triggered, and stops producing when it is not triggered anymore.

The Sensor is located in the conveyor line that is with orange circles and because of the separated conveyor lines; Labeller CPL112 is modeled to start producing by counting the amount of Star Bottles (SBs) on the conveyor that pass through the sensor. There were three possible positions on the conveyor and when all three positions are occupied, the sensor should be triggered. Therefore it is modeled that when the number of SBs on the conveyor with the sensor is equal to three, the processing time should go to nominal speed. If all three positions are empty for 30 seconds, CPL112 will stop. This modeling is done for all relevant sensors.

Furthermore, the conceptual model works with aggregated sizes of Star Bottles (SBs). In real life every hour 70,000 SBs are on the conveyor and staying in the system for several minutes, but to mimic the real life situation with conceptual model, it will cost a lot of processing time, therefore conceptual model uses aggregated size of 1:100, which means that 1 SB in conceptual model is equal to 100 bottles in real life.

Assumptions

Several assumptions were made because it is almost impossible to approximate a real life situation. The assumptions are as follows;

1. No bottles will collapse on the production line, zero losses due to bad quality of the material.
2. Processing times of machines have fixed values.
3. The average mean time to failure and mean time to repair of the last year is representative and is used for the model.

4. The lines/conveyors will not fail/ have breakdowns because in real life it is negligible but machine breakdown is included in the model.
5. No maintenance activities have to be done.
6. Extra material is available and setup times are zero. Some machines require availability of extra material in order to fulfill its activity (e.g., the labeling machine needs labels).

We use several components for the simulation model. These five main components are:

Input data. This is data that will not be changed during the experiments. It is implemented once, and will not be influenced.

Stochastic variables: The values of these variables are subject to variations due to chance (e.g., a machine failure).

Experimental factors: These are controllable variables, set by the experimenter and can be different per experiment.

Output data: This data results from a run of an experiment. It is influenced by the stochastic variables and experimental factors.

We use the input data with the stochastic variables and the experimental factors which results in the output data.

Machine availability: In the conceptual model the machine availability includes the machines that are not modeled (fillers & packer) but have an influence on the machines described in the conceptual model. For example, the impact of starvation, blockage and failures of machine outside our scope on the machines modeled. It also includes the breakdowns of the machines modeled.

3.5 Experimental Verification and Validation through Model Simulation

Verification tool used in Tecnomatrix Plant Simulation was animation. When experiment was running, Star Bottles (SBs) were seen as movable units, in animated form. These animations helped to know when the beer bottles stuck on a certain conveyor. When this is the case, it indicates that there is a bug in the model otherwise the Star Bottles (SBs) will move to the next conveyor. Validation was checked through the comparisons of the output of the model with the input, which should be equal if no beer bottles remain in the system or conveyors. Final verification of the simulation model was checked on how the system is sustained regarding the output, whenthere is a change in the input variables. If the processing time of machine is changed in real life and simulation, and the simulation is run, the output of the simulation and real life should be very close, to further validate the model. There are three types of parameters defined in the simulation model:

1. **Processing times** is time that a machine needs to produce a beer.

2. **Mean Time Between Failures (MTBF)**, means time it takes between machine failures.

3. **Mean Time To Repair (MTTR)** is time it takes for repairing a machine after it failed.

   The processing times, MTBF, MTTR and destination table are determined.

Validation of this model checks the accuracy of the simulation model when compared with the reality. There are several options to measure validation. Sargent (2005) measured the possibility of validating a model by determining the output quantity of the beer bottles in real life and compared it with the output of simulation model. Furthermore the processing time was used to validate the model. In order to check the processing time output quantities over a time period of 8 hours was considered.

3.5.1 Location of Sensors

Simulation is used in order to find optimal locations for the sensors with ideal speed levels for the Labellers (CPLs). Figure 3.21 shows a print screen of the simulation model from Tecnomatix Plant Simulation.

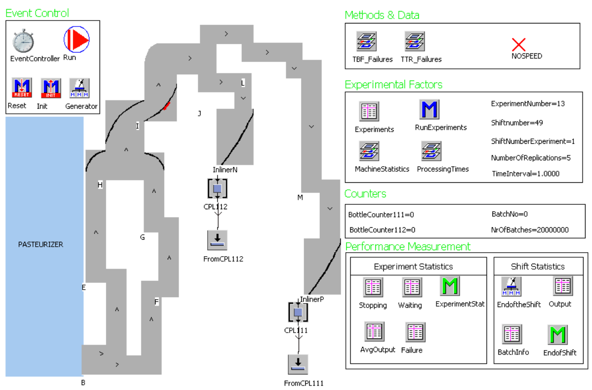


Figure 3.21: Print Screen of Main Frame Plant Simulation

The pasteurizer has two sources, one for the upper deck and one for the lower deck. The lower deck is the left side of the lines from the pasteurizer towards part I and the upper deck is the right side.

MTBF

To calculate the MTBF operating-dependent failures are applied, this means that a machine can only have a breakdown when it is in operation. To determine the mean time between failures, production time between two machine failures are determined, excluding starvation and blocking periods.

MTTR

In MES there is a distinction between short (< 5 minutes) and long (>= 5 minutes) failures. Minor Stoppage <5min is fallen bottles and are not part of a pattern in the duration of the failure mode. For those reason only long failures is considered. The MTTR there is a theoretical distribution that fits the data from the process, namely the Weibull distribution.

Destination Table

In order to deliver these priorities as input to our simulation model, a destination table is developed. This destinationtableshowsthe priorities from the first layer at part I to the second layer at part I.

Warm-up period

To enter the steady state in our system, the first beer bottles exit the system. This took 6 minutes for the LABELLER112 and 8 minutes for the LABELLER111, which is negligible. Therefore warm-up period is not considered.

3.5.2 Number of replications

According Law (2006), replication-deletion method is used in order to determine the number of replications and the number of replications guarantees 95% confidence interval with a width of at most 5% of the mean.

The following formula computes the required precision: $\gamma = \frac{\gamma}{1+\gamma}$Where γ' is the required precision and has a value γ =0.04619 If the precision is not sufficient, another replication is executed in order to decrease the confidence interval half width until the required precision is achieved.

3.6 Experimentaldesign

Experimental design helped us in this research to select the best result from 12 experiments. The main experimental factors are the location of the sensors and the number of speed levels of the LABELLERs. Few sensors were considered and speed levels to limit the number of experiment. The moment of switching of the LABELLERs were programmed on current locations of the sensors. LABELLER112 has at the current situation no low speed and therefore it has only three speed levels. LABELLER111 has four speed levels, which are:

1. Down.
2. Low.
3. Nominal.
4. High.

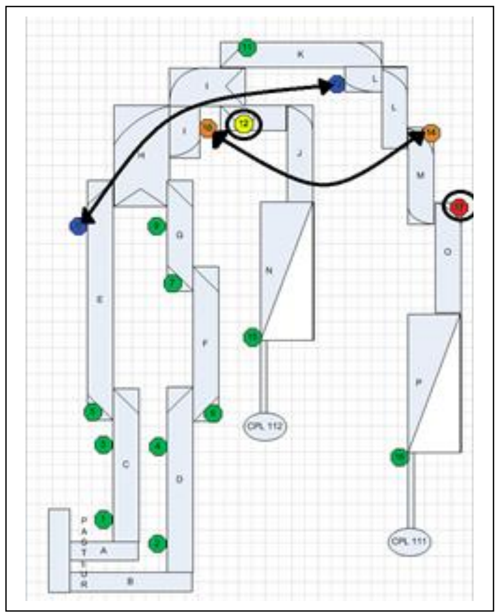


Figure 3.22: 5 Possible Sensors to Regulate Speed of Conveyor

There were 17 sensors where the speed of LABELLERs can be regulated. Possible options for this simulation are shown in Figure 3.22. The sensors colored green were neglected in the simulation for several reasons. Sensors 1 till 7 are too close to the pasteurizer, and were used to determine the speed of the pasteurizer. Using these sensors for changing the speed of the LABELLERs, the risk that the pasteurizer will create blockage will increase significantly.

Sensor 9 was not used because Sensor 8 was used and lower deck from the pasteurizer is always filled. Skipping the use of sensor 9 will decrease the amount of experiments, without having any influence on the outcome. We neglected Sensors 15 and Sensor 16 because they serve for a security and when they are triggered the line has an emergency shutdown. If not, the LABELLERs (CLP 111 and CLP 112) will be damaged. When there are no Star Bottles, the labels stick in the machine. Sensor 11 was neglected because it has little value when also sensor 13, 14 and 17 are regulating LABELLER111. Sensor 11 regulates conveyor K.There were 16 combination of four different speed levels of sensors on conveyors connected two labelers to pasteurizer, Conveyor speed of labeler CLP 111 and CLP 112 are controlled by the sensors. Out of 16 experimental run, only 12 is possible. After the running of the 12 possible experiment, the output and the line balancing, waiting time and failures are determine. The figure that give you the optimal value is selected. Note that the experiment is model with the original production system, after which the sensors will be changing on different location of conveyors according to the possible combination.

3.7 Application of Kaizen and CILT to Optimize Preventive Maintenance Strategy.

The research determined the current state of the production system maintenance and management maintenance practices in place. Strategic inspection, examination, and overview of production facilities were carried to determine the maintenance level, identify current maintenance methods, causes of failures, breakdowns and defects.

The optimum maintenance investigative using Kaizen and CILT were adopted and were as follows:

1. Machine breakdown from the individual components of the Filler were collected from week 38 to week 52 to develop breakdown deployment and improvement to know the contribution of breakdown of each component to the system downtimes. Low fill was found to be the major contributor of Filler problems. Kaizen was developed to eliminate low fills caused by gushing of bottles. Why? Statement was developed to know the causes with target reduction set up.

2. A general route for defect reduction was developed and project plan sequence to defect reduction routes, which has step 1 to step 6 with responsible worker, actions and completion date.

3. Root causes and failure analysis of core machine (Filler) was developed for Line 4 and operation learning of beer inlet line procedure was developed as a one of the guide to tackle the problem of gushing bottles, followed by the development of improvement project plan which states the target of reduction.

4. Kaizen improvement sequence of production lines was developed with stage 1 to stage 11, followed by QX Matrix of low fill which detailed 4M (Man, Machine, Method and Materials) in tackling the problem of low fill of the filler and crowner.

5. CILT procedure was developed for Filler preventive maintenance strategy.

3.8 Development of Excel spreadsheet interface tool.

The tool was developed by linking different sheets together, using excel formulas to calculate different parameters. These are used for easy data analysis, performance and improvement tracking over time.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Production System Analysis: Process and Data Analysis Result and Discussion.

During the production system analysis, work-study was carried out from January 2014 to January 2017 to study production line 1, 2 and 4. Process and data analysis were carried out to understand the existing production problems and the following results were obtained:

4.1.1 Process Analysis Result and Discussion

Table 4.1: Machine capacities, machine efficiencies, MER: Source AB Breweries

S/N	Machines	$C_{mac\,h\%}$	$\eta_{mac\,h\%}$	$MER_{mac\,h\%}$
1	Depalletizer	135	97	131
2	Washer	110	98	99
3	Filler (Core Machine)	100	98	98
4	Pasteurizer	100	99	99
5	Labeller	125	95	119
6	Packer	130	93	121
7	Palletizer	135	96	130

Source: AB Breweries

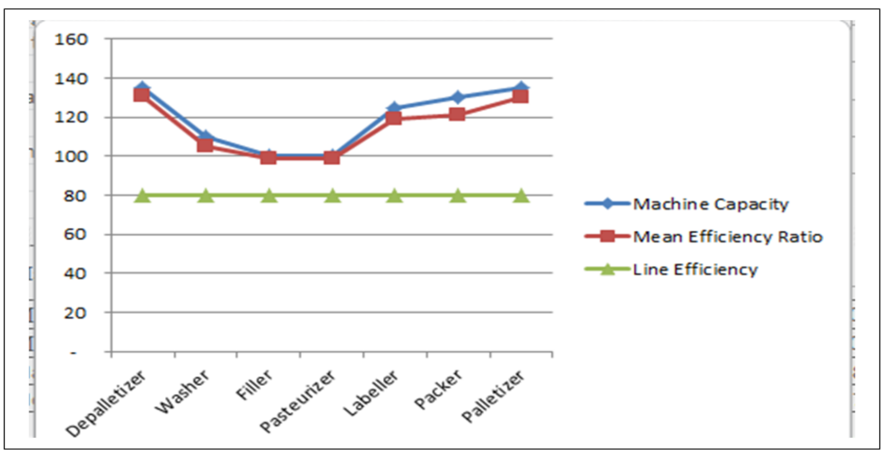


Figure 4.1: MER, Machine Capacity and Line Efficiency

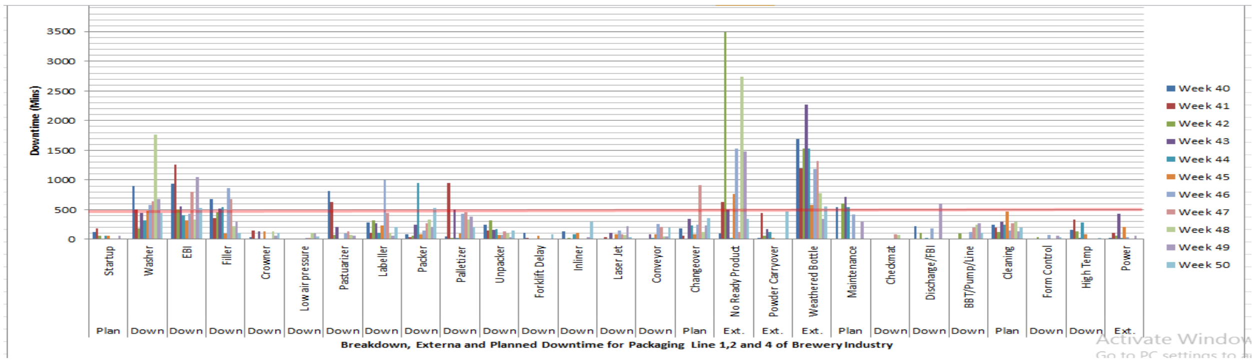


Figure 4.2: Machine Downtime showing the high effect of weathered bottle on the downtime.

In Table 4.1, Figure 4.1 and Figure 4.2 The result of the process analysis reveal that functioning of lines depends on the quality of the returned and input materials, capacities of different machines especially the core machine with corresponding conveyors and the functioning of the buffer. Analysis revealed that Filler, Pasteurizer and Labeller are the most important machines of the production lines. Pasteurizer and Filler have the same production capacities and are regarded as the core machines; all other machines around them have continuous increase in capacities from the core machines towards downstream and upstream of the production lines as shown in Table 4.1. The analysis also revealed that any loss on the core machines cannot be recovered since it has the lowest production capacities across the production lines. Three operations were carried out at the Filler, which includes crowning, filling and CILT activities, and are inherent to problems which can further reduce the existing capacities of the core machines. Starvation, Blockage and longtime failure of core machines should be avoided to increase the overall efficiency of the line and ensure maximum utilization of existing production capacities, which is the main focus of these studies.

1. Ideal situation: Machine produces

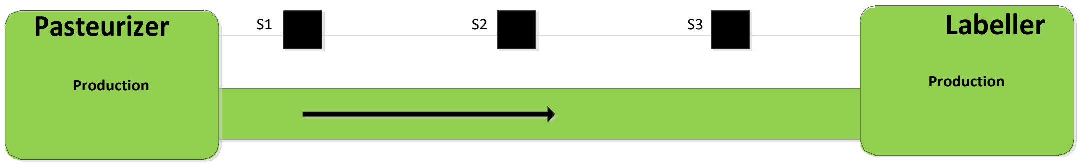


Figure 4.3: Machine is producing

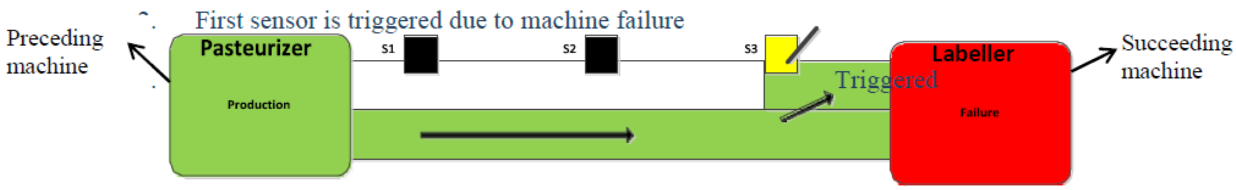
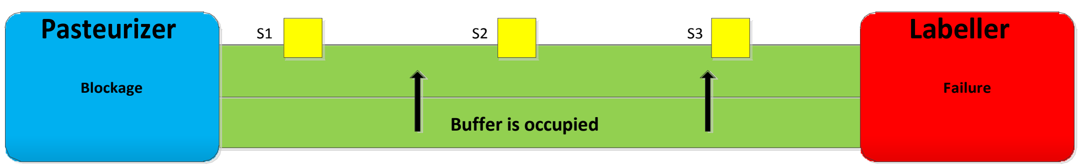


Figure 4.4: Machine is in failure mode and first sensor triggered



2. Third sensor is triggered due to machine failure (Blockage Occurred)

Figure 4.5: Machine in failure mode and third sensor triggered

3. Pasteurizer is completely starved as result of failure of Filler

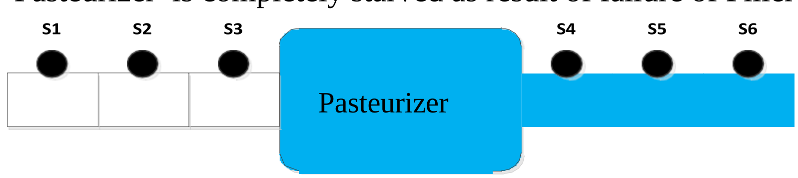


Figure 4.6: Pasteurizer is completely starved

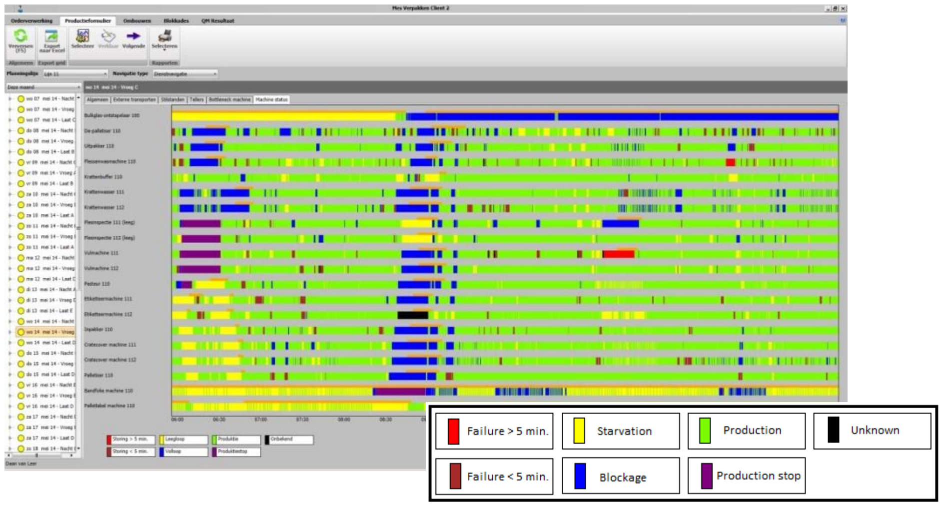


Figure 4.7: MES DNA Strand-8 Hours Work Schedule

Different machines states, which might affect production performance and underutilization of existing production capacities, were analyzed. Figure 4.3 indicates the ideal state of the core machine, when production is not interrupted. Figure 4.4 indicates when machine downstream of core machine is in failure mode, which can cause the blockage of the core machine depending on the recovery time of the failed machine after startup and the capacity of the buffer. Figure 4.5 indicates when core machine is blocked as a result of failure of succeeding machine and completely filling up of buffer, while figure 4.6 shows the starvation of the core machine by another bottleneck machine. Figure 4.7 shows the result of all states of production system as captured in MES of production system, in a print screen of the machine status of a 8-hour shift.

In conclusion, avoiding starvation, blockage and bottlenecks at core machines and machines next to core machines at both downstream and upstream is an important way of improving the utilization of the capacities of core machine and efficiency of the line. And also, internal failures (machine failures) and external failures (bad quality, power outage, non-availability of raw materials, etc) should be seriously considered in improving the overall production performance.

4.1.2 Production Data Analysis

During the work study, machine breakdown data were collected within week 40 to week 52 as shown in Appendix 1, 2 and 3 attached through measurement and use of Line Monitor System (LMS). The result of the collected data included the following;

4.1.2.1 Static Data Analysis

Machine Capacity: It is the percentage with respect to core machine of 80,000 bottles per hour.

It is the nominal capacity of core machine, which is 100%

The result of static data in Table 4.2-4.3 show machine capacities, efficiencies, Mean Effective Rates (MER), machine events, buffer performance, upper and lower efficiency limits. Figure 4.8 represent the trend of machine speeds.

Table 4.2: Machine capacities, machine efficiencies,MER& Events: Source AB Breweries

S/N	Machines	$C_{mac\,h\%}$	$\eta_{mac\,h\%}$	$MER_{mac\,h\%}$
1	Depalletizer	135	97	131
2	Washer	110	98	99
3	Filler	100	98	98
4	Pasteurizer	100	99	99
5	Labeller	125	95	119
6	Packer	130	93	121
7	Palletizer	135	96	130

Source: AB Breweries

In table 4.2, Filler is the core machine, it is very important machine in the series machine, any failure of the machine will affect the entire production system. It is therefore important to optimize the production flow of the Filler and also carry out the proactive maintenance strategy to ensure minimum downtime of the machine. Cleaning, Inspection, Lubrication and Tightening plan must be carried out the Filler to ensure all the machine components are in good conditions at all times. Other machine like Washer, Pasteurizer and Labeller are also very important in achieving smooth production flow and should also be focused on.

Table 4.3: Machine Events of Filler

Machine State	**Sum(s)**	**Number**	**Mean**	**Min**	**Max**	**Std Error**
Running	22163	112	198	12	554	16
Internal Failure	1354	32	41	7	223	15
Starved for bottle	1742	27	65	53	242	24
Blocked by bottles	3117	59	53	23	139	19
Lack of Material	424	12	35	19	77	34
Total	28,800					

$$\text{Machine Efficiency} = \frac{Running\ \ Time}{Running\ \ Time + Internal\ \ machine\ \ failure} = \frac{22163}{22163+1354} = 94\%. \qquad (3.31)$$

Applying equations (3.9), (3.11), (3.12), (3.13), (3.10) table 4.3 is obtained.

Table 4.4: Lower and Upper efficiency limit and buffer performance. Source: AB Breweries

Lower limit			Upper limit	Buffer strategy performance
R^{low}	A^{low}	η_{line}^{0}	$\eta_{\text{line}}^{\infty}$	ß
100%	72%	72%	98%	78%

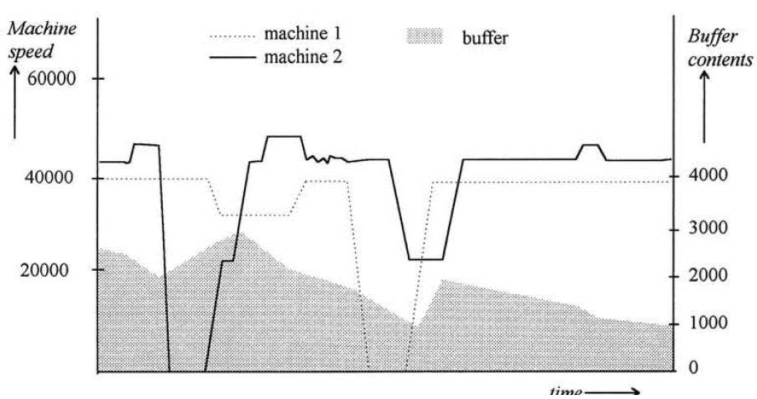


Figure 4.8: Trend of machine speeds and buffer contents: Source AB Breweries

Table 4.2 show machine capacities, machine efficiency and Mean effective rate (MER) and Machine events. Filler and Pasteurizer have the lowest Capacities and MER, hence refers as core machines. All other machines upstream and downstream have higher capacities in increasing order to cope with failure. Table 4.4 indicated the Lower and Upper Efficiency Limit from which the buffer performance is calculated.

Figure 4.8, show the machine speeds and buffer contents, which is important in solving problems of starvation and blockage, which can reduce the existing production output of core machines. The buffer contents are below the machine speed to be able to increase efficiency and utilize the machine capacities. Figure 4.9 compares the machine capacity and MER, with the Line efficiency of 80% as the benchmark. Line efficiency is always lower than the machine efficiency of core machines because of the time it takes for the products to move from the pasteurizer to the labeller. Further reducing the existing capacity will drastically affect the line efficiency.

V-graph Analysis Result

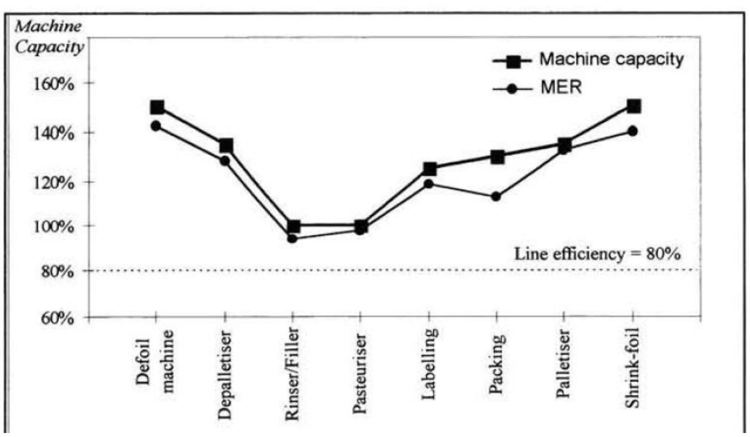


Figure 4.9: V-graph: Machine capacities, MER and Line efficiency

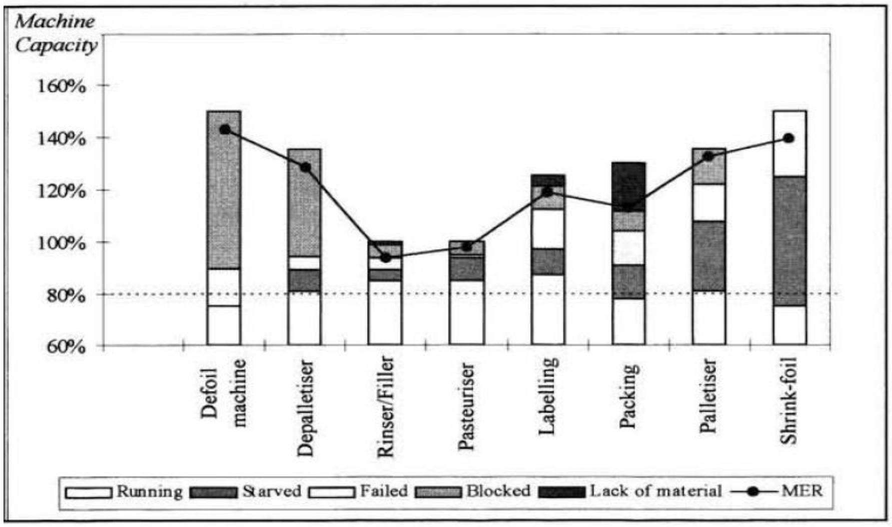


Figure 4.10: V-graph: partition of machine capacities over machine states and MER

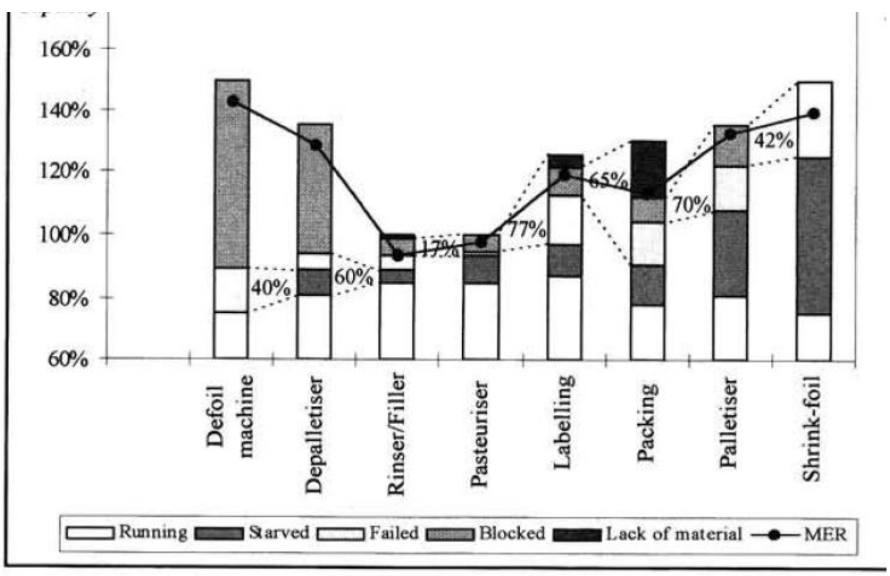


Figure 4.11: V-graph: machine capacities and buffer efficiencies

Figure 4.10-4.11 shows the V-graph, with different machine capacities and the effect/percentage of running time, starvation, failure, blockage and lack of materials. The percentage of the running time is far below the percentage downtimes caused by starvation, failure, blockage and lack of materials, hence the need to tackle each of the problems to increase the utilization of machine capacities on running mode and reduce downtime modes. Figure 4.10, show the machine capacities and buffer efficiencies. The buffer upstream and downstream of core machines must have higher buffer efficiencies to prevent blockage and starvation of the machines. Static data which is measured from the existing production line is very essential as it is used to calculate some other machine parameters, which can be changed after the modeling and simulations.

4.1.2.2 Dynamic Data Analysis Result and Discussion

Production output compared running time result

Figure 4.12 to Figure 4.15and Table 4.5 to Table 4.8show the result of production output compared with the running time for week 30 to 51 data analysis. These were carried out to establish the relationship between production output and running time to enable us analyze the result of the low production output against running time. Production Output was the primary parameter while running time was the secondary.

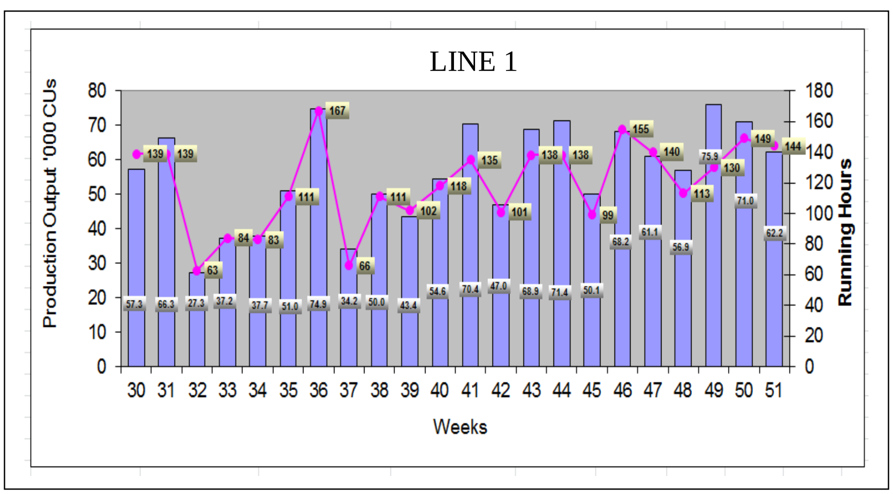


Figure 4.12: Production Output compared with Running Time of Line 1

Table 4.5: Production Output compared with Running Time of Line 1

Week	Runing hour	Line 1			
wks	hrs	Cus	000 Cus	Cus/hr	Bottles/hr
30	139	57,336	57.3	412	4,950
31	139	66,342	66.3	477	5,727
32	63	27,283	27.3	433	5,197
33	84	37,234	37.2	443	5,319
34	83	37,732	37.7	455	5,455
35	111	51,049	51.0	460	5,519
36	167	74,873	74.9	448	5,380
37	66	34,203	34.2	518	6,219
38	111	50,048	50.0	451	5,411
39	102	43,386	43.4	425	5,104
40	118	54,578	54.6	463	5,550
41	135	70,364	70.4	521	6,255
42	101	46,953	47.0	465	5,579
43	138	68,901	68.9	499	5,991
44	138	71,404	71.4	517	6,209
45	99	50,102	50.1	506	6,073
46	155	68,225	68.2	440	5,282
47	140	61,121	61.1	437	5,239
48	113	56,895	56.9	503	6,042
49	130	75,919	75.9	584	7,008
50	149	70,962	71.0	476	5,715
51	144	62,212	62.2	432	5,184
TOTAL	2,625	1,237,122	1,237	10,367	124,408

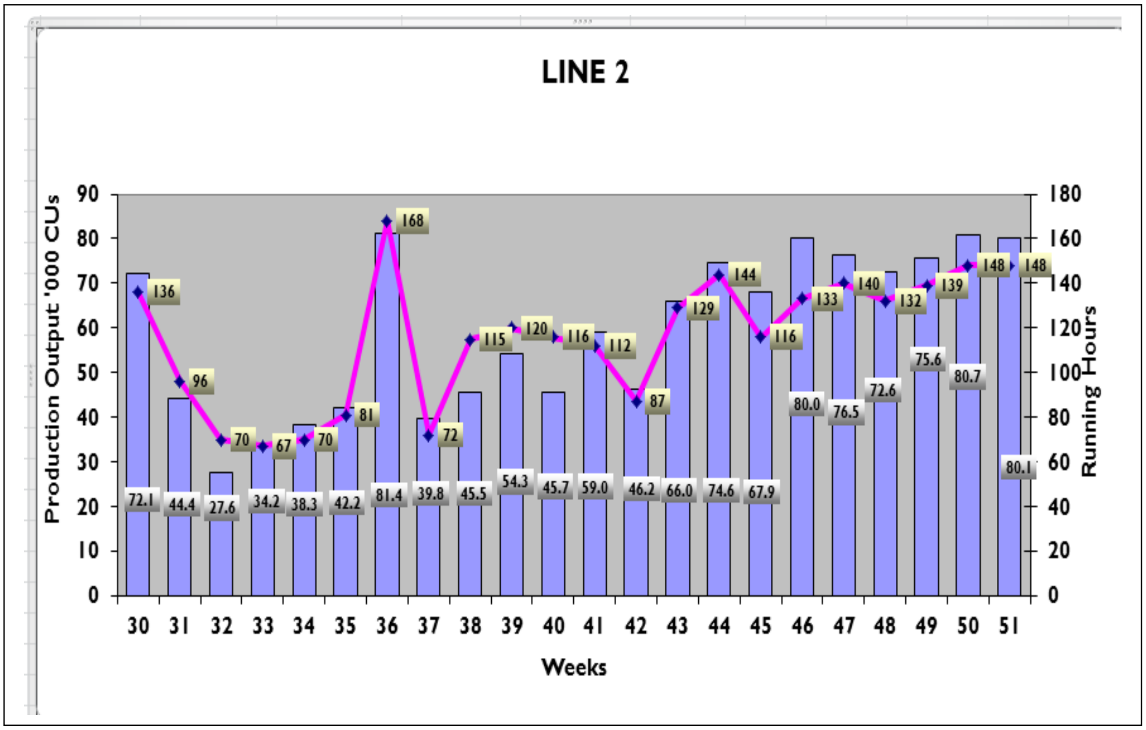


Figure 4.13: Production Output compared with Running Time of Line 2

Table 4.6:Production Output compared with Running Time of Line 2

Week	Runing hour	Line 2			
Wks	Hrs	CUS	000 Cus	cus / hr	Bottle/hr
30	136	72,149	72.1	531	6,366
31	96	44,350	44.4	462	5,544
32	70	27,566	27.6	394	4,726
33	67	34,170	34.2	510	6,120
34	70	38,331	38.3	548	6,571
35	81	42,221	42.2	521	6,255
36	168	81,362	81.4	484	5,812
37	72	39,763	39.8	552	6,627
38	115	45,496	45.5	396	4,747
39	120	54,288	54.3	452	5,429
40	116	45,710	45.7	394	4,729
41	112	59,028	59.0	527	6,324
42	87	46,180	46.2	531	6,370
43	129	66,040	66.0	512	6,143
44	144	74,576	74.6	518	6,215
45	116	67,893	67.9	585	7,023
46	133	80,009	80.0	602	7,219
47	140	76,512	76.5	547	6,558
48	132	72,599	72.6	550	6,600
49	139	75,623	75.6	544	6,529
50	148	80,703	80.7	545	6,543
51	148	80,047	80.1	541	6,490
TOTAL	2,539	1,304,616	1,305	11,245	134,940

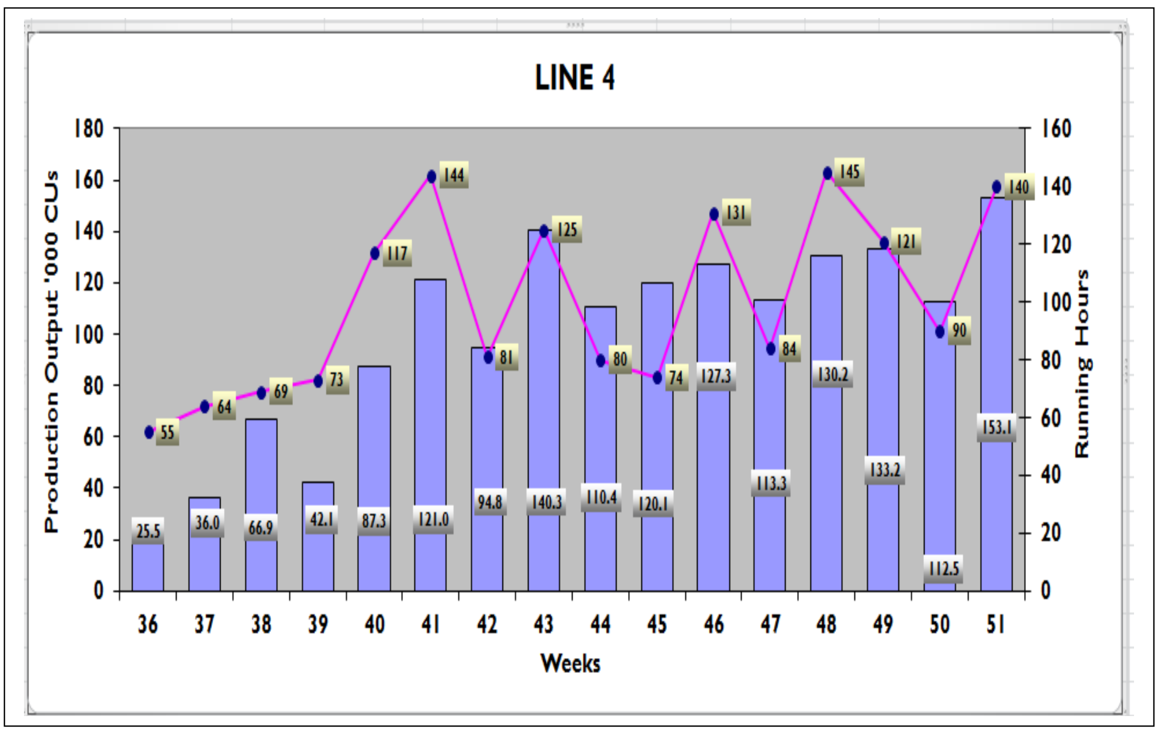


Figure 4.14: Production Output compared with Running Time of Line 4

Table 4.7:Production Output compared with Running Time of Line 4

Week	Runing hour	Line 4			
Wks	Hrs	CUS	000 Cus	Cus/hr	Bottle/hr
36	55	25,521	25.5	464	5,568
37	64	35,993	36.0	562	6,749
38	69	66,925	66.9	970	11,639
39	73	42,100	42.1	577	6,921
40	117	87,286	87.3	746	8,952
41	144	121,049	121.0	841	10,087
42	81	94,788	94.8	1,170	14,043
43	125	147,617	140.3	1,181	14,171
44	80	103,187	110.4	1,290	15,478
45	74	120,071	120.1	1,623	19,471
46	131	127,293	127.3	972	11,660
47	84	113,266	113.3	1,348	16,181
48	145	130,169	130.2	898	10,773
49	121	133,200	133.2	1,101	13,210
50	90	112,468	112.5	1,250	14,996
51	140	153,135	153.1	1,094	13,126
TOTAL	1,593	1,614,068	1,614	16,085	193,025

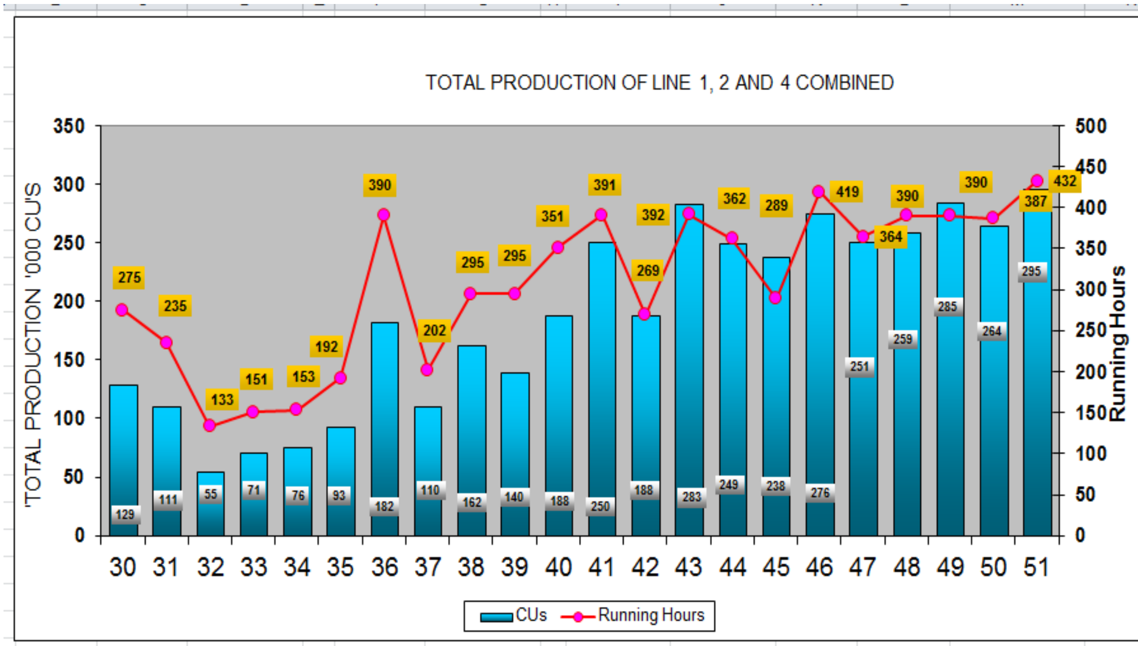


Figure 4.15: Total Production Output compared Running Time of Line 1, 2 & 4

Table 4.8:Total Production Output compared Running Time of Line 1, 2 & 4

Line 1, 2 & 4 Running Time compared with Production Output in Cartons Units												
	LINE 1			LINE 2			LINE 4			COMBINED		
Week	Runing hour	Line 1		Runing hour	Line 2		Runing hour	Line 4		Running Hour	Cus	
Wks	hrs	Cus		hrs	CUS		hrs	CUS		hrs	Cus	
30	139	57,336		136	72,149					275	129,485	129
31	139	66,342		96	44,350					235	110,692	111
32	63	27,283		70	27,566					133	54,849	55
33	84	37,234		67	34,170					151	71,404	71
34	83	37,732		70	38,331					153	76,063	76
35	111	51,049		81	42,221					192	93,270	93
36	167	74,873		168	81,362		55	25,521		390	181,756	182
37	66	34,203		72	39,763		64	35,993		202	109,959	110
38	111	50,048		115	45,496		69	66,925		295	162,469	162
39	102	43,386		120	54,288		73	42,100		295	139,774	140
40	118	54,578		116	45,710		117	87,286		351	187,574	188
41	135	70,364		112	59,028		144	121,049		391	250,441	250
42	101	46,953		87	46,180		81	94,788		269	187,921	188
43	138	68,901		129	66,040		125	147617		392	282,558	283
44	138	71,404		144	74,576		80	103187		362	249,167	249
45	99	50,102		116	67,893		74	120071		289	238,066	238
46	155	68,225		133	80,009		131	127293		419	275,527	276
47	140	61,121		140	76,512		84	113266		364	250,899	251
48	113	56,595		132	72,599		145	130169		390	259,363	259
49	130	75,919		139	75,623		121	133200		390	284,742	285
50	149	70,962		148	80,703		90	112468		387	264,133	264
51	144	62,212		148	80,047		140	153135		432	295,394	295
TOTAL	2,625	1,236,822		2,539	1,304,616		1,593	1,614,068		5,548	3,311,237	3,311

Production Output compared with Running Time: Line 1, 2 and 4 shows individual line production output result compared with running time, while Figure 4.15 show the combined production output of Line 1, 2& 4 compared with running time. Figure 4.12 to Figure 4.15 gave the result of production output compared with the production running time. Figure 4.12 and Table 4.5 of Line 1, week 49 recorded 584 cartons per hour while week 30 recorded 412 cartons per hour as the highest and lowest production per hour respectively. The standard deviation is 41 cartons per hour, with an average of 470 cartons per hour for the 22 weeks productions. The range of hourly production was 172 cartons. Figure 4.13 and Table 4.6 of Line 2, week 46 recorded 602 cartons per hour while week 32 recorded 394 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 58 cartons per hour, with an average of 511 cartons per hour for the 22 weeks productions. The range of hourly production was 208 cartons. Figure 4.14 and Table 4.7 of Line 4, week 45 recorded 1,623 cartons per hour while week 36 recorded 464 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 316 cartons per hour, with an average of 1,005 cartons per hour for the 16 weeks productions. The range of hourly production was 1,159 cartons. Combined production output against running time was analyzed in Figure 4.15 and Table 4.8 of Line 1, 2, & 4, week 51 recorded 295 cartons per hour while week 33 recorded 71 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 80 cartons per hour, with an average of 189 cartons per hour for the 22 weeks productions. The range of hourly production was 224 cartons. From the analysis results of Line 1, 2 & 4, Production Line 1 & 2 has relatively low Standard deviation and range compared with line 4. Line 1 & 2 runs on regulated lines while line 4 runs on unregulated line. Speed loss was recorded more on line 1 & 2 while total downtime was very high in line 4 but productions was at its peak when machine was running. In unregulated line, machine can be producing at 100% or not producing at 0%, while in regulated lines, speed of machines automatically adjust its speed to cope with starvation, blockage and minor stoppages. It is now important to ascertain if there is proportionality or correlation between running time and production output to analyze production system problems that are causing high running time against production output in line 1 & 2 and high downtime on the part of line 4. Again, coefficient of determination was employed to determine the percentage of problems in correlation, which is known and that which is unknown. The next stage is to discuss the result of correlation analysis and coefficient of determination.

Correlation Analysis

The main objective of the companies is to increase production volume or capacity to meet customer's daily demands in timely manner; Correlation analysis was carried out considering running time against production output at nominal speed. The running time depends on the following factors; starvation, blockage and internal downtime while the production outputs depend on running time and speed loss.

The correlation was carried out to determine the worthiness to consider the production volume based on running hours of Line 1, 2 & 4. Table 4.9 to Table 4.11 shows the correlation analysis and coefficient of determination results for Line 1, 2 and 4

Production Line 1 Correlation (r_1 =93%; Coefficient of Determination r^2=86%)

Table 4.9: Result of Correlation Analysis of Line 1

Week	Run Time RT(hr)	Run Time RT(min)	Prod. Volume PV(Cartons)	Prod. Volume PV(Cartons)	RT(x) (Min) x	PV(y)(Cartons) y			
n	RT (hrs)	RT(min)	PV (000)	PV	0000RT	0000 PV	y2	x2	xy
1	139	6,120	57.3	57,336	0.61	5.7	33	0.37	3.51
2	139	7,080	66.3	66,342	0.71	6.6	44	0.50	4.70
3	63	8,100	27.3	27,283	0.81	2.7	7	0.66	2.21
4	84	6,060	37.2	37,234	0.61	3.7	14	0.37	2.26
5	83	8,280	37.7	37,732	0.83	3.8	14	0.69	3.12
6	111	8,280	51.0	51,049	0.83	5.1	26	0.69	4.23
7	167	5,940	74.9	74,873	0.59	7.5	56	0.35	4.45
8	66	9,300	34.2	34,203	0.93	3.4	12	0.86	3.18
9	111	8,400	50.0	50,048	0.84	5.0	25	0.71	4.20
10	102	6,780	43.4	43,386	0.68	4.3	19	0.46	2.94
11	118	7,800	54.6	54,578	0.78	5.5	30	0.61	4.26
12	135	8,100	70.4	70,364	0.81	7.0	50	0.66	5.70
13	101	6,060	47.0	46,953	0.61	4.7	22	0.37	2.85
14	138	8,280	68.9	68,901	0.83	6.9	47	0.69	5.71
15	138	8,280	71.4	71,404	0.83	7.1	51	0.69	5.91
16	99	5,940	50.1	50,102	0.59	5.0	25	0.35	2.98
17	155	9,300	68.2	68,225	0.93	6.8	47	0.86	6.34
18	140	8,400	61.1	61,121	0.84	6.1	37	0.71	5.13
19	113	6,780	56.9	56,895	0.68	5.7	32	0.46	3.86
20	130	7,800	75.9	75,919	0.78	7.6	58	0.61	5.92
21	149	8,940	71.0	70,962	0.89	7.1	50	0.80	6.34
22	144	8,640	62.2	62,212	0.86	6.2	39	0.75	5.38
TOTAL			1,237	1,237,122	16.87	123.71	738.00	13.19	95.17

Production Line 2 Correlation (r_2 =93%; Coefficient of Determination r^2=86%)

Table 4.10: Result of Correlation Analysis of Line 2

Week	Run Time RT(hr)	Run Time RT(min)	Prod. Volume PV(Cartons)	Prod. Volume PV(Cartons)	RT(x) (Min) x	PV(y)(Cartons) y			
n	RT (hrs)	RT(min)	PV (000)	PV	0000RT	0000 PV	y2	x2	xy
1	136	6,120	72.1	72,149	0.61	7.2	52	0.37	4.4
2	96	7,080	44.4	44,350	0.71	4.4	20	0.50	3.1
3	70	8,100	27.6	27,566	0.81	2.8	8	0.66	2.2
4	67	6,060	34.2	34,170	0.61	3.4	12	0.37	2.0
5	70	8,280	38.3	38,331	0.83	3.8	15	0.69	3.1
6	81	8,280	42.2	42,221	0.83	4.2	18	0.69	3.5
7	168	5,940	81.4	81,362	0.59	8.1	66	0.35	4.8
8	72	9,300	39.8	39,763	0.93	4.0	16	0.86	3.7
9	115	8,400	45.5	45,496	0.84	4.5	21	0.71	3.8
10	120	6,780	54.3	54,288	0.68	5.4	29	0.46	3.6
11	116	7,800	45.7	45,710	0.78	4.6	21	0.61	3.5
12	112	6,720	59.0	59,028	0.67	5.9	35	0.45	3.9
13	87	5,220	46.2	46,180	0.52	4.6	21	0.27	2.4
14	129	7,740	66.0	66,040	0.77	6.6	44	0.60	5.1
15	144	8,640	74.6	74,576	0.86	7.5	56	0.75	6.4
16	116	6,960	67.9	67,893	0.70	6.8	46	0.48	4.7
17	133	7,980	80.0	80,009	0.80	8.0	64	0.64	6.3
18	140	8,400	76.5	76,512	0.84	7.7	59	0.71	6.4
19	132	7,920	72.6	72,599	0.79	7.3	53	0.63	5.7
20	139	8,340	75.6	75,623	0.83	7.6	57	0.70	6.3
21	148	8,880	80.7	80,703	0.89	8.1	65	0.79	7.1
22	148	8,880	80.0	80,047	0.89	8.0	64	0.79	7.1
TOTAL			1,305	1,304,616	16.78	130.46	839.74	13.06	99.9

Production Line 4 Correlation (r_4) =75%; Coefficient of Determination r^2=56%)

Table 4.11: Result of Correlation Analysis of Line 4

Week	Run Time RT(hr)	Run Time RT(min)	Prod. Volume PV(Cartons)	Prod. Volume PV(Cartons)	RT(x) (Min)*	PV(y)(Cartons)			
n	RT (hrs)	RT(min)	PV (000)	PV	0000RT	0000 PV	y2	x2	xy
1	55	6,120	25.5	25,521	0.61	2.6	7	0.37	1.56
2	64	7,080	36.0	35,993	0.71	3.6	13	0.50	2.55
3	69	8,100	66.9	66,925	0.81	6.7	45	0.66	5.42
4	73	6,060	42.1	42,100	0.61	4.2	18	0.37	2.55
5	117	8,280	87.3	87,286	0.83	8.7	76	0.69	7.23
6	144	8,280	121.0	121,049	0.83	12.1	147	0.69	10.02
7	81	5,940	94.8	94,788	0.59	9.5	90	0.35	5.63
8	125	9,300	147.6	147,617	0.93	14.8	218	0.86	13.73
9	80	8,400	103.2	103,187	0.84	10.3	106	0.71	8.67
10	74	6,780	120.1	120,071	0.68	12.0	144	0.46	8.14
11	131	7,800	127.3	127,293	0.78	12.7	162	0.61	9.93
TOTAL			972	971,830	8.21	97.18	1,025.14	6.26	75.43

Correlation and Coefficient of Determination Result Discussion:

Tables 4.9-4.11 show the result of correlation analysis. The main objective of the companies is to increase production volume or capacity to meet customer's daily demands for different product brands in a timely manner; it is important to find the worthiness to consider the production volume based on running hours. To achieve that, degree of correlation between running time (min) and production volume (cartons) was calculated. Line 1; Percentage Correlation r=93%; Coefficient of Determination r^2=0.86. Line 2; Percentage Correlation r=93%; Percentage Coefficient of Determination r^2=86%. Line 4; Percentage Correlation r=75%; Percentage Coefficient of Determination r^2=56%. Line 1,2 &4 have Correlation Coefficient of greater than 70%, an indication that both lines have strong positive correlation. We have confidence that as the production time is increasing; production output is equallyincreasing in positive trend. There were little deviations in Line 1 & 2, which recorded high running time against output. This is caused by reduction in machine speed to cope with starvation and blockage. Line 4 recorded high downtime as a result of high speed and unregulated system. When there is starvation or blockage machine automatically stop and wait until the failed machine startproduction.**Percentage** Coefficients of Determination of Line 1 & 2 were both 86%, an indication that 86% of total variation in production output can be explained while 14% cannot be explained. In Line 4, 56% of the total variation can be explained while 46% cannot be explained. These leads to the calculation of Overall Equipment Effectiveness (OEE), from where Operation Performance Index is calculated.

Overall Equipment Effectiveness (OEE) and OPI Analysis Result and Discussion

Table 4.12 calculated 8 hours single shift of OEE line 4, it is used to determine the efficiency of machines of the production lines, when external and planned downtime are considered it will give OPI, which is used to measure the performance of the entire production system

Table 4.12: OEE calculation of Production Line 4 per 8 hours shift

PRODUCTION DATA (Calculated Values from Production Machines)			Data Source
Run Time	355	Total Production Minutes per Shift	Run Time
Break Times	60	Total Break Minutes per Shift	Run Time
Down Time	45	Total Downtime Minutes Per Shift	Down Time
Setup Time	20	Total Setup Minutes per Shift	Setup Time
Total Count	13,800	Total Parts Produced per Shift	Total Count
Good Count	13,500	Good Parts Produced per Shift	Bad Count
Target Counter	14,200	Expected Parts per Shift	Target Counter

ProcessData	Formula	Result
Run Time	TotalProductionTime oftheMachine	355
TotalTime	DownTime+RunTime+Setup Time	420
Good Count	TotalGoodPartsProducedontheMachine	13,500

OEEVariables	Formula	Result
Availability	RunTime/Total Time(355/420)	84.52%
Performance	TotalCount /TargetCounter(13,800 / 14,200)	97.18%
Quality	GoodCount/ TotalCount13,500/14,200)	95.51%

OEE	AvailabilityxPerformancexQuality	78.45%

Total Time = Shift hours-Breaktime

= (8hr*60-breaktime (60mins)=480Min-60Min = 420Min

OPI Result

Weekly OPI of the three production lines were calculated in this research to find the performance of each line over production target (benchmark.) The result of Weekly and Average OPI of the lines were presented in Table 4.13, while Figure 4.16 to Figure 4.18 represents the graphical OPI against the Target of week 38 to week 51.

Table 4.13: OPI and Target of Line 1, 2 and 4

WEEK	OPI LINE 1	OPI LINE 2	OPI LINE 4	TARGET
38	51.4%	74.3%	12.6%	61.0%
39	52.5%	76.0%	3.4%	61.0%
40	64.6%	60.1%	22.3%	61.0%
41	63.1%	75.6%	30.9%	61.0%
42	68.6%	69.3%	23.2%	61.0%
43	58.3%	70.5%	34.9%	61.0%
44	62.7%	75.0%	28.7%	61.0%
45	56.1%	71.2%	35.2%	61.0%
46	49.2%	66.9%	28.1%	61.0%
47	60.0%	72.2%	24.3%	61.0%
48	53.2%	71.8%	32.4%	61.0%
49	53.6%	74.0%	27.3%	61.0%
50	49.1%	77.3%	19.2%	61.0%
51	64.1%	67.9%	42.5%	61.0%
52	62.1%	68.0%	34.7%	61.0%
AVERAGE	57.9%	71.3%	26.7%	61.0%

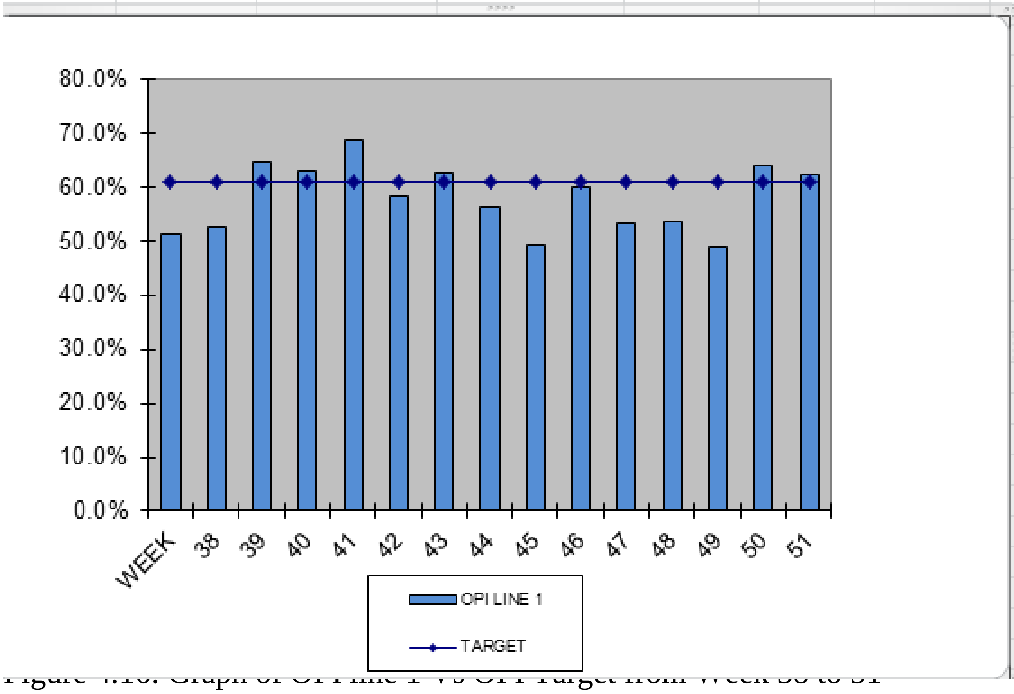


Figure 4.16: Graph of OPI line 1 Vs OPI Target from Week 38 to 51

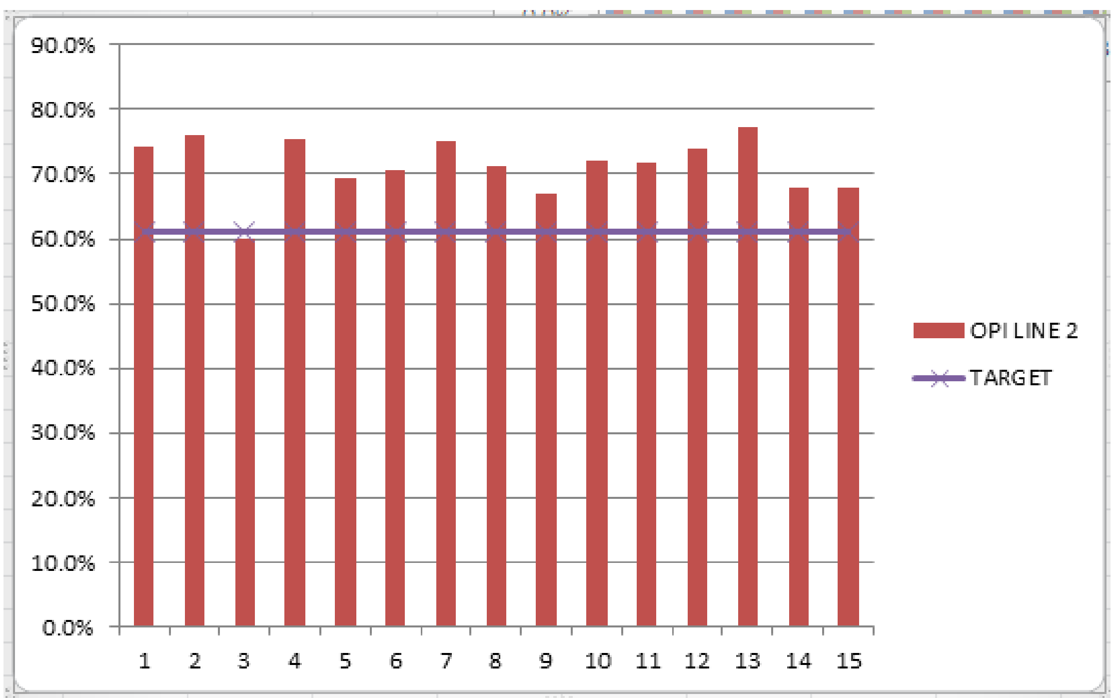


Figure 4.17: Graph of OPI line 2 Vs OPI Target from Week 38 to 51

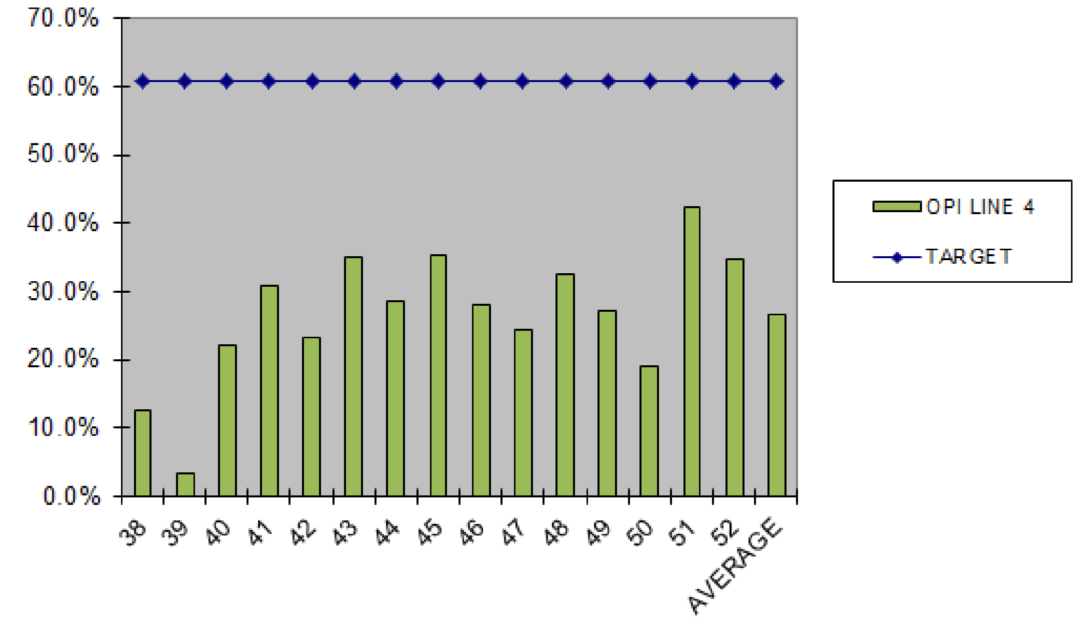


Figure 4.18: Graph of OPI line 4 Vs OPI Target from Week 38 to 51

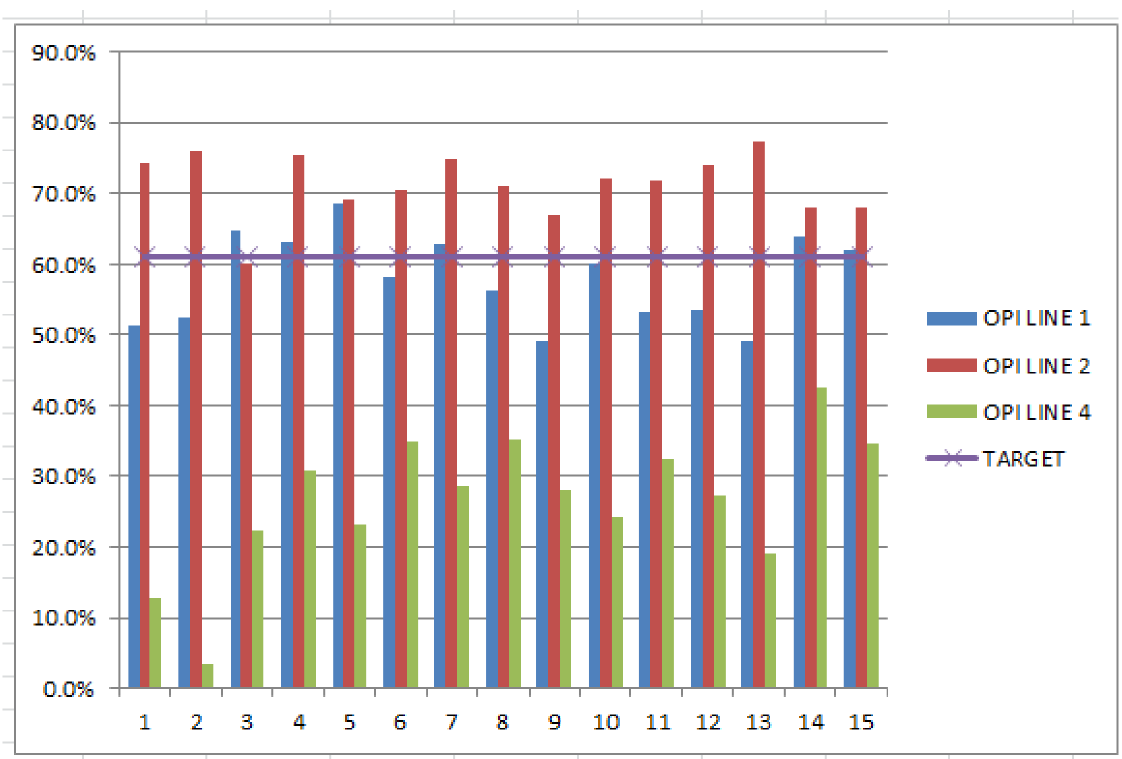


Fig 4.19: Graph of OPI of line 1,2 and 4 Vs OPI Target from Week 38 to 51

OverallEquipment Effectiveness (OEE) Result Discussion

The OEE of Line 4 is first calculated because we tried to find why there was a decrease in running time although the weekly outputs were high with the time the machine is running as revealed by graphical result of Figure 4.18. Looking at Line 4, which runs 3x 8hrs shift per day from week 38 to week 52, it is observed that there were high downtimes which drastically affect the production output. On this effect, the OEE of Line 1, 2 and 4 were calculated with set production target, while focus more on Line 4 which has recorded high downtime and low running time against production output. From OEE, external downtime where put into consideration to calculate the OPI of Line 1, 2 and 4.

From the OEE of Line 4, The Target Counter interval period or Ideal Cycle Time = 40 Cartons in every 60 seconds (16,800 cartons should be produced in 420 total minutes of the machine). If downtime is reduced by 15 minutes (900 seconds), the machine could produce 600 more cartons. (900 seconds x 40 cartons / 60 seconds = 600 cartons From the result, it can be deduce that only 15 minutes reduction in downtime will produce additional more 600 cartons. And the OEE will rise from 74% to 97%. Availability improves to; 370/420) = 88.10% ; Performance improves to (14,400/14,200) = 100.14% ; Quality improves to (14,00/14,400) = 97.22%

OEE improves to (.8810 x 1.14 x .9722) = 97.64% Reducing your downtime by 15 minutes will produce 19.19% increase in OEE. Downtime is the most critical factor to improving OEE because when the process is not running you cannot address other metrics. Many Brewery companies have capacity constraints and consider adding overtime, hiring new workers, or buying new equipment. The bottom line is a modest investment to optimize the performance of their existing machines may outweigh the major investment to purchase new equipment. By reducing down time, minimizing setup time, and improving operator performance, Brewery

Company can unleash hidden capacity and benefit from monitoring OEE data. The next stage is to categorize line downtimes to know the impact of breakdown, external stops and planned downtime on the three production lines.

Categorizations of Lines Downtimes: Breakdown, External Stops and Planned Stops

Appendix 4.5-4.7 show results of categorized Machine breakdown, external and planned downtimes and Appendix 4.9 of Weekly Average Downtimes while Figure 4.20 to Figure 4.23 shows the result of the percentage of contributions of three categorized downtimes (Machine Breakdown, External and Planned Downtimes) of line 1, 2 and 4.

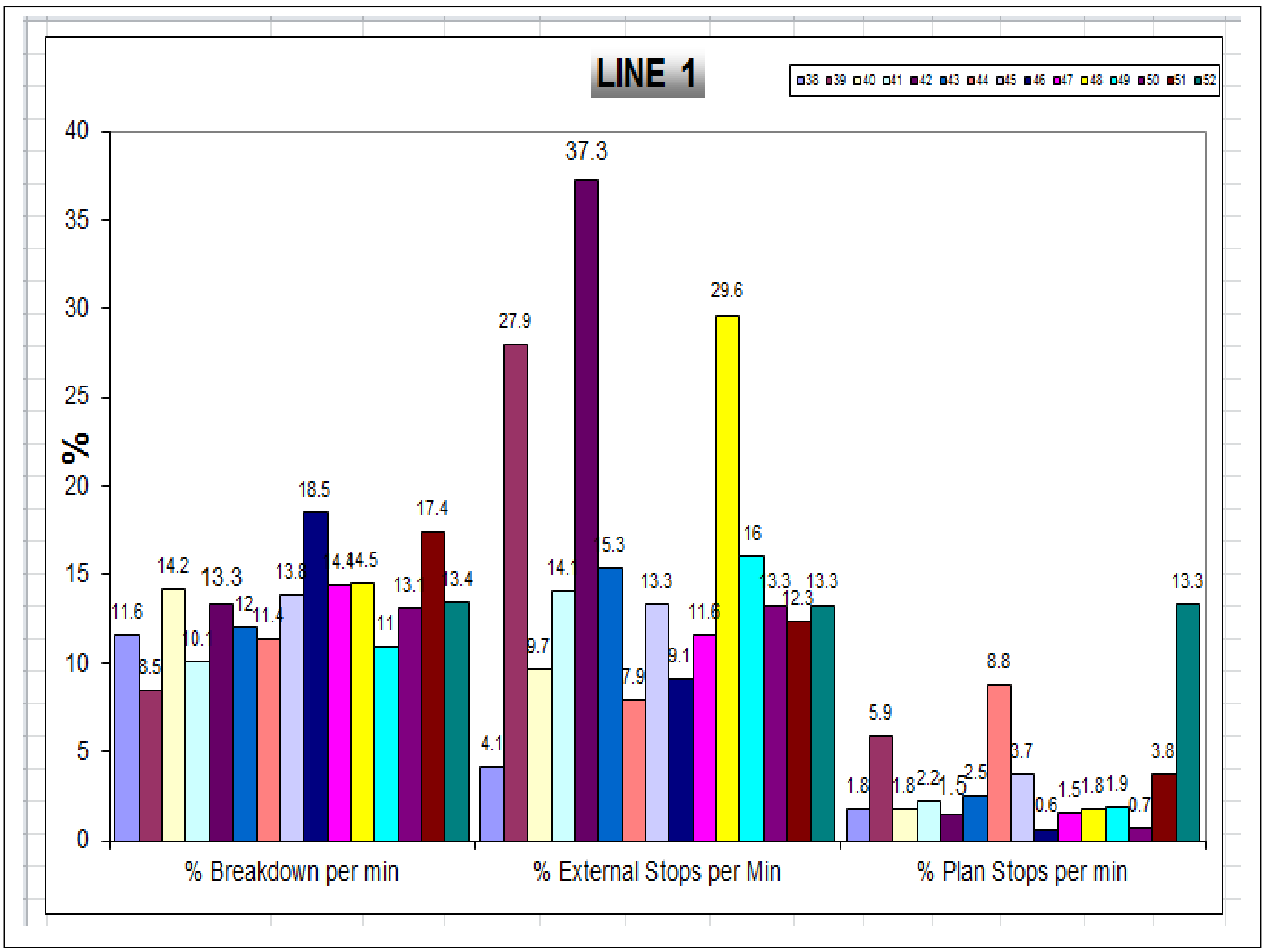


Figure 4.20: Percentage categorized three downtimes in Line

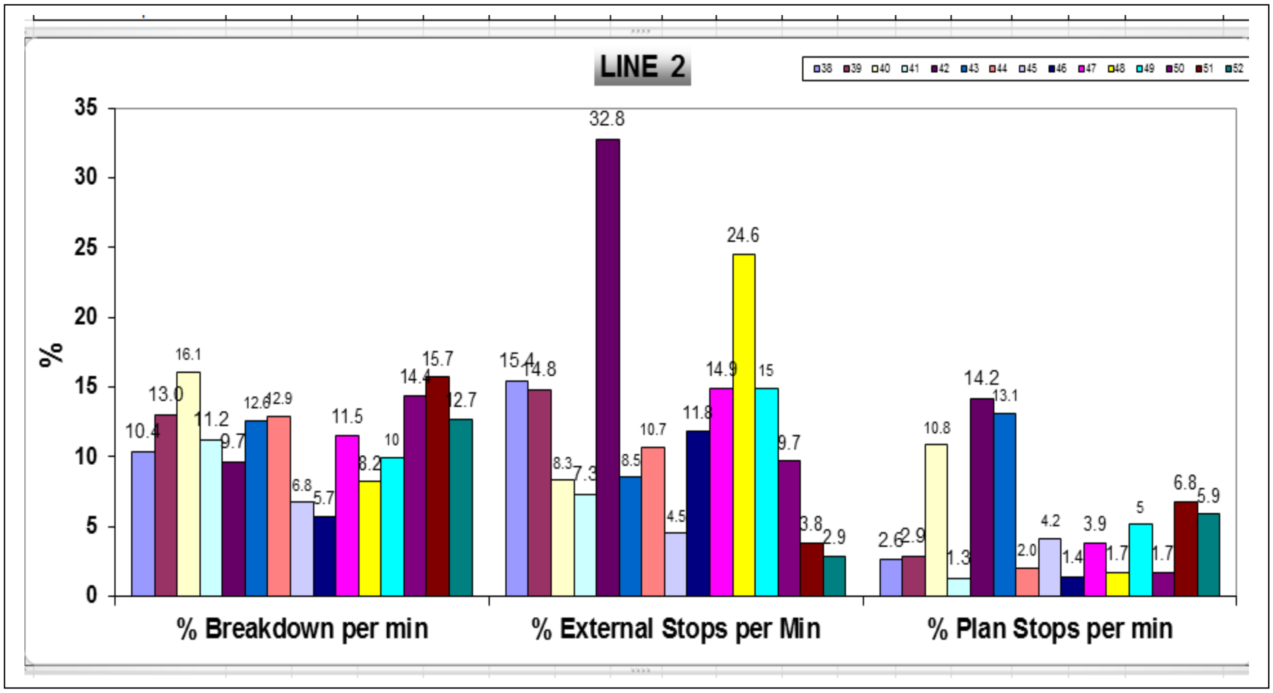


Figure 4.21: Percentage categorized three downtimes in Line 2

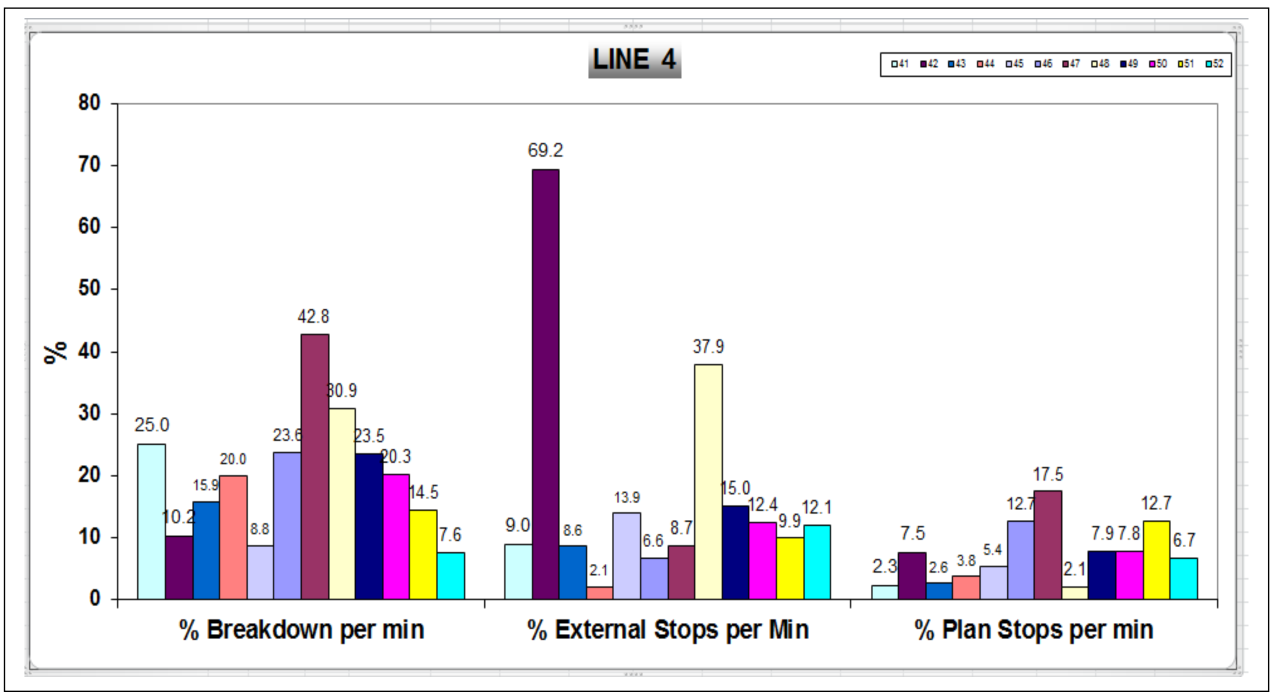


Figure 4.22: Percentage categorized three downtimes in Line 4

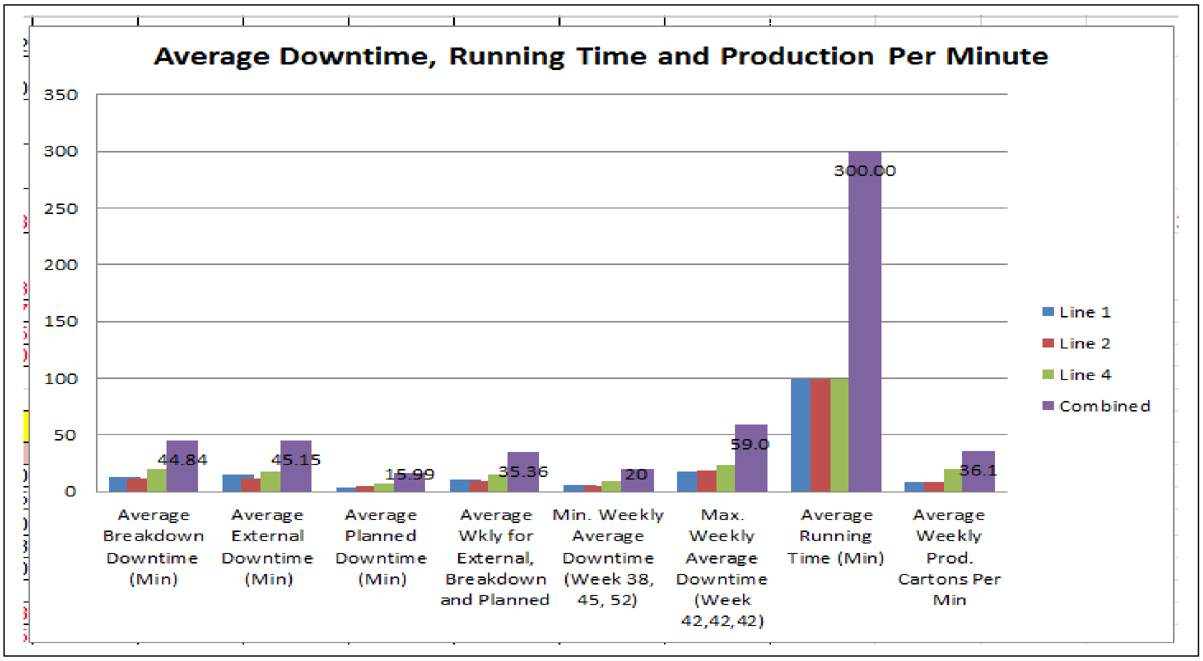


Figure 4.23: Average Downtime, Running Time and Production Output Per Min.

Categorized Downtime Analysis

External, downtime, Machine breakdown and planned downtime were categorized. These are useful to know the effect on production output. From the result in Figure 4.20- Figure 4.23, In summary, Line 4 recorded the highest average external, breakdown and planned downtime. Again, the same Line 4 recorded the highest number of Cartons produce per minute on weekly basis. Line 1 & 2 run for 15 weeks while Line 4 runs for 12 weeks, but Line 1 & 2 each having highest production running time, their average production per minute remain low. It is an indication that Line 1 & 2 are running below the production capacity, while Line 4 runs on maximum capacity, which is prone to high downtimes. Line 1 & 2 are running below production capacity as a result of the followings; 1. Line 1 & 2 were running below the nominal speed of the core machines, there is inherent speed loss due to regulated lines. 2. They were regulated lines with two labellers supplied with one pasteurizer which can cause system in-balance resulting in blockage, starvation and minor stoppages. In Line 4, breakdown and external downtimes were high because the machine is not regulated and run on maximum speed, which prone to frequent breakdown. Averages of 36 cartons are loss due to external, machine breakdown and planned downtime and a total of 35.36 Minutes are loss for the three production lines. These result in total loss of 1277 cartons. To optimize the existing production capacity;

The external, machine breakdown and planned downtime should be further analyzed with Pareto into various components to fine the area of focus, which solving 20% will give 80% result Increase the speed level of the machine above nominal speed of core machines through modeling and design of experiment, since un-optimized speed levels of sensors can cause machine speed loss. Since the problem has been established, Pareto was applied for the problem analysis to establish area of focus in solving the problem.

Graphical Representation of Weekly Downtimes and Frequencies Analysis of Line 1, 2 and 4

Appendix 1 to 13 of Week 40 to Week 51 and Figure 4.24 to Figure 4.35 shows the result of downtimes breakdown, downtime graphs and Frequencies of occurrences of individual components of 4M (Machine, Method, Material & Man).This is to enable us understand the contribution of individual system components to the overall production system downtimes. This will help to find out contributions of each 4M Pareto Analysis that will follow this analysis to the overall production system downtimes.

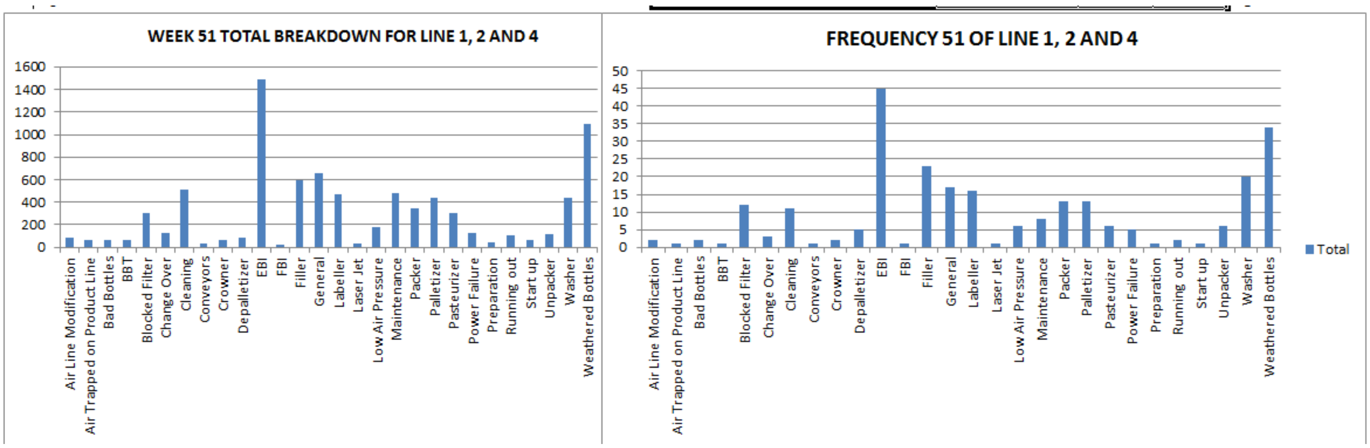


Figure 4.24: Week 51 Breakdown and Frequency Analysis of Line 1, 2 and 4

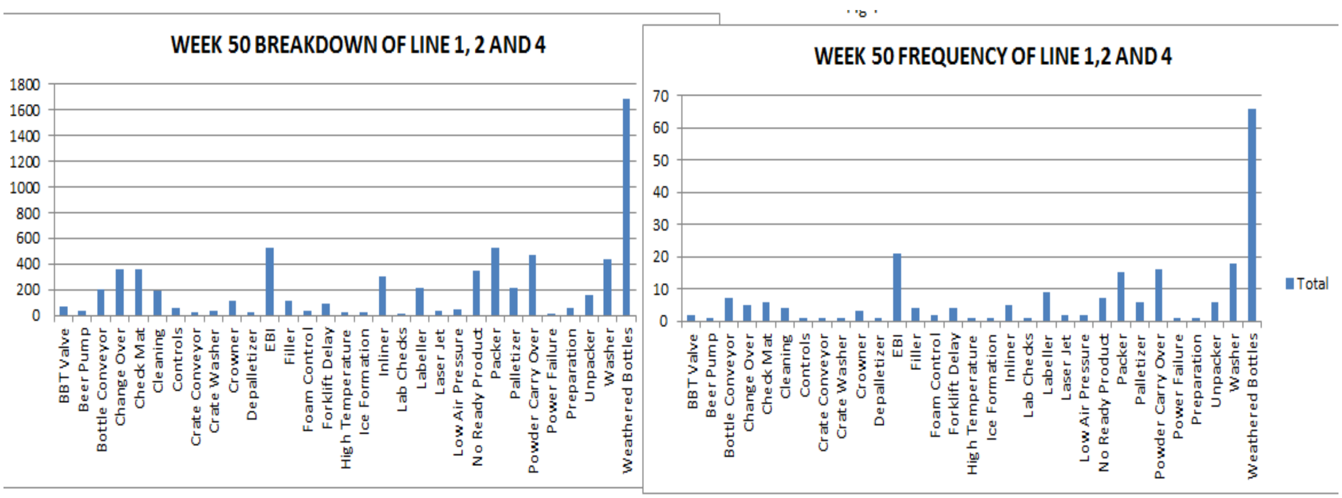


Figure 4.25: Week 50 Breakdown and Frequency Analysis of Line 1,2 and 4

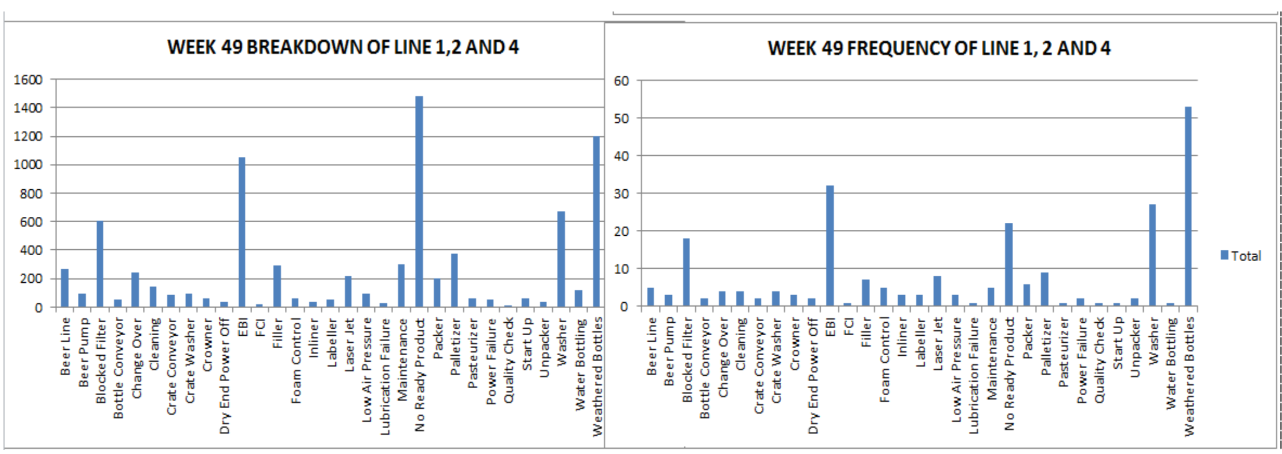


Figure 4.26: Week 49 Breakdown and Frequency Analysis of Line 1,2 and 4

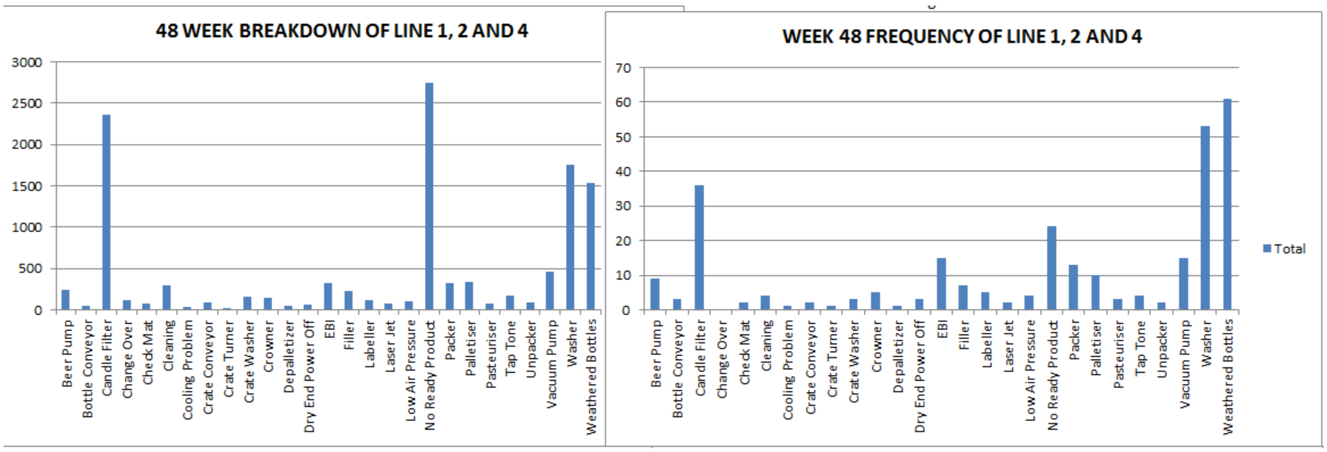


Figure 4.27: Week 48 Breakdown and Frequency Analysis of Line 1,2 and 4

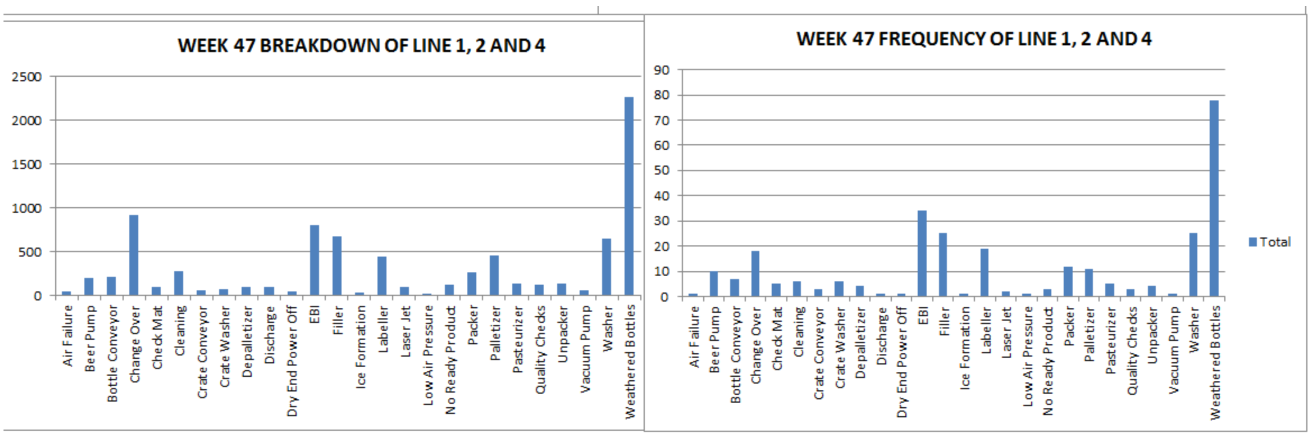


Figure 4.28: Week 47 Breakdown and Frequency Analysis of Line 1,2 and 4

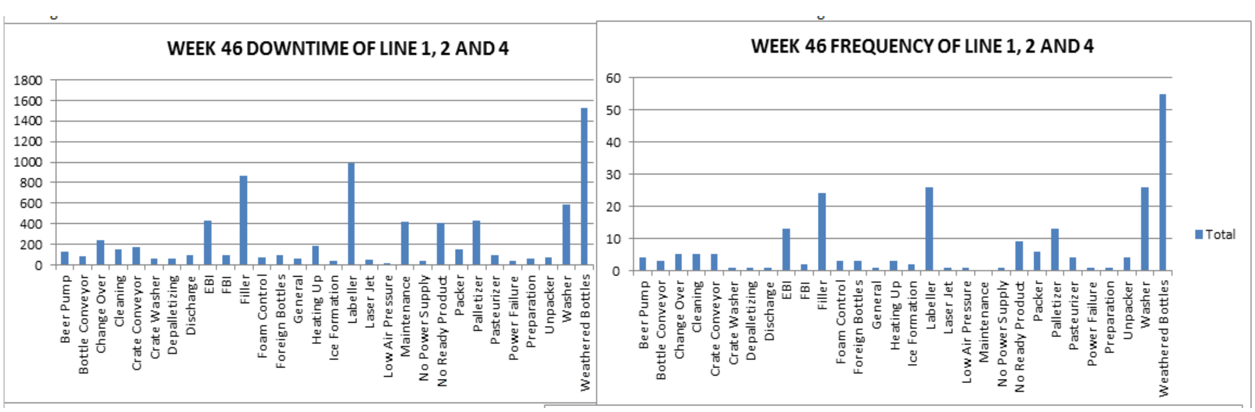


Figure 4.29: Week 46 Breakdown and Frequency Analysis of Line 1,2 and 4

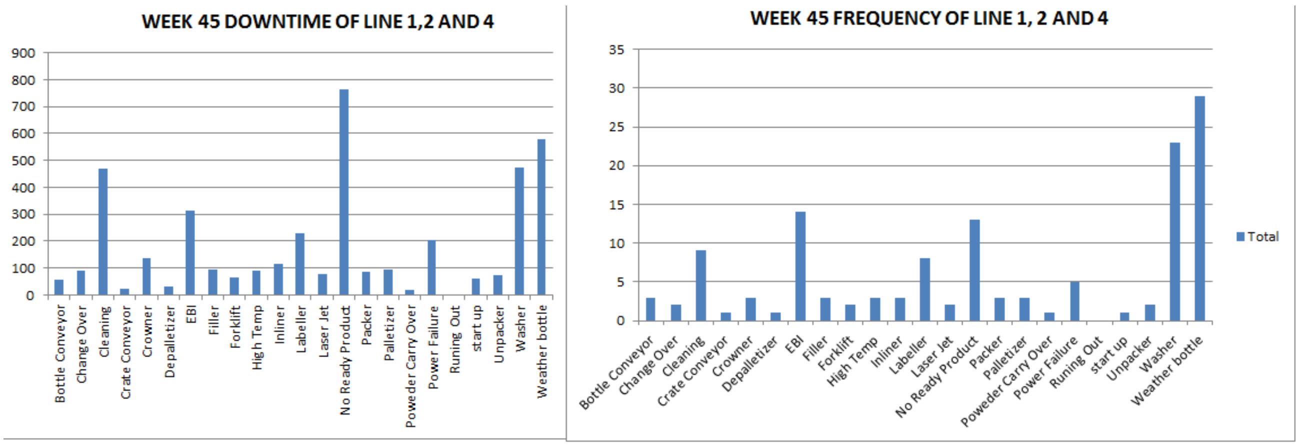


Figure 4.30: Week 45 Breakdown and Frequency Analysis of Line 1,2 and 4

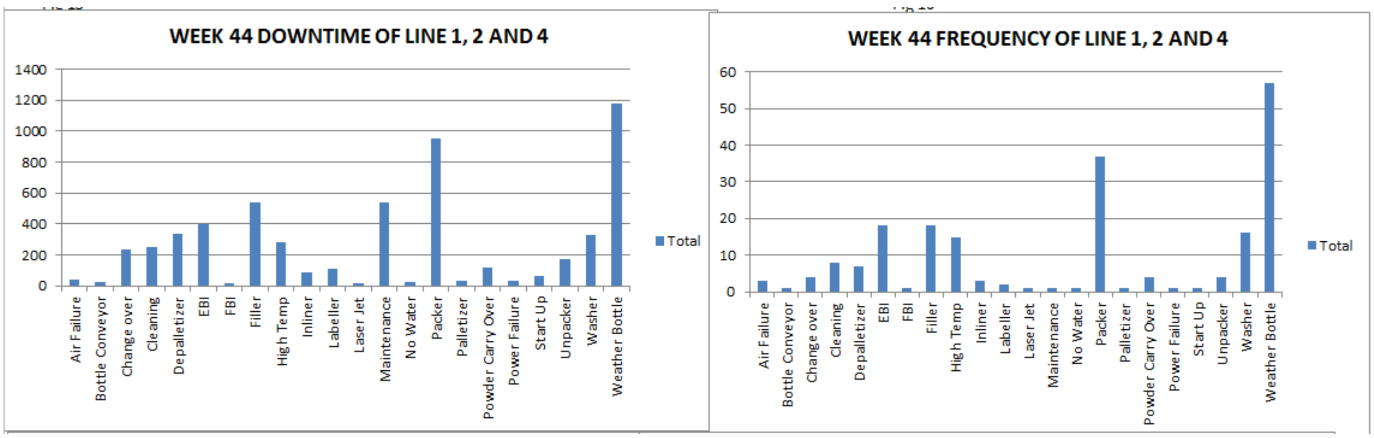


Figure 4.31: Week 44 Breakdown and Frequency Analysis of Line 1, 2 and 4

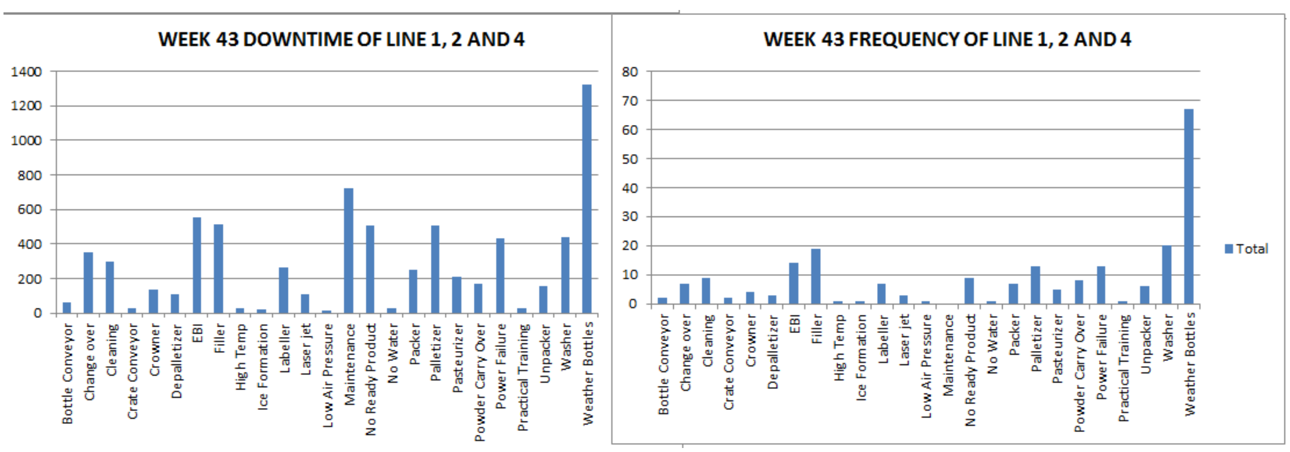


Figure 4.32: Week 43 Breakdown and Frequency Analysis of Line 1, 2 and 4

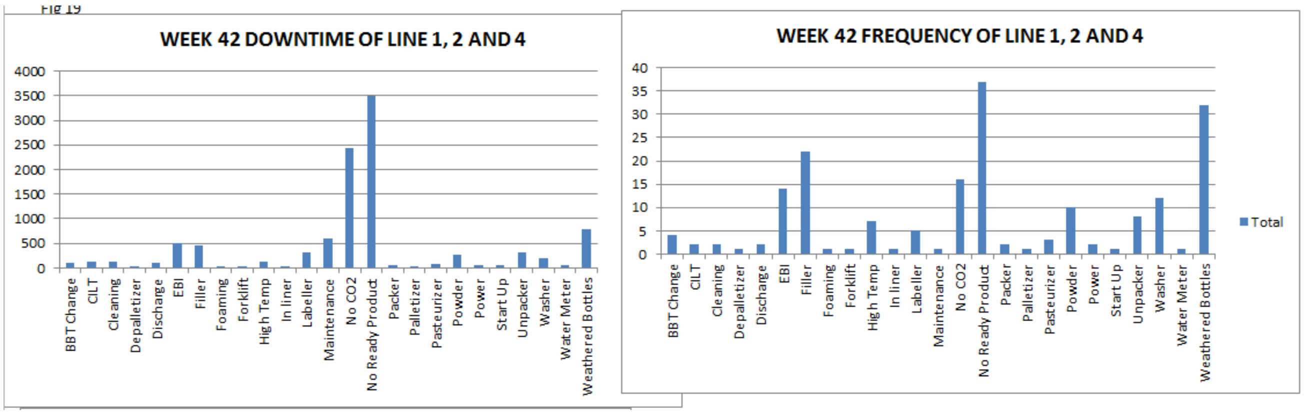


Fig. 4.33: Week 42 Breakdown and Frequency Analysis of Line 1, 2 and 4

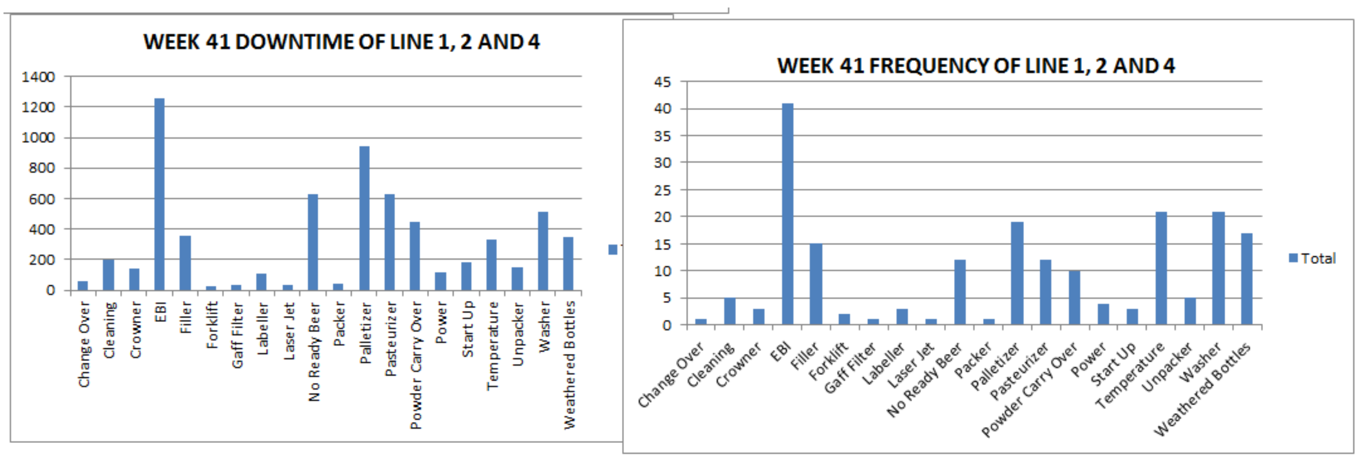


Figure 4.34: Week 41 Breakdown and Frequency Analysis of Line 1, 2 and 4

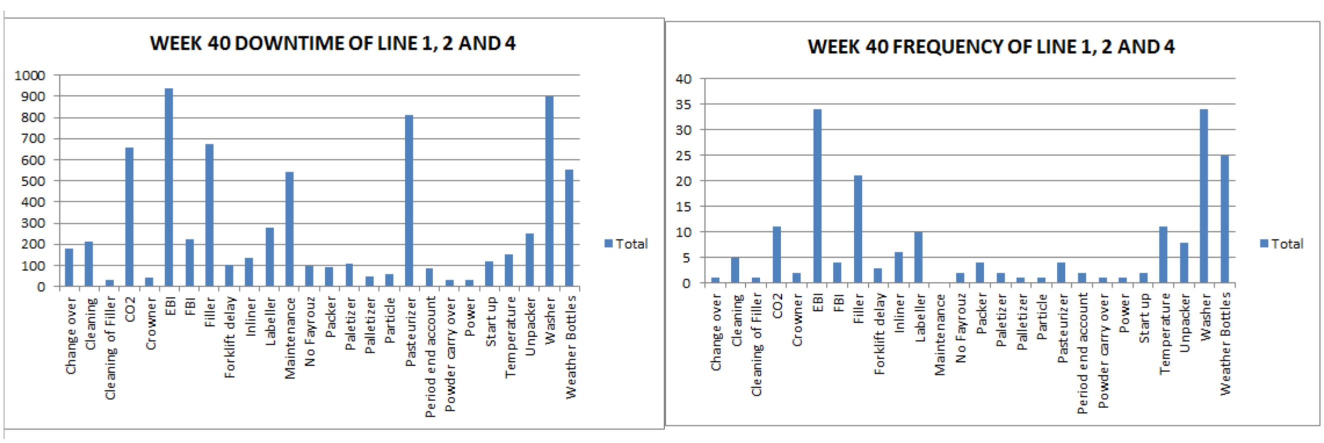


Figure 4.35: Week 40 Breakdown and Frequency Analysis of Line 1, 2 and 4

Table 4.14: Summary table of week 40 to 51 of downtime and frequencies

WEEKS	AREA	MINUTES BREAKDOWN CONTRIBUTION	FREQUENCY OF BREAKDOWN (TIMES)
51	**EBI**	**1450**	**45**
	WEATHERD BOTTLE	**1100**	**35**
	FILLER	**600**	**24**
	LABELLER	**450**	**11**
50	**WEATHERD BOTTLE**	**1650**	**65**
	EBI	**500**	**20**
	PACKER	**450**	**18**
	WASHER	**400**	**15**
49	**NO READY PRODUCT**	**1500**	**21**
	WEATHERD BOTTLE	**1200**	**52**
	EBI	**1050**	**32**
	WAHER	**650**	**28**
	BLOCKED FILLER	**600**	**18**
48	**NO READY PRODUCT**	**2700**	**24**
	CANDLE FILTER	**2400**	**38**
	WASHER	**1700**	**52**
	WEATHERD BOTTLE	**1500**	**60**
47	**WEATHERD BOTTLE**	**2300**	**78**
	CHANGE OVER	**900**	**18**
	EBI	**800**	**33**
	FILLER	**700**	**23**
	WAHER	**650**	**22**
	LABELLER	**400**	**18**
46	**WEATHERD BOTTLE**	**1500**	**56**
	LABELLER	**1000**	**27**
	FILLER	**840**	**25**
	WASHER	**600**	**26**
	EBI	**400**	**12**
45	**NO READY PRODUCT**	**780**	**15**
	WEATHERD BOTTLE	**580**	**28**
	WASHER	**480**	**18**
	CLEANING	**480**	**9**

Table 4.14: Summary table of week 40 to 51 of downtime and frequencies

	EBI LABELLER	300 220	14 8
44	WEATHERD BOTTLE PACKER FILLER MAINTENANCE EBI DEPALLITIZER WASHER	1200 950 580 572 400 380 378	58 36 18 1 18 8 16
43	WEATHERD BOTTLE MAINTENANCE EBI FILLER NO READY PRODUCT PALLETIZER WASHER LABELLER	1320 700 580 520 500 490 420 250	69 1 13 18 9 12 20 6
42	NO READY PRODUCT WEATHERD BOTTLE MAINTENANCE EBI FILLER LABELLER	3500 800 520 500 498 350	37 32 1 14 25 5
41	NO READY PRODUCT EBI PALLETIZER PASTEURIZER WASHER FILLER WEATHERD BOTTLE CHANGE OVER	6200 1300 950 600 500 380 379 200	12 42 18 12 21 15 17 1
40	EBI WASHER PASTEURIZER FILLER CO2 WEATHERD BOTTLE MAINTENANCE	920 900 820 680 650 540 520	34 34 4 22 11 25 1

Table 4.14: Summary table of week 40 to 51 of downtime and frequencies			
	LABELLER	**280**	**10**

Overall Downtimes and Frequencies Contribution Result and Discussion

Appendix 8 to 13, Figure 4.36 and 4.37 shows the Overall Downtimes and Frequencies of Line 1, 2 & 4, to view the contributions of the three categories of downtimes to the production process. In Figure 4.36, machine downtime and external downtime were highest, while in Figure 3.37, the frequencies of occurrences were still high in external and machine downtime**.**

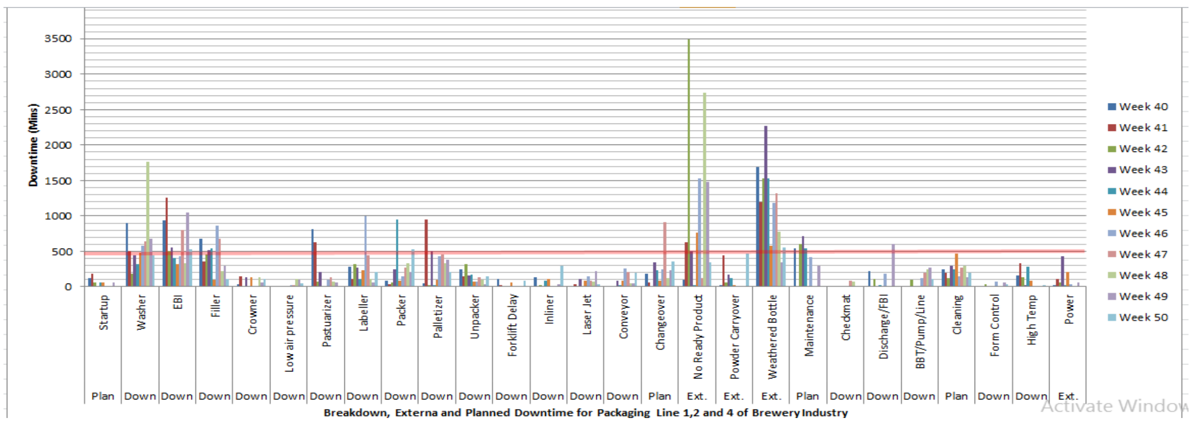


Figure 4.36: Overall Downtime Contribution of Line 1, 2 & 4 for 11 Week

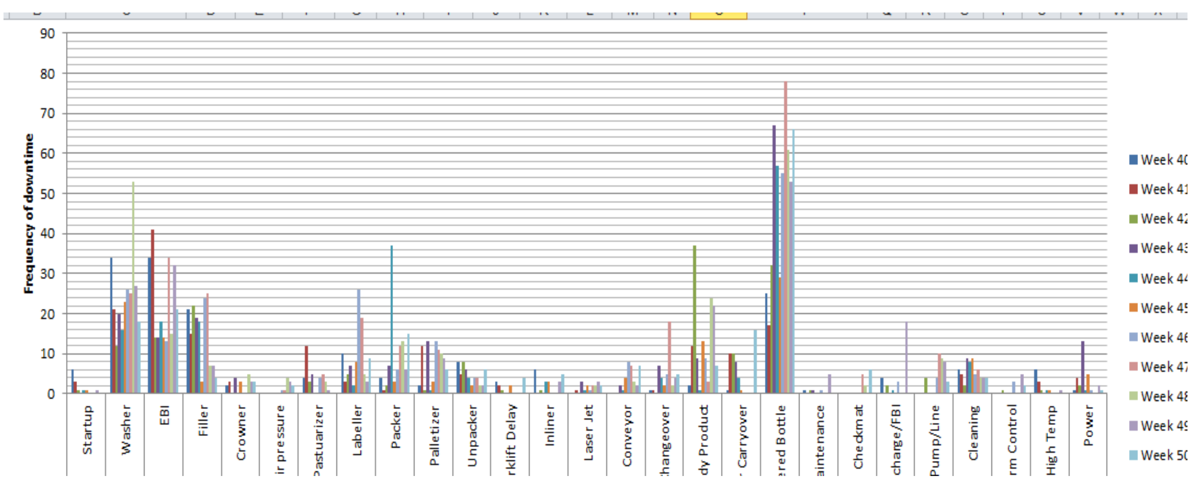


Figure 4.37: Overall Frequency Contributions of Line 1, 2 & 4 for 11 Weeks

Pareto Analysis

Weekly Frequencies of Occurrences and Downtimes Pareto Analysis

Appendix 8 to 13, Figure 4.24 to Figure 4.35 represents weekly downtime and frequencies contributions from week 40 to week 51. Figure 4.36 to Figure 4.37 and Table 4.14 represent the overall downtimes and frequency contribution of weekly downtimes for the 11 weeks. The frequencies and downtimes of the machine breakdown, external and planned downtime can be compared.

In Table 4.14, it is observed in almost all the weeks that EBI, Weathered bottles, Filler, Labeller, Pasteurizer, No ready product and Washer recorded the highest downtime and frequencies. These areas in table 4.14 with high downtime and frequencies of occurrences should be the topmost priority in solving the problems of the entire production system. Solving problems of those mentioned areas will bring more than 80% improvement in downtime reduction, reduce frequency machine stoppages and improve the overall production flows. The next stage is to group the categorized downtimes in Figure 4.20- Figure 4.23into 4M groups to enable us plot Pareto graphs, which will show us the particular area of focus. The four groups are 4M (Machine, Man, Method and Materials). These are critical because knowing the area of focus will assist us greatly in reducing downtimes.

Pareto Analysis of 4 M (Machine, Method, Material and Man)

Appendix 4 to 7, Table 4.15-17 and Figure 4.38-40 of week 40 to week 52 of packaging line 1& 2 & 4 respectively. The raw data was filtered in the following sequence; Weeks, Date, Lines, Issues, Area, 4 M (Man, Method, Material and Machine), Minutes of Breakdown and Frequency of Breakdown.

The result is shown in the figures below.

Table 4.15: 4M Analysis Breakdown of Line 1

WEEK 52-40 OF LINE 1				
S/N	4M	Total Downtime	% Contribution	%Cumulative Contribution
3	Material	14,828	46%	46%
1	Machine	11,456	35%	81%
2	Man	3,245	10%	91%
4	Method	2,980	9%	100%
	Total	**32,509**	**100%**	

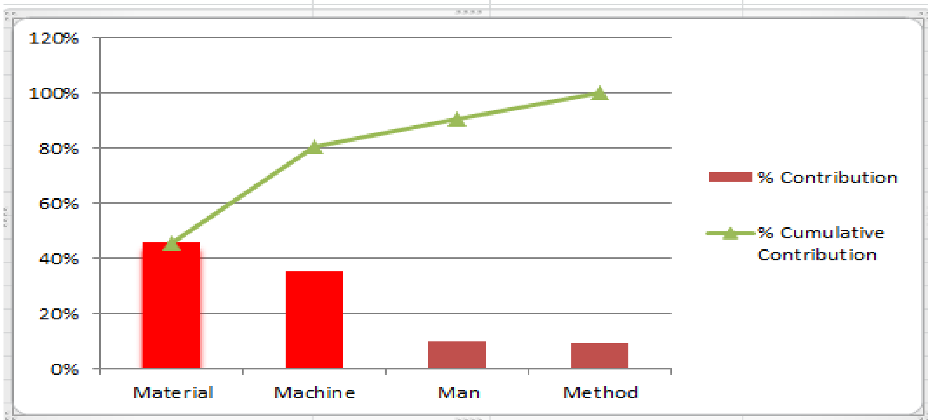


Figure 4.38: 4M Pareto Analysis of Downtime Line

Table 4.16: 4M Analysis Breakdown of Line 2

WEEK 52-40 OF LINE 2				
S/N	4M	Total Downtime	% Contribution	% Cumulative Contribution
3	Material	11,230	39.75%	39.75%
1	Machine	10,041	35.54%	75.29%
4	Method	4,725	16.72%	92.01%
2	Man	2,257	7.99%	100.00%
	Total	**28,253**	**100%**	

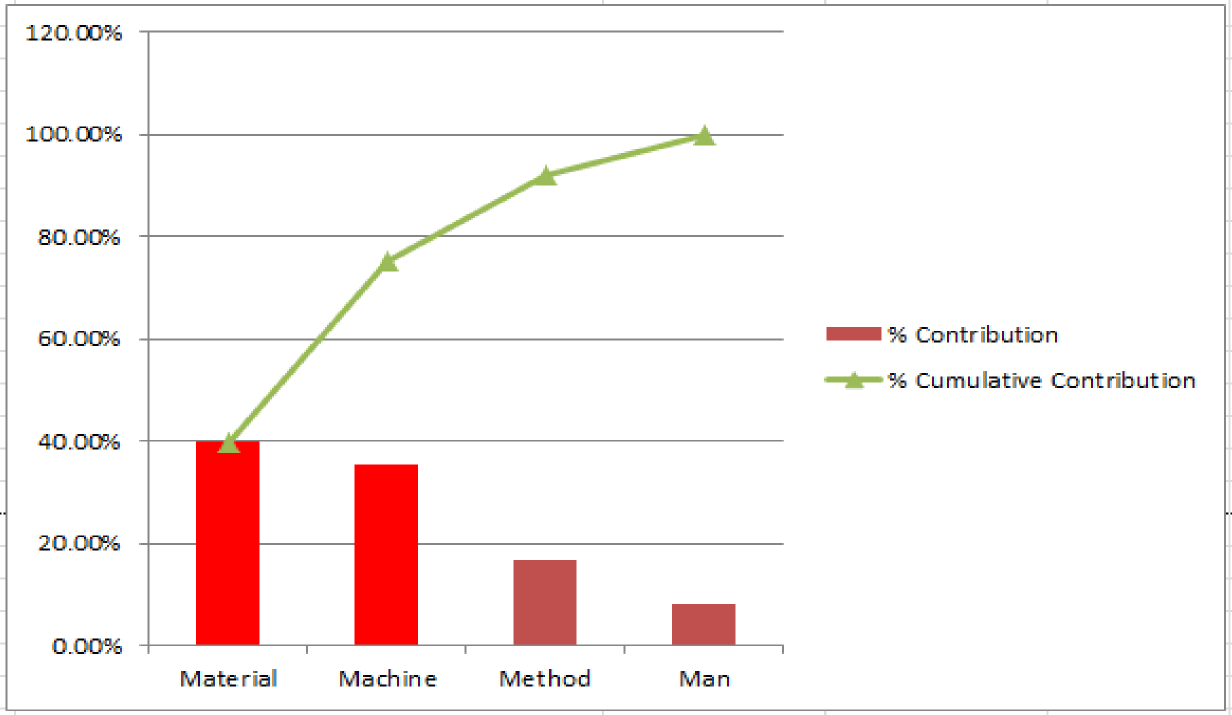


Fig 4.39:4M Pareto Analysis of downtime line 2

Table 4.17: 4M Analysis Breakdown of Line 4

WEEK 38-47 OF LINE 4				
S/N	4M	Total Downtime	% Contribution	Cumulative % Contribution
1	Machine	17,883	63%	63%
2	Man	6,416	23%	86%
3	Material	2,520	9%	95%
4	Method	1,425	5%	100%
	Total	**28,244**	**100%**	

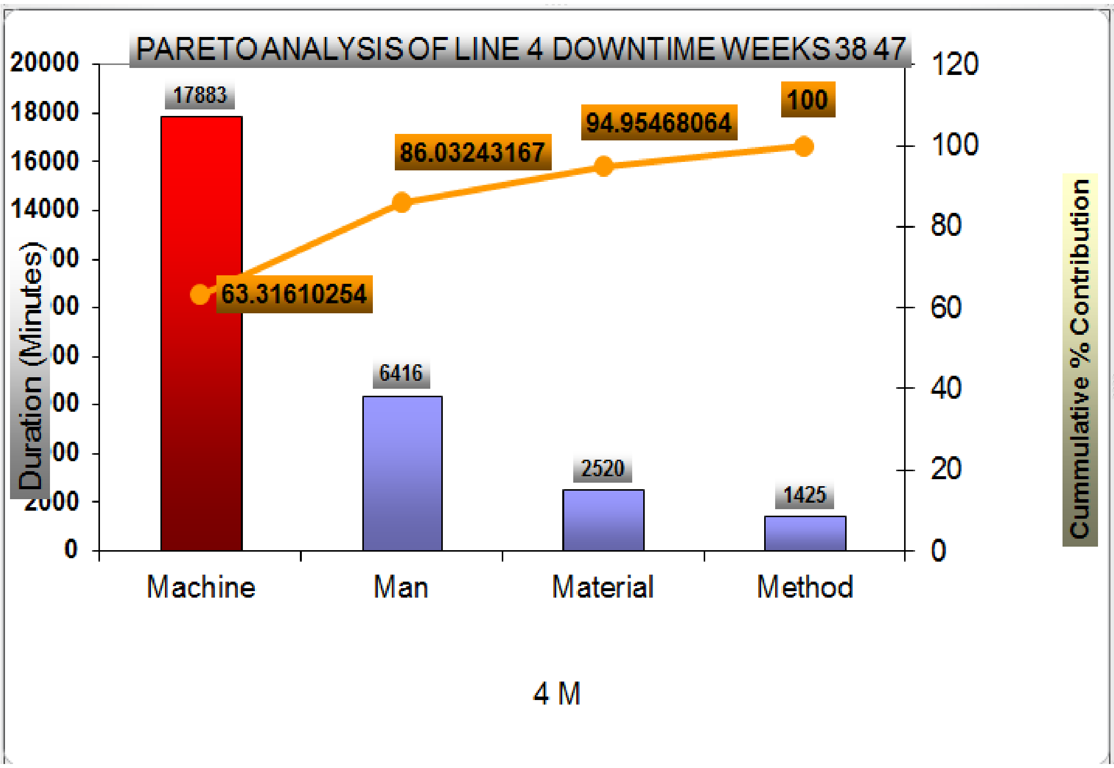


Figure 4.40: 4M Pareto Analysis of downtime in Line 4

4M Pareto Analysis

Appendix 1 to 3 of line 1, 2 & 4 represent the breakdown of machine downtimes, external downtimes and planned downtimes of line 1, 2 & 4. Table 4.15-4.17 show the breakdown of categorized downtimes into 4M (Machine, Method, Materials and Man) while Figure 4.38 to Figure 4.44 represent the Pareto Analysis graph of the four lines. Tables 4.9 and 4.10, Material downtime recorded highest contribution in line 1 and 2 with 46% and 39.75% respectively, while Machine recorded highest in line 4 with 63%. Method recorded low in line 1and 4 with 9% and 5% respectively. Man was the lowest in line 4 with 7.99%.

From the 4M Pareto Analysis in Table 4.16 and Figure 4.39 of Line 2, it is observed that the major contributors to downtimes are material and machine with 39.75% and 35.54% respectively. Focusing on these two of 4Ms will greatly reduce the downtime of the overall system to above 75%. As Pareto rules, indicate that tackling 20% of the problem will bring about 80% positive improvements to the system

From the 4M Pareto Analysis Table 4.17 and Figure 4.38 of Line 4, it is observed that the major contributors to downtimes are Machine and Human Error/Lack of Human Knowledge of the process. 63.3% of the downtime was caused by Machine while Man is 23%. Machine breakdown has a total downtime of 17,883 mins out of total 4M downtime 28,244 mins. Focusing on the highest downtime contributor of 4Ms will greatly reduce the downtime of the overall system to above 80%. As Pareto rules, indicate that tackling 20% of the problem will bring about 80% positive improvements to the system. Considering the line 1, 2 and 4; it is important to focus on Material, Machine and Man to reduce overall system downtime and improve production performance. Method has little contribution to the total downtime on the three lines. These will lead us to the Pareto Analysis of contributor of Individual components downtimes.

Pareto Analysis of Downtime of System Components and Frequency of Contribution

All the components of 4M were analyzed for Line 1, 2 & 4 to understand the individual downtime contributions and frequencies with the following results and discussion

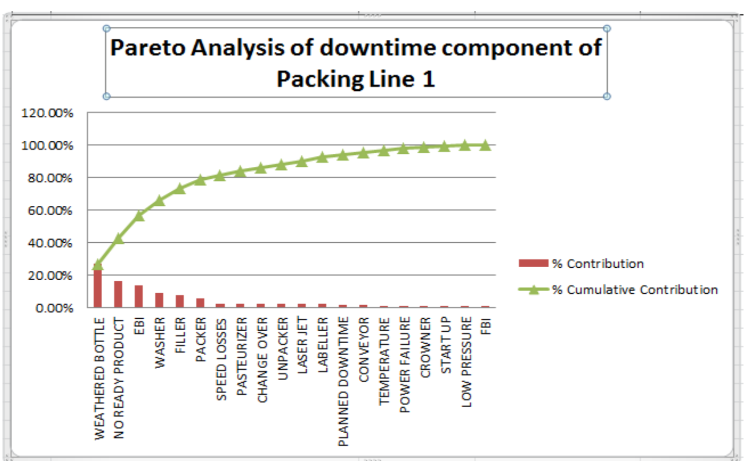


Figure 4.41: Pareto Analysis of categorized downtime of line 1

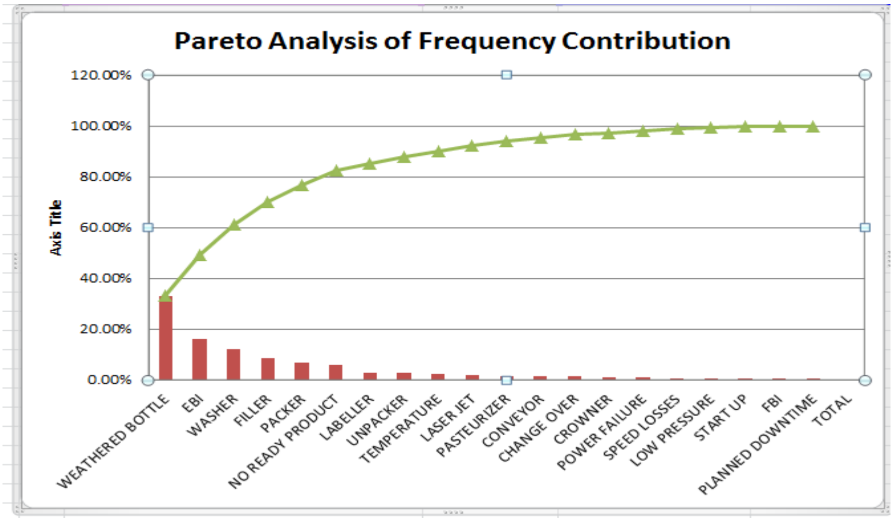


Figure 4.42: Pareto Analysis of frequency contribution of categorized downtimes of Line 1

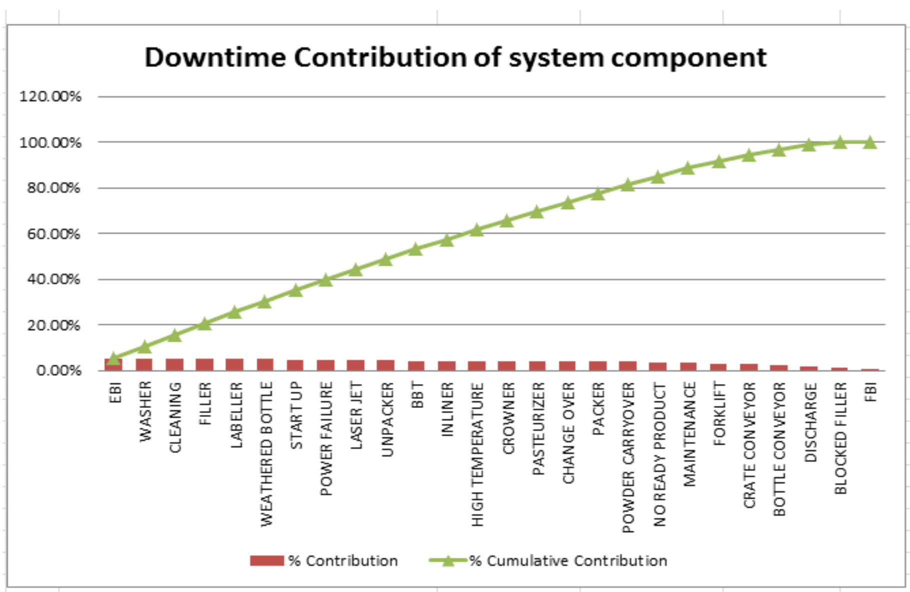


Fig 4.43: Pareto Analysis of Downtime contributor of categorized of line 2

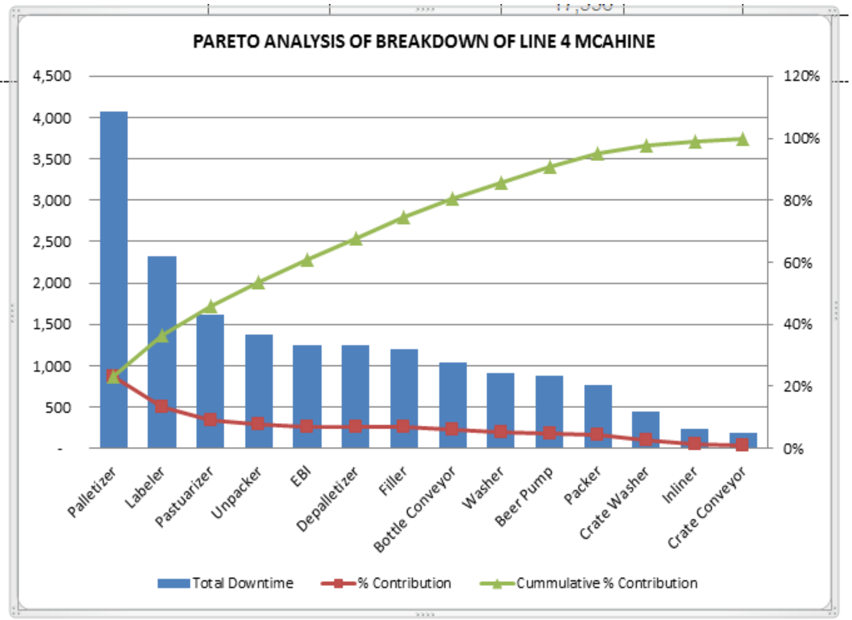


Figure 4.44: Pareto Analysis of Breakdown Contributions of categorized downtimes of line 4

Figure 4.41 to Figure 4.44show individual contributors of categorized downtimes from the Pareto graph for both the downtime and frequency were plotted for Line 1, 2 & 4. The result revealed that Weathered Bottle, which was the external downtime, has the highest downtime and frequency of downtime. Weathered Bottle, EBI, Washer and Filler are the main focus to solve the problem. It shows that in line 2, there are uniform contributions to the overall downtime of the system. Palletizer, Labeller, Pasteurizer, Unpacked, EBI, De-palletizer, Filler and Bottle Conveyor are the major contributor to the downtime. Finally, we have concluded the discussion of the production system result Analysis. The next step is to go to the modeling and simulation and design of experiment to solve the problem of speed loss cause by unregulated and unbalance lines.

4.2 CONCEPTUAL MODELING

The result of the conceptual modeling which was modeled to solve the problems of speed loss, frequent stoppages occasioned by starvation, blockage and failures caused by the unregulated lines, un-optimized sensor speed levels and unbalance labellers labeled.

4.2.1 Movement of Beer Bottles in Conveyor System in Real Life and Simulation

Figure 4.45 to Figure 4.48 show behavior of bottles in conveyor system when in straight lines, bend and blocking list.

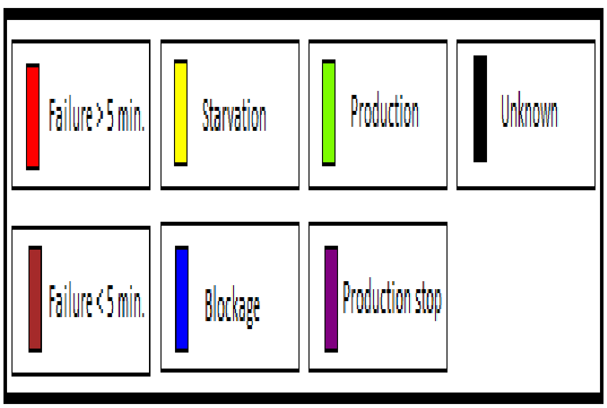


Figure 4.45: Conveyor Belt - Differences in Real Life and Simulation

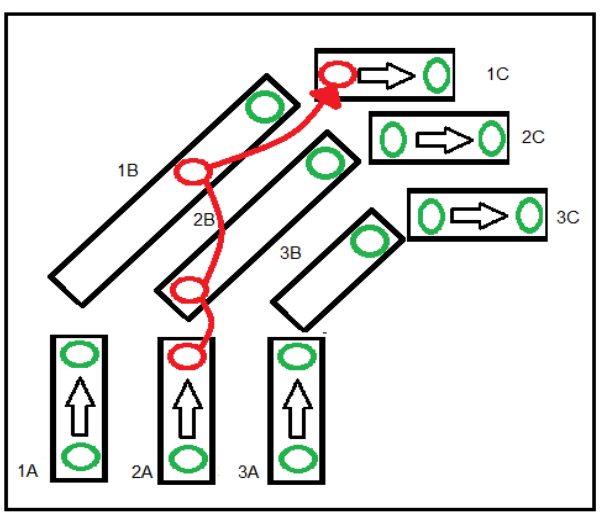


Figure 4.46: Behavior of a Star Bottle in a Bend

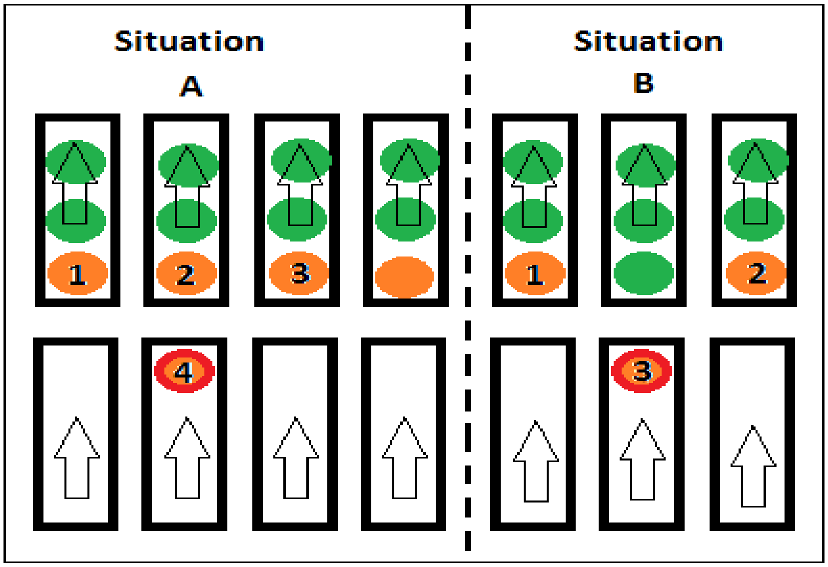


Figure 4.47: Star Bottles in straight line

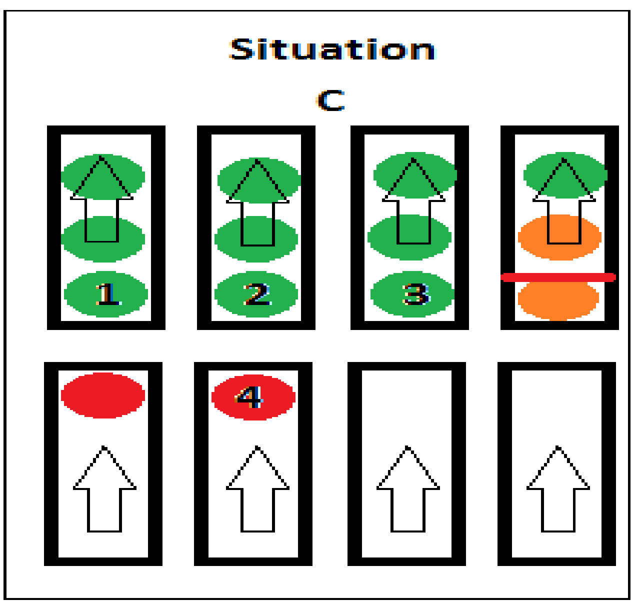


Figure 4.48: Star Bottles in BlockingList

4.2.2 Flowchart Summary Analysis of Star Bottle Movement

Flow Chart is used to represent the result of the summary of the movement of Star Bottles in Conveyor both in Real Life and Simulation. It logically represent the movement of Star bottle and blocking list as was represented by Tecnomatrix Plant simulation software in Figure 4.46 to Figure 4.48.This is the moving of a Star Bottle (SB) over the production lines.

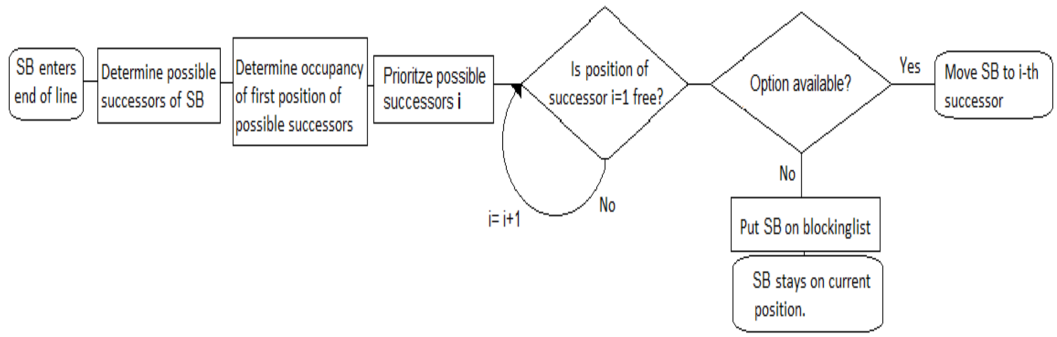


Figure 4.49: Flowchart Conceptual Model 1A - Moving SB Forward

This blocking list is triggered by another part of the model, which is described in Figure 4.46.

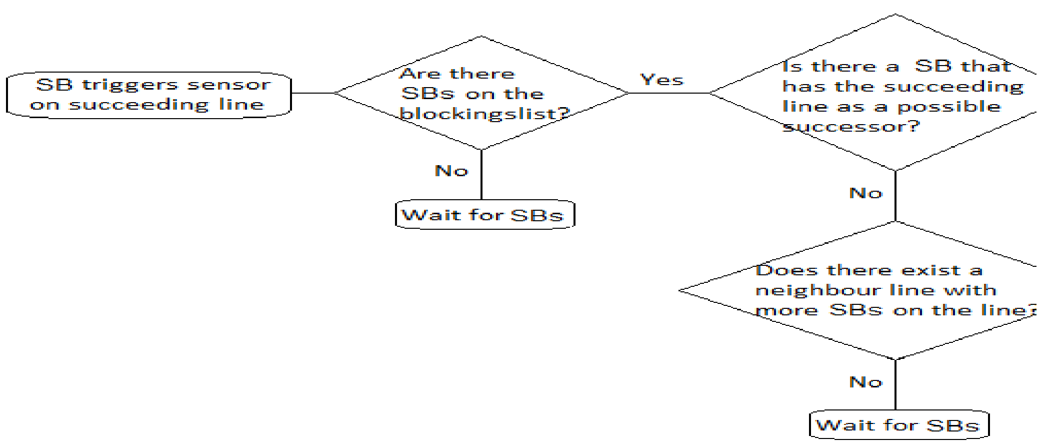


Figure 4.50: Flowchart Conceptual Model 1B - Take SB from Blocking List

Movement of Beer Bottles in Conveyor System in Real Life and Simulation

Figure 4.45 shows conveyor belt in real life and simulation. In real life, the result show that sensors are triggered when bottles hit the sensor and only when conveyor is occupied. Sensor is placed vertically in real life but horizontally on a total line in conceptual model. The result show in Model that red line representing sensor is triggered every time when a single bottle passes. The result of the Model shows that when conveyor is divided into multiple parts, that it prevent sensor to trigger when a single bottle is passed. Figure 4.46 show the behavior of a Star Bottle in a bend. In real life, result shows that the Star bottle will move towards the outside of the bend. A red Star Bottle that moves towards the outsides of the bend is considered when conveyor line is separated into three components parts; A, B and C as it is always in real life. In Figure 4.46, result shows that Star Bottle (SB) moves from 2A to 2B to 1B to 1C and the conceptual model takes into account the distribution of the Star Bottles (SBs) between conveyors. The possible successor of a Star Bottle is determined and it is not possible for a Star Bottle to move from 1A to 3B, if a bend 'turns' right. Star Bottles (SBs) on a bended line have a tendency to move towards the outer of the bend and it is deterministic process, which is modeled with priorities. Figure 4.44 explains the behavior of a Star Bottle which always moves towards the outside of the bend.Figure 4.45 show Star Bottle in straight line, which in the conceptual model there are four possibilities where the Star Bottle can flow after triggering a sensor at the 'end of the line'. This Star Bottle has four succeeding options 1, 2, 3 and 4. The Star Bottle can move to three positions: 1, 2 or 3 while number 4 means that the Star Bottle stays on the same position and can only occur when 1, 2 and 3 are not available. Note that at the right side of number 3 is also space, but it is not a possible successor as it cannot move to this position, because the distance is too large. Determining the possible successors and occupancy of the first position are the first and second steps in conceptual model. The second step was achieved by determining the capacity of a line and counting the current amount of Star Bottles (SBs) on this line, if it is equal, the succeeding conveyor is occupied. Figure 4.47 indicated that the red Star Bottle with #4 will move to number 2 with priority 1 but in situation B occurs the Star Bottle will move to position 1 or 2 with equal priorities in straight line and the chances of moving to these positions are random. Considering a bent line, the chances are deterministic because as in Figure 4.46, the Star Bottles (SBs) will move to the outside of the bend. Considering the Star Bottle (SB) in Figure 4.46, it will eventually move to position 1C with priority 1, to 2C with priority 2 and to 3C with priority 3. These priorities are input to the conceptual model since that are deterministic. If there is no possible successor and option 4 is chosen, which place the Star Bottle on the blocking list. Blocking list trigger sensor is placed on the succeeding production line. Thus, when a first position becomes empty, a sensor checks whether there are Star Bottles (SBs) on the blocking list and if true, then the sensor check if the Star Bottle in the list is allowed to fill the first position, as described in Figure 4.47 and if true, conveyor move the Star Bottle which is ranked highest in the blocking list (longest waiting), and delete this SB from the blocking list. Star Bottle on the blockings list always is preferred above those on the conveyor at the end of a line. In figure 4.48 the red Star Bottle (4) is located in the blocking list. Orange, which is the first position is not a possible successor of the red Star Bottles (SBs) but because in real life the conveyors will be constantly flowing, therefore the Star Bottle with number 3 will eventually moves to the orange position. This is also taken into account in the conceptual model. Model method compares the amount of Star Bottle on the line of the neighbor, if no SBs are available on the blocking list and the amount of SBs on the neighbor line is more than 2, it takes the last SB of the line. Figure 4.48 has succeeding line with only one neighbor, and the amount of Star

Bottle on the line next to the orange circles is above two, so conveyor t moves Star Bottle #3 to the orange circle, which now make it possible for the red Star Bottle to move to position 3. Figure 4.49 and Figure 4.50 show the result of flowchart of conceptual model 1A-moving SB forward and Model 1B-Taking SB from blocking list.

4.2.3 Result of Overview of Line Regulation in Conceptual Model

Figure 4.51 to Figure 4.54 represent the result of built conceptual model in Tecnomatrix Plant Simulation Software, 17 possible sensors, which determined speed change that will regulate conveyor speed to achieve the desired goal, also required is the buffer capacities and Pasteurizer capacity change. The conceptual model consists of eight lines, but simplified to four lines for easy simulation. Sensor 10 located at conveyor part H/I ensures that CPL 112 start producing when triggered, and stops producing when it is not triggered anymore

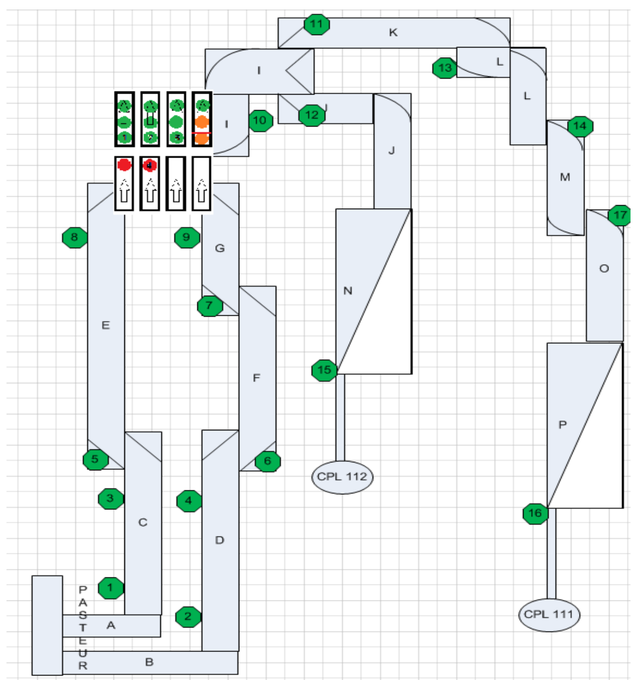


Figure 4.51: Regulation of Labellers In Conceptual Model

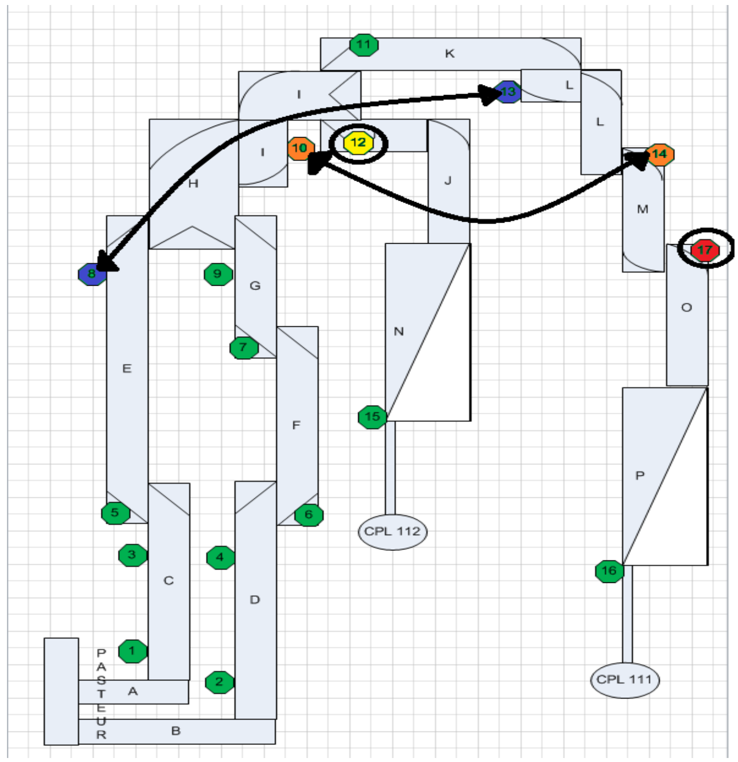


Figure 4.52: 17 Possible Sensors to Regulate Speed of Conveyor

Table 4.18: Speed Changes Dependent on Sensors - Current and Alternative Situation

Machine – 'Change to'	Triggered Sensor	Triggered Sensor
LABELLER112 – Low	No low speed	Sensor 12 (J4)
LABELLER111 – Low	Sensor 17 (O4)	No low speed
LABELLER111 –	Sensor 14 (M4)	Sensor 10 (I8)
LABELLER111 – High	Sensor 13 (L111)	Sensor 8 (E51)

The speed changes from Table 4.18 are translated into the letters.

Table 4.18 representsthe different between the conveyor and the sensor located in it at real life and when the system is model in Tecnomatrix simulation software.

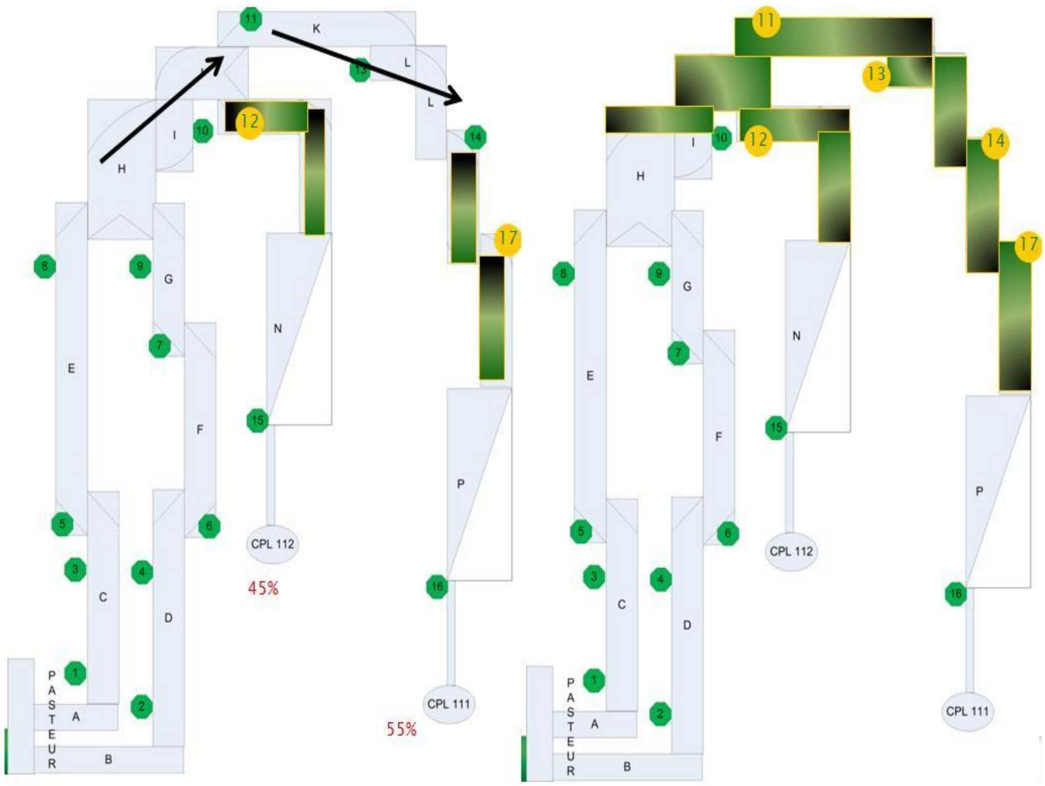


Figure 4.53: Buffer Position – Current (Left) and New Situation (Right)

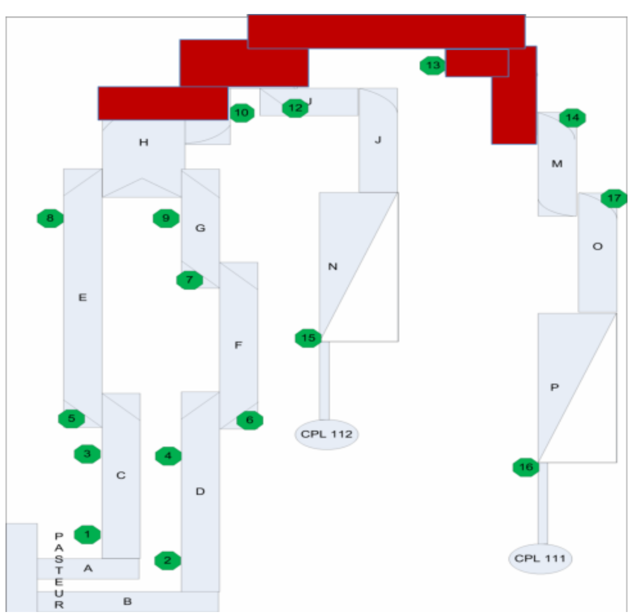


Figure 4.54: Buffer Enlargement - Current Vs New Alternative

Result of Overview of Line Regulation in Conceptual Model

Figure 4 .51 show the result of conceptual model regulating two labellers CPL111 and CPL112. In the conceptual model, the conveyor line with the orange circles is the one where the sensor is located. Conveyor lines of Labeler CPL 111 and CPL 112 are separated; therefore Labeller CPL112 is modeled to start producing by counting the amount of Star Bottles (SBs) on the conveyor with the sensor. There were three possible positions on the conveyor and when all three positions were occupied, the sensor was triggered. The processing time moved to nominal speed when the Star Bottles on the conveyor with the sensor is equal to three, but if all the three positions are empty for 30 seconds, CPL112 will stop. The same model was performed for all the relevant sensors. The conceptual model works with aggregated sizes of Star Bottles, because in real life every hour there are entering about 70,000 Star Bottles and staying in the system for several minutes. This caused lots of processing time but in order to mimic the real life situation, the conceptual model uses aggregated size of 1:100. 1 Star Bottle in the conceptual model represents 100 Star Bottles in real life. Figure 4.50 show the positions options of 17 possible sensors in the simulation to regulate speed of Labellers. The sensors colored green were neglected in the simulation for several reasons. Sensors 1 to 7 are too close to the pasteurizer, and were used to determine the speed of the pasteurizer. There is a risk of pasteurizer being blocked, when sensors 1 to 7 is used to determine the speed of the pasteurizer. This has a reverse result on the desired situation. The lower deck from the pasteurizer is always filled. Skipping the use of sensor 9 will decrease the amount of experiments, without having any influence on the outcome. Sensors 15 and Sensor 16 were neglected because these sensors served for a security and will trigger the line to have emergency shutdown. If not, the LABELLERs will be damaged. When there are no beer bottles, the labels stick in the machine. Sensor 11 was neglected because; this has little value when also sensor 13, 14 and 17 are regulating LABELLER111. Sensor 11 regulates Conveyor K is regulated with sensor 11 located the K. The colors in Figure 4.50 mean that these will change over the experiments. Sensor 12 (yellow) and sensor (17) were only considered when LABELLERs have a low speed or will not (on/off).When a sensor of a higher speed is triggered, the sensor of the lower speed is overruled. For example when in the current situation sensor 13 is triggered, so LABELLER111 changes to high speed , then sensor 14 is overruled until sensor 13 is not triggered any more. Table 4.18 shows the speed change which is dependent on sensor. There are 4 different factors which have two different speed levels. No low speed means that the LABELLERs directly change to the nominal speed, so only three speed levels are available. Thus, at the moment LABELLER112 has no low speed and the alternative situations checks if it is valuable to add a low speed on the LABELLER112 on sensor 12. The colors are equal to those of Figure 4.50, so one can see what is changing. Figure 4.53 shows the current (left) and New Situation (Right) when buffer capacity is increased. The first positive result from the change in buffer capacity is that the problem with the bend is solved. At the current situation the problem arises that after a starvation all bottles move to LABELLER111 and assumed that this was the reason for a production imbalance. In Figure 4.52 shows buffer enlargement current vs new. The difference in buffer size is shown with the red part. The capacity of the red part is 2517 beer bottles. This means that in the current setting, when the LABELLERs have starvation, LABELLER111 produces 2517 beer bottles more than LABELLER112. In addition, in the current situation the LABELLER111 starts at high speed when LABELLER112 is still down. On average this is 5 minutes, which means that another 3500 beer bottles are produced by LABELLER111 until LABELLER112 starts producing. When combine these beer bottles, every starvation, LABELLER111 produces

6017(=2517+3500) beer bottles more than LABELLER112. Considering the new alternative solution, both effects will be solved. In the new situation LABELLER111 and LABELLER112 will start and end simultaneously on sensor.

4.3.1 Experimental Modeling Verification and Validation through Simulation

Simulation is used in order to find optimal locations for the sensors with ideal speed levels for the CPLs. Figure 4.54 to Figure 4.55 show the print screen of simulation and process time and machine speed of labellers. Table 4.13 to Table 4.16 represents distribution, destination, and number of replication and validation of our experiment.

There are three types of parameter to define in the simulation model.

Processing times: Time that a machine needs to produce a beer, **Mean Time Between Failures (MTBF):** the mean time it takes between machine failures, Mean **Time To Repair (MTTR):** Time it takes for repairing a machine after it failed. The processing times, MTTF, MTTR and destination table are determined.

Processing times

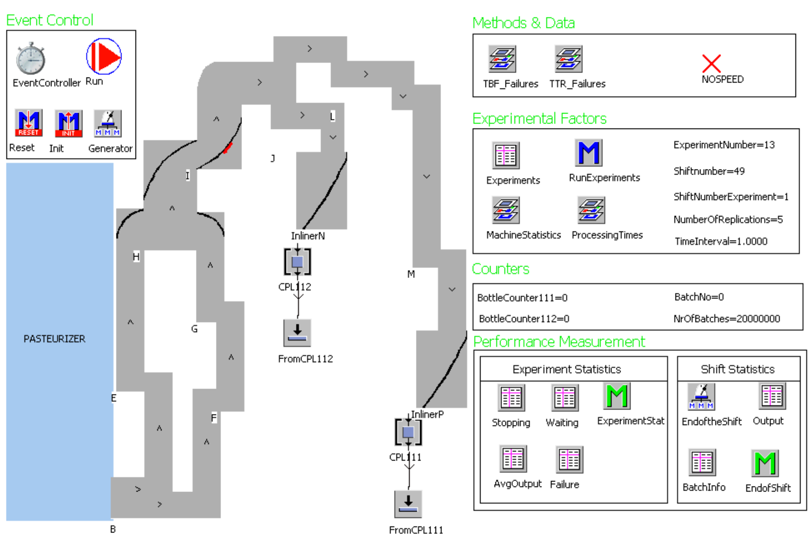


Figure 4.55: Print Screen of Main Frame Plant Simulation using Tecnomatix Plant Simulation

Reference to Table 4.16, when the experiment was modeled with the current production system and as simulated, the bottle was moving in animated form and the total input of 239038 bottles of labeler CPL 111 came out as the output value and 195577 bottles which was the input value of Labeler CPL 112 came out as the output value of the experiment. Bottles were moving in conveyors, No bottle was stocked on any of the machine, there were no bug in the experiment hence the verification of our model.

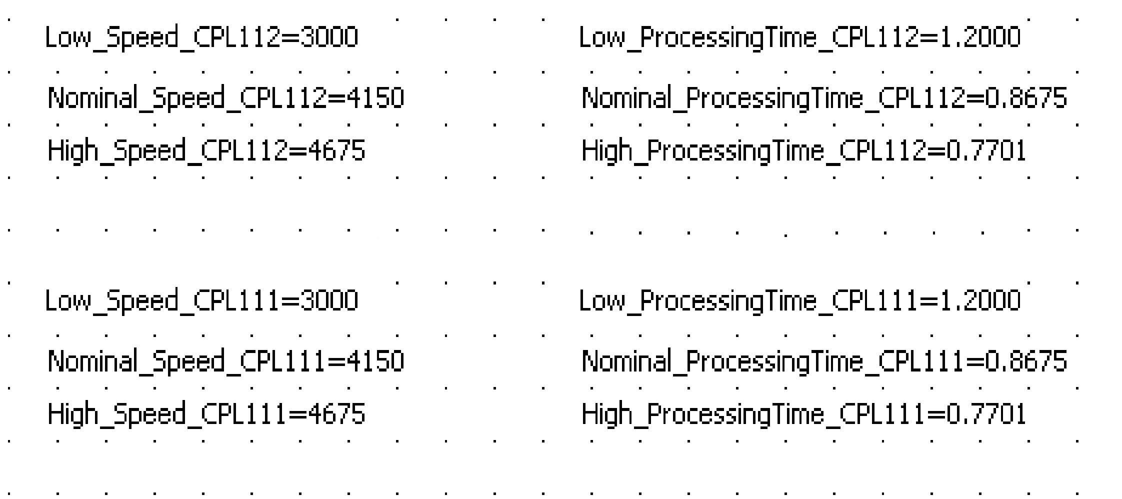


Figure 4.56: Machine Speeds/Processing Times of Labellers

MTBF

To calculate the MTBF operating-dependent failures are applied, this means that a machine can only have a breakdown when it is in operation. To determine the mean time between failures, production time between two machine failures are determined, excluding starvation and blocking periods.

MTTR

In MES there is a distinction between short (< 5 minutes) and long (>= 5 minutes) failures. Minor Stoppage <5min is fallen bottles and are not part of a pattern in the duration of the failure mode. For those reason only long failures is considered. The MTTR there is a theoretical distribution that fits the data from the process, namely the Weibull distribution. In Table 4.15, show the parameters of the Weibulldistribution of both Labellers.

Table 4.19– Distributions with Corresponding Parameters -MTTR

LABELLER111	**Weibull**	**α = 0.83029**	β = 36.428
LABELLER112	Weibull	α = 0.78302	β = 28.755

Destination Table

In order to deliver these priorities as input to our simulation model, a destination table is developed. The result of a destination table in Plant Simulation is shown is Figure 4.14.

Table 4.20: Destination Table Part I of Layout

File Edit Format Navigate View Tools Help

	object 0	integer 1	integer 2	integer 3	integer 4	integer 5	integer 6	integer 7	integer 8	integer 9
object		.Models.PasteurCPL.I.I1	.Models.PasteurCPL.I.I2	.Models.PasteurCPL.I.I3	.Models.PasteurCPL.I.I4	.Models.PasteurCPL.I.I5	.Models.PasteurCPL.I.I6	.Models.PasteurCPL.I.I7	.Models.PasteurCPL.I.I8	
1	.Models.PasteurCPL.I.I11	1	1	0	0	0	0	0	0	
2	.Models.PasteurCPL.I.I21	2	2	1	0	0	0	0	0	
3	.Models.PasteurCPL.I.I31	3	3	2	1	0	0	0	0	
4	.Models.PasteurCPL.I.I41	0	0	3	2	1	1	0	0	
5	.Models.PasteurCPL.I.I51	0	0	0	3	2	2	1	0	
6	.Models.PasteurCPL.I.I61	0	0	0	0	3	3	2	1	
7	.Models.PasteurCPL.I.I71	0	0	0	0	0	0	3	2	
8	.Models.PasteurCPL.I.I81	0	0	0	0	0	0	0	3	
9										
10										
11										
12										

This destinationtableshowsthe priorities from the first layer at part I to the second layer at part I.

Warm-up period

To enter the steady state in our system, the first beer bottles exit the system. This took 6 minutes for the LABELLER112 and 8 minutes for the LABELLER111, which is negligible. Therefore warm-up period is not considered.

Number of replications

The number of replications guarantees 95% confidence interval with a width of at most 5% of the mean. The following formula computes the required precision: $\gamma' = \frac{\gamma}{1+\gamma}$Where γ' is the required precision and has a value γ =0.047619 If the precision is not sufficient, another replication is executed in order to decrease the confidence interval half width until the required precision is achieved. In Table 4.15 the computation of the number of replications is shown. The required precision was achieved in replication 5 where the width of the confidence interval is lower than the relative error. This means that 5 replications per experiment will be run.

Table 4.21: Number of Replications

Replication	Data	Average	Variance	T-value	Relative error	Confidence interval width
1	461600	461600			0,047619	
2	427580	444590	578680200	12,7062	0,047619	0,48613901
3	448250	445810	293805300	4,302653	0,047619	0,095511502
4	435920	443337,5	220323225	3,182446	0,047619	0,053275405
5	423330	439336	245302430	2,776445	0,047619	0,044264771
6	451950	441438,3	222760777	2,570582	0,047619	0,035481758
7	402980	435944,3	396925895	2,446912	0,047619	0,042266183
8	468830	440055	475405971	2,364624	0,047619	0,041423091
9	401590	435781,1	580375361	2,306004	0,047619	0,042493735
10	461570	438360	582395889	2,262157	0,047619	0,039382294
11	456620	440020	554467900	2,228139	0,047619	0,03595106
12	454830	441254,2	522339736	2,200985	0,047619	0,032908964
13	459530	442660	504504200	2,178813	0,047619	0,030662698
14	411750	440452,1	533941049	2,160369	0,047619	0,030290872
15	466360	442179,3	540550207	2,144787	0,047619	0,029117766

Simulation, Verification and Validation

A verified and validated model means that this model can run experiments, and assures that the model mimics a real life situation.

Verification

Verification was applied through animation to debug the simulation model with Tecnomatix Plant Simulation. When experiment was running, beer bottles were seen as movable units,, which helped to check when beer bottles stuck on a certain conveyor. These animations helped to know when the beer bottles stuck on a certain conveyor. When this is the case, it indicates that there is a bug in the model otherwise the beer bottles will move to the next conveyor. No bottle was stuck on conveyor during the simulation and to validate the simulation, the output of the model with the input was equal after all the bottles have been exited the model. Finally, verification of the simulation model was checked on how the system is sustained regarding the output, when there is a change in the input variables, e.g., distributions and processing times (Sensitivity Analysis)

Validation

Table 4.22-Validation of Simulation Model

	Output = (crates * # of btls. in crate)	Real life	Simulation model - # of beer bottles
LABELLER111	Output	(18109 * 24) * 0.55= 239038	253100 btls.
LABELLER112	Output	(18109 * 24) * 0.45= 195577	206990 btls.

EXPERIMANTAL VERIFICATION AND VALIDATION

4.4 Experimental modeling verification and validation through Simulation

Processing times

Figure 4.53 shows the print screen of main frame of plant simulation using Tecnomatrix Plant Simulation. It indicated the experiment methods & data, Experimental Factors, Counters and performance measurement. In event Control, there was Reset, Generator for input, and Run for the experimental run. The pasteurizer has two sources, one for the upper deck and one for the lower deck. The lower deck is the left side of the lines from the pasteurizer towards part I and the upper deck is the right side. The lower deck is always filled with beer bottles, due to the failure mode of the Labellers. Therefore, the source of the lower deck produces more beer bottles compared to the upper deck. The beer bottles were counted with a production counter. The partition of the deck was as follows:

- Lower deck: 39,138 bottles per hour.
- Upper deck: 36,257 bottles per hour.

The difference between the lower and the upper deck is 7. 4%. This means that the upper deck produce 7.4% less than the lower deck. The source at the upper deck has therefore a failure rate of 7.4%. The upper deck has availability of 92.6% and MTTR of 1 minute. Therefore 92.6% of the total time, the upper deck has beer bottles at in feed. Figure 4.54 shows the speed levels of two labellers CPL111 and CPL112 and the processing time of each labeller. Each of the Labellers has the same speed and processing time in Low Speed, Nominal Speed, and High Speed as indicated in the Figure 4.45. **In MTTR,** Minor Stoppage <5min is fallen bottles and are not part of a pattern in the duration of the failure mode. Only long failures >5min is considered. The MTTR there has a theoretical distribution that fits the data from the process.**Destination**

Table: Destination Table 4.14 was used to deliver priorities to different Labellers as input to our simulation model. This destinationtableshowsthe priorities from the first layer at part I to the second layer at part I.**Warm-up period**: The first beer bottles exit the system to enter steady state and it took 6 minutes for the LABELLER112 and 8 minutes for the LABELLER111, which is negligible. Therefore warm-up period is not considered. **Number of replications:** Law (2006) on replication-deletion method is applied to determine the number of replications, which guarantees 95% confidence interval with a width of at most 5% of the mean.is used in order to determine the number of replications. The number of replications guarantees 95% confidence interval with a width of at most 5% of the mean. After calculation precision: $\gamma = \frac{\gamma}{1+\gamma} = 0.04619$ Another replication was executed to get sufficient precision and decrease the confidence interval half width. From the result of computation in Table 4.15, the required precision was achieved in replication 5 where the width of the confidence interval is lower than the relative error. This means that 5 replications per experiment will be run. **Verification of Model:** A verified and validated model means that this model can run experiments, and assures that the model mimics a real life situation. The verification tools applied in Tecnomatix Plant Simulation was animation. When experiment was running, beer bottles were seen as movable units. During animations the beer bottles did not stuck on a certain conveyor, which verify our model otherwise it indicated that there is a bug in the model and the beer bottles will move to the next conveyor. Output of the model was compared with the experimental input and the result was equal after all the beer bottles have exited the system. **Validation:** Through validation of the model, the accuracy of the simulation model was measured, with reality. To achieve that output quantity of the beer bottles was determined and applies lead time to validate the model. In order to check the lead time output quantities over a time period of 8 hours was considered. The output of the simulation model was compared with the output in real life shown in Table 4.16 and the production balance is checked. LABELLER111 produces in real life 55% of the total output and LABELLER112 produces 45%. As shown in Table 4.16, the difference between real life and the simulation model is sufficiently small. The production balance in our simulation model was 55.15% (LABELLER111) against 44.85% (LABELLER112). These validated our model.

4.4.1 Design of Experiment

The input data obtained during the design of experiments are distribution functions MTTR and MTBF for the two labellers, calculated in Appendix 17 to 25 of page 289 to 292; Data for conveyor capacities, no of strokes, efficiencies calculated in Appendix 36 of page 309; Line information on conveyors capacities is given in Appendix 37 of page 310; Number of replications is calculated in page 171 and data shown in table 4.21; Machine processing time and speeds for Labeller CPL 111 and CPL 112 is shown in figure 4.56; Experimental result after simulations was represented in Appendix 28 of page 297. Labeller CPL 112 has conveyor J4 with sensor 12 of low speed mounted on it. Labeller CPL 111 have conveyor O4, with sensor 17 of low speed, conveyor M4 and I8 with sensor 14 and 10 respectively of nominal speed and. conveyor E51 and L11 with sensor 8 and 13 of high speed. There is four speed levels of Nospeed, low speed, nominal speed and high speed considered in the experiment. 2 factors and four levels have 4*4 experimental runs, which is 16 runs but 4 experimental runs where not feasible because of moment of speed change of low to high speed gave four runs. Machine that suddenly changes from low speed to high speed is prone to failures and should be avoided; therefore 12 experimental runs were applied to determine the two labeller optimal outputs, production balance, waiting time, stopping time and failure rates.

Figure 5.57 show 5 possible sensors to regulate labeller CPL 112 and 111.

1. Down.
2. Low.
3. Nominal.
4. HIGH

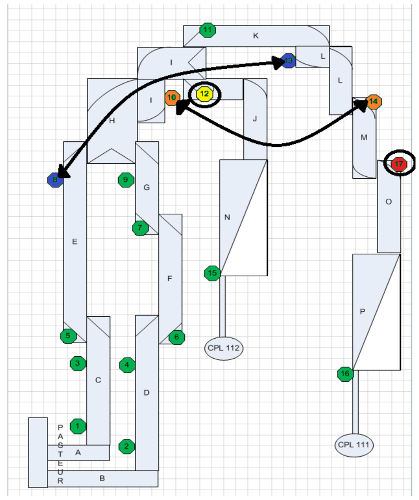


Figure 4.57: 5 Possible Sensors to Regulate Speed of Conveyor

Table 4.23: Speed Changes Dependent on Sensors - Current and Alternative Situation

	Current situation	**Alternative situation**
Machine – 'Change to'	Triggered Sensor	Triggered Sensor
LABELLER112 – Low speed	No low speed	Sensor 12 (J4)
LABELLER111 – Low speed	Sensor 17 (O4)	No low speed
LABELLER111 – Nominal speed	Sensor 14 (M4)	Sensor 10 (I8)
LABELLER111 – High speed	Sensor 13 (L11)	Sensor 8 (E51)

In Table 4.24, changing the speed of the machineis indicated. First column therefore means: changing low speed of LABELLER112.

Table 4.24: Experiments on production outputs

	LABELLER112 <> low Speed	LABELLER111 <> low Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	Output Results No. of Bottles
Exp 1	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	441313
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	416625
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	388495
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	435440
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	444508
Expe 6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	453103
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	439100
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	379278
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	408198
Exp 10	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	449990
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	430915
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	444338

Running all these experiments takes certain period. In order to calculate how long it takes to run all experiments the total run time is determined.

Table 4.25: Experiments on two labellers' production balance

	LABELLER112 <> low Speed Speed	LABELLER111 <> low Speed Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	LABELLER 111 Production Balance	LABELLER 112 Production Balance
Exp 1	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	57%	43%
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	29%	71%
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	19%	81%
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	58%	42%
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	57%	43%
Expe 6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	53%	47%
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	62%	38%
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	23%	77%
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	31%	69%
Exp 10	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	58%	42%
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	57%	43%
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	54%	46%

The total run time of all experiments is 2.5 hours

$$= \frac{60(\text{Number of Experiments}) * 2.5 \text{ Run time per experiment in minutes})}{60(\text{Convert hours in minutes})}$$

Table 4.26: Experiments on two labellers' starvations

	LABELLER112 <> low Speed Speed	LABELLER111 <> low Speed Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	LABELLER 111 % Starvation	LABELLER 112 % Starvation
Exp 1	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	29,77%	38,08%
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	67,77%	9,51%
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	69,40%	7,03%
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	1,72%	39,03%
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,82%	38,79%
Expe 6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,01%	30,61%
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	24,65%	48,17%
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	76,67%	10,80%
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	66,44%	13,59%
Exp 10	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	2,90%	28,48%
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,78%	37,09%
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,08%	33,84%

Table 4.27: Experiments on two labellers' failures

	LABELLER112 <> low Speed Speed	LABELLER111 <> low Speed Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	LABELLER 111 % Failure	LABELLER 112 % Failure
Exp 1	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	2,22%	0,85%
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	0,43%	1,33%
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	1,03%	0,24%
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	1,65%	0,54%
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	1,20%	0,18%
Expe 6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	1,42%	0,04%
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	0,84%	0,13%
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	0,46%	1,36%
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	0,39%	1,06%
Exp 10	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	1,99%	1,03%
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	2,83%	0,86%
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,78%	0,80%

Table 4.28: Experiments two labellers' waiting time

	LABELLER112 <> low Speed Speed	LABELLER111 <> low Speed Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	LABELLER 111 % Waiting Time	LABELLER 112 % Waiting Time
Exp 1	**NOSPEED**	**O4 (Sensor 17)**	**M4 (Sensor 14)**	**L11 (Sensor 13)**	**0,78**	**38,08**
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	0,05	9,51
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	0,00	7,03
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	1,72	39,03
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,82	38,79
Expe 6	**NOSPEED**	**NOSPEED**	**I8 (Sensor 10)**	**E51(Sensor 8)**	**0,01**	**30,61**
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	2,45	0,00
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	0,03	1,39
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	0,00	1,34
Exp 10	**J4 (Sensor 12)**	**NOSPEED**	**M4 (Sensor 14)**	**L11 (Sensor 13)**	**2,90**	**8,77**
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,78	34,63
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,08	33,33

Table 4.29: Experiments two labellers' stopping time

	LABELLER112 <> low Speed Speed	LABELLER111 <> low Speed Speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed	LABELLER 111 % Stopping Time	LABELLER 112 % Stopping Time
Exp 1	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	28,99	0,00
Exp 2	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	67,71	0,00
Exp 3	NOSPEED	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	69,40	0,00
Exp 4	NOSPEED	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	0,00	0,00
Expt 5	NOSPEED	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,00	0,00
Expe 6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,00	0,00
Expt 7	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)	22,20	48,17
Exp 8	J4 (Sensor 12)	O4 (Sensor 17)	M4 (Sensor 14)	E51(Sensor 8)	76,64	9,41
Exp 9	J4 (Sensor 12)	O4 (Sensor 17)	I8 (Sensor 10)	E51(Sensor 8)	66,44	12,25
Exp 10	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	L11 (Sensor 13)	0,00	19,71
Exp 11	J4 (Sensor 12)	NOSPEED	M4 (Sensor 14)	E51(Sensor 8)	0,00	2,46
Exp 12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)	0,00	0,51

4.4.2 Current Situation

The total average output of experiment 1 is 441,313 bottles per shift, with a production balance of 57% on LABELLER111 and 43% on LABELLER112. The other performance measures are shown below in Table 4.23.

Table 4.30: Results of Experiment 1 when speed level and position not altered

	LABEL LER111	LABELLER112
Waiting	0.78%	38.08%
Stopping	28.99%	0.00%
Failure	2.22%	0.85%

The waiting time + the stopping time were the starvation time. Therefore the starvation time of LABELLER111 is 29.77% is less than on the LABELLER112 which is 38.

Table 4.31: Sensor Positions Top 3 Alternative Solutions

Experiment	LABELLER112	LABELLER111	LABELLER111	LABELLER111
Current	NOSPEED	O4 (Sensor 17)	M4 (Sensor 14)	L11 (Sensor 13)
6	NOSPEED	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)
10	J4 (Sensor 12	NOSPEED	M4 (Sensor 14)	L11(Sensor 13)
12	J4 (Sensor 12)	NOSPEED	I8 (Sensor 10)	E51(Sensor 8)

Remarkable on Table 4.22 is that experiment 10 is close to the current situation and experiment 6 and 12 are different in almost every setting. This proves that the combination of sensors is far more important than the sensors itself. Furthermore, the amount of speed levels at LABELLER111 decreases at all the three alternative solutions. In experiment 10 and 12, the amount of speed levels on the LABELLER112 increases to three.

4.4.3 Graphical Representation of Output against Production Balance

In Figure 4.58 show all the experiments in a graph, with on the X- axis the output quantity and on the Y-axis the production balance.

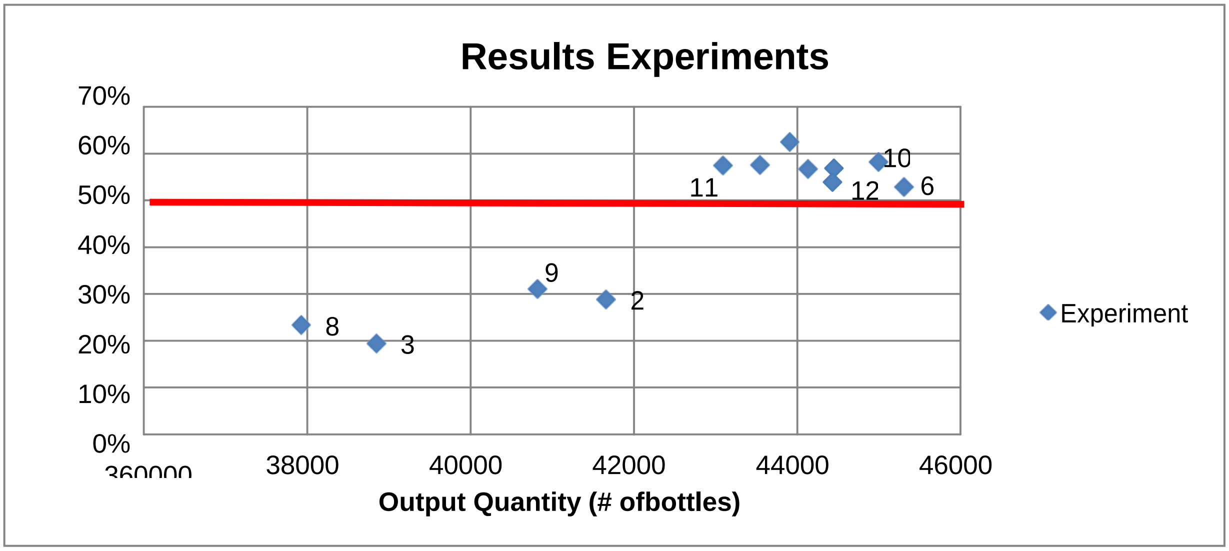


Figure 4.58: Results of Experiments Regarding Output and Balance

4.4.4 Correlation of Production Balance against Output

In Figure 4.59 the results of the experiments is considered again to determine if there is a correlation with the production balance and the output quantity.

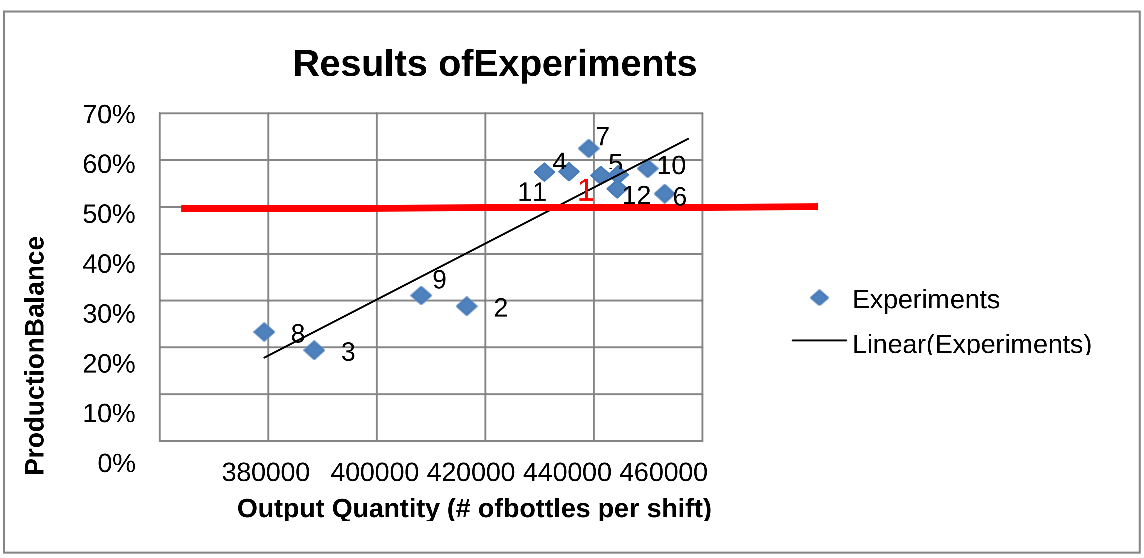


Figure 4.59: Correlation between the production balance and output

4.4.5 Correlation between the Starvation and Output

In order to determine if there is a correlation between the starvation and output, Figure 4.60 is considered.

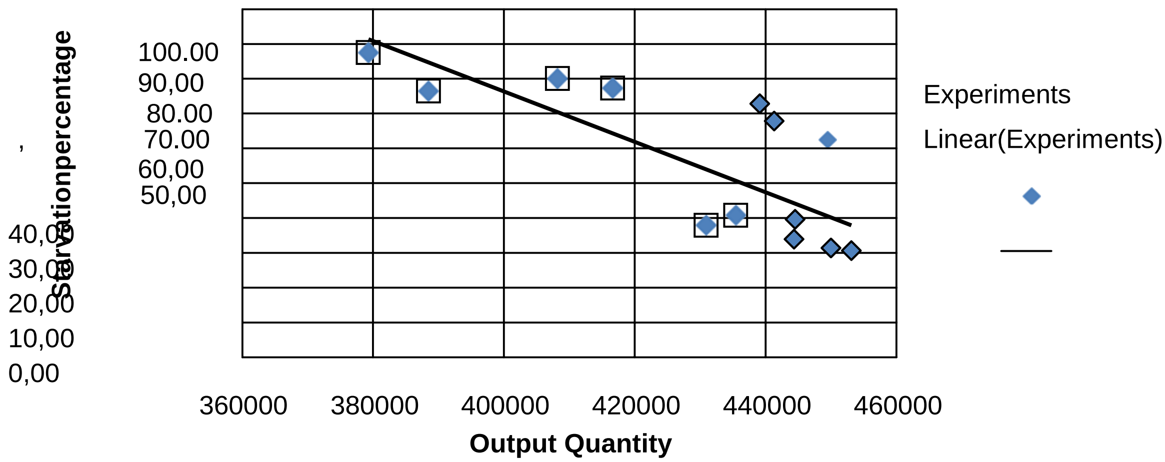


Figure 4.60: Correlation of Starvation Percentage and Output Quantity

<u>Experimental Result Conclusion</u>

The conclusion of all the experiments in the following experiments ranked 1st, 2nd, 3rd:

Table 4.32: Best Three AlternativeSolutions

Rank	**Experiment**	**Output**	**Production balance**	
		Average	LABELLER111	LABELLER112
Current:	1	441313	57%	43%
1st	6	453103	53%	47%
2nd	10	449990	58%	42%
3RD	12	444338	54%	46%

This means that the current regulation should be changed into the settings of experiment

6, translating the Table 4.33 into the different sensors.

Table 4.33: Sensors of BestAlternative

Experiment	LABELLER112 + low speed	LABELLER111 - low speed	LABELLER111 <> nominal speed	LABELLER111 <> high speed
Current	NOSPEED	Sensor 17	Sensor 14	Sensor 13
6	NOSPEED	NOSPEED	Sensor 10	Sensor 8
10	Sensor 12	NOSPEED	Sensor 14	Sensor 13
12	Sensor 12	NOSPEED	Sensor 10	Sensor 8

4.4.6Visualization of New Regulation of Sensors

The new regulation of sensors of experiment 6 is visualized in Figure 4.61 and Figure 4.62Furthermore, the amount of speed levels at LABELLER111 will reduce from three levels to two levels. No more low speed in Labeller 111.This means that the amount of speed levels of the LABELLERs is the same in the new situation.

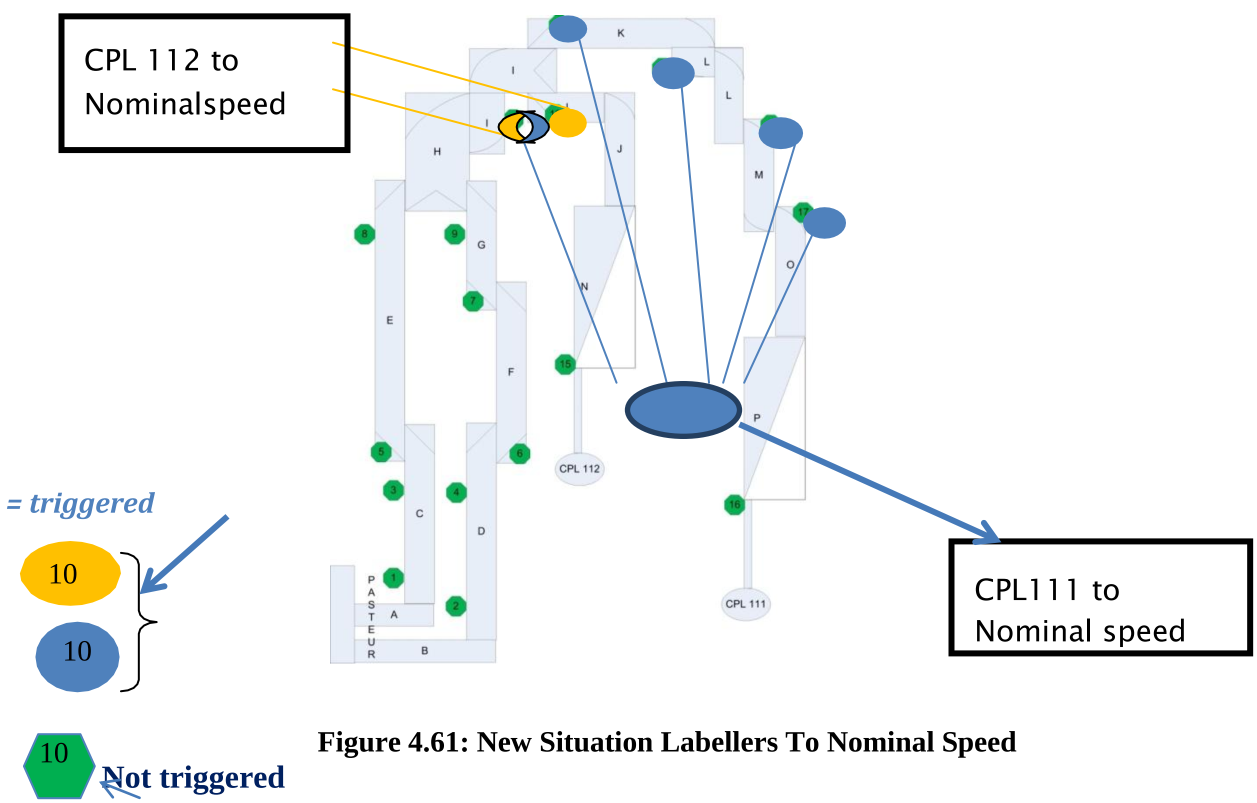


Figure 4.61: New Situation Labellers To Nominal Speed

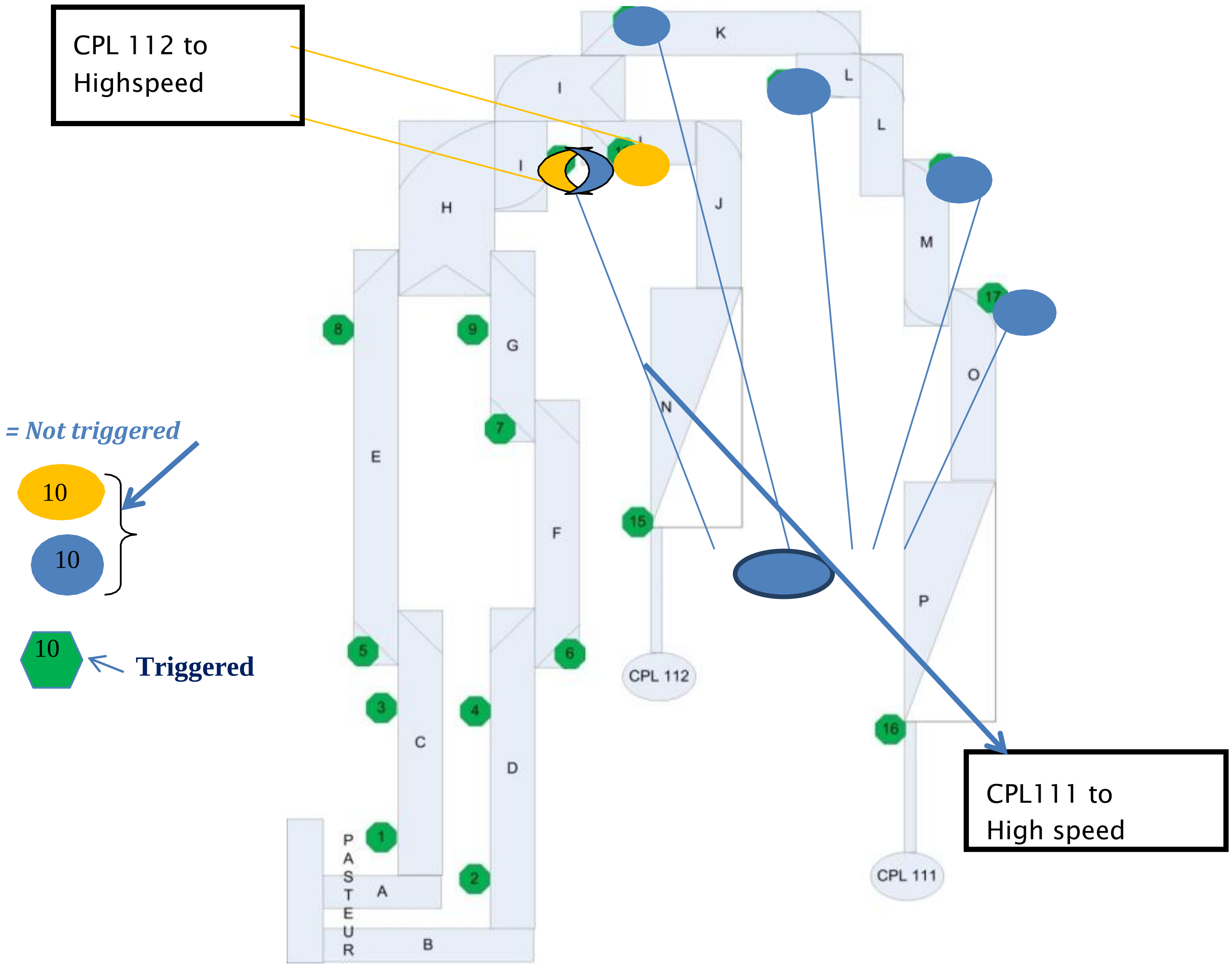


Figure 4.62: New Situation Labellers To High Speed

DESIGN OF EXPERIMENT RESULT DISCUSSION

4.4.7 Experimentaldesign

Table 4.34: Processing time and outputs of the speed levels

LABELLER112/111 – Low	70 seconds	514 bottles
LABELLER111/112 – Nominal	52.05 seconds	957 bottles
LABELLER111/112 – High	46.206 seconds	1,214 bottles

The main experimental factors are speed and processing time and the numbers of speed levels of the LABELLERs are four. LABELLER112 has at the current situation no low speed and therefore it has only three speed levels. LABELLER111 has four speed levels, which are: 1. Down 2.Low 3.Nominal and 4.HIGH

The Labellers speeds were regulated by 17 sensors but the result in Figure 4.57 indicated the sensors colored green were neglected in the simulation for several reasons. Sensors 1 till 7 are too close to the pasteurizer, and were used to determine the speed of the pasteurizer and will not be used to change the speed of Labellers to avoid the risk of pasteurizer blockage increase. Sensor 9 was not be used because sensor 8 was used. The lower deck from the pasteurizer is always filled. Sensor 9 was skipped to decrease the amount of experiments, without having any influence on the outcome. Sensors 15 and 16 were neglected because these sensors serve for a security. When these are triggered the line has an emergency shutdown. If not, the LABELLERs will be damaged. When there are no beer bottles, the labels stick in the machine. Sensor 11 was neglected because it has little value when also sensor 13, 8, 14 and 17 are regulating LABELLER111 while sensor 12 regulates LABELLER 112. Sensor 11 regulates conveyor K, and therefore it is positioned at that location. The colors in Figure 4.58 mean that these will change over the experiments. Sensor 12 (yellow) and sensor (17) were only considered when LABELLERs have a low speed. When a sensor of a higher speed is triggered, the sensor of the lower speed is overruled. For example when in the current situation sensor 13 is triggered, so LABELLER111 changes to high speed , then sensor 14 is overruled until sensor 13 is not triggered anymore. In Table 4.23, there are two factors which have four different speed levels. No low speed means that the LABELLERs directly change to the nominal speed, so only three speed levels are available. Thus, at the moment LABELLER112 has no low speed, and the alternative situations checks if is valuable to add a low speed on the LABELLER112 on sensor 12. The colors are equal to those of Figure 4.57, so one can see what is changing. Table 4.24 shows the design of 12 experiments with different sensor speed level changed to regulate labellers.In Figure 4.59 show all the experiments in a graph, with on the X- axis the output quantity and on the Y-axis the production balance. The experiment which lies the closest to the 50% (marked with the red line) and the closest to the 46,000 is the best option. Experiments located above the red line have more beer bottles produced on the LABELLER111 than the LABELLER112, and for experiments below the red line it is the reverse. Alternatively, 6 score the best on both performance measures. The second best will be 10 or 12, depending on the weight of the performance measure. In Table 4.28 Results of experiments regarding output and balance, experiments 8 and 3 have a lower output quantity compared with the other experiments. When all buffers are completely filled with beer bottles, the source will stop producing.

Table 4.34.1: Difference Current, New Alternative and Real Life

Situation	Output	Production balance		Difference on
	Average	LABELLER111	LABELL	
Current (simulation)	441313	57%	43%	**14%**
Alternative (simulation)	453103	53%	47%	**6%**
Difference (simulation)	**11790**	**4%**	**4%**	8%
Average(real life *before*	420193	57%	43%	**14%**
REAL test (real life	447480	52%	48%	**4%**
Difference (real life)	27287	5%	5%	10%

Table 4.34.1 shows the outputs and production balance results of the simulation of the current production system and real life outputs and production balance results of current production system. After the modification, the outputs and production balance of the real life and simulation were obtained. There were increases in production of 27,287 bottles in real life and 11, 790 bottles in simulation model. 4% difference in production balance of simulation and 5% difference in production balance of real life after modification.

Table 4.34.2: Experimental Ranking

Rank	Experiment	Output (Sim)	Buffer	Real Ouput
		Average		Average
Current:	1	441313		420193
1st	6	453103	1300	447480
2nd	10	449990		438990
3rd	12	444338	1300	443038

Table 4.34.2indicated the best three experimental result. From the three results, experiment 6 was chosen for implementation because the output was very high compared to experiment 10 and 12. The production balance of experiment 6 was very good when compared with other

experiments.

Correlation

In Figure 4.57 the results of the experiments is considered again to determine if there is a correlation with the production balance and the output quantity. In first instance it seems that there is a correlation between the performance measures. Nevertheless, there should be some correlation because one LABELLER cannot produce more than 360,000 bottles (45,000btls/hr*8hr) bottles. Thus when the production balance is out of proportion, the output quantity should be less than average. All the experiments above the red line mean that the LABELLER111 produces more than the LABELLER112. All the experiments close to the red line have a higher output quantity. Overall this means that there is some correlation. From the overall experiment, an equal production balance (50/50) increases the output quantity. This means that an equal production balance improves the output quantity, and therefore the line performance. In Figure 4.56, starvation percentage is compared with the output quantity. From the graph, there is a negative correlation between the two performance indicators. This means that when the starvation percentage decreases, the output quantity increases. This is obvious because when LABELLERs in starvation it cannot produce. The next correlation is the starvation percentage with the production balance. These performance indicators are shown in Figure 4.61. In this figure there is no obvious correlation between the starvation percentage and the production balance. The experiments with a production balance around the 50/50 (60/40) have a lower starvation percentage. From the graph, when a shift has a starvation percentage above average, the LABELLER111 produced more bottles than LABELLER112. This was because the beer bottles have the tendency to transfer to the outer of the bend. This matches with the results from the experiments. When considering the best experiments regarding the production balance, no correlation with the starvation percentage was observed. Table 4.28 is that experiment 10 is close to the current situation and experiment 6 and 12 are different in almost every setting. The amount of speed levels at LABELLER111 decreases at all the three alternative solutions. In experiment 10 and 12, the amount of speed levels on the LABELLER112 increases to three.

Table 4.34.3: Saving made from the studies

	Higher	**Line regulation**	**Decrease**	**Total**
Ideal Cycle Time of Production Line	500 bottles per min			
70% Target of Ideal Cycle Time	350 bottles per min			
Different in Average Production Output before and after modification	27,287 bottles			
Average Reduction (minutes)	77.96	5		
Total Shifts per week	20	20		
Shifts per week*Total reduction per	1559	100		1659
Production weeks per year				**52**
Less CILT-activities per shift			10	
Shifts per week			20	
Total CILT reduction per week				200
Total Reductions per year (minutes)			(1659+200)*52=	96,668
Salable Cost per Beer bottle (NGN)			**200**	
Total cost of producing a beer bottle (NGN)			**190**	
Production gain per bottle (NGN)			(200-	
Total Additional Bottles Produced per year as a result of improvement made		96,668*350 = 33,833,800		
Total Production Gain made per year (NGN)		33,833,800*10 =	338,338,000	

OPTIMIZE MAINTENANCE STRATEGY USING CILT AND KAIZEN RESULTS AND DISCUSSION

4.5.1 *Breakdown Deployment and Improvement of Core Machine*

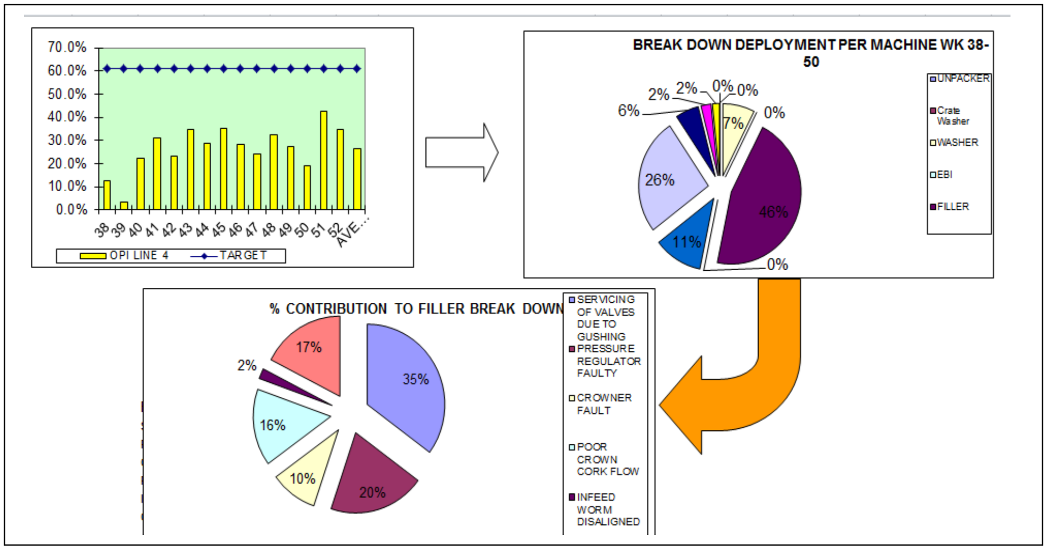


Figure 4.63: Breakdown Deployment of Core Machine

Figure 4.63 shows the breakdown deployment of core machine for Line 4. First OPI was calculated and compared with Production OPI target, followed breakdown analysis of line and contributions to Filler breakdown. From the contribution, it is obvious to understand the area to tackle in solving Filler breakdown problem.

4.5.2 Kaizen Improvement Plan of Core Machine (Low Fill Reduction)

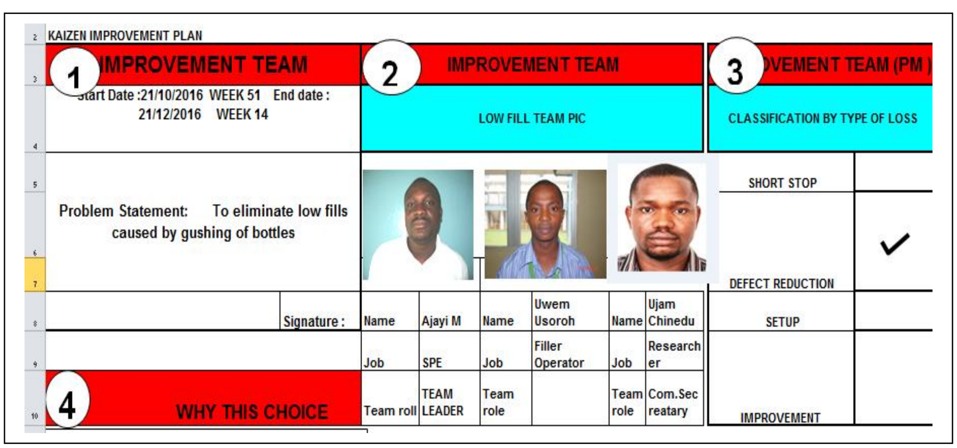


Figure 4.64: Improvement Team Formation

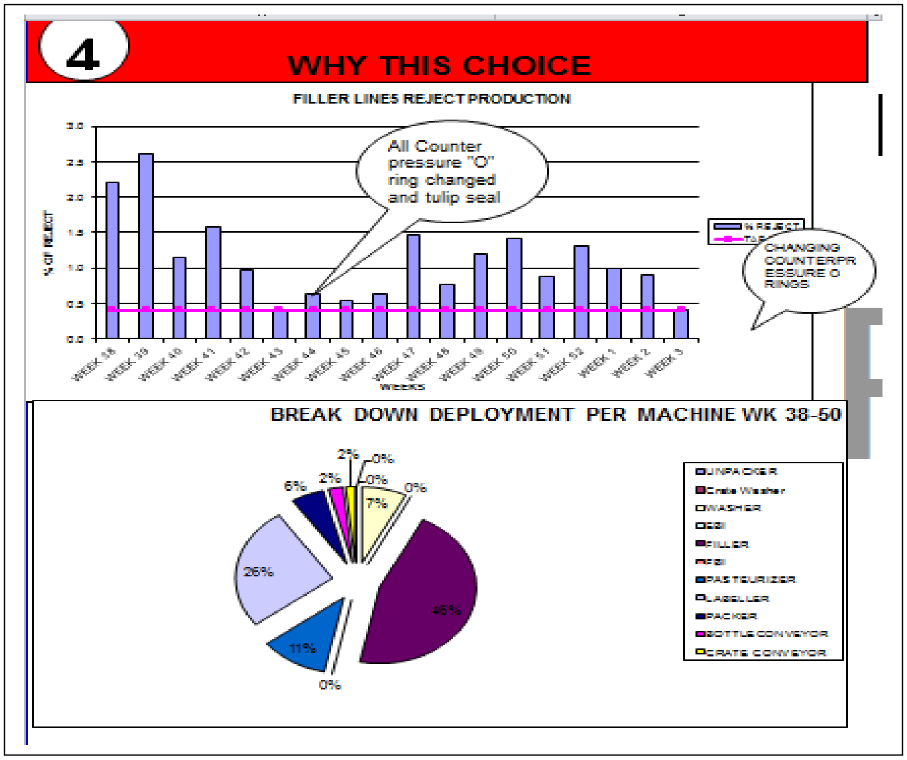


Figure 4.65: Why Choice?

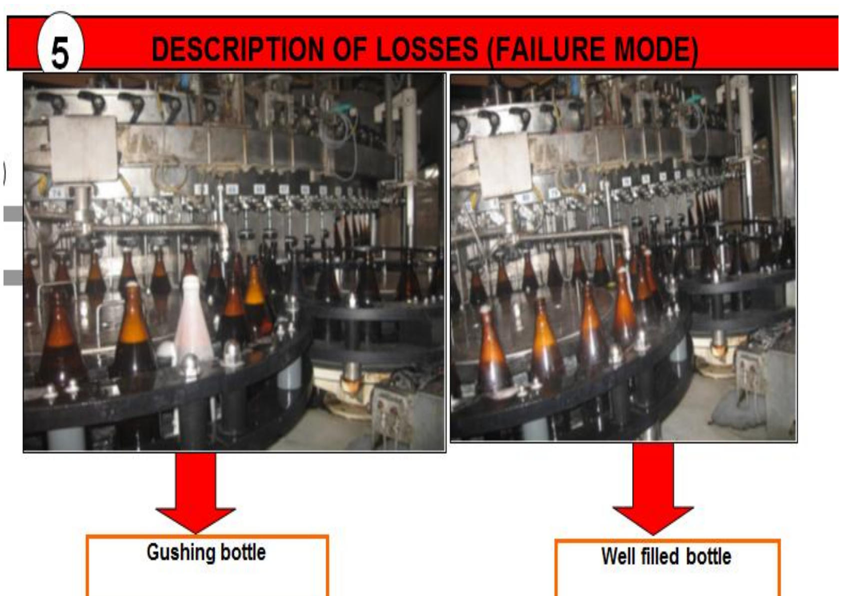


Figure 4.66: Description of Losses (Failure Mode)

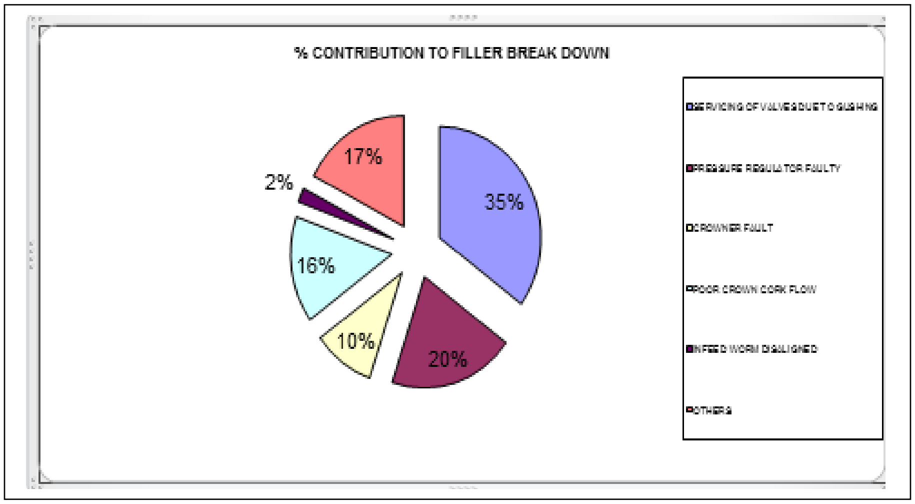


Figure 4.67 Percentage Contribution of Core Machine Breakdown (Filler)

The Route for Defects Reduction Activities

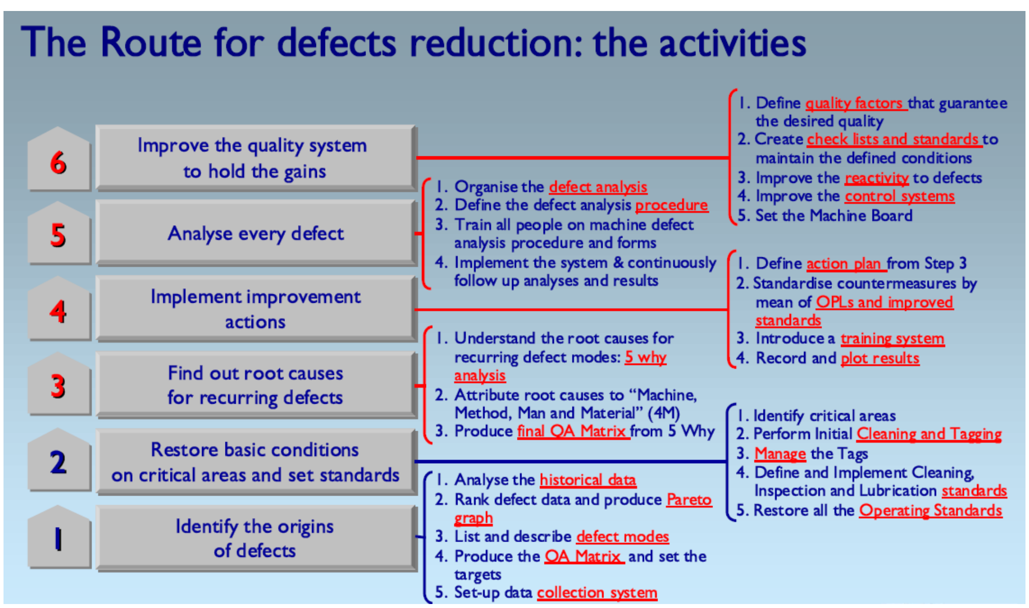


Figure 4.69: Route for Defects Reduction

Project Plan Sequence to Defect Reduction Routes

Table 4.35: Project Plan Sequence to Defect Reduction Routes

ACTION			WEEEK										Owner	REMARKS
Identify Origins of Defect			wk51	wk52	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8		
Step 1	1	Analyze historical data											Ajayi	Done
	2	Rank Defect loss data, produce pareto graph and set priorities											Ajayi	Done
	3	Describe and understand the process (process map and loss points identification)											Ajayi	Done
	4	List and describe loss defect modes											Ajayi	Done
	5	Produce QA matrix and set target											Ajayi	Done
	6	Set up data collection system											Ajayi	Done
Restore Basic Conditions On Critical Areas And Set Standards														
Step 2	1	Identify critical areas											USOROH	Done
	2	Perform initial tagging (equipments and procedures/recipes anomalies)											USOROH	Done
	3	Manage the tags											USOROH	Done
		Define and implement machine handling, setting and conditions related standards											USOROH	Done
	3	Restore all operating standards											USOROH	Done
Finding Out Root Causes recouring defect														
Step 3	1	Understand the root cause for re-occuring defect,											UJAM	Done
	2	Produce 5 why analysis											UJAM	Done
	3	Attribute root causes to ' Man, Machine, Material, Method' - 4 M's											UJAM	Done
	4	Produce final QA matrix from 5 Why's											UJAM	Done
Implement Improvement Actions														
Step 4	1	Define action plan from step 3											UJAM	Done
	2	Standardize countermeasures by mean of OPL's an improved standards											UJAM	Done
	3	Introduce the training system											UJAM	Done
	4	Record and plot results											USOROH	Done
Analyse every defect														
Step 5	1	Organize the defect analysis											UJAM	Done
	2	Define the defect analysis procedure											UJAM	Done
	3	Train all people on defect analysis procedure and forms											UJAM	Done
	4	Implement the system and countineously follow up analyses and result											UJAM	Done
Improve the quality system To Hold The Gains														
Step 6	1	Define quality factors that guarantee the desire quality												
	2	Create check list and standard to maintain and define conditions												
	3	Improve the reactivity to defect												
	4	Improve the control system												
	5	Set the machine board												

Root Causes and Failure Analysis of Core Machine (Filler)

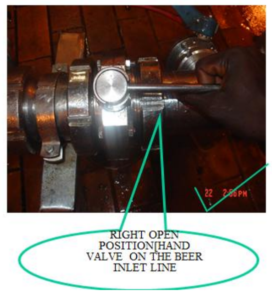
Table 4.36: Root Cause and Failure Analysis of Line

ROOT CAUSES AND FAILURE ANALYSIS OF LINE 4

Problem	1 WHY	CHECK	5 WHY	CHECK	6 WHY	CHECK	Root End	countermeasure	4M	WHO	DUE DATE	STATUS
		Y					Misalignment of starwheel with carosel	proper timing during MAINTENANCE,	MACHINE	Ujam/Uwem	18-Nov-16	DONE
		Y					No standard	Stand marking to be made	METHOD	Ajayi	20-Nov-16	DONE
								Include in CILT standard and part of running checks	METHOD	Ujam	20-Nov-16	
		Y					formation of slime in beer after long stoppage	During sterilisation hot water to flow to vaccum channels. Valve 44Y13 not opening. Hot water to run every 48 hrs of prodn.	MACHINE	Ajayi	28-Dec-16	
		Y	Design Error				Design Error	Enlarge the snifting orifice	MACHINE	Uwem/Ujam	20-Nov-16	
		Y					Long usage	No inspection regime in place ; Bi weekly inspection recommended	METHOD	Uwem/Ujam	26-Dec-16	
e								Monthly inspection ;OPL on how to time	MACHINE	Ujam/Uwem	26-Dec-16	
A	B	I	J	K	L	M	N	O	P	Q	R	S
Reject on the mach	Gushing Bottle	Y					Bad Quality O- ring	Write to manufacturers on quality of the O-rings.	MATERIAL	Ajayi	26-Dec-16	
							Bad Quality O- ring	Write to manufacturers on quality of the O-rings.	MATERIAL	Ajayi	26-Dec-16	
							Long Usage	Include in the CILT standard	METHOD	Ujam	26-Dec-16	
		Y	Poor understanding of pressure	Y			Poor understanding pressure of transimtter /controller	Change transmitter/controller to Sipart type .	MACHINE	Ajayi	26-Dec-16	
							Quality	Write to manufacturers on quality of the O-rings.	MATERIAL	Ajayi	26-Dec-16	
		Y	Worn teflon bushing	N								
							Long usage	Include replacement regime in PM CARD yearly	METHOD	Ajayi	26-Dec-16	
		Y	Block of exchanger by dirt	Y	Lack of cleaning regime	Y	Lack of cleaning regime	Include in the CILT standard	METHOD	Uwem/Ujam	26-Dec-16	
		Y	Slimy substance generated over time	Y			Slimy substance generated over time	hot water sterilisation to filler/ vacuum tank every 48 hours of production	METHOD	Ajayi	26-Dec-16	
		Y					Procedure of locking alcohol inlet valve when filler stops for >=10 mins	Automation to design a system in place to automate process.	MACHINE	Adetokunbo	20-Nov-16	

Operational Learning of Opening of Beer Inlet Lines

	Plant: Line 5 Machine/Zone : Filler	OPL - One Point Lesson	OPL n.001
		RIGHT WAY TO OPEN BEER LINE	
Basic Knowledge	X	Problem	Improvement
Filled by: _Alo B. S_		Assessed by:__Ajayi M.A__	Date: 28-Aug-16



	Plant: Line 5 Machine/Zone : Filler	OPL - One Point Lesson	OPL n.002
		RIGHT WAY TO OPEN BEER LINE	
sic Knowledge	X	Problem	Improvement
led by: _Falana_		Assessed by:__Ajayi Michael__	Date: 30/08/2016

aining date										
ainer										
ainee	Kareem	Alo	Falana							
gn										

Figure 4.70: Operational Learning of Opening of Beer Inlet Lines

Improvement Report Project

Summary Sheet of improvement Project

Project Name Reduction of low fill by 70%

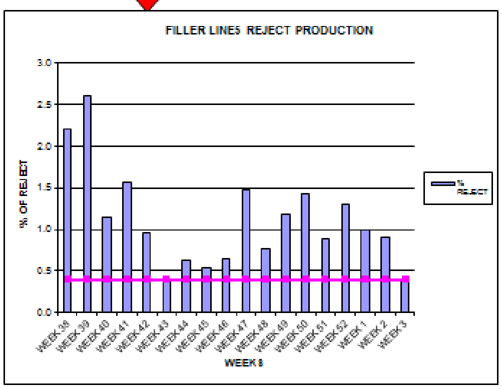
Pillar : Progressive Quality Pillar

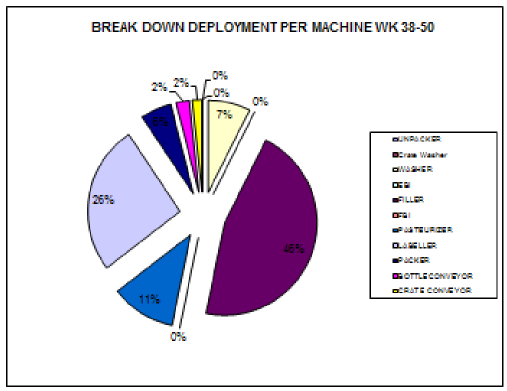
Start Date : 1/10/2016 **End Date:** 1/11/2016

Base line value : 1.40% **Initial Target** 0.50%

Improvement Route Defect Reduction Route **Final Target :** 0.40%

Deployment graphs

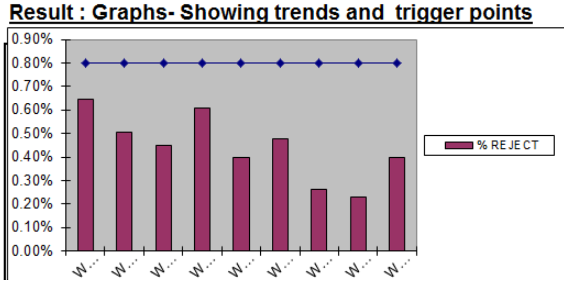




Main improvement activities

1 A design error was corrected on the filling valve whereby the snifting office was increased
2 OPL on how to fix deflector on vent tube was created in other to increase the skill operator
3 Changing of the controller on filler to a more friendly type(sipart) and parameterisation
4 Deflectors are stored in air conditioned room in the store to prepent caking
to enable complete snifting
5 OPL was developed for correct counter pressure setting and the operators were trainned
6 OPL on how to fix the tulip seals on the centring cone was developed and the operators were trained
were carried out.
8 OPL for the proper fixing of o ring was developed

Result : Graphs- Showing trends and trigger points



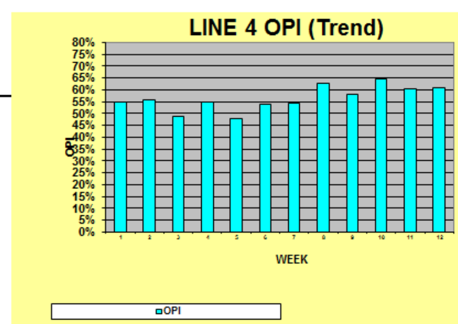


Figure 4.71: Improvement Report Project

Kaizen Improvement Plan of Core Machine

Figure 4.65 shows the Improvement team formation. The problem statement is clearly defined, team and responsibilities formed and problem classified. Breakdown deployment per machine is plotted for the weeks in consideration and target setup. Step 5 in Figure 4.67 described the losses (Failure Mode) of low fill and the contributions. Figure 4.69 defined the step by step approach to reduce defect on low fill and other defects in the production system. Table 4.31 shows the project plan sequence to defect reduction. Table 4.31 shows the project plan sequence to defect, which starts at identifying origin of defect, restore basic conditions on critical areas as set standard, find root cause of recurring defect, implement improvement actions, analyze every defect, and improve the quality system to hold the gain. This is done on weekly basis, while the responsible workers and remarks are noted. Table 4.32 presented the root cause and failure analysis of reject on the machine. The procedure should be applied in other areas of machine. Machine, Method, Material and Man were reviewed critically and each area contributing to the problem identified and solved. Figure 4.70 presented the operational learning in the opening of inlet valve. Figure 4.71 is the result of the improvement project carried out on Filler Line rejects reduction.

4.5.3 Create Improvement Kaizen Sequence of Production Lines

Stage 1

Selection of Start Date and End Date and Defining Problem Statement

Table 4.37: Define Problem Statement with Start and End Date

1.	**CREATE IMPROVEMENT TEAM**
Start date: 15/09/16 (WK No. 35)	End date:11/11/16 (WK No 37)
Problem Statement: Frequent hooking of empty crates at 1st crate turning unit.	
	Signature:

Stage 2

Appointment of team leader and team members

Table 4.38: Form Improvement Team

IMPROVEMENT TEAM (Create Washer)		
1	Francis Amike	Team Leader
2	Kola Taiwo	Member
3	UjamChinedu James	Member

Stage 3

Classification of Type of Problem

Table 4.39: Classification of Problem Type

CLASSIFICATION BY TYPE OF LOSS		
1	SHORT OR MINOR STOPPAGE	√
2	BREAKDOWN	
3	SETUP AND ADJUSTMENT	

Stage 4

Why this Choice? (Pareto Analysis)

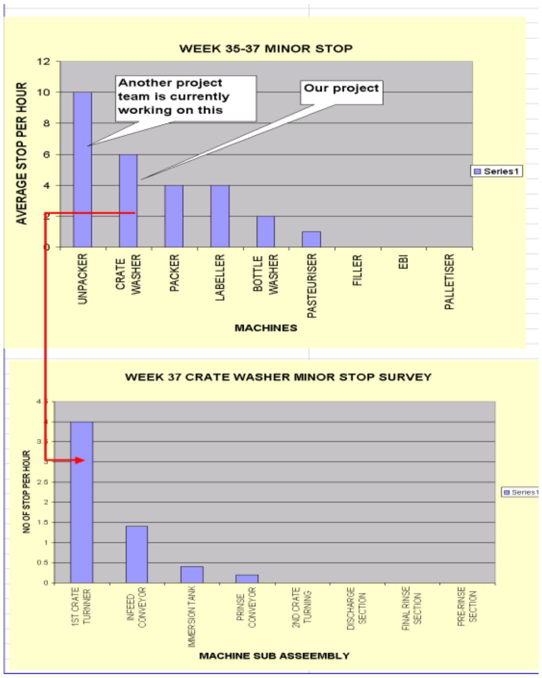


Figure 4.72: Pareto Analysis and Create Washer Minor Stop Survey

Describe Losses or Failure Mode

Figure 4.73: Description of Losses and Failure

Stage 6:

Target Plan on Minor Create Washer Reduction

Table 4.40: Target Plan on Minor Create Hooking Washer Reduction

TARGET
:To reduce the number of minor stops at Crate Washer from 6 stops to 2 stops per hour
: To reduce the number of minor stops at first crate turner from 4 stops per hour to 0 stops per hour

Stage 7

Action Plan

Table 4.41: Action Plan on Create Washer Reduction

S/N	ACTIVITY	WK 37	WK 38	WK 39	WK 40	WK 41	WK 42	WK 43	WK 44	WK 45	OWNER	STATUS	PLAN
1	MINOR STOP DATA COLLECTION										Ujam	DONE	PLAN
2	DEPLOYMENT										Amaike	DONE	DEVIATION FROM PLAN
3	CODE AND TAGGING										Ujam/Amike	DONE	
4	5 WHY ANALYSIS AND IMPLEMENTATIONS										Taiwo	INPROGRESS	
5	OPI GENERATION										Ujam	INPROGRESS	
6	FOLLOW UP RESULT										Ujam/Amike	INPROGRESS	

Stage 8

FISH BONE DIAGRAM (4 M ANALYSIS)

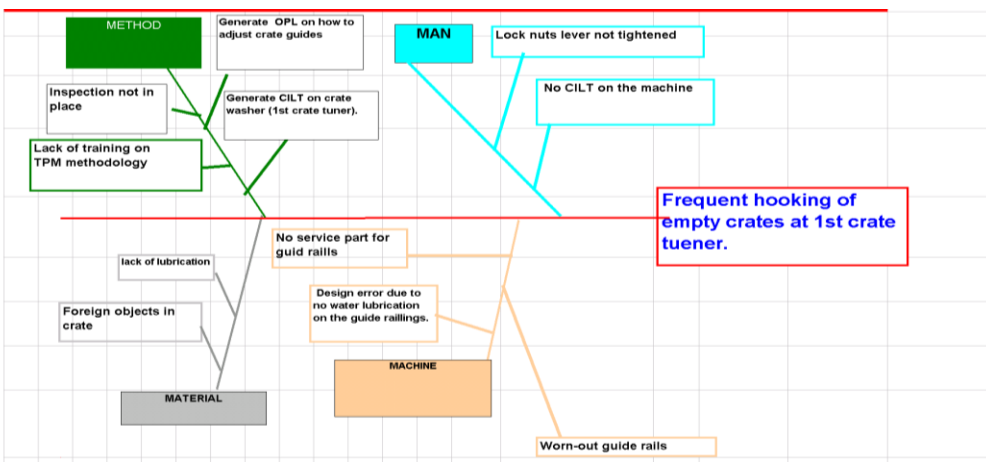


Figure 4.74: Cause and Effect Diagram of Create Washer Line

Stage 9

ROOT CAUSES ANALYSIS (5 WHY AND CAUSE AND EFFECT DIAGRAM)

Table 4.42: Cause and Effect Diagram of Create Washer in Lines

ROOT CAUSE FAILURE ANALYSIS								
Problem Definition								
REDUCTION OF SHORT STOPS RELATING TO HOOKING CRATES								
FAILURE MODE		1st Why	2nd Why	3rd Why	4th Why	5th Why	4m Analysis	Root end
Frequent hooking of empty crates								
	1	Wrong adjustment of guide rails	No marked points for adjustment on guide rails	No standard measurement	Lack of knowledge		Method	lack of knowledge on guide rail adjustment.
	2	Hooking as a result of dirt on rails	Foreign objects in crate	Deposit on guide rails	Causes friction		Method	Causes friction on guide rails
	3	Wear of guide rails	Long usage	Material failure			machine	No service part of the guide rail.
			Lack of lubrication on guide rails	Not present in the design of the machine			machine	Error in design of lubrication line.
			No inspection				method	No inspection on guide rail.
		Work-loosened guide rail	locking mechanism not properly	Lack of knowledge			Man	Lack of knowledge on how to tight the lock nut.

Stage 9a

Counter Measure

Stage 9

Counter measure

Table 4.43: Counter Measure on Hooking of Empty Create Reduction

COUNTER MEASURE											
NO	Problem Statement	Root end	Tag No.	Proposed Solution	Action Points	Part Number	Expected Result	Preventive Measure	Owner	Due date	Status
1	hooking of empty crate										
		Lack of knowledge on guide rail adjustment	Nil	Set standard measurement for the guidelines and train all mechanical support	Set standard measurement	Nil	Free flow crates	Follow standardised measurement for adjustment	Ujam	13-11-2016	DONE
		Causes friction on guide rails	Nil	Cleaning	Clean during CILT in the morning between 9-10	Nil	Clean guide	Dialy Cleaning	Taiwo	15-11-2016	DONE
		No service part of the guide rail	L4/CW/099	To replace guide rails	Replace guide rails	Nil	Smooth flow of crate	Dialy Inspection & ensure free flow of water lubrication	Amaike	20-11-2016	DONE
		Error in design of lubrication line	l4/CW?131	Install spraying line	Install and align to the guide rail	Nil	Free flow crates	Check water spray daily & clean strainer	Ujam	25-11-2016	In progre
		No inspection on guide rail	Nil	Plan how to insert it in CILT	CILT in place	Nil	Free flow crates	Daily inspection & cleaning	Taiwo	26-11-2016	DONE
		Lack of knowledge on how to tighten the lock nut	Nil	Train all mechanical support on how to tight the lock nut	Training	Nil	Proper tightning of lock nut	Daily inspection & tightening during CILT	Taiwo	30-11-2016	In progre

Improvement Result and Result Monitoring

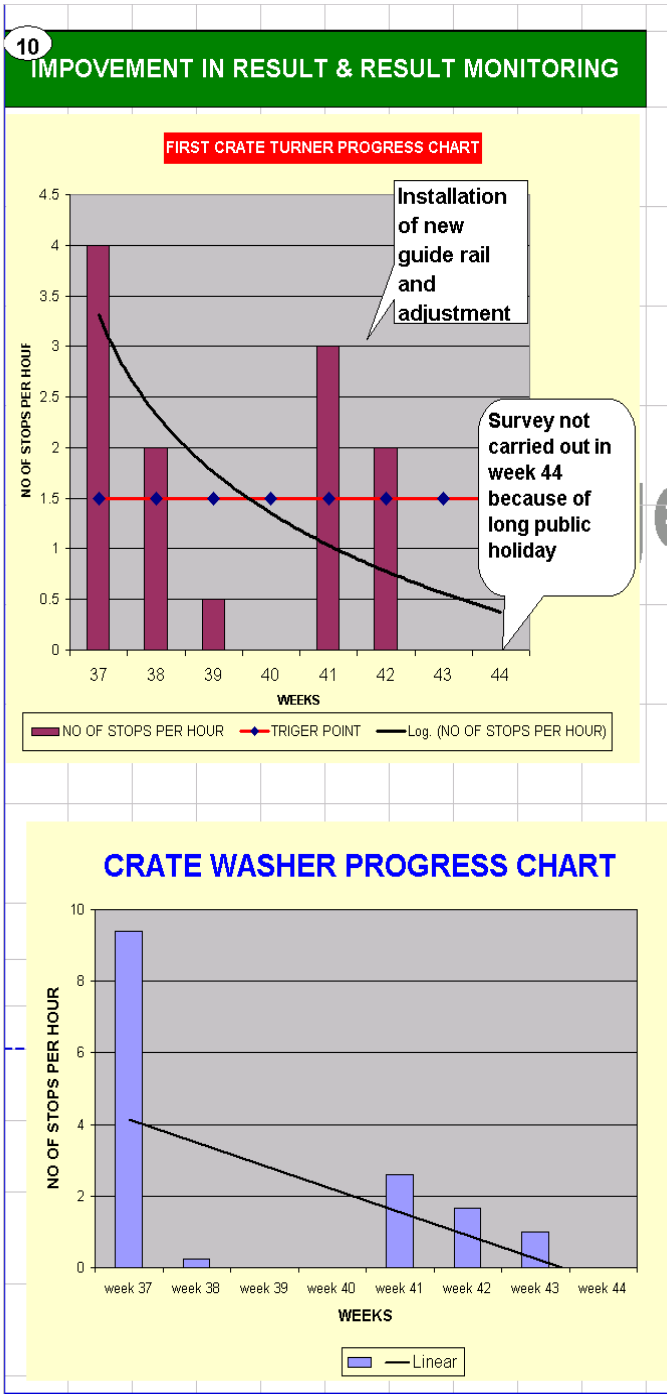


Figure 4.75: Improvement Result and Result Monitoring

Stage 11

Standard Procedure Check for Crate Washer

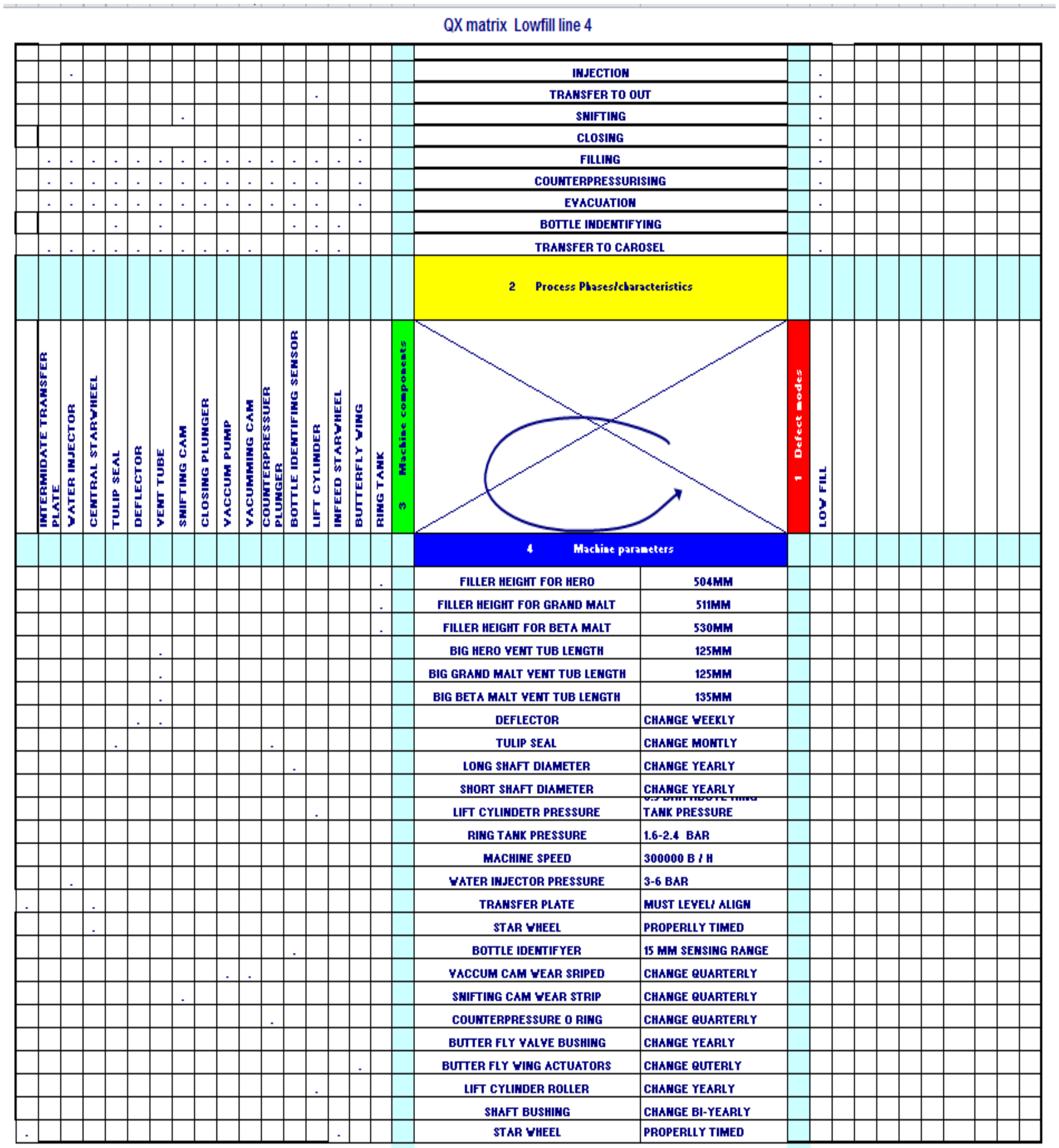
Table 4.44: Standard Procedure Check for Create Washer

S/N	STANDARD OPERATING PROCEDURE CHECKS FOR CRATE WASHER	LINKED TO CILT	FOLLOW UP
1	Check that all guide rail locks are properly locked	Ref CILT tightening regime S/N 5	√
2	Ensure bolts and nuts are properly tightened always	Ref CILT Tightening regime S/N 6	√
3	Ensure water lubrication system functions always	Ref CILT Inspection regime S/N 1	x
4	Ensure conveyor is free of breakages and dirts	Ref CILT Inspection regime S/N 2	√
5	Ensure the adjustment measurement are always correct. Width=360-370mm,Height=340-350mm	Ref CILT inspection regime S/N 3	√
6	Ensure the CILT is carried out on the conveyor and the guide rails	Ref CILT Inspection regime S/N 3	√
7	Ensure the measurement of the guide rails are the same at both ends and middle	Ref CILT Inspection regime S/N 5	√
8	Ensure proper cleaning of guide rails at S turner during daily CILT	Ref CILT Cleaning regime	√

Create Improvement Kaizen Sequence of Production Line.

Kaizen is the continuous improvement strategy, which has several sequential stages followed to solve a particular problem in production system. Table 4.33 to Table 4.40, Figure 4.75 stage 1 to stage 11 result of solving the problems of hooking of empty create. It is the comprehensive analysis, which should be adopted in every part of production system for loss reduction and continuous improvement of optimized system.

4.5.4 Preventive Maintenance Strategy (Low Fill) using 4M)



.**Figure 4.76: Quality Improvement Matrix of Low Fill of Filler**

Machine

Table 4.45: Machine Problem Analysis and Solution

		Section 2 - Machine																					
Parameter		FILLER HEIGHT FOR HERO	FILLER HEIGHT FOR STOUT	FILLER HEIGHT FOR GRAND MALT	HERO VENT TUB LENGTH	STOUT VENT TUB LENGTH	GRAND MALT VENT TUB LENGTH	DEFLECTOR	TULIP SEAL	LIFT CYLINDER PRESSURE	RING TANK PRESSURE	MACHINE SPEED	WATER INJECTOR PRESSURE	TRANSFER PLATE	STAR WHEEL	BOTTLE IDENTIFYER	VACCUM CAM WEAR STRIP	SNIFTING CAM WEAR STRIP	COUNTERPRESSURE O-RING	BUTTER FLY VALVE BUSHING	BUTTER FLY WING ACTUATORS	LIFT CYLINDER ROLLER	STAR WHEEL
Specification		METER RULE	METER RULE	METER RULE	METER RULE	METER RULE	METER RULE			PRESSURE INDICATOR	PRESSURE INDICAT	SPEED INDICATOR	PRESSURE INDICAT			Vernier caliper							
Measurement		246MM	256MM	246MM	118MM	114MM	118MM			0.5 ABOVE RING TANK PRESSURE	1.6-2.4 BAR	30000	3-6 BAR	ALIGN	TIMED	15 mm	ALIGN	ALIGN			AK		TIMED
Frequency		DAILY	DAILY	DAILY	DAILY	DAILY	DAILY	PERFORMANCE CHECK	PERFORMANCE CHECK	RUNNING CHECK	RUNNING CHECK	RUNNING CHECK	RUNNING CHECK	WEEKLY	DAILY	weekly	WEEKLY	WEEKLY	QUARTERLY	6 MONTHLY	WEEKLY	WEEKLY	DAILY
Responsible		OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	OPERATOR	MAINTENANCE	OPERATOR	Automation Support	MAINTENANCE	MAINTENANCE	MAINTENANCE	MAINTENANCE	MAINTENANCE	MAINTENANCE	OPERATOR
Q characteristic		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Defect mode																							
---		LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL	LOW FILL
Are the material quality characteristics clear?	List of characteristics													1			1	1	1	1	1	1	
	Unit of measure defined for each characteristic														3	3							
	Tolerances defined	5	5	5	5	5	5	5	5	5	5	5	5										5
Is the supplier capability enough?	Cpk very low, many problems due to suppliers							1															
	1<Cpk<1,33, sporadic problems	3	3	3	3	3	3		3					3	3	3	3	3		3			3
	Supplier certified, Cpk>1,33									5	5	5	5						5		5	5	
Is the incoming inspection method clearly defined?	No standard, some random inspection							1			1												
	Procedures are defined, good application								3					3			3	3	3	3		3	
	Effective and efficient inspection	5	5	5	5	5	5			5		5	5		5	5					5		5
Is it possible to avoid using or loading a defective material?	Impossible								1							1	1	1	1	1	1		
	Possible but the inspection cost will be very high	3	3	3	3	3	3																3
	Yes, Poka Yoke in place							5		5	5	5	5	5	5							5	
Is it easy to recover from a material problem in process?	Very difficult, many scrap and Quality problems on the line and downstream									1													
	Yes, local scrap, no problems downstream	3	3	3	3	3	3	3	3					3	3	3	3	3	3	3	3	3	3
	Very easy to correct the problem, only incoming										5	5	5										
Total		19	19	19	19	19	19	15	15	21	21	25	25	15	19	15	11	11	13	11	15	17	19
Poka Yoke																							
AM Check		xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx		xxxx		xxxx	xxxx					xxxx
OPL																							
Work procedure																							
Maintenance operator check		xxxx	xxxx	xxxx					xxxx					xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

Materials

Table 4.46: Material Defect Analysis and Solutions

		Section 2 - Material			
Parameter		powder presence in Gaf filter	product rest	CO2 in product	Bottle
Specification		Inlet & outlet Press guage = 5 bar	≥ 6 hrs	within spec per brand	No cracks on bottles
Measurement		Press Differential across Gaf filter	time	CO2 meter	visual
Frequency		hourly	per BBT	per BBT	continuos
Responsible		BBT Operator	Brewer	Brewer	Auto support
Q characteristic		1	2	3	4
Defect mode		Lowfill	Lowfill	Lowfill	corked empty
Are the material quality characteristics clear?	List of characteristics				
	Unit of measure defined for each characteristic				
	Tolerances defined	5	5	5	5
Is the supplier capability enough?	Cpk very low, many problems due to suppliers		1		
	1<Cpk<1,33, sporadic problems			3	3
	Supplier certified, Cpk>1,33	5			
Is the incoming inspection method clearly defined?	No standard, some random inspection	1			
	Procedures are defined, good application		3		3
	Effective and efficient inspection			5	
Is it possible to avoid using or loading a defective material?	Impossible				
	Possible but the inspection cost will be very high	3	3	3	3
	Yes, Poka Yoke in place				
Is it easy to recover from a material problem in process?	Very difficult, many scrap and Quality problems on the line and downstream	1			
	Yes, local scrap, no problems downstream				3
	Very easy to correct the problem, only incoming material scrap is generated		5	5	
Total		15	17	21	17
Poka Yoke			xxxx		
AM Check					
OPL					
Work procedure		xxxx	xxxx	xxxx	
Maintenance operator check		xxxx			xxxx

Method

Table 4.47: Method Adopted in Preventive Maintenance of System for Low Fill

		Section 3 - Method						
Parameter		Timing of infeed star wheel	bottle tulip seal replacement	Bottle Deflector Replacement	closing cam adjustment	adjustment of snifting cam	Storage of tulip seals	Product Rest
Specification		Vent tube enters centre of the transferred bottle	Weekly	Weekly	close to shut the valve fully	to remove top pressure	Stored cold <25°C	rest for ≥6hrs
Measurement		visual	Maximo	Maximo		visual	Thermometer	time
Frequency		Continuous	Running/weekly	Running/weekly	weekly	weekly	Continuous	Continuous
Responsible		operator	operator	operator	machine leader/operator	machine leader/operator	Store keeper	Shift brewer
Q activity		1	2	3	4	5	6	7
Defect mode		low fills	low fills	low fills	low fill	low fill	low fills	lowfill
Does it exist?	No standard method						1	
	It exists but it is not documented enough	3			3	3		
	It exists, and it is documented		5	5				5
Does it guarantee the required quality level?	No and many defects also downstream							
	Cpk is not enough but no defects downstream							
	100% defects prevention, Cpk>1.33	5	5	5	5	5	5	5
Does it guarantee the required production rate?	Impossible to guarantee the production rate							
	Rate is ok but still very variable							
	The production rate is 100% guaranteed	5	5	5	5	5	5	5
Is it well documented?	Documentation not enough for training				1	1	1	
	OPL, pictures, sketches	3	3	3				
	Video (example with Audio explanation)							5
Is it easy to learn ?	2/3 months to learn							
	1 month to learn							
	Less than 5 days to learn	5	5	5	5	5	5	5
Total		21	23	23	19	19	17	25
Poka Yoke								
AM Check				xxxx				
OPL								
Work procedure							xxxx	
Maintenance operator check				xxxx	xxxx	xxxx		

Manpower

Table 4.48: Competency of Operators in Solving System Problems

		Section 4 - Manpower				
Parameter		Counterpressure Setting	water injector setting	Timing of infeed star wheel	tightening of the bottle idenrifyer	Setting of the snifting cam
Specification		1.6-2.4	4-8 bar	Vent tube enters centre of the transferred bottle	Tighten using spring washer &locknut	set to remove top pressure
Measurement		PIC	PI	visual	Colour code the bolt	visual
Frequency		Continuous	Continuous	Continuous	weekly	weekly
Responsible		Operator	Operator	Operator	Auto Support	Machine leader
Q skill		1	2	3	4	5
Defect mode		Lowfill	Lowfill	corked empty	corked mty	Low fill
Work skills	Basic Skills=can do with supervision					
	Advanced Skills=needs no supervision	3		3	3	3
	Expert Skills=has preventive analysis and execution capability		5			
Condition Management skills	He/she knows, minimum hands-on experience					
	Has demonstrated minimum requirements	3		3	3	3
	Has demonstrated Advanced capability		5			
Application	Does not follow standards					
	Some failure in execution	3	3	3	3	3
	Follows all standards, SOPs, CBAs					
Does she/he make mistakes?	Many mistakes					
	Only sporadic mistakes		3	3		3
	Zero mistakes (can remember when)	5			5	
Is she/he motivated?	Lack of interest in his/her job					
	Sense of responsibility, willingness to improve	3	3	3		
	Improves his/her work standards, he/she is a leader				5	5
Total		17	19	15	19	17
Poka Yoke						
AM Check		xxxx	xxxx	xxxx		
OPL				xxxx	xxxx	
Work procedure			xxxx			
Maintenance operator check				xxxx	xxxx	xxxx

Preventive Maintenance Strategy Using 4M (Machine, Method, Materials and Man) of Core Machine

The quality improvement matrix of low fill of Filler was first presented in Figure 4.73 and has four areas of focus which include the following; Defect Mode, which is Low Fill, which is the problem. 2. Process Phases/Characteristics, which is the process in filling operations. 3. Machine Components, which the machine components involved in filling operations, and Machine Parameters, which is the setting of machine parameter during filling operations. From the quality improvement matrix, the area of problem can be identified easily. Table 4.41 to Table 4.44 contained breakdown problems of low fill caused by Machine component, Method of filling, Material input during filling operations and the competency of operators involved in filling operation. Through the thorough analysis and result obtained, the problem of low filling of line 4 is solved.

4.5.3 Using CILT As a Strategy of Preventive Maintenance of Core Machine (Filler)

Table 4.49: CILT Preventive Maintenance of Filler

CILT SEQUENCY IN PREVENTIVE MAINTENANCE

MACHINE

FILLER CROWNER

ASSEMBLY

Inner ring
Outer ring
Carousel
Table equipment
Crowner
Main drive

SUB-ASSEMBLYS

Ring Tank
Filling valve
Height adjustment
Media distributor
Electrical distributor

KEY
C = CLEANING
I = INSPECTION
L = LUBRICATION
T = TIGHTENING

COMPONENTS	OPERATORS TASKS
Tank housing	C,I
Level probe transmitters	C,I
Temperature transmitter	C,I
Pressure transmitter	C,I
Product chamber	C,I
Vacuum chamber	C,I
Snifting chamber	C,I
suspension columns	C,I
Oil pot	C, I & L

Valve body	C,I
Product channel	C,I
Counter pressure channel	C,I
vacuum channel	C,I
snifting channel	C,I
product spring	C,I
Counter pressure spring	C,I
counter pressure rod	C,I
Vacuum pin	C,I
Vacuum spring	C,I
Snifting pin	C,I
Snifting Spring	C,I
Vacuum and Snifting pins retain	C,I
Vent tube	C,I
Deflector	C,I
O rings	C,I
Switching lever	C,I
Switching lever spring	C,I
Switching lever rod	C,I

Height adjustment motor	C,I
Gearbox	C, I & L
Encoder	C,I
Pinion	C,I
transmission gears	C,I
transmission shafts	C,I

Product pipe	C,I
Product seals	C,I
Vacuum pipe	C,I
Vacuum seals	C,I
Snifting pipe	C,I
Snifting seals	C,I
C02 pipe	C,I
C02seals	C,I
Bearings	C, I & L
Leakage escape holes	C,I

Electrical signal unit	C,I
Lift cylinder air supply	C,I
C02 recovery line	C,I
Seals	C,I
Bearings	C,I

Adjustable ring
Height adjustment

Bottle identifier sensor	C, I & T
first vacuuming track	C,I
C02 flushing/closing track	C,I
second vacuuming track	C,I
Counter pressure track	C,I
Mid-position track	C,I
Half filled track	C,I
Bottle confirmation sensor	C,I
bottle burst flushing pipes/nozzl	C,I
Filling closing track	C,I
Snifting track/ filling closing trac	C,I
three cleaning tracks	C,I
Valve hanging sensor	C, I & T
Blow off opening/closing track	C,I

Carrousel body
Lifting Element

Height adjustment motor	C,I
Gearbox	C, I & L

Table 4.49: CILT Preventive Maintenance of Filler

transmission gears	C,I
transmission shafts	C,I

Product pipe	C,I
Product seals	C,I
Vacuum pipe	C,I
Vacuum seals	C,I
Snifting pipe	C,I
Snifting seals	C,I
C02 pipe	C,I
C02seals	C,I
Bearings	C, I & L
Leakage escape holes	C,I

Adjustable ring
Height adjustment

Electrical signal unit	C,I
Lift cylinder air supply	C,I
C02 recovery line	C,I
Seals	C,I
Bearings	C,I

Bottle identifier sensor	C, I & T
first vacuuming track	C,I
C02 flushing/closing track	C,I
second vacuuming track	C,I
Counter pressure track	C,I
Mid-position track	C,I
Half filled track	C,I
Bottle confirmation sensor	C,I
bottle burst flushing pipes/nozzl	C,I
Filling closing track	C,I
Snifting track/ filling closing trac	C,I
three cleaning tracks	C,I
Valve hanging sensor	C, I & T
Blow off opening/closing track	C,I

Carrousel body
Lifting Element

Height adjustment motor	C,I
Gearbox	C, I & L

Gearbox	C, I & L
Encoder	C, I
adjustment rods /unions	C, I & T
suspension pistons	C, I
Maximum and minimum height	C, I & T

Star wheels
Infeed worm
Bottle guides
Fobbing unit

Carrousel stands	C,I
Ring gear	C,I
Pinion	C,I
Carrousel gearbox	C, I & L
Propeller shaft	C,I
Water nozzles for lifting elemen	C,I
Pull down cam	C,I
Bearings	C, I & L
Air manifold/ ring line	C,I

Bottle carrier	C,I
Lifting cylinder	C,I
Piston	C,I
Seals	C,I
matchet cup	C,I
pressure inlet/outlet	C,I
Lifting element interlocking leve	C,I

Infeed star wheel	C, I & T
Infeed star wheel shaft	C, I & T
Infeed star wheel locking ring	C, I & T
Bearings	C, I & T
Infeed star wheel gear	C, I & T
Infeed star wheel seat	C, I & T
Transfer star wheel	C, I & T
transfer star wheel shaft	C, I & T
transfer star wheel locking ring	C, I & T
Bearings	C, I & T
Transfer star wheel gear	C, I & T
Transfer star wheel seat	C, I & T
Crowner star wheel	C, I & T
Crowner star wheel shaft	C, I & T
Crowner star wheel locking ring	C, I & T
Bearings	C, I & T

Table 4.49: CILT Preventive Maintenance of Filler

Gearbox	C, I & L
Encoder	C, I
adjustment rods /unions	C, I & T
suspension pistons	C, I
Maximum and minimum height	C, I & T

Star wheels
Infeed worm
Bottle guides
Fobbing unit

Carrousel stands	C,I
Ring gear	C,I
Pinion	C,I
Carrousel gearbox	C, I & L
Propeller shaft	C,I
Water nozzles for lifting elemen	C,I
Pull down cam	C,I
Bearings	C, I & L
Air manifold/ ring line	C,I

Bottle carrier	C,I
Lifting cylinder	C,I
Piston	C,I
Seals	C,I
matchet cup	C,I
pressure inlet/outlet	C,I
Lifting element interlocking leve	C,I

Infeed star wheel	C, I & T
Infeed star wheel shaft	C, I & T
Infeed star wheel locking ring	C, I & T
Bearings	C, I & T
Infeed star wheel gear	C, I & T
Infeed star wheel seat	C, I & T
Transfer star wheel	C, I & T
transfer star wheel shaft	C, I & T
transfer star wheel locking ring	C, I & T
Bearings	C, I & T
Transfer star wheel gear	C, I & T
Transfer star wheel seat	C, I & T
Crowner star wheel	C, I & T
Crowner star wheel shaft	C, I & T
Crowner star wheel locking ring	C, I & T
Bearings	C, I & T

Bearings	C, I & T
Crowner star wheel gear	C, I & T
Crowner star wheel seat	C, I & T
Discharge star wheel	C, I & T
Discharge star wheel shaft	C, I & T
Discharge star wheel locking rin	C, I & T
Bearings	C, I & T
Discharge star wheel gear	C, I & T
Discharge star wheel seat	C, I & T

Infeed worm	C, I & T
Infeed worm gearbox	C, I & L
Infeed worm drive shaft	C, I & T
Bearings	C, I & L
Infeed worm drive gear	C, I & T
Infeed worm locking ring	C, I & T
Infeed worm adjuster	C, I & T

Infeed worm bottle guide	C, I & T
Infeed star wheel bottle guide	C, I & T
infeed star wheel transfer plate	C, I & T
Transfer star wheel bottle guide	C, I & T
Transfer star transfer plate	C, I & T
Crowner star wheel bottle guide	C, I & T
Crowner neck bottle guide ledg	C, I & T
Crowner bottle seats	C, I & T
Discharge star wheel bottle guid	C, I & T
Discharge star wheel transfer pl	C, I & T

Cork supply unit
Crowner body
Crowning element
Height adjustment

Water inlet	C, I
20 Bar pressure pump	C, I
over-pressure relief line	C, I
Water heater	C, I
water heater temperature gaug	C, I
Unused water byepass line	C, I
Injecting pressure hose/nozzle	C, I

Table 4.49: CILT Preventive Maintenance of Filler

Unused water byepass line	C, I
Injecting pressure hose/nozzle	C, I
Injecting water temperature gau	C, I
Solenoid valve for injector	C, I
Injector support	C, I & T

Crown cork dispenser	C, I
Crown channel	C, I
Crown cork conveyor magnetic	C, I
Crown cork conveyor belt	C, I
Crown cork conveyor belt tensio	C, I
Crown cork conveyor belt rollers	C, I
Crown cork conveyor motor and	C, I
Crown cork hopper	C, I
Crown cork hopper level sensor	C, I
Crown cork diverting flaps	C, I
Crown cork magnetic stirrers	C, I
Crown cork magnetic stirrers dri	C, I
Crown cork magnetic stirrers pu	C, I
Crown cork chute	C, I
Crown cork rectifying chute	C, I
Rectifying chute drive belt	C, I
Crown cork regulator	C, I
Crown cork air blower	C, I
Crown cork injectors	C, I
Damage cork removal plates	C, I
Crown cork positioning plate	C, I

Main drive
Central lubrication
Air supply unit

Crowner support columns	C, I
Crowner drive shaft	C, I
Bearings	C, I & L
Crowner cam Profile	C, I

Cam follower	C, I
Crowning cylinder	C, I
Crowning piston	C, I
Compensating spring	C, I
Plunger spring	C, I
Magnetic rod	C, I
Pressure ring	C, I
Pressure ring support plate	C, I
Crimp adjuster	C, I

Height adjustment motor and ge	C, I & L
Height adjustment screw	C, I
Bearing	C, I & L
Encoder	C, I
Locking flange releasing sensor	C, I & T
Maximum and minimum height	C, I & T

main drive motor	C, I
Air compressor blower	C, I
Motor Pulley	C, I
Toothed belt	C, I
Gearbox pulley	C, I
main drive gearbox	C, I
Pinion	C, I
Gear train	C, I
Propeller shaft Carrousel gearbo	C, I & L

Grease pot	C, I & L
Grease pump	C, I
Grease sensor	C, I
Grease pipe	C, I
Grease distributor	C, I
Pressure sensor	C, I
Grease pipings/hoses	C, I
Grease distributors	C, I
Grease pipings/hoses	C, I

Shut off valve	C, I
Silencer	C, I
Electrical pressure sensor	C, I
Supply pressure gauge	C, I
Condensate trap	C, I
Regulated pressure gauge	C, I

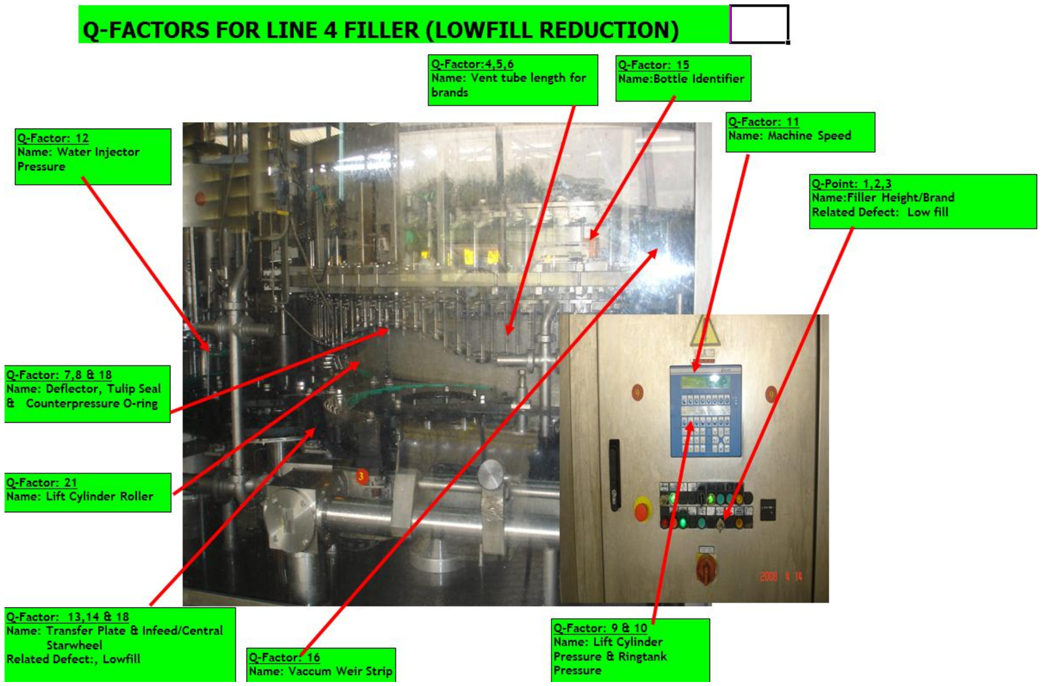


Figure4.77: Quality Factor for Line (Lowfill Reduction)

Using CILT as Strategy of Preventive Maintenance of Core Machine (Filler) CILT stand for Cleaning, Inspection, Lubricating and Tightening. This is very important process that helps to prevent machine breakdown caused by wear and tear from friction, loose nuts in moving parts and dirt deposited on the machine surface and electronic components of machine. Table 4.38 presented the sequential procedure adopted in maintenance of Filler using CILT. The result of the process was a total decrease in machine downtime and planned maintenance from 40% to 20%. CILT is a robust strategy of preventive maintenance of system components and machines that guarantees good result and total reduction in downtime of equipment.

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONSAND CONTRIBUTION TO KNOWLEDGE

5.1 Conclusion

The first objective of the studies, which is the discovering of bottleneck machines and prioritizing problems areas, were achieved by analyzing and grouping production system data to find the existing problems and area of focus in addressing the current problems. It revealed each category of the problems and magnitude in percentage of overall downtimes; it exposed the huge impact of external factors on production system performance. The result also revealed the imbalance in the output of labellers.

The second objectives, which is development of conceptual model led to discovering of the causes of imbalance in the outputs of line 1 & 2, and high machine breakdown of unregulated line 4. The conceptual modeling revealed constraints to the production performance of individual lines which include the followings; Line 1 & 2 run on regulated continuous speed mode (0, 25, 50, 75, 100%). Machines automatically adjust its speed to cope with minor failures, starvation and blockage thereby increasing production flow and speed losses of the production system. It is revealed that continuous flow guaranteed safety of equipment and reduces machine downtimes than system with frequent minor stoppages and downtimes. Line 4 was unregulated; either it produces at 100% speed or not producing (down). Because of high speed of the line, it recorded high machine downtimes compared to Line 1 & 2. As a result, high percentage of downtimes were recorded which affected the overall production performance of the system. It also revealed that although, line 1 & 2 were regulated, the sensor positions were not optimized which created the imbalance in the output of labeller CPL 111 & CPL 112 respectively and increase blockage and starvations.

To have 95% confidence of the conceptual model, experimental validation of production system was carried out on the production system through simulation. The result was validated. The led to the 4th stage of the studies, which adopt design of experiment to optimize sensor position to solve the imbalance in the output of labeller CPL 111 and CPL 112.

Design of experiment was carried out, which gave the result on table 4.4.8. From the 12 experiments carried out, experiment 6 was the best alternative out of the best three experiments chosen.

To enhance the optimized system and make it robust, it is very important to consider further improvement strategy especially on core machines and machines around it. These improvement strategies led to stage 5 of the experiment which adopt CILT and Kaizen as a preventive maintenance strategy to further reduce machine downtimes, increase operator's efficiency and improve quality of input materials to the production systems.

The gain from these studies between the current situation and experiment 6 was determined based on the five stages of the studies. Nevertheless, the results of the implementation closely match with those of simulation study in Table 4.4.8, where real test show the results in real life after the implementation.

Reference to table 4.34.1The modification has a positive effect on the output and production balance. Besides, the production balance moves towards the 50/50 which was a constraint for a validatedmodel. Nevertheless, in order to validate our modification, the modification is run for several weeks more. Now the 8-hour work shift has an output with 27287 beer bottles more than the current situation. Savings are based on the difference between the current situations in our simulation model with the alternative situation, colored yellow.

The table 4.34.1shows that the output per shift increases with an average of 11790 beer bottles and the production difference between the LABELLERs is reduced from 14% to 6%, with a total of 8%.

Comparing this amount with the amount of beer bottles that experiment 6 yields over the current situation it is still the best solution to implement experiment 6, as one can see in Table 4.40. With an output of 447480 experiments 6 is still the best experiment.

Reference to Table 4.34.2, from the experimental analysis, experiment 6 should be implemented on the beer bottles production line. Remember that the pasteurizer and Filler are the bottleneck machines, and therefore these have a direct positive influence on the production output.

There are two main issues after these analyses, which are:

1. *The pasteurizer creates blockage due to an inefficient regulation of the LABELLERs.* This results in an incorrect downtime of theLABELLER112.

2. *The production balance between the LABELLERs was uneven (LABELLER111: 57% against LABELLER112: 43%).*

This results in extra activities (CILT) of an operator, due to an incorrect maintenance schedule (which isbased on a 50/50balance). Production line 1 & 2 has two labelers with different sensors controlling the speed of the two labellers. Inefficient positioning of the sensors causes blockages in pasteurizer and minor stoppages in both labellers creating unbalance production system.

In order to solve these two inefficiencies and therefore to improve the line performance, a model was developed and translated into a simulation model to test possible changes on the production line. Twelve different experiments, including the current situation, were run to determine the best solution. The best solution was experiment 6, which states that three out of four sensors settings have to be changed and that the speed level of LABELLER112 should be decreased from three to two levels. LABELLER111 & LABELLER112 are triggered on the same sensor, which means that they will start and stop at the same time.

The efficiency of the regulation between the pasteurizer and LABELLERs decreased production shifts stops on average 77.96 minutes earlier, in the new situation, because the throughput of the production line is increased, and therefore more products can be produced at the same time. The inefficiency of the blockage of the pasteurizer is corrected, which decreased the production shifts stops 5 minutes earlier, CILT result in 10 minutes less activities per shift. In total this is **92.96 minutes** of the 480 minutes per shift. The CILT tasks over the operators are reduced, because the production balance in the new situation is **LABELLER111: 52% against LABELLER112: 48%**. Reference table 4.34.3implementing all the improvement strategies across the production line resulted in yearly savings of **NGN338, 338,000.00 per line.**

5.2 Recommendations

In addition to the recommendation to implement the new regulation, line balance, preventive maintenance strategy with CILT, Kaizen Sheet Development, Quality Deployment to optimize the production performance and maintenance strategy, other inefficiencies or possible improvements during this research were found. Below are the overviews of our recommendations:

The company should pay more attention on conveyors/lines. On all packaging lines the focus is on the machines. Several teams focus on improving machine efficiencies. Mostly the thoughts at company consists, that the line performance is determined by all machine performances, which is understandable. Nevertheless, the conveyors and buffers alsoplay an important role in the line performance. The conveyors between the machines can be seen as a machine itself, which is proven by this research. The implementation of the outcome of this research is relative small, but the results are relativelarge.

Create an overview of the functioning of sensors on the production line. In order to Improving the efficiency **between** machines require a clear understanding of the function of the sensors, this will make the superficial inefficiencies of machines to be solved directly. This is also very useful to visualize the operation of the productionline.

Hire extra Process Automation /Process Instrumentation engineer: When inefficiencies are noted by employees, they have to write a label. Different aspects on these labels are possible, from safety issues till machines issues.When such an aspect consists of technical issues arrive on the desk of a PA-/PI engineer. Some identified problems of the production system are on stack

Improving the administration of changing small objects. The exchange of small objects (e.g., Teflon cylinders, glue sprayer) and their location is not registered by the maintenance department. Known is the amount of spare parts changed, but not the destiny of it. Therefore it is not possible to determine the frequency and amount of small objects changed on parallelmachines.

*Visualization of inefficiencies for operators.*At the moment every machine for six months. This slow response discourages the operators to help improving the lineperformance.

has its own ‘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 inefficiency of 11.5% (6 out of 52 empty pockets). Therefore an operator should know if fallen bottles are present at the entrance of the bottle washer. This can be done with another light for ‘fallen bottles at entrance’ in order to prevent machineinefficiencies

Labeller and Crowner should be monitored very closely; When a bad crown cork block the rectifier and prevent the crowner from crowning the bottles, delay by the operator to remove the bad crown cork can result in rejection of up to 10 bottles with extracts

Quality of raw material input to the system should be critically monitored; bad crown cork can cause a lot of downtime on Filler and create high extract losses. Supplier’s capability assessment is very important to ensure that quality raw materials and spare parts are supplied to the company.

5.3 Contribution to Knowledge

1. Development of a methodology that discovered the hidden bottleneck in the system studied, which can be applied in other breweries.
2. An easy and effective excel spreadsheet based platform for evaluating the performance of AB Breweries production lines in order to enhance the company's competitive advantage has been successfully introduced.

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