ABSTRACT

This paper presents an approach for improving productivity in breweries. A case study of AB brewery was adopted. Traditionally, packaging line improve performance and productivity based on extrapolation of past experience, but in recent times, the traditional method could not meet up with high increase in demand of products, hence the need to adopt a new approach of using information technology and software to analyze problems and improving performance. Eleven weeks of the following data were collected and calculated; production outputs and running time; OPI and Target; and Packaging line downtimes. Downtimes were grouped into machine breakdown, planned downtime, and external downtimes and analyzed with histogram to know the impact of each group to the overall downtimes. To apply fishbone diagram, it was further grouped into Material, Method, Man and Machine after which a Pareto graph was plotted to understand the area of focus in tackling production system problems. Tecnomatrix plant simulation software was adopted to develop a simulation model that mimic the real system which further found hidden problems existing within the production system. Design of experiment was carried out to select the best alternatives from the results generated, and finally excel spreadsheet interface was developed for better analysis and performance tracking of optimized system. Result of data analysis indicated that machine breakdown and external downtimes were the major problems affecting performance, while simulation model revealed that unregulated system and un-optimized regulated lines recorded high...
machine breakdown and speed losses which affected the production performance output respectively. Design of experiment found the best speed combination of sensors to optimize two labellers.

Keywords: Pareto analysis; fish bone diagram; OPI; machine efficiency; V-graph; MER; line efficiency; bottleneck machine; core machine; design of experiment; cycle time and tecnomatrix plant simulations.

NOMENCLATURES

PLC = Programmable Logic Controller
\( \eta_{machine} \) = Machine Efficiency
MTBF = Mean Time Between Failure
MTTR = Mean Time To Repair
\( \eta_{line} \) = Line Efficiency
MER = Mean Efficiency Rate
\( W \) = width (in mm)
\( \Phi \) = 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
\( Nm \) = number of bottles or cans per meter conveyor
\( Sb \) = speed of bottles in translation (in m/min) when the conveyor is filled with bottles on its whole width.
\( Sc \) = chain speed of the conveyor
\( L_{buffer} \) = length of the buffer, taken as the distance between the block and the starve sensors.
\( \rho \) = 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
\( \Phi \) = 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.
\( \Phi_{nom} \) = nominal fill level is the fill level of the conveyor in the ideal state as set in the control.
\( T_{acc} \) = Nominal Accumulation
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
\( T_{acc} \) = Actual Accumulation
\( T_{rec} \) = 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.
\( T_{rec} \) = 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 maximum speed.
\( \eta_{line}^{0} \) = lower limit of the line efficiency \( \eta_{line} \) for a series system without buffers.
\( C_{mach} \) = Machine Capacities
Line Capacity = \( A_{low}^{mach} \) = rate
\( R_{low} \) = Machines of minimum \( \eta_{line}^{0} \). Upper limit = \( \eta_{line}^{\infty} \) = Machines of minimum \( \eta_{line}^{0} \)
\( \beta \) = Buffer Performance Strategy
\( \eta_{buffer}^{AB} \) = Buffer Efficiency
OPI = Operational Performance Indicator

1. INTRODUCTION

In today's highly competitive beer and beverage market, AB Brewery needs to stay ahead of its competitors. HNS Visie [1] emphasized that in competitive market more product brands will enter the market as customer demand is changing, volume of product demand is increasing, 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. A packaging line is a series system which frequently has to deal with failures. The machines are put in a sequence and connected by conveyors, which can also serve as buffers. The capability to cope with customers’ demands is priority in today's market where competition drives the market with continuous decrease in product price [2]. Every of avoidable wastage must be removed and existing capacity increased to compete favorably with new companies coming with ever emerging new technology. S. K. Subramaniam et al. [3] stressed that the efficiency of industrial production lines is crucial as it result in an improve production and utilization of available resources. The efficiency of most packaging lines
is too low because of the occurrence of various machine failures. The average line efficiency is between 60% and 90% and the total production costs of beer consist mainly of packaging costs. Production continues almost seven days per week and 24 hours per day. Each day consists of three shifts of 8 hours and every shift the line is run by a team of operators. In order to improve packaging lines, it is necessary to have some means of predicting and explaining their performance and identifying the influence of the key line parameters (e.g. machine capacities, failure behavior, conveyor speed, buffer capacities, etc.). The recent developments in information technology within the packaging process enable the use of analysis methods to assess the efficiency of packaging lines. These methods can help to avoid line failures. Improving performance involves efficiency analysis of system using mathematics and information technology, which is applied on both process data of existing lines as well as in simulation studies. The activity involves gathering the appropriate data, representing these data in a comprehensible manner, calculating the relevant performance indicators [4] and interpreting these figures. The main goal is to understand or explain the loss of production output. The raw data is collected (in a database) manually and/or automatically from the line monitor System. The data analyst corrects these data for errors and noise, and filters out irrelevant data. For existing packaging lines the operators supply data either by writing events on a list or by pushing buttons on the line monitor system, the production manager provides the production schedules (including stops and change-over, and the administrator gives information about all costs. For new packaging lines data from comparable existing lines can be used or data can be generated by simulation; a sensitivity analysis of the efficiency analysis for these data can be performed. The data analyst transforms the edited data into information by combining these data and then constructing comprehensible graphs and calculating performance indicators [5]. The data should be analyzed over different production shift teams, different time periods, different product types, and different packaging lines. By creating standard and generally applicable methods, the efficiency analysis of packaging lines is made easier, more familiar and comparable. Comprehensive data analyses reveal the constraints that will be seen as an opportunity for improving the existing capacities and downtime reduction [6]. Just as Rahman [7] 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 determines the performance of a system. There is a need to see the identified constraints as an opportunity for improvement especially in the area of improving the existing production capacities currently underutilized.

2. STATEMENT OF THE PROBLEMS

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. Process analysis revealed that the company is underutilizing existing production capacities and investing in new production lines requires huge capital expenditure. The best option and cost effective way is to increase the existing production capacities, currently underutilized due to lack of optimal line regulations, high machine breakdown, external and planned downtime and inability to develop a platform for better data analysis and tracking of improvement made overtime for sustainability.

3. AIM

The aim of this paper is to improve performance through line regulation optimization and downtimes reduction.

4. OBJECTIVES OF THE STUDY

The objectives pursued in the research included to:

- Carry out production system analysis through work-study; perform process and data analysis on the production system of AB breweries.
- Apply Tecnomatrix Plant Simulation to build a conceptual model.
- Verify and Validate model developed with Simulation Software.
- Apply Design of Experiment to establish optimum alternative.

5. REVIEW OF RELATED LITERATURE

Kegg [8], 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, [8] 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, N.G.P.C, Lee, [9] 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.

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. Härtte, [10] 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.

The machine efficiency $\eta_{\text{machine}}$ 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:

$$\eta_{\text{machine}} = \frac{\text{Total Running Time}}{\text{Total Running Time + Total Time Internal Failure}} \times 100\%$$  

(1)

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:

$$\eta_{\text{machine}} = \frac{MTBF}{MTBF + MTTR} \times 100\%$$  

(2)
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 units per 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.

F. L. Härtle, [10] 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. Two types of models are typically used to estimate performance measures: simulation models and analytical models. Shannon, [11] define 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 [12]. 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 & Chevalier, [13] 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 [14]. 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 optimization by simulation can be easily embedded into the proposed simulation environment. A. Tolk et al. [15] 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.

6. METHODOLOGY

The following system production data were collected: Availability, Performance and Quality to calculate OPI for 11 weeks, which is the performance indicator adopted; Raw downtime data were collected and filtered, then grouped in machine downtimes, external downtimes and planned downtimes and histogram graph was plotted to understand the impact of the group on the overall performance of the system. The data was further grouped into machine, method, material and man with the application of Fishbone Diagram, which further revealed the area of focus in attending the existing problems. With Pareto Analysis graph, the area of focus is clearly revealed. To further understand the system and know if there exist other hidden problems affecting production performance, a continuous discrete event simulation model was built with Tecnomatrix Plant Simulation Software, discovering that regulating and optimizing are the best approach to increase productivity. Factorial design of experiment was applied through changing of the existing sensors speeds of the two labellers and selecting the best result from alternative results, which optimized the system.

6.1 Line Efficiency

The line efficiency \( \eta_{\text{line}} \) is a measure of the efficiency of the packaging line during the period specified, and is calculated as follows:

\[
\eta_{\text{line}} = \frac{\text{Net Production time}}{\text{Actual Production Time}} \times 100\% \quad (3)
\]

\[
\eta_{\text{line}} = \frac{\text{Net Production time}}{\text{Net Production time} + \text{Internal Unplanned Downtime}} \times 100\% \quad (4)
\]
6.2 Machine Efficiency Analysis

The machine efficiency $\eta_{\text{machine}}$ 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:

$$\eta_{\text{machine}} = \frac{\text{Total Running Time}}{\text{Total Running Time} + \text{Total Time Internal Failure}} \times 100\%$$

(6)

Machine with the lowest capacity is called Core Machine, while Machine with the lowest MER is called Bottleneck Machine. V-Graph is the plot of Machine Capacities and MER with Line Efficiency as the benchmark.

6.3 MER (Mean Efficiency Rate)

$$\text{MER} = \frac{\text{Production Time}}{\text{Production Time} + \text{Internal Failure Time}} \times \frac{\text{Machine Capacity}}{1}$$

(10)

6.4 The Operational Performance Indicator (OPI) is Calculated as Follows

$$\text{OPI} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

(11)

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

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

(12)

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

(13)

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

(14)

6.5 For a Given Bottle or Can Conveyor

Conveyor Theory Kwo [16]: 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). Kwo’s work was expanded by Muth [17] who treated both continuous time and discrete time material flow, multiple load and unload stations and stochastic material flow.

$W =$ width (in mm)

$\varnothing =$ bottle or can diameter (in mm)

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

$\text{Nb} =$ number of rows of bottles or cans standing on the width of the conveyor

$$A = \text{ROUND} \left[ \frac{W - \varnothing}{\varnothing \cos \varnothing} + 1 \right]$$

(15)

$\text{Nm} =$ number of bottles or cans per meter conveyor $= \text{Nb} \times \frac{100}{\varnothing}$

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

$$= \frac{C_{\text{line}}}{\text{Nm}}$$

$S_c =$ chain speed of the conveyor

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

$\rho =$ 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. $S_b$ 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 $\Phi =$ 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.

$\Phi^{\text{nom}} =$ 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
6.6 Nominal Accumulation

The nominal accumulation is the accumulation when the buffer is in the ideal or nominal state, i.e., the state when the machine is producing without failures. The nominal accumulation is equal to:

\[ T_{\text{acc}}^{\text{nom}} = L_{\text{buffer}} \left[ \frac{1}{S_p} - \frac{1}{S_c} \right] \]  

(16)

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 it 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 it takes to fill the conveyor over the length of the buffer minus the time it 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.

\[ T_{\text{acc}} = L_{\text{buffer}} \left[ \frac{1}{S_p} - \frac{1}{S_c} \right] \]  

(17)

\[ T_{\text{acc}} = L_{\text{buffer}} \left[ \frac{1}{S_b} - \frac{1}{S_c} \right] \]  

(18)

**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.

\[ T_{\text{rec}}^{\text{nom}} = \frac{T_{\text{Stop}} C_{\text{line}}}{C_{M} - C_{\text{line}}} \]  

(19)

Accumulation rate:

\[ \eta_{\text{acc}}^{\text{nom}} = \frac{\text{Accumulation Capacity in bottles}}{C_{B}^{\text{nom}} + \text{MTTR}_{A}} \]  

(20)

Nominal recovery rate:

\[ \text{MTBF}_{A}(C_{\text{A}} - C_{\text{B}}^{\text{nom}}) \]  

(21)

Mean recovery rate:

\[ \text{MTBF}_{A}(C_{\text{A}} - C_{\text{B}}^{\text{nom}}) \]  

(22)

6.7 Buffer Performance Strategy Analysis

The data collected for the buffer strategy performance include:

- Line efficiency limits
- Actual line efficiency

For the lower limit of the line efficiency $\eta_{\text{line}}^{\text{low}}$ for a series system without buffers it is assumed that the production rate of the line is the minimum of the machine capacities. Then the line efficiency lower limit or zero-buffer limit is the product of the line production rate and the line availability.

**Line production rate** $R_{\text{low}} = M\text{achines of minimum } M^{\text{mach}}$  

(23)

**Line Availability** $A_{\text{low}} = \prod_{\text{machine}} \eta_{\text{line}}$  

(24)

**Lower Limit** $\eta_{\text{line}}^{\text{low}} = R_{\text{low}} \times A_{\text{low}}$  

(25)

The upper limit of the line efficiency $\eta_{\text{line}}^{\text{up}}$ 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.

**Mean Effective Ratio** $\text{MER}_{\text{mach}} = \eta_{\text{machine}} \times C^{\text{mach}}$  

(26)

**Upper limit** $\eta_{\text{line}}^{\text{up}} = \text{Machines of minimum } \text{MER}_{\text{mach}}$  

(27)

The buffer strategy performance is calculated as the difference between the actual line efficiency $\eta_{\text{line}}$ and the line efficiency lower limit as percentage of the difference between the line efficiency upper limit and the line efficiency lower limit:

**Buffer Performance Strategy** $\beta = \frac{\eta_{\text{line}}^{\text{low}} - \eta_{\text{line}}^{\text{low}}}{\eta_{\text{line}}^{\text{up}} - \eta_{\text{line}}^{\text{low}}} \times 100\%$  

(28)
Where Line Efficiency = \( \eta_{\text{line}} = \frac{\text{Net Production time}}{\text{Actual Production Time}} \times 100\% \)  (29)

Buffer Efficiency

\[ \eta_{\text{Buffer}} = \frac{(r_{\text{up}} - r_{\text{st}})}{r_{\text{stop}}} \]  (30)

If there would be no buffer the starve time of machine B would be equal to the stop time of machine A.

7. RESULTS OF DATA ANALYSIS

The data analysis result was carried out to understand the current system performance and analyze the data necessary to understand the system problems. Table 1 show the result of the Machine Capacities, Efficiencies and Mean Effective Rate of the line. Table 2 shows the machine events of the production line 4, where running time, starvation, blockage, machine internal failure and lack of materials were determined. Table 4 calculated the OPI of the Line 1, 2 and 4 to understand the performance of the each line compared with OPI target of 60%. Table 5 show the weekly production output against the running time of Line 1, 2 and 4 to understand the causes of differences in production output against running time. Chart 4 and 5 clearly represent the differences that exist between Line 2 and 4 output and running time. Table 6 and 7 analyzed the downtimes of regulated Line 2 and Unregulated Line 4 understand the importance of regulation and the average downtimes recorded for the two lines. Table 9 compared the weekly frequencies of downtimes and downtimes to individual components of the system to ascertain how often system breakdown and time taken to restore the system downtimes while the result of Table 9 and 10 present Pareto Analysis of the grouped downtime to understand the area of focus in tackling downtimes problems.

### Table 1. Machine capacities, machine efficiencies and mean effective rates

| S/N | Machines  | \( C_{\text{mach}}\% \) | \( \eta_{\text{mach}}\% \) | \( MER_{\text{mach}}\% \) |
|-----|-----------|----------------|----------------|----------------|
| 1   | Depalletizer | 135          | 97             | 131           |
| 2   | Washer     | 110          | 105            | 99            |
| 3   | Filler     | 100          | 98             | 99            |
| 4   | Pasteurizer| 100          | 99             | 99            |
| 5   | Labeller   | 125          | 95             | 119           |
| 6   | Packer     | 130          | 93             | 121           |
| 7   | Palletizer | 135          | 96             | 130           |

The lower and upper limits for the time period specified are shown in Table 2: Real efficiency for the period was \( \eta_{\text{line}} = 87\% \) the resulting buffer performances is 50%.

### Table 2. Lower and upper efficiency limit and buffer performance

| Lower limit | Upper limit | Buffer strategy performance |
|-------------|-------------|-----------------------------|
| \( R_{\text{low}} \) | \( A_{\text{low}} \) | \( \eta_{\text{line}} \) | \( \eta_{\text{line}} \) | \( IS \) |
| 100\%       | 76\%        | 98\% | 50\% |
7.1 Machine Event States for Filler

Table 3. Machine event states for 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 |        |      |     |     |           |

Machine Efficiency = \( \frac{\text{Running Time}}{\text{Running Time} + \text{Internal machine failure}} \times 100\% = 94\% \) (31)

Chart 2. V-graph: Partition of machine capacities over machine states and MER

7.2 OPI Measurement as Performance Indicator Adopted

Table 4. 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%  |
Chart 3. Graph of OPI of line 1,2 and 4 Vs OPI target from week 38 to 51

7.3 Performance Measurement: Production Outputs against Running Time

Table 5. Weekly output of line 1, 2 & 4 and combined

| Week | Line 1 | Line 2 | Line 4 | Combined |
|------|--------|--------|--------|----------|
|      | Running hour | Running hour | Running hour | Running hour |
| Wks  | Line 1 Cus hrs | Line 2 Cus hrs | Line 4 Cus hrs | Combined CUS hrs |
| 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 | 121 103 | 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 | 125 147,617 | 392 282,558 | 283 |
| 44   | 138 71,404 | 144 74,576 | 80 103,187 | 362 249,167 | 249 |
| 45   | 99 50,102 | 116 67,893 | 74 120,071 | 289 238,066 | 238 |
| 46   | 155 68,225 | 133 80,009 | 131 127,293 | 419 275,527 | 276 |
| 47   | 140 61,121 | 140 76,512 | 84 113,266 | 364 250,899 | 251 |
| 48   | 113 56,595 | 132 72,599 | 145 130,169 | 390 259,363 | 259 |
| 49   | 130 75,919 | 139 75,623 | 121 133,200 | 390 284,742 | 285 |
| 50   | 149 70,962 | 148 80,703 | 90 112,468 | 387 264,133 | 264 |
| 51   | 144 62,212 | 148 80,047 | 140 153,135 | 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 |

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From data analysis result, in Table 1 the wide differences in machine capacities of the lines in addition with long conveyor systems help the line to cope with internal failures of proceeding and succeeding machines to drastically reduce blockage, starvation and ensure continuous flow. Chart 1 indicates that Filler and Pasteurizer are the core machines and all other machines have increasing order of capacities upstream and downstream of core machines. The result of Table 3, the machine event states, indicate that blockage and starvation were very high, hence the need to regulate the system. In Table 4, the OPI of line 2 in most of the weekly production met the OPI target of 60%, though some weeks; the production was below the target. In Line 4, the weekly production fall below the OPI target of 60% with an average of 26.7%. This is because Line 4 was not regulated and runs on (0 or 100%) speed resulting in high internal failure, blockage and starvation, while line 2 was regulated with speed adjustment of 25%, 50%, 75% and 100% depending on the need to adjust the speed. Chart 3 clearly represents the OPI results in histogram form. Table 5, the production running time of line 4 was highest but due to high internal failure, blockage and starvation, the output of 1,614,068 Carton units were small when compare to running time of 5,548 hours. This leads us to downtime analysis of the lines.
7.4 Downtimes Analysis Results: Grouped Downtimes (Machine, Planned and External)

Table 6 compared the average downtimes of week 41 to week 52 of unregulated line 4 with Table 7 of regulated line 2.

**Table 6. Grouped weekly downtimes of line 4**

| Weeks | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|
| Downtime in 100 mins | Average | |
| Breakdown | 2160 | 455 | 1159 | 962 | 396 | 1657 | 2158 | 2689 | 1706 | 1995 | 1221 | 594 |
| External Std | 776 | 3385 | 645 | 100 | 618 | 522 | 440 | 3296 | 1092 | 688 | 833 | 884 |
| Plan Stops | 200 | 365 | 195 | 180 | 246 | 995 | 880 | 180 | 1070 | 446 | 5741 | 478.42 |
| PROD | 121,049 | 94,783 | 147617 | 193157 | 120971 | 127293 | 113269 | 130169 | 133209 | 112480 | 153135 | 141659 |
| Running Time | 8040 | 4050 | 7600 | 4200 | 4444 | 7666 | 5040 | 3072 | 7260 | 5400 | 8460 | 9660 |
| Downtimes/Average | 2343.1 | 20.3 |

**Chart 6. Graphical weekly downtimes of Line 4**

**Table 7. Grouped weekly downtimes of Line 2 (Machine, Planned and External)**

| Weeks | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Downtime in 100 mins | Average | |
| Breakdown | 1905 | 1085 | 520 | 490 | 716 | 350 | 520 | 311 | 540 | 1270 | 1040 | 1240 | 450 | 340 | 230 |
| External Std | 1902 | 1060 | 520 | 490 | 716 | 350 | 520 | 311 | 540 | 1270 | 1040 | 1240 | 450 | 340 | 230 |
| Plan Stops | 1902 | 1060 | 520 | 490 | 716 | 350 | 520 | 311 | 540 | 1270 | 1040 | 1240 | 450 | 340 | 230 |
| PROD | 45,495 | 54,208 | 45,710 | 55,028 | 49,196 | 55,049 | 37,470 | 37,003 | 60,606 | 37,112 | 70,159 | 70,023 | 87,972 | 90,047 | 27,871 |
| Running Time | 8,009 | 7,200 | 8,560 | 7,073 | 12,026 | 7,780 | 8,480 | 8,560 | 7,680 | 8,400 | 7,920 | 8,260 | 8,980 | 8,600 | 6,620 |
| Downtimes/Average | 2343.1 | 20.3 |

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7.5 Downtimes and Frequencies Results of Components of Machine, Planned and External Downtimes

Table 8. Weekly downtimes and frequencies analysis result of components of external planned and machine downtimes
Chart 8. Graphical representation of weekly frequencies of downtimes

Chart 9. Graphical representation of weekly downtimes of components of machine, planned and external downtimes

7.6 Pareto Analysis Result

Table 9. 4M downtimes analysis result 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%           |                          |
The following results were obtained from downtimes analysis of line 2 and 4: In Table 6 of unregulated Line 4, when downtimes were grouped into Machine Breakdown (1,368.92 mins), External Downtimes (1,096.58 mins) and Planned Downtimes (478.42 mins), the result
showed a high percentage of machine breakdown and external downtimes on line 4 when compared with Table 7 of regulated line 2, where machine breakdowns was 880.4 mins, External downtimes was 908.8 mins and planned downtimes of 380 mins. It is a clear indication that regulating line 4 will drastically reduce downtimes of the system. Chart 6 clearly represents the different downtimes of line 4. In Table-8, Weekly Downtimes and Frequencies of Components of External Planned and Machine Downtimes were further breakdown to know the impact of the each components on the overall downtimes, the result indicated in Fig. 8 of Frequencies and corresponding downtimes in Chart-9 that weathered bottles, and no ready products as components of external downtimes where very high, while Filler, Washer, EBI and Labeller were very high on the components of machine breakdown. Again, Pareto Analysis was applied to understand the area of focus when downtimes were grouped into 4M (Machine, Material, Method and Man), it was observed in Chart-10 and 11 of line 4 and 2 respectively, that Machine and Material problems took almost 80% of the entire problems. Tecnomatix Plant Simulation Software was applied to further understand the hidden problems after all the data analysis. A model was developed that mimic the current production system to understand the causes of high machine downtimes and speed losses recorded in output of production against running time.

8. TECNOMATRIX MODEL RESULT

The Discrete Continuous Modeling of Star Bottles on Conveyor System was built with Tecnomatix Plant Simulation Software to monitor system behaviors, know the reasons for differences in production output of the two labellers of the same capacities and low OPI in line 4. Again ascertain the causes of high downtime in line 4 when compared to line 2.

![Fig. 1. Print screen of the developed Tecnomatix plant simulation software](image-url)
Input data

The Lower Deck produced 39138 bottles per hour while the Upper Deck produces 36257 bottles per hour. The difference between lower and Upper-deck is 7.4%, therefore the upper deck has failure rate of 7.4% less than lower deck. Upper deck has availability of 92.6% and MTTR of 1 minute. 92.6% of total time, the upper deck has Star Bottles at the in-feed.

![Figure 2. Production output (bottles) per hour and processing time (hrs) for Labeller CPL 112 and CPL 111](image)

Table 11. Conveyor capacities parameters

| Name | Line | Length (m) | # of strokes | Eff capacity |
|------|------|------------|--------------|--------------|
| A    | 2.6  | 2.60       | 5            | 341.2        |
| B    | 2.8  | 2.80       | 5            | 360.6        |
| C    | 11   | 11.00      | 5            | 1452         |
| D    | 9    | 9.00       | 5            | 1188         |
| E    | 12   | 12.00      | 5            | 1584         |
| F    | 7    | 7.00       | 5            | 923          |
| G    | 9    | 9.00       | 5            | 1188         |
| H    | 4.4  | 4.40       | 8            | 932.8        |
| I    | Angle | 1.10      | 8            | 233.1062     |
| J    | Straight | 4.5 | 8            | 954          |
| K    | 5.6  | 5.60       | 8            | 1187.106     |
| L    | Angle | 0.55      | 4            | 4            |
| M    | 6.55 | 6.55       | 12           | 687.7628     |
| Q    | 4    | 4.00       | 4            | 420          |

From the result of the model, the labellers CPL 112 and CPL 111 of Line 2 were regulated and run on 25% or 75% or 100% of the designed speed but not optimized while Line 4 was not regulated and runs on 0 or 100% of the designed speed. Machine that runs on high speed has inherent downtimes compared to regulated speed.
Fig. 3. Result of the model built to balance the output of the two Labellers

9. DESIGN OF EXPERIMENT RESULT

From the result of model, the regulated line has speed losses which affected the output, hence the need to optimize the speed level to minimize speed losses and increase the OPI. Table 12 indicates the speed levels and corresponding sensors for the 12 experimental runs. Table 13 shows the result of the experiments showing production balance, starvation and failure.

The results of the Design of Experiment were shown on Tables 12 to 17. Three experiments (6, 10 & 12) were selected as the experiments that gave optimal results. When the three experiments were ranked, experiment 6 was chosen as the best result with the following reasons: The output of experiment 6 was high compared to other two. The line was better balanced, 53% for CPL 111 and 47% for CPL 112 than in the other two experiments. Finally, only two sensors were changing from Nominal to high and from High to Nominal while other sensors remained unchanged.

Table 12. Possible combination of sensors speeds using factorial design ($2^k$)

| Experiment | LABELLER112<> low speed speed | LABELLER111<> low speed speed | LABELLER111<> nominal speed | LABELLER111<> high speed |
|------------|-------------------------------|-------------------------------|-----------------------------|--------------------------|
| Experiment 1 | NOSPEED | O4 (Sensor 17) | M4 (Sensor 14) | L11 (Sensor 13) |
| Experiment 2 | NOSPEED | O4 (Sensor 17) | M4 (Sensor 14) | E51(Sensor 8) |
| Experiment 3 | NOSPEED | O4 (Sensor 17) | I8 (Sensor 10) | E51(Sensor 8) |
| Experiment 4 | NOSPEED | NOSPEED | M4 (Sensor 14) | L11 (Sensor 13) |
| Experiment 5 | NOSPEED | NOSPEED (low S) | M4 (Sensor 14) | E51(Sensor 8) |
| Experiment 6 | NOSPEED | NOSPEED | I8 (Sensor 10) | E51(Sensor 8) |
| Experiment 7 | J4 (Sensor 12) | O4 (Sensor 17) | M4 (Sensor 14) | L11 (Sensor 13) |
| Experiment 8 | J4 (Sensor 12) | O4 (Sensor 17) | M4 (Sensor 14) | E51(Sensor 8) |
| Experiment 9 | J4 (Sensor 12) | O4 (Sensor 17) | I8 (Sensor 10) | E51(Sensor 8) |
| Experiment 10 | J4 (Sensor 12) | NOSPEED | M4 (Sensor 14) | L11 (Sensor 13) |
| Experiment 11 | J4 (Sensor 12) | NOSPEED | M4 (Sensor 14) | E51(Sensor 8) |
| Experiment 12 | J4 (Sensor 12) | NOSPEED | I8 (Sensor 10) | E51(Sensor 8) |
Table 13. The result of the 12 possible experimental runs

| Experiment | Output (# of bottles) | Production balance | Starvation | Failure |
|------------|-----------------------|--------------------|------------|---------|
|            | Average               | LABELLER111        | LABELLER112| LABELLER111 | LABELLER112 |
| 1          | 441313                | 57%                | 43%        | 29.77%   | 38.08%   | 67.85%   | 2.22%    | 0.85%    |
| 2          | 416625                | 29%                | 71%        | 67.77%   | 9.51%    | 77.28%   | 0.43%    | 1.33%    |
| 3          | 388495                | 19%                | 81%        | 69.40%   | 7.03%    | 76.42%   | 1.03%    | 0.24%    |
| 4          | 435440                | 58%                | 42%        | 1.72%    | 39.03%   | 40.75%   | 1.65%    | 0.54%    |
| 5          | 444508                | 57%                | 43%        | 0.82%    | 38.79%   | 39.61%   | 1.20%    | 0.18%    |
| 6          | 453103                | 53%                | 47%        | 0.01%    | 30.61%   | 30.62%   | 1.42%    | 0.04%    |
| 7          | 439100                | 62%                | 38%        | 24.65%   | 48.17%   | 72.82%   | 0.84%    | 0.13%    |
| 8          | 379278                | 23%                | 77%        | 76.67%   | 10.80%   | 87.47%   | 0.46%    | 1.36%    |
| 9          | 408198                | 31%                | 69%        | 66.44%   | 13.59%   | 80.03%   | 0.39%    | 1.06%    |
| 10         | 449990                | 58%                | 42%        | 2.90%    | 28.48%   | 31.38%   | 1.99%    | 1.03%    |
| 11         | 430915                | 57%                | 43%        | 0.78%    | 37.09%   | 37.86%   | 2.83%    | 0.86%    |
| 12         | 444338                | 54%                | 46%        | 0.08%    | 33.84%   | 33.92%   | 0.78%    | 0.80%    |

Table 14. The result of the experimental runs

| Experiment | Output | Production balance | Waiting | Stopping |
|------------|--------|--------------------|---------|----------|
|            | Average| LABELLER111        | LABELLER112| LABELLER111 | LABELLER112 |
| 1          | 441313 | 57%                | 43%        | 0.78%    | 38.08%   | 28.99%   | 0.00%    |
| 2          | 416625 | 29%                | 71%        | 0.05%    | 9.51%    | 67.71%   | 0.00%    |
| 3          | 388495 | 19%                | 81%        | 0.00%    | 7.03%    | 69.40%   | 0.00%    |
| 4          | 435440 | 58%                | 42%        | 1.72%    | 39.03%   | 40.75%   | 1.65%    |
| 5          | 444508 | 57%                | 43%        | 0.82%    | 38.79%   | 39.61%   | 1.20%    |
| 6          | 453103 | 53%                | 47%        | 0.01%    | 30.61%   | 30.62%   | 1.42%    |
| 7          | 439100 | 62%                | 38%        | 24.65%   | 48.17%   | 72.82%   | 0.84%    |
| 8          | 379278 | 23%                | 77%        | 76.67%   | 10.80%   | 87.47%   | 0.46%    |
| 9          | 408198 | 31%                | 69%        | 66.44%   | 13.59%   | 80.03%   | 0.39%    |
| 10         | 449990 | 58%                | 42%        | 2.90%    | 28.48%   | 31.38%   | 1.99%    |
| 11         | 430915 | 57%                | 43%        | 0.78%    | 37.09%   | 37.86%   | 2.83%    |
| 12         | 444338 | 54%                | 46%        | 0.08%    | 33.84%   | 33.92%   | 0.78%    | 0.51%    |
Table 15. Ranking of the three best results of the 12 experiments

| Rank   | Experiment | Output  | Production balance |
|--------|------------|---------|--------------------|
|        |            | Average | LABELLER111     | LABELLER112     |
| Current: | 1         | 441313  | 57%               | 43%            |
| 1<sup>st</sup> | 6         | 453103  | 53%               | 47%            |
| 2<sup>nd</sup> | 10        | 449990  | 58%               | 42%            |
| 3<sup>rd</sup> | 12        | 444338  | 54%               | 46%            |

Table 16. Combination of sensors speed that yield the best results

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

Table 17. Summary of the experimental results before and after modifications

| Situation                  | Output       | Production balance | Difference on LABELLERs       |
|----------------------------|--------------|--------------------|-------------------------------|
|                            | Average      | LABELLER111        | LABELLER112                   |
| Current (simulation)       | 441313       | 57%                | 43%                           | 14%                        |
| Alternative (simulation)  | 453103       | 53%                | 47%                           | 6%                         |
| Difference (simulation)    | 11790        | 4%                 | 4%                            | 8%                         |
| Average(real life before modification) | 420193 | 57% | 43% | 14% |                  |
| REAL test (real life after modification) | 447480 | 52% | 48% | 4% |                  |
| Difference (real life)     | 27287        | 5%                 | 5%                            | 10%                        |

10. CONCLUSION

The first four stages of the objective, which is production system analysis, has revealed the followings; the ways of 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.

These led us to the stage two of the studies to understand the courses of imbalance in the outputs and high machine breakdown of line 4. The conceptual modeling revealed constraints to the production performance of the lines include the followings; Line 2 run on regulated continuous speed mode (0, 25, 50, 75, and 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. Nakajima [19] 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 regulated line. As a result, high percentage of downtimes were recorded which affected the overall production performance of the system. It also revealed that although, line 2 was 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. These 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 Tables 13 to 14. From the 12 experiments carried out, experiment 6 was the best alternative out of the best three experiments chosen. The gain from these studies between the current situation and experiment 6 was determined based on the four stages of the studies. Nevertheless, the results of the implementation closely match with those of simulation study in Table 17, where real test show the results in real life after the implementation.

Table 17 shows the differences between the current and alternative situations of both our simulation as well as real life. The 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 validated model. 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 27,287 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 17 shows 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 15. With an output of 447480 experiments 6 is still the best experiment. 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.

- 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 production line.
- 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 parallel machines.
- Visualization of inefficiencies for operators. At the moment every machine 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 machine inefficiencies
- 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.

11. RECOMMENDATIONS

- Focus more 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 also play an important role in the line performance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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