Journal of Engineering Research and Reports

1(1): 1-22, 2018; Article no.JERR.41033

Optimization of Packaging Line Performance: A Case Study of AB Breweries in Nigeria

Chinedu James Ujam[1]* and Harold Chukwuemeka Godwin[1]

[1] *Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2018/v1i19764
Editor(s):
(1) Leandro A. Pasa, Professor, Campus Medianeira da Universidade Tecnologica Federal do Parana, Brazil.
Reviewers:
(1) Shashidhar K. Kudari, CVR College of Engineering, Jawaharlal Nehru Technological University, India.
(2) Yesim Benal Oztekin, Ondokuz Mayis University, Turkey.
(3) Hamid Tebassi, May 8th 1945 University, Algeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/24376

Short Research Article

Received 9th February 2018
Accepted 20th April 2018
Published 28th April 2018

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

---

**Corresponding author: E-mail: ujamismj@yahoo.com;*

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
ŋ$machine$ *Machine Efficiency*
$MTBF$ *=Mean Time Between Failure*
$MTTR$ *= Mean Time To Repair*
ŋ$line$ *= Line Efficiency*
MER= Mean Efficiency Rate
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
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.*
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
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 is the fill level of the conveyor in the ideal state as set in the control.*
T_{acc}^{nom} *= 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}^{nom} *= 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.*
$ŋ_{line}^{0}$ *= lower limit of the line efficiency* $ŋ_{line}^{0}$*for a series system without buffers.*
C^{mach} *Machine Capacities*
Line production rate
$R^{low} = Machines\ of\ minimum\ C^{mach}$
Line Availability =$A^{low} = \prod_{machine} ŋ_{line}$
Lower Limit=$ŋ_{line}^{0} = R^{low} * A^{low}$
Upper limit = $ŋ_{line}^{\infty}$ *= Machines of minimum* MER_{mach}
ß = Buffer Performance Strategy
$ŋ_{\boldsymbol{Buffer}}^{\boldsymbol{AB}}$ *= 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 pursed 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. Härte, [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 η_{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:

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

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:

$$\eta\text{machine} = \frac{MTBF}{MTBF+MTTR} * \frac{100\%}{1} \tag{2}$$

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. Härte, [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 η_{line} is a measure of the efficiency of the packaging line during the period specified, and is calculated as follows:

$$\eta\text{line} = \frac{\text{Net Production time}}{\text{Actual Production Time}} * \frac{100\%}{1} \tag{3}$$

$$\eta\text{line} = \frac{\text{Net Production time}}{\text{Net Production time+Internal Unplanned Downtime}} * \frac{100\%}{1} \tag{4}$$

$$\eta\text{line} = \frac{\text{Output in Production units}}{\text{Actual Production time}*\text{Norminal Line Capacity}} * \frac{100\%}{1} \qquad (5)$$

6.2 Machine Efficiency Analysis

The machine efficiency η_{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:

$$\eta\text{machine} = \frac{\text{Total Running Time}}{\text{Total Running Time}+\text{Total Time Internal Failure}} * \frac{100\%}{1} \qquad (6)$$

$$\text{MTTR} = Mean\ Time\ to\ Repair =$$

$$\frac{Total\ Time\ Internal\ Failures}{Number\ of\ Internal\ Failures} \qquad (7)$$

$$\text{MTBF} = Mean\ Time\ Between\ Failures =$$

$$\frac{Total\ Running\ Time}{Number\ of\ Internal\ Failures} \qquad (8)$$

$$\eta\text{machine} = \frac{\text{MTBF}}{\text{MTBF}+\text{MTTR}} * \frac{100\%}{1} \qquad (9)$$

6.3 MER (Mean Efficiency Rate)

$$\text{MER} =$$

$$\frac{\text{Production Time}}{\text{Production Time}+\text{Internal Failure Time}} * \frac{\text{Machine Capacity}}{1} \qquad (10)$$

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

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

$$\text{OPI} = \text{Availability} * \text{Performance} * \text{Quality} \qquad (11)$$

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

$$\text{Quality} = \frac{\text{No.of Good Product}}{\text{No of Good Product}+\text{No.of Rework}\ \&\ reject} \qquad (12)$$

$$\text{Performance} = \frac{\text{Production Time}}{\text{Operating Time}} \qquad (13)$$

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Manned Time}} \qquad (14)$$

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)
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

$$= A = ROUND\left[\frac{W-\emptyset}{\emptyset-COS30^\circ}+1\right] \qquad (15)$$

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

[18]. 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 F.L. Härte, [10].

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 line is producing without failures. The nominal Accumulation is equal to:

$$T_{acc}^{nom} = L_{buffer} * [\frac{1}{Sb} - \frac{1}{Sc}] \quad (16)$$

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 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.

$$T_{acc} = L_{buffer} * [\frac{\rho}{Sb} - \frac{1}{Sc}] \text{ for anti-starve buffers} \quad (17)$$

$$T_{acc} = L_{buffer} * [\frac{1-\rho}{Sb} - \frac{1}{Sc}] \text{ for anti-block buffers} \quad (18)$$

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.

$$T_{rec}^{nom} = [\frac{T_{Acc}^{nom} * C_{line}}{C_M - C_{line}}] \quad (18)$$

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 maximum speed.

$$T_{rec} = [\frac{T_{Stop} * C_{line}}{C_M - C_{line}} \quad (19)$$

Accumulation rate=

$$\frac{T_{acc}^{nom}}{MTTR_A} = \frac{Accumulation\ Capacity\ in\ bottles}{C_B^{nom} * MTTR_A} \quad (20)$$

$$\text{Nominal recovery rate} = \frac{MTBF_A * (C_A - C_B^{nom})}{C_B^{nom} * T_{acc}^{nom}} \quad (21)$$

$$\text{Mean recovery rate} = \frac{MTBF_A * (C_A - C_B^{nom})}{C_B^{nom} * MTTR_A} \quad (22)$$

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 η_{line}^0 for a series system without buffers it is assumed that the production rate of the line 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.

Line production rate $R^{low} =$

$$Machines\ of\ minimum\ C^{mach} \quad (23)$$

$$\text{Line Availability} = A^{low} = \prod_{machine} \eta_{line} \quad (24)$$

$$\text{Lower Limit} = \eta_{line}^0 = R^{low} * A^{low} \quad (25)$$

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.

$$\text{Mean Effective Ratio } (MER_{mach}) = \eta_{machine} * C^{mach} \quad (26)$$

$$\text{Upper limit} = \eta_{\text{line}}^{\infty} = \text{Machines of minimum } MER_{mach} \quad (27)$$

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 the line efficiency lower limit:

$$\text{Buffer Performance Strategy ß} = \frac{\eta_{line} - \eta_{line}^0}{\eta_{line}^{\infty} - \eta_{line}^0} * 100\% \quad (28)$$

Where Line Efficiency = $\eta\text{line} =$

$$\frac{Net\ Production\ time}{Actual\ Production\ Time} * \frac{100\%}{1} \tag{29}$$

Buffer Efficiency

$$\eta_{Buffer}^{AB} = \frac{(T_{Stop}^{A} - T_{Starve}^{B})}{T_{Stop}^{A}} \tag{30}$$

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	$C_{mach\%}$	$\eta_{mach\%}$	$MER_{mach\%}$
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 η_{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^{low}	A^{low}	η_{line}^{0}	$\eta_{\text{line}}^{\infty}$	ß
100%	76%	76%	98%	50%

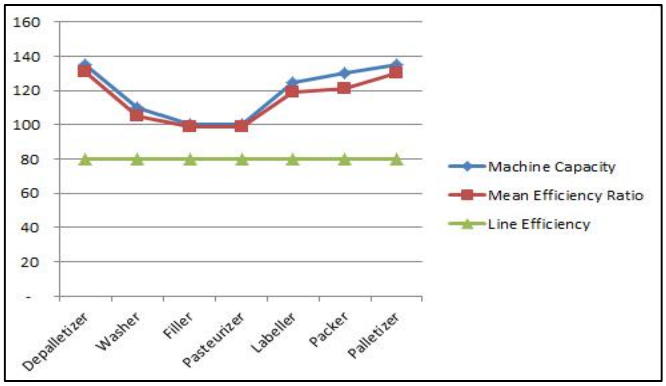


Chart 1. V-graph: Machine capacities, MER and line efficiency

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					

$$\text{Machine Efficiency} = \frac{\text{Running Time}}{\text{Running Time+Internal machine failure}} = \frac{22163}{22163+1354} = 94\% \qquad (31)$$

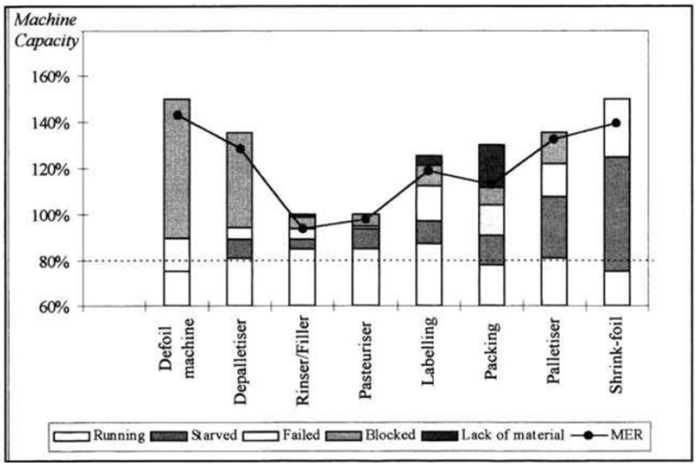


Chart 2. V-graph: Partition of machine capacities over machine states and MER

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%

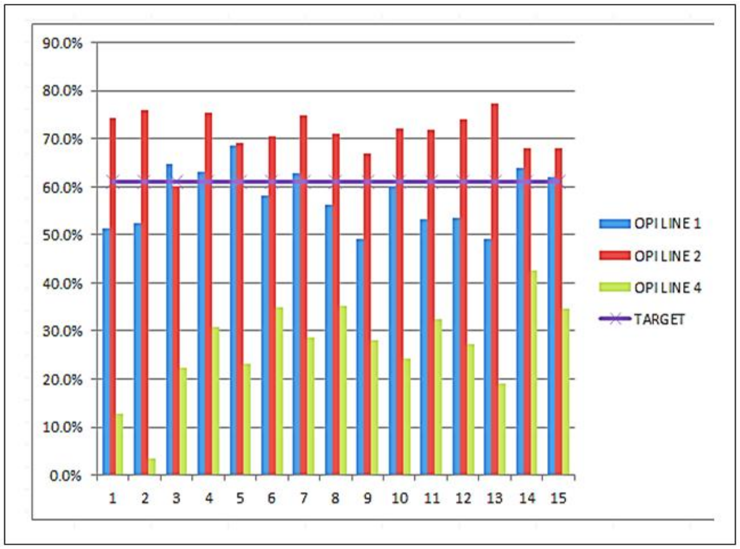


Chart 3. Graph of OPI of line 1,2 and 4 Vs OPI target from week 38 to 51

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		
	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

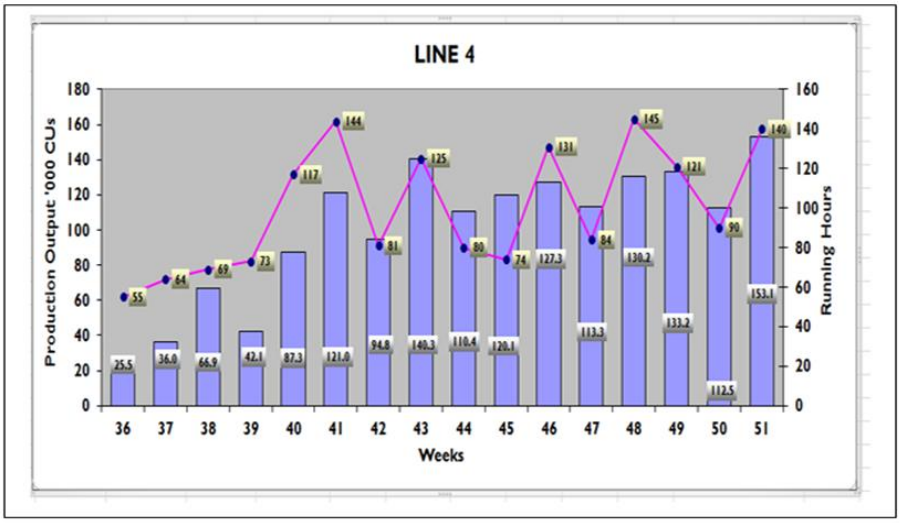


Chart 4. Graphical representation of output against running time for line 1, 2 & 4

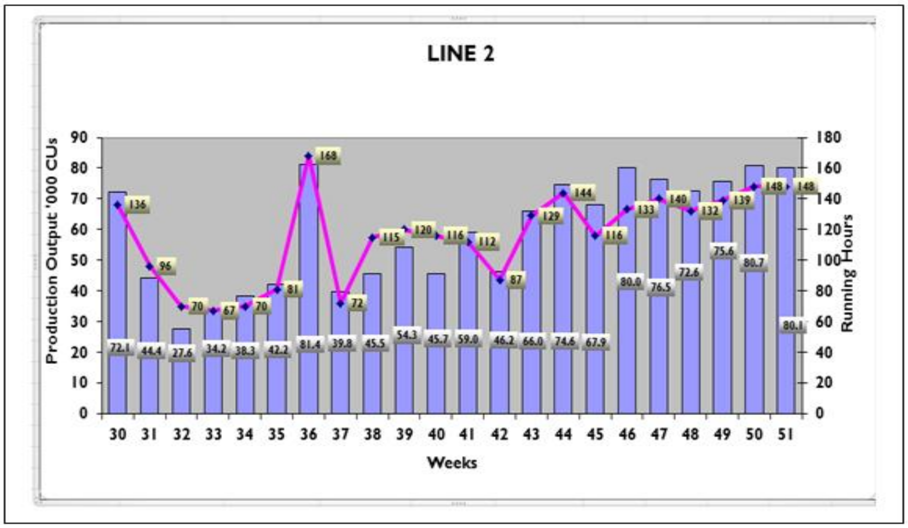


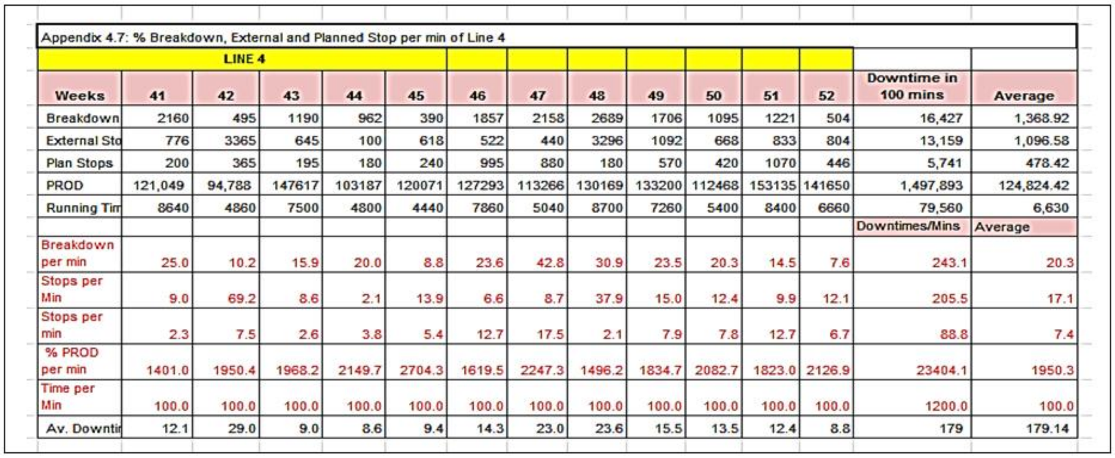
Chart 5. Graphical representation of output against running time for line 2

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



Appendix 4.7: % Breakdown, External and Planned Stop per min of Line 4

LINE 4

Weeks	41	42	43	44	45	46	47	48	49	50	51	52	Downtime in 100 mins	Average
Breakdown	2160	495	1190	962	390	1857	2158	2689	1706	1095	1221	504	16,427	1,368.92
External Sto	776	3365	645	100	618	522	440	3296	1092	668	833	804	13,159	1,096.58
Plan Stops	200	365	195	180	240	995	880	180	570	420	1070	446	5,741	478.42
PROD	121,049	94,788	147617	103187	120071	127293	113266	130169	133200	112468	153135	141650	1,497,893	124,824.42
Running Tim	8640	4860	7500	4800	4440	7860	5040	8700	7260	5400	8400	6660	79,560	6,630
													Downtimes/Mins	Average
Breakdown per min	25.0	10.2	15.9	20.0	8.8	23.6	42.8	30.9	23.5	20.3	14.5	7.6	243.1	20.3
Stops per Min	9.0	69.2	8.6	2.1	13.9	6.6	8.7	37.9	15.0	12.4	9.9	12.1	205.5	17.1
Stops per min	2.3	7.5	2.6	3.8	5.4	12.7	17.5	2.1	7.9	7.8	12.7	6.7	88.8	7.4
% PROD per min	1401.0	1950.4	1968.2	2149.7	2704.3	1619.5	2247.3	1496.2	1834.7	2082.7	1823.0	2126.9	23404.1	1950.3
Time per Min	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1200.0	100.0
Av. Downti	12.1	29.0	9.0	8.6	9.4	14.3	23.0	23.6	15.5	13.5	12.4	8.8	179	179.14

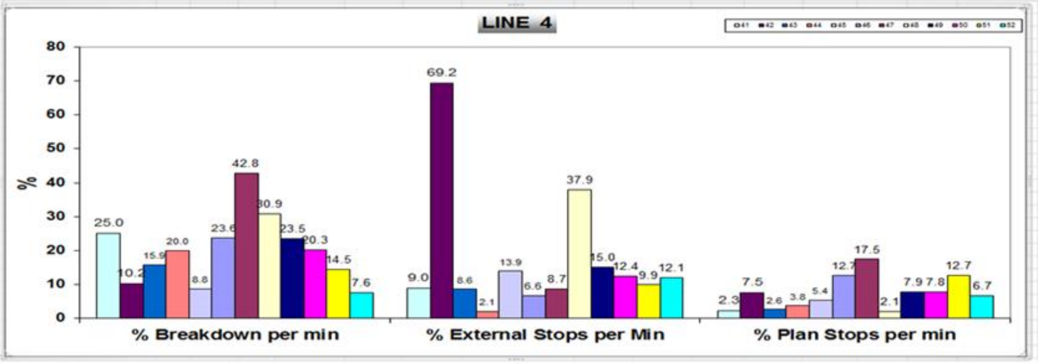
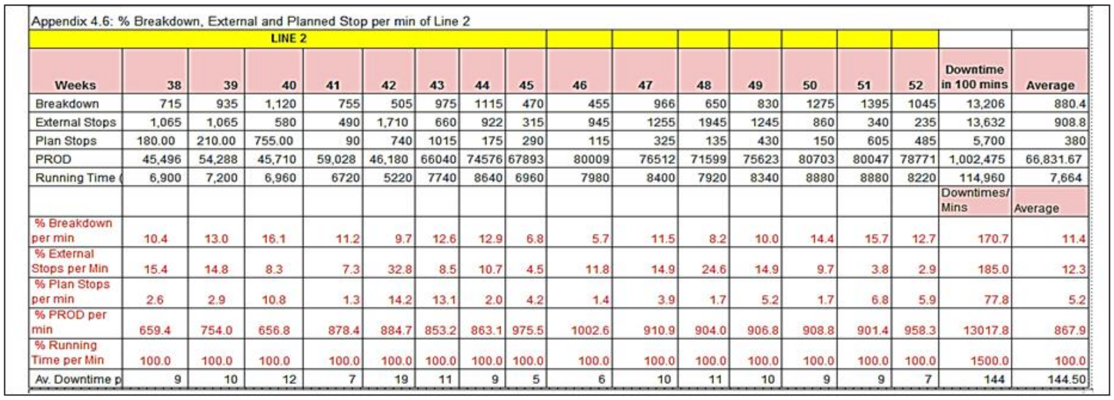


Chart 6. Graphical weekly downtimes of Line 4

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



Appendix 4.6: % Breakdown, External and Planned Stop per min of Line 2

LINE 2

Weeks	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	Downtime in 100 mins	Average
Breakdown	715	935	1,120	755	505	975	1115	470	455	966	650	830	1275	1395	1045	13,206	880.4
External Stops	1,065	1,065	580	490	1,710	660	922	315	945	1255	1945	1245	860	340	235	13,632	908.8
Plan Stops	180.00	210.00	755.00	90	740	1015	175	290	115	325	135	430	150	605	485	5,700	380
PROD	45,496	54,288	45,710	59,028	46,180	66040	74576	67893	80009	76512	71599	75623	80703	80047	78771	1,002,475	66,831.67
Running Time (	6,900	7,200	6,960	6720	5220	7740	8640	6960	7980	8400	7920	8340	8880	8880	8220	114,960	7,664
																Downtimes/ Mins	Average
% Breakdown per min	10.4	13.0	16.1	11.2	9.7	12.6	12.9	6.8	5.7	11.5	8.2	10.0	14.4	15.7	12.7	170.7	11.4
% External Stops per Min	15.4	14.8	8.3	7.3	32.8	8.5	10.7	4.5	11.8	14.9	24.6	14.9	9.7	3.8	2.9	185.0	12.3
% Plan Stops per min	2.6	2.9	10.8	1.3	14.2	13.1	2.0	4.2	1.4	3.9	1.7	5.2	1.7	6.8	5.9	77.8	5.2
% PROD per min	659.4	754.0	656.8	878.4	884.7	853.2	863.1	975.5	1002.6	910.9	904.0	906.8	908.8	901.4	958.3	13017.8	867.9
% Running Time per Min	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1500.0	100.0
Av. Downtime p	9	10	12	7	19	11	9	5	6	10	11	10	9	9	7	144	144.50

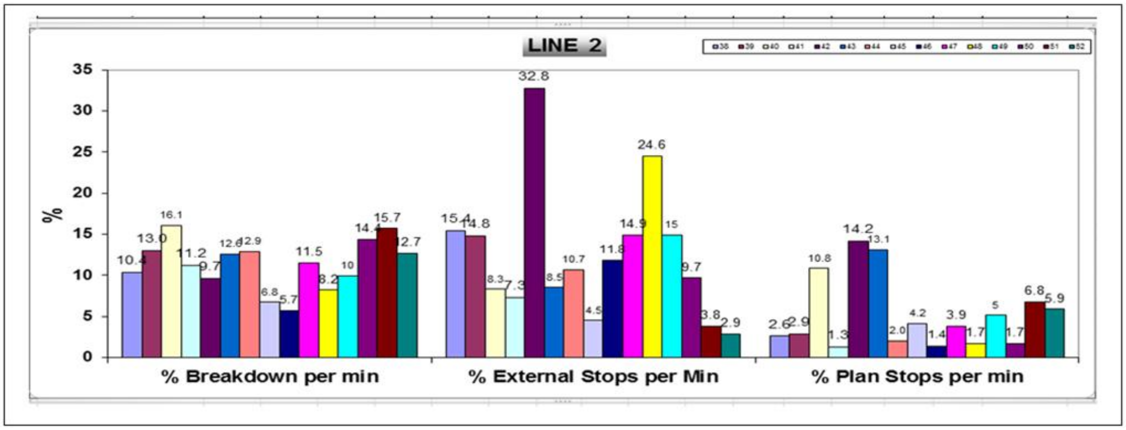
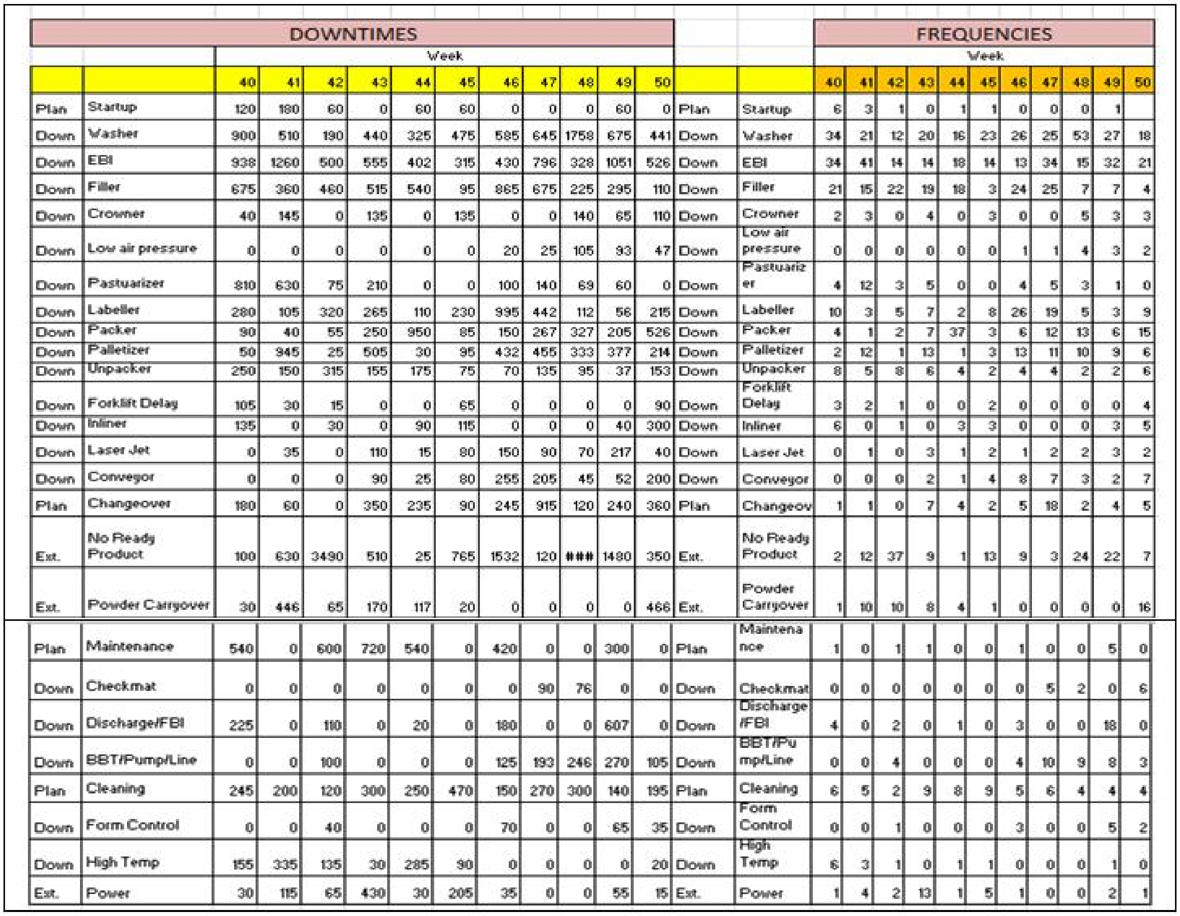


Chart 7. Graphical weekly downtimes of line 2

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



DOWNTIMES												
		Week										
		40	41	42	43	44	45	46	47	48	49	50
Plan	Startup	120	180	60	0	60	60	0	0	0	60	0
Down	Washer	900	510	190	440	325	475	585	645	1758	675	441
Down	EBI	938	1260	500	555	402	315	430	796	328	1051	526
Down	Filler	675	360	460	515	540	95	865	675	225	295	110
Down	Crowner	40	145	0	135	0	135	0	0	140	65	110
Down	Low air pressure	0	0	0	0	0	0	20	25	105	93	47
Down	Pastuarizer	810	630	75	210	0	0	100	140	69	60	0
Down	Labeller	280	105	320	265	110	230	995	442	112	56	215
Down	Packer	90	40	55	250	950	85	150	267	327	205	526
Down	Palletizer	50	945	25	505	30	95	432	455	333	377	214
Down	Unpacker	250	150	315	155	175	75	70	135	95	37	153
Down	Forklift Delay	105	30	15	0	0	65	0	0	0	0	90
Down	Inliner	135	0	30	0	90	115	0	0	0	40	300
Down	Laser Jet	0	35	0	110	15	80	150	90	70	217	40
Down	Conveyor	0	0	0	90	25	80	255	205	45	52	200
Plan	Changeover	180	60	0	350	235	90	245	915	120	240	360
Ext.	No Ready Product	100	630	3490	510	25	765	1532	120	###	1480	350
Ext.	Powder Carryover	30	446	65	170	117	20	0	0	0	0	466
Plan	Maintenance	540	0	600	720	540	0	420	0	0	300	0
Down	Checkmat	0	0	0	0	0	0	0	90	76	0	0
Down	Discharge/FBI	225	0	110	0	20	0	180	0	0	607	0
Down	BBT/Pump/Line	0	0	100	0	0	0	125	193	246	270	105
Plan	Cleaning	245	200	120	300	250	470	150	270	300	140	195
Down	Form Control	0	0	40	0	0	0	70	0	0	65	35
Down	High Temp	155	335	135	30	285	90	0	0	0	0	20
Ext.	Power	30	115	65	430	30	205	35	0	0	55	15

		FREQUENCIES										
		Week										
		40	41	42	43	44	45	46	47	48	49	50
Plan	Startup	6	3	1	0	1	1	0	0	0	1	
Down	Washer	34	21	12	20	16	23	26	25	53	27	18
Down	EBI	34	41	14	14	18	14	13	34	15	32	21
Down	Filler	21	15	22	19	18	3	24	25	7	7	4
Down	Crowner	2	3	0	4	0	3	0	0	5	3	3
Down	Low air pressure	0	0	0	0	0	0	1	1	4	3	2
Down	Pastuarizer	4	12	3	5	0	0	4	5	3	1	0
Down	Labeller	10	3	5	7	2	8	26	19	5	3	9
Down	Packer	4	1	2	7	37	3	6	12	13	6	15
Down	Palletizer	2	12	1	13	1	3	13	11	10	9	6
Down	Unpacker	8	5	8	6	4	2	4	4	2	2	6
Down	Forklift Delay	3	2	1	0	0	2	0	0	0	0	4
Down	Inliner	6	0	1	0	3	3	0	0	0	3	5
Down	Laser Jet	0	1	0	3	1	2	1	2	2	3	2
Down	Conveyor	0	0	0	2	1	4	8	7	3	2	7
Plan	Changeov	1	1	0	7	4	2	5	18	2	4	5
Ext.	No Ready Product	2	12	37	9	1	13	9	3	24	22	7
Ext.	Powder Carryover	1	10	10	8	4	1	0	0	0	0	16
Plan	Maintenance	1	0	1	1	0	0	1	0	0	5	0
Down	Checkmat	0	0	0	0	0	0	0	5	2	0	6
Down	Discharge /FBI	4	0	2	0	1	0	3	0	0	18	0
Down	BBT/Pump/Line	0	0	4	0	0	0	4	10	9	8	3
Plan	Cleaning	6	5	2	9	8	9	5	6	4	4	4
Down	Form Control	0	0	1	0	0	0	3	0	0	5	2
Down	High Temp	6	3	1	0	1	1	0	0	0	1	0
Ext.	Power	1	4	2	13	1	5	1	0	0	2	1

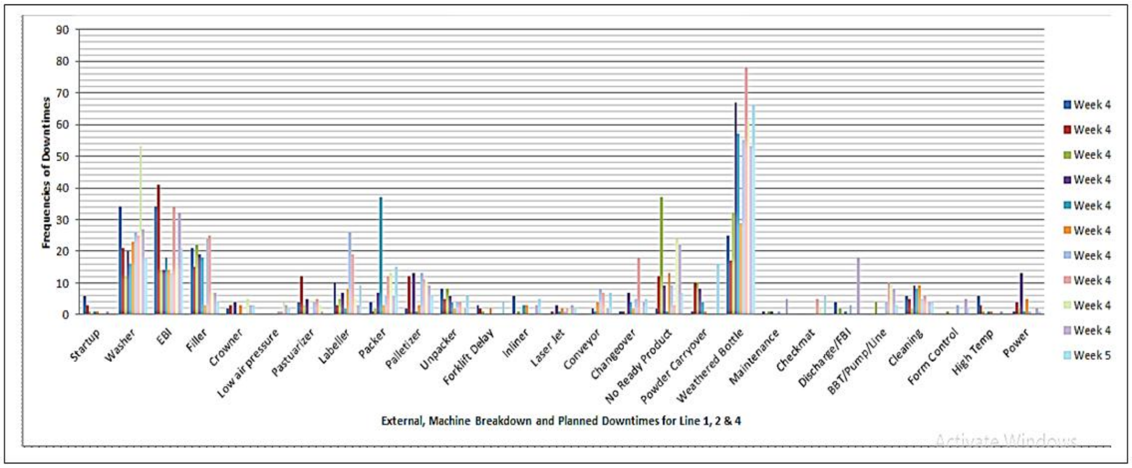


Chart 8. Graphical representation of weekly frequencies of downtimes

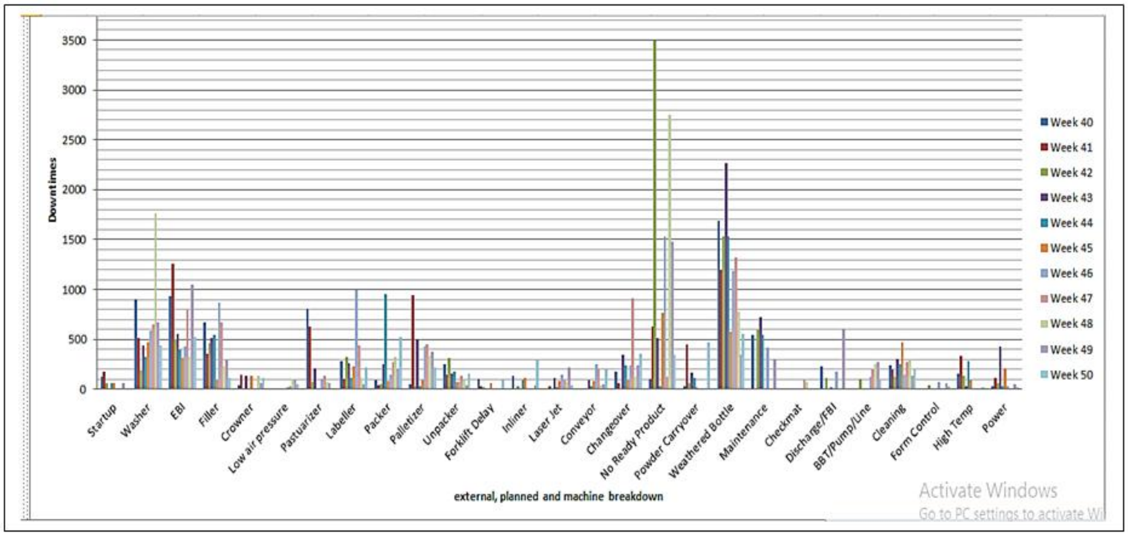


Chart 9. Graphical representation of weekly downtimes of components of machine, planned and external downtimes

7.6 Pareto Analysis Result

Table 9. 4M downtimes analysis result of line 4

Week 40-50 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%	

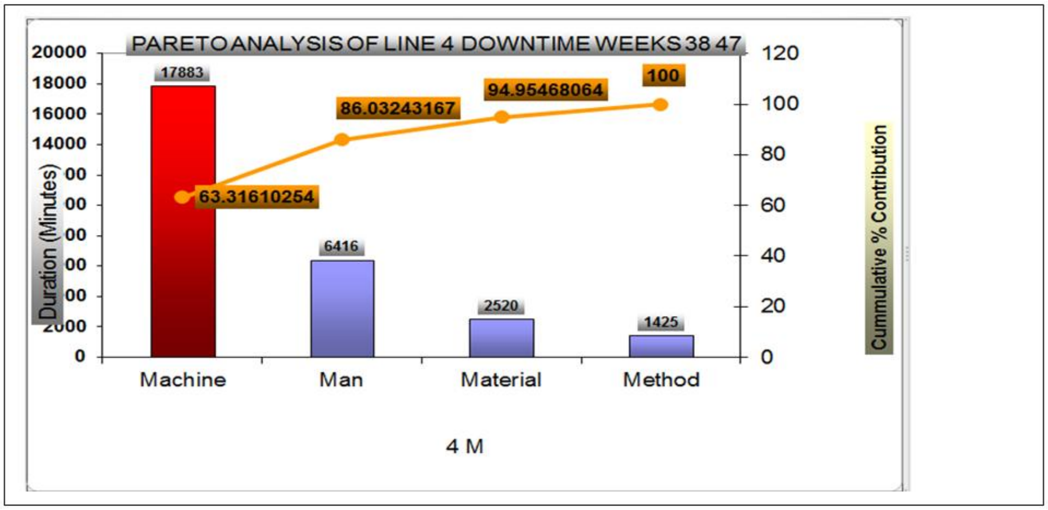


Chart 10. Pareto analysis of line 4

Table 10. 4M downtime analysis result of line 2

Week 40-50 of line 2				
S/N	4M	Total downtime	% Contribution	% Cumulative contribution
1	Material	11,230	39.75%	39.75%
2	Machine	10,041	35.54%	75.29%
3	Method	4,725	16.72%	92.01%
4	Man	2,257	7.99%	100.00%
	Total	28,253	100%	

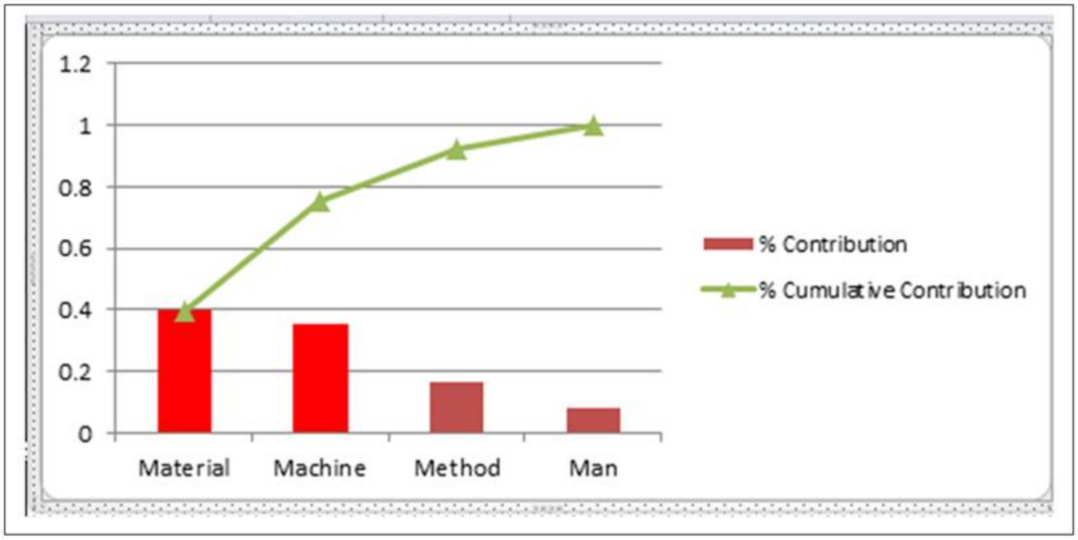
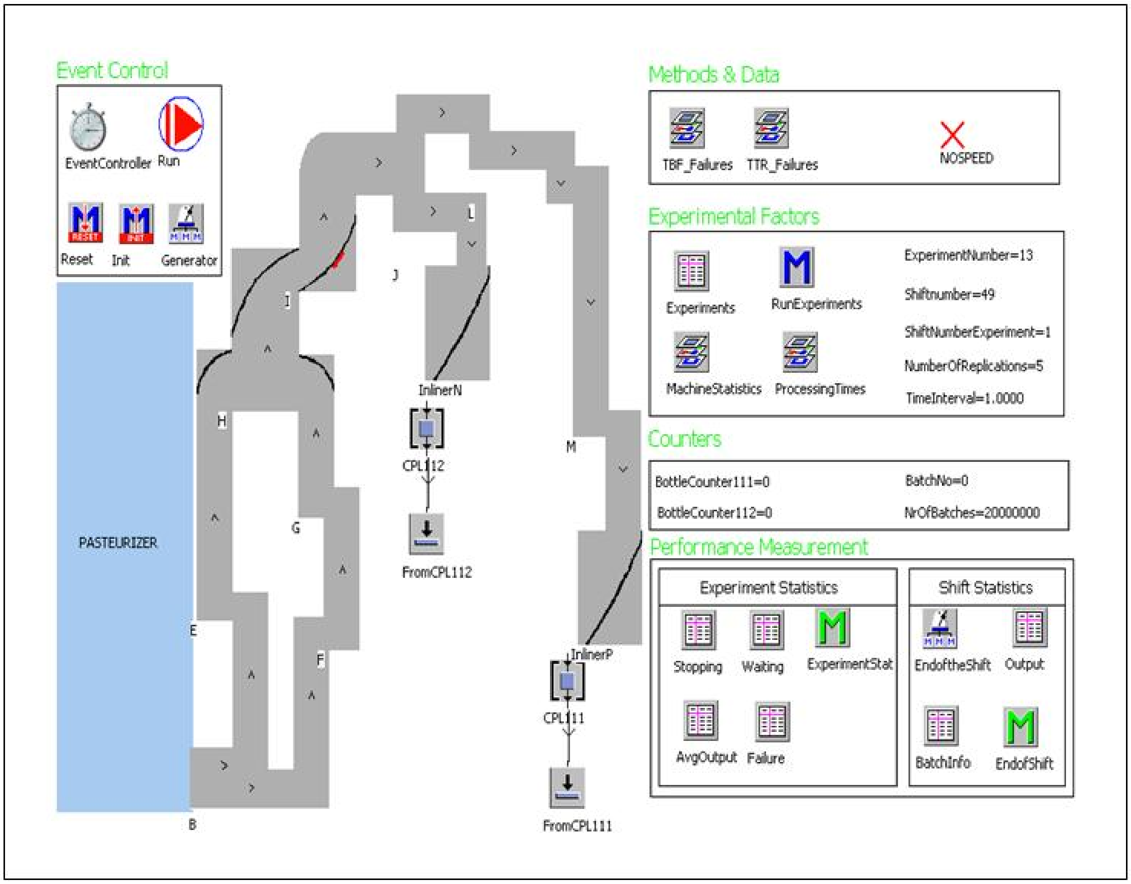


Chart 11. Pareto analysis result of line 2

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. Tecnomatrix 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 Tecnomatrix 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.



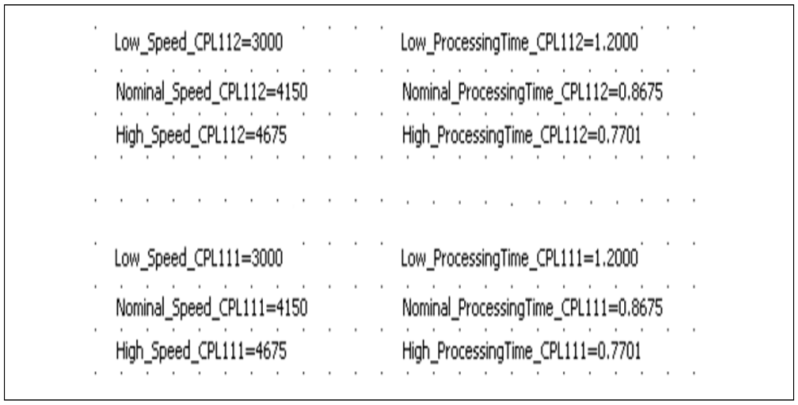
ExperimentNumber=13
Shiftnumber=49
ShiftNumberExperiment=1
NumberOfReplications=5
TimeInterval=1.0000

BottleCounter111=0
BottleCounter112=0
BatchNo=0
NrOfBatches=2000000

Fig. 1. Print screen of the developed Tecnomatrix plant simulation software

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.



Low_Speed_CPL112=3000
Nominal_Speed_CPL112=4150
High_Speed_CPL112=4675

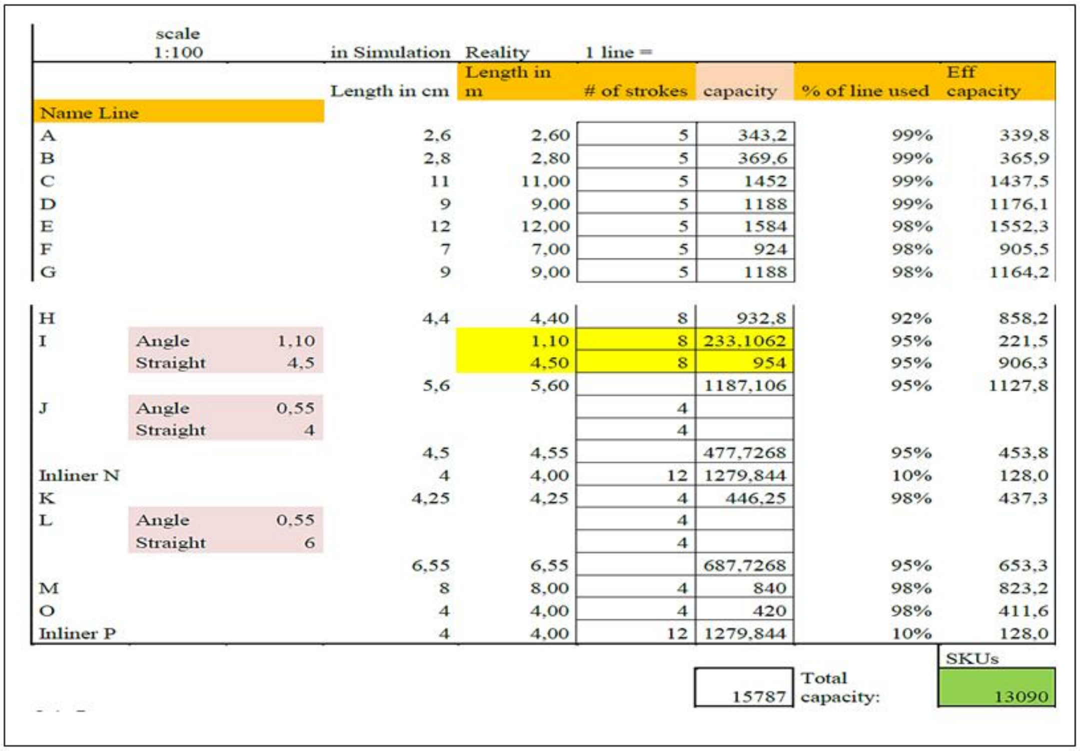
Low_ProcessingTime_CPL112=1.2000
Nominal_ProcessingTime_CPL112=0.8675
High_ProcessingTime_CPL112=0.7701

Low_Speed_CPL111=3000
Nominal_Speed_CPL111=4150
High_Speed_CPL111=4675

Low_ProcessingTime_CPL111=1.2000
Nominal_ProcessingTime_CPL111=0.8675
High_ProcessingTime_CPL111=0.7701

Fig. 2. Production output (bottles) per hour and processing time (hrs) for Labeller CPL 112 and CPL 111

Table 11. Conveyor capacities parameters



	scale 1:100		in Simulation	Reality	1 line =			
			Length in cm	Length in m	# of strokes	capacity	% of line used	Eff capacity
Name Line								
A			2,6	2,60	5	343,2	99%	339,8
B			2,8	2,80	5	369,6	99%	365,9
C			11	11,00	5	1452	99%	1437,5
D			9	9,00	5	1188	99%	1176,1
E			12	12,00	5	1584	98%	1552,3
F			7	7,00	5	924	98%	905,5
G			9	9,00	5	1188	98%	1164,2
H			4,4	4,40	8	932,8	92%	858,2
I	Angle	1,10		1,10	8	233,1062	95%	221,5
	Straight	4,5		4,50	8	954	95%	906,3
			5,6	5,60		1187,106	95%	1127,8
J	Angle	0,55			4			
	Straight	4			4			
			4,5	4,55		477,7268	95%	453,8
Inliner N			4	4,00	12	1279,844	10%	128,0
K			4,25	4,25	4	446,25	98%	437,3
L	Angle	0,55			4			
	Straight	6			4			
			6,55	6,55		687,7268	95%	653,3
M			8	8,00	4	840	98%	823,2
O			4	4,00	4	420	98%	411,6
Inliner P			4	4,00	12	1279,844	10%	128,0
								SKUs
						15787	Total capacity:	13090

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.

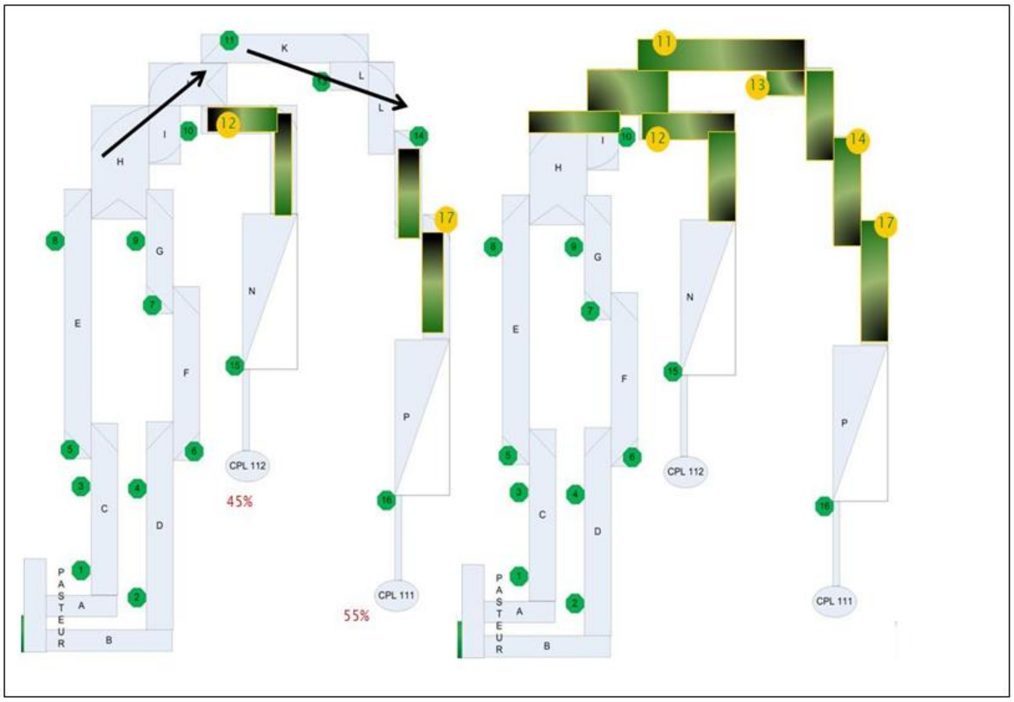


Fig. 3. Result of the model built to balance the output of the two Labellers

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)

	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**	**Total**	**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**	**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	0,00	0,00
5	444508	57%	43%	0,82	38,79	0,00	0,00
6	453103	53%	47%	0,01	30,61	0,00	0,00
7	439100	62%	38%	2,45	0,00	22,20	48,17
8	379278	23%	77%	0,03	1,39	76,64	9,41
9	408198	31%	69%	0,00	1,34	66,44	12,25
10	449990	58%	42%	2,90	8,77	0,00	19,71
11	430915	57%	43%	0,78	34,63	0,00	2,46
12	444338	54%	46%	0,08	33,33	0,00	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%
1st	6	453103	53%	47%
2nd	10	449990	58%	42%
3RD	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	NOSPEED	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.

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.
- *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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. HNS Visie. HNS Nieuws Special (pp. 1-12). Zoeterwoude: Heineken Nederland Supply, 2011; 2015.

2. Godwin et al. Optimum maintenance strategy for paint manufacturing industries: A case study. International Journal of Advanced Engineering Technology; 2013.
3. Subramaniam SK, Husin SH, Yusop Y, Hamidon AH. Machine efficiency and man power utilization on production lines. Proceedings of the 6th WSEAS International Conference on Circuits, Systems, Electronics, Control & Signal Processing (CSECS'07) World Scientific and Engineering Academy and Society, 29-31 December. 2007;185-190.
4. Parmenter D. Key performance indicators (KPI): Developing, implementing, and using winning KPIs. John Wiley & Sons; 2010.
5. De Ron A, Rooda J. OEE and equipment effectiveness: OEE revisited. Semiconductor Manufacturing, IEEE Transactions. 2006;18(1):190-196.
6. Neely AD. The performance measurement revolution: Why now and what next? International Journal of Operations & Production Management. 1999;19(2):205-228.
7. Rahman S. Theory of constraints: A review of the philosophy and its applications. International Journal of Operations & Production Management. 1998;18(4):336-355.
8. Kegg RL. The development of sensors for manufacturing automation, manufacturing control and monitoring. Computers in Industry. 1990;123-129.
9. Mahalik NGPC, Lee SK. A study on production line automation with Lon Works control networks. Computer Standards & Interfaces. 2001;21-27.
10. Härte FL. Efficiency analysis of packaging lines. Delft University Press; 1997.
11. Shannon R. Systems simulation: The art and science. Upper Saddle River, New Jersey: Prentice-Hall; 1975.
12. Law A. Simulation modeling and analysis. Europe: Mc-Graw-Hill Education; 2006.
13. Wein LM, Chevalier PB. A broader view of the job shop scheduling problem. Management Science. 1992;1018-1025.
14. Bastani AS. Analytical solution of closed-loop conveyor systems with discrete and deterministic material flow. European Journal of Operational Research. 1998;35: 187-192.
15. Proceedings of the 2014 Winter Simulation Conference Tolk S, Diallo Y, Ryzhov IO, Yilmaz L, Buckley S, Miller JA, eds.
16. Kwo TT. A theory of conveyors. Management Science. 1958;5(1):51-71.
17. Muth EJ. Analysis of closed-loop conveyor systems; the distribution flow case. AIIE Transactions. 1974;6(1):73-83.
18. Banks J. Handbook of simulation. Library of Congress Cataloging in Publication data, Copywright by John Wiley & Sons; 1998.
19. Nakajima S. Continuous improvement in operations. Cambridge, MA: Productivity Press; 1991.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/24376