2025 Volume: 01 Issue: 07 www.ijrpa.com ISSN 2456-9995 Research Article

International Journal Research Publication Analysis

Page: 01-56

PRODUCTION OPTIMIZATION IN BREWERIES: A COMPREHENSIVE ANALYSIS OF OPERATIONS MANAGEMENT PRACTICES

Chinedu James Ujam*

Department of Mechatronics Engineering, Federal University Otuoke, Bayelsa State, Nigeria.

Article Received: 13 November 2025
Article Revised: 03 December 2025
Published on: 23 December 2025

***Corresponding Author: Chinedu James Ujam**

Department of Mechatronics Engineering, Federal UniversityOtuoke, Bayelsa State, Nigeria.

DOI: https://doi-doi.org/101555/ijrpa.5658

ABSTRACT

The global beverage industry, a key player in the global beverage sector, is under increasing pressure to optimize production processes due to rising competition, evolving consumer preferences, and environmental concerns. This study explores the impact of operations management practices on production optimization within the brewery industry, focusing on key strategies such as lean manufacturing, Total Quality Management (TQM), and Just-In-Time (JIT). The research highlights how these practices impact production processes, cost management, quality control, and overall performance. The findings suggest that integrating effective operations management practices leads to enhanced productivity, reduced waste, and improved product quality, thereby boosting operational efficiency. The study contributes to understanding the critical role of operations management in optimizing production processes and highlights the benefits of system optimization. The study evaluates the operations management practices employed in the brewery industry and their impact on production performance, identifying key practices and challenges while providing actionable recommendations for optimization. The findings emphasize the importance of lean manufacturing, supply chain integration, and technological advancements in improving production efficiency and sustainability.

KEYWORDS: Operations Management, Production Optimization, Lean Manufacturing, Total Quality Management, Just-In-Time, Efficiency.

1.0 INTRODUCTION

The brewery industry is characterized by its complex production processes, reliance on raw agricultural materials, and stringent quality standards. To remain competitive, breweries must adopt operations management practices that enhance efficiency and reduce waste. This article examines how these practices influence production optimization, focusing on lean principles, technology integration, and workforce management. The study aims to provide a comprehensive understanding of effective strategies to address operational challenges and improve overall performance. In today's competitive manufacturing landscape, companies strive to achieve the highest level of efficiency in their production processes. Operations Management (OM) is central to this objective, focusing on managing resources, processes, and systems effectively. It encompasses strategies such as lean manufacturing, Total Quality Management (TQM), and Just-In-Time (JIT), all of which are aimed at optimizing production, reducing costs, and improving product quality. These practices not only enhance productivity but also play a crucial role in achieving long-term operational sustainability. This article provides an in-depth analysis of how OM practices contribute to production optimization. The purpose is to explore the relationship between these practices and their effect on operational performance, particularly in production settings. Heineken Nederland Supply Visie (2015, 2011) states that in competitive market more product brands will enter the market as customer demand is changing, volume of product demand is decreasing, new product is being introduced, fixed costs as well as variable costs are increasing, and customers expect the same service and quality at reduced price. Therefore, Companies must strive for optimization and continuous improvement of her production system performance and maintenance strategies in order to maximize the utilization of existing production line capacities, reduce operational cost, production wastages and improve on quality to stay ahead of competitors. The main goal is to improve the production management to maximize the existing production capacity. To achieve this, efficient operation management and preventive maintenance strategy must be optimized to minimize downtimes and increase performance and productivity while maintaining quality to achieve production target and customers satisfaction. According to the study done by Subramaniam, Husin, Yusop & Hamidon, (2007), the efficiency of industrial production system is crucial as it result in an improve production and utilization of available resources. Manpower utilization and machine efficiency contribute to production system efficiencies. Management should be able to look for relevant machine data and/or production data and accurately interpret the data in order to identify the various faults at production level and take step to improve efficiency. Effective operation management will minimize planned production stop and planned maintenance; reduce starvation, blockage, short failures and long failures. Lack of effective production management can result in production system inefficiency and low production performance Operations management should focus on the following; Improper regulated lines, line imbalance, conveyor/buffer strategy and sensors speed problems, production viability problem, operator's inefficiencies, machine running below the nominal speed, losses, machine breakdown, lack of efficient maintenance and Cleaning, Inspection, Lubrication and Tightening (CILT) implementation strategies. All these problems are the constraints that limit the efficiency of production system. Just as Rahman (1998) stated in theory of constraint that every system must have at least one constraint and that the existing constraints represent opportunities for improvement and that positive constraints 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 which might be underutilized as a result of mentioned constraints. Therefore these constraints form the focus of improving and optimizing the production processes of Companies, which lies on the throughput. The theory also encourages researchers to discover hidden bottlenecks, which will be an opportunity for improvement. Again, Ramdeen and Pun (2005) emphasized the need for the maintenance of production machineries and equipment and complete assurance of spare parts and raw material availability to the utilization of existing production capacities. This is another key important of this research in ensuring that optimized system is not starved of raw materials input and spare parts through effective operations management. Godwin and Achara (2013) carried out industrial based research showing how manufacturers are feeling the heat to hit their production targets in an increasingly competitive global market with heavy industries losing 30 to 40 percent of profits annually due to unplanned downtime occasioned by machine breakdown, failure and defect. In Companies, adopting preventive maintenance strategy and optimizing operations management is the key to reduce downtimes and increase the existing production capacities.

2.0 LITERATURE REVIEW

Operations management has been extensively studied as a critical determinant of production efficiency across industries. Lean manufacturing, as outlined by Womack et al. (1990), emphasizes waste reduction and process improvement, which are particularly relevant in breweries where raw material costs and energy consumption are significant concerns. Stevenson (2017) highlights the importance of supply chain management in maintaining production consistency and meeting customer demands.

Industrial technologies, including IoT and data analytics, have been recognized for their potential to revolutionize manufacturing processes (Schuh et al., 2017). Research by Deming (1986) underscores the role of workforce training and quality management in sustaining operational excellence. However, studies specific to breweries remain limited, underscoring the need for targeted research in this area.

Operations Management encompasses various practices that help optimize production. Some of the most influential practices include:

1. **Lean Manufacturing**: Developed by Toyota, lean manufacturing emphasizes waste reduction, continuous improvement, and value stream optimization. By eliminating non-value-added activities, lean practices aim to enhance operational efficiency. According to Womack and Jones (1996), the application of lean principles can lead to substantial reductions in inventory, lead time, and operating costs while improving product quality.
2. **Total Quality Management (TQM)**: TQM focuses on continuous improvement, customer satisfaction, and employee involvement in quality control. The practice emphasizes the importance of consistent quality at every stage of the production process. According to Deming (1986), the principles of TQM lead to a reduction in defects, rework, and scrap, resulting in higher productivity and improved customer satisfaction.
3. **Just-In-Time (JIT)**: JIT is a strategy that focuses on producing and delivering goods in the exact quantity needed and at the precise time required. By minimizing inventory and reducing waste, JIT helps companies achieve higher production flexibility and lower costs (Ohno, 1988). JIT is particularly beneficial in industries where demand is volatile, and production needs to be aligned with customer requirements.

4. **Six Sigma**: Six Sigma aims to reduce variability in processes to achieve near-perfect quality. By using data-driven methodologies, Six Sigma identifies defects and implements solutions to eliminate them. This results in more consistent production and enhanced operational efficiency (Pande, Neuman, & Cavanagh, 2000).

2.2.5 OEE/OPI Analysis

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

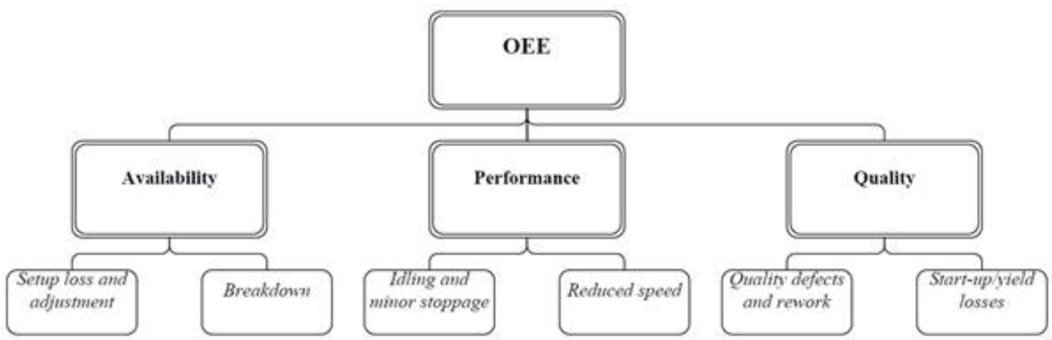

Figure 2.1: Relation Between OEE And Six Big Losses - (Chan, 2005).

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

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

OPI = Availability * Performance * Quality………….............(i)

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

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

$$Performance = \frac{\text{Production Time}}{\text{Operating Time}} \quad \text{.......................................(iii)}$$

$$Availability = \frac{\text{Operating Time}}{\text{Manned Time}} \quad \text{...(iv)}$$

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

Table 2.1: Detailed Description of OEE/OPI Calculation.

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

Starvation Time	Blockage Time	External stop	Speed losses and Minor stops	Reject and Rework
V	W	X	Y	Z
time conveyor fail to feed the subsequent machine	Time last machine is blocked from producing	External caused stop (no beer, no utility, no raw materials, power outage, etc)	speed less than nominal speed , minor stops <5mins	All quality defects, including products on hold and rework products

C	D	E	F	**G**
Total Time	Manned Time	Operating working time	Effective Working Time	**Available Production time**

=P+Q+R+S+T+U+V+W+X+Y+Z	=C-P	=D-Q	=E-R	=F-S-T

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

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

The Available

$$\text{Time} = \text{Total Time} - \text{unused time} - \text{nonteam maintenance} - \text{No order No activity} - \text{Changeover time} - \text{Planned downtime} - \text{Breakdown time}$$

……………..(v)

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

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

Machine Failure Behaviors

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

$$\text{MTTR} = Mean\ Time\ to\ Repair = \frac{Total\ Time\ Internal\ Failures}{Number\ of\ Internal\ Failures} \ldots\ldots\ (vi)$$

$$\text{MTBF} = Mean\ Time\ Between\ Failures = \frac{Total\ Running\ Time}{Number\ of\ Internal\ Failures} \ldots\ldots\ (vii)$$

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

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2.6 Total Productive Management (TPM) and Performance Measurement

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

2.6.1 Continuous improvement strategies and Performance Measure

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

Lean management

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

Variability Reduction

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

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

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

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

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

Hackman and Wageman (1995); Kenney and Florida,(1993) emphasized that **respect for workers** also is encouraged by the lean production/TQM practice of grouping workers into teams according to their production line or cell. It calls for the transfer of certain types of authority and responsibility (including inspection, trouble-shooting, statistical quality control, and equipment maintenance) to lower levels of the organization. Whereas Rinehart, Huxley and Robertson (1997) stated that production tasks under lean production usually are carried out by individuals teams of workers collaborate to attack quality problems and carry out lateral tasks. Teams take responsibility for quality and discipline members who do not perform tasks correctly and teams reallocate tasks when a member is injured or absent. Boyer (1996);; MacDuffie (1995a); McLachlin (1997); Sakakibara, Flynn, Morris and Schroeder (1997) discovered that team membership has been observed in lean production implementations to be a source of both supports. Rinehart et al., (1997) noted that the practice of decentralization of authority as discussed in the lean production literature consists primarily of the transfer of technical tasks rather than a true shifting of power.

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

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

Six Sigma

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

2.7 Maintenance Analysis

2.7.1 Total Productive Maintenance (TPM)

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

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

TPM pillars

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

Table 2.2: TPM Pillars (Ahuja & Khamba, 2008).

Pillar	Operational skills
Autonomous maintenance (AM)	Carry out CILT, adjustment and readjustment of production equipment to fostering operator ownership

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

CILT

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

2.7.2 Optimum Maintenance Strategy

Ramdeen and Pun, (2005) stated that the maintenance of production machinery and equipment and assurance of availability of spare parts are becoming increasingly important while manufacturers are finding it extremely difficult to hit their production targets in an increasingly competitive global market, to enable them maintain their edge and maximize their profits; they consider operational efficiency a top most priority. From research carried out by Godwin and

Achara (2013), some heavy industrial segments loss as much as 30 to 40 percent of profits annually due to unplanned downtime occasioned by machine breakdowns, failure and defects. The result of the Analysis of findings from the maintenance assessment throughout 2012 reveals a significant progressive increase in the cumulative equipment downtime hours which impacted on rising maintenance cost and drop in plant output across three paint industries. In Breweries industries, adopting maintenance strategy is a key to reduce frequent stoppage, breakdown, failure and longtime changeover, set up and adjustment; which is currently affecting production performance and output. The need for an optimum maintenance strategy cannot be over-emphasized as it offers a proactive and holistic approach to maintenance towards creating additional value in maintenance system for improved maintenance productivity. Kelly and Harris (1998) noted that optimum maintenance strategy entails ensuring the plant functions (availability, reliability, product quality etc); ensuring the plant reaches its design life; ensuring plant and environmental safety; ensuring cost effectiveness in maintenance and the efficient use of resources (energy and raw materials).

2.7.3 Problem identification techniques

Look out for Six Big Losses

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

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

Six Big Loss Category	**OEE Loss Category**	**Event Examples**	**Comment**
Breakdowns	Down Time Loss	▪ Tooling Failures ▪ Unplanned Maintenance ▪ General Breakdowns ▪ Equipment Failure	There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss) or minor stoppages.
Chang over, Setup and Adjustments	Down Time Loss	▪ Setup/Changeover ▪ Material Shortages ▪ Operator Shortages ▪ Major Adjustments ▪ Warm-Up Time	This loss is often addressed through setup time reduction programs.
Small Stops (Minor Stoppages)	Speed Loss	▪ Obstructed Product Flow ▪ Component Jams ▪ Misfeeds Sensor Blocked,	Stops that are under five minutes and that do not require maintenance personnel are minor stoppages,

		Delivery Blocked, Cleaning and Checking	which the root causes of this type of stops can be found.
Reduced Speed	Speed Loss	▪ Rough Running ▪ Under Nameplate Capacity ▪ Under Design Capacity ▪ Equipment Wear ▪ Operator Inefficiency	Anything that keeps the process from running at its theoretical maximum speed (a.k.a. Ideal Run Rate or Nameplate Capacity).
Startup Rejects	Quality Loss	▪ Scrap ▪ Rework ▪ In-Process Damage ▪ In-Process Expiration ▪ Incorrect Assembly	Rejects during warm-up, startup or other early production. May be due to improper setup, warm-up period, etc.
Production Rejects	Quality Loss	▪ Scrap, incorrect assembly ▪ Rework ▪ In-Process Damage	Rejects during steady-state production. Check out the root causes.

Changeover (C/O) Time

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

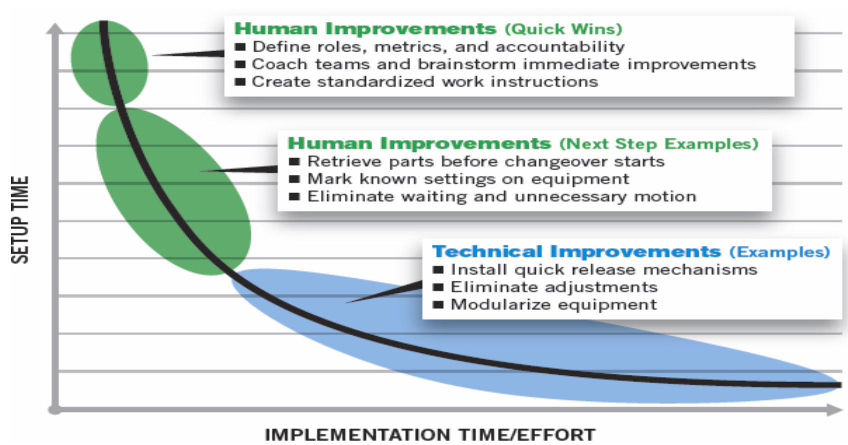


Figure 2.8: Step to Achieve Single Minute Exchange of Die (SMED).

5-Why?

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

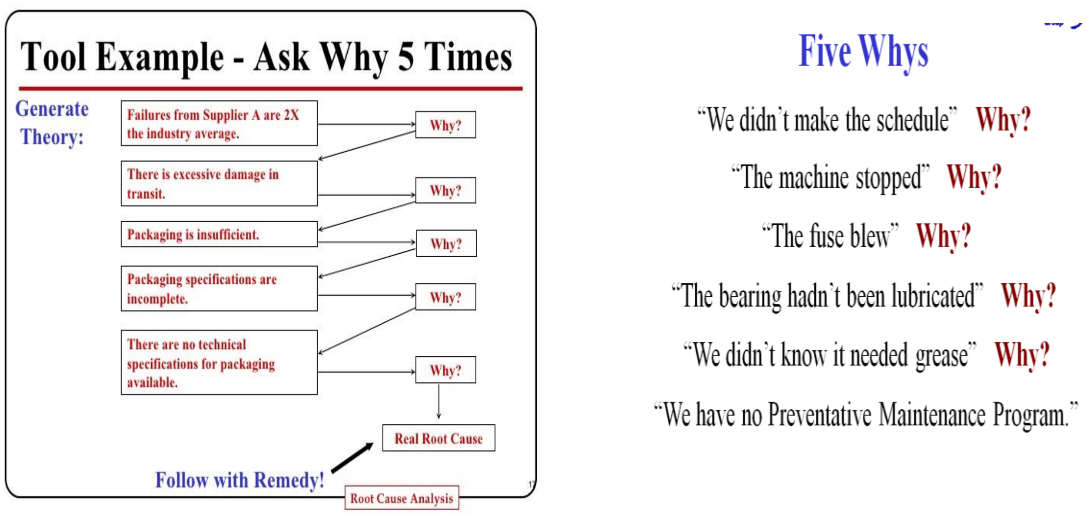


Figure 2.9: Example of Steps to Achieve 5 Why.

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

Fish Bone Diagram or Cause and Effect Diagram

Ishikawa or "fishbone" diagram (Cause and Effect Diagram) use graphical tool to expose the possible causes of a certain effect. Classic fishbone diagram is applied when causes group naturally under the categories of Materials, Methods, Machine, Environment, and Man. The benefit of Ishikawa Diagram includes but not limited to the following; It helps teams understand that there are many causes that contribute to an effect by graphically displaying the relationship of the causes to the effect and to each other. It also helps to identify areas for improvement in a production system with inherent problems. Figure 2.9 below is the graphical representation of Fish Bone Diagram.

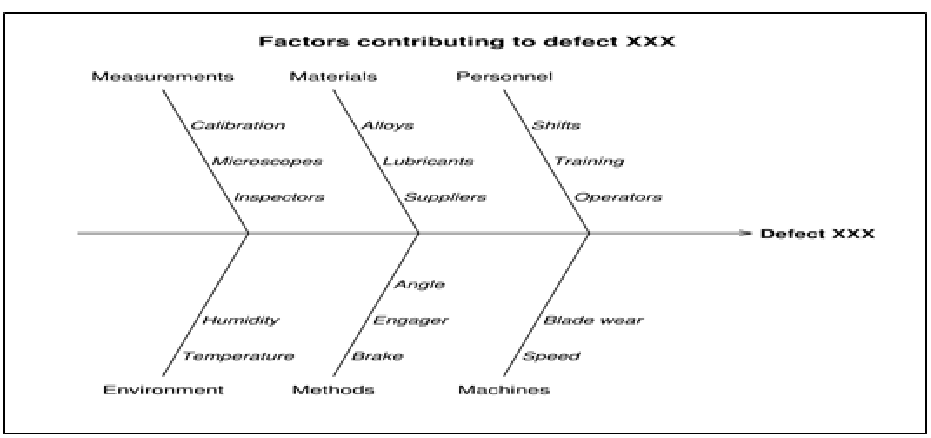


Figure 2.10: Fish Bone Diagram. Source: https://whatis.techtarget.com.

2.7.4 Problem Analysis Techniques

Pareto Analysis

Using the 80:20 Rule to Prioritize

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

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

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

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

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

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

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

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

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

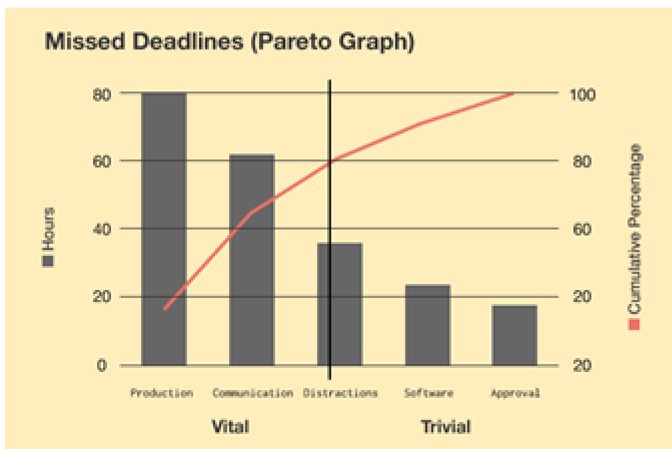


Figure 2.11: Pareto Analysis of Missed Deadline in Organization.

2.8 Conclusion/Research Contribution

Several literature have been written on efficiency of packaging lines and machines, continuous improvement and lean concept, maintenance strategies, simulation modeling of packaging lines, optimization of buffer but having discovered the importance of core machine in capacity utilization and its numerous inherent problems which further reduces its design capacity through this study, this research takes into accounts, in addition to literature review;

1. The study emphasis on the core machine and machines around it on the optimization process in addition to buffer capacity optimization.

2. The studies integrate CILT and Kaizen as part of optimization process for system robustness and reduction of downtimes occasioned by lack of strategic preventive maintenance after regulated line optimization.
3. It also emphasis the importance of operators efficiency at the core machine/machines around it and quality of raw material inputs to machines in increasing the capacity utilization of the available production capacity.
4. It considered not only machine and buffer efficiencies in the optimization process like the reviewed literature but also external and planned downtime reduction optimization to achieve system optimization holistically.
5. It considered the optimization of in-feed and discharge at core machine and the important of V-graph to discover the bottleneck, and use of design of experiment to discover the best speed of sensors to optimize machine speed levels, which will significantly reduce starvation and blockage of bottleneck and core machines, increase speed and production capacities. To achieve efficient and effective results, the research combined modeling, design of experiment, lean manufacturing, preventive maintenance strategies, and Kaizen tools to achieve overall improvement in production system performance.
6. There incorporation of tools for easy analysis and performance tracking which the literature is not captured. The excel spreadsheet developed is a unique tool that will enhance data analysis and record tracking.

Previous studies indicate that when these practices are effectively integrated, they lead to substantial improvements in production optimization. For instance, Singh et al. (2013) demonstrated that a combination of lean, TQM, and JIT led to significant reductions in production costs and improvements in product quality.

RESULTS

The analysis of case studies and performance metrics reveals several key findings regarding the impact of OM practices on production optimization:

1. Improved Production Efficiency: Companies that implemented lean manufacturing experienced substantial improvements in production efficiency. For example, a manufacturing plant in the automotive industry reduced its cycle time by 25% after adopting lean principles.

Similarly, JIT practices contributed to faster turnaround times and more responsive production schedules.

2. **Cost Reduction**: Firms that integrated JIT and lean manufacturing saw significant cost reductions due to decreased waste and inventory costs. One electronics manufacturer reduced its material costs by 15% through the application of JIT inventory practices.

3. **Enhanced Quality Control**: The integration of TQM principles resulted in improved product quality and consistency. A consumer goods company that adopted TQM saw a 30% reduction in defects and a 20% improvement in customer satisfaction within the first year of implementation.

4. **Waste Reduction**: Lean manufacturing practices were particularly effective in reducing waste across various stages of production. For instance, a company in the food processing industry was able to reduce scrap material by 18% by eliminating non-value-added activities and optimizing production flow.

2.0. Evaluation and Results

To analyze the effect of OM practices on production optimization, this study follows a mixed-methods approach. First, a literature review is conducted to examine previous research and theoretical frameworks. This is supplemented by a case study analysis of companies that have implemented various OM practices. Interviews with operations managers, production supervisors, and quality control personnel are used to gather qualitative insights on the challenges and successes of adopting these practices. Quantitative data is collected through performance metrics such as production rate, defect rate, and cost reduction. The case studies focus on industries such as automotive, electronics, and consumer goods, where OM practices have been widely applied. Data is analyzed to assess the impact of these practices on production efficiency, quality, and waste reduction

2.1 Production System Analysis

The case studies of brewery Industries. Primary and secondary data were collected on operations managements of production system.

2.1.1 Static Data Collection

The static data of production lines from week 41 to week 51; the machine capacities, the configured machine speed levels, and the conveyor width, length and speed

2.1.2 Dynamic Data Collection

From week 41 to 51, the dynamic data of a production lines; Production Output, Production Running Time, Machine breakdown, External downtimes, Planned Downtimes, Machine speed change, Buffer fill grade. These data are collected automatically with Line Monitor System (LMS

2.1.3 Automatic data collection

The layers of the Line Monitor System (LMS) in figure 1 for automatic data collection on production lines gave insight into the functioning of the line and to improve its performance. An LMS has three tasks: monitoring, visualizing, and recording the line performance. The process of registration can consist of a host of counts, timers, signals etc. The machines and conveyors of a production line are each controlled by a so-called Programmable Logic Controller (PLC), a computer using a program code for the process tasks. The PLC's give signals or instructions to the machines. These PLC's are connected by a network. The signals of the PLC's are collected by the Supervisory Control And Data Acquisition (SCADA) system. This system visualizes the machine and line information on monitors for the operators. The operator also receives signals directly from the machines from different colour light bulbs or text displays. From the SCADA system the data is stored in a database. Dynamic data information can be collected through links with other computer systems or databases.

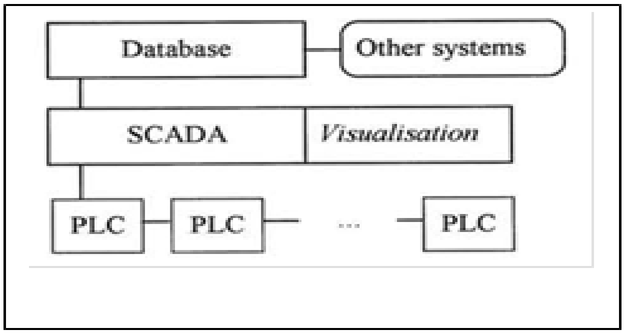


Figure 1: Layer of Data Monitor System.

2.1.4 Manual data collection

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

2.1.5 Line Parameter

Production line is a series system, with the machines or machine groups connected by conveyors/buffers. This is depicted in figure 2, in which the buffers upstream of the core machine were full and the buffers downstream were partly empty. The line efficiency was determined by the line parameters, which were formed by the machine parameters and the buffer parameters.

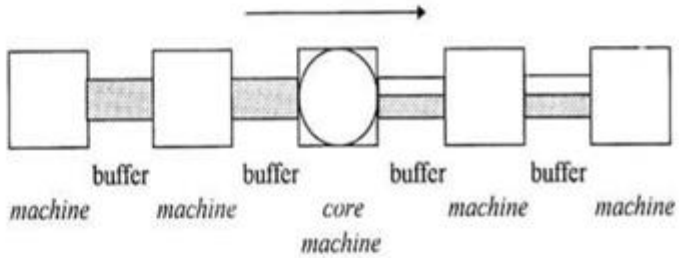


Figure 2: Packaging Line as series system.

2.1.6. 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:

$$\eta line = \frac{Net\ Production\ time}{Actual\ Production\ Time} * \frac{100\%}{1} \quad \text{.................................(i)}$$

$$\eta line = \frac{Net\ Production\ time}{Net\ Production\ time + Unplanned\ Downtime} * \frac{100\%}{1} \ldots\ldots\ldots\ldots\text{(ii)}$$

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

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

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

2.1.7. Machine Parameter

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

Machine states are as follows

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

2.1.8 Machine Failure Behaviors

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

$$\text{MTTR} = Mean\ Time\ to\ Repair = \frac{Total\ Time\ Internal\ Failures}{Number\ of\ Internal\ Failures} \text{...........(i)}$$

$$\text{MTBF} = Mean\ Time\ Between\ Failures = \frac{Total\ Running\ Time}{Number\ of\ Internal\ Failures} \text{.......(ii)}$$

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

2.1.9 Machine Efficiency

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

$$ŋ\text{machine} = \frac{Total\ Running\ Time}{Total\ Running\ Time + Total\ Time\ Internal\ Failure} * \frac{100\%}{1} \text{.........(i)}$$

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

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

2.2.0 Machine Production Rate

Machine speed (V_{mach}) = $\frac{Production\ Output}{Production\ Running\ Time}$..................(i)

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

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

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

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

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

Nominal/line capacity (C_{line}.): The nominal line capacity is the smallest machine (group) capacity for the specific product, i.e. the capacity of the core machine (group) for the specific product.

These production rate parameters are very important in the optimization problem. It is used to plot V-graphs to determine the preceding and succeeding machines around core machine.

3.0 Method of Analysis of production line, machine and buffers

3.1.0 Buffer Performance Strategy

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

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

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

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

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

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

Where

Line production rate $\boldsymbol{R^{low}} = Machines\ of\ minimum\ C^{mach}$........(iii)

Line Availability = $\boldsymbol{A^{low}} = \prod_{machine} \eta_{line}$..............(iv)

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

Upper limit = $\eta_{\mathrm{line}}^{\infty}$ = Machines of minimum MER_{mach}.......(v)

Where

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

The line efficiency is

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

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

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

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

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

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:

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

Figure 3. Shows the seven machines of a (series system) packaging line. The Pasteurizer and Filler are considered as the core machines. The buffer upstream of this machine is full and the buffers downstream are partly empty.

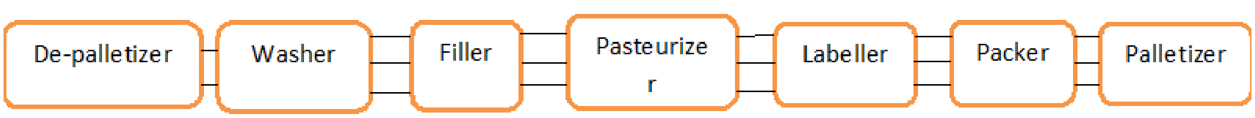


Figure 3: Component of Packaging Line.

Table 1 shows the data from the calculation of the machine capacities as a percentage with respect to the core machine (Filler), Machine Efficiencies and Machine MER.

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	98	99

3	Filler	100	98	98
4	Pasteurizer	100	99	99
5	Labeller	125	95	119
6	Packer	130	93	121
7	Palletizer	135	96	130

The lower and upper limits are shown in table 3.2: Real efficiency for the period was η_{line} = 87% the resulting buffer performances is 89%

Applying equation (IV): Buffer Performance Strategy ß $= \frac{\eta_{line} - \eta_{line}^{0}}{\eta_{line}^{\infty} - \eta_{line}^{0}} * 100\%$.........(i)

From 2, Buffer Performance Strategy is calculated.

Table 2: Lower and Upper efficiency limit and buffer performance.

Lower limit			Upper limit	Buffer strategy performance
R^{low}	A^{low}	η_{line}^{0}	η_{line}^{∞}	ß
100%	78%	78%	98%	89%

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

Accumulation rate=$\frac{T_{acc}^{nom}}{MTTR_A} = \frac{Accumulation\ Capacity\ in\ bottles}{C_B^{nom} * MTTR_A}$………(i)

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

Nominal recovery rate=$\frac{MTBF_A * (C_A - C_B^{nom})}{C_B^{nom} * T_{acc}^{nom}}$**…………….(ii)**

Mean recovery rate=$\frac{MTBF_A * (C_A - C_B^{nom})}{C_B^{nom} * MTTR_A}$ **……..............(iii)**

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

Buffer Efficiency $\eta_{Buffer}^{AB} = \frac{(T_{Stop}^{A} - T_{Starve}^{B})}{T_{Stop}^{A}}$ ....**(iv)**

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

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

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

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

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

3.1.1 Machine Efficiency Analysis

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

Goal

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

Data

The data needed for the machine event summary table are:

• Total time that a machine was in each of its possible machine states,

• Number of occurrences of each machine state,

• Minimum, average and maximum event duration for each machine state

• Standard error of the event duration

The data needed for the machine pie chart are

• Total time that a machine was in each of its possible machine states.

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

The data needed for the machine efficiency are

• Total time that the machine was running

• Total time that the machine had an internal failure

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

Table 3: 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 = $\frac{Running\ Time}{Running\ Time + Internal\ machine\ failure} = \frac{22163}{22163+1354}$ = 94%..........(vi)

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

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

3.1.3 V-graph Analysis

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

Goal

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

Data

The data needed to create the V-graph are:

• Line component system, i.e. a description of the machines of the line and where they are connected.

• Machine capacities for each machine

• Mean Effective Rate (MER) of each machine, or machine efficiency of each machine to calculate the MERs

Mean Effective Rate ($MER_{mach} = \eta_{mach} * C^{mach}$……………….(i)

Where η_{mach} is machine efficiency

C^{mach}=machine capacities

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

Machine state bar segment $= \frac{Total\ Time\ of\ Machine\ State}{Total\ Time\ of\ Period\ Specified} * Machine\ Capacity$……..(ii)

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

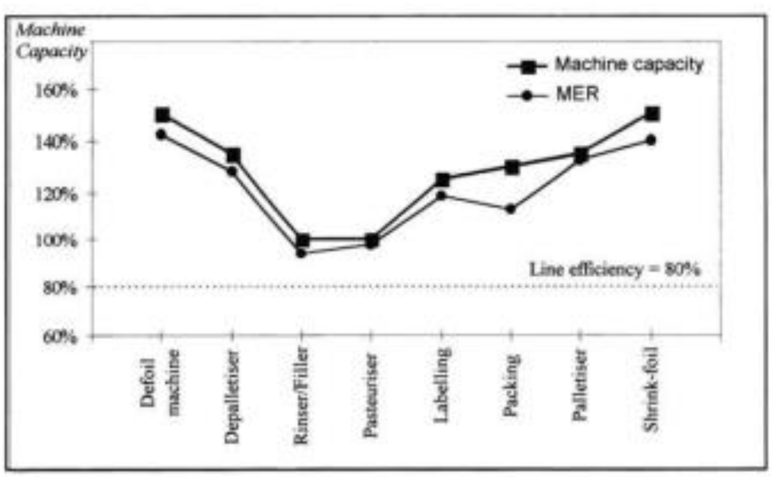


Figure 4: V-graph: Machine capacities, MER and Line efficiency.

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

3.1.4 Statistical Analysis

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

Pareto Analysis

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

Cause and Effect Analysis

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

Correlation Analysis

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

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

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

Coefficient of Determination r^2

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

.

Performance Measurement

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

OEE/OPI Calculation

OEE = Availability x Performance x Quality.......(i)

Availability $= \frac{Running\ Time}{Total\ Time} * 100\%$..................(ii)

Performance $= \frac{Total\ Count}{Target\ Count} * 100\%$..................(iii)

Quality $= \frac{Good\ Count}{Total\ Count} * 100\%$...........................(iv)

OEE $= \frac{Final\ Machine\ Run\ Time}{Planned\ Machine\ Run\ Time} * 100\%$...............(v)

OPI Analysis

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

4.1.2.2 Dynamic Data Analysis Result and Discussion

Production output against running time result

Appendix 4.1-4.4 and Figure 4.10 to Figure 4.13 show the result of production output against running time of week 30 to 51 data analysis. These are carried out to establish the relationship between production output and running time to enable us analysis the result of the low production output against running time.

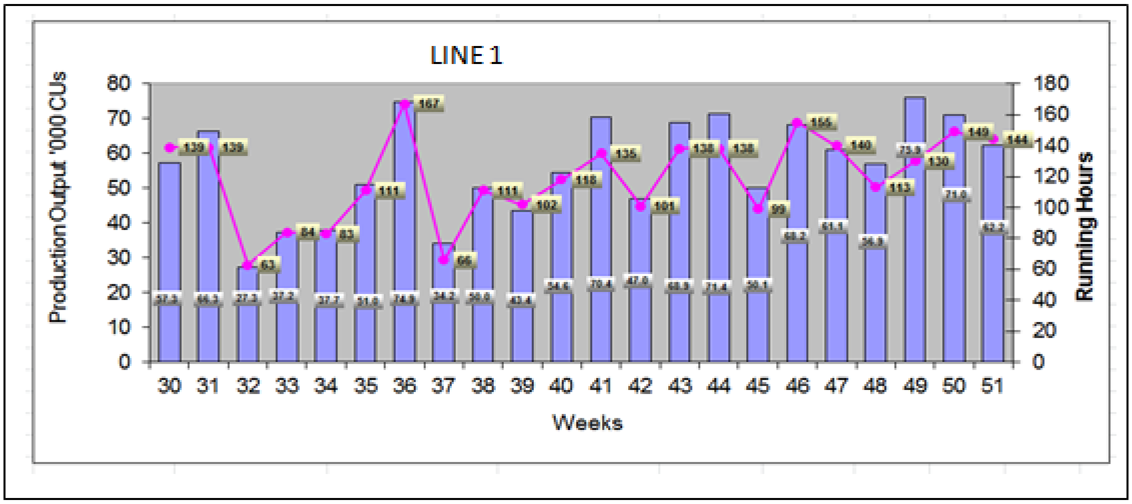


Figure 4.10: Production Output against Running Time of Line 1.

Dynamic Data Analysis Result Discussion

Production Output against Running Time Result: Appendix 4.1-4.3 of Line 1, 2 and 4 show individual line production output result against running time, while Appendix 4.4 show the combined production output of Line 1, 2& 4 against running time. Figure 4.10 to Figure 4.13 gave the result of production output against the production running time. Figure 4.10 of Line 1, week 49 recorded 584 cartons per hour while week 30 recorded 412 cartons per hour as the highest and lowest production per hour respectively. The standard deviation is 41 cartons per hour, with an average of 470 cartons per hour for the 22 weeks productions. The range of hourly production was 172 cartons. Figure 4.11 of Line 2, week 46 recorded 602 cartons per hour while week 32 recorded 394 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 58 cartons per hour, with an average of 511 cartons per hour for the 22 weeks productions. The range of hourly production was 208 cartons. Figure 4.12 of Line 4, week 45 recorded 1,623 cartons per hour while week 36 recorded 464 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 316 cartons per hour, with an average of 1,005 cartons per hour for the 16 weeks productions. The range of hourly production was 1,159 cartons. Combined production output against running time was analyzed in Figure 4.13 of Line 1, 2, & 4, week 51 recorded 295 cartons per hour while week 33 recorded 71 cartons per hour as the highest and lowest production per hour respectively. The standard deviation was 80 cartons per hour, with an average of 189 cartons per hour for the 22 weeks productions. The range of hourly production was 224 cartons. From the analysis results of Line 1, 2 & 4, Production Line 1 & 2 has relatively low Standard deviation and range compared with line 4. Line 1 & 2 runs on regulated lines while line 4 runs on unregulated line. Speed loss was recorded more on line 1 & 2 while total downtime was very high in line 4 but productions was at its peak when machine was running. In unregulated line, machine can be producing at 100% or not producing at 0%, while in regulated lines, speed of machines automatically adjust its speed to cope with starvation, blockage and minor stoppages. It is now important to ascertain if there is proportionality or correlation between running time and production output to analyze production system problems that are causing high running time against production output in line 1 & 2 and high downtime on the part of line 4. Again, coefficient of determination was employed to determine the percentage of problems in correlation, which is known and that which is unknown. The next stage is to discuss the result of correlation analysis and coefficient of determination.

Correlation Analysis Result and Discussion

The main objective of the companies is to increase production volume or capacity to meet customer's daily demands in timely manner; Correlation analysis was carried out considering running time against production output at nominal speed. The factors considered include the production running time, production output and speed loss. These was carried out to determine the worthiness to consider the production volume based on running hours of Line 1, 2 & 4. Table 4.3 to Table 4.5 shows the correlation analysis and coefficient of determination results for Line 1, 2 and 4.

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

Table 4.3: Result of Correlation Analysis of Line 1.

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

Production Line 2 Correlation (r_2) =0.75; Coefficient of Determination r^2=0.56)

Correlation and Coefficient of Determination Result Discussion:

Tables 4.3-4.5 show the result of correlation analysis. The main objective of the companies is to increase production volume or capacity to meet customer's daily demands for different product brands in a timely manner; it is important to find the worthiness to consider the production volume based on running hours. To achieve that, degree of correlation between running time (min) and production volume (cartons) was calculated. Line 1; Correlation Coefficient r=0.93; Coefficient of Determination r^2=0.86. Line 2; Correlation Coefficient r=0.93; Coefficient of Determination r^2=0.86. Line 4; Correlation Coefficient r=0.75; Coefficient of Determination r^2=0.56. Line 1,2 & 4 have Correlation Coefficient of greater than 0.7, an indication that both lines have strong positive correlation. We have confidence that as the production time is increasing; production output is equally increasing in positive trend. There were little deviations in Line 1 & 2, which recorded high running time against output. This is caused by reduction in machine speed to cope with starvation and blockage. Line 4 recorded high downtime as a result of high speed and unregulated system. When there is starvation or blockage machine automatically stop and wait until the failed machine start production. Coefficients of Determination of Line 1 & 2 were both 0.86, an indication that 86% of total variation in production output can be explained while 14% cannot be explained. In Line 4, 56% of the total variation can be explained while 46% cannot be explained. These leads to the calculation of Overall Equipment Effectiveness (OEE), from where Operation Performance Index is calculated.

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

Table 4.6 calculated 8 hours single shift of OEE line 4, it is used to determine the efficiency of machines of the production lines, when external and planned downtime are considered it will give OPI, which is used to measure the performance of the entire production system

Table 4.6: OEE calculation of Production Line 4 per 8 hours shift.

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

Target Counter	14,200	Expected Parts per Shift	Target Counter

Process Data	Formula	Result
Run Time	Total Production Time of the Machine	355
Total Time	Down Time + Run Time + Setup Time	420
Good Count	Total Good Parts Produced on the Machine	13,500

OEE Variables	Formula	Result
Availability	Run Time / Total Time (355 / 420)	84.52%
Performance	Total Count / Target Counter (13,800 / 14,200)	97.18%
Quality	Good Count / Total Count 13,500 / 14,200)	95.51%

OEE	Availability x Performance x Quality	78.45%

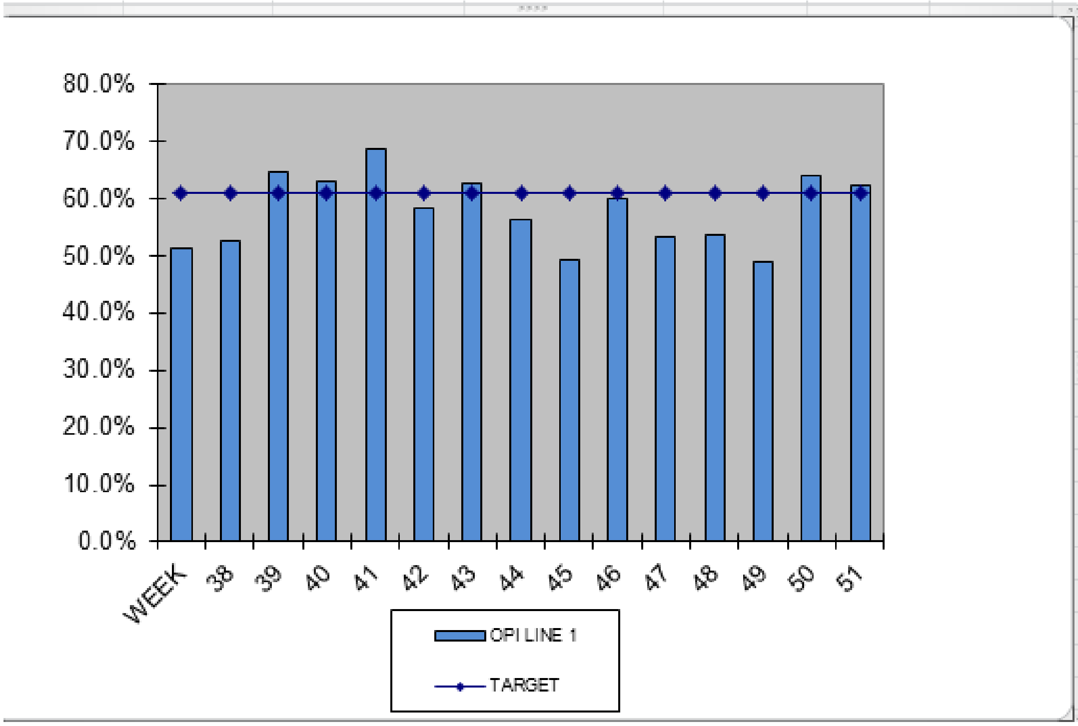
Total Time = Shift (8hr*60(480mins-breaktime (60mins)

OPI Result

Weekly OPI of the three production lines were calculated in this research to find the performance of each line over production target (benchmark.) The result of Weekly and Average OPI of the lines were presented in Table 4.7, while Figure 4.14 to Figure 4.16 represents the graphical OPI against the Target of week 38 to week 51.

Table 4.7: OPI and Target of Line 1

WEEK	OPI LINE 1
38	51.4%
39	52.5%
40	64.6%
41	63.1%
42	68.6%
43	58.3%
44	62.7%
45	56.1%
46	49.2%
47	60.0%
48	53.2%
49	53.6%
50	49.1%
51	64.1%
52	62.1%
AVERAGE	57.9%



Operational Equipment Effectiveness (OEE) Result Discussion.

The OEE of Line 4 is first calculated because we tried to find why there was a decrease in running time although the weekly outputs were high with the time the machine is running as revealed by graphical result of Figure 4.16. Looking at Line 4, which runs 3x 8hrs shift per day from week 38 to week 52, it is observed that there were high downtimes which drastically affect the production output. On this effect, the OEE of Line 1, 2 and 4 were calculated with set production target, while focus more on Line 4 which has recorded high downtime and low running time against production output. From OEE, external down time where put into consideration to calculate the OPI of Line 1, 2 and 4.

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

(.8810 x 1.14 x .9722) = 97.64% Reducing your downtime by 15 minutes will produce 19.19% increase in OEE. Downtime is the most critical factor to improving OEE because when the process is not running you cannot address other metrics. Many Brewery companies have capacity constraints and consider adding overtime, hiring new workers, or buying new equipment. The bottom line is a modest investment to optimize the performance of their existing machines may outweigh the major investment to purchase new equipment. By reducing down time, minimizing setup time, and improving operator performance, Brewery Company can unleash hidden capacity and benefit from monitoring OEE data. The next stage is to categorize line downtimes to know the impact of breakdown, external stops and planned downtime on the three production lines.

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

Appendix 4.5-4.7 show results of categorized Machine breakdown, external and planned downtimes and Appendix 4.9 of Weekly Average Downtimes while Figure 4.18 to Figure 4.21 shows the result of the percentage of contributions of three categorized downtimes (Machine Breakdown, External and Planned Downtimes) of line 1, 2 and 4.

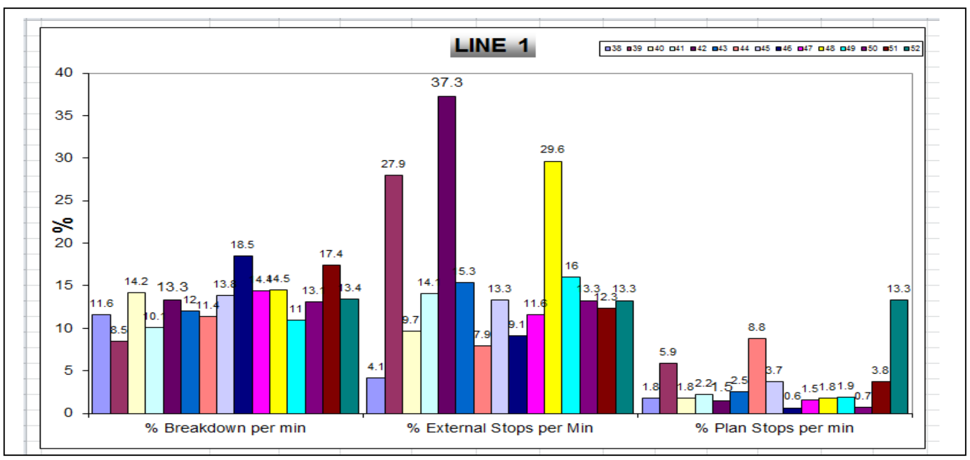


Figure 4.18: Percentage categorized three downtimes in Line 1

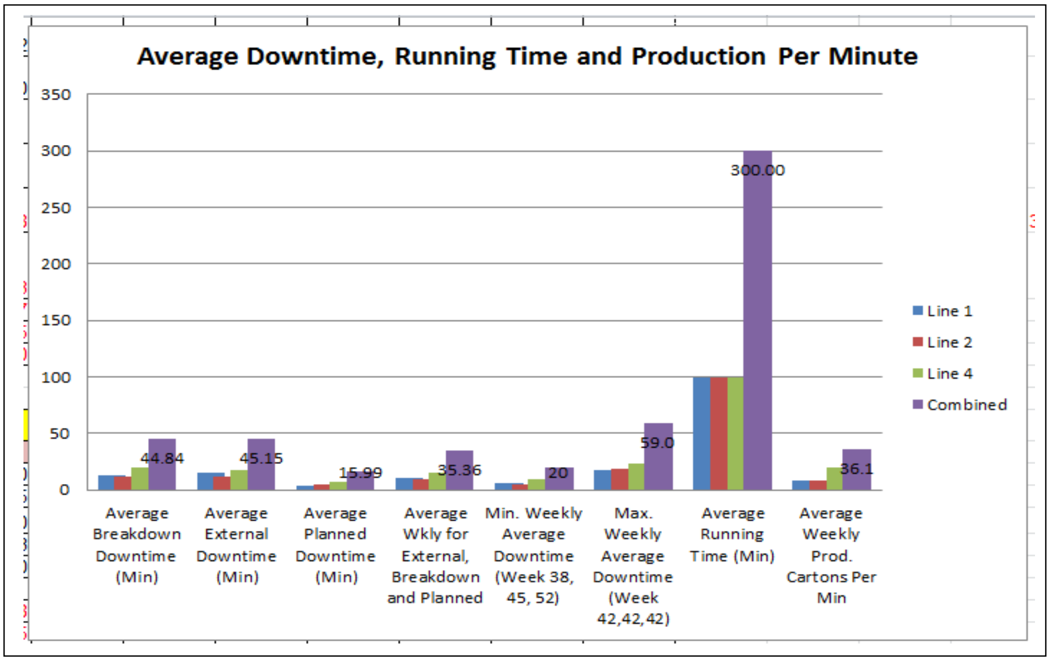


Figure 4.21: Average Downtime, Running Time and Production Output Per Min.

Categorized Downtime Analysis Result Discussion

We now categorized the downtime, into External, Machine Breakdown and Planned Downtimes. This is useful to know the effect on production output. From the result in Figure 4.18- Figure 4.21, In summary, Line 4 recorded the highest average external, breakdown and planned downtime. Again, the same Line 4 recorded the highest number of Cartons produce per minute on weekly basis. Line 1 & 2 run for 15 weeks while Line 4 runs for 12 weeks, but Line 1 & 2 each having highest production running time, their average production per minute remain low. It is an indication that Line 1 & 2 are running below the production capacity, while Line 4 runs on maximum capacity, which is prone to high downtimes. Line 1 & 2 to running below production capacity as a result of the followings; 1. Line 1 & 2 were running below the nominal speed of the core machines, there is inherent speed loss due to regulated lines. 2. They were regulated lines with two labellers supplied with one pasteurizer which can cause system in-balance resulting in blockage, starvation and minor stoppages. In Line 4, breakdown and external downtimes were high because the machine is not regulated and run on maximum speed, which prone to frequent breakdown. Average of 36 cartons are loss due to external, machine breakdown and Planned downtime and a total of 35.36 Minutes are loss for the three production lines. These result in total loss of 1277 cartons. To optimize the existing production capacity;

- The external, machine breakdown and planned downtime should be further analyzed with Pareto into various component to fine the area of focus, which solving 20% will give 80% result
- Increase the speed level of the machine above nominal speed of core machines through modeling and design of experiment, since un-optimized speed levels of sensors can cause machine speed loss.

Since we have established the problems, we now move to Pareto Analysis to find area of focus.

Table 4.8: Summary table of week 40 to 51 of downtime and frequencies

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

	WASHER CLEANING EBI LABELLER	480 480 300 220	18 9 14 8
44	WEATHERD BOTTLE PACKER FILLER MAINTENANCE EBI DEPALLITIZER WASHER	1200 950 580 572 400 380 378	58 36 18 1 18 8 16
43	WEATHERD BOTTLE MAINTENANCE EBI FILLER NO READY PRODUCT PALLETIZER WASHER LABELLER	1320 700 580 520 500 490 420 250	69 1 13 18 9 12 20 6
42	NO READY PRODUCT WEATHERD BOTTLE MAINTENANCE EBI FILLER LABELLER	3500 800 520 500 498 350	37 32 1 14 25 5
41	NO READY PRODUCT EBI PALLETIZER PASTEURIZER WASHER FILLER WEATHERD BOTTLE CHANGE OVER	6200 1300 950 600 500 380 379 200	12 42 18 12 21 15 17 1
40	EBI WASHER PASTEURIZER FILLER CO2 WEATHERD BOTTLE MAINTENANCE LABELLER	920 900 820 680 650 540 520 280	34 34 4 22 11 25 1 10

Overall Downtimes and Frequencies Contribution Result and Discussion

Appendix 4.22G-4.22H, Figure 4.34 and 4.35 shows the Overall Downtimes and Frequencies of Line 1, 2 & 4, to view the contributions of the three categories of downtimes to the production process. In Figure 4.34, machine downtime and external downtime were highest, while in Figure 3.35, the frequencies of occurrences were still high in external and machine downtime**.**

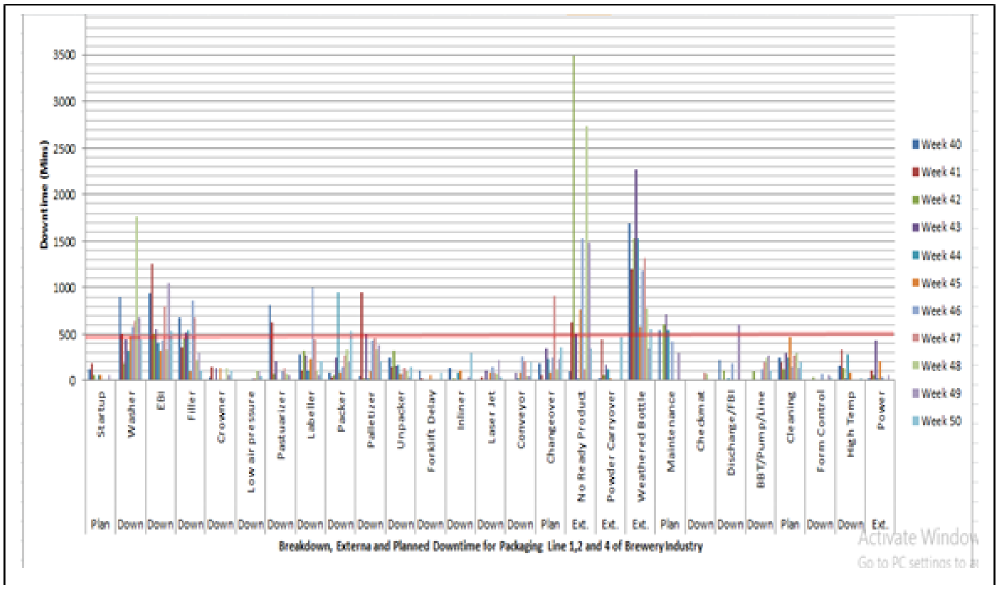


Figure 4.34: Overall Downtime Contribution of Line 1 for 11 Weeks.

Pareto Analysis Result Discussion

Weekly Frequencies of Occurrences and Downtimes Pareto Analysis Result Discussion

Appendix 4.10A-D to 4.21A-D, Figure 4.22 to Figure 4.33 represents weekly downtime and frequencies contributions from week 40 to week 51. Figure 4.34 to Figure 4.35 and Table 4.8 represent the overall downtimes and frequency contribution of weekly downtimes for the 11 weeks. The frequencies and downtimes of the machine breakdown, external and planned downtime can be compared.

In Table 4.8, it is observed in almost all the weeks that EBI, Weathered bottles, Filler, Labeller, Pasteurizer, No ready product and Washer recorded the highest downtime and frequencies. These areas in table 4.8 with high downtime and frequencies of occurrences should be the topmost priority in solving the problems of the entire production system. Solving problems of those mentioned areas will bring more than 80% improvement in downtime reduction, reduce frequency machine stoppages and improve the overall production flows. The next stage is to group the categorized downtimes in Figure 4.18- Figure 4.21 into 4M groups to enable us plot Pareto graphs, which will show us the particular area of focus. The four groups are 4M

(Machine, Man, Method and Materials). These are critical because knowing the area of focus will assist us greatly in reducing downtimes.

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

Appendix 4.23A-I, 4.24A-H, 4.25A-J, Table 4.9-11 and Figure 4.36-42 of week 40 to week 52 of packaging line 1& 2 & 4 respectively. The raw data was filtered in the following sequence; Weeks, Date, Lines, Issues, Area, 4 M (Man, Method, Material and Machine), Minutes of Breakdown and Frequency of Breakdown.

The result is shown in the figures below.

Table 4.9: 4M Analysis Breakdown of Line 1.

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

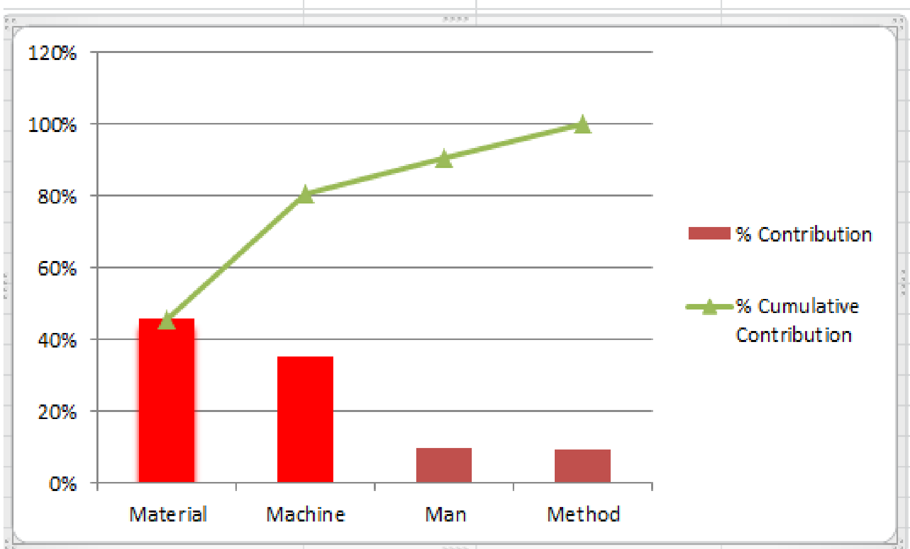


Figure 4.36: 4M Pareto Analysis of Downtime Line 1.

4M Pareto Analysis Result Discussion

Appendix 4.23A-I, 4.24A-H, 4.25A-J of line 1, 2 & 4 represent the breakdown of machine downtimes, external downtimes and planned downtimes of line 1, 2 & 4. Table 4.9-4.11 show the breakdown of categorized downtimes into 4M (Machine, Method, Materials and Man) while Figure 4.36 to Figure 4.42 represent the Pareto Analysis graph of the four lines. Tables 4.9 and 4.10, Material downtime recorded highest contribution in line 1 and 2 with 46% and 39.75% respectively, while Machine recorded highest in line 4 with 63%. Method recorded low in line 1and 4 with 9% and 5% respectively. Man was the lowest in line 4 with 7.99%.

From the 4M Pareto Analysis in Table 4.10 and Figure 4.37 of Line 2, it is observed that the major contributors to downtimes are material and machine with 39.75% and 35.54% respectively. Focusing on these two of 4Ms will greatly reduce the downtime of the overall system to above 75%. As Pareto rules, indicate that tackling 20% of the problem will bring about 80% positive improvements to the system.

From the 4M Pareto Analysis Table 4.11 and Figure 4.38 of Line 4, it is observed that the major contributors to downtimes are Machine and Human Error/Lack of Human Knowledge of the process. 63.3% of the downtime was caused by Machine while Man is 23%. Machine breakdown has a total downtime of 17,883 mins out of total 4M downtime 28,244 mins. Focusing on the highest downtime contributor of 4Ms will greatly reduce the downtime of the overall system to above 80%. As Pareto rules, indicate that tackling 20% of the problem will bring about 80% positive improvements to the system. Considering the line 1, 2 and 4; it is important to focus on Material, Machine and Man to reduce overall system downtime and improve production performance. Method has little contribution to the total downtime on the three lines. These will lead us to the Pareto Analysis of contributor of Individual components downtimes.

Pareto Analysis of Downtime of System Components and Frequency of Contribution Results and Discussion

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

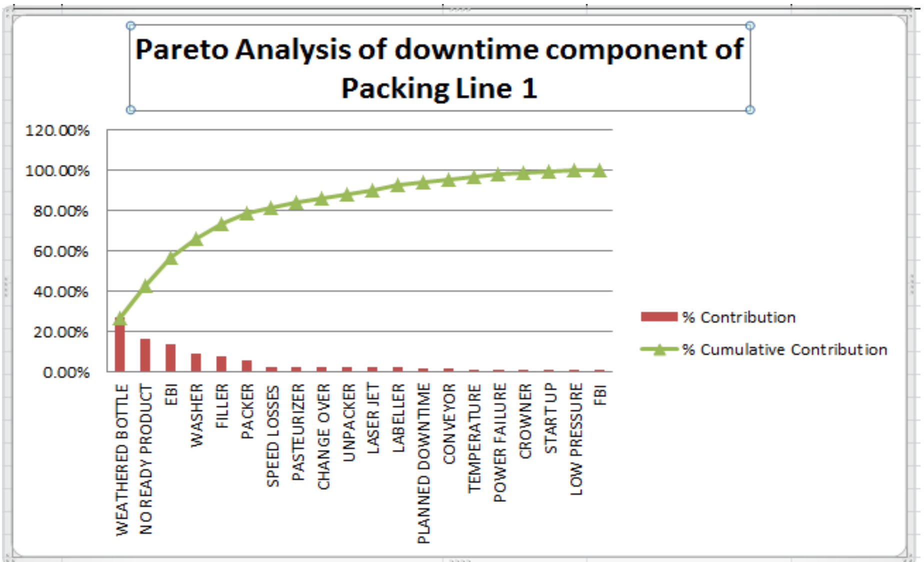


Figure 4.39: Pareto Analysis of categorized downtime of line 1.

Figure 4.39 to Figure 4.42 show individual contributors of categorized downtimes from the Pareto graph for both the downtime and frequency were plotted for Line 1, 2 & 4. The result revealed that Weathered Bottle, which was the external downtime, has the highest downtime and frequency of downtime. Weathered Bottle, EBI, Washer and Filler are the main focus to solve the problem. It shows that in line 2, there are uniform contributions to the overall downtime of the system. Palletizer, Labeller, Pasteurizer, Unpacked, EBI, De-palletizer, Filler and Bottle Conveyor are the major contributor to the downtime. Finally, we have concluded the discussion of the production system result Analysis. The next step is to go to the modeling and simulation and design of experiment to solve the problem of speed loss cause by unregulated and unbalance lines.

CONCLUSION

This study demonstrates the significant impact of Operations Management practices on production optimization. Lean manufacturing, Total Quality Management, Just-In-Time, and Six Sigma are all critical strategies that contribute to enhancing production efficiency, reducing costs, improving product quality, and minimizing waste. The integration of these practices enables organizations to remain competitive in today's global market, where efficiency and quality are paramount.

It is clear that the successful application of OM practices requires a strategic approach and a commitment to continuous improvement. As industries continue to evolve, the role of OM in optimizing production processes will remain crucial, particularly in the face of emerging challenges such as supply chain disruptions and increasing demand for customization.

5.2 Recommendation

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

- *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. The conveyors between the machines can be seen as a machine itself, which is proven by this research. The implementation of the outcome of this research is relative small, but the results are relative large.
- *Create an overview of the functioning of sensors on the production line.* In order to improve the efficiency **between** machines, it is necessary to have a clear understanding of the function of the sensors. Then superficial inefficiencies can be solved directly. This is also very useful to visualize the operation of the production line.
- *Hire extra Process Automation /Process Instrumentation engineer:* When inefficiencies are noted by employees, they have to write a label. Different aspects on these labels are possible, from safety issues till machines issues. When such an aspect consists of technical issues arrive on the desk of a PA-/PI engineer. Some filled in labels are on stack for six months. This slow response discourages the operators to help improving the line performance.
- *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.

5.3 Contributions

5.3.1 Contribution to Knowledge

Several literature have been written on efficiency of packaging lines and machines, continuous improvement and lean concept, maintenance strategies, simulation modeling of packaging lines, optimization of buffer but having discovered the importance of core machine in capacity utilization and its numerous inherent problems which further reduces its design capacity through this study, this research takes into accounts, in addition to literature review;

1. The study emphasized on the core machine and machines around it on the optimization process in addition to buffer capacity optimization.
2. The study integrate CILT and Kaizen as part of optimization process for system robust and reduction of downtimes occasioned by lack of strategic preventive maintenance especially on the core machine and machines around it.
3. It also emphasized the importance of operator's efficiency at the core machine/machines around it and quality of raw material inputs to machines in increasing the capacity utilization of the available production capacity.

4. It considered not only machine and buffer efficiencies in the optimization process like the reviewed literature but also external and planned downtime reduction optimization to achieve system optimization holistically.
5. The methodology adopted in this research helped to discover the hidden bottlenecks in the system and give solution for optimization of the packaging line 1, 2 and 4 of AB breweries which can be applied in other brewery and beverage companies across the globe
6. The excel spreadsheet platform designed and developed will helped to track the record of yearly improvement, total breakdown, area of focus and make the data analysis of production system simple.

5.3.2 Benefits of the studies to Brewery Industries

1. The research incorporated five important stages of which includes; Analysis of production process, which look at the overview of the current production system: Analysis of problems affecting production performance: Development of model to optimize the existing production lines: Application of design of experiment to get the best alternative of the 12 possible solutions: And finally, application of CILT and Kaizen as a preventive maintenance strategy to make the optimized system more robust.
2. Considering the current pressure in brewery industries, trying to cope with numerous products demands with limited production capacities and huge capital expenditure in the construction of new production lines, this research optimize the production performance and preventive maintenance of production lines to increase production output from the existing underutilized capacities.
3. Production line design engineers will utilize this research to optimize regulated lines with two labellers at the initial stage of design, using plant simulation software before embarking on the construction and installations, which will avoid unnecessary cost incurred in redesign after project execution and commissioning.
4. The knowledge from this research will enable operators and maintenance engineers adopt this preventive maintenance strategy to avoid machine breakdown that will affect the utilization of existing capacities.
5. The excel spreadsheet platform for data analysis and data management will help to keep yearly accurate record machine breakdown, external and planned downtimes and perform

analysis to know the area of focus and improvement made.

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

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