

Influence of Lean Automation on Resource Wastage in Sugar Industries: Case in Kenya

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Abstract— Sustainability of resource utilization in local sugar industries is on a decline due to the adoption of obsolete technology, among other factors. In this regard, there is a need for an advanced manufacturing approach to address resource wastages in the local industries. Resource utilization efficiency of a sugar cane industry can be varied through combinations of energy consumption, setup time, and cycle time. However, this depends on manufacturing technology used by the industry that is embodied in different levels of automation. Thus, this study carried out an analysis of the different levels of automation at different stages of the pre-milling process of sugarcane in the case industry to determine the optimum automation level for efficient resource utilization. A randomized block experiment was adopted, and for each indicator under investigation, seven replicates were conducted for the reliability of results. It was found that the rate of power consumption employing LoA 4 (conventional automation) was relatively higher with a total of 45044 kW compared to when LoA 5 (SCADA) or LoA 6 (DCS) was used with a total power consumption of 42058 kW and 42008 kW respectively. Similarly, LoA 5 and 6 have virtually negligible setup and cycle times involved except when it is after a general plant overhaul. This is as a result of minimum variations in the process parameters due to their real-time monitoring and control. Therefore, lean automation proves to be the ultimate technique that should be adopted in our sugar industries.

Keywords— the level of automation; waste reduction; lean thinking; power consumption; cycle time; set up a time.

I. INTRODUCTION

According to KSB [1], Kenyan sugar factories are high-cost producers of sugar, which have led to reduced competitiveness than the same industry in other countries. Sugar production cost in Kenya is comparatively higher at an estimated cost of USD 870 per MT compared to other competing COMESA countries like Zimbabwe, Malawi, Swaziland, Sudan, and Zambia with an estimated cost of USD 300, 350, 340, and 400 respectively [2]. The sugar industry in Kenya is facing several challenges that have affected its efficiency. These challenges range from low production capabilities, poor management, unclear harvesting schedules, unpredictable weather patterns, increased internal competition for canes, and, most importantly, process wastages due to lack of modern equipment and manufacturing technology. The factories continue to operate at low capacities due to inadequate technical efficiency and wastages [3]. The primary determinant of the productivity of a sugar factory is the ratio of total sugar cane crushed to real sugar made (TC/TS ratio). This ratio shows the MT of cane crushed to yield one MT of sugar. A comparison of TC/TS ratios between private and government-owned factories reveals a significant difference. In 2012, the conversion rate for Butali was 9.74, while

Chemelil was 18.41 [4]. This value means Chemelil had to crush an extra 9MT of cane to produce one MT of sugar like Butali. Being a member of COMESA free trade agreement, Kenya is bound by the provisions of the free trade protocol that allows sugar imports from COMESA FTA countries to gain access to the Kenyan market without any quota or duty restrictions. This has resulted in an influx of sugar imports whose prices are much lower in comparison to sugar produced in the country caused render locally produced sugar non-competitive and factories collapsing.

According to Ondiek and Kisome [5], adoption of lean manufacturing techniques and proper sensitization of its prospects on the performance of industrial competitiveness in Kenya is non-existence. They revealed that in Kenya, sugar companies exhibited either partial application of lean techniques or improper consideration of the level of automation. In their conclusion, there is no understanding of lean manufacturing principles, and therefore little benefits have been realized. They recommended the need for a holistic integration of advanced techniques, for full benefits.

Therefore, a proper integration between lean techniques and ideal level of automation to have lean automation, its adoption and implementation can be investigated on processes to see if it can achieve this. There is a possibility that effective process performance in the sugar industry will

be realized when the lean approach is applied fully before appropriate selective automation. Thus, the need to assess the potential of integrating lean techniques with the appropriate level of automation in lean automation on resource wastage.

According to Garcia [21], any industrial activity can either lead to value addition or cost addition (waste). Value addition is only when there is a physical conversion of a product to the customers' intention or provision of services that satisfies the worth of a customer's money in terms of design and engineering. In most sugar industries, 90% of the process lead time does not add value and needs elimination.

As attributed to Shaman and Sanjiv [6] through their research, waste reduction tools are vital elements of lean manufacturing and thus need to be understood by all the manufacturers. Also, using conventional statistical process controls in industries, variable parameters are not monitored. In developing countries, the cost of production of goods is unfriendly due to the adoption of conventional manufacturing processes, and this has led to the unsustainability and collapse of local industries. In Kenya, the sugar industry is an example where companies are collapsing.

By implementing and simulating the integration of lean and level of automation, this research will assess the technical importance of adopting improved manufacturing processes through lean automation. Also, the research will draw on a case sugar industry firm employing automation to identify the drivers and obstacles behind the competitive trend. Consequently, the dynamic capabilities of automated manufacturing systems will be considered.

A. Conceptual synergy

The research was guided by three theories, namely theory of constraints (TOC), lean manufacturing and six sigmas. The three theories are geared towards improving the process performance, and they collaborate in terms of general criticisms on the cause of industrial failure. Also, they make a few of the same assumptions. The emphasis on constraints by TOC gives a clear indication at every stage of a production line to enhance improved output. This conforms to lean thinking, where waste reduction is conducted to rectify the weak cell/modules to achieve increased outputs. Consequently, it conforms to six sigmas in that when the weak cell is improved, there will be fewer process variations, and this will improve quality. Ultimately, all the models derive at attaining improved quality and, subsequently, effective industrial performance.

B. Waste reduction

Shaman and Sanjiv [6], observed that the performance of any industrial process is directly linked to the application of lean manufacturing. Customer satisfaction is used to gauge the quality of a product. However, the success of a production process is pegged on the amount of waste generated during the process. An excellent process line should eliminate waste through appropriate applications, such as lean thinking [7]. Also, implementation of lean automation coupled with appropriate SWOT analysis can have a direct impact on the total elimination of industrial waste [8]. Consequently, it will lead to increased production

by reducing the cycle time as well as work in process and inventory [9].

Also, Zafarzadeh [10] asserts that emphasis should be concentrated on the smooth flow of those activities that only add value. In line with the customers' expectations, production departments should only be on the subsequent operation that is yet to take place within the shortest time possible. Therefore, continuous improvement of the process line is essential since we are interested in reducing the time that will be taken from the order placement to the product collection. Time reduction can only be a reality if non-value adding activities are eliminated [11].

As attributed to Padraic [12], waste is that which is bought but not utilized. Sustainable manufacturing denotes the adoption of a manufacturing process that decreases negative impacts on the environment, improves energy and resource conservations, provides safety, and is economical in operation. On the other hand, competitiveness is the ability of a company to produce goods more than its competitors efficiently and effectively. The competitive indicators include the rate of exportation, the market share of the company, and its profitability. Sustainability is the bottom line in the achievement of social, environmental, and economic performance. These two core values are lacking in our key local sugar industries, thereby initiating the need to undertake this study. The study will propose alternative technology for the sugar company for increased resource utilization.

According to Oliverio et al. [13], juice extraction in sugarcane is a process operation where the water and sugars in the cane are extracted, and it occurs after cane preparation stages. Some techniques are employed commercially to achieve before cane preparation. Mechanical squeezing is employed to operate mill tandems, or by diffusion where the prepared cane fibers are washed in many stages. The sugar contents and water are subsequently dissolved and sucked in a diffuser from the unbroken fibers constituting 10% and leaching in broken fibers comprising 90%. The primary concern during the extraction process is the production of quality juice and final removal of the bagasse with the least moisture content of at least 50% of moisture, which can support burning in the boilers to produce steam and power. The goal is to extract the maximum mass amount of sugar content in the cane fibers and make bagasse with optimum moisture content suitable as biomass fuel in steam or power boilers.

C. Lean thinking

Human supervision is limited in terms of monitoring any production process. Thus, automation is employed to provide visual control to monitor all processes and then call for human intervention to arising issues. It implies that functional automation must be intelligent and self-transformative with a human touch [14]. The aim of automating any manufacturing environment is to improve the production processes through elimination of waste, provision of flexible procedures and improvement of self-correcting processes via enhanced visual inspection and elimination of inventory through the integration of production scheduling and automated equipment. [15].

With these expectations of lean automation, the sugar industries may achieve zero inventory, shorter product cycles, and improved quality. Many industries noted that quality control was achieved easily with automation than human-based. Lean automation also minimizes capital outlays related to waste and inventory as a result of absolutely investing the capital in the automation of equipment, process, and product [15].

Lean automation has a maximum reliability index due to its self-regulatory and corrective application. It involves detection, repair, and maintenance programs that can predict, prevent, and control or instead maintain production processes. With the use of lean robotics by Toyota, there is simplicity in process visualization and usability on production resources through enhanced process inspection and reduced cycle times [16].

In comparison to conventional automation, lean automation's investment cost is relatively low because all matters are "on the table" from the beginning, and all eventualities are considered. This suggests that lean automation is cost-effective [17]. In order to attain flexibility and efficiency in manufacturing processes, Harris and Harris [18] stated that any manufacturer of lean equipment should master the knowledge of design that matches the prospects of various types of automation. To minimize resource utilization, then an optimum level of automation is integrated with lean manufacturing to enhance and improve flow. Thus, the ideal level of automation is crucial.

Therefore, according to all these researchers, lean manufacturing methods are adopted by industries to compete favorably by matching existing technology trends. However, this can be improved further by integrating higher levels of automation within the process, an n advanced technology called lean automation. Thus, lean automation is the application of an ideal quantity of smartness on a task through the integration of a high level of automation to minimize wastage of resources like cycle time, inventory, set up times among many.

D. Lean Automation

The competitiveness of a company is accessed based on the number of parts produced within the shortest time and lowest production cost possible. Mostly, this is attained through lean manufacturing techniques linked to waste reduction. However, this alone cannot assess, forecast, and monitor waste reduction trends, creation of sensitivity analysis and scenario reports, competitive viability, and prevailing market demands [19]. The deficit of lean manufacturing can be addressed by adopting an optimum level of automation, which can result in shorter cycle times and flexibility through the design of assembly and deployment of quality functions [15]. It was also noted that just in time (JIT), implementation could improve automation. It should then first be implemented to simplify the manufacturing processes before applying automation is sought to attain waste reduction [20].

E. Power transmission and setup time

Kent and Lewinski [21], explored the comparison between electromechanical mill tandems and the conventional drive (turbine). The electromechanical mill

drive has the following merits: higher efficiency and speed ranges, better speed control, easier monitoring, higher torque range, and lower maintenance cost. Further, a comparison between variable speed electromechanical drives and electro-hydraulic drives concerning efficiency and torque-speed was also determined, and the following was deduced:

- Electro-hydraulic drives have a better torque-speed advantage.
- Both electromechanical and electro-hydraulic drives have the same efficiencies in similar applications
- The efficiency of a hydraulic drive is relatively easy to measure compared to that of an electromechanical (VFD) drive.
- Power losses and service factors must be considered when determining the efficiency of the drives.

It was observed that the efficiency of the variable speed electromechanical drives is higher than that of the electro-hydraulic drive.

Also, Ali et al. [22], confirmed that productivity is related to value-adding activities in the manufacturing transformation process. Thus, any activity that not adding value is regarded as a waste. Therefore, it is essential to minimize these resource wastes if productivity is to improve, and this is in line with the theory of waste elimination, which emphasizes the reduction of non-value adding activities.

F. Sigma Level for Sustaining Control

Garcia [23] highlighted six different levels of automation, commonly referred to as the sigma levels for control monitoring as follows:

- 6s: Six Sigma automated process is autonomous and designed to automatically monitor and adjust or eliminate any errors with no human involvement.
- 5s: The process automatically shuts down the operation and prevent the occurrence of the next activity in the sequence until the appropriate action is taken.
- 4s: An error detected on a production line will prevent a part from proceeding to the next stage.
- 3s: The presence of statistical process controls and their cause on dependent variables are spotted and rectified by trained personnel in line with the set rules and regulations.
- 2s: Only statistical process controls on independent variables are spotted manually and corrected by personnel.
- 1s: Involves the design of process audit and statistical operation plans through training schedules.

II. MATERIALS AND METHOD

A. Study Area

Mumias Sugar Company Ltd, located in Mumias Town of Kakamega County in Kenya, was selected as a case study company. It is a local sugar industry that has upgraded its operations progressively from conventional to full automation to most of its work cells. It has three major functions, namely sugar production, power cogeneration, and ethanol processing. It prides itself on both a modern automatic diffuser and conventional mill tandem production lines as juice extraction techniques. The different techniques

laid an excellent basis to adopt the company for experimental set up to assess the impact of higher levels of automation resource waste reduction.

The experimental design involved a holistic single case study comprised of the following attributes: context was the case industry, the case was the lean automation, and the cell was the process stages (P. Stages).

B. Materials

- Digital Stopwatch to measure time responses
- Visual digital cameras and LCD screens to provide high-level time monitoring responses
- Digital temperature sensors and their probes to provide high-level temperature monitoring responses
- Supervisory Control and Data Acquisition system to provide a five sigma level of automation
- Distributed Computerised System to provide six sigma level of automation

C. Measurement Procedure

- The pre-milling section was grouped into eight different process stages sequentially as weighbridge (PS), cane loading (CL), feed tables and kickers (FT), knives (KNIV), main cane carrier (MC), Shredder, heavy-duty knives (HD KNIV), and juice extraction.
- Three different levels of automation under study were subjected to each of the eight stages of the pre-milling section and the response to parameters (power consumption, cycle time, and set up time) affecting resource utilization on the production line recorded.
- These three levels of automation were 4, 5, and 6 sigma levels (dabbed LoA 4, LoA 5 and LoA 6 respectively), and were purposefully chosen to represent: conventional automation (control experiment) employed by all sugar industries in Kenya, SCADA platform and DCS systems respectively.
- The response to process parameters by the different levels of automation was recorded, analyzed, and the significance of each level concerning waste reduction compared.

The following attributes characterized the different levels of automation:

TABLE I
CHARACTERISTICS OF THE DIFFERENT AUTOMATION LEVELS

LoA	Characteristics
LoA 4	<ul style="list-style-type: none"> • Open-cell method of cane preparation • Constant speed drive motors, compressor and pumps • Standalone safety and operational control buttons • Manual troubleshooting techniques of machinery (monitoring of process temperature, pipe and dust flow, mill processes) • A random sampling of juice extract to monitor the quality of juice (temperature, Brix, production rate)
LoA 5	<ul style="list-style-type: none"> • Preparation index method of cane preparation (HD KNV) • SCADA • Variable speed drive motors, compressors, and pump • Autonomous diffuser and millers • Automatic safety and operational controls • Automatic troubleshooting • Audio and visual process alert system • Verification systems
LoA 6	<ul style="list-style-type: none"> • DCS • Variable speed drive motors, compressors, and pump • Autonomous diffuser and millers • Automatic safety and operational controls • Automatic troubleshooting • Audio and visual process alert system • Verification systems

Key: LoA =Level of automation

D. Experimental Setups

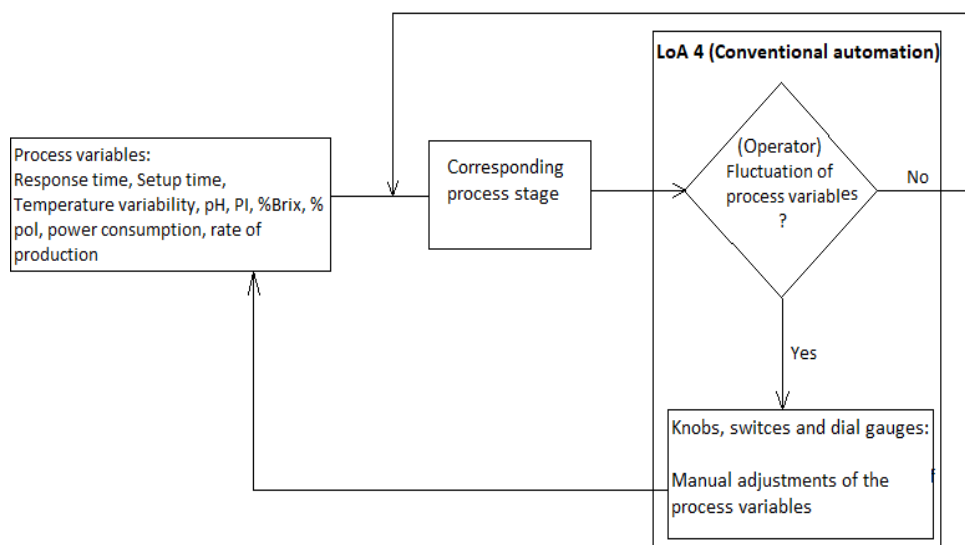


Fig. 1 Experimental setup for the four-sigma level of automation (LoA 4) using control circuits

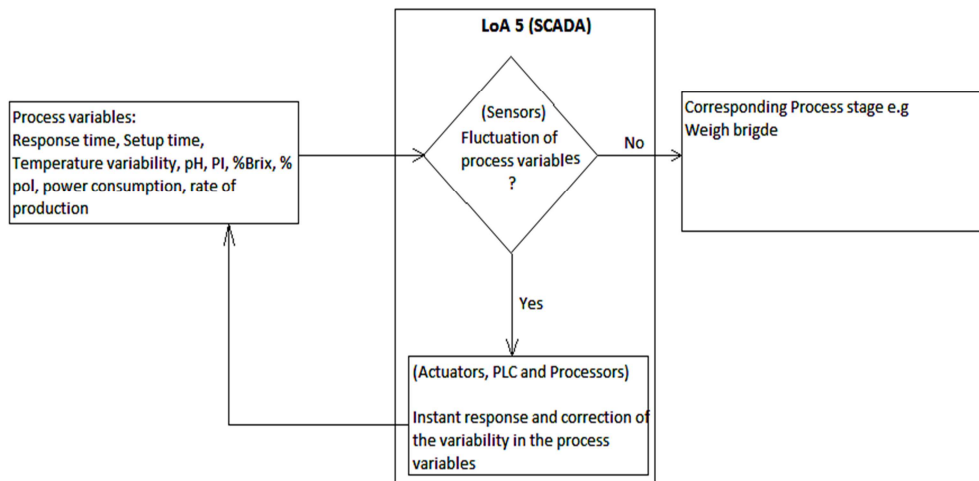


Fig. 2 Experimental setups for the five sigma level of automation (LoA 5) using SCADA

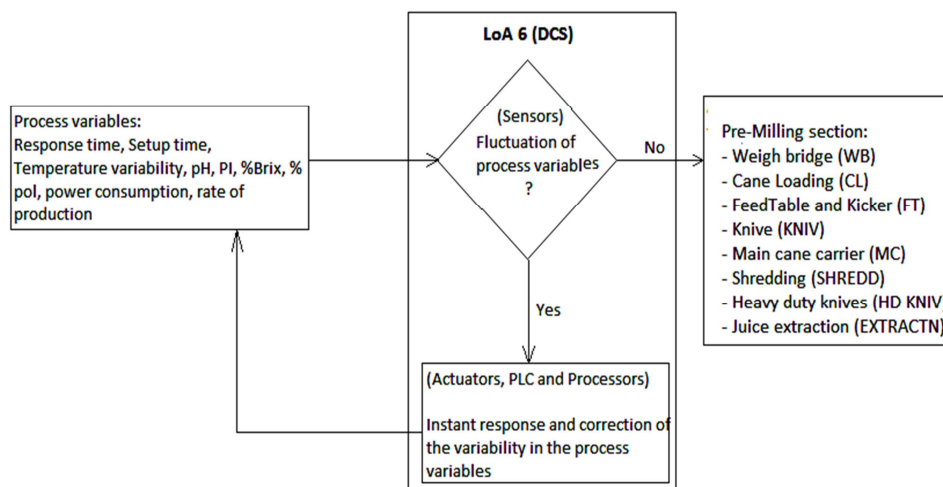


Fig. 3 Experimental setup for the six-sigma level of automation (LoA 6) using DCS

III. RESULTS AND DISCUSSION

The experimental design adopted was a randomized block design with two factors, namely LoA and P.Stage, investigated on the three critical major indicators that affect resource utilization through minimized wastages, namely power consumption, setup, and cycle time. Seven replications for each treatment level under study were conducted. The analysis revealed that resource wastage in the Sugar industry reduced with the increase in the level of automation, and this agrees with Martinez et al. [24], who reported that for optimum resource wastages, these mentioned manufacturing indicators must decrease, as demonstrated in Figure 4. The summarized probability plot and summarized ANOVA table for the variables that affect resource utilization are summarized in Figure 5.

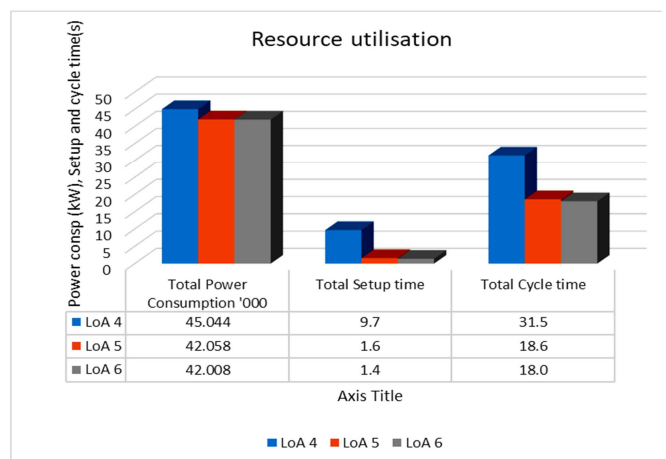


Fig. 4 graph of power consumption, cycle time, and setup time for different LoA at different process stages

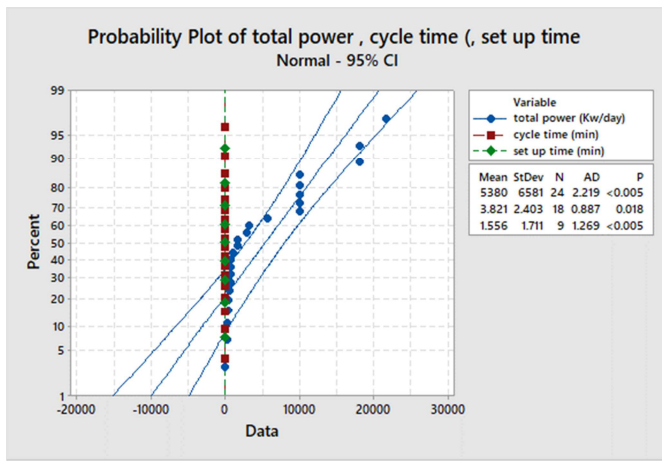


Fig. 5 Probability plot of total power, cycle time, and setup time at 95% CI

TABLE II
ANALYSIS FOR IMPACT OF LEAN AUTOMATION ON MINIMISATION OF
WASTAGE REDUCTION

Descrip tion	LoA	No. of P.stag	Mean	Variance	Test for significance (ANOVA)
Power consu mption	LoA 4	8	8272	52344365.4	F _{Calc} = 3.98 F _{Crit} = 3.74 P-Value = 0.045 $\alpha = 0.05$ DF = 2 F _{Calc} > F _{Crit} and $\alpha > P$ -Value Com = Significant at 0.05 level
	LoA 5	8	5257	3	
	LoA 6	8	5251	44893754.2	
Setup time	LoA 4	3	3.23	1.423	F _{Calc} = 15.61 F _{Crit} = 6.94 P-Value = 0.013 $\alpha = 0.05$ DF = 2 F _{Calc} > F _{Crit} and $\alpha > P$ -Value Com = Significant at 0.05 level
	LoA 5	3	0.53	0.003	
	LoA 6	3	0.47	0.023	
Cycle time	LoA 4	4	12.3	4.40	F _{Calc} = 4.47 F _{Crit} = 4.10 P-Value = 0.041 $\alpha = 0.05$ DF = 2 F _{Calc} > F _{Crit} and $\alpha > P$ -Value Com = Significant at 0.05 level
	LoA 5	4	13.5	4.52	
	LoA 6	4	13.5	4.52	

From both Fig. 4 and Table 2, wastage in the sugar processing was depicted by three variables, namely: power consumption, cycle time, and set up time. The rate of power consumption of the entire juice extraction process line when employing LoA 4 (conventional automation) is relatively higher with a total of 45044 kW compared to when LoA 5 (SCADA) or LoA 6 (DCS) are used with a total power consumption of 42058 kW and 42008 kW respectively. Conventional automation is characterized using mill tandems that do not require a high PI; hence there is no shredding

stage, but still, the power consumption is high. Whereas LoA 5 and 6 are associated with the use of diffusers but can also be incorporated with mills. The high-power consumption could be due to the machines at respectful stages, drawing power without performing meaningful work due to unprecise mechanisms of sensing, monitoring, and regulating the process parameter.

Therefore, using LoA 5 or 6, the overall power consumption was lower than the conventional milling technologies. This is due to the characteristics of the LoA 5 and 6, where speed variable electromechanical and hydraulic drives are employed in the form of efficient shredders and high-density knives compared to the conventional drives used in LoA 4 turbines. Also, LoA 5 and 6 use a diffuser in the extraction, which is exclusively automated with frequency variable drives, thus consuming less power while producing quality sugar with adaptive control on parameters. Besides, it is contrary to when LoA 4 is employed where mill tandems are withdrawing relatively high power to operate at the expense of low quality and production rate.

These results conform well with Kent and Lewinski [21], who observed that the use of frequency variable electromechanical and hydraulic drives registered an array of advantages compared to the conventional drives by turbines, ranging from prompt monitoring, increased speed and torque control, and low cost of maintenance.

Setting up of machines was conducted at three process stages, namely weighbridge (PS), Cane Loading (CL) and Feed table and kicker (FT). In all the three stages, LoA 4 recorded the highest setup time whenever the machines needed to be readjusted. In total LoA 4 recorded a setup time of 9.7 min compared to LoA 5 and LoA 6, which indicated a total of 1.6 min and 1.4 min respectively, for readjustments. It can be seen that LoA 5 and 6 have virtually negligible setup involved except when it is after a general plant overhaul as a result of minimum variations in the process parameters due to their real-time monitoring and control. The self-regulation minimizes the setup and reduce wastages in the production line and consequently improves performance and quality. A similar case happens with cycle time.

Therefore, both LoA 5 and LoA 6 employs efficient shredders, which consumes less power as compared to LoA 4, which utilizes high torque knives. Thus, additional power is required when conventional automation (LoA 4) is used. Ultimately, this will consequently increase both the lead and set up times and reduce production in LoA 4. Hence, the sugar industries have a high potential to adopt either LoA 5 (SCADA) or LoA 6 (DCS) for minimal wastes.

This result conforms to Ali et al. [22], who confirmed that productivity is related to value-adding activities in the manufacturing transformation process. Thus, any activity that not adding value is regarded as a waste. Therefore, it is essential to minimize these resource wastes if productivity is to improve. This result is in line with the theory of waste elimination, which emphasizes the reduction of non-value adding activities. The probability of the three parameters shows $p < 0.05$.

With LoA 5 or 6, the overall power consumption was lower than the conventional milling technologies, and this is attributed to the characteristics of the LoA 5 and 6, where

speed variable electromechanical and hydraulic drives are employed in the form of efficient shredders and high-density knives compared to the conventional drives used in LoA 4 turbines. Also, LoA 5 and 6 use a diffuser in the extraction, which is exclusively automated with frequency variable drives, thus consuming less power while producing quality sugar with adaptive control on parameters. However, this is contrary to when LoA 4 is employed where mill tandems are withdrawing relatively high power to operate at the expense of low quality and production rate. Level 5 (SCADA) or Level 6 (DCS) automation requires an additional shredder that consumes power compared to LoA 4 that does not require shredding. Only efficient and economical shredders and high-density knives should be installed to reduce power consumption and ultimately reduce both the cycle and set up time and thus enhance efficient production.

IV. CONCLUSION

The rate of power consumption of the entire juice extraction process line when employing LoA 4 (conventional automation) was relatively higher with a total of 45044 kW compared to when LoA 5 (SCADA) or LoA 6 (DCS) are used with a total power consumption of 42058 kW and 42008 kW respectively. Therefore, using LoA 5 or 6, the overall power consumption was lower than the conventional milling technologies. This is attributed to the characteristics of the LoA 5 and 6, where speed variable electromechanical and hydraulic drives are employed in the form of efficient shredders and high-density knives compared to the conventional endeavors used in LoA 4 turbines. Also, LoA 5 and 6 use a diffuser in the extraction, which is exclusively automated with frequency variable drives, thus consuming less power while producing quality sugar with adaptive control on parameters. However, this is contrary to when LoA 4 is employed where mill tandems are withdrawing relatively high power to operate at the expense of low quality and production rate. It can be seen that LoA 5 and 6 have virtually negligible setup involved except when it is after a general plant overhaul as a result of minimum variations in the process parameters due to their real-time monitoring and control. In summary, lean automation, which consists of LoA 5 (SCADA) and LoA 6 (DCS), according to Garcia [23], provides the optimum lean automation that local sugar industries require to have a sustainable and competitive process performance. Therefore, it should be considered for adoption and implementation within the sugar processing line as the appropriate advanced manufacturing technique to minimize resource wastages in the sugar industry.

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