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Characterization of Levels of Automation on the Quality of Sugar Cane Juice Extraction: Case of Kenya

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Abstract Quality of sugar from the industry is dependent on the appropriateness of the advanced automation technique that is employed for the extraction of sucrose concentration (brix) from the sugarcane and also, monitoring and regulation of process parameters like the amount of imbibition water, amount of suspended solids, temperature, pH and the leanness of automation technique that determines an optimum extraction. This in turn affects the cost of sugar production. Thus, the need to determine the best automation approach of attaining optimum sucrose concentrations in juice extracts. To achieve this, a comparative analysis of three different levels of automation found in Kenyan Sugar industries was carried out in a case company to assess their impact on the purity of juice extracted and hence the quality of sugar produced. It was found that, levels of automation (LoA) 6 and 5 recorded the highest brix of 96% compared to 75% recorded by level 4. Also, LoA 6 allowed adjustments to achieve improved process balance of juice brix, bagasse moisture, extraction and energy consumption in juice evaporation. Therefore, LoA 6 also called six-sigma automation should be adopted in the sugar industry for optimum sugar quality and reduced cost of production.

Keywords: *levels of automation, quality of sugar, automation, apparent purity and lean*

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1. Introduction

1.1. Lean Manufacturing

As reviewed by Naveen et. al [1], lean manufacturing is a technique known by many industrial set ups [2]. It emphasizes on waste elimination in a process line [3]. The waste can be termed as an intangible or tangible activity along the process line that don't add value to the finished goods or services. Though, for lean manufacturing, the essence is to produce as per the customers' requirement, it necessitates appropriate elimination of these wastes in the process line [4]. Since lean is an operational culture that will initiate an organizational change, it is vital first to enlighten the employees on the action that will be taken and the expected outcomes before the adoption of lean techniques. Otherwise resistance to change may arise and cause hindrance to effective production [5,6]. The essence being to achieve high performance efficiency in the processes [7]. According to Huang et. al [8], proper implementation to lean can result to reduction, if not elimination, of waste such as high inventory and delayed material handling. Consequently it will realize low production cost.

As reviewed by Shaman and Sanjiv [9], implementation of lean manufacturing is directly allied to the performance of industrial processes. Currently, the quality of a product is judged by the customers' satisfaction, which can only be achieved when the process line is excellent, that is, free from any waste. The waste elimination can only be achieved through lean thinking. The combination of SWOT (strength, weakness, opportunity, threats) analysis and lean techniques in an industry will further enhance the waste elimination [10]. If well implemented, all the waste will be eliminated, the cycle time will reduce, the work in process and inventory will be low, productivity will be high and ultimately the production cost will be low [11,12].

1.2. Automation

In reference to Delkhosh [13], due to technological advancement, automation was initiated in manufacturing industries. Flexible equipment can work tirelessly for repeatable tasks. This improves efficiency and subsequently the competitiveness of the industry [14].

Automation can be regarded as either fully automated or full manual, and it is aimed at acquisition of value addition, better process throughputs and increased productivity [15,16]. Similarly, the competitive approach of reducing the unit cost of a product agitated the need for a faster production pace, and this is through automation of crucial tasks [17]. In addition, there are extreme ordinary situations where human intervention is impractical and thus calls for the implementation of automation [18]. Examples are hazardous products, sensitive nanotechnology components, accuracy, high tolerance components and strenuous activities. Therefore, automation provides an excellent ergonomics [19].

A number of factors are important to consider when designing competitive production systems. These include changes in: customization, integrated information systems, rapid changeability, robustness, level of automation, and flexibility in terms of changeovers, production volume, and product variants.

Industries that aim at reaping the full advantage of automation must first enlighten the employees to avoid resistance to change, and these new implementations should be gradual and stepwise [15]. Automation is regarded as a key to transformation in an industry, whose goal is to reduce production cost. This is demonstrated in the automotive industry which has recorded tremendous improvement in lowering the cost of production through less dependency on human labour [20]. Industrial robots have been incorporated to substitute human in performing labour intensive activities and in unsuitable environments [18,21].

Automation has been further advanced to achieve product design within the shortest time possible and increase the productivity. The leads to reduced costs and increased volume outputs. These are as a result of appropriate process control through planning methods and manufacturing tool selection that is provided by automation [15].

On the contrary, automation considered not to be suitable in the following cases: when ramping up manufacturing of new products, manufacturing of a large variety of products and variants in small volumes, very short product life cycle and requisites of product e.g. visual inspection [16].

Decisions about automation is made on the basis of the following important factors namely: desired product quality, conduciveness of work environment and rationalization. Product quality is associated to the customer perspective, the work environment is concerned with the internal perspective while rationalization can be described as the shareholder perspective [22]. Kaplan & Atkinson argued that automation offers reliability and permits flexibility through virtually eliminating setups or change over times. Theodore et.al [23] and Hoque [24] suggested that through automation sustainability and competitiveness can be assured, and this can increase process performance.

The best of automation efforts are realized if they only conform to the industry's goals and objectives. The main key to success is to integrate good organizational structure and manufacturing tools [16]. If the main goal is to reduce production cost, then the concern will only be to automate with a mere implementation strategy on human labour such as task allocation. Otherwise, if the aim is to achieve advanced manufacturing technology, then automation will mainly focus on long term technological solutions for the company with no regard to implication on human force. In this regard, a proper balance of an optimum level of automation will apply in the task allocation [25].

For optimum technological solutions, an integration of automatic and manual functions of a manufacturing plant to have semi-automatic processes will result into efficient monitoring and control of both physical and statistical quantities that affect the processes. This integration will result to the so called level of automation that ranges from purely manual to fully automated process operations. Choosing an optimum level of automation will have a positive outcome on the manufacturing process, contrary to if automation is under or over applied [25].

1.3. Levels of Automation

According to Harris and Harris [18], there exist five levels of automation in manufacturing. Level 1 consist of pure manual tasks by an operator, that is manual loading and starting of a machine, cycling or operation, unloading and finally transferring the machined part to the next manufacturing stage like in a manual press. In level 2 the loading onto the machine is done manually by an operator, followed by an automatic machine cycling or operation, the manual unloading and transfer of the machined part to the next manufacturing stage. In level 3 the loading is done manually by the operator, next the machine cycles automatically, same to unloading of the part from the machine. Finally, the part is transferred manually by the operator to the next stage. In level 4, the part is loaded automatically, followed by automatic machine cycling, automatic unloading and finally manual transfer to the subsequent production stage. Level 5 is fully automatic, that is loading and cycling, unloading and transfer of parts are all automated.

The gap between level 3 and level 4 is great. This gap is in terms of equipment cost, cost of maintenance and ergonomic costs among others. A shift to level 4 implies an increase in cost and decrease in flexibility. A third level machine operates with 95% uptime, yet fourth level operates at 70-75% uptime while level 5 operates at 65-70% uptime. As the process is more automated the uptime decreases gradually. This gap can also be in terms of changeover time which is shorter in Levels 1, 2 and 3 than it is in levels 4 and 5. This makes the upper levels of automation to have a desirable change over cycle rate called takt time. However, when the takt time is low, tasks will be accomplished easily due to less inventories in the industry, thus the three lower levels of automation are suitable [18].

When level 5 machine is employed to achieve production, it is common that an engineer and a technical must be hired to maintain that machine. Thus, if individual machines performing specific functions are implemented by a company with the optimum level of automation, there will be flexibility, faster change over and quick uptime. The parameter to compete in the industry is to be flexible rather than just implementing automation design for future demands which can change anytime [18].

Another model for work functions was developed by Sheridan and where LoA was classified as LoA 1 (with work functions totally manual) to LoA 10 (with work functions totally automatic) and these are grouped into two major activities namely: mechanized tasks and computerized tasks. Classifications of manufacturing systems is based on the kind of operation, type of layout, automation level and part or product variety [22].

Groover [26] also proposed three automation levels and three different layout. This was obtained from the learning rate curves plotted for different types of work. Three control and automation levels comprises system positioning, production system and machine tool. Five possible levels of automation in a production plant can be identified as the device automation, Machine automation, Cell automation, Plant automation and organizational automation. Level 2 encompasses automation of individual machine tools like PLC, CNC, industrial robots and computerized controllers. The material handling equipment represents technologies at level 2, although some of the handling equipment is sophisticated. In all these levels, the working environment should be properly selected.

In summary, automation enhances efficiency, quality and reduces cost of production. It permits much greater manufacturing flexibility, that is, products which have larger volumes or ergonomically awkward to manipulate can be produced in an easy way. Since automation focuses on problems related to human engineering, then it is important to observe level of automation between the human being and the equipment. There are a lot of classifications of level of automation between researchers from five-levels of Harris's classification to three levels of Groover's classification. Meanwhile, the best level which could be called "rightomation" may be Semi-Automation.

1.4. Automation Challenges

Orr [15] observed that low capital per unit and low complexity resulted when a mass production system was automated. This is because a new product cannot be introduced on an existing process line unless the line is redesigned or completely replaced. Thus in mass production, machine changeovers also need to be automated. Similarly, the equipment involved are customized or specialized and thus can cause increased equipment cost.

Winroth said that the most important barriers for automation are “technical feasibility”, “education and qualification”, and “economic viability”. Other problems are: adapting the product to automation, the high number of different products and variants, problems to get the money back from the investment and the lack of competence at shop floor level. In the vaster view, he investigated that automation is never related to the production capabilities, the equipment are too complicated and challenges occurs when trying to balance manual approach along the process line. Work in process cost will then be increased by the huge buffers which will adversely increase the cost. This implies that automation is challenging if not well related to the expected long term production strategies [14,16].

Frohm believes that automation involves more complex production processes while in more advanced automation, it include investment cost. This makes it challenging too in machining and manufacturing. Automation is also not suitable if it is applied to newly introduced products, short term products or short product life cycles. Equally variations in the production is challenging to automation. On the contrary, high volumes of production and ergonomics problems cannot be addressed manually. However, as manufacturing becomes more complex as demand for specialized parts increase, higher levels of automation will record undesirable outcomes. It is affirmed that a variation in product and adapting the products for automated production can be a problem. In their research, some firms mentioned untimely automation planning or operator training and also, a challenge in getting payback from automation. Most industries admit that operator’s competence is the main issue when automating activities involving seasonal products. This results to high changeover times and cost-inefficiency [27].

Hedelind believes that lack of flexibility could be considered as a challenge to automation. The flexibility of a manufacturing system can be defined and determined by its sensitivity to change and serves as a measure for a number of variant products in a production system. A flexible system is that which can accommodate changes effectively at a low cost within a manufacturing system. Lack of re-configurability could be another challenge to the automation which is defined as a systems’ response to changes. The main barriers to small industries in investments in industrial robotics are cost and the need for expertise and experience [28].

Hedelind's asserts that automation is accomplished by complexity. Many reasons have also hindered the adoption of industrial robots including scarcity of robotic cells, lack of understanding of robotic technology by the operator which creates uncomfortable environment and a lot of protocols that needs to be followed yet they don’t give information on procedures. Other challenges include fear to invest in automation when there is variation of products, shorter cycle times, high costs, failure to consider advanced manufacturing techniques and the need to hire maintenance engineers and technicians, configuration and flexibility costs. However, sophisticated machines could give interference due to fixed solutions and limited transparency into the automated process [21].

Hedelind noted that there are many detailed and specific challenges that any firm may be encountered as such the small buffers between stations may cause stops in one station and affect other stations too. The times of set ups in the stations may be another challenge, but the observation noticed was the availability of a wide range of automation solutions in the industry. This was because various suppliers and system integrators were utilized without any detailed technical specifications provided from the company. In the same category, there was also low confidence in the ability of the operators employed by the company to resolve issues arising in the automated stations [29]

1.5. Effect of Pol and Brix on Sucrose Content

According to Xiao [30] in his analysis of sugar cane juice quality indexes it was found out that, the effect of polarization (%Pol) and %brix on sucrose content is directly proportional to the apparent purity of the juice. Further, sucrose content is the quotient of %pol to %brix, thus it increases with an increase in %pol and decreases with an increase %brix. This in turn influences the effect of apparent purity and %brix on the sucrose content while maintaining %pol in that, sucrose content decreases with an increase in apparent purity and %brix. In addition, this conforms to Six Sigma theory that emphasizes on reduction of variations to enhance processes. Through the help of statistical techniques, it is possible to forecast the process outcomes. If unexpected outcome is noticed, then advanced control tools can be used to explain the phenomenon. In relation to lean automation, the integration of lean and proper levels of automation provides a suitable advanced control tool to best understand and identify parameters that affect or vary the process, and hence the overall performance of the organization [31].

1.6. Minimization of Sucrose Losses in Sugar Industry by pH and Temperature Optimization

According to Panpae et. al [32], the rate of sucrose inversion in sugar cane juice extraction is largely depended on the solid content, temperature and pH. When these parameters are increased, they equally increase sucrose inversion rate. To lower the total reducing sugar, temperature control is important in regulating the sucrose inversion while a high pH in the OH^- from lime slightly affects the properties of the juice extract in comparison to the high apparent purity of the pure sugarcane juice. It was observed that at 80°C, sugars and %pol magnitudes were relatively significant compared to lower temperatures. However, when solid content was increased at 80°C, it recorded a lower %pol which is the sucrose content. Therefore, juice extraction process is highly depended on the pH and temperature fluctuations, which must then be maintained for optimum production.

According to Day J.M [33], most sugar mills implement pH control technique via feedback loop relaying a mA electric signal to an actuator valve or pump for corrective reagent delivery into the process line. The usual technique in conventional automation consists only a proportional control instead of a more complex PID control. The proportional control is only possible because sugar processing is an operation which requires an appropriate recipe. The cane feed stock often exhibits small variabilities in acidity or alkalinity. In most sugar industries in developing countries, pH monitoring and control is absolutely manual where samples are manually scooped from mills for pH measurements at intervals without precise electronic pH sensing techniques. In some mills, pH is measured using pH papers. The only challenge in monitoring pH in sugar mills is getting an accurate equipment with the ability to withstand the harsh conditions within this environment. pH sensors must be appropriately located and installed due to two reasons. First, the sensor must visualize the process fluid in real time without experiencing any time lags. This must be at the operating flow rate, pressure and temperature. Because temperature change affects pH and chemical reactions in the process fluid, it is therefore, necessary that pH measurements are taken upon reagent addition and resulting reaction at process operating temperatures.

1.7. Technical Comparison: Milling and Diffusers

Following the main goal of the juice extraction process, the industry should select wisely the optimum technique to adopt for optimum production. In comparison, the factors in considering the viability and impact of any of the two techniques includes the frequency and quality of maintenance required, quality of juice extracts and power consumptions. Ideally, mill tandems are subject to severe wear during their operation and this subsequently affects the average extraction rates, compared to diffusers. However, extraction rates by diffusers are more sensitive to impurities caused by vegetable minerals present in the cane feedstock [34].

2. Materials and Methods

2.1. Study Area

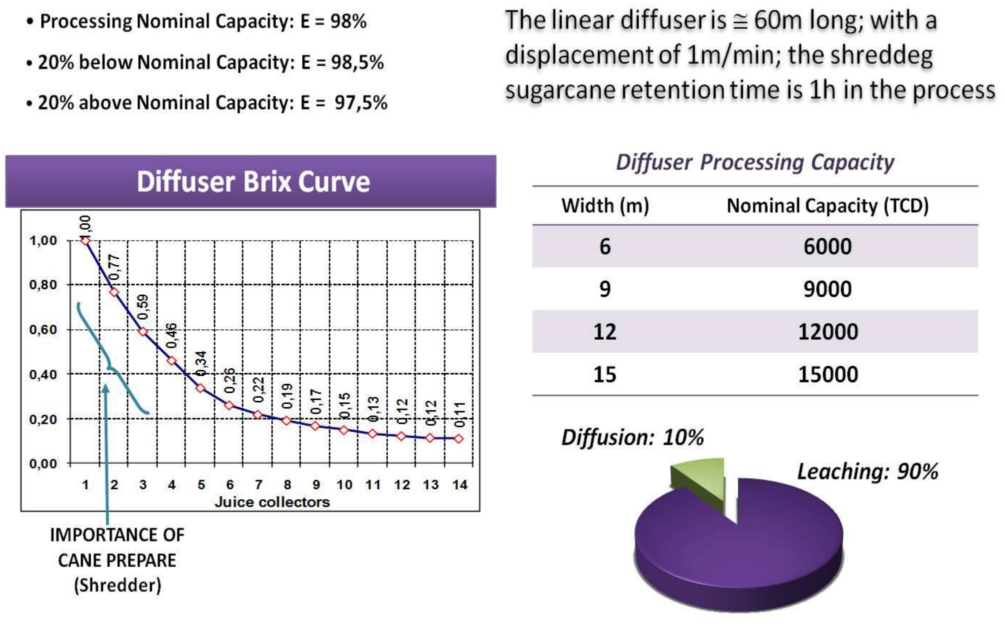

Figure 1. Typical diffuser extraction parameters (Source: [34])

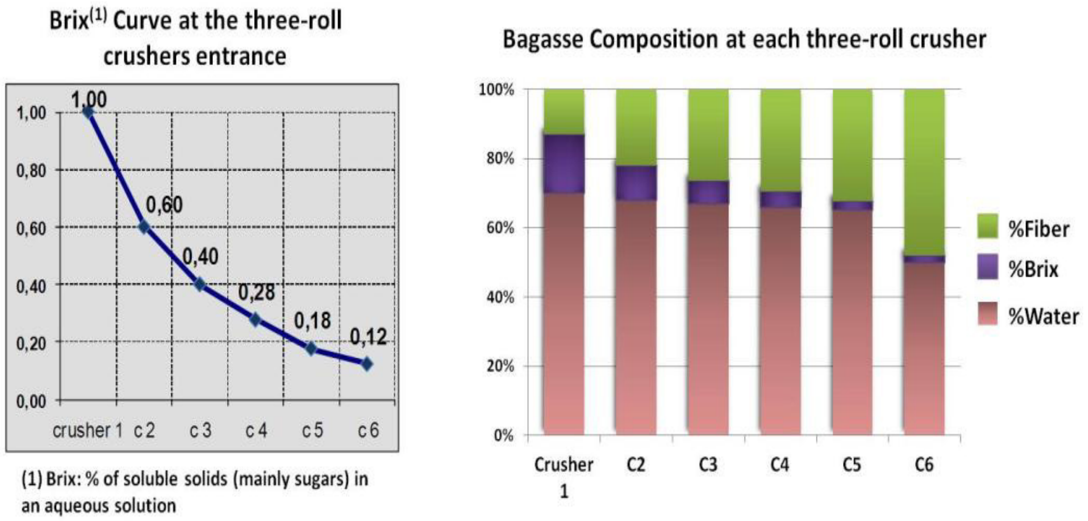

Figure 2. Typical extraction parameters in mill tandems (Source: [34])

A holistic single case design was chosen where the context was the case study industry that practiced automation, the case was the lean automation, and the unit was the material handling modules or cells (P. Stages). Mumias sugar company which is situated in Mumias town in Kakamega county of Kenya was selected as a case company. It is a local sugar industry that has progressively upgraded its plant operations from semi-automatic to full automation in some work modules of its layout. It also has both the conventional and automatic juice extraction techniques in terms of modern mills and diffusion. This provided an opportunity to set up experiments for the various levels of automation to ascertain the impact of various levels of automation on the process performance.

2.2. Materials

1. Digital refractometer to measure directly Brix degrees or HFCS %
2. Stop watch
3. Visual display cameras and screens to provide high level of automation
4. Temperature sensor and probes provide high level of automation
5. SCADA platform provide high level of automation
6. DCI platform provide high level of automation
7. Polarimetre for measuring the %pol

2.3. Measurement Procedure

1. The pre-process line was categorized into various process stages namely weigh bridge (PS), cane loading (CL), feed tables and kickers (FT), knives (KNIV), main cane carrier (MC), Shredder, heavy duty knives, shredded cane conveyor and juice extraction.
2. At each process stage, respective levels of automation were adopted through the different process lines and relevant parameters that affect the process were recorded. Level 4 was represented by the conventional process line which is common in all the local sugar industries while Levels 5 and 6 were represented by the new process line with automated mills and diffuser.
3. The three levels of automation namely 4, 5 and 6 were evaluated purposefully with level 4 being the conventional semi automation process technique that use control circuits and buttons employed by all the local sugar industries in Kenya.
4. Level 5 involved the use of SCADA system incorporated with autonomous independent machines within work cells.
5. Level 6 involved the use of DCS incorporated with autonomous independent machines within the entire plant or wide area.
6. The general procedure involved identification of lean automation prospects with the optimum level of automation and to design and simulate lean automation outcomes in quality of sugar cane juice production.

The various levels of automation were defined by the following characteristics:

Table 1. Characteristics of the various levels of automation (Source: Author, 2019)

LoA	Characteristics
LoA 4	• 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) • Random sampling of juice extract to monitor the quality of juice (temperature, brix, production rate)
LoA 5	• 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	• 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

2.4. Experimental Set Ups

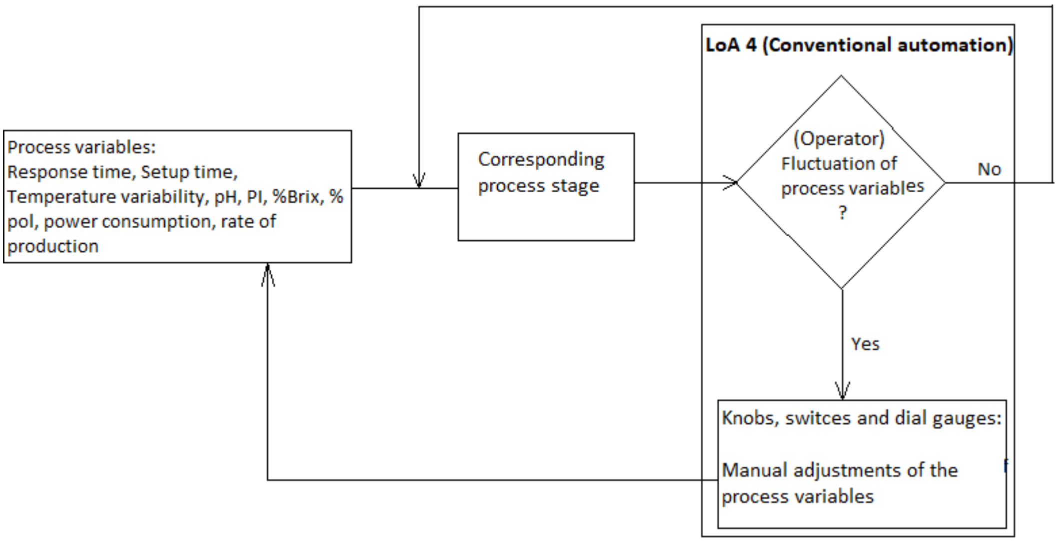

Figure 3. Experimental setup for Level 4 of automation (LoA 4) using control circuits

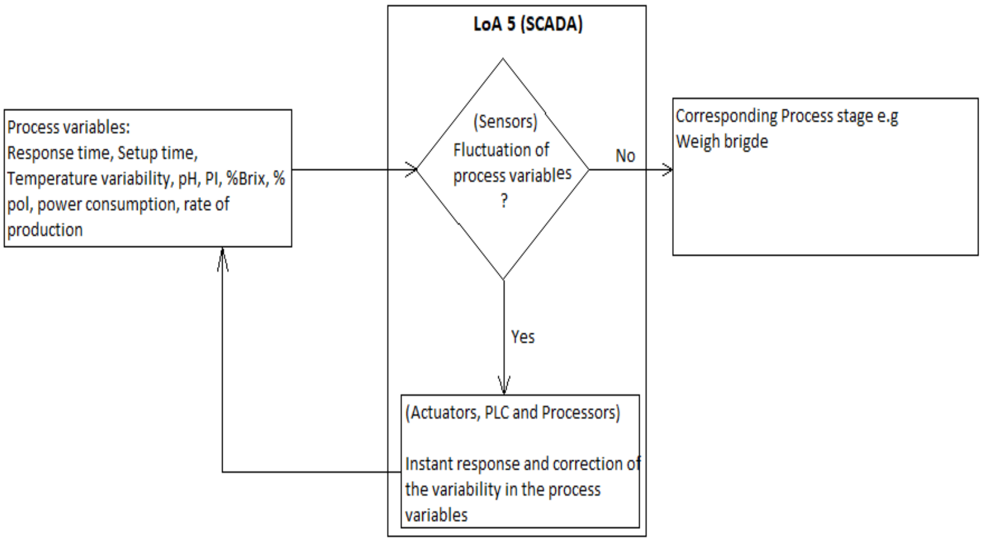

Figure 4. Experimental setup for Level 5 of automation (LoA 5) using SCADA

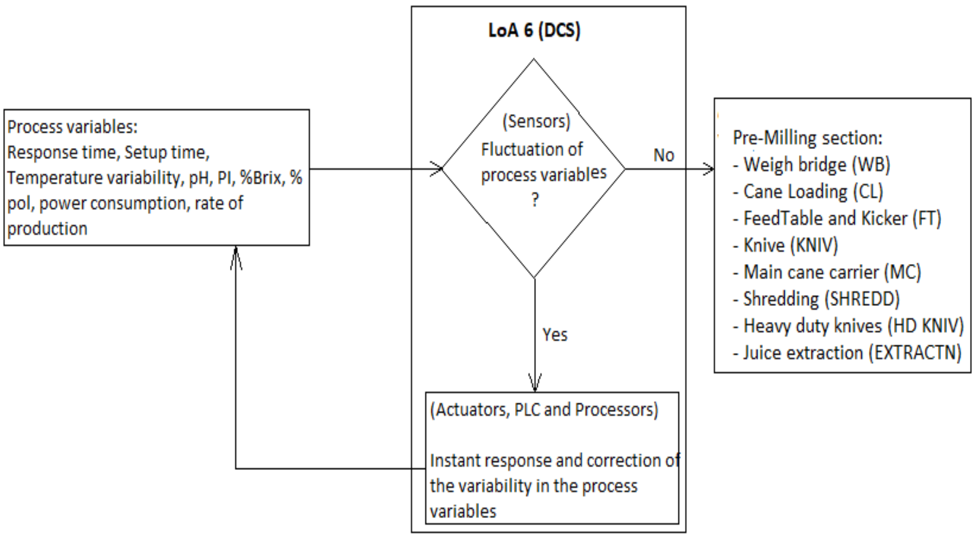

Figure 5. Experimental setup for Level 6 of automation (LoA 6) using DCS

3. Results and Discussion

3.1. %Brix

The convectional mill tandems (LoA 4) recorded the least % brix averagely 16.9%, SCADA (LoA 5) and DCS (LoA 6) recorded averagely 18% each. Since brix % is a measure of the sucrose concentration, it shows that higher sucrose concentrations can be extracted from the sugar cane if a diffuser and the adoption of SCADA or DCS are employed.

3.2. %pol

The conventional automation (LoA 4) recorded a low mean pol value of 15.1% compared to LoA 5 and LoA 6 which recorded a relatively high mean pol value of 16.1% for the final juice extract. The high pol value is as a result of the adoption of HD KNIV stage along the process line when a diffuser which only complies with SCADA or DCS automation systems. In this stage, the cane fibers are further scattered to expose more sucrose which increase the pol% compared to LoA wit mill tandems which do not incorporate the HD KNIV.

3.3. Apparent Purity of the Sugar Juice Extracted

The purity was calculated as the quotient of pol to brix of the sugar juice at the final stage of the extraction and the result depicted by Figure 6.

The graph indicates that the purity of sugar juice when conventional automation (LoA 4) is employed is relatively low with a mean value of 86.5% compared to when SCADA and DCS are used where a mean purity level of 89.6% was realized. Therefore, with LoA 5 and 6, the purity of the sugar will be high as described and this consequently gives high quality of the sugar production compared to the conventional automation.

The experiment was a randomized block with two factors (LoA and P.Stage) investigated on three key indicators that affect the quality of sugar produced through the purity of the juice extract namely PI, % brix and pH variability. There were 7 replicates for each separate treatment levels under investigation. The analysis indicated that apparent purity of the juice extracted and subsequently the quality of production is directly proportional to the three key performance indicators and this concurs with Martinez et.al, 2001 who alluded that optimum production quality can be attained when the mentioned manufacturing indicators increases. This is summarized in both the probability plot and the summarized ANOVA table shown in Figure 7 and Table 2.

From Table 2, the p-values for the LoA given as **0.000** is less than 0.05. This implies that the effect of LoA on the juice purity is significant. Thus, the mean %purity is different for the different LoA. But this also depends on the respective process stages involved. This model explains **99.30%** of the variation in % purity when you use it for prediction. This is good for comparing different % purity models since R^2 is maximum.

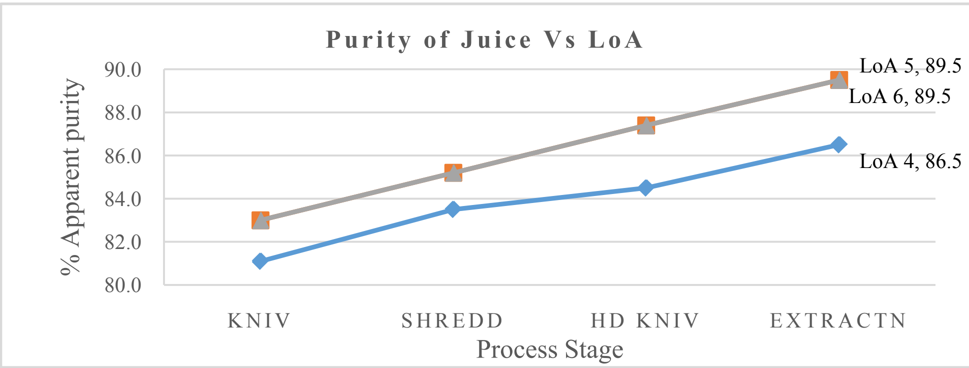

Figure 6. Apparent purity graph of the sugar juice extracted (Source: *Author*, 2019)

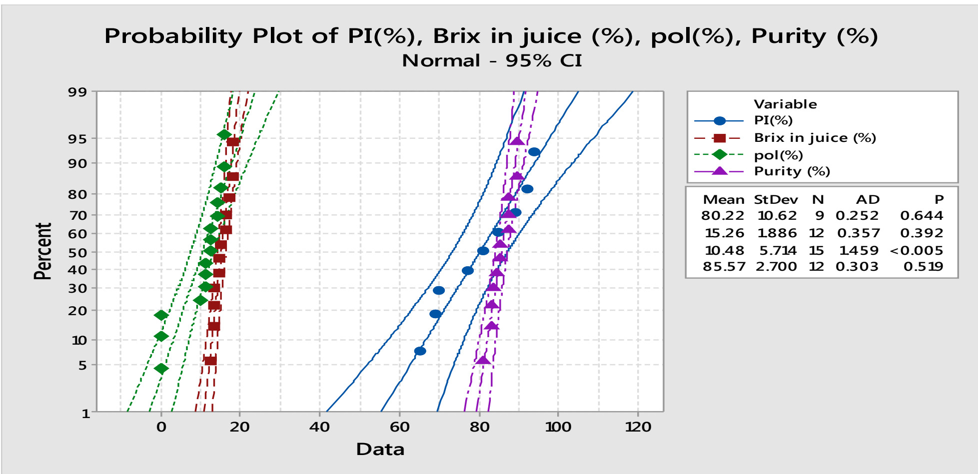

Figure 7. Probability plot of PI, % brix, % pol and apparent purity for 5 - 95% CI (Source, Field data, 2019)

Table 2. Analysis for impact of lean automation on quality sugar production (Source: Field data, 2019)

Description	LoA	No. of P.stages	Mean	Variance	Test for significance (ANOVA)
PI	LoA 4 LoA 5 LoA 6	3 3 3	77.0% 80.7% 83.0%	144.0 132.3 147.0	F_{Calc} = 29.06 F_{Crit} = 6.94 P-Value = 0.004 α = 0.05 DF = 2 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level
% brix	LoA 4 LoA 5 LoA 6	4 4 4	14.6 15.6 15.6	4.46 3.82 3.82	F_{Calc} = 85.49 F_{Crit} = 5.14 P-Value = 0.000 α = 0.05 DF = 2 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level
% pol	LoA 4 LoA 5 LoA 6	4 4 4	12.3 13.5 13.5	4.40 4.52 4.52	F_{Calc} = 124.38 F_{Crit} = 4.76 P-Value = 0.000 α = 0.05 DF = 2 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level
Apparent purity	LoA 4 LoA 5 LoA 6	4 4 4	84.15 86.27 86.27	5.04 7.85 7.85	F_{Calc} = 50.2 F_{Crit} = 5.14 P-Value = 0.000 α = 0.05 DF = 2 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level

From the coefficients, all the levels of both LoA and P.Stage depicted p-values less than α=0.05. Therefore, the analysis is significant and consequently, the effect of one predictor does not depend on the value of the other predictor. Also, The VIFs are all less than 5, which indicates that the predictors are not highly correlated. From the regression equations, employing Conventional automation (LoA = 4) in the 4 process stages applicable gives a mean %purity of 84.15%, while SCADA (LoA = 5) and DCS (LoA = 6) results to 86.275% each. This is evidence that SCADA (LoA = 5) and DCS (LoA = 6) are efficient in enhancing the sucrose concentration and consequently the quality of the sugar juice extract.

This implies that LoA 5 or 6 is the optimum automation level for high juice purity in a sugar industry if quality production is to be achieved. From the probability plot in Figure 7, all the three parameters have $p < 0.05$. Therefore, results are significant.

3.4. Discussion

The quality of sugar production will depend on the quality of sugar juice. This is consequently indicated by the apparent purity of the juice extract which depends on %brix, %pol and the preparation index (PI). Quality of the sugar is determined by the apparent purity of the sugar juice extracted, and this depends further on the nature of the technology employed which dictates the process parameters. A high quality sugar is characterized by a high preparation index (PI), high sugar concentration in the juice (%brix) and (%pol). From Table 2, PI is only measured at the knives, shredders and (High density knives for LoA 5 and 6) while brix and moisture at the extraction stage. In all the stages level 6 recorded the highest PI and Brix values of 94% and 18%, and the lowest moisture in the bagasse of 40% at HD KNV and Extraction stages, compared to level 4 with PI and Brix values of 77% and 17.3% at Shredder and Extraction stages respectively and a moisture content of 50%. This is because in level 6, the process parameters desired to optimize the process, are well monitored and regulated by the real time sensors. Also, the diffusion extraction that is usually fully automated provides an optimum means of extracting all the sucrose from the fibers compared to the mill tendons that are mainly monitored remotely. The diffuser has sensors and actuators that detects a variation in the process parameter and initiate appropriate corrective measure to maintain the optimum values. Level 6 involved the use of these sensing devices, visual and audio devices for communication. Thus adopting levels 5 or 6 the product, the apparent quality of the juice extract will be high, and consequently quality will be achieved and this will provide competitiveness in the sugar industry. This is due to negligible variability in the set process parameters when using LoA 5 or 6, as the response to changes is rapid compared to when LoA 4 is employed. It is therefore observed that the purity is directly proportional to the polarization and inversely proportional to the brix.

This concurs with Xiao [30] in his analysis of sugar cane juice quality indexes who found out that, the effect of polarization (%Pol) and %brix on sucrose content is directly proportional to the apparent purity of the juice. Further, sucrose content is the quotient of %pol to %brix, thus it increases with an increase in %pol and decreases with an increase %brix. This in turn influences the effect of apparent purity and %brix on the sucrose content while maintaining %pol in that, sucrose content decreases with an increase in apparent purity and %brix.

In addition, this conforms to Six Sigma theory that emphasizes on reduction of variations to enhance processes. Through the help of statistical techniques, it is possible to forecast the process outcomes. If unexpected outcome is noticed, then advanced control tools can be used to explain the phenomenon. In relation to lean automation, the integration of lean and proper levels of automation provides a suitable advanced control tool to best understand and identify parameters that affect or vary the process, and hence the overall performance of the organization [31].

According to Winroth, the most important barriers for automation are “technical feasibility”, “education and qualification”, and “economic viability”. Other problems are: adapting the product to automation, the high number of different products and variants, problems to get the money back from the investment and the lack of competence at shop floor level. In the vaster view, he investigated that automation is never related to the production capabilities, the equipment are too complicated and challenges occurs when trying to balance manual approach along the process line. Work in process cost will then be increased by the huge buffers which will adversely increase the cost. This implies that automation is challenging if not well related to the expected long term production strategies [14,16].

Frohm believes that automation involves more complex production processes while in more advanced automation, it include investment cost. This makes it challenging too in machining and manufacturing. Automation is also not suitable if it is applied to newly introduced products, short term products or short product life cycles. Equally variations in the production is challenging to automation. On the contrary, high volumes of production and ergonomics problems cannot be addressed manually. However, as manufacturing becomes more complex as demand for specialized parts increase, higher levels of automation will record undesirable outcomes. It is affirmed that a variation in product and adapting the products for automated production can be a problem. In their research, some firms mentioned untimely automation planning or operator training and also, a challenge in getting payback from automation. Most industries admit that operator’s competence is the main issue when automating activities involving seasonal products. This results to high changeover times and cost-inefficiency [27].

This confers with the objective and findings of this study that, effective lean manufacturing combines both manual and automation to obtain the right type of automation. The concern for engineers is to identify what should and what should not be automated. It was found that level 3 performs well in a lean manufacturing system because the loading and transfer of parts can easily be achieved by operators, making it unworthy to incur the expenses of investing in levels 4 and 5. It also has faster changeover times and improved uptimes than level 4 and 5, since it uses simple and special purpose machines. The higher automation levels will also interfere with the flexibility expected by the customer [18,35]. One concern during employment of lean manufacturing is the conformity of traditional automation to the techniques and principles of lean. Thus, the term lean automation. This is the proper integration of automation into the techniques and principles of lean manufacturing. That is, choosing the appropriate level of automation [21].

The relatively high %pol, %brix and %purity indices were recorded by LoA 5 (SCADA) and 6 (DCS) as compared to LoA 4. Therefore, levels 5 or 6 of automation will provide an optimum apparent purity of juice and subsequent steadfast quality production that will be competitive and this will render the sugar industries sustainable in their production.

4. Conclusion

In summary, automation enhances efficiency, quality and reduces cost of production. It permits much greater manufacturing flexibility, that is, products which have larger volumes or ergonomically awkward to manipulate can be produced in an easy way. Since automation focuses on problems related to human engineering, then it is important to observe level of automation between the human being and the equipment. There are a lot of classifications of level of automation between researchers from five-levels of Harris's classification to three levels of Groover's classification. Meanwhile, the best level which could be called "rightomation" may be Semi-Automation.

In relation to the improvement of sugar quality objective, a high quality sugar is characterized by a high preparation index (PI), high sugar concentration in the juice (%brix) and (%pol). In all the stages level 6 recorded the highest PI and Brix values of 94% and 18%, and the lowest moisture in the bagasse of 40% at HD KNV and Extraction stages, compared to level 4 with PI and Brix values of 77% and 17.3% at Shredder and Extraction stages respectively and a moisture content of 50%. This is because in level 6, the process parameters desired to optimize the process, are well monitored and regulated by the real time sensors. Also, the diffusion extraction that is usually fully automated provides an optimum means of extracting all the sucrose from the fibers compared to the mill tendons that are mainly monitored remotely. The diffuser has sensors and actuators that detects a variation in the process parameter and initiate appropriate corrective measure to maintain the optimum values. Level 6 involved the use of these sensing devices, visual and audio devices for communication. Thus adopting levels 5 or 6 the product, the apparent quality of the juice extract will be high, and consequently quality will be achieved and this will provide competitiveness in the sugar industry. This is due to negligible variability in the set process parameters when using LoA 5 or 6, as the response to changes is rapid compared to when LoA 4 is employed. It is therefore observed that the purity is directly proportional to the polarization and inversely proportional to the brix.

5. Recommendation

Quality of sugar was demonstrated by the apparent quality of the juice extract when respective LoA was employed. Good quality depends on the % PI and sugar concentration (%brix and %pol). The results revealed that LoA 6 recorded the highest %PI and %Brix and a reduced moisture content, followed be LoA 5. Unlike in LoA 4 which was contrary. In LoA 6, the real time sensors monitors and regulates parameters to the optimum process range, thereby giving good quality products and consequently, a desired quality of sugar. In Level 5 (SCADA) or Level 6 (DCS) automation will provide a steadfast quality production that will be competitive and this will render the sugar industries sustainable in their production.

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