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IMPACT OF LEAN AUTOMATION ON ADAPTIVE CONTROL FOR IMPROVED REAL-TIME PROCESS CONTROL IN SUGAR INDUSTRY: CASE OF KENYA

Osore E.A.E, Ogola J.M and Madara O.M
Department of Mechanical and Manufacturing Engineering, School of Engineering, University of Nairobi, Nairobi, Kenya, Nairobi
E-Mail: eebinga@yahoo.com

ABSTRACT

The basic criterion of performance in a production system is response time and variability of process parameters, and it is reasonable if all of these are at their lowest value to demonstrate the rapid rate at which an anomaly can be detected by the system and appropriate action taken. With lean automation technique in the sugar industry, process variability and real time control can be monitored. Also, to note is the consistency of the response times where sharp variations will imply erroneous system operation. This technology is achievable through the different levels of automations that sugar industries adopt. Thus, an analysis of the different levels of automation was carried out at different stages of pre-milling process of sugarcane to determine the optimum automation level for adaptive control in a case sugar company. It was found that level 4 of automation had a slow response to anomaly with the longest mean response time of 3.33 minutes compared to levels 5 and 6 which depicted a rapid response to anomaly with the shortest response time of 0.54 min. Also, conventional automation (LoA 4) resulted to an average temperature variability of 2.75 ºC. While the SCADA (LoA 5) and DCS (LoA 6) showed no temperature variability in the three process stages. Thus, adopting levels 5 or 6 the process parameters are controlled and maintained at the optimum levels and provide a steadfast real time monitoring, control and maintenance of process parameters that will enhance quality production.

Keywords: lean automation, level of automation (LoA), real time, process variability.

1. INTRODUCTION

The impact of lean automation was analyzed based on its ability to improve on the adaptive real time control of processes. The lean automation was accomplished through the integration of three different levels of automation in a lean system of sugar production.

The Kenya's manufacturing industry, in which the sugar industries belongs, has declined in its GDP contribution. The stagnation has been at an average of 10% for more than ten years, with Sugar industry contributing 41% decrease in manufactured products. The Kenya vision 2030 stipulates that the industry should account for a GDP of 20%. Attaining this goal needs that the underlying constraints which hinder rapid growth be addressed. As reviewed by Ondiek and Kisome (2013), In spite of the availability of 11 sugar companies in Kenya as highlighted by KESREF (2010), sustainability and self-sufficiency in sugar production continues to drop as consumption demands continues to increase. Several challenges like high cost of production continues to affect the performance of sugar industries depicted by undesirable process efficiencies and productivity with average sugar productivity of 85%, which is below 92% recommended world average. In Kenya, the sugar production cost is approximately Ksh 46,000 per metric ton, and this is almost twice that of countries like Swaziland in Southern Africa register which is Ksh 24,000, KESREF (2010) confirms. It will be beneficial therefore, if sugar industries in Kenya can give consideration to the holistic application of key components of lean thinking so that they can reap maximally and more importantly enhance their process performance among them lead time. These lean techniques among them employee involvement, visual display and control, 5S, and standardization are applied prior to adoption of advanced techniques like production smoothing and value stream mapping. This is because the advanced methods can only be implemented when there is good quality, stable machine condition and good layout. Current studies in the sugar industries show that, instead of a holistic approach, lean thinking is not embraced or employed selectively with no regard to its knowledge and principles. The optimum outcomes of a production system therefore, requires a proper determination and integration of all the related and associated advanced technology. Thus, the need to investigate the impact of integration levels of automation with a holistic implementation of lean manufacturing techniques to satisfy customer needs. With the help of process indicators such as lead and cycle times, product quality and frequency of injuries, the effectiveness of this integration can be evaluated, Ondiek and Kisome (2013). Therefore, a proper integration between lean techniques and optimum 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 sugar industry will be realized when lean approach is applied full prior to appropriate selective automation. Thus, the need to assess the potential of integrating lean techniques with appropriate level of automation in lean automation on adaptive control.

With lean automation approach, a process can be made lean and be automated simultaneously. Automation is mainly employed to increase outputs and reduce process times, but these cannot be compared to the productive lean parameters like improving maintenance, enhancing cellular modules and reducing set up time. Automation with a sole intention to increase output with no consideration to the effect on the downstream operations, can lead to occurrence of new bottlenecks in the process flow and poor material flow that makes change very costly. Womack *et al*. (1990) found that competitive markets such as lean manufacturing that are aimed at saving cost have influenced many industries like motor industry especially Toyota. Lean manufacturing focuses on the reduction of waste in terms of scrap, manpower, high inventory and work in process, process complexity, improper space utilization, high investment on equipment among others. Jackson *et al*. (2011) asserts that the adoption of lean techniques has often enhanced competitive process performance in industries. In addition, industries can adopt advanced technology like automation to further improve manufacturing competitiveness.

Granlund (2012) alluded that, automation as an advanced manufacturing technique, is mainly divided into two categories namely: mechanization and computerization. Mechanization is related to the physical flow of goods while computerization is the flow of information. According to Frohm (2006), automation can lead to many benefits depending on the type of industry, among them: improved working environment, increased throughput, flexible material handling, less workforce, improved productivity, reduced costs, and improved quality. However, in lean environments, if the same automation is not well planned, it may cause challenges ranging from maintenance, difficulties in visualization, time consumption, and difficult machine-human interface.

According to Garcia (2013), any industrial activity can either lead to value addition or cost addition (waste). Value addition is only when there is 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 therefore, needs elimination. Resurgence manufacturing sector in the world and adoption of traditionally value chains, poses a threat in manufacturing's world order. Yet, the current environment in the manufacturing sector provide a competitive opportunity for transition to an advanced level. To achieve his transition, industries should not just look at product innovation and forget the process that will translate that product to the expected customer satisfaction. Process performance can only be realized through the advanced manufacturing techniques which provides a significant contribution to industries competitiveness (European Commission, 2013). In manufacturing, process improvement is vital in modifying and transforming raw materials into final product. In response, Western companies adopted crucial changes to their operations, by mimicking the JIT (just-in-time) and adoption of TQM (total quality management) processes adopted by the likes of Toyota (Westkämpfer *et al*., 2011).

1.1 Conceptual Synergy

The research was guided by three theories namely: theory of constraints (TOC), lean manufacturing and six sigma. The three theories are geared towards improving the process performance and they collaborate in terms of general criticisms on the cause of industrial failure. In addition, 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 with the aim of achieving increased outputs. Consequently, it conforms to six sigma in that when the weak cell is improved, there will be less process variations and this will improve quality. Ultimately, all the models derive at attaining improved quality and subsequently effective industrial performance.

1.2 Waste Reduction

As reviewed by Shaman and Sanjiv (2013), 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 (Upadhye, Deshmukh, & Garg, 2010). 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 he production cost will be low (Seth & Gupta, 2005; Dennis, 2007).

Also, Zafarzadeh (2013) asserts that emphasize should be concentrated on the smooth flow of those activities that only add value. In line 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 important 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 (Liker, 2004).

1.3 Lean Thinking

Automation provides for visual control where the current state of processes can be monitored and any issues arising are immediately attended to by the human. *Jidouka* originally meant automation, but was changed to autonomation at Toyota to mean *with human touch*. This meant that *jidouka* was to be as intelligent as human, that is, self-transformation with human touch (Hedelind and Jackson, 2008b). In the automation of lean manufacturing environment, the aim is to ease job design, improve existing production principles, eliminate waste, ease production process, provide flexible automation, make the processes self-correcting, enhance easy visual inspection of the production line and eliminate inventory through integration of production scheduling and automated equipment. (Orr, 1997).

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. This is a result of absolutely investing the capital in the automation of equipment, process and product (Orr, 1997).

Lean automation can enhance the repair and maintenance of processes since they can incorporate maintenance programs like predictive, preventive and total productive maintenance. This will in turn maximize reliability of lean automated equipment and continuous improvement by the trained staff. Through the use of reliable equipment and robustness, lean automation will minimize over complicated practices. This will ease configuration, enhance visual inspection and reduced cycle times. Some of the key-enablers in the Lean Robotics which are vital for future robotic working cells are: increased ease-of-use, intuitive user interfaces, and better ways to visualize what is going on in the cell and focus on simplicity and usability (Hedelind *et al*., 2008a).

Lean Automation aims at improving cost effective methods in the production line. Leanness does not necessarily mean lowest investment cost, but the total investment cost will be lower compared with the traditional route because all matters are “on the table” from the beginning and all eventualities are considered (Hollingum, 1994). Harris and Harris (2011) stated that a manufacturer of lean equipment should have a knowledge in machine design and prospects of different types of automation. The knowledge will help in achieving flexibility and efficiency in the manufacturing process. Lean manufacturing is implemented to enhance flow while automation is chosen and integrated into that flow to improve it. Thus, the optimum level of automation is crucial.

Adding together what all researchers believe, many organizations adopted lean manufacturing methods to ensure competitiveness through technology trends. Lean philosophy helps to ease automation of a company due to increased quality and short cycle times. Lean automation can employ both automatic and manual principles. However, it first need to adopt automation onto the practices and principles of lean manufacturing. Lean automation can then be described as the approach of applying the optimum quantity of *smart* on a task and can be utilized for faster product, lower inventory levels, simplifying operation processes, increasing turnover rates, improving quality and maximizing the reliability of equipment.

1.4 Lean Automation

To be the strongest competitor, a company should manufacture the most number of parts within the shortest time and lowest costs. In many cases, this can be through adopting lean manufacturing methods like continuous improvements. But this alone will not help the industry to forecast and monitor the trends in technology and demand in the market, gauge their competitive viability, create scenario reports and sensitivity analysis (Chen, 2010).

Thus depending on the method and level upon which automation has been adopted, lean manufacturing will have the following impacts: (Orr, 1997).

- Automation may be designed for specific attributes only like flexibility.
- Cycles times through design for assembly and quality function deployment can be shortened.

Hoque (2000) asserted that JIT implementation can facilitate automation. Thus, JIT should first be implemented so that manufacturing processes can be simplified before automation is sought. This may respond to increased quality and shorter cycle times.

1.5 Response Time in a Production System

The basic criterion of performance in a production system is response time. In ordinary production processes, the response time is measured in the range of five to ten millisecond. Thus, the response time in a process is reasonable if it is at its lowest value to demonstrate the rapid rate at which an anomaly can be detected by the system and appropriate action taken.

In a case of the computer processor, to check whether the performance of a CICS® system is in line with the system's required capability, then investigations should be on the hardware, the software, and the applications that are in the installation. However, response time depends on the speed of the processor, and on the nature of the application being run on the production system. Thus the shorter the response time, the more rapid a process will be executed in a production system. Also, to not is the consistency of the response times. Sharp variations will imply erroneous system operation. (Colledani, 2006).

The impact of lean automation was analyzed based on its ability to improve on the adaptive real time control of processes. The lean automation was accomplished through the integration of three different levels of automation in a lean system of sugar production. Based on IEEE POSIX Standard (Portable Operation System Interface for Computer Environments), a real-time system is one in which the correctness of a result not only depends on the logical correctness of the calculation but also upon the time at which the result is made available (Gambier, 2004). Also, Gambier (2004) asserted that, the correctness of an output in a real-time monitoring system does not only depend on the logical accuracy of the calculation but also on the time at which the output is displayed. According to Gambier (2004), this assertion validates the importance of time factor for a real time setup in any manufacturing and industrial system, and that there exist timing constraints which will always hinder cycle times of manufacturing tasks. As a result, these tasks must be able to synchronize with the real-time events in the external environment within the industry. Therefore, a

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real-time setup must synchronize with the external events associated with it.

Martinez noted that the effectiveness of an automated lean technique to provide real time monitoring is subject to the response time and process parameter variability within the system. The lower the response time and variability in process parameters, the better the performance of the level of automation in enhancing real time monitoring of the manufacturing process and vice versa.

1.6 Sigma Level for Sustaining Control

According to Garcia (2013), the following are the sigma levels for control monitoring:

- 5 to 6s: Six Sigma automated process is autonomously designed to monitor and automatically eliminate or adjust any error condition with no human intervention.
- 4 to 5s: the automatic process will shut down the operation in case of an error and prevent any further activities until the necessary action is undertaken.
- 3 to 4s: error detection will prevent a part from moving to the next stage on a production line.
- 2 to 3s: statistical process control on dependent variables with their cause are spotted and amended by trained operators in line with the rules and regulations.
- 1 to 2s: statistical process control on independent variables are spotted and corrected y operators.
- 0 to 1s: design of process audits and statistical operational plans through training programs

2. MATERIALS AND METHODS

2.1 Study Area

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

a) Stop watch
b) Visual display cameras and screens to provide high level of automation
c) Temperature sensor and probes provide high level of automation
d) SCADA platform provide high level of automation
e) DCI platform provide high level of automation

2.3 Measurement Procedure

a) 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.
b) 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.
c) 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.
d) Level 5 involved the use of SCADA system incorporated with autonomous independent machines within work cells.
e) Level 6 involved the use of DCS incorporated with autonomous independent machines within the entire plant or wide area.
f) 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:

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Table-*Error! No text of specified style in document.***-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 Setups

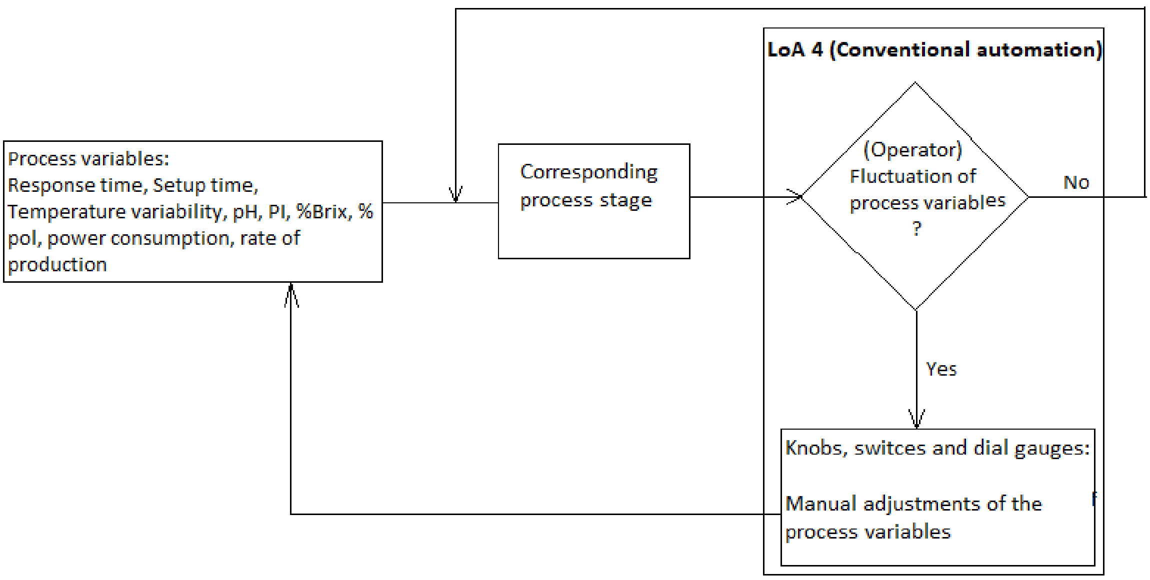

Figure-*Error! No text of specified style in document.***-1.** Experimental setup for Level 4 of automation (LoA 4) using control circuits.

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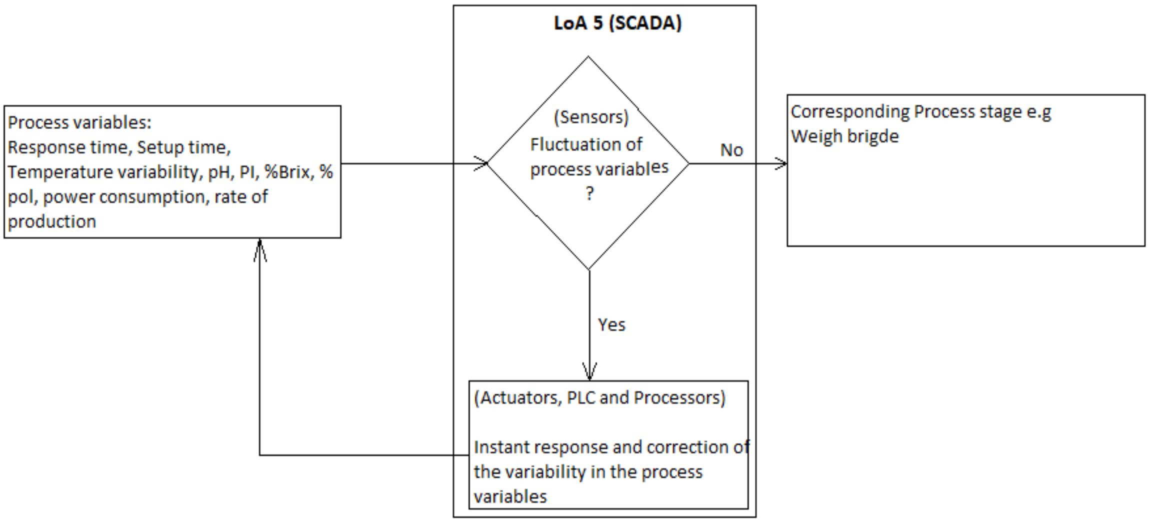

Figure-Error! No text of specified style in document.**-2.** Experimental setup for Level 5 of automation (LoA 5) using SCADA.

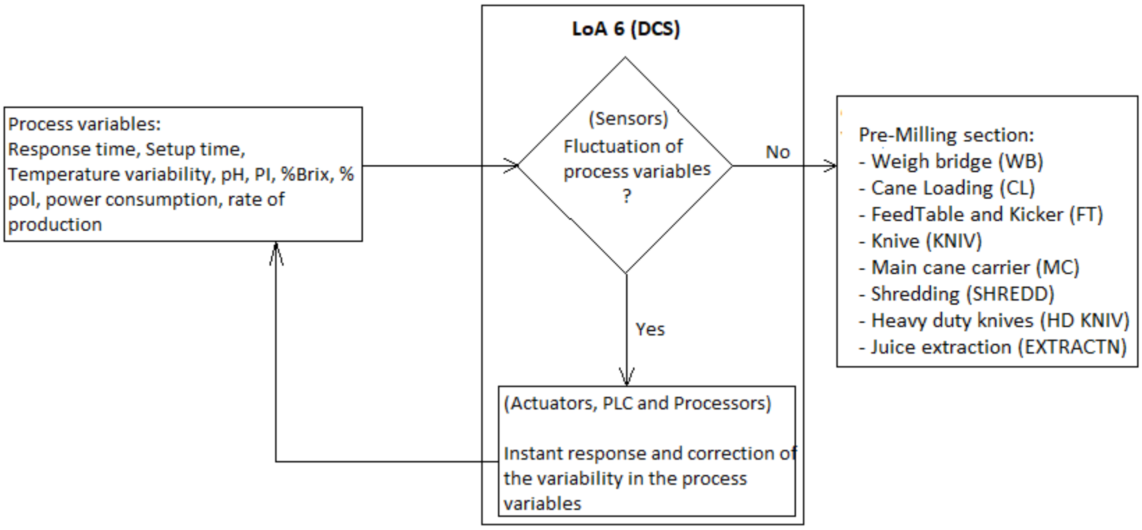

Figure-Error! No text of specified style in document.**-3.** Experimental setup for Level 6 of automation (LoA 6) using DCS.

3. RESULTS AND DISCUSSIONS

In this experiment, adaptive real time control was demonstrated by three variables that were measured at the respective stages of the sugar pre-process line for different levels of automation. They included: response time to anomaly, process temperature variability and the process pH variability. The rate at which the anomaly was corrected and the variability in process parameters when using different levels of automation were analyzed to ascertain the level of automation that will give the best adaptive control, and whether it is dependent on the process stage.

The experiment was a randomized block with two factors (LoA and P.Stage) investigated on three key indicators that affect adaptive control through real time monitoring namely response time, process temperature variability and pH variability. There were 7 replicates for each separate treatment levels under investigation. The analysis indicated that real time monitoring and subsequently adaptive control is inversely proportional to the three key performance indicators and this concurs with Martinez *et al*, 2001 who alluded that for optimum real time monitoring, these mentioned manufacturing indicators must decrease. This is summarized in both the probability plot and summarized ANOVA table shown below.

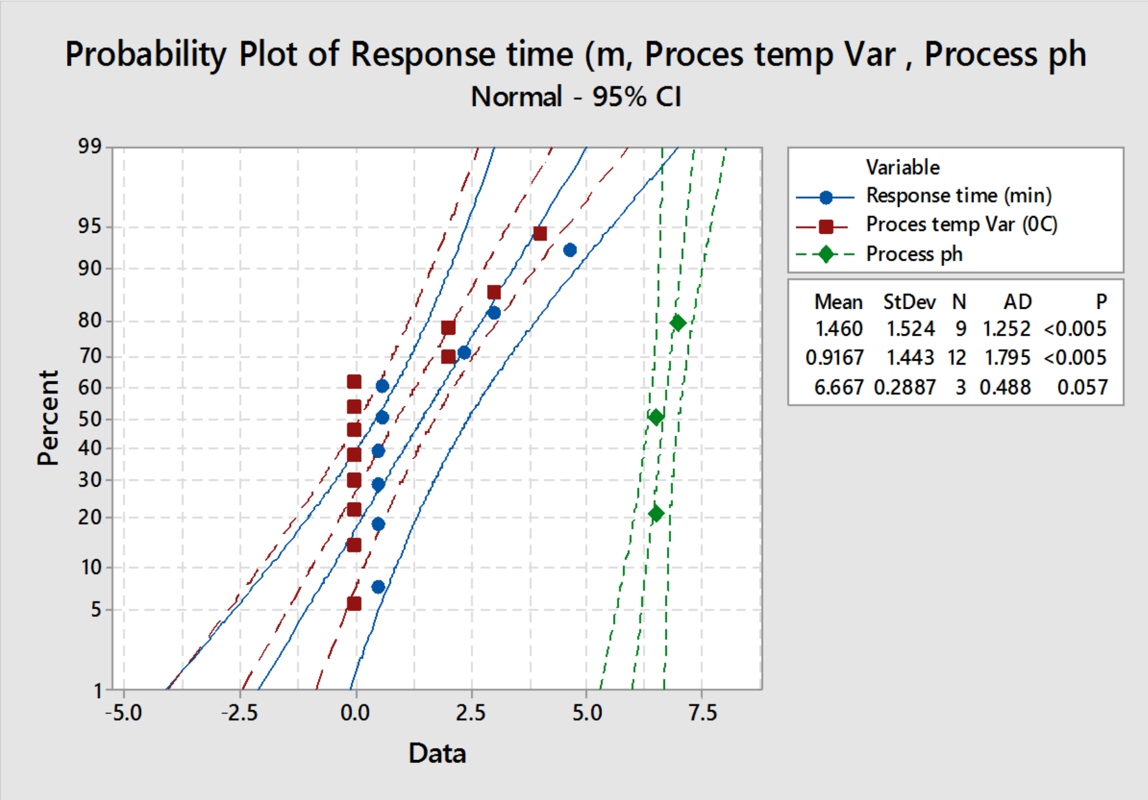

Figure-Error! No text of specified style in document.**-4.** Probability plot of response time, process temperature variability and process pH for
5 - 95% CI (Source, Field data, 2019).

Table-Error! No text of specified style in document.**-2.** Analysis for impact of lean automation on adaptive process control (Source: Field data, 2019).

Description	LoA	No. of P. stages	Mean	Variance	Test for significance (ANOVA)
Response time to anomaly	LoA 4 LoA 5 LoA 6	3 3 3	3.33 0.54 0.54	1.3894 0.0017 0.0017	F_{Calc} = 16.21 F_{Crit} = 6.94 P-Value = 0.012 α = 0.05 DF = 2 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level
Process temperature variability	LoA 4 LoA 5 LoA 6	4 4 4	2.75 0 0	0.9167 0 0	F_{Calc} = 33.00 F_{Crit} = 5.14 P-Value = 0.001 α = 0.05 DF = 3 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level
pH variability	LoA 4 LoA 5 LoA 6	1 1 1	0.2 0 0	0	F_{Calc} = 65535 F_{Crit} = 0 P-Value = 0 α = 0.05 DF = 0 $F_{Calc} > F_{Crit}$ and α > P-Value Com = Significant at 0.05 level

From both **Figure-**Error! No text of specified style in document.**-4** and Table-Error! No text of specified style in document.**-2**, adaptive control in the sugar processing was evaluated by three variables namely: response time, process temperature variability and the process pH control. The response time to an anomaly conducted in three stages showed that level 4 of automation had a slow response to anomaly with the longest mean response time of 2.4-4.6 minutes compared to levels 5 and 6 which depicted a rapid response to anomaly with the shortest response time of 0.5 min. Also, conventional automation (LoA 4) at the chopping stage (HD KNIV), shredding and juice extraction resulted to an average temperature variability of 2ºC, 3ºC and 4ºC respectively. While the SCADA (LoA 5) and DCS (LoA 6) showed no temperature variability in the three process stages. The lowest temperature variability in the conventional automation was 1ºC recorded at HD KNIV (replicate 1) and the highest temperature variability being 5ºC at SHREDD (replicates 3) and EXTRACTN (replicate 1, 3, 4, and 5). It is evident that LoA 4 has the highest temperature variability in the three process stages while both LoA 5 and 6 indicated the lowest temperature variability. Unlike in levels 5 and 6 where set temperatures are easily monitored, controlled and maintained by the system. This applies to pH control too. Thus, adopting levels 5 or 6 the process parameters are controlled and maintained at the optimum levels. This is in line with the requirement that the optimum process temperatures at the Knives, shredders and heavy duty knives should be maintained at 60ºC, while at the extraction stage 85ºC should be maintained to enhance dissociation of sugars from the fibers. Also, a mild acidic condition of pH 6.5 should be maintained to prevent the survival of bacteria and microorganisms

From the analysis of variance, the p-values for LoA and stage respectively $< \alpha = 0.05$, it is concluded that there is a statistically significant association between the response variables and the term. The modal explains 89.51% of the variation in the response. S indicates that the standard deviation between the data points and the fitted values is approximately 0.698 units.

From the coefficients table, all the variance inflation factor (VIF) are in the range of 1 to 5 thus the parameters are moderately correlated, thus no much multicollinearity in the variances.

Furthermore, the model equation for the response time, process temperature monitoring and pH variability depicts increasing values in level 4 due to (+) sign and reducing values both in levels 5 and 6 due to (-) sign. This implies that LoA 5 or 6 is the optimum automation level for real time monitoring in a sugar industry if adaptive control is to be achieved. From the probability plot in

Figure-Error! No text of specified style in document.**-4**, all the three parameters have $p < 0.05$. Therefore, results are significant.

This conforms to the findings of Gambier (2004) who asserted that, the correctness of an output in a real-time monitoring system does not only depend on the logical accuracy of the calculation but also on the time at which the output is displayed. According to Gambier (2004), this assertion validates the importance of time factor for a real time setup in any manufacturing and industrial system, and that there exist timing constraints which will always hinder cycle times of manufacturing tasks. As a result, these tasks must be able to synchronize with the real-time events in the external environment within the industry. Therefore, a real-time setup must synchronize with the external events associated with it.

According to Panpae *et al* (2008), 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, the extent of 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. This critical contribution of pH, temperature and response time regulation serves a good reason for all the local sugar industries to adopt LoA 5 (SCADA) or 6 (DCS) for its processes.

In addition, it concurs with Six Sigma theory, which 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 (Dave, 2015)

Therefore, levels 5 or 6 of automation will provide a steadfast real time monitoring, control and maintenance of process parameters that will enhance quality production.

4. CONCLUSIONS

In relation to Adaptive control in the sugar processing objective, the response time to an anomaly conducted in three stages showed that LoA 4 had a slow response to anomaly with the longest mean response time of 2.4-4.6 minutes compared to LoA 5 and 6 which depicted a rapid response to anomaly with the shortest response time of 0.5 min. Also, conventional automation (LoA 4) at the chopping (HD KNIV), shredding and juice extraction stages resulted to an average temperature variability of 2ºC, 3ºC and 4ºC respectively. While the SCADA (LoA 5) and DCS (LoA 6) showed no temperature variability in the three process stages. The lowest temperature variability in the conventional automation (LoA 4) was 1ºC recorded at HD KNIV (replicate 1) and the highest temperature variability being 5ºC at SHREDD (replicates 3) and EXTRACTN (replicate 1, 3, 4, and 5). It is evident that LoA 4 has the highest temperature variability in the three process stages while both LoA 5 and 6 recorded the lowest temperature variability. Thus LoA 5 and 6 provides set temperatures and pH to be easily monitored, controlled and maintained by the system... Thus, adopting levels 5 or 6, the process parameters will be controlled and maintained at the optimum levels. Therefore, levels 5 or 6 of automation will provide a steadfast real time monitoring, control and maintenance of process parameters that will enhance quality production.

RECOMMENDATION

Adaptive control is highly dependent on real time monitoring of process parameters. The more rapid parameter variability are monitored and controlled, the better the real time monitoring and consequently the better the adaptive control of the automation system. Real time monitoring was tested using three major parameters namely response time, temperature variability and pH variability monitoring along the process line. The results demonstrated that either LoA 5 or 6 recorded the shorter response times and low variability in temperature and pH changes, as compared to LoA 4. The minimal variabilities in process temperatures and pH, and the rapid responses to changes in the slight variabilities confirms the potential of LoA 5 (SCADA) or LoA 6 (DCS) as the optimum levels of automation for real time monitoring, and thus for good adaptive control monitoring in sugar industries. Therefore, Level 5 (SCADA) or Level 6 (DCS) automation can provide a steadfast real time monitoring, control and maintenance of process parameters that will enhance quality production in sugar industries.

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