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Prospects of diffusion as a Six-Sigma automation in enhancing continuous improvement of cane juice extraction in Kenya

E. A. E. Osore¹*, J. M. Ogola¹ and M. M. Ogot¹

Abstract: Continuous improvement encompasses identification of threats and opportunities, proposal and implementation of the solutions, and lastly monitoring and evaluation of sugar production. Cane juice extraction in Sugar production is achieved through two techniques namely milling tandem or diffuser. In Kenya, out of the 12 sugar industries available, the means of juice extraction in 11 industries is by milling tandems. Only one industry has both diffuser and milling tandems with conventional automation. However, sugar productivity from these industries is 85% which is lower than 92% recommended worldwide. The cost of production of 46,000/MT is twice that of small economy countries like Swaziland and Uganda. This can be attributed to the type of juice extraction technique which will determine the rate of sugar production. It is therefore aimed to assess the impact of a diffuser which employs Six-Sigma automation on the improvement of the production. A case company having both diffusion

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PUBLIC INTEREST STATEMENT

In Kenya, sugar industry is one of the promising manufacturing sectors of the economy. There are 11 sugar companies that are not surviving competition from similar companies globally. This is majorly attributed to technological inadequacy. Of importance, it is observed that all the sugar companies in Kenya are utilizing mill tandems which are automated with control, safety and regulatory switches in the pre-milling section to crash and extract juice from the sugarcane. These Mill tandems are said to utilize the fourth level of automation. However, their adoption impacts negatively in terms of energy efficiency, quality of juice extracted and unit cost of sugar production due to high fuel consumption, high variability of process control and low efficiency of mills respectively.

Therefore, to attain continuous improvement and meet a competitive sugar production industry, it was important to ascertain the impact of diffusers incorporating self-monitoring automation mechanism called Six-Sigma automation utilizing Supervisory control and data acquisition (SCADA) or distributed control system (DCS), referred to the fifth or sixth levels of automation respectively.
and milling was selected and operations compared. It was found that 98.5% of sugar extraction from diffuser with 6-σ automation can be achieved compared to 80% in mills and a production rate of 360 T/h compared to 100 T/h in mills. However, extensive cane preparation has to be achieved.

**Subjects:** Industrial Engineering & Manufacturing; Manufacturing & Processing; Production Systems & Automation; Manufacturing Engineering Design

**Keywords:** diffuser; mill tandems; 6σ-automation; continuous improvement; lean automation

### 1. Introduction

The Kenya’s manufacturing sector which encompasses the sugar industry has stagnated in its contribution to Gross Domestic Product (GDP) at an average of 10% from the year 2008 to 2014, thereafter it declined to 8.4% in 2017 (Kenya National Bureau of statistics, 2018). It is apparent that instead of industrializing, Kenya is deindustrializing (Kenya Association of Manufacturers, 2019). The Kenya vision 2030 stipulates that this sector should account for 20% of the GDP. Achieving this goal requires addressing of constraints that hinder faster growth among them technological advancement (Otieno, 2010). The Kenyan sugar industry has 11 operational sugar factories, which operates on conventional mill tandems (Figure 1) for juice extraction and equipped with level 3 of automation (Kenya National Assembly, 2015). Despite the availability of these companies, as reviewed by Ondiek and Kisombe (2013), sustainability and self-sufficiency in sugar production continues to drop as consumption demands increases. Several challenges like high cost of production continues to affect the performance of sugar industries depicted by low average productivity of 85%, which is below 92% recommended worldwide. In Kenya, the sugar production cost is approximately Ksh 46,000/MT, which is almost twice that of countries like Swaziland at Ksh 24,000, Kenya Sugar Board (2010). In addition, Maria (2015) observed that fluctuating demand for sugar exports and their declining production is on a rise yet major sugar industries derive the advantage of being automated. With automation, better process performance and high production are expected. According to Ondiek and Kisombe (2013) production rate as a process indicator can be used to evaluate the effectiveness of technology on continuous improvement of a production line. Current studies in the sugar industries show that advanced technology like Six-Sigma automation has not been embraced or it is 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, this paper investigated the impact of integrating optimum levels of automation with a holistic implementation of lean manufacturing techniques to attain continuous improvement in sugar industries in Kenya. Thus, the need to assess the potential of Six-Sigma automation integrating diffusion technique in enhancing continuous improvement.

The research was guided by the 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 6-σ 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).

2. Literature review

2.1. Continuous improvement

Continuous improvement also known as Kaizen or Toyota technology is a commitment by firms to utilize small and on-going positive changes in reaping transformation in manufacturing with the aim of lowering defects, elimination of wastes, increase productivity, promotion of innovation and enhance employee satisfaction. Continuous improvement encompasses identification of threats and opportunities, propose solutions, implementation of the solutions and lastly monitoring and evaluation. In reference to Delkhosh (2012), 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 (Winroth, Säfsten, & Stahre, 2006; Säfsten, Winroth, & Stahre, 2007).

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. (Winroth, Säfsten, & Stahre, 2007; Orr, 1997). 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 (Ribeiro & Barata, 2011). In addition, there are extreme ordinary situations where human intervention is impractical and thus calls for the implementation of automation. (Harris & Harris, 2008). Examples are hazardous products, sensitive nanotechnology components, accuracy, high tolerance components and strenuous activities. Therefore, automation provides an excellent ergonomics (Kochan, 1998).

Automation requires high investment costs, maintenance and complex interface, specialized training and space utilization among others (Delkhosh, 2012). With these challenges of high automation, it is important to implement just in time before automating. This is because automation aims at increasing improvements on quality and lead times. Thus, it should not be of concern as to whether lean is manual or fully automated, since it can integrate both manual and integrated tasks (Granlund & Friedler, 2012). Therefore, it’s key to determine the optimum automation level in a lean environment to obtain lean automation benefits (Granlund, 2011).

2.2. 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.

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 (Harris & Harris, 2008; Mehrabi, 2002). 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 (Jackson, Hedelind, Hellström, Granlnd, & Friedler, 2011).

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 automation 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 & Jackson, 2008). 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).

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, Jackson, & Hellström, 2008).

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 (2008) 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.

2.3. Sigma level for sustaining control

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

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

2.4. Sugarcane extraction systems

Oliverio, Avila, Faber, and Soares (2014) alluded that the juice extraction can reach only up to 80% with mill tandems, but can be higher when a diffuser incorporated with dewatering mills are used. In relation to lean automation, Six-Sigma emphasizes that the integration of lean
and proper levels of automation will provide a suitable advanced control tool to best understand and identify parameters that affect or vary the process, and hence the overall performance of the organizations. Also, Ali, Arif, Pirzada, Khan, and Hussain (2012) confirms to this finding through his study that to attain a continuous improvement, advanced manufacturing techniques like lean automation should be in place together with lean philosophy that will enable elimination of waste and efficient utilization of resources.

According to Oliverio et al. (2014), Sugarcane juice extraction (Figure 2) is the mill operation that takes place after cane is received, cleaned and prepared, in which the water and sugars contained in the cane are removed. Basically there are two ways to perform this operation commercially: by cane preparation and mechanical squeezing, which is the case of the mills, or by washing the prepared cane in many stages when the sugars are extracted by diffusion in the unbroken cells (around 10% of the cells) and by leaching in open cells (around 90% of cells), the diffusers. As part of the extraction process the following steps were considered: extraction itself and final removal of the bagasse moisture, so that bagasse can be sent to the boilers to be burnt with near 50% of moisture. The goal of extraction is to remove the maximum mass amount of the sugar present in the prepared cane and, at the same time, produce bagasse with suitable moisture content to be burnt in biomass or bagasse boilers.

3. Research methodology

3.1. Study area
A holistic single case design was chosen where the context was the case study industry that practices automation, the case was lean automation, and the unit was the material handling modules or cells. 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.

3.2. 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) Supervisory Control and Data Acquisition (SCADA) platform provide high level of automation
(6) Distributed Control System (DCS) platform provide high level of automation
(7) Polarimetre for measuring the %pol

3.3. Measurement procedure
(1) The pre-process line was categorized into various process stages namely weigh bridge (WB), cane loading (CL), feed tables and kickers, knives (KNIV), main cane carrier, shredder, heavy-duty knives, shredded cane conveyer 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 Distributed Control System (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 continuous improvement on material handling.

The various levels of automation were defined by the following characteristics in Table 1

**Table 1. Characteristics of the three LoA selected (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.
3.4. Experimental set ups

Figure 3. Experimental setup for Level 4 of automation (LoA 4) using control circuits (Source: Author, 2019).

Figure 4. Experimental setup for Level 5 of automation (LoA 5) using SCADA (Source: Author, 2019).

Figure 5. Experimental setup for Level 6 of automation (LoA 6) using DCS (Source: Author, 2019).
4. Results and discussions
In relation to this study, continuous improvement was indicated by the rate of production of the sugar juice extract, and results were as shown in Figure 6.

From the graph in Figure 6, level of automation (LoA) 4 recorded the least loading rate, conveyance rate and the rate of juice extraction for a given production batch. With a loading rate of 250 T/h, the extracted juice was 100 T/h. Comparing this to the rate of production by LoA 5 (Figure 4) and 6 which of 500 T/h each for loading and conveying that yielded juice at the rate of 360 T/h, then it can be observed that LoA 5 and 6 which utilizes SCADA and DCS respectively on a diffuser, provides a noticeable improvement in the entire rate of production of the sugar. Thus, these are the optimum options to be adopted in the sugar industries if increased production is to be realized.
The experiment was a randomized block with two factors (LoA and P. Stage) being investigated on PI. There were seven replicates for each separate treatment levels under investigation. The linear model for the production rate was analysed as shown in the table below.

From analysis of variables in Table 2, the effects of LoA and the process stage were assessed. The commonly chosen \( \alpha \)-level of 0.05 was chosen and the results indicate the following: The \( p \)-value for both the LoA and P. Stage factor given as 0.000 and 0.001 are less than 0.05. Since these are less than the chosen \( \alpha \)-level of 0.05, it means the effect of LoA and P. Stage on the rate of production is significant. This implies that, the mean rate of production is different for the different LoA and P. Stages. From the model summary, \( R^2 \) is 99.97%, and adjusted \( R^2 \) equals 99.93% which indicates that the model explains 99.97% of the variation in production rate when you use it for prediction. This is good for comparing different rate of production models since \( R \) is maximum.

From the regression equation, employing Conventional automation (LoA = 4) in the two process stages applicable gave a mean rate of production of 175 T/h (345–170 + 71.67–71.67), while SCADA (LoA = 5) and DCS (LoA = 6) results to a mean rate of production of 430 T/h each (345 + 85 + 71.67–71.67). This was evident that SCADA (LoA = 5) and DCS (LoA = 6) are efficient in enhancing an increase in the sugar juice extraction and consequently the overall rate of production.

For relationship analysis, let:

\[ H_0: \text{There is no linear relationship between LoA and rate of production (all the population means for the various treatments are equal)} \]

\[ H_1: \text{There exist a functional relationship between LoA and rate of production. True if } F_{\text{cal}}>F_{\text{crit}}. \]

Since for LoA, \( F_{\text{cal}} (2601) > F_{\text{crit}}, (6.94) \), \( H_0 \) is rejected and it is concluded that at 95% confidence level, there is sufficient evidence that there exist a relationship between LoA and power consumption. Similarly for P. Stage, \( F_{\text{cal}} (1849) > F_{\text{crit}}, (6.94) \), thus \( H_0 \) is rejected and it is concluded that at 95% confidence level, there is sufficient evidence that there exist a relationship between P. Stage and power consumption.
Continuous improvement is simply the improvement of the customer’s value through improved product quality and increased production. This can only be achieved through advanced manufacturing techniques that will enable real time and adaptive control of parameters to have faster productions. Alternative approach can be implementation of waste reduction and efficient resource utilization through strategies like lean manufacturing. In the sugar processing, continuous improvement is realized when there is an increase in the rate of extraction of quality juice, which subsequently increases the rate of quality sugar production. From Figure 7, the rate of production conducted at three LoA indicates that LoA 4 (Figure 3) recorded a low juice extraction rate of approximately 100 T/h (345–170–71.67) compared to levels 5 and 6 which depicted an extraction rate of approximately 360 T/h (345 + 85–71.67).

Thus, from the experimental findings, a diffuser incorporating Six-Sigma automation enhanced an improved rate of production than the both conventional semi-automated and Six-Sigma mill tandems. This conforms to the findings of Oliverio et al. (2014) where the juice extraction can reach only up to 80% with mill tandems, but can be higher when a diffuser incorporated with dewatering mills are used. In relation to lean automation, Six-Sigma emphasizes that the integration of lean and proper levels of automation will provide a suitable advanced control tool to best understand and identify parameters that affect or vary the process, and hence the overall performance of the organizations. In this regard, an autonomous diffuser employing Six-Sigma automation (LoA 5 or LoA 6) provided rapid changeability, reduced variability and changeover flexibility of process parameters, and reduced wastage of resources. These combined attributes of Six-Sigma automation of a diffuser, proposes an optimum advanced technology suitable of attaining continuous improvement and sustainability in sugar industries. Also, Ali et al. (2012) conforms to this finding through his study that to attain a continuous improvement, advanced manufacturing techniques like lean automation should be in place together with lean philosophy that will enable elimination of waste and efficient utilization of resources.

This concurs with the theory of constrains and waste reduction relying on two conceptual relationship of productivity, that is economistic concept which focuses on improving production efficiency by minimizing resource utilization (inputs) to attain goals (outputs) and the engineering concept which looks at the relationship between the actual and expected outputs (reduction of...
### Table 2. ANOVA for rate of production (T/h) versus LoA, P. Stage (Source: Author, 2019)

| Source        | DF | Seq SS | Contribution | Adj SS  | Adj MS  | F-Value | P-Value | Pcrit |
|---------------|----|--------|--------------|---------|---------|---------|---------|-------|
| LoA           | 2  | 86700  | 73.76%       | 86700.0 | 43350.0 | 2601.00 | 0.000   | 6.94  |
| P. Stage      | 1  | 30817  | 26.22%       | 30816.7 | 30816.7 | 1849.00 | 0.001   | 6.94  |
| Error         | 2  | 33     | 0.03%        | 33.3    | 16.7    |         |         |       |
| Total         | 5  | 117550 | 100.00%      |         |         |         |         |       |

**Model Summary**

| S             | R-sq | R-sq(adj) | PRESS | R-sq(pred) |
|---------------|------|-----------|-------|------------|
| 4.08248       | 99.97% | 99.93% | 300   | 99.74%     |

**Regression Equation**

\[
\text{Rate of production(T/h)} = 345.00 - 170.00 \text{ LoA}_4 + 85.00 \text{ LoA}_5 + 85.00 \text{ LoA}_6 + 71.67 \text{ P. Stage}_\text{CL} - 71.67 \text{ P. Stage}_\text{EXTRACTN}
\]

**Coefficients**

| Term   | Coef  | SE Coef | 95% CI           | T-Value | P-Value | Variance Inflation Factor (VIF) |
|--------|-------|---------|------------------|---------|---------|---------------------------------|
| Constant | 345.00 | 1.67    | (337.83, 352.17) | 207.00  | 0.000   |                                 |
| 4      | -170.00 | 2.36   | (-180.14, -159.86) | -72.12  | 0.000   | 1.33                            |
| 5      | 85.00   | 2.36   | (74.86, 95.14)    | 36.06   | 0.001   | 1.33                            |
| 6      | 85.00   | 2.36   | (74.86, 95.14)    | 36.06   | 0.001   | *                               |
| P. Stage | CL     | 71.67   | 1.67             | (64.50, 78.84) | 43.00   | 0.001 | 1.00                           |
|        | EXTRACTN | -71.67 | 1.67            | (-78.84, -64.50) | -43.00  | 0.001 | *                             |

Significance level, \( \alpha = 5\% \); LoA = Level of automation; P. Stage = process stage.
losses in the production lines). Therefore, a diffuser and Six-Sigma mill tandem incorporated with SCADA (LoA 5) or DCS (LoA 6) at all the process stages should be adopted if continuous improvement in sugar industries is to be realized.

Ultimately, the following mathematical model was obtained from the field data as a reference for adoption of the optimum level of automation in improving the rate of production in sugar industries.

\[
\text{Rate of production (T/h)} = 345.00 - 170.00 \text{LoA}_4 + 85.00 \text{LoA}_5 + 85.00 \text{LoA}_6 + 71.67 \text{P. Stage CL} - 71.67 \text{P. Stage EXTRACTN}
\]

From the regression equation, it is evident that LoA 6 (Figure 5) exhibited high rates of production both at the individual process stages (P. Stage) and the overall mean rate of production with respective coefficients summarized in Table 2. This is built on the assumptions that the regression model is linear, the mean of residuals is zero and that there is no perfect multicollinearity as evidenced by low P values and Variance Inflation Factor (VIF) values in Table 2.

5. Conclusion
Continuous improvement focuses on the improvement of the customer's value through improved product quality and increased production. This can only be achieved through implementation of reducing waste and employing strategies like advanced manufacturing techniques that will enable real time and adaptive control of parameters to have faster productions. The rate of juice extraction at LoA 4 was 100 T/h which was low compared to LoA 5 and 6 at a rate of 360 T/h each. The trend was similar to loading and conveyance rates. In this regard, an autonomous diffuser employing Six-Sigma automation (LoA 5 or LoA 6) provided rapid changeability, reduced variability and changeover flexibility of process parameters, and reduced wastage of resources. These combined attributes of Six-Sigma automation of a diffuser, proposes an optimum advanced technology suitable of attaining continuous improvement and sustainability in sugar industries. Therefore, levels 5 or 6 of automation utilizes the efficient shredders that consume less power compared to level 4 that uses high torque knives. Hence, more power required with conventional level of automation. Consequently, this will ultimately increase both the lead and set up times in LoA 4 and thus reducing production rates. Thus, sugar industries have a potential to adopt either SCADA (LoA 5) or DCS (LoA 6) as a fourth industrial revolution technology.

6. Recommendations
Six-Sigma advanced manufacturing techniques will enable real time and adaptive control of parameters leading to faster productions. Thus, a diffuser and Six-Sigma mill tandem will enhance an improved rate of production than the conventional semi-automated mill tandems. It is therefore, highly recommended that sugar industries should adopt the use of Six-Sigma automated diffusers or retrofit the conventional semi-automated mill tandems to Six-Sigma mill if high production rates and consequently continuous improvement is to be realized.
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