Experimental Application of DMAIC for Equipment Efficiency Improvement in Cocoa Processing Plant

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ORIGINAL RESEARCH

Abstract— In dealing with productivity within the manufacturing operations, the first focus is efficiency improvement. Efficiency improvement can be operational efficiency or asset efficiency. Asset efficiency is best explained by Overall Equipment Effectiveness (OEE). Equipment efficiency has been one of the major perennial problems of the cocoa processing plant due to the nature of the raw materials (main crop and lean crop) used. Lean crops proved to be cocoa beans with low quality, low yield, and difficult to process. During lean crop season, equipment efficiency used to drop compared to the main crop. Cocoa processing is the conversion of raw cocoa beans to finished products such as cocoa butter, cocoa powder, cocoa cake, and cocoa liquor. This work looks at the application of DMAIC (Define, Measure, Analyse, Improve, and Control) to improve the equipment efficiency in the cocoa processing plant. The methodology used is DMAIC. The define phase gives definitions and scope of the problem, The Measure Phase applies statistical methods to measure the current situation and analyze the phase that gives a proper root cause analysis of the problem. Improve phase tends to solve and improve the situation. The control phase makes use of Control Charts. The case study factory has its Tempering machine as its bottleneck and this recorded 40% efficiency loss. Its overall standard deviation is 2.8244 before improvement and became 2.20 after improvement. Pareto shows that the biggest problem is from the sector control system. This work concluded that DMAIC is well-suitable as the structured problem-solving tool for the cocoa processing company.

Keywords— Lean Six Sigma, Tempering Machine, DMAIC, Root Cause,

1 Introduction

After the COVID-19, manufacturing industries in Nigeria have been struggling to regain their stability in the areas of productivity and profitability. In the 21st century, operational excellence, continuous improvement, world-class manufacturing, lean manufacturing, Six Sigma, and statistical process control are the common terms used to describe the tools for operational improvement and optimization in today's manufacturing industries. In dealing with productivity within the manufacturing sector, the first point of focus is efficiency improvement. Efficiency improvement can be operational efficiency or asset efficiency. Asset efficiency is best explained by Overall Equipment Effectiveness (OEE) which has three elements, and each element has two variables namely: performance (ideal output and actual output), availability (available and running time), and quality (good product and bad products) (John, 2015). The equipment efficiency talks about the cost associated to the losses from the production line. Lean manufacturing strategies and principles focus on waste elimination and enhancement of operational value stream flow. It makes use of process mapping systems to understand value-added and non-value-added services within the manufacturing processes. Six Sigma strategies are centred around eliminating variations and defects in the manufacturing process. This variation can be from man, machine, method, and materials.

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Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
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Lean Six Sigma strategies and methodologies have emerged as pivotal strategies in enhancing efficiency, improve quality and reducing variations (Adeodu et al. 2021). Equipment efficiency has been one of the major perennial problems of the cocoa processing plant due to the kind of raw materials used. The raw materials are seasonal and out of control for the processors (Helyette & Seth, 2020). Cocoa processing is the conversion of raw cocoa beans to finished products such as cocoa butter, cocoa powder, cocoa cake, and cocoa liquor. There are steps (as seen Figure 1) involved in turning cocoa beans into various cocoa-based products, starting from cleaning raw cocoa beans to remove dust, stones, and other foreign materials with the uses of destoner and beans cleaner. The next stage is drying for easy winnowing and for the winnower to break the cocoa beans into shells and to separate the shell from cocoa Nibs. Also, Cocoa bean treatment (to destroy the micro-organism), roasting (to reduce the moisture), and grounding machine that will turn it into cocoa liquor. Then the pressing that will separate (extract) cocoa butter from the cocoa cake. Cocoa butter would be tempered using tempering machine while the pulverizer will grind the cocoa cake to cocoa powder. The productivity of the cocoa processing plant lies on the tonnages of finished products it can dish out to the market. Another issue with this line is the continuous productions that are connected. Any failure or efficiency drop in one unit will impact the whole operations (Adabe and Ngo-Samnick, 2014).
Cocoa processing plant need a structural problem-solving methodology to improve its efficiency, especially during lean crop that equipment efficiency used to dop. This work looks at the application of DMAIC which has been

proven over the years to improve efficiency in cocoa processing plants. DMAIC has been known over the years

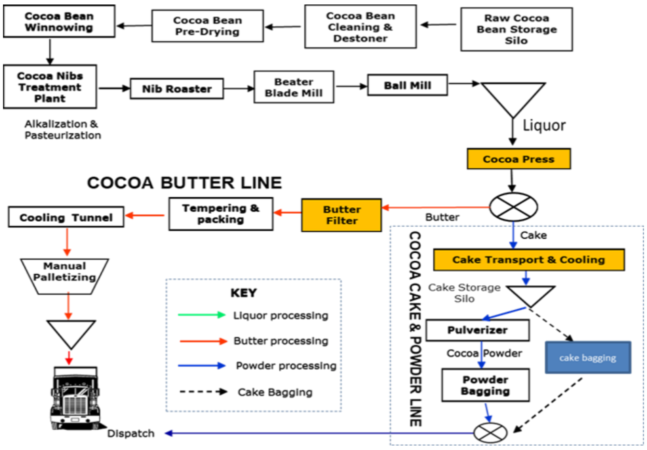

Figure 1. Schematic of a thermoelectric couple (Manoj and Walke, 2012)

as the methodology used to implement Lean Six Sigma. DMAIC is a terminology formed from the first words of the five phases of Lean Six Sigma. These phases are Define, Measure, Analyse, Improve, and Control (Shrivastava, 2017). Founded by Motorola, USA in 1986, Six Sigma is a strategy that optimizes the process of outputting products and services by getting rid of errors so that results are always constant and always growing. Lean Six Sigma is a management approach for business performance improvement, blending the specialisms of Lean and Six Sigma. Lean focuses on speed, efficiency, and reducing waste; Six Sigma's strength is in continuous improvement including effectiveness and removal of errors (Shrivastava, 2017).

Sordan et al. (2021) worked on Contact points between Lean Six Sigma and Industry 4.0. They worked systematic review and conceptual framework with the aim of developing a conceptual framework for the implementation of the contact points (CPs) between Lean Six Sigma practices and Industry 4.0 technologies. This work is more theoretical without a practical approach. Research on an innovative Agile Model of Smart Lean–Lean-Green approach for sustainability enhancement in Industry 4.0. was done by Tripathi, et at, (2021). This work developed an innovative agile model using the lean, smart, and green approaches to improve operational performance within limited constraints in Industry 4.0. The case studies used in their work were the automotive and mining industries.

Ramanand et al. (2020) also work on the development of a Big Data-Driven Lean Six Sigma Framework for Khadi Industry. This study involves the integration of two autonomous concepts, one from the field of operations management as Lean Six Sigma (LSS) and the other from the field of information technology as Big Data Analytics (BDA). Henny et al (2019) applied Lean Six Sigma to minimize waste. This work focused on the production of Chili and shrimp sauce. The methodology adopted was DMAIC (Define, Measure, Analyze, Improve, and Control). Chili sauce processes were broken down into two operations and 10 categories of waste were identified. The Shrimp sauce process was also broken down into 8 operations and 9 categories of wastes were identified. The measure stage recorded levels of 3.9 and 4.1 sigma in Chili and Shrimp sauce respectively. The two major wastes from their operations are transportation and processing waste. The improve and control stages were not implemented by the research due to the constraint from the case studies company, however, improvement suggestions were given.

Khawarita et al. (2019), did a literature review on Lean Six Sigma for the manufacturing industry. This work covered fifty-three journals between 2005 and 2019. Nineteen of the journals were case studies. This work highlighted ten advantages of implementing Lean Six Sigma quality improvement, waste reduction, cycle time reduction, production cost reduction, efficiency and production volume increases, downtime reductions process capability improvement, shipping time reduction, and customer satisfaction. Five motivations that make companies implement Lean Sigma six were mentioned as cost reduction, customer satisfaction, waste elimination, quality improvement, and defect reduction in products. This paper rounded up the three major factors that caused failure in Lean Six Sigma implementation were mentioned as poor employee involvement, no awareness, & lack of communication about Lean Six Sigma.

Nurul and Sarina (2020) researched the preparations needed to implement Lean Six Sigma and tagged it as an exploratory study and readiness factors. This work gave a clear Key Performance Indicator (KPI) and Key Activities Indicators (KAI) to follow in the implementation of Lean Six Sigma. This work answered two questions about the factors that make companies adopt Lean Six Sigma and the factors put into consideration before implementing Lean Six Sigma in the industries. Qualitative approaches were used to collate data from 12 professionals responsible for Lean Six Sigma implementation. The Pareto Chart used for this work showed that training program, management support, and availability of finance are the 3 top factors required for the success of this program. It was also noted that time, change management, and community representation are the least factors considered. Lean Six Sigma implementation was also divided into three as Pre-implementations, Implementation, & Post-Implementation.

2. MATERIALS AND METHOD

The methodology applied for this work is DMAIC which stands for Define, Measure, Analyse, Improve, and Control.

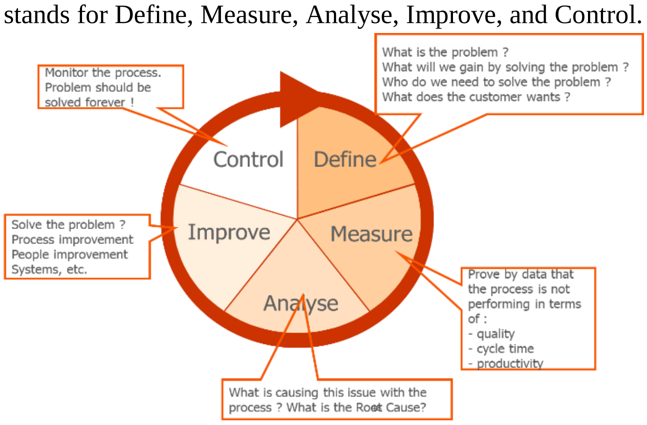

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Figure 2. DMAIC Cycle (Source: Self-computing)

A. Define Phase

Define phase gives definitions and scope of the problem, identifies the key metric and the team that will work on the project, and creates a project charter. The issues to be treated at the phase are project charter, problem/opportunity statement, objective, primary/secondary metrics, problem-solving team selection, and project schedule. The major tool used is bottleneck analysis which determines where low volume or drop in production throughput comes from.

B. Measure Phase.

This is the phase that applies statistical methods and concepts to measure the current situation of the process or operations to improve. The tools used are process mapping, basic statistical concepts, graphical tools, process capability, measurement system analysis, etc. Reliability and validity testing was done.

C. Analyse Phase.

This is the phase that gives a proper root cause analysis of the problem or situation found at the measure phase: The tools used are a fishbone diagram, failure modes, and effects analysis (FMEA), hypothesis testing, multi-vari analysis, correlation/regression, simple regression, and multiple regression.

D. Improve Phase.

This phase tends to solve and improve the situation/problems found in the analysis phase. The major tools used are Design of Experiments (DOE) and full 2k factorial designs.

E. Control Phase

This phase makes use of Statistical Process Control (Control Charts) and Control Plans to ensure that problems solved, and improvements achieved are within the control and can sustained.

3. Result and Discussion

The case study is a cocoa processing line. Based on the methodology applied, below are the details results achieved.

A. Define Phase

The Design capacity throughput is 30tn per day using a ball mill as a base metric. with the separation of 12 tons for cocoa butter and 18 tons for both cocoa cake and cocoa powder. Over the previous months, this throughout has not been met because of low plant operational efficiency. Proper bottleneck analysis was done and compared with the actual capacity to understand the current condition as shown in Table 1. Based on the available data, the Cake Pulverizer and Tempering machine have loss efficiency of 53% and 40 % respectively as shown in the below bottleneck analysis table. Meanwhile, based on Figure 1, Cake Pulverizer is not a threat due to the availability of the cake bagging system. The cake bagging system will cater for the loss on the Cake Pulverizer. Tempering machines become a major focus for this work to improve.

Table 1: Bottleneck Analysis

Equipment	Products	Target (kg/hr)	Actual (kg/hr)	Variance (kg/hr)	Variance (%)
Beans Cleaner & Pre-Drier	Cocoa Bean	1700	1620	80	5%
Winnower	Cocoa Bean	1500	1435	65	4%
Treatment Plant / Roaster	Cocoa Nibs	1500	1500	0	0%
Beater Blade Mill	Cocoa Nibs	1600	1510	90	6%
Ball Mill	Cocoa Liquor	1450	1387	63	4%
Cocoa Press	Cocoa Liquor	1800	1800	0	0%
Tempering Machine	Cocoa Butter	800	480	320	40%
Cooling Tunnel	Cocoa Butter	1900	1900	0	0%
Cake Cooler	Cocoa Cake	2000	2000	0	0%
Cake Pulverizer	Cocoa Cake	1500	700	800	53%
Cake Bagger	Cocoa Cake	2000	2000	0	0%

(Source: Case Study Factory)

B. Measures Phase

This is done to understand the condition of the tempering machine before improvement. Below are the parameters measured.

1. Process capability of Tempering machine throughput before improvement
2. Cocoa butter throughput per day for 30 days

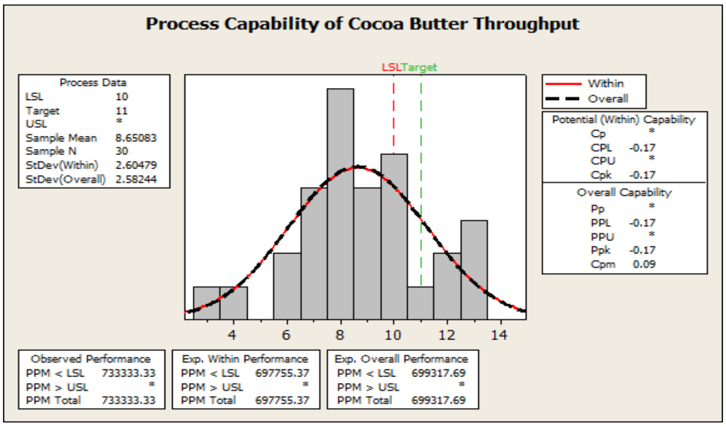

Figure 3: Pre-improvement process capability of cocoa butter throughput (Source: Self-computing)

From the above chart (Figure 3), the overall standard deviation is 2.60479. This shows that the process capability variation has a wider margin and is out of control.

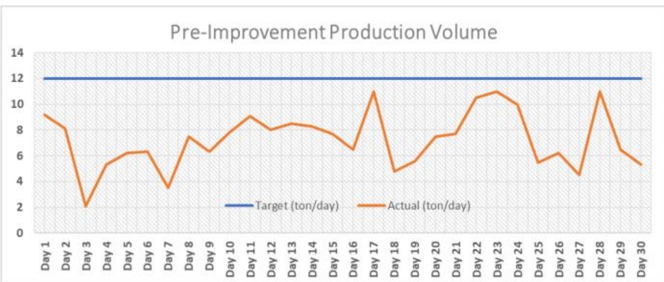

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Figure 4: Pre-improvement cocoa butter throughput per day

The Pre-improvement cocoa butter throughput per day (Figure 4) is far below the set target. The average daily throughput is 7.25 tons as against the daily target of 12 tons.

C.Analyse Phase

Gaps Analyses were done to understand the causes of the difference between the target and the actual. Fishbone analysis with 4M (Man, Machine, Materials, and Methods) was used as shown below. Its explanations are given in Table 2 below.

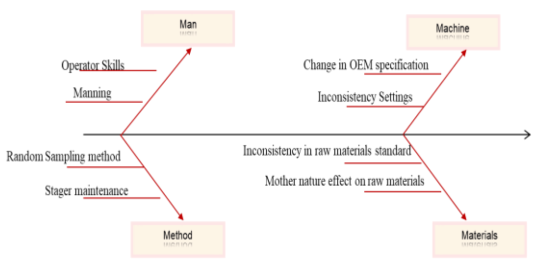

Figure 5: Root Cause Analysis (Fishbone analysis with 4M)

Table 2: Explanation of the Root Cause Analysis

Components	Issues	Explanations
Man	Operator skills	Many of the operators are not technically sound enough to handle machines
	Manning	Too much contract staff leads to high attrition.
Machine	Change in OEM specifications	OEM specifications on the major components have been changed by the technicians due to the non-availability of spare parts
	Inconsistency settings	There was variation in machine settings by the operators in all shifts
Method	Random sampling method	The mode of product sampling creates a vacuum on product quality
	Stager maintenance	Schedule maintenance is not followed to meet production volume. Stager maintenance were adopted in-leu
Materials	Inconsistency in raw materials standard	There is variation in the raw materials standard from entrance control.
	Mother nature's effects on raw materials	Raining and dry season has a great impact on the quality of cocoa beans

The machine-related issues were further investigated using the Pareto chart as shown in figure 6.

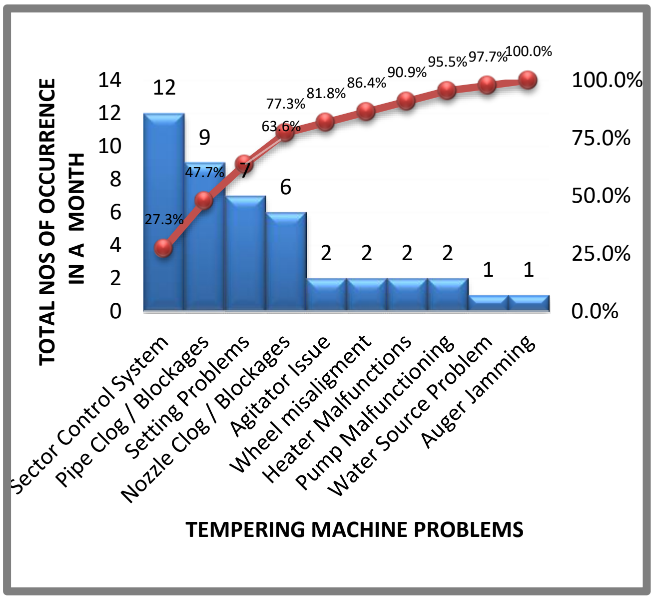

Figure 6: Root Cause Analysis (Pareto Chart) (Source: Self-computing)

From the above Pareto chart, the sector control system was the major problem with pipe blockage follow. A deep dive study was done to check the performance of the sector control system using cocoa butter temperature and tempering sector outlet temperatures.

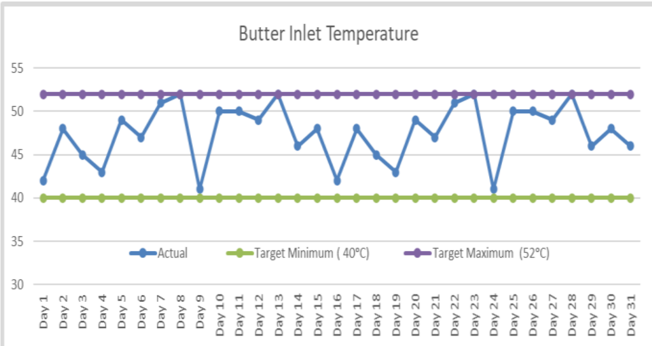

Figure 7: Butter Inlet Temperature (Source: Self-computing)

Butter inlet temperature (Figure 7) shows that the material temperature that passes through the tempering machine is within the set standard. To relate this result with Tempering sector Temperature. The Tempering sector temperature performance is shown in Figure 8 below. Tempering Sector Temperature is out of control as the actual temperature is not within the upper and lower limit of the temperature set point.

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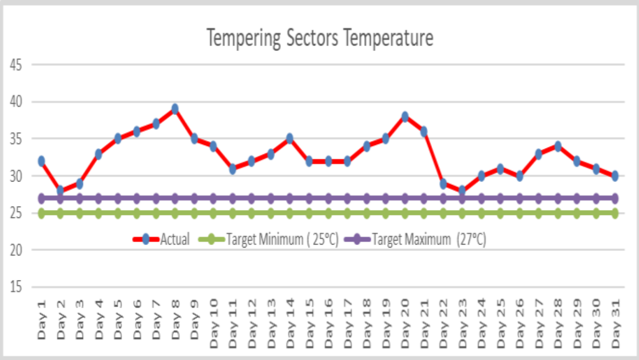

Figure 8: Tempering Sector Temperature (Source: Self-computing)

D. Improve Stage

Based on the gap analysis done above. Below are the two major improvements.

Table 3: Improvement Actions

Root Cause	Countermeasure	Completion Status
Malfunctioning of the Tempering Sector Control System	Remodification of the Tempering sector electrical control system	100%
Pipe clog / Blockage due to piping design error of the Tempering Machine	Remodification of the pipework of the Tempering Machine	100%

All the parameters of the machines that needed to be centreline were checked and compared to the original equipment manufacturer standards to know the level of deviation of the machines and process capability centreline parameters as shown below.

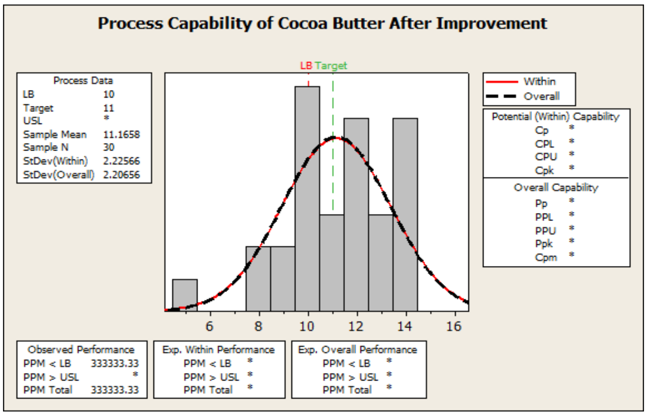

Figure 9: Post-improvement process capability of cocoa butter throughput (Source: Self-computing)

From the chart in Figure 9, the overall standard deviation was reduced to 2.20656. This shows that the process capability variation is within the control compared to 2.60479 before the improvement (Figure 3), Also, Production performance (volume) is stabilized and can be predicted due to the improvement process. This is shown in the figure 10 below. The production volume average per day is now 10.3 tons as against 12 tons target per day.

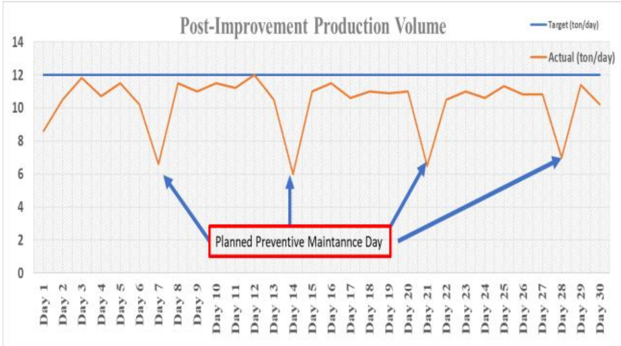

Figure 10: Post-improvement cocoa butter throughput per day (Source: Self-computing)

E. Control Phase.

For the gaps discovered using Root Cause Analysis (Fishbone analysis with 4M), below are the controls put in place.

Table 4: Control Measure – Issues

Components	Issues	Control Measure
Man	Operator skills	Employment of skilled operators
	Manning	Reduce the contract staff to 25% and replace them with permanent staff
Machine	Change in OEM specifications	Ensure availability of spares from OEM
	Inconsistency settings	A train operator on machine settings
Method	Random sampling method	Increase the frequency of product sampling
	Stager maintenance	Schedule maintenance should be followed to the letter
Materials	Inconsistency in raw materials standard	Standardized raw materials specifications
	Mother nature's effects on raw materials	Procure and store cocoa beans during the main crop for the light crop season

For the deep dive done on the tempering machine, below are the controls put in place.,

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Table 5: Control Measure – Special Cause

S/N	SPECIAL CAUSES	ACTIONS TO BE TAKEN
1	Temperature of Tempering Machine above 27°C max	Check and ensure the Tempering Machine's electrical system is not malfunctioning. Check and ensure the valves for water pipes are in their appropriate on and off position
2	Downtime on chiller	Dedicated engineering personnel for the section should quickly find the root cause and fix the problem. Dedicated engineering personnel for the section should escalate the problem to more senior personnel on-site for quick intervention

4 Conclusion

DMAIC applications for process improvement on cocoa processing plants yielded a very good result and this helped the case study factory to improve their daily output from an average of 7.25 tons to 10.3 tons per day. It also helps to bring the equipment back to base condition by fixing all the pending issues on the line. Their reliability and revenue are improved as well. This tool can also be used to improve other functions of the production line and get the same result.

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