Process Reliability Improvement of Slitting Machines in an Industrial Setting

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Abstract
This paper aims to demonstrate an effective approach for improving process reliability within a flexible packaging manufacturing organization. As the need for efficient industrial processes grows globally, industries tend to seek robust methodologies to chart their path to business excellence in terms of quality products and services. This research is focused on DMAIC methodology for investigating the root causes of slitting machines, and to proffer the best solution to improve the process. A data collection plan which is based on the lowest-performing machines was obtained, followed by qualitative and quantitative process analysis to identify the potential cause(s) for the machines' low process reliability. Statistical tools were used to validate the potential factors that are most probably critical for the machine's performance. The analysis indicates that actual operating slitting speed was below standard speed due to the possibility of defective slit rolls, and the presence of flags on jumbo rolls that accounted for 20% – 40% of the gross downtime. Employee's inability to capture downtime was also identified as one of the critical factors affecting the performance of slitting machines. After implementing solutions, a 25% improvement in the process reliability was achieved without compromising the quality of the products.

Keywords
Six Sigma, DMAIC, Process Reliability, Slitting Machines, Flexible Packaging

1. Introduction
Top-notch organizations worldwide have been pushing the boundaries of their processes to either set the pace or meet the benchmark in the industrial space. The globalization of markets, growth of customers' expectations, and widening competition in all spheres necessitate fulfilling customer's requirements who occupy the leading position on the market (Kostina et al. 2012). More recently, SMEs and local businesses have become more open to ensuring their processes achieve international standards while employing best practices in their businesses. Process efficiency can be increased by adopting the Six Sigma (SS) methodology. Defects can equally be reduced using the same approach and this will in no doubt improve the quality of products made to satisfy customers (Sudari et al. 2019). According to Raisinghani et al. (2005), this technique has become a prevailing method implemented by top companies during the third industrial revolution and capable of achieving a 99.9% quality level. The SS data-driven improvement cycle for stabilizing business process in manufacturing or industrial settings is the DMAIC, where the D represent-define, M represent-measure, A represent-analyze, I represent- improvement in operation and C the control process. This improvement strategy is applicable in virtually all sectors be it a product or service-based (Chakrabarty and Chuan 2007).

This research is focused on the application of SS-DMAIC in product based industrial system. The flexible packaging industry has experienced a significant shift as the influx of new technology has opened new possibilities to improve quality and meet more challenging customers' specifications and business requirements. Therefore, an important managerial decision to invest in improving process reliability (PR) and quality became necessary. According to Barringer (2000), PR is a method for identifying problems, which have significant cost reduction opportunities for improvements, and manufacturing processes need to assess the system's health and maximize gross profits. Wei Dai et al. (2015) believes that a timely and cost-effective manufacturing process is increasingly significant in today's globally competitive market. One key parameter for increasing manufacturing competitiveness is the continuous drive to enhance manufacturing processes equipment's capability. Chu-Hua and Christian (2003), iterated that adequate attention should be given to product quality and PR for Six Sigma's practical achievements. They noted that reliability issues are often part of the common causes that the operators do not control and, therefore, argue that reliability management is part of the strategic decision-making, which the top management is responsible for. Salman and Suliman (2008) opined that SS has proven successful in manufacturing and service applications and seems to be very promising for reliability applications. The quality of the production process means a reliable and sustainable process by looking for output maximization of their current resources, reducing waste of equipment, increasing product quality, minimizing production cost, and reducing production losses. (Kostina et al.2012; Jamaluddin et al. 2011).

2. Review of Literature on Six Sigma

Six-Sigma has received much attention during the last decades due to breakthrough results achieved in the manufacturing sector. Many practitioners and SS professionals consider that SS methodology is a way to improve bottom-line results and a management culture to ensure the long-term transformation of the business units (Atallah and Ramudhin 2010). According to Jamaluddin et al. (2011), it has been proven to reduce costs, improve cycle times, eliminate defects, raise customer satisfaction, and significantly increase profitability. It has been successfully used to solve problems by utilizing an extensive set of rigorous tools, uncompromising use of statistical and advanced mathematical tools, and a well-defined methodology that quickly produced significant results. SS is also recognized as a strategy that drives the cultural change to improve the company's profitability, increasing the benefits from savings generated when the defect is detected at a very early stage. The SS methodology is a structured and rigorous approach for improving process performance and efficiency by identifying the critical process inputs having the most significant influence on the overall performance (Atallah and Ramudhin 2010). One of the advantages of the SS methodology over other improvement programs is that it enables practitioners to accurately remove hindering issues and demonstrate the improvements using statistical tools such as Pareto Chart and control charts (Tongdan et al. 2011). Some tools employed by the team in narrowing down crucial root causes for building reliability in-process and achieving high process performance such as Histograms, Pareto Charts, 5 Why's technique, Statistical Process Control (SPC), Response Surface Models, and Design of Experiment (DOE), Reliability allocation; Accelerated testing; Highly accelerated life testing; Safety Analysis and Failure Mode Effects and Analysis (FMEA) (Tongdan et al. 2011; Kostina et al. 2012; Atallah and Ramudhin 2010; Zhao et al. 2012).

3. Methodology

3.1 DMAIC Six Sigma

According to Salman and Suliman (2008), it has been shown that SS is a successful strategy for reducing errors and improving the efficiencies of a variety of applications. With the intensive use of statistics, the measured data is analyzed to establish a statistical correlation between defects and potential root causes. Improvements on root causes are then implemented and put in tight statistical control. The current research aims to show how SS can be used to improve PR in flexible packaging industries. The paper's main task is to show how the DMAIC approach would be successfully used in improving the PR of an existing system. Systematically using data from the process, the team of subject matter experts was engaged to suggest the most efficient ways to improve reliability. The presented approach can be similarly implemented in a similar manufacturing process with the possibility of substantial improvement. This research presents the practical application of the SS -DMAIC approaches in improving the PR of slitting machines.

Define: This is the first phase of the Six Sigma DMAIC methodology. This phase involves understanding the organization's pain areas using tools like a prioritization matrix for project selection with adequate critical to quality (CTQ) drill-down analysis. The project's scope and boundary, identifying the voice of the process (VOP) (i.e., business requirements) and goals of the project. A project charter which is regarded as a living document is designed and presented to management for approval. The define phase is divided into three elements: Significance of problem, Scoping of problem, and Process capability, which requires a baseline performance analysis (Salman and Suliman 2008). According to Atallah and Ramudhin (2010) creating SIPOC diagram (suppliers, inputs, processes, outputs, customers) at the early stage of a project helps the team to identify all relevant elements of the process and provides a simple way to get a comprehensive picture of the current situation. Then, the appropriate metrics to be measured are identified by the project objectives. These may include time, cost, delays, risks, and gaps that reflect customer satisfaction, process efficiency, reliability, and financial performance.

Measure: The "measure" phase of the DMAIC methodology enables the team to carry out a quantified evaluation of the process. Here, the performance standard is done to understanding all the metrics of the project; measurement system analysis is done to check if the measurement system is reliable; Data collection is also done for the current performance level (baseline) of the process, and process capability analysis is done to set a SMART goal for the project. Salman and Suliman (2008) divided the measure phase into two elements: Ensuring the adequacy of a measurement system that require measurement system analysis (MSA) and Measuring the potential factors through several techniques such as process mapping, fishbone diagram, and FMEA.

Analysis: This is the third phase of the DMAIC approach. Here, probable factors responsible for the performance gap are evaluated; these factors are gotten from brainstorming with subject experts or using the business's voice. After that, probable factors are funneled down to potential factors using tools like Pareto charts. Statistical tests, like Hypothesis testing, ANOVA, Regression Analysis, are done to identify critical factors to the process amongst potential factors. Validation of root causes is done to know the validated critical factors; these factors can be realistically improved. Statistical tools such as sampling, statistical comparison, correlation, and regression are all highly promoted whenever applicable. (Salman and Suliman 2008).

Improve: in this phase, alternative solutions are generated and evaluated for validated critical factors; tools like Cycle time, Value Added, and Non-Value-Added Analysis, Brainstorming (round Robin), De Bono Six Thinking Hats, FMEA, DOE and Benchmarking are employed. The best solutions are selected and optimized, and a pilot test is done before the full implementation of the solutions. Improvements are statistically validated to show improvement in performance through examining the change in performance by re-measurement of process capability after the implementation of improvements (Salman and Suliman 2008).

Control: the last phase involves implementing control systems to sustain the improved system. According to Salman and Suliman (2008), once the process is proven to have improved, this improvement must be sustained. Risk management and Mistake Proofing like Poka-Yoke are implored here. Control plans are developed to monitor the improved process, to ensure performance stays within specified limits. The most frequent tools used at this phase are control charts, SOPs, and SPC. SS requires that the performance be continuously monitored and controlled through SPC. SPC methods are extensively used to monitor the quality of manufacturing processes and service operations, and it is an integral part of the SS approach. The project is closed at the end of this phase and transferred to the process owner, and financial benefits are validated for the project with replication opportunities evaluated in similar processes.

3.2 Information on Flexible Packaging Manufacturing and Slitting Process

Flexible packaging involves the conversion processes used to manufacture flexible packaging products. The conversion processes are printing, blown film extrusion, lamination, extrusion, and slitting. Substrates are feed into the printing machine, which could be a rotogravure or flexographic machine. The Blown-film extrusion machine produces barrier films usually called Low-density polyethylene (LDPE), and this could be a 3- or 5-layers type. Printed films can be either laminated or extruded; for a laminated process, the blown film's barrier films are laminated onto the printed film through a solvent-less or solvent-based process. For the extrusion process, barrier resins or chips are extruded onto the printed films. Laminated and extruded films under the slitting process at the Slitting section give the finished products packaged for dispatch to customers.

The slitting process can be done through a razor blade, shear cut, or score cut. Razorblade was used during this project due to the nature of the films been produced. Laminated or extruded jumbo rolls are loaded onto the unwinder shaft end of the machine, the web of the film is passing through series of rollers, the web is slit at the middle section where a screw with razor blades at predefined width of finish products. The films are slit onto cores located at the rewinder end of the machine. Before slitting takes place, required job settings are done and strictly followed by the operators. The Slitting process involves the following process parameters; Machine utilization (MU), Production Efficiency (PE), and PR. MU gives the percentage of the machine running time against the total available time. The PE shows the percentage of the machine's actual performance against the standard performance of the machine. While PR is the product of MU and PE. For this project, improvement of PR for BIMEC Slitting machines was carried out. The slitting operation for the process studied and investigated in this paper, are orderly categorized into seven steps as follows: Mounting of Jumbo roll unto the unwinder shaft; The setting of Machine Parameters; Slitting of Laminated or Extruded Film; Rewinding of Film at Rewinder Shaft; Unmounting of slit rolls from the shaft.

4. Six Sigma-DMAIC Application in Slitting Operation

This section presents the practical application of the SS-DMAIC approaches in a manufacturing company in Lagos, with a focus on improving the process reliability of slitting machines in the system. This section is sub-divided based on the sequential stages that were systematically followed, according to the SS-DMAIC problem-solving approach.

4.1 Define Phase

In the first phase of the SS-DMAIC methodologies, the organization's pain areas were understood using a prioritization matrix tool with adequate CTQ drill-down analysis. In the case of this improvement project, the team was comprised of 10 persons which included the production manager (process owner), two supervisors (for different shifts), four experienced operators, the improvement project leader (a SS greenbelt or blackbelt), a financial analyst and project champion or sponsor. The Six Sigma project was selected based on the VOP. The project focused on having a significant and positive impact on customers as well as obtaining monetary savings (Nonthaleerak and Henry 2008; Jirasukprasert 2014), the project addresses the bottleneck of the overall process by improving the process reliability of slitting machines to output finish products to meet customers demand, and savings on manpower and utility. Therefore, the VOB concept means identifying the pain areas of the business or process; in this case, the customers are internal stakeholders who also have external stakeholders' interests closely align with VOB.

To ensure that Project Champion, Financial Analyst, and other vital stakeholders fully buy-in to the project (Montgomery 2001), the project's business case, opportunity, and goal statement should be explicitly stated and communicated. This research was done to improve the PR of slitting machines in a flexible packaging company to ensure that the process efficiently meets customers' requirements (demand) and projected production forecast. The over opportunity loss with financial savings on utility and power is due to low PR in the slitting section was calculated. The resulting figures were presented to the organization's top management; assured of their commitment towards the project as it demonstrated that improved PR would directly produce a significant cost saving for the company. The project charter summarised the project's scope, boundary, VOC, objective, and the team's role in this improvement project. The project charter for this research presented in Table 1, a process map and SIPOC were developed.

Table 1. Project Charter

Project Title	Process Reliability Improvement in Slitting Section
Background and reasons for selecting the project	In a prioritization matrix conducted on all pain areas, Slitting Section's low performance was ranked to be the most critical. The low process reliability in this section causes several types of losses to the company, such as time, materials conversion rate to finish goods, cost of manpower and utility, inability to meet customer demand, which negatively affects the business's overall plans or budget.
Project objective	To improve the process reliability to 40% by applying the DMAIC methodology
Voice of the Process (VOP)	Low Performance
Project boundary	Slitting Machines' Process Reliability.
Key Team members	Production Manager, Supervisors, Experienced Operators, and the Project Leader.
Expected financial benefits	Considerate cost savings from Utility and Manpower due to improved reliability.
Expected Business benefits	Eliminate the bottleneck in the process to ensure customers' demands are met.

4.2 Measure Phase

In the measure phase of the Six Sigma-DMAIC methodologies, the team carried out a quantified evaluation of the process. Here, the performance standard is done to understand all the metrics of the project; measurement system analysis is done to check if the measurement system is reliable; Data collection is also done for the current performance level (baseline) of the process, and process capability analysis is done to set a SMART goal for the project. The metrics uncovered during the performance standard for operational definition are machine utilization and production efficiency. Choosing a good measure requires a clear understanding of the definitions of and relationships between output, process, and input measures. The critical process variables used as improvement metrics were identified and explained to team members (Jirasukprasert et al. 2014).

An MSA was conducted to prove that the system is accurate and precise, and the data collected are trustworthy. The validity of the measurement system (weighing scales) was quantitatively done using Gage Repeatability and Reproducibility Study. The inference of this analysis based on Gage R&R criteria captured in Table 2 shows no variability in the measurement system caused by the weighing scale, and the operators were consistent in their measurements. % contribution and % study variance "Total Gage R & R". PR data was collected for one month to evaluate the process capability and the baseline for the project. The mean of all Stock Keeping Units (SKU) PR was taken as the PR performance for the machine. The baseline performance were 26.69%, 28.97%, 30.77% and 24.52% for Machine 1 to 4 respectively. Data were collected from daily production reports with sample sizes of 86, 85, 88, and 101 for Machine 1, 2, 3, and 4. Descriptive statistics summary reports in Table 3 show that current process performance is below the historical best performance of 30.25%, and off the slitting production, the target mean is 40%. The data is continuous, lower and upper specification limits were identified, and capability analysis was used to determine the target, evaluated as USL: 40% and Target: 40%.

Table 2. Measurement System Validation

Parameters	Machine 1	Machine 2	Machine 3	Machine 4
Variance Components: % contribution	0.38	1.09	0.95	0.00
Gage Evaluation: % Study Variance	6.18	10.42	9.77	0.65
Number of Distinct Categories	22	13	14	21
Inference	Accepted	Accepted with caution	Accepted	Accepted

Table 3. Descriptive Statistics Summary

Machinery	Mean	Std Dev	Remark
Machine 1	26.69%	11.60%	The data are accepted as normally distributed as P-value = 0.241 > 0.05.
Machine 2	28.97%	10.78%	The data is Non-normal, and a Box-Transformation was done which gave a value of p = 0.557
Machine 3	30.77%	13.35%	The data is Non-normal, and a Box-Transformation was done which gave a value of p = 0.646
Machine 4	24.52%	11.61%	The data are accepted as normally distributed as p-Value = 0.104 > 0.05.

4.3 Analyse Phase

In the analysis phase of the DMAIC methodology, a brainstorming session with team members was carried out after a Gemba visit to the production floor, an Affinity Diagram was done to capture the Potential Factors from Probable Factors and then categorized into Machine Speed, Machine Utilization, Measurement Inaccuracy, Process, and Output. Proposed Critical factors were identified using the Fishbone diagram shown in Figure 1.

Low Machine Speed: Machine Speed Analysis was done for the following input/process metric: Poorly Laminated Jumbo Rolls, Poorly Extruded Jumbo Rolls, Bad Jumbo Roll Core, and Presence of Flagged Joints/Defects. Here, the Actual Machine Speed for each job was collected from a production report spanning from April 1 to May 7 (37 days) and were compared to standard machine speed. The Mean of the Actual and Standard were statistically compared using Mann-Whitney Median Test.

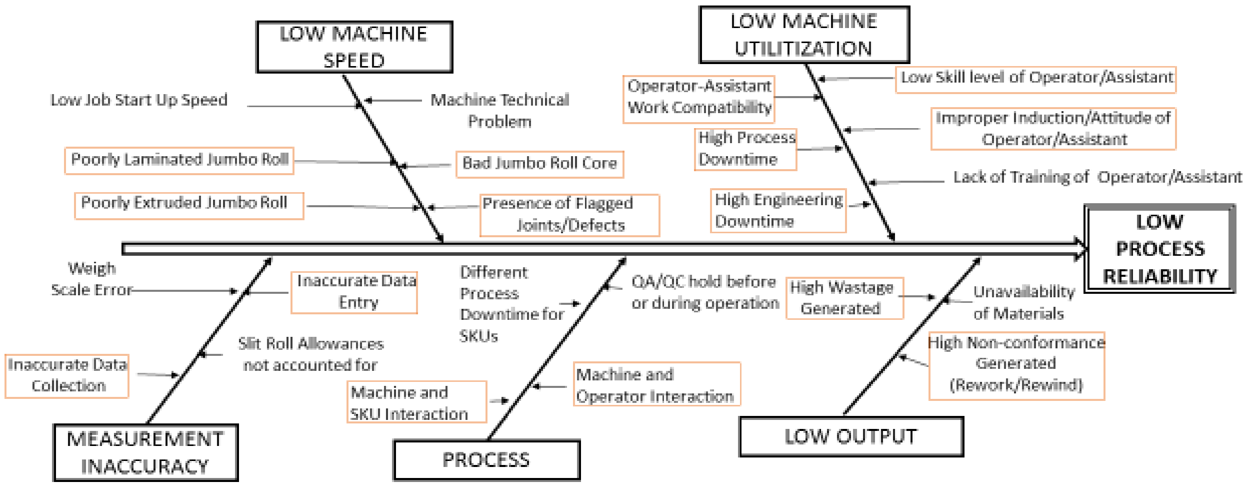


Figure 1. Fishbone Diagram to Propose Critical Factors

Measurement Inaccuracy: Measurement inaccuracy analysis was done for the following input/process metric: Data Collection and Entry. For Data Collection; Production output report from Production Admin and Production Planning & Inventory Control (PPIC) were collected and collated with Data collected by the Project Leader between 2nd of May to 21st of May. 2 Proportion Test was used to check if the means were equal. Furthermore, for Data Entry; the Standard Gross Working time for each SKU was compared to the Actual Gross Work time recorded by Operators and Assistants. The Mann-Whitney Median test was used to compare the means if equal.

Low Machine Utilization: here, the process downtime, engineering downtime, operators output, and operators & assistants' productivity were analyzed. For process downtime analysis, the actual process downtime recorded by the operators and the expected downtime (calculated from the difference between the gross time and expected uptime at standard speed) was statistically compared to the Mann-Whitney median test. For the engineering downtime, the engineering downtime for 2019 (January to May), all machines were compared to the standard of 2%, above this standard engineering downtime would be considered critical.

Operators Output & Operators Vs. Assistant: the operators' actual output was compared to the slitting production target using One-Way ANOVA. Also, the two operators' productivity was compared to a regular operator and assistant using One-Way ANOVA.

Low Output: Here, the Wastage and Non-conformance (Rework/Scrap) were analyzed. For Wastage generated; wastage generated for each shift or job was collected for three weeks and compared against the standard of 5%. A Pareto Chart was also done to show the SKUs contributing most to the waste generated and Non-conformance. For Non-conformance generated; here, the slit rolls do not conform to the standard rolls for rework and scrap.

Process: factors in the process considered probable factors were; the interaction between machine & material and interaction between the machine & operator. For the interaction between machine and material, 2 sample t-test was done to compare individual SKU performance on each machine. Here, we use the statistical test to determine the machine of choice for each SKU. For interaction between machine and operator; we needed to analyze if the operator's performance on different machines is statistically significant. One-way ANOVA was used to compare the mean of operator performance against slitting production targets on different machines.

4.3.1 Validation of Critical Factors

Probable factors for low PR were suggested during a brainstorming session with the project team members, after which an Affinity diagram was done to identify potential factors. Critical factors were identified using a Fishbone diagram, and appropriate statistical testing tools were used to validate selected critical factors. Table 4 below shows the summary of the analysis and validated critical factors considered in the Improvement Phase.

Table 4. Validated Critical Factors (C=Critical; NC=Not Critical; AS=All SKUs; AO=All Operators; AM=All M/C)

Input/Process Metrics	Proposed Critical Factors	Test	Category	Result
Machine Speed	Poorly Laminated Jumbo Roll	Mann-Whitey Test	AS	C
	Poorly Extruded Jumbo Roll			
	Bad Jumbo Roll Core			
	Flagged Joints/Defects			
Measurement Inaccuracy	Inaccurate Data Collection	ANOVA	AS	C
	Inaccurate Data Entry	Mann-Whitey Test	AS	C
Machine Utilization	Operator-Assistant Work Compatibility	ANOVA	AO	NC
	High Process Downtime	Mann-Whitey Test	AS	C
	High Engineering Downtime	Bar Chat	AM	NC
	Low Skill Level of Operator/Assistant	ANOVA	AO	NC
Output	High Wastage Generated	Pareto Chart	AS	C
	High Non-Conformance (Rework/Rewind)	Pareto Chart	AS	NC
Process	Machine and Operator Interaction	ANOVA	AO	NC
	Machine and SKU Interaction	2 Sample T-test	AS	C

4.4 Improve Phase

In this phase of the SS-DMAIC methodologies, the factors that have been statistically validated to be critical to the PR performance were evaluated, and a brainstorming session was done to generate alternative improvement ideas. Also, a cycle time study was done, from which the number of flags (presence of defects from printing, lamination, or extrusion section) was discovered to take 20% - 40% of the Total Gross Time which significantly contributed to the downtime. A Solution Selection Matrix was done as shown in Table 5 to rank solutions ideas based on the potential to meet the goal, positive customer impact, cost to implement, stakeholder buy-in, and time to implement.

Table 5. Solution Selection Matrix

Solution Selection Matrix							
Project Goal ***Enter Goal Statement below: (As stated on Project Charter)***	Please rank each solution for each criterion by using the 1-5 Scale as indicated below						
To Improve Process Reliability of Slitting Section (Machine 1 to 4)	Very Low (less good)		Moderate		Very High (best)		
	1	2	3	4	5		
Potential Solution (Provide Brief Description)	**Potential to Meet Goal**	**Positive Customer Impact**	**Cost to Implement (1 = $$$ & 5 = $)**	**Stakeholder Buy-in**	**Time to Implement (1 = Long 5 = Quick)**	**Total Score**	**Implement? Yes/No**
Weighted Criteria	10	9	8	7	5		
Constant monitoring of Laminated and Extruded Films operation (parameters) and ensuring conformance with SOP.	4	4	5	4	4	164	**Yes**

Study Man and Machine to understand other challenges that might be critical for both Lamination and Extrusion	3	3	5	3	4	138	Yes
Sensitization of operators and assistants on the essence of quality roll and First Time Right for both Lamination and Extrusion	3	2	5	4	4	136	Yes
Constant monitoring of Jumbo Roll Cores supplied and ensuring good cores are always used.	4	4	4	4	4	156	Yes
Constant monitoring of Operators to ensure Defects and Joints are properly flagged.	5	5	3	4	4	167	Yes
Constant monitoring to ensure the maximum numbers of Flagging (Joints/Defects) are not exceeded at Lamination, Extrusion, Doctoring, and Printing Machine. Work towards achieving Flagless Jumbo Rolls	5	5	5	4	4	183	Yes
Training of Production Admin on Yellow Belt (Data collection and Analysis) and continuously monitor progress by comparing with PPIC Report.	3	3	5	3	4	138	Yes
Sensitization of Operators and Assistants on the essence of accurate data entry and documentation.	4	4	5	4	4	164	Yes
Constant monitoring of Operators and Assistants to ensure accurate entry of data.	3	3	5	3	4	138	Yes
The supervisor should Plan Slitting Roaster considering Operator and Assistant Skill level, Speed and personality.	3	3	5	3	4	138	Yes
Installation of Timer for an accurate record of downtime time for every shift and job.	5	4	3	4	4	158	Yes
Repair and Installation of Stroboscope lights (Improve defect capturing) and Installation of Laser Light (reduce of laminate film waste when setting slit cores)	4	4	1	3	1	110	Yes
The weighing Scale in Machine 1 should be changed to a higher capacity that can support all SKUs	3	2	2	3	2	95	No
PPIC to develop a comprehensive Weekly Slitting Production Plan.	4	3	5	3	4	148	Yes
Review of SKUs Target base on Process downtime and Standard Speed (Target will closely fit PR AOP of 40%)	5	4	5	4	4	174	Yes
Monitor performance of individual SKU on machines to plan slitting production plan better.	4	3	5	3	3	143	Yes
Constant monitoring of laminate waste generated and ensuring a proper record of generated waste.	4	3	5	3	3	143	Yes
Sensitize Operators and Assistant on the need for wastage reduction without compromising the quality of the roll.	4	3	5	3	4	148	Yes
Constant monitoring of Slitting Speed for Machine (Speed should not be exceeded because of the possibility of defects) and recommendation for SKUs Standard speed review if Actual machine speed cannot be improved to match Standard machine speed.	3	3	5	3	3	133	Yes
Continuous Monitoring to reduce Non-Value Added Activities in the Process Flow	4	4	4	3	3	144	Yes

After the Solution Implementation Matrix, the project team agreed on recommended actions; team members with their respective departments were assigned various tasks with the target end date. The Installed timers were to accurately capture the machine's uptime and be used to monitor each operator's productivity. The Core Rack was fabricated due to a 5S activity carried out in the Slitting Section; this also reduced the downtime incurred in getting cores for loading on the rewinder shafts. Also, Checklists were designed for Suppliers (Extrusion/ Lamination Section) and Slitting Section. After implementing Solution Ideas, the machines' current performance was checked against the baseline to validate for improvement. A two-Sample Equivalence Test was done to check if the means of before and after had statistical differences. As shown in Table 6, all machines are shown statistical improvement with the implemented solution as against baseline performance. Figure 2 shows the Year to Date (YTD) Trend of the Slitting Department.

Table 6. Improvement Validation Summary

Parameters	**Machine 1**		**Machine 2**		**Machine 3**		**Machine 4**	
	Before	After	Before	After	Before	After	Before	After

Data Points	10	10	10	10	10	10	10	10
Normality Test (Normal if P-Value >= 0.05)	0.654	0.471	0.632	0.684	0.072	0.558	0.879	0.428
Variance Test (Equal Variance if P-Value >= 0.05)	0.257		0.351		0.041		0.872	
Mean	27.80%	33.70%	30.60%	37.50%	31.50%	35.20%	23.60%	35.30%
Two- Sample Equivalence Test (Equal Mean if P-Value >= 0.05)	0.026		0.014		0.046		0.005	
Inference	PR After is statistically greater than Before							

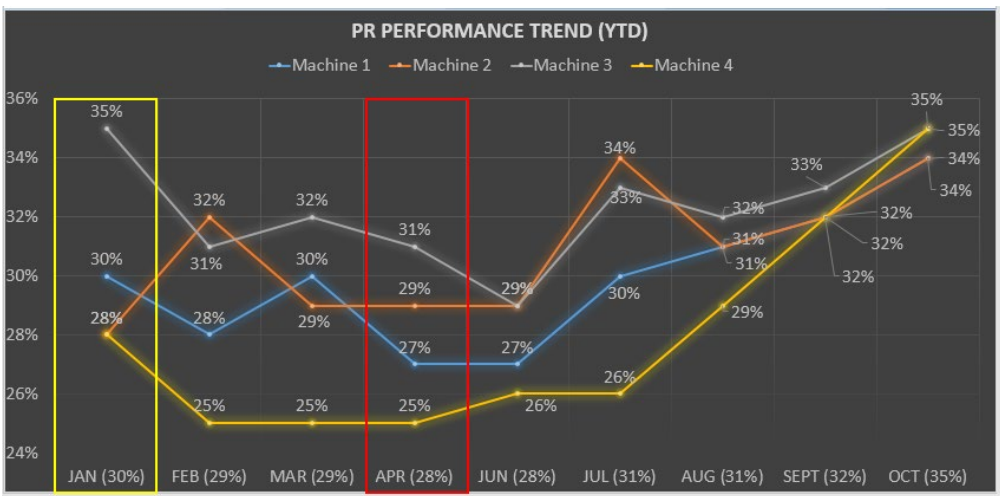
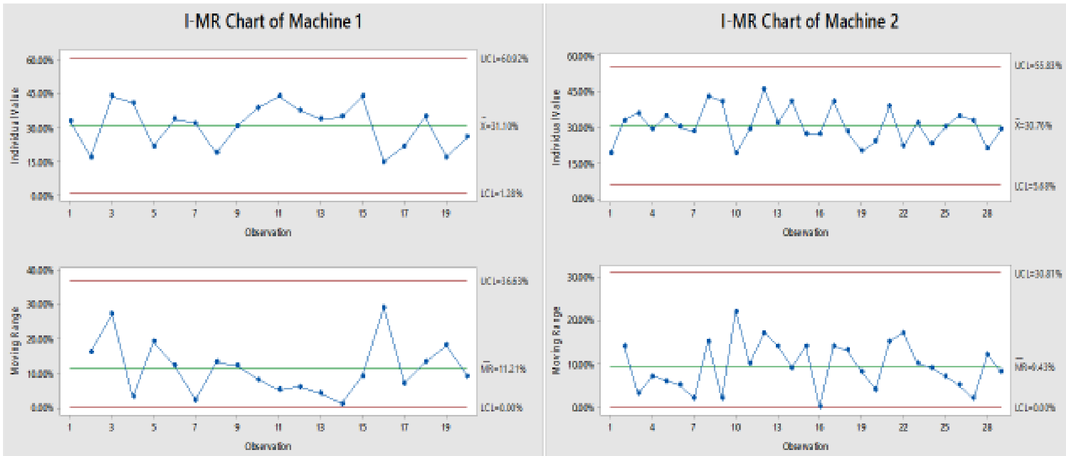


Figure 2. Process Reliability Performance Trend (MTD)

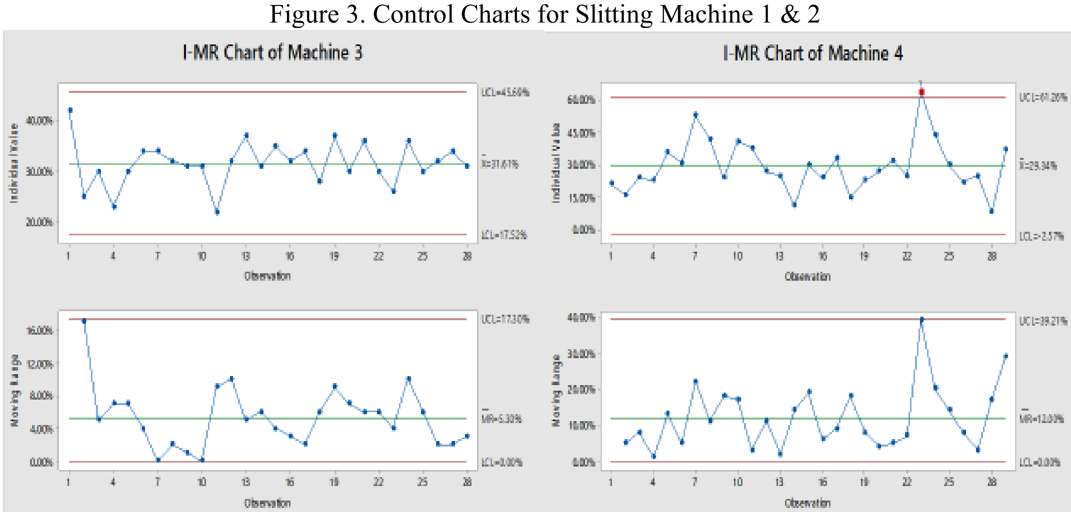
4.5 Control Phase

In the DMAIC methodology's control phase, Control charts were done to monitor the process and identify special causes. Figures 3 and 4 represent Control Charts for all Machines. Other Measures initiated were Visual Display of Operators Performance and Daily Performance Report of Slitting Production. With the process performance in all machines been stable and in control, a Control Plan was designed as shown in Table 7. A detailed Control Plan was handed over to the Process Owner during the project closure meeting. From a baseline of 28% in April 2019, the average PR improved to 35% in October 2019, which is also higher than the best historical performance of 30% in January 2019. PR Performance Trend shows the PR to be steadily improving. The meeting was held for Project closure, and necessary Project Documents were transferred to the Process Owner.



INFERENCE: The Process Reliability of Machine 1 and 2 is stable and in statistical control

Figure 3. Control Charts for Slitting Machine 1 & 2



INFERENCE: The Process Reliability of Machine 3 and 4 is stable and in statistical control

Figure 4. Control Charts for Slitting Machine 3 & 4

Table 7. Control Plan

Input/Output Variables	Control Method	Process Performance Evaluation Criteria	Reaction Plan
Jumbo Roll Quality	Monitoring	Poor Roll from Extrusion/Lamination	Notify Supervisor and Complaint should be lodged at Extrusion/Lamination Section for immediate action
Number of Flags	Visual Inspection	Number of Flags (especially above 3)	Notify Supervisor and Complaint should be lodged at Extrusion/Lamination Section for immediate action
Laminate Waste	Laminate Waste Weighing	Laminate Wastage above 5%	Notify Supervisor to provide a reason for high waste. The reason reported to SS Personnel/Process Owner.
Non-conformance	Recording of all Non-conformance	High Number of Slit Rolls for Rewind/ Rework/Scrap	Recheck Machine Settings; engage engineering team if it is a technical problem; Lodge complaints to Extrusion/Lamination for immediate action
Measurement Inaccuracy	All required data must be entered correctly and	Inaccurate data entry (timer, gross time, Laminate Waste,	Notify Supervisor of Inaccuracy. The operator and Assistant responsible should be warned. Proper Induction should be given to new staff. Training should

	promptly	Output, Input, etc.)	be organized to address gaps in Personnel.
Production Output	Visual Board	Output & PR Performance per Machine/Operator	Daily Visual Display of Production Performance on Visual Board in Slitting Section. Short Standup Meetings twice/thrice weekly to discuss performance
Slitting Production Performance	Slitting Target Daily Report	PR Performance below LSL 30% and above USL 45%	Performance below LSL or above USL reported to SS Personnel or Process Owner should be engaged for immediate action.

5. Conclusion

This research presented a successful case study of PR improvements of slitting process in flexible packaging manufacturing by using the SS-DMAIC problem-solving methodologies. After the investigation carried out in the analysis and improvement phases, the improvement project presented in this paper found that the machine speed, inaccurate downtime capturing, wastage regenerated, and interaction between the films and machine had a statistically significant impact on the PR of the slitting process. By considering these factors for improvement, the PR increased by 25%from a baseline of 28% to 35%, which exceeds the best historical performance of the machines. This project demonstrates the successful application of SS-DMAIC to industrial challenges, therefore, organizations that continue to embrace Six Sigma's continuous improvement culture increase their product quality, achieve customer satisfaction and reduce waste. Therefore, the paper can be used as a reference for managers to guide specific process improvement projects, in their organizations, similar to the one presented in this paper.

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