



The Integration of TPM in SS-DMAIC Framework to Reduce Production Losses and Enhance Process Performance: a Case Study

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| Article Info | ABSTRACT |
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| <p>Corresponding Author: Chukwuebuka Martinjoe U-Dominic E-mail: bukkyudom@yahoo.com</p> | <p>The primary cause of production system losses is widely recognised to be unplanned stoppages and breakdowns, as idle machines waste time and lower output and throughput. Many firms have undergone a paradigm shift from traditional methods to more sophisticated process improvement strategies to address the dynamic and ever-changing production constraints. To lower production downtimes and other process-related issues, an integrated improvement approach of TPM-SS-DMAIC was used in this study. The new suggested approach was validated in the cable manufacturing industry. The goals of the study were achieved in terms of increased worker knowledge, better quality, and fewer unplanned stoppages and breakdowns. Standard operating procedures were updated in response to suggestions for ways to reduce needless stoppages in extrusion line operations. Furthermore, following the process change, the overall equipment effectiveness (OEE) increased from 58% to 63%, indicating a noteworthy level of improvement.</p> <p>Keywords: TPM, Six Sigma-DMAIC, Downtime losses, Process improvement, FMEA</p> |

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INTRODUCTION

The rapidly changing global market place now call for effective improvements in a company's performances by focusing on cost cutting, increasing productivity levels, quality and guaranteeing deliveries in order to satisfy customer. This demand for improvements in the manufacturing industry has triggered the unending quest to unravel the best form of interaction between maintenance and production that will yield to an optimal performance in the manufacturing industry. Many companies have undergone a paradigm shift from traditional methods to more sophisticated methods and programs designed to help them deal with process improvement problems in response to the dynamic and ever-evolving business difficulties. The constant changes in the field of maintenance are acknowledged to have enabled new and innovative developments in the field of maintenance science (Pintelon et al (2007)). As maintenance is an integral part of manufacturing that influences

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manufacturing performance positively, so are the penalties for equipment negligence numerous, and can militate against improved production efficiency and effectiveness. Although it is preferable to have optimal output and efficiency, manufacturing entails waste and losses, but how they are handled is important because every loss has consequences (Roosefert et al., 2021).

With the advent of Total productive Maintenance methodology (TPM), a lot of positive reports have been documented in area of productivity improvement and equipment reliability in manufacturing. TPM is much more than just a concept, actually it is even considered a maintenance philosophy, and an improvement process based on team work, with a view of getting as close to zero breakdowns and zero defects as possible (Irfan et al., 2025). TPM concept has practically handled more challenges than any other maintenance concept in terms of equipment condition, working processes, skill and knowledge, standards and measurement, efficiency, people, techniques, losses, and performances (Singh et al., 2013; Rathi et al., 2021). Although TPM methodology is complete and formidable to any maintenance difficulty, its challenges are majored on implementation due to its operational complexity. Many firms continue to face challenges while implementing TPM (Tortorella et al., 2021; Mwanza et al., 2015). Rodrigues and Hatakeyama, (2006), attribute TPM implementation failures to poor structure and unsustainable operational framework. Notably, poor TPM deployment or upkeep can increase workloads and have a detrimental effect on dependable production equipment, maintenance procedures, and staff enthusiasm (Slavina & Štefanić, 2024).

A number of TPM implementation model modifications have been reported but case specific modification model of implementation is recommended due to varying nature of problems and organizations level of knowledge on maintenance best practices (Hartman 1992, Pinto et al., 2019). Hence there exists a need for an efficient TPM 'deployment strategy that will aid organizations in their improvement studies to solve process related problems. Encouragingly, combining Six Sigma's DMAIC (SS-DMAIC) technique with TPM can improve equipment durability, reduce downtime, and boost overall production (Trubetskaya et al. (2024)). The main operational approach for implementing this model is the DMAIC iterative process, which aims to continuously improve maintenance activities and ultimately achieve world-class performance in terms of both sigma level and overall equipment effectiveness (Alsubaie & Yang, 2017). Thomas et al. (2005) and Trubetskaya et al. (2024) have both observed similar integrations of TPM and DMAIC in the literature. TPM's focus on equipment reliability and DMAIC's approach to problem-solving would help organizations deal with equipment failures and other process issues. Thus, the main objective of this article is to illustrate the synergetic potentials of incorporating TPM into SS-DMAIC approaches to address maintenance and quality challenges.

Literature Review

Both TPM and SS-DMAIC are key business process strategies, which are employed by companies to enhance their manufacturing performance (Thomas et al., 2005). This section will provide a theoretical background on SS-DMAIC, TPM and reported integration tactics in process enhancement studies.

Total Productive Maintenance (TPM)

A breakdown in facilities or equipment not only causes lost production but also delays customer service and can potentially result in environmental and safety issues (Alsyouf 2006). Thus, it may be exciting in a variety of ways to develop a strong relationship between quality control and equipment maintenance to predict process downtime and poor quality losses (Lesage & Dehombreux, 2012). Total Productive Maintenance (TPM) enhances manufacturing efficiency, quality, and safety in a production system (Wolska et al., 2023). Production issues that arise in every production environment are effectively addressed by the TPM pillars of operation. The first pillar provides a systematic team-working method aimed at identifying losses in any process (Meza Jiménez et al., 2025). The second phase focuses on maintenance of equipment at the greatest possible level of availability and performance. Two separate maintenance tasks - maintenance prevention and quality maintenance are essential to the third phase. TPM reduces production flaws, accidents, and equipment breakdowns by offering a thorough life-cycle approach to equipment management (Rajesh et al., 2021). Beyond merely being a maintenance philosophy that the Japanese adopted to suit their culture, TPM is much more. TPM emphasis on manufacturing priorities such as productivity, quality, cost, delivery, safety, and morale (PQCDSM) (Tajiri & Gotoh (1992), and maintaining these objectives is the true goal of TPM. TPM is aimed at reducing waste and enhancing the flow of information and materials through best practice and group engagement. TPM improves productivity and thus ensured that the symbiotic relationship between maintenance and organizational productivity has beneficial effects (Brah & Chong, 2004; Thorat and Mahesha (2019).

Six Sigma-DMAIC Strategies

Six Sigma (SS)-DMAIC is a business strategy that focuses on outputs that are important to the customer in order to find and eliminate the reasons behind faults or failures in business processes (Ninerola et al. 2020). One of the most successful breakthrough improvement techniques nowadays is SS-DMAIC (Desai et al., 2015). It is widely known that SS-DMAIC has a significant and positive effect on enhancing business performance. The four main tenets of SS-DMAIC are improvement, cost savings, variation reduction, and quality measurement (Wang et al., 2024; Jadhav et al., 2023). A problem-solving technique called SS-DMAIC is primarily applied in manufacturing processes to remove bottlenecks and provide consistent quality (Mittal et al., 2023). SS-DMAIC has been used in numerous sectors. For instance, Wang et al. (2024) use SS-DMAIC in conjunction with MCDM to lower manufacturing faults in microlens. Mishra et al. (2024) used the SS-DMAIC technology to boost productivity and sustainability in the cement production industry. In a large-scale food processing industry, SS-DMAIC was utilized to lower process variability. The SS approach was successfully applied by Gilligan et al. (2023) to improve process yields in Irish meat processing. Specifically, the strategy can be modified to satisfy various business goals, allowing companies to establish targets according to particular market needs. The presumption that SS-DMAIC has a standardized approach to implementation is typically untrue (U-Dominic et al., 2025). In industrial, design, and customer-focused operations, the methodology is always changing and can focus on a specific production or service system division with a significant emphasis on statistical analysis and a mathematical model. Notwithstanding its remarkable performance in reality, research on the SS-DMAIC issue is

currently at a low level (Zhang et al. 2009). Any process can reach infinite improvement with the right integration of the SS-DMAIC approach with other improvement initiatives. Nevertheless, as shown in the extant literature, organizational limitations prevent the majority of these integrations from fully utilizing each methodology. The quality community has been working to maximize the benefits of the Six Sigma method through a number of studies in recent years that have focused on the shared relationship between SS and other innovative management methods. These include integration with the theory of constraints (Ehie& Sheu, 2005), integration with lean production (Gupta 2013), integration with the Balanced Score Card SCOR model (Knowles et al., 2005), integration with ISO 9000 (Catherwood, 2002), integration with ISO 9001 (Dalglish, 2005), and integration with the capability maturity model (Murugappen& Kenni, 2003). In the analysis stage, Martin (2006) uses an operation research technique. According to recent research, TPM and SS-DMAIC have been extensively documented in the literature. Lean, Total Productive Maintenance (TPM), and Six Sigma are three well-known process optimization techniques that Alsubaie& Yang (2017) conceptually integrated to create a strategic paradigm. A fleet of military vehicles was maintained using the established model as an example. To eliminate waste in the mini loader maintenance process, Bazan-Torres et al. (2021) suggested an improvement method based on combining the DMAIC approach, total productive maintenance (TPM) strategy, and lean manufacturing (LM) tools. In order to optimize processes, Barriga et al. (2024) provided a case study application of TPM and the Integrated Lean Six Sigma (LSS) methodology in the service sector. A management-based methodology on TPM and SS was presented by Porrás et al. (2024) to improve the total equipment efficacy in a Peruvian textile clothing firm. Similarly, Sharma & Sharma (2014) have combined the TPM framework with SS culture to enhance SMEs' manufacturing performance.

Research Methodology and Analysis

In this study, we looked at the causes of production line failures and how to improve and manage the process by utilizing TPM's integrated support in the SS-DMAIC architecture. The complete system was validated at the PDB cable manufacturing facility located in Southern Nigeria. The company, which mostly manufactures different cables and has a strong reputation for creating high-quality cables throughout Africa, has an ISO 9001-certified quality management system. Over the years, the example organization has encountered several production obstacles in its operations, and it genuinely wants to take a more methodical approach to lessen the impact of these issues on its outputs. This study was carried out methodically in stages using a mixed-methods research methodology which incorporates qualitative and quantitative techniques.

Define

During this stage, the issues like prolonged downtime or equipment malfunctions are well-defined. The project charter was used to establish clear project objectives. The project charter as shown in Table 1, containing necessary information pertaining manufacturing priorities of the case organization as centered on productivity (P), quality (Q), morale (M) and delivery (D) (PQMD).

Table 1: Project charter for the improvement studies

| | |
|---|---|
| Project Priorities | |
| <ol style="list-style-type: none"> 1. Productivity (P) -reduce unplanned stoppages and breakdown. 2. Quality (Q) - reduce quality problems from unstable production. 3. Morale (M) - increase in workers skills and knowledge. 4. Delivery (D) - Improve efficiency of delivery and maintain efficient work procedures. | |
| Reasons for the prioritized projects | |
| <p>Unplanned stoppages and breakdowns are widely recognized to be the primary cause of production system losses. This is because idle machines squander valuable time, which has a negative impact on production and throughput. The origin of extrusion defects in terms of quality losses are also not always understood due to the complexity of extrusion coating processes but failures or defects that typically occur in cable extrusion processes include insulation surface flaws, extruder surging, thickness variation, uneven wall thickness, diameter variation, and centering problems, among other things. It is important to remember that when these production line flaws arise, the process is halted to fix the irregularity, wasting valuable time in the process to eliminate the system's defect sources. Furthermore, inexperienced workers leads to more stoppages, shorter production times, and more quality flaws in manufacturing system and need to be appropriately resolved (Tayal et al., 2021). Based on these ills, it becomes necessary to implement logical and systematic procedures of improvement strategies that are more engaging and accommodating of all stakeholder's views on the process, given that critical knowledge loss occurs through job transfers, retirement, retrenchments, mobility, and alternative work arrangements. Last but not least, the production line frequently experiences a rise in faults as a result of impractical work targets. The study's objectives are to preserve effective work practices, increase delivery efficiency, and minimize production losses.</p> | |
| Aim of the Project | |
| <p>The goal of this study is to integrate TPM in SS-DMAIC's improvement framework to enhance process performance in a cable manufacturing industry.</p> | |
| Project scope | Productivity efficiency |
| Proposed work sequence | <ol style="list-style-type: none"> 1. Team formation (Production & maintenance staff). 2. Survey and analysis of the standard operating procedures (SOP), OEE assessment guide and training. 3. Collection of machine 12 weeks' data on machine failures and down time losses (OEE, PCA). 4. Identification & analysis of main problems and their causes (Fishbone diagram, FMEA). 5. Implementation of the two (2) TPM pillars- autonomous maintenance, planned maintenance), work study. 6. Collection of 12 weeks data on machine failure and downtime losses (PCA). 7. OEE result comparisons and updating of the SOP manual based on the assessment result. |

Measure

The main objective of this phase is to collect data on equipment performance, maintenance activities, and downtime in order to establish the system's baseline performance. The performance is then assessed using OEE measures. The organization operates three shifts a day, and the analysis was limited to bottleneck operations. The study's bottleneck, which is a piece of machinery that quickly increases production output, was the DATO-65 extruding machine. This machine was selected based on certain criteria. The implementation guide and basic OEE assessment tools were provided to the participating team members. These resources included the OEE training guide, OEE pocket guide, OEE fast start, OEE manual of loss report, OEE stop event record, OEE stop cause tick sheet, and more. The team was familiar with the OEE phase, as required by the OEE guidelines, and the procedure produced the necessary data on losses in the machine that was determined to be the bottleneck. Over the course of 12 weeks, information on machine failures and downtime was collected from the maintenance unit of the case company. All of the production indicators needed for the overall equipment effectiveness estimations were obtained from observational data. The OEE was calculated as the product of the three OEE rates after each rate was calculated independently. Under the availability rating, OEE loss falls under the category of downtime loss (breakdown, set adjustment loss). Unplanned maintenance hours, equipment malfunctions, material shortages, machine replacements, tool damage, and process up are some examples.

$$\text{Availability (A) \%} = \frac{\text{Runtime}}{\text{Planned Production Time}} \tag{1}$$

Where,

$$\text{Run time} = \text{Planned production time} - \text{stop time} \tag{2}$$

$$\text{Performance (P) \%} = \frac{\text{Ideal cycle time} \times \text{Total count}}{\text{Run time}} \tag{3}$$

$$\text{Quality (Q) \%} = \frac{\text{Good count}}{\text{Total count}} \tag{4}$$

$$\text{OEE} = \frac{\text{Ideal cycle time} \times \text{Good count}}{\text{Planned Production time}} \tag{5}$$

OEE loss under performance rating is categorized as speed loss. In operation, this category of loss could be as a result of products that are not well feed into machine, component jams, and product flow stoppage, poor level of machine operator's training, aged and tooling wear. Three months data on the GATO-65 extruding machine history was gathered prior to ascertain the OEE baseline value.

Table 2. Baseline assessment of the OEE of the extrusion machine at plant

| Weeks | Availability | Performance | Quality | OEE |
|-------|--------------|-------------|---------|-------|
| 1 | 0.68 | 1.02 | 0.94 | 0.65 |
| 2 | 0.64 | 0.95 | 0.88 | 0.54 |
| 3 | 0.76 | 0.96 | 0.89 | 0.64 |
| 4 | 0.72 | 0.90 | 0.81 | 0.53 |
| 5 | 0.64 | 0.92 | 0.82 | 0.48 |
| 6 | 0.77 | 0.90 | 0.88 | 0.61 |
| Total | ∑ 70% | ∑ 96% | ∑ 88% | ∑ 58% |

(OEE = A*P*Q)

Following the determination of the current OEE value, a process capacity analysis was carried out to evaluate the process's baseline performance. The CR is 84.67%, and the CP is equivalent to 1.181. This percentage indicates that 84.67% of the engineering requirement

is used by the process's "natural tolerance," which is obviously inadequate. Despite this discrepancy, centering the process can still yield significant improvements. The Cpk value is 0.73, which is 0.451 less than the Cp number. According to the chart in Appendix D, we have $ZU = 1 - 0.9854$, or 1.46%, and the calculated ZU for the process is 2.18. By this prediction, approximately 1.46% of the production will surpass the top standard. The process's computed ZL is 4.98, which is acceptable because the ZL number must be at least +3.

Analyze

A fishbone diagram and Failure Mode and Effects Analysis (FMEA) were used to evaluate the reason of low OEE and determine the underlying causes of the issue. Simple systems or those with few components or failure modes are the ideal candidates for FMEA. It performs well on small systems and individual pieces of equipment, but it is not easily adaptable to bigger systems, such as entire facilities and processes (De Vasconcelos et al., 2018). In order to get insight into the possible ways a process may fail, the FMEA methodology uses the practical knowledge of its users, recruiting a varied set of users who are working on different sections of the process as subject matter experts (Ullah et al., 2022).

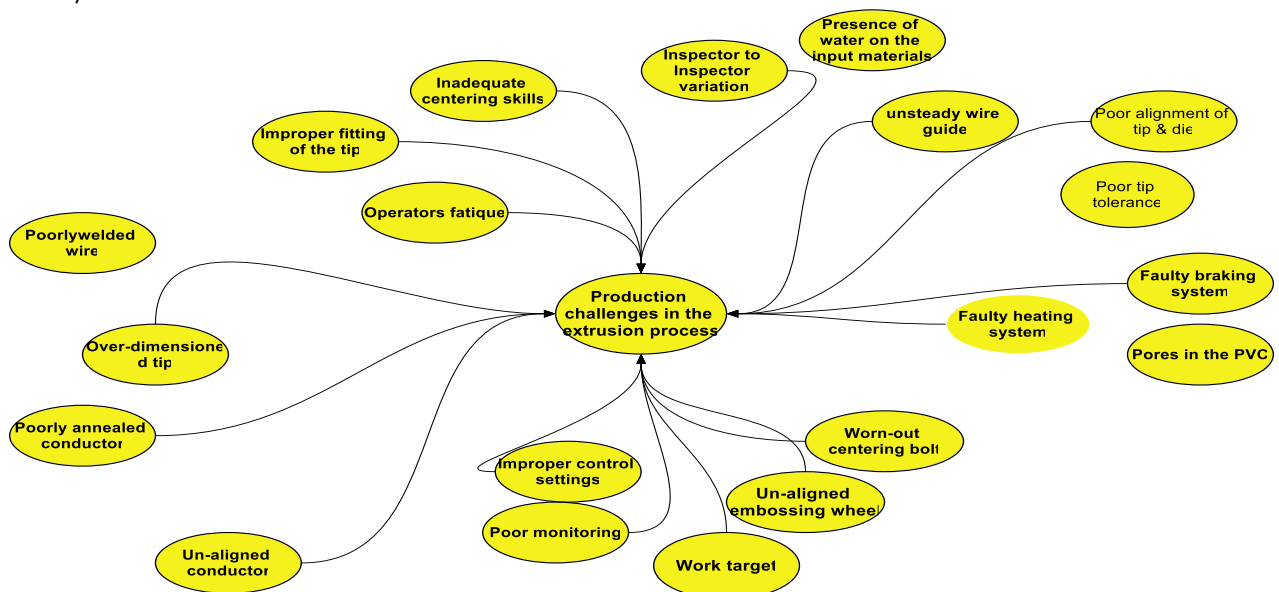


Figure 1. Brainstorming outcome of production challenges that lead to machine downtimes

A group of the organization's knowledgeable employees were brought together to create a community of practitioners for this investigation. This includes six employees with at least five years of relevant experience in the extrusion process from the manufacturing and maintenance departments. Personnel from this industry's production and maintenance units were the only ones selected as responders for this study. Because the participants were able to discuss their specific areas of competence, the adoption of these two noteworthy worker groups in this study increased the dependability of the data collected. The GATO-65 machine was the focus in order to arrive at a credible assessment. Identifying process issues that result in machine downtime and other productivity concerns was done by the team through a brainstorming session. Afterwards, a fishbone diagram was then

utilized to further classify these failures into causes related to personnel, material, measurement, method, and machine.

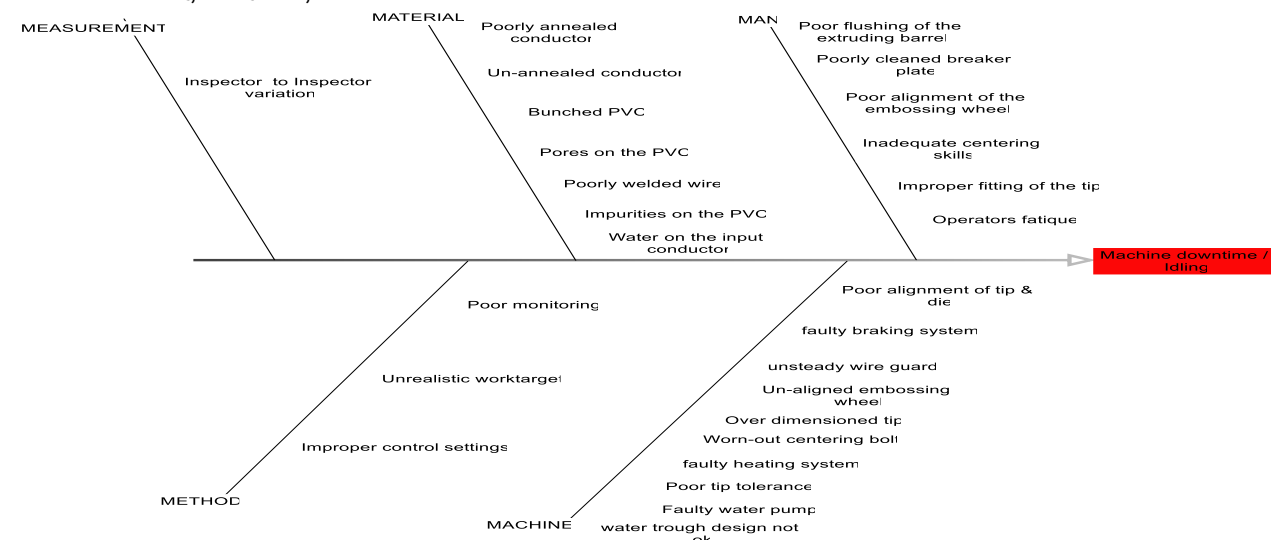


Figure 2. Fish bone diagram of machine downtime causatives as categorized by 5M's

The team members conducted FMEA on the GATO-65 machine's extrusion process line to determine the effect of failure on the production system. Failures that affect product quality, safety, environmental risks, process dependability, and customer satisfaction are found using FMEA (Anjalee et al., 2021; Huang et al., 2020). Since, the FMEA works best on small systems and specific pieces of equipment (De Vasconcelos et al., 2018), the FMEA in this study focused on the causes of loss hours exclusively in the extrusion process of GATO-65 machine and that extrudes only 1.00mm single wires.

Table 3. FMEA on the extrusion process line

| S/N | Causes of Downtime losses | SEV | OCC | DET | RPN |
|-----|---|-----|-----|-----|-----|
| 1 | Un-aligned embossing wheel | 9 | 5 | 3 | 135 |
| 2 | Worn-out centering bolts | 9 | 4 | 5 | 180 |
| 3 | faulty heating tools | 10 | 5 | 2 | 100 |
| 4 | Over dimensioned tip | 8 | 3 | 7 | 168 |
| 5 | Improper speed setting | 8 | 7 | 3 | 168 |
| 6 | Unsteady wire guard | 2 | 4 | 2 | 16 |
| 7 | Poor tensioning system | 4 | 7 | 3 | 84 |
| 8 | Poor tip tolerance | 8 | 4 | 7 | 224 |
| 9 | Water trough design not ok | 2 | 3 | 1 | 6 |
| 10 | Faulty water pump | 8 | 3 | 4 | 96 |
| 11 | Inadequate skill/ negligence | 10 | 5 | 5 | 250 |
| 12 | Impurities on the PVC | 3 | 6 | 2 | 36 |
| 13 | Poorly welded Joints. | 7 | 4 | 7 | 196 |
| 14 | Poor flushing of the extrusion barrel | 2 | 8 | 2 | 32 |
| 15 | Bunched PVC (PVC pellets stringing together) | 6 | 8 | 2 | 96 |
| 16 | Management Interferences/ Poor material Logistic / lack of motivation | 10 | 6 | 4 | 240 |
| 17 | Presence of water on the input conductor | 6 | 6 | 4 | 144 |
| 18 | Pores on the PVC | 5 | 5 | 5 | 125 |

| S/N | Causes of Downtime losses | SEV | OCC | DET | RPN |
|-----|--|-----|-----|-----|-----|
| 19 | Presence of moisture on the PVC | 2 | 9 | 3 | 54 |
| 20 | Operators fatigue | 9 | 4 | 5 | 180 |
| 21 | Poorly annealed / un-annealed conductor | 7 | 5 | 5 | 175 |
| 22 | Inspector to Inspector variation | 3 | 3 | 2 | 18 |
| 23 | Poor fitting of the tip to the core tube | 8 | 4 | 4 | 128 |
| 24 | Poor monitoring | 6 | 3 | 5 | 126 |

Priorities were established with the help of RPNs; larger RPNs would be given more attention than smaller RPNs. The team members also established that out of control processes that eventual results in machine downtime is caused by these causative elements with RPN > 120. Eliminating the unique reasons of variation is thought to stabilize the process and bring it under control. Three parts of the FMEA analysis reveal the losses that define this production system:

1. Downtime losses. These include losses brought on by equipment failure as well as losses that occur during setup and transitions, such as worn-out bolts,
2. Speed losses. Machine idle, small stoppages, and decreased speed for example, due to incorrect control settings—are all signs of these losses.
3. Quality losses. Defective products and the additional expense of rework are examples of these losses. For example, inadequately flushed extruding barrels, poorly welded joints, etc.

It is impossible to overestimate the significance of quality in cable manufacturing, and any noticeable production reaction that deviates from the organization's criteria commonly causes machine stoppages. Consequently, quality losses, such downtime losses and product defects, account for the majority of production system losses. The next step is to implement TPM to slow down the rate at which these losses occur to easily keep the system under control.

Improve

At this phase, TPM was introduced in the extrusion process to enhance the machine's performance and efficiency. The correct implementation of strategic initiatives and methods, each tailored to the unique operating reality of a given organization, enables the more effective utilization of device and personnel capabilities (Wolska et al., 2023). However, poorly implemented TPM can hurt maintenance procedures, workers' motivation, and the reliability of production equipment, as well as increase workloads (Slavina, et al., 2024). In the improvement phase, a transition to a proactive maintenance approach occurs, and two TPM pillars are implemented: autonomous maintenance and planned maintenance. One definition of autonomous maintenance (AM) is a scheduled maintenance approach in which operators are responsible for maintaining the equipment (Bali et al., 2022). AM can drastically lower costs and increase quality and productivity when used correctly (Loures et al., 2021). On Plant 1's production job floor, an autonomous maintenance program was implemented. Production and maintenance staff worked on the program, primarily on the extrusion equipment's continuously failing parts and according to the corresponding RPN rating of downtime losses. The training, which lasted roughly two months, included both practical sessions and theories of machine operations. The in-depth meetings took place three times a week, with two days dedicated to practical demonstrations and one day to

theoretical lectures. The training session was organized for participants to attend during their shift off because the case organization operates in three shifts. Some fixes that were previously performed by the maintenance unit are taught to the operators during the hands-on training sessions. Knowledge of the process, information from manuals, and technical know-how between the maintenance workers and the machine operators were shared among the team members during this stage of cross-functional information transmission and knowledge spiral enhancement. Basic maintenance procedures for the extrusion machine's parts, including the embossing wheel, heating band replacement, water pump maintenance, and correct braking system tensioning, were taught to the operators. The regular inspections of the measuring instruments, and input materials, and the creation of maintenance schedules to be adhered to at the start and finish of each production shift were the key ways that the scheduled maintenance component was perceived. The bottleneck operation—the extrusion machine—was selected as the study's pilot region, and the team's primary objectives were to restore the equipment to optimal operating conditions and implement solutions to deal with the sources of inefficiencies and downtime that were discovered. The implementation of TPM is not straightforward; most firms have failed in their endeavors due to bureaucratic, cultural, and behavioral issues (Poduval et al., 2015). Accordingly, a phased method approach was used during the TPM implementation, and consideration was given to other important success elements for the TPM implementation as well as the upcoming dilemmas. The FMEA, TPM implementation, and members' prior experiences with extrusion processes in terms of equipment modifications, process designs, improved maintenance procedures, skill enhancement, etc., were used to propose solutions to the failure reasons that were found.

Table 4. Recommended solutions for the process challenges and inefficiencies






| S/N | Causes | machine | Solutions for reducing the rate of machine stoppages in the downtime in cable extrusion process. |
|-----|----------------------------|-----------|---|
| 1 | Un-aligned embossing wheel | | Careful check by the operator on the position of the embossing wheel to the cable, and confirmed by the process engineer on the line immediately after secondary centering has taken place. The process engineer should from time to time check the movement of the embosser in relation to the extruding cable, and also feel the extruding cables to check the quality of the embossment. |
| 2 | Worn-out centering bolts | | Improvement on centering techniques and use of high temperature yielding bolts and nut, basically medium carbon steel composition of 8.8MPa and above. |
| 3 | Faulty tools | measuring | Digital calipers should not be placed on vibrating machines. Secondly, before measurement, operators must first measure a reference dimension with the caliper before taking any online measurements. |
| 4 | Faulty system | heating | The condition of the heating system should be checked properly by both the operator and the process engineer and validated at the start of every production shift. The functionality of the heater bands should always be checked at |






| S/N | Causes | machine | Solutions for reducing the rate of machine stoppages in the downtime in cable extrusion process. |
|-----|--|---------|---|
| | | | least every 20 minutes using water sprays. Always use candle stick heater bands at the crosshead section for easy replacement and correction. |
| 5 | Inadequate skill | | Training on “centering” techniques and Standard Operating Procedures (SOP). Adequate training, monitoring and to also make sure that the operators always adhere to standard operating procedure |
| 6 | Faulty heating system | | The condition of the heating system should be checked properly by both the operator and the process engineer and validated at the start of every production shift. The functionality of the heater bands should always be checked at least every 20 minutes using water sprays. Always use candle stick heater bands at the crosshead section for easy replacement and correction. Use of high quality heater bands. Temperature settings have to be reduced while the machine operators are on break |
| 6 | Poorly annealed copper conductor | | If it will be used at all, then extremely care must be taken by assigning the job to the most experienced operator. Secondly, the extrusion parameter settings must be varied in such a way to increase the cable dimension, thus eliminating the possibility of producing off-centered cables. |
| 7 | Over dimensioned tip | | Not to be used at all. |
| 8 | Poor monitoring system | | Improve monitoring system by ensuring that during extrusion that both process-based monitoring and product-based monitoring are used to achieve product improvement. [Process-based monitoring watches production process conditions such as melt temperature and pressure. While Product-based monitoring follows properties of the product, such as clarity and thickness]. |
| 9 | Faulty tensioning system | | Total overhaul on the braking system. |
| 10 | Operator’s fatigue | | Work appraisal |
| 11 | Poor tip fitting | | The fitted tip should be sighted by the process engineer before in use |
| 12 | Presence of water on the input conductor | | Use of oxyacetylene gas flame on every input conductor before extrusion and at intervals while extruding. |
| 13 | Pores in the PVC | | Compromised quality must not be used |
| 14 | Poor monitoring system | | Review monitoring strategy by ensuring that during extrusion that both process-based monitoring and product-based |

| S/N | Causes | machine | Solutions for reducing the rate of machine stoppages in the downtime in cable extrusion process. |
|-----|---|---------|---|
| | | | monitoring are used to achieve product improvement. [Process-based monitoring watches production process conditions such as melt temperature and pressure while Product-based monitoring follows properties of the product, such as clarity and thickness]. |
| 15 | Improper setting of speed | | Optimal parameter settings through experimental designs. |
| 16 | Poor flushing of the extrusion barrel | | Proper flushing and adequate monitoring. The process engineer has to certify it ready before the next activities |
| 17 | Water trough design not ok. | | Redesigning of the water trough guide, interval check on the cable guide. |
| 18 | Poor alignment of the embossing wheel or shifting embosser. | | Interval check and proper tightening of the wheel. |
| 19 | Poor tip tolerance | | Not to be used. |
| 20 | Poorly welded wire. | | Careful filling of the welded joint (measure the welded point after weld) |
| 21 | Management problems / lack of motivation | | Review the existing incentive programme, improvise adequate resource planning system that will ensure needed parts and materials are readily available. |

In order to minimize the majority of production anomalies that often lead to production loss hours, the team conducted extra work to address the underlying causes of these production losses. The investigation team thoroughly investigated all the elements, factors, resources, and relationships affecting the productivity and efficiency of the GATO-65 production line's 1.0mm single-house wire cable extrusion process. The type of extrusion machine, operational layout, material handling and supply, planning procedures' effectiveness, and possible idle periods were all evaluated with the current operating processes. The mnemonic SREDIM, a common-sense heuristic that uses a six-stage procedure, was employed in the Method Study. Work was selected in order to reduce scrap and eliminate unnecessary motions and procedures, which would improve quality when employing the recommended strategy.

Table 5. Flow Process Chart (AS -IS)






| Step | Time | Distance (meter) |  |  |  |  |  | Step Description |
|------|------|------------------|---|---|---|---|---|---|
| 1 | | 17 | X | | | X | | Conveying of the reels (input/output). Most times operators have to wait for the conveying forklift |
| 2 | | | | | X | X | | Inspection of the input diameter by the QA staff |

| Step | Time | Distance (meter) |  |  |  |  |  | Step Description |
|------|------|------------------|---|---|---|---|---|--|
| 3 | | | X | | | | | Load the input reel at the take-off end |
| 4 | | | X | | | | | Pass the input wire through the core tube, tip and the die |
| 5 | | | X | | | | | Open the crosshead |
| 6 | | | X | | | | | Clean the breaker plate and change the wire mesh |
| 7 | | | X | | | | | Flush the barrel and couple back the crosshead |
| 8 | | | X | | | | | Tie the input wire with the existing wire |
| 9 | | | X | | | | | Load the output reel and tie with the wire at the pay-off section. |
| 10 | | | X | | | | | Start the line at low speed and do centering |
| 11 | - | | | | X | X | | Inspect Centricity with QA staff |
| 12 | - | | X | | | | | Extrusion |
| 13 | - | | X | | | | | Unloading the output reel |
| 14 | 3 | | | X | | | | Transport to corner |

The job chosen for the method research was evaluated from an economic, technological, and human perspective. One of the company's core business operations is the extrusion of the primary coil, and the "Start-up Operation," or bottleneck operation, was the extrusion task selected for examination. According to the highlights above, "Start-up Operation" is the most crucial aspect of the extrusion process since it is relevant to production and demands greater care and attention to detail. For a more thorough analysis, the "Start-up" task was divided into fourteen (14) components in Table 5. It was noted that in order to save time and enhance the quality of the final product, certain operations needed to be removed. Table 5 summarizes the "AS-IS" process sequence. It shows that there are ten operational steps (10), transportation = 2, and inspection = 2. The current process revealed that the majority of idle times were caused by the time lost moving the input copper conductor from the wire drawing section to the extrusion line, which takes five to ten minutes to obtain the input reel. This is because the input reels are typically not easily accessible at the extrusion line and must be transported to the process line by the machine operator using a forklift. Additionally, time is wasted needlessly when checking the input wire's diameter. Waiting for additional input material inspection before beginning an operation is a waste of productive hours and idle time, as all of the wires drawn at the drawing section were certified by the Quality Assurance team after drawing and were identified with tags. Following an analysis of the current procedure, an enhanced approach was suggested, as indicated in Table 6. The enhanced approach made sure that supplies and components were available for production and that finished products were ready for shipping by adhering strictly to the company's master schedule. The responsibility of carrying, particularly the input reels, was not assigned to the machine operators. Every

manufacturing shift begins with the conveyance of the input materials, and because of the potential for entangled wires in a reel, the number of input reels is always greater than the number of other input materials during conveyance. It was suggested that at least two machine operators work on a single extrusion line so that one of them might compensate for a material deficit while the line was in operation without necessarily stopping the production process. According to the new technique's process sequence summary, some inefficient production tasks can be significantly shortened by using the new method.

Table 6. Chart (Improved method)

| Step | Time | Distance (meters) |  |  |  |  |  | Step Description |
|------|------|-------------------|---|---|---|---|---|--|
| 1 | - | - | X | | | | | Load the input reel at the take-off end |
| 2 | - | - | X | | | | | Pass the input wire through the core tube, tip and the die |
| 3 | - | - | X | | | | | Open the crosshead |
| 4 | - | - | X | | | | | Clean the breaker plate and change the wire mesh |
| 5 | - | - | X | | | | | Flush the barrel and couple back the crosshead |
| 6 | - | - | X | | | | | Load the output reel at the pay-off & tie |
| 7 | - | - | X | | | | | Continue to flush the barrel while the line is still and start your centering. |
| 8 | - | - | X | | | | | Start the line at low speed and continue centering |
| 9 | - | - | | | X | X | | Inspect Centricity with QA staff |

Work estimation was conducted to derive the standard time of operations and the extrusion start-up task was divided into work elements, and timed. The standard time for the start-up operation was derived to be 68 minutes using equations (6), (7), (8) and (9).

$$S_x = \left[\frac{\sum [(t_i - \bar{t})^2]}{n} \right]^{0.5} \tag{6}$$

$$\text{Lower limit} = \bar{t} - 2S_x \tag{7}$$

$$\text{Upper limit} = \bar{t} + 2S_x \tag{8}$$

$$n = \left[\frac{(k * S_x)}{(r * \bar{t})} \right]^2 \tag{9}$$

Where; \bar{t} = Average time for performing the element, S_x = Sample variance for the element; n = number of data points in the data sample; k = number of standard deviations at the confidence level; r = measure of error precision; and t_i = individual observed time.

$$\text{Basic Time (B}_T) = \frac{\text{Observed Performancerating}}{\text{NormalRating}} \tag{10}$$

$$\text{Standard Time (S}_T) = B_T + R_{TA} + C_{TA} \tag{11}$$

Where R_{TA} = Relaxation Time Allowance; C_{TA} = Contingency Time Allowance (contingency time allowance are allowances due to unanticipated official disturbance to one

at work). Since Standard time is a common denominator for measuring productivity, the value gotten was implied to ascertain the expected productivity rate for this operation. From the FMEA, the common knowledge of the extrusion process drawn from the team's interaction attributed downtime losses to extrusion machine operating below the designed speed. The next step was to determine the optimum parameter settings that would result in the lowest amount of defects using Central Composite Design (CCD) using equations (12), (13) & (14).

$$Y = f(x_1, x_2, x_3, x_4 \dots x_n) \tag{12}$$

Where f is a multivariate function, the items represent the factors (independent variables), and the relationship describes a curved surface $y = f(x_1, x_2, x_3, x_4 \dots x_n)$ that is known as a response surface.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \tag{13}$$

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \varepsilon \tag{14}$$

After the experimental design, process capability study was conducted and the capability metric values are as follows; Cp = 7.55, CR = 13.25%, ZU = 22.88, ZL = 22.39, CPK = 7.46, CPM = 6.4. With the CP index value of 7.55 is an indication that the existing engineering tolerance is far apart from each other with a large standard deviation. Appropriate tolerance intervals that clearly depict Six Sigma Process were derived using equation (15) & (16).

$$\bar{X} \pm Ks \tag{15}$$

$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{N - 1}} \tag{16}$$

Where N is the sample size, s is the sample standard deviation, x is the mean of the data, and K is a constant that is chosen so that the interval will cover a proportion P of the population with confidence α . The capability index values were as follows after PCA was performed with the newly designed engineering tolerance of 2.705±0.032: The "natural tolerance" of the process consumes 69.96% of the engineering requirement, or roughly 14.71% less than the initial value of 84.67%, according to CP = 1.43, CR = 69.99%. ZU = 1-0.9999, or 0.01%, while the process's estimated ZU is 3.68. The estimated ZL for the process is 4.89, and since the ZL value is at least +3, approximately 0.01% of the production will surpass the top specification. The anticipated yield is 99.99% since the total reject rate is 0.01%.

Control

The control phase is to continuously track progress and to ensure that all the implemented solutions were maintained and controlled consistently. At first, the OEE was computed to evaluate the effectiveness of TPM initiatives. The differences between the before OEE values and OEE values after TPM implementation against the world class OEE benchmark is as highlighted on Table 8.

Table 7. OEE evaluation after the deployment of TPM practices in the Process line

| Weeks | Availability | Performance | Quality | OEE |
|-------|--------------|-------------|---------|------|
| 1 | 0.72 | 0.96 | 0.94 | 0.65 |
| 2 | 0.69 | 0.95 | 0.95 | 0.62 |
| 3 | 0.70 | 0.95 | 0.94 | 0.63 |

| Weeks | Availability | Performance | Quality | OEE |
|-------|--------------|-------------|------------|------------|
| 4 | 0.72 | 0.93 | 0.89 | 0.60 |
| 5 | 0.68 | 0.91 | 0.90 | 0.56 |
| 6 | 0.79 | 1.00 | 0.91 | 0.72 |
| Total | \sum 72% | \sum 95% | \sum 92% | \sum 63% |

Table 8. OEE evaluation values before and after in comparison with the world class benchmark

| OEE Factor | World class | Before Improvement | Differences | After Improvement | Differences |
|--------------|-------------|--------------------|-------------|-------------------|-------------|
| Availability | 90.00% | 70.00% | 20.00% | 72.00% | 18.00% |
| Performance | 95.00% | 96.00% | -1.00% | 95.00% | 0% |
| Quality | 95.00% | 88.00% | 7.00% | 92.00% | 3.00% |
| OEE | 85.00% | 58.00% | 27.00% | 63.00% | 22.00% |

The availability value increased by 2.85% from its initial 70% value to 72% after implementation, while the quality value increased by 4.6% from the initial 88% to 92%. These two OEE parameters availability and quality exhibit significant gains, even though the performance parameter did not increase following the improvement. The OEE value after the deployment has considerably shown there was about an 8.62% incremental difference from the initial OEE value of 58% to 63% after the improvement. However, the world-class overall OEE for discrete manufacturing plants is generally considered to be 85%, meaning that the improvement we attained is about 35% less than the standard OEE value. The SOP was updated based on the findings from the entire study to overcome the problems that lead to all the inefficiencies in the production process. After that, visual management (VM) tools that enable quick detection of performance concerns and subsequent quick response delivery were introduced. The VM tools introduced are the use of whiteboards showing daily progress against the target, displaying of weekly scorecards in the common areas and posting of job aids in each work post.

CONCLUSION

The intrinsic potential of these two effective lean techniques, TPM and SS-DMAIC, to increase productivity through loss reduction in a manufacturing organization was investigated in this study. The effects of the new methodology have been examined, and the suggested TPM-SS-DMAIC integrated strategy has been validated in a cable manufacturing company. The study's objectives were met in terms of fewer unscheduled stoppages and breakdowns, improved quality, effective work practices, and an increase in workers' expertise. Time wastage was minimized by learning the production process and conducting a comprehensive analysis of the sources of useless hours. Through a time study, standard time for important operations which is regarded as a common denominator for determining productivity was determined. Solutions for removing needless stoppages in the extrusion line operation were suggested, and standard operating procedures were revised. Following the implementation of the recommended method, the capacity analysis demonstrated an improvement in the quality of the items produced. The Overall equipment

effectiveness (OEE) rose sharply from 58% to 63% after the process change, as well as the process quality, thus demonstrating a remarkable degree of improvement.

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