PONTE
Florence, Italy
International Journal of Sciences and Research

Utilizing Lean Techniques Through a P-D-C-A Approach to Drive Built-In-Quality in a Thermoforming Line for an Automotive Component Manufacturer.

Edward Sontaga Makua
Durban University of Technology
Department of Industrial Engineering
South Africa
21300904@dut4life.ac.za
Corresponding author

Bakhe Nleya
Durban University of Technology
Department of Electronic Engineering
South Africa
bakhen@dut.ac.za

Mendon Dewa
Durban University of Technology
Department of Industrial Engineering
South Africa
mendond@dut.ac.za

Abstract

Automotive component manufacturers are faced with competitive challenges globally. At the heart of these challenges is the need to produce parts that are of high-quality standards. Now more than ever before, organizations need to work as a unit to drive the fundamentals of built-in-quality if they are to maintain good quality standards and overall cost competitive leadership. An automotive component manufacturer was struggling with managing the thermoforming line outflow of defects to their customers. Substantial amounts of resources in the form of inspectors were being added on their manufacturing lines to form quality gates and inspect for quality. This has resulted in cost implications and major profitability losses and further expanded their cost of quality. The severity of the problem was further exacerbated by the acceptance of the quality gates as a status quo with little or no initiatives to turn around the situation. The aim of this study was to subdue the traditional quality management approach of inspecting for quality by introducing a series of lean manufacturing techniques that process capability and built-in-quality. The study streamlined a sequence of lean manufacturing techniques that supported each other in their findings and results to develop a Plan-Do-Check-Act (PDCA) based strategic approach to drive in-process quality capability in the manufacturer’s Thermoforming line. The results of study were significant manpower reduction on the lines, improved quality capability results, reduced expected scrap rates and reworks, and an overall strategic guideline for the implementation of built-in-quality in automotive component manufacturer’s thermoforming line.

Keywords: Built-In-Quality, Thermoforming line, In-process capability, P-D-C-A, Lean techniques

1. Introduction

Product built-in-quality (BIQ) has been recognized by several studies as a key competitive edge strategy for manufacturing organizations. Psarommatis (2020) recognizes product BIQ as a tool to overcome cost implications such as labour, reworks, and defect outflow to enhance competitiveness. This study focuses on determining a structured and strategic approach to implement BIQ in the automotive component manufacturer that considers the different manufacturing complexities involved in this sector. A further dive into innovations associated with the Fourth Industrial Revolution will be explored as to how best can they be incorporated into process BIQ through a strategic approach. In this study, the traditional 100% inspection of components approach on end-of-line manufacturing will also be explored to determine the organizational impact from a cost, profitability, and competitiveness perspective. The development of an approach to implement BIQ necessitates the exploration of different quality tools to gather information and develop root-causes for improvement. Several authors have identified several tools as key to quality improvement in any quality management system. These tools include, but are not limited to 5why analysis, Ishikawa diagram, Pareto analysis, scatter diagrams and FMEAs. According to Neyestani (2017) these tools are significant towards process improvement across manufacturing streams and play a significant role in ensuring product quality.

1.1 Objectives of the study

- To outline some of the major constraints hindering the implementation of BIQ in automotive component manufacturers
- To rank and identify the defects that plague the Vacuum-forming line.
- To apply the lean tools through categorising them into PDCA to develop a BIQ implementation approach.
- To conduct a comparative analysis on the BIQ approach and the traditional approach of using quality gates.
- To evaluate the process capability results between the BIQ approach and the use of quality gates.

2. Literature Review

BIQ is one of the fundamental structures of lean manufacturing and dates to the initial writings of Deming within the sphere of quality. Soliman (2020) outlines the fundamental aspect of the BIQ principle to be that of driving proactivity towards responding to defect occurrences, implementation of fool-proof systems, measuring, and continuously building an organizational culture that bears the responsibility of quality in its entirety. The key attributes of the principle mainly focus on value adding aspects of manufacturing particularly during the conversion phase of a component or an assembly. BIQ seeks to address the gap that lies in many manufacturing companies whereby quality responsibility is seen as departmental responsibility as opposed to an organizational responsibility.

Donada, Nogatchewsky, and Pezet (2016) expand on the BIQ approach by outlining that it is a process of equipping manufacturing employees with the necessary skills and capabilities to execute their jobs with ease while adhering to good quality practices. Assessing and driving process capability in component manufacturing industries is crucial for good quality features of the components (Dobránsky, Pollák and Doboš 2019). To attain the transition to BIQ, measures around skills development and training need to be undertaken. Building process capability in the scope of BIQ entails challenging the traditional approach of end-of-line inspections to in-process inspections. Capability building through in-process inspections needs to be done both from a technological perspective and employee perspective (Hafeez and Akbar 2015). The employment of the BIQ approach is presented with significant constraints in manufacturing organizations ranging from but not limited to the following:

- **Lack of manufacturing capacity**: Over-promises to customers results in quality elements being the first to fall away from manufacturing operations in an effort to buy time and speed-up production to meet over promised capacities, most of which are long term. A trade-off study conducted by Owen and Blumenfeld (2008) between speeding up lines and impact on quality indicated that increases in operating speeds result in deterioration of product quality. Such fast paced work results in high scrap rates, high number of reworks and severe cost implications.
- **Transformation resistance**: Transformation resistance talks to changing the status quo. For BIQ to be implemented, there needs to be a transformational drive from top management. Pussella and Yapa (2020) argue that lack of management support hinders transformation in the establishment of a sustainable quality environment. Resistance from top management to drive BIQ and move away from traditional quality gates dismantles unified organizational wide assumption of the responsibility of quality. Further to this, Kumar et al. (2020) argues that the absence of management support is a barrier to the implementation of quality systems. This becomes a limitation as management support is key to investment and cultural change in any organization.
- **Layout constraints**: Silva and Cardoza (2010) stress on the layouts that do not have continuous flow as limiting the ability to detect defective parts before they are moved to proceeding processes. Such a limitation comes in the form of space constraints in ACMs, whereby innovations cannot be undertaken in the manufacturing stream due to congestion, disruption in work sequence and safety implications. This results in manufacturers not being able to fully implement BIQ initiatives and resorting to the traditional layout designs of having inspections not being done in the manufacturing process, but at the end of the line.
- **Workforce flexibility**: Workforce flexibility in the aspect of quality refers to BIQ initiatives being perceived as added work to manufacturing employees. This has the potential to spark union and management tensions as the perception is met with the request of compensation to added work. If the bigger picture of BIQ innovations and initiatives is not understood or in line with union requirements, it becomes a limitation to its implementation. Bryson and Dale-Olsen (2020) highlight in their study that one of the major hinderances to innovations in organizations is the demand for higher reward by

unions, especially where there are technological innovations. This poses a great threat to the implementation of BIQ as it can render management reluctant to invest in initiatives that will see them having to reward employees more.

In line with the first objective of the study, research indicates that the use of a quality gate to inspect for quality is the predominant approach towards subduing the BIQ implementation constraints in ACMs. This is a traditional system that is being used to check components and assemblies if they are rejects or acceptable post manufacturing (Genta, Galetto, and Franceschini, 2020). The process of establishing quality gates is fundamentally driven by pre-determined criteria in which quality inspectors are expected to ensure adherence to the criteria or specifications. Further to this, the process of using quality gates also supports the establishment of rework stations and turning parts back at the end of the line for rework (Filz, Herrmann and Thiede 2020).

3. Methodology

The research methodology embraced the use of lean manufacturing techniques that were categorized according to the P-D-C-A approach. For the Planning phase, the study outlined the process flow of the line through a Value Stream Map (VSM) to paint a clear picture of the flow of operations and how quality gates were positioned on the line. The Pareto Analysis technique was then used to stratify the defects on the line, to narrow the focus of the approach to vital few defects. The vital few defects were subjected to a root-cause analysis approach using Fishbone Diagrams. Further to this, the Planning phase embraced the use of Standard Operating Procedure (SOP) analysis to understand the gaps that existed in operator SOPs to drive BIQ. The next phase of the methodology was the Doing phase. Based on the gaps identified on the SOP analysis technique, this phase focused on addressing the gaps and moving all elements of quality gates into the main conversion operations to drive self-inspections and eliminate quality gates. A Technological value analysis and Time study technique were carried out. The Check phase comprised of checking capability comparison between the use of quality gates and BIQ. The last phase of the research methodology was the Act phase. This phase outlined a continuous improvement model for the for the BIQ approach and outlining critical measurables to monitor post the execution of the techniques to ensure the effectiveness of the approach.

3.1 Planning Phase

3.1.1 Value Stream Map

The Value Stream Map is recognized as one of the most powerful techniques in developing a clear picture of the flow of materials, processes, and the lead times taken in each process (de Paula Ferreira et al. 2022). The value stream map (VSM) for the Thermoforming line indicated the flow of material from raw state to the completion of the product. The map commenced with the acquisition of a monthly forecast plan that was received by the production planning department from the customer. Weekly plans were derived from the monthly forecast and sent to production supervisors. Daily demand was then filtered down to manufacturing operators according to the derivatives that were required by the customer.

3.1.2 Pareto Analysis

According to Brooks (2014), the Pareto analysis method is a one that is used to prioritize problems in most companies through statistical ranking to tackle 20% of the major contributors to eliminate 80% of problems in manufacturing lines. This technique was used to analyse the defects that are contributing significantly to quality issues on the lines. This was in the form of ranking the defects from highest to lowest using a bar graph. The defects that fell within the 20% boundary were regarded as the vital few, and those that fell beyond the 20% boundary on the vertical axis were regarded as the significant many (Patel and Patel 2021).

3.1.3 Fishbone Diagram

The Fishbone diagram approach is a technique used predominantly in automotive industries to outroot the reasons for the occurrence of a problem by means of a fishbone brainstorming diagram that is centered around the 5Ms and environment (Wolniak 2019). This technique first outlined the defects that were identified as the vital few on the line, identified possible root-causes to the problems, and verified the actual root-causes to the problems. The study then tabled preventative measures and technological aids that can be employed to overcome and drive BIQ to prevent future defect occurrences.

3.1.4 SOP Analysis

The execution of this technique was that of taking each process and analyze the number of operations in the process, the possible number of defects that can occur in the process as per Pareto analysis outline, and the number of possible defects to self-inspection and appraisal elements in the operations. Further to this, an analysis of whether the vital few defects identified in the Pareto analysis could possibly occur in the process was conducted. The tabling of this technique was also supported by a root-cause analysis technique that was conducted for the vital few defects in each process prior to the SOP analysis. The SOP analysis formed part of the foundation of re-distributing quality elements from quality gates back into the conversion processes to drive BIQ.

3.2 Doing Phase

3.2.1 Technological Value Analysis

This analysis focused on some of the corrective actions that were identified on the Fishbone diagrams of each of the prioritized defects. The aim of this analysis was to bring about practical technological additions that could be employed on the manufacturing lines to drive BIQ. Detailed illustrations of each of the recommended automation improvement ideas were carried out. The illustrations were supported by a detailed description of how they will be integrated into the manufacturing systems and the type of support that was required to carry out the implementations.

3.2.2 Time study

Building quality into manufacturing process entails dissolving elements from final line inspectors and re-training them into production processes. For this study, time studies were conducted for all the manufacturing processes. For each operation, 10 cycles of times studies were carried out, thereafter, the weighted average of each operation was summed up to conclude the operation time. Quality gate operations were also subjected to time studies. The time study technique further indicated graphically the impact of adding self-inspection elements for the defects that have been identified in the Pareto analysis and SOP analysis phases.

3.3 Checking Phase

Following the re-distribution of elements, a comparative analysis was conducted to compare the quality results between the employment of BIQ against the conventional approach of quality gates. This was conducted in the form of an experimental study. The analysis commenced with the elimination of quality gates for a controlled number of components that were produced. For that sample of parts, quality inspectors were not responsible for inspecting quality, but rather operators on the floor inspected their own work. This was a sample of 30 parts for each of the lines. Statistical Process Control analysis was conducted for capability analysis, and a comparative conclusion was then drawn between the two quality approaches.

3.4 Acting Phase

The goal of this study is to develop a strategic approach model to implement BIQ in the ACM. The strategic approach had to be structured in a way that details out a systemic approach or guideline to implement BIQ. The study used the PDCA technique to develop the strategic approach. The development of the strategic approach model was guided by all the techniques encompassed in the research methodology. Based on the results of each technique, the strategic approach took into consideration the processes that were followed to collect data, interpret data, and come up with results.

4. Results and Discussion

4.1 Value Stream Map

The value stream map (VSM) for the Thermoforming line indicates the flow of material from raw state to the completion of the product. Figure 1 indicates the entire VSM for the manufacturing line.

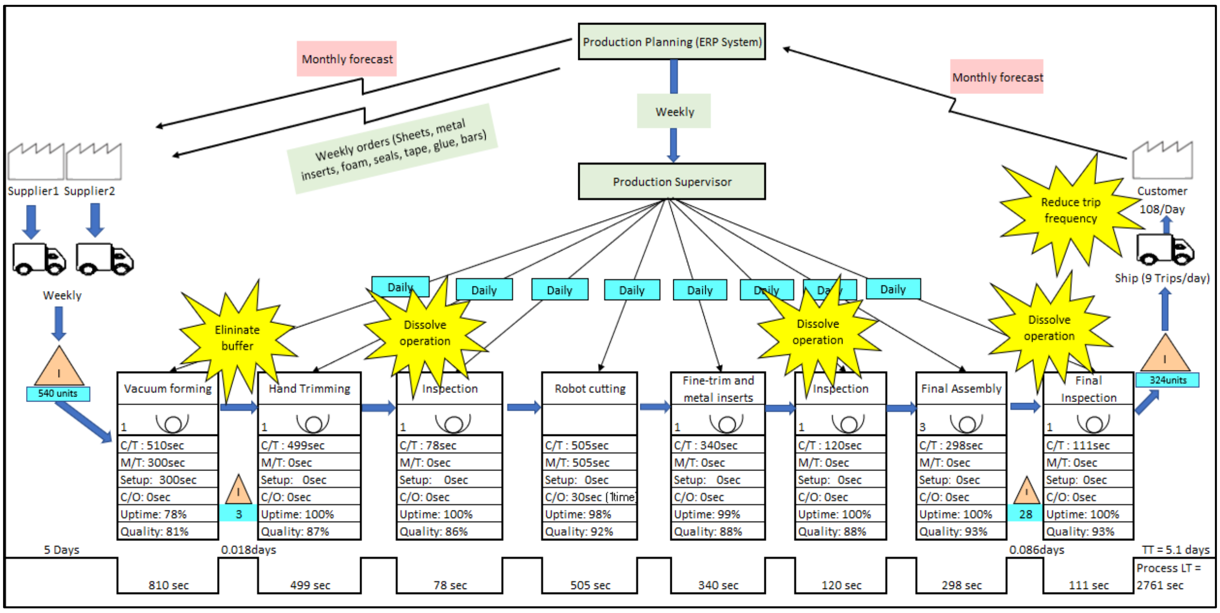

Fig.1 Thermoforming line VSM

The map commences with the acquisition of a monthly forecast plan that is received by the production planning department from the customer. The plan is then filtered to two main suppliers based on the weekly demand of raw material. Material for the Thermoforming line is delivered on a weekly basis and the stock holding capacity in the plant is for one week's demand. Further to this, weekly plans derived from the monthly forecast are sent to production supervisors and demand is filtered down to manufacturing operators on a daily basis according to the derivatives that are required by the customer. Commencing with a raw material stock holding of 5 days, the process converts the raw material into finished goods at different

PONTE
Florence, Italy
International Journal of Sciences and Research

manufacturing stages. Internal to the processes are inventory points that are kept in the process at two stages i.e., post vacuum forming process and post the final assembly process which serve as replenish points. The last process on the map is the final inspection, which feeds into the finished goods inventory with a stock holding capacity of 324 units, which equates to a 3 days' worth of stock. Between the customer and the manufacturing line, 9 truck deliveries with a carrying capacity of 12 units are made daily.

4.2 Pareto analysis

The results of the Pareto analysis indicated that the highest-ranking defects on the line were material tearing, lip deformation, soft knuckles, and miscuts on robot. These were the four main defects that needed to be subjected further to the root cause analysis technique. Figure 2 is the graphical depiction of the Pareto analysis indicating the defects that fell within the 20% vital few and the 80% significant many.

Defect description	Number of defects	Percentage	Cumulative %
Material tearing	77	26.28%	26.28%
Lip deformed	57	19.45%	45.73%
Soft Knuckles	49	16.72%	62.46%
Miscut On Robot	31	10.58%	73.04%
Soft Corner	22	7.51%	80.55%
Rim Lock	9	3.07%	83.62%
Plugs Touching	9	3.07%	86.69%
Bubbles	7	2.39%	89.08%
Adjustment	6	2.05%	91.13%
Deformed	5	1.71%	92.83%
Length Under	5	1.71%	94.54%
Marks / Lines	5	1.71%	96.25%
Cold Spot	4	1.37%	97.61%
Slide issue	3	1.02%	98.63%
Holes misaligned	1	0.34%	98.98%
Lifting Table	1	0.34%	99.32%
Sheet Sag	1	0.34%	99.66%
Wall Thickness NG	1	0.34%	100.00%
TOTAL	293	100%	

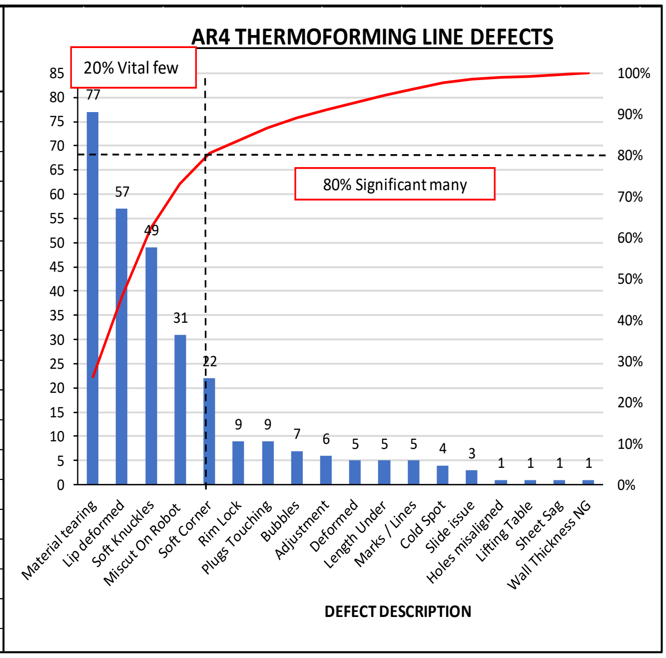

Fig.1 Thermoforming line Pareto analysis

4.3 Fishbone Diagrams

4.3.1 Material tearing defect

The first defect that ranked the highest on the Thermoforming line was material tearing. Figure 3 illustrates the Fishbone diagram that was undertaken to determine the possible root causes of the material tearing defect.

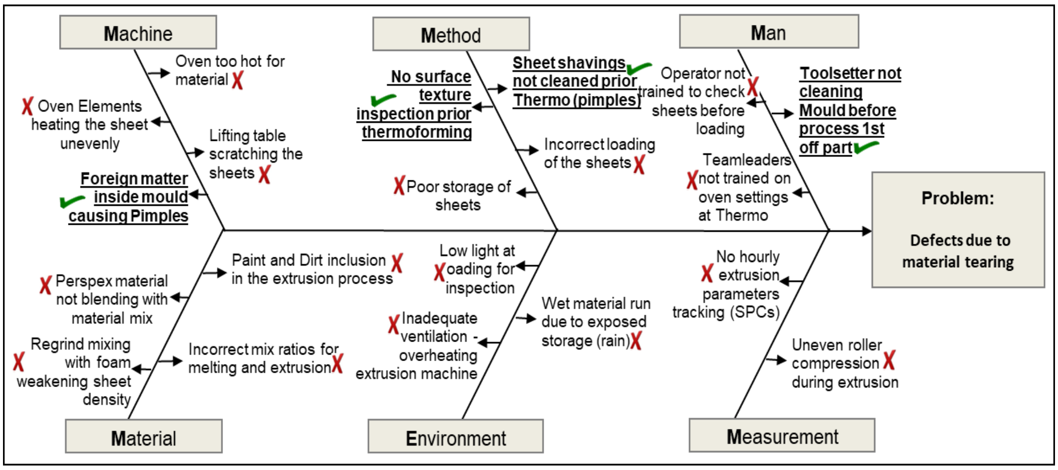

Fig.2 Material tearing Fishbone diagram

The results of the Fishbone Diagram on the material tearing defect indicated four possible root causes to the defect. Table 1 was created to depict the results of the Fishbone approach and the possible corrective actions that needed to be carried out to instill BIQ in the operation.

Table1. Material tearing corrective actions

Possible root cause	5M1E Category	Corrective action	Corrective action category
			Technological/Operational
No surface texture inspection prior thermoforming.	Method	Update SOP to inspect sheets prior loading.	Operational
Sheet shavings not cleaned prior forming (pimples).	Method	Update SOP to inspect shavings prior loading	Operational
Tool setter not cleaning Mould before process 1st off part.	Man	Mould cleaning to be part of shift start up-procedure – Maintenance.	Operational
Foreign matter inside mould causing Pimples.	Machine	Shift inspection of the mould for foreign matter – Maintenance.	Operational

4.3.2 Lip deformation defect

The second highest ranked defect on the Thermoforming line was lip deformation. Figure 4 illustrates the Fishbone diagram that was undertaken to determine the possible root causes of the material tearing defect.

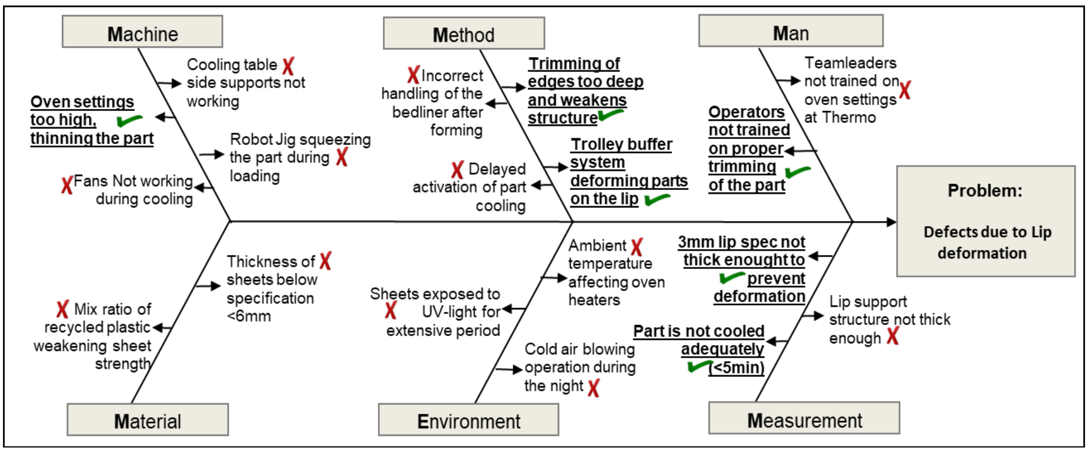

Fig.3 Lip deformation Fishbone diagram

The results of the Fishbone diagram for the lip deformation defect indicated six possible root causes post verification. The root causes were tabulated in Table 2 together with the corrective measures that need to be taken to drive BIQ into the manufacturing operation.

Table2. Lip deformation corrective actions

Possible root cause	5M1E Category	Corrective action	Corrective action category Technological/Operational
Oven settings too high, thinning the part.	Machine	Log Oven settings according to ambient ranges and create ambient temperature monitor.	Technological
Trimming of edges too deep and weakens structure.	Method	Train and guide current and new operators on the correct trimming.	Operational
Trolley buffer system deforming parts on the lip.	Method	Remove all buffer trolleys and implement a One-Piece-Flow system.	Operational
Operators not trained on proper trimming of the part.	Man	Train and guide current and new operators on the correct trimming.	Operational
3mm lip spec not thick enough to prevent deformation.	Measurement	Lower oven settings as much as possible on the lip section for greater thickness.	Operational
Part is not cooled adequately (<5min).	Measurement	Install a fan trigger for the fan that is linked to an actuator button/sensor and a cooling timer.	Technological

4.3.3 Soft Knuckles defect

The third highest ranked defect on the Thermoforming line was soft knuckles. Figure 5 illustrates the Fishbone diagram that was completed for the soft knuckles defect.

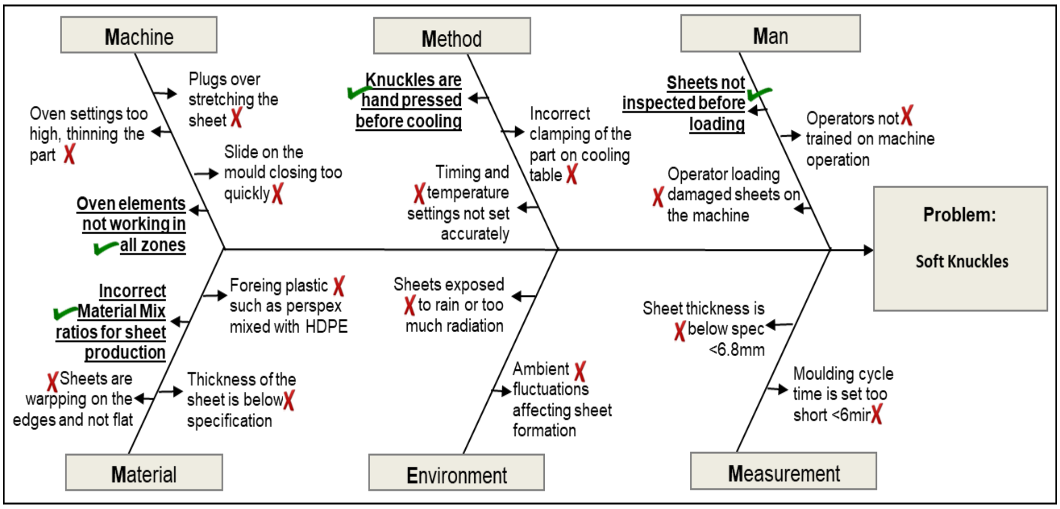

Fig.4 Soft Knuckles Fishbone diagram

The results of the Fishbone diagram for soft knuckles indicated that there were four possible root causes to the knuckles defect post verification. Table 3 was then created to depict the countermeasures or corrective actions to the root causes. The possible corrective actions were tabulated with the aim of instilling BIQ within the manufacturing operations.

Table3. Soft Knuckles corrective actions

Possible root cause	5M1E Category	Corrective action	Corrective action category Technological/Operational
Knuckles are hand pressed before cooling	Method	Update SOP to indicate that knuckles must only be touched after cooling.	Operational
Sheets not inspected before loading	Man	Update SOP to inspect sheets prior loading.	Operational
Oven elements not working in all zones	Machine	Periodic inspection and maintenance of the heater wiring and heater elements – Maintenance.	Operational
Incorrect Material Mix ratios for sheet production	Material	Supplier for sheets must adhere to 80/20 virgin and regrind mix ratio. Sheets to be supplied with mix ratio test reports.	Operational

The corrective actions for the soft knuckles defect indicated the need for operator SOPs to be updated, maintenance of the machine, and liaison with material supplier to adhere strictly to the technical specifications of extruding sheets.

4.3.4 Robot miscut defect

The fourth and last highest ranked defect on the Thermoforming line that fell within the 20% vital few was robot miscut. Figure 6 illustrates the Fishbone diagram that was carried out to determine the root causes of the robot miscut defect.

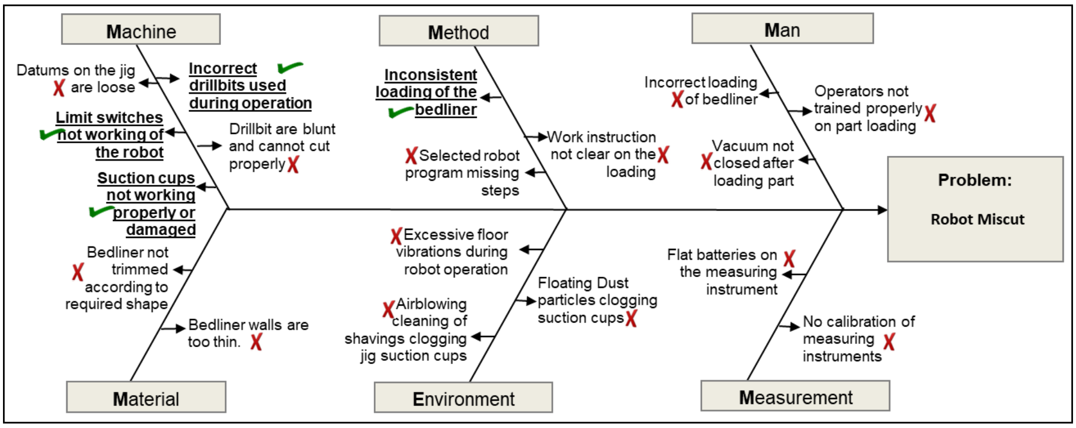

Fig.5 Robot miscut Fishbone diagram

The results of the Fishbone diagram for the robot miscut defect indicated four possible root causes post verification. The root causes were tabulated on Table 4 with the corrective measures that need to be taken to drive BIQ into the manufacturing operation.

Table4. Robot miscut corrective actions

Possible root cause	5M1E Category	Corrective action	Corrective action category Technological/Operational
Inconsistent loading of the bedliner.	Method	Operators need to be re-trained on the correct standard of loading.	Operational
Incorrect drill bits used during operation.	Machine	Drill bit sequence to be verified by robot technician every start of shift.	Operational
Limit switches not working of the robot.	Machine	Broken limit switches need to be repaired to ensure correct loading sensing – Maintenance.	Technological
Suction cups not working properly or damaged.	Machine	Worn out suction cups need to be replaced and periodic maintenance needs to be implemented.	Operational

Overall, the corrective actions of the robot miscut defect indicated the need for operator training, machine operation periodic inspections, and periodic planned maintenance. There were technologies in the robot cell that were not maintained and fully utilized to aid the assurance BIQ in the manufacturing operations.

4.4 SOP analysis – Thermoforming line

The results of the Thermoforming line SOP analysis indicated that there was a lack of self-inspection elements in the core manufacturing operations that added value. Majority of the inspections were left to the mercy of quality inspectors. Across all the operations, the study recorded 22 possible defects that could occur in the operations. Out of the 22 possible defects, only 5 inspection elements were identified in the operator SOPs. There were no appraisal elements that could possibly be linked to any of the defects on the line on each of the operations. Table 5 provides a summary of the results that were deduced from the SOP analysis approach for the Thermoforming line.

Table0. Thermoforming line SOP analysis statistical results

Operation	SOP Description	Number of steps in SOP	Number of self-inspection steps on SOP	Appraisal elements on SOP	Number of possible quality defects	Possible defects description		
1	Part forming	8	1	0	7	Material Tearing Bubbles Sheet sag	Soft Knuckles Cold spot	Soft corner Wall Thickness
2	Cutting and Trimming	8	1	0	4	Lip deformation Deformation	Length Under Marks/Lines	
3	Quality check 1	5	3	2	0			
4	Robot cutting	22	3	0	7	Miscut on Robot	Lip deformation	Holes Misaligned
5	Final Trimming					Marks/Lines	Lip deformation	Bubbles
6	Quality check 2	5	4	0	0			
7	Quality assurance	15	0	4	0			
8	Glue application	5	0	0	2	Lip deformation	Deformation	
9	Seals and foam assy	11	0	0	2	Wall Thickness	Deformation	
10	Quality Check 3	12	4	2	0			
	Total	91	16	8	22			

4.5 Technological Value Analysis

The first defect on the Thermoforming line that required technological additions to the process was lip deformation. The root cause of the problem was oven settings being too high and thinning the part. The corrective action recommended was the development of oven settings log according to ambient temperatures and the addition of a monitoring instrument. Figure 7 suggests the addition of a programmable temperature measuring instrument that is responsible for measuring ambient temperature around the machine. The temperature measuring instrument was linked to a temperature range indicator, where different color codes signaled the change in ambient temperature and for the operator on the line to log the required settings. At the highest range (33◦c to 40◦c), the temperature measuring instrument gave impulses to the light indicator to change to a red color, which meant the lowest standard temperature settings had to be engaged to the oven to prevent the part from overheating and coming out thin, thereby leading to the lip deforming. The same applied to a moderate range of (25◦c to 33◦c) where the orange color signaled the engagement of moderate temperatures. The temperature setting logs where trialed and simulated over different ambient temperatures and proved to be effective in preventing the occurrence of the lip deformation defect. The implementation of this technological aid required the aid of an instrumentation technician.

Vol. 79 | No. 8/1 | Aug 2023
DOI: 10.21506/j.ponte.2023.8.1

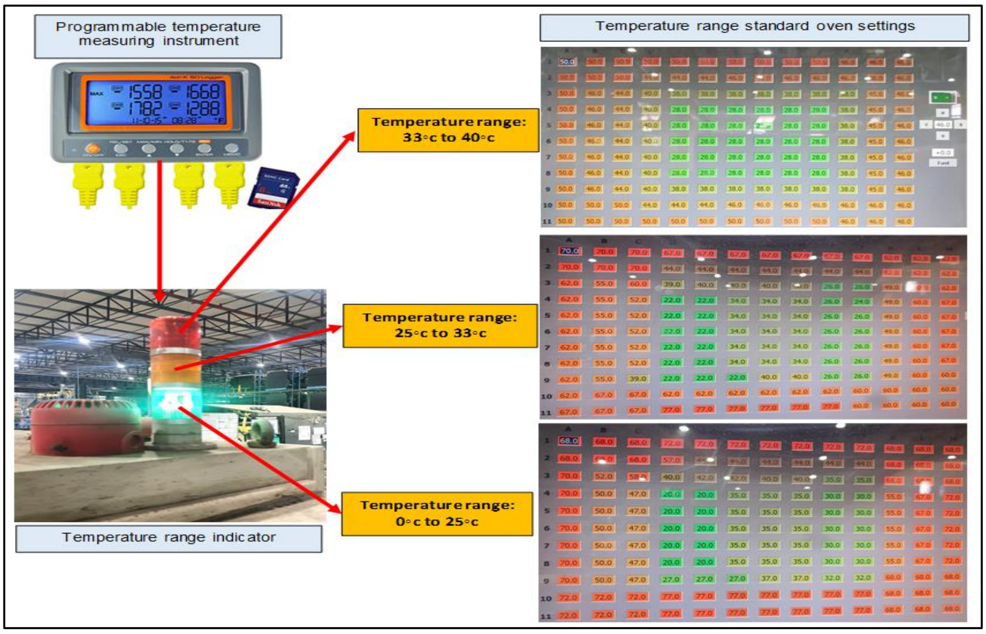

Fig.6 Automatic temperature detection signal

Figure 8 illustrates additional technological aid that was proposed by the study to also tackle the lip deformation defect. One of the root causes to the defect that was identified was that the Parts were not cooled adequately due to a lack of cooling time indicator. There was a need to implement a technological aid that ensured the adherence to the 5-minute cooling time. The proposed technological aid to the process in this regard was as follows:

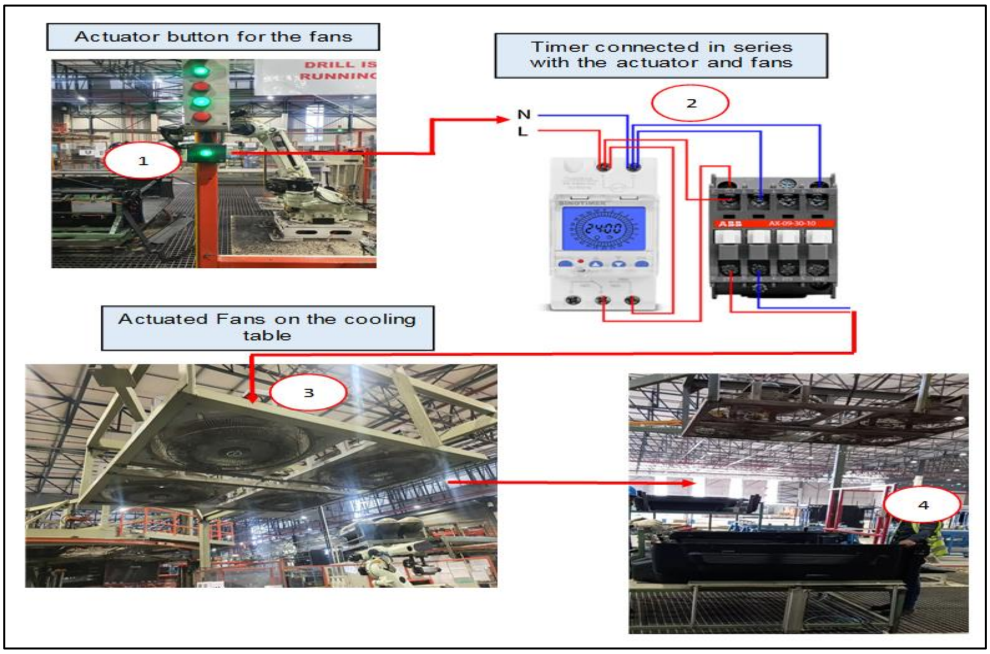

Fig.8 Timer addition to cooling system

Figure 8 proposed the inclusion of a timer that is connected in series with the fan actuator button and the cooling fans. The time needed to be connected in such a way that when after the part was placed on the cooling jig, the operator pressed the actuator button, which engaged the cooling timer to start counting down for a period of 5 minutes. When the 5 minutes is over, the timer would automatically cut-off the cooling process. The fool-proof approach in this regard was that the operator was not allowed to move the part to the robot operation before the cooling fans stop running. The technological aid could later be improved to make use of a weight sensor that actuates the fans upon part placement on the jig, and a light indicator to give a signal when the part is ready to move to the next operation. The proposal required the aid of an electrician or instrumentation technician for implementation.

4.6 Time studies

The results of the time study presented by Figure 9 graph A indicated the time study for the traditional quality gates. The time study graph indicated that operators in the various operations were not fully loaded with work and presented an opportunity for resource loading with BIQ elements and dissolving the current quality gates elements into the manufacturing stream. With a takt time of 450 seconds, the line was set up to manufacture a fully assembled bedliner every 4050 seconds across the 9 operations. The formation ratio (Resource loading) of the line, which is derived from the formular $FR = \frac{Tva}{Takt\ (Nva)} * 100$, sat at 43.64%. a healthy formation ratio in the manufacturing plant ranges from 80% and above. This meant that there was over 50% gap for element distribution and loading across the value adding operations.

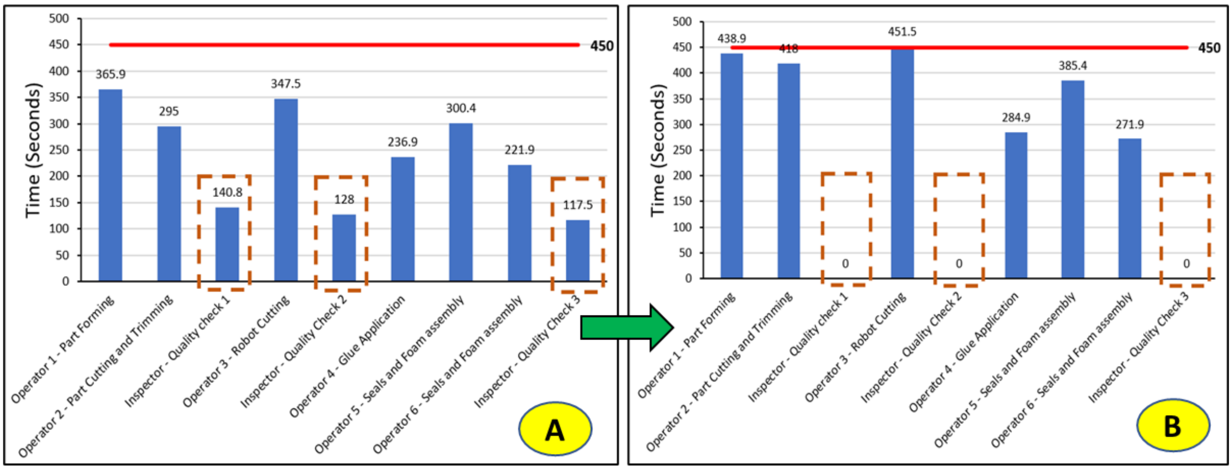

Fig.7 Time study – Moving from quality gates to BIQ

The results of the time study graph depicted by Figure 9 graph B were those of the BIQ implementation approach. The data indicated the process post element distribution from quality gates, addition of elements from gaps identified in the SOP analysis and technological improvements, and operator training for the BIQ approach. The results indicated a significant reduction in the number of operations on the line and a complete dissolve all quality gates on the line. The quality gates exclude the Quality assurance operation which is mandatory for compliance with the customer. With a Takt time of 450 seconds, the total time taken to manufacture a fully assemble part reduced from 4050 seconds to 2700 seconds. The number of operations on the line reduced from 9 to 6 operations. The element distribution presented a significant labor reduction benefit for the manufacturing line. The overall formation ratio of the line improved from a low of 43.64% to a high of 83.35%.

4.7 Comparative analysis of quality gates against BIQ

The comparison summary provides an overview of the results based on the key elements of the experimental study. The Process performance index (Ppk) results of the study paved a direction of whether each of the quality methods were capable of driving quality in the processes. Mahapatra et al. (2020) advises that the capability of a process to maintain long term quality standards is determined by the following ranges:

- Ppk $\geq$ 1.67 : Process can yield good results for the long term.
- Ppk 1.33 – 1.67 : Results are acceptable, maintain quality method.
- Ppk $\leq$ 1.33 : Process is unstable and requires 100% inspections.

Based on the outline of the ranges, Table 6 indicates the comparison results between the quality gates approach and the BIQ approach for the Thermoforming line. The results indicate that the BIQ is a more capable approach than quality gates. This is because of more passes and acceptable Ppks from the BIQ approach as compared to the quality gates approach.

Table6. Capability analysis summary – Thermoforming

	Measurement	Trimming Headboard	Trimming _RHS	Trimming_LH	Trimming Horizontal Rear Edge	Trimming Rear vertical Edge	Hole Diameter : Main Installation Hole
Quality Gates	Boundary Non-conformance	10.00%	0.00%	0.00%	0.00%	0.00%	40.00%
	Expected Scrap rate	34.00%	1.57%	0.00%	0.03%	0.00%	64.30%
	Expected defect Parts Per Million	340822	15744	0	292	0	643262
	Process performance index (Ppk)	0.17	0.72	6.36	1.15	1.97	0.09
	Pass /Acceptable/ Fail	Fail	Fail	Pass	Acceptable	Pass	Fail
Built-In-Quality	Boundary Non-conformance	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Expected Scrap rate	0.00%	0.00%	0.00%	0.49%	0.00%	0.00%
	Expected defect Parts Per Million	0	0	16	4885	0	1
	Process performance index (Ppk)	2.24	1.76	1.38	0.86	2.07	1.61
	Pass /Acceptable/ Fail	Pass	Pass	Acceptable	Fail	Pass	Acceptable

4.8 P-D-C-A strategic approach model

The outcomes of the various techniques that were employed by the study presented significant gaps and opportunities for improvement. This laid the foundation of the center of thought that the ACM needed to embody to effectively drive BIQ in their manufacturing operations. Given the outcomes of each of the techniques, the study established a summarized journey of the entire implementation process as depicted by Figure 10.

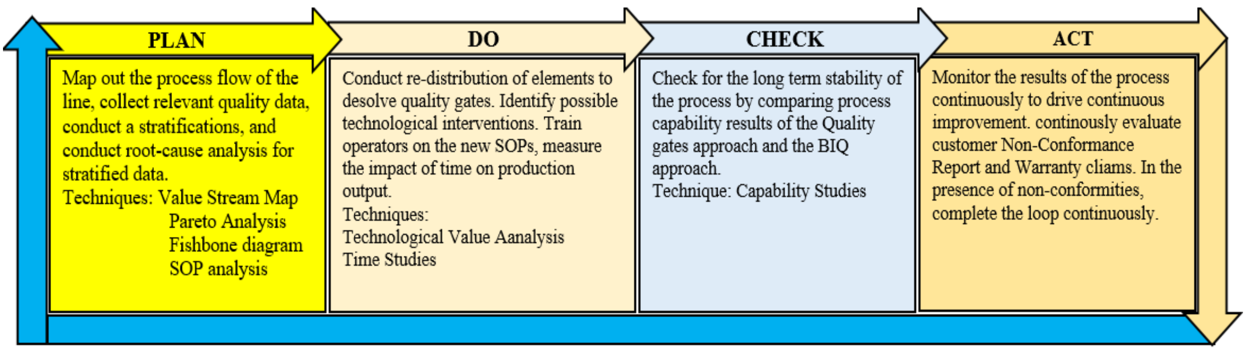

Fig.10 PDCA strategic approach model

5. Conclusion

The study has demonstrated to a large extent how the ACM can utilize a combination of lean manufacturing techniques to analyse and interpret data that is key to implementation of BIQ. The results provided an indication that through the utilization of techniques such as Pareto analysis, Ishikawa diagrams and SOP analysis, the foundation of a focused approach towards combatting defects can be developed. The results of the study went to an extent of unearthing much needed technological interventions that the ACM need to commence centering their idea generation towards, to effectively implement BIQ in the manufacturing lines. This study will go a long way in aiding the ACM in their drive to reduce both current and future financial costs and will contribute significantly to streamlining operations and improving the competitive edge of the ACM.

References

Brooks, C. 2014. What is a pareto analysis?. Business News Daily Senior, 29(1): 1-5.

Bryson, A. and Dale-Olsen, H. 2020. Unions, tripartite competition, and innovation (No. 13015). IZA Discussion Papers.

de Paula Ferreira, W., Armellini, F., de Santa-Eulalia, L.A. and Thomasset-Laperrière, V. 2022. Extending the lean value stream mapping to the context of Industry 4.0: An agent-based technology approach. Journal of Manufacturing Systems, 63: 1-14.

Dobránsky, J., Pollák, M. and Doboš, Z. 2019. Assessment of production process capability in the serial production of components for the automotive industry. Management systems in production engineering.

Donada, C., Nogatchewsky, G. and Pezet, A. 2016. Understanding the relational dynamic capability-building process. Strategic Organization, 14(2): 93-117.

Filz, M.A., Herrmann, C. and Thiede, S. 2020. Simulation-based assessment of quality inspection strategies on manufacturing systems. Procedia CIRP, 93: 777-782.

Genta, G., Galetto, M. and Franceschini, F. 2020. Inspection procedures in manufacturing processes: recent studies and research perspectives. International Journal of Production Research, 58(15): 4767-4788.

Hafeez, U. and Akbar, W. 2015. Impact of training on employee’s performance (Evidence from pharmaceutical companies in Karachi, Pakistan). Business Management and strategy, 6(1): 49-64.

Kumar, V., Verma, P., Mangla, S.K., Mishra, A., Chowdhary, D., Sung, C.H. and Lai, K.K. 2020. Barriers to total quality management for sustainability in Indian organizations. International Journal of Quality & Reliability Management.

Mahapatra, A.P.K., Song, J., Shao, Z., Dong, T., Gong, Z., Paul, B. and Padhy, I. 2020. Concept of process capability indices as a tool for process performance measures and its pharmaceutical application. Journal of Drug Delivery and Therapeutics, 10(5): 333-344.

Neyestani, B. 2017. Seven basic tools of quality control: The appropriate techniques for solving quality problems in the organizations.

Owen, J.H. and Blumenfeld, D.E. 2008. Effects of operating speed on production quality and throughput. International Journal of Production Research, 46(24): 7039-7056.

Patel, A.S. and Patel, K.M. 2021. Prioritization of Lean Six Sigma Success Factors using Pareto Analysis. In IOP Conference Series: Materials Science and Engineering, 1070(1): 012133. IOP Publishing.

Psarommatis, F., May, G., Dreyfus, P.A. and Kiritsis, D. 2020. Zero defect manufacturing: state-of-the-art review, shortcomings, and future directions in research. International journal of production research, 58(1): 1-17.

Pussella, H.D.M.M. and Yapa, S.T.W.S. 2020. Barriers in Implementing Total Quality Management in Organizations: A Literature Review. In Proceedings of International Conference on Business Management, 17.

Silva, A.L. and Cardoza, E. 2010. Critical analysis of layout concepts: Functional layout, cell layout, product layout, modular layout, fractal layout, small factory layout. In Proceedings of international conference challenges and maturity of production engineering: Competitiveness of enterprises, working conditions, environment: 2-13.

Soliman, M.H.A. 2020. Jidoka: The Toyota Principle of Building Quality into the Process.

Wolniak, R. 2019. Downtime in the automotive industry production process–cause analysis. Quality Innovation Prosperity, 23(2): 101-118.