Process Improvement through Built-in-quality in Automotive Component Manufacturers

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

Mendon Dewa
Lecturer
Durban University of Technology,
Durban, South Africa
mendond@dut.ac.za

Abstract

The competitiveness of automotive component manufacturers is no longer driven by the price at which they sell their components but by the quality of the products they deliver. Vehicle assembling corporations are inclined to moving their business to component manufacturers that deliver quality components as opposed to delivering low-priced components with poor quality. An automotive component manufacturer which manufactures vehicle side-steps through a blow-moulding process was struggling with the implementation of the principle of built-in-quality. This was reflected in their traditional reactive approach of using quality gates as opposed to driving built-in-quality in their conversion operations. This has resulted in high labour requirements (inspectors), high rate of reworks and scrap which impacted significantly on the profitability of the manufacturer. Given the severity of this problem, the aim of the study was to develop a strategic approach to aid automotive component manufacturers in the implementation of built-in-quality in their manufacturing streams. Several lean manufacturing techniques such as Pareto analysis, 5why analysis, standard operating procedures, time studies, and statistical process controls were employed to identify operational gaps and opportunities in the manufacturing streams, to develop a strategic approach to implement built-in-quality. The results of the study were the implementation of built-in-quality on a manufacturing line, and the development of a 4-step approach for manufacturers to attain built-in-quality in their processes that was guided by Deming's Plan-Do-Check-Act cycle.

Keywords

Automotive component manufacture, Built-in-quality, Lean manufacturing techniques, Quality gates, Strategic approach.

1. Introduction

Automotive component manufacturers hold core to the fundamental roots of mobility, which is one of the key drivers of economic participation. The manufacturers have the mammoth task of ensuring that the quality of their products is at the highest standard to remain competitive and claim market share. Reklitis et al. (2021) strongly advises that businesses need to focus on quality as the key driver of competitiveness as opposed to focusing on price tags only. This has seen most automotive component manufacturers going about the formation of quality gates in their manufacturing processes to inspect for quality as opposed to building quality into their products. The consequences of the formation of quality gates are a reduction in process capability, high scrap rates, high manpower costs and an overall reactive approach to product quality. Once quality issues are detected at the customer, the mindset is not on improving the process during the build, but on allocating the task of inspecting to a quality inspector as a quality gate. Ensuring product built-in-quality during manufacturing is one approach that manufacturers need to consider as a way of life and be embedded in the culture of the organization to remain competitive and profitable. Psarommatis (2020) recognizes product built-in-quality as a tool to overcome cost implications such as labour, reworks, and defect outflow to enhance competitiveness. The Fourth Industrial Revolution comes with many digital age innovations and enablers that can be encompassed in manufacturing processes to overcome the burden of traditional manual 100% inspections, store and draw accurate product quality data and provide ease of reference to defect root-causes. The need for these digital systems and innovations can be derived from the application of lean manufacturing techniques such as root-cause analysis to identify automation opportunities as corrective measures to drive process built-in-quality. It is with these considerations that the aim of this study is to improve processes through the application of core lean manufacturing techniques to drive built-in-quality in automotive component manufacturers as a key enabler that fosters growth, profitability, and competitiveness. There is very little literature that is structured around the implementation of built-in-quality to specifically aid automotive component manufacturers to realise the quality and cost benefits of this principle, which is key to competitiveness.

1.1 Objectives

- To evaluate and rank the highest defect contributors that warrant the need for quality gates.
- To identify root-causes to the defects and how to overcome them through implementing process Built-in-quality.
- Measure the impact of process built-in-quality against the quality gates approach on product quality yield.
- To identify technological improvements that can be employed on the manufacturing line to aid with driving process built-in-quality.
- To develop a strategic approach for process improvement towards achieving process built-in-quality without compromising customer satisfaction.

2. Literature review

Automotive component manufacturers are faced with the ongoing challenge of ensuring that they deliver quality products to their main customers, mainly being vehicle assembling industries. In any given industry, the delivery of poor-quality products or services can greatly weaken the competitive edge of the business (Wahyu 2019). Such has seen many organizations, particularly automotive companies such as Toyota and Rolls Royce adopting built-in-quality as a principle that drives their manufacturing processes. The contrast between vehicle manufacturing industries and automotive component manufacturers in the sphere of quality is that vehicle manufacturers have gone through the school of hard knocks to build systems that ensure built-in-quality into their products. Most component manufacturers are second to the adoption of building quality into their products due to being relatively new and have the immense pressure to deliver to the already established organizations. This has led to the establishment of quality gates by component manufacturers that inspect for quality as opposed to building in quality.

The absence of a simplified and specific strategic approach towards implementing built-in-quality leads to quick and easy solutions, yet very costly, such as 100% inspections for quality. Singh et al. (2023) describes built-in-quality as a journey of building capability in a process such that it can detect defects without passing them on to the next process. Chiarini and Kumar (2022) further expand the description to a system of giving employees ownership of the quality of products they build through empowering them with decision making. In many automotive component manufacturers, the concept is lost at the design phase of their processes. This has led to the traditional approach of designing processes and layouts that have final inspections at the end of the line (Borkowski and Knop 2016). The expectation is that a quality inspector will detect all abnormalities that have been carried over throughout the manufacturing stream at the end of the line. Built-in-quality 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. Hoe and Mansori (2018) further argue that customer satisfaction through product quality requires the burden of quality to rest with all employees in any organization. Built-in-quality comes as a systematic principle that aims to drive lean manufacturing and lean leadership through instilling ownership and building a capable environment to enhance product quality in manufacturing organizations.

The approach of having end of line inspections is the formation of quality gates to try and curb the outflow of defects to the customer. Filz et al. (2020) defines quality gates as the process of using predefined criteria to either reject or pass a product. The unseen problem faced by automotive component manufacturers is that the criteria that are being used to gauge the quality of a product have now become job descriptions at design phase instead of building them into the product conversion processes. The approach of using quality criteria as job descriptions bears significant cost implications to the companies. Psarommatis (2020) narrows down the cost implications to increased labour, high number of reworks and defect outflow to customers. Mohammed (2020) further outlines that the allocation of resources to catch errors and defects through quality inspection systems and not building quality bears significant costs and puts companies at risk of closure. An added disadvantage to this is a reduction of quality accountability and ownership from the 4 key elements of any production stream – Man, Machine, Material and Method (Nomura 2021). The full might of adherence to quality standards and specifications rests with an inspector as opposed to the manufacturing stream.

The quality mindset of having inspectors doing full defect detection denies automotive component manufacturers the opportunity of doing things right the first time. It further weakens process stability and having a capable workforce that produces zero defects (Bertagnolli 2022). The transition from conducting end-of-line inspections as the primary course for defect prevention to built-in-quality talks to the art of building process capability. Chen et al (2023) describe process capability as the degree in which a process can perform optimally and produce products that are conforming to specifications. Donada, Nogatchewsky, and Pezet (2016) expand the description to 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 et al. 2019). To attain the transition from quality gates to built-in-quality, measures around skills development and training need to be undertaken. Building process capability in the scope of built-in-quality entails challenging the traditional approach of end-of-line inspections to in-process inspections. Moreover, manufacturing companies are fast moving towards innovative technologies and artificial intelligence to gain competitive strength and attain Quality 4.0 status. The drive to attain Quality 4.0 is primarily driven by the need to ascertain product quality compliance achieved through automation of inspections to maintain process integrity (Sisodia 2019). With the Fourth Industrial Revolution unfolding at such speed, Hyun Park et al. (2017) urges organizations to employ digitalization and automated quality assurance mechanisms to attain global competitiveness and technological superiority. These modern technologies can be employed by automotive component manufacturers as enablers to further cement the principle of built-in-quality in their processes.

Literature has indicated that there are crucial factors such as process design and the integration of technological advances into manufacturing that pose as a gap in the implementation of built-in-quality. This are fundamental elements to building process capability. There has been great consensus from various authors that built-in-quality as a principle is a key driver of enhancing product quality and competitiveness for manufacturing organizations. Through the exploration of research conducted by various authors, several considerations were deduced on embarking on built-in-quality implementation which included a change in organizational mindset around quality gates, training and development, building process capability at design phase, and the need to shift focus into technological advances that come with the new era.

3. Methods

With built-in-quality holding core to the practices of lean manufacturing, the study took a swipe towards the employment of core lean and industrial engineering techniques as a method of approach towards developing a strategic approach to implement built-in-quality in automotive component manufacturers. There are great benefits of employing Industrial engineering techniques in the development of organizational strategies (Tinh et al. 2021). The techniques used in the method of approach were Pareto analysis for narrowing focus, 5Why analysis for determining root-causes of defects in the Pareto analysis, standard operating procedure study to determine relationship between SOPs and built-in-quality, time studies to measure the impact of introducing self-inspection elements to operators' standard operating procedures, and a comparative analysis of quality gates against built-in-quality approach in terms quality results once digital and self-inspection elements have been built into the manufacturing process.

- **Pareto Analysis:** Ranking of the defects affecting the quality of the components manufactured was conducted with the aim of building prevention on 20% of the issues to attain 80% results through Pareto analysis. Pareto analysis holds that resolving 20% of issues yields 80% results (Pyzdek 2021). The technique was executed by means of deriving the various defect descriptions on the manufacturing line and detailing a count on the number of occurrences over for a period of 6 months. Thereafter, the occurrences by description were ranked from highest to lowest. An 80/20 boundary was established on the graphical representation where the 20% boundary indicated the vital few defects and the 80% indicated the significant many.

- **5Why Analysis:** This technique was developed by Sakichi Toyoda in 1930 (Serrat 2017) and is primarily concerned with addressing a failure through exploring a series of causes that resulted in the failure by asking 'why' after every cause. At the fifth 'why' the root-cause to the problem should be identified. For the purpose of this study, the technique was used to determine and verify the root-causes that are attributed to the chronic defects that fell within the boundary of the vital few as per the Pareto analysis. Each of the defects that were in the 20% boundary were analysed seperately and on completion of the analysis, possible preventative measures to improve the process were tabled for each of the root-causes. The technique paved a way to understand quality issues to the root and the development of prevention and appraisal measures to enhance built-in-quality.

- **Standard operating procedure study:** A study of standard operating procedures was conducted on the sampled line to identify whether there was a relationship between defects and elements contained in the standard operating procedures for line operators. The significance bearing of this approach was to establish the gap in training, process design and the main hinderances that warrant the presence of quality gates as opposed to process built-in-quality. A summary of all standard operating procedures, containment of quality and appraisal elements, and links to defects was tabled. Standard operating procedures are used predominantly in automotive component manufacturers as a fundamental base of work description, instruction and attainment of monotomous work. Such holds key to any quality system in the expansion of the responsibility of quality to the whole organization (Gupta, 2019).

- **Time studies:** Manuafcturing time measurement is one of the key fundamentals that need to be undertaken as the built-in-quality implementation approach looks into dissolving quality gate elements into conversion processes to build process capability and built-in-quality. Palange and Dhatrak (2021) advise that for any slight modification in operational work sequence, a time study needs to be conducted again to analyse impact on line performance. The time study technique looked at the possible delays associated with the removal of quality gates and filtering gate inspection elements into line operator standard operating procedures. The time studies consisted of 10 cycles of study for each of the operations on the line, thereafter the weighted avaerage of the cycletimes was taken as the standard time for each operation. The formation ratio depicting the utilization before and after built-in-quality element distribution was also calculated using the formula $FR = \frac{Tva}{Takt\ (Nva)} * 100$ where FR is the formation ratio, Tva is the total actual time for all value adding processes, $Takt$ is the takt time and Nva is the total number of of value adding processes on the line.

- **Comparative Analysis – Quality gates againts Built-in-quality**: Following the re-distribution of elements time-study, a comparative analysis was conducted to compare the quality results between the employment of built-in-quality 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 10 parts on the lines. The second part of the experiment was to bring in quality gates into the processes, produce a sample of 10 controlled parts where dependency on quality gates was as per normal process. Based on these runs, a quality report was obtained from quality engineers and statistical process control specialists detailing out the overall outcome of each of the controlled parts and the number of defects the customer could have pick up post-delivery relative to the two methodologies. A comparative conclusion was then drawn between the two quality approaches.

The findings of the techniques outlined above were used with the intent of identifying the gaps that are hindering automotive component manufacturers to achieve built-in-quality. Further to this, the findings were used as a baseline to developing a detailed strategic approach towards implementing built-in-quality in automotive component manufacturers. A detailed Plan-Do-Check-Act table of the startegic approach was developed from the gaps identified through the Industrial Engineering lean manufacturing techniques.

4. Data collection

To achieve the objectives of the study, primary data was collected to support the results of the study and to paint a clear picture of the gaps and opportunities that lie with the implementation of built-in-quality on the side-step blow moulding line. From the methodology, the study focused on five techniques that required the collection of primary and secondary data, which are the Pareto analysis, standard operating procedure study, time studies, comparative analysis between quality gates and built-in-quality, and fool-proof systems analysis.

4.1 Pareto analysis data

The Pareto analysis data was extracted from a secondary source using historical defect data for a period of 6 months. The data was then tabled to depict all the defects that have occurred on the line while ranking them from the defect with the highest number of occurrences to the defect with the least number of occurrences. The defect percentage contributions were then calculated and summed up cumulatively to aid with constructing a Pareto analysis graph for results deduction. Table 1 is the depiction of the data that was collected to support the Pareto analysis technique.

Table 1. Side-step defects Pareto analysis data

Defect description	Left hand	Right hand	Number of defects	Percentage	Cumulative %
Grain Burr	273	347	620	22.85%	22.85%
Weight (Under/Over)	222	375	597	19.77%	42.62%
Appearance	87	424	511	18.57%	61.19%
Deform	113	110	223	14.90%	76.09%
Wrong Holes	33	57	90	6.01%	82.10%
Contaminated	41	31	72	4.81%	86.91%
Parting Line	36	36	72	4.81%	91.72%
Nut insert NG	31	19	50	3.34%	95.06%
Part Dent	7	11	18	1.20%	96.26%
Plastic Clips	12	6	18	1.20%	97.46%
Through Hole	3	12	15	1.00%	98.46%
White Mark	8	4	12	0.80%	99.27%
Double Parting Line	2	4	6	0.40%	99.67%
Parting Line Cut Off	1	4	5	0.33%	100.00%
			1497	100.00%	

4.2 Standard operating procedure study data

Data was also collected to aid with the results of the standard operating procedure study technique. The primary data that was collected for this technique focused on understanding the current state of self-inspections in the manufacturing operations. The data looked at the number of elements that each operation consisted of, then tabled the number of self-inspection and appraisal elements that were contained in the standard operating procedure that drive the operators to check their own work before passing it on to the next operation, which is key to the implementation of built-in-quality. Over and above the operational elements, data was also extracted to indicate the number of possible defects that can occur in each operation relative to the execution of the standard operating procedure. The possible defects were then outline on the data sheet for each operation. Table 2 indicates a summary of all the standard operating procedure study data that was collected.

Table 2. Side-step blow moulding line standard operating procedure element study

Operation	SOP Description	Value adding/ Non-value adding	Number of operation steps on SOP	Number of self-inspection steps on SOP	Appraisal elements on SOP	Number of possible quality defects	**Possible defects from the process**	
1	Material Loading	Value adding	13	1	0	2	Contamination	White Marks
2	Part moulding	Value adding	14	1	1	8	Appearance Adjust Through Hole Double Parting Line Part Dent	Weight Adjust Deform Parting Line Cut Off Nut insert NG
3	Cutting and Trimming	Value adding	9	0	0	5	Deform Plastic Clips Double Parting Line	Part Dent Parting Line
4	Burr removal	Value adding	9	1	0	4	Double Parting Line Parting Line	Part Dent Grain Burr
5	Bracket assembly	Value adding	17	0	2	2	Wrong Holes	Plastic Clips
6	Final Inspection	Non-Value add	21	0	3	1	Part Dent	
7	Rework	Non-Value add	4	0	0	2	Part Dent	Double Parting Line
		Total	**87**	**3**	**6**	**24**		

4.3 Time study data

The time study technique took the form of using the standard operating procedure process outline as base data to take times for each element in each operation. All the number of elements were listed for each operation and time was taken for each element for ten cycles. Data of the total cycle times for each operation were then tabled and the average cycle time for the ten cycles was then calculated. The data collected was instrumental to the development of utilization graphs to depict possible redistribution of inspection elements from quality gates to core manufacturing operations and convert them into self-inspections for operators. The data collected further indicated the takt time to which each process was working to, which in-turn formed a boundary for process loading during redistribution of elements. Table 3 provides a summary of the data collected during the time study exercise.

Table 3. Side-step blow moulding line time study

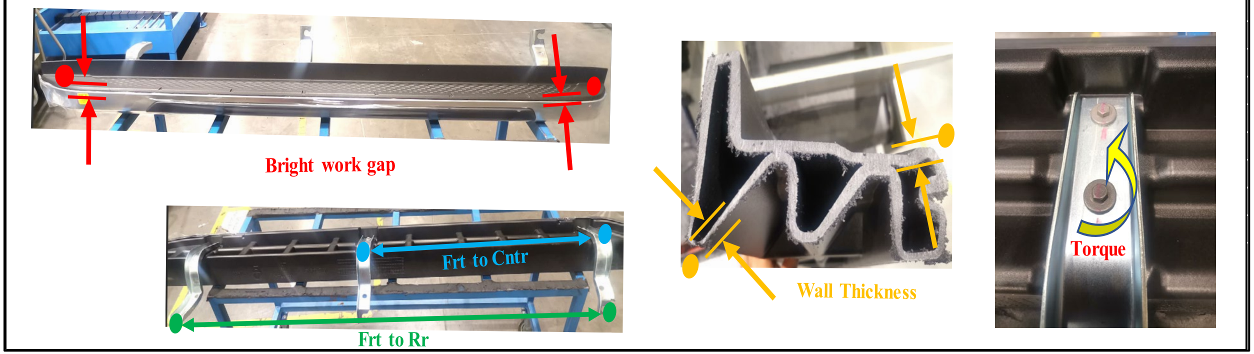
Time Study Data (#Seconds)												
Process	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 5**	**Cycle 6**	**Cycle 7**	**Cycle 8**	**Cycle 9**	**Cycle 10**	**Average cycle time**	**Takt Time**
Material Loading	242	235	233	227	245	243	236	236	230	243	**237**	**340**
Part moulding	326	312	299	306	309	315	318	301	309	315	**311**	**340**
Cutting and Trimming	289	307	309	292	299	302	312	306	300	294	**301**	**340**
Burr removal	246	256	287	262	247	274	290	293	255	260	**267**	**340**
Bracket assembly	334	324	309	303	317	302	302	312	316	311	**313**	**340**
Final Inspection	200	173	172	181	186	176	174	193	186	179	**182**	**340**
Rework	48	67	52	92	89	63	54	67	88	97	**71.7**	**340**
Throughput cycle time											**1682.7**	**2380**

4.4 Comparative analysis data

The foundation of comparison between the use of the traditional approach of quality gates and built-in-quality prompted the need to conduct a statistical process control analysis for both quality methods in the form of an experiment. The experiment was done by producing parts from the manufacturing line and selecting a sample of 10 parts that were subjected to a statistical process control analysis to gauge the effectiveness of quality gates. The measurement characteristics were outlined, and aesthetics inspections were also conducted for the sampled parts. A similar experiment was done where the quality gates for the manufacturing line were removed, and operators were inspecting their own work. A controlled sample of ten parts was subjected to a similar statistical process control analysis to analyse the impact between the use of the two methods. The results of the data were then analysed using the Minitab software to deduce capability results based on the experiment. Table 4 indicates the data that was collected to compare the parameter and aesthetics outcomes of the two quality methods.

Table 4. Comparative analysis - Quality gates vs built-in-quality

Statistical Process Control Measurement data



	Characteristic		**Sample number**										
Quality gate	1C316-P,B/304-B		Spec standard	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Bright work gap	🔴	**2 ± 0.25mm.**	1.9	1.9	1.85	1.9	1.9	1.85	1.9	1.9	1.9	1.9
	Frt to Rr bracket distance	🟢	**1554 ± 3mm.**	1556	1556	1556	1556.5	1556	1556.2	1556	1556	1556	1556
	Frt to Cntr bracket distance	🔵	**883 ± 2mm.**	882	882	882	882.5	882	882	882	882	882	882.5
	Wall Thickness	🟡	**≥1mm**	4				4				6	
	Part weight		**8 ± 0.4kg.**	8.1	8.1	8.1	8.1	8.15	8.15	8.1	8.1	8.15	8.15
	Torque spec		**10.5 ± 1.6Nm**	11.1	11.3	11	11	11	11.2	11	10.9	11.2	11
	Grain distribution	ok/nok		**OK**	**OK**	**OK**	**OK**	**NOK**	**OK**	**OK**	**OK**	**OK**	**OK**
	Scratches	ok/nok		**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**NOK**
	Trim/burrs	ok/nok		**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**
Built-In-Quality	**Characteristic**		**Sample number**										
	1C316-P,B/304-B		Spec standard	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Bright work gap	🔴	**2 ± 0.25mm.**	1.85	1.85	1.85	1.9	1.9	1.88	1.88	1.9	1.9	1.9
	Frt to Rr bracket distance	🟢	**1554 ± 3mm.**	1555.5	1556	1555	1555	1555.2	1555	1555.2	1555	1555	1556
	Frt to Cntr bracket distance	🔵	**883 ± 2mm.**	881.8	881	881	881.5	881.5	881.5	881	881	881.3	881
	Wall Thickness	🟡	**≥1mm**	1.9				3				5	
	Part weight		**8 ± 0.4kg.**	8	8	7	7.4	7.7	8.1	8.4	8.6	7.8	8
	Torque spec		**10.5 ± 1.6Nm**	11.3	11	11	10.4	10.7	11	10.8	11	11.3	10.6
	Grain distribution	ok/nok		**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**
	Scratches	ok/nok		**NOK**	**NOK**	**OK**	**OK**	**OK**	**OK**	**OK**	**NOK**	**OK**	**OK**
	Trim/burrs	ok/nok		**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**	**OK**

5. Results and discussion

5.1 Pareto analysis

From the data that was collected to support the Pareto analysis technique, the vital few defects that were contributing to 80% of the problems on the line were identified within the 20% boundary. The results indicated that the highest contributing defects were grain burrs, weight imbalances and appearance issues. This subsequently were the focus that built-in-quality needs to be heavily directed on to effect change on the line. Figure 1 indicates the results deduced from conducting the analysis on the side-step blow moulding line. The next step to support the results of the technique was to conduct root-cause analysis on the prioritized defects to identify suitable measures that would drive the prevention of the occurrences through a built-in-quality approach.

Defect description	Number of defects	Percentage	Cumulative %
Grain Burr	620	26.85%	26.85%
Weight (Under/Over)	597	25.86%	52.71%
Appearance	511	22.13%	74.84%
Deform	223	9.66%	84.50%
Wrong Holes	90	3.90%	88.39%
Contaminated	72	3.12%	91.51%
Parting Line	72	3.12%	94.63%
Nut insert NG	50	2.17%	96.80%
Part Dent	18	0.78%	97.57%
Plastic Clips	18	0.78%	98.35%
Through Hole	15	0.65%	99.00%
White Mark	12	0.52%	99.52%
Double Parting Line	6	0.26%	99.78%
Parting Line Cut Off	5	0.22%	100.00%
	2309	100.00%	

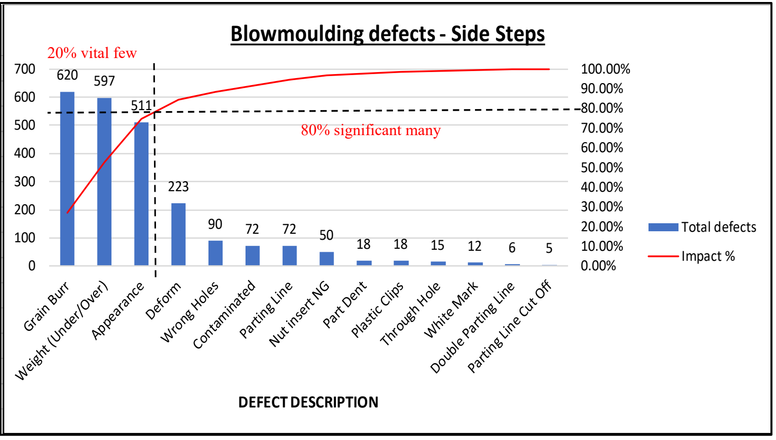
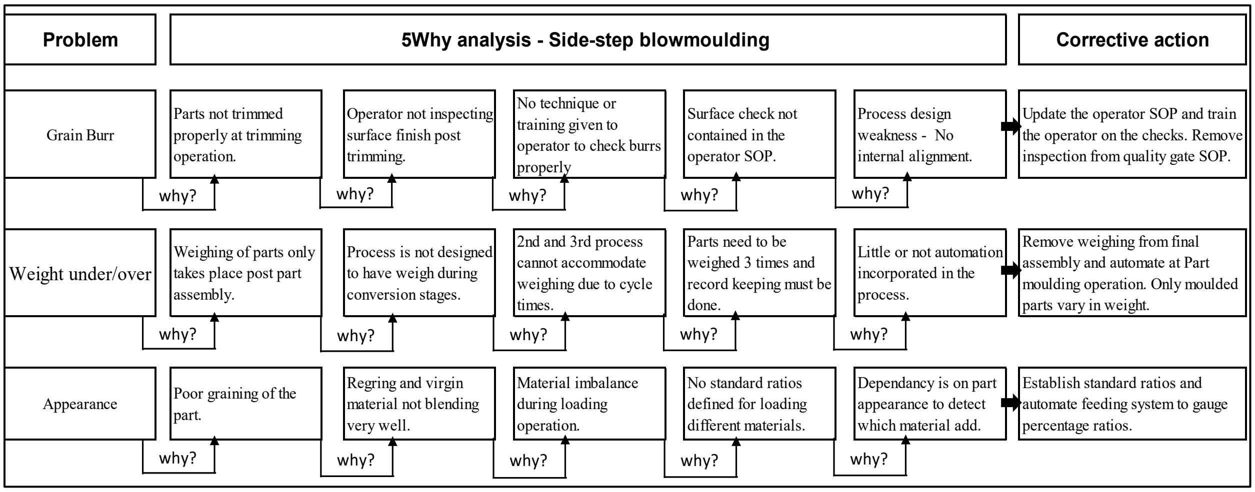


Figure 1. Side-steps blow moulding line Pareto analysis

5.2 5Why analysis results

The root causes identified from the 20% vital few called for the review of standard operating procedures, training of operators and the introduction of technological advancements to enhance process capability. A further deduction from the root causes points to a weakness in internal alignment in the process design phase where manufacturing standard operating procedure were designed separate to quality standard operating procedures. This has driven quality gates to be the norm in the organization and defeating built-in-quality initiatives. Moreover, it was also deduced that the traditional approach of having end of line inspections is a hinderance towards building in-process capability and the principle of doing things right the first time. Defects are found late on the line when all assemblies have already been added to the product. Figure 2 depicts the actual analysis that was undertaken to deduce the results of the 5Why technique.



Problem	5Why analysis - Side-step blowmoulding					Corrective action
Grain Burr	Parts not trimmed properly at trimming operation.	Operator not inspecting surface finish post trimming.	No technique or training given to operator to check burrs properly	Surface check not contained in the operator SOP.	Process design weakness - No internal alignment.	Update the operator SOP and train the operator on the checks. Remove inspection from quality gate SOP.
Weight under/over	Weighing of parts only takes place post part assembly.	Process is not designed to have weigh during conversion stages.	2nd and 3rd process cannot accommodate weighing due to cycle times.	Parts need to be weighed 3 times and record keeping must be done.	Little or not automation incorporated in the process.	Remove weighing from final assembly and automate at Part moulding operation. Only moulded parts vary in weight.
Appearance	Poor graining of the part.	Regring and virgin material not blending very well.	Material imbalance during loading operation.	No standard ratios defined for loading different materials.	Dependancy is on part appearance to detect which material add.	Establish standard ratios and automate feeding system to gauge percentage ratios.

Figure 2. 5Why defect analysis

5.3 Standard operating procedure study results

The results of the study indicated a significant low drive when it comes to defect prevention on the line. There were minimal self-inspection and appraisal elements incorporated in the standard operating procedures of operators which were at ratios of 12.5% and 25% respectively. Overall, the line had a defect prevention ratio of 37.5% on average relative to the possible number of defects that could occur in each process. Further to this, manufacturing operations such as the moulding operation and cutting and trimming operation had significantly high percentages of possible defects that could occur in them, however, there was little preventative elements built into the standard operating procedures of the operators. The detection of all defects on the line was depicted in the final inspection process with 100% correspondence to standard operating procedure. The results indicated a gap and very little effort put into building quality at the manufacturing phase of the product. Table 5 indicates a summary of the results based on the initial data collected.

Table 5. Standard operating procedure defect prevention analysis

Measurables	Ratio of Self-inspection to total possible defects		Ratio of part appraisals to work elements		Average % defect prevention	
Percentage ratios	12.50%		25.00%		37.50%	
Operation	Material Loading	Part moulding	Cutting and Trimming	Burr removal	Bracket assembly	Final Inspection
Possible defect ratio by operation (%)	8.30%	33.30%	20.80%	16.60%	8.30%	4.20%
Ratio of defect prevention to occurance	50.00%	25.00%	0.00%	25.00%	100.00%	100.00%

5.4 Time Study results

The results obtained from the time study data are depicted by Figure 3. When taking the rework operation out, the overall time required to make one a full assembly of a component was 2040 seconds based on takt time. The actual cycle times have indicated a lesser time and have presented an opportunity to dissolve the final inspection quality gate and change the inspection elements to be self-inspection for the operators. The transition from the original process to that of adding built-in-quality elements to the conversion operations indicated an improvement in the overall line balancing formation ratio from 84% to 91.6% calculated as per the formation ratio formula highlighted in the data collection phase. The incorporation of the built-in-quality elements into the operations left the quality gate with only one inspection of the nut inserts which required the use of a checking fixture and was done hourly. Changing this element into a self-inspection element was restricted by the process layout and sequence.

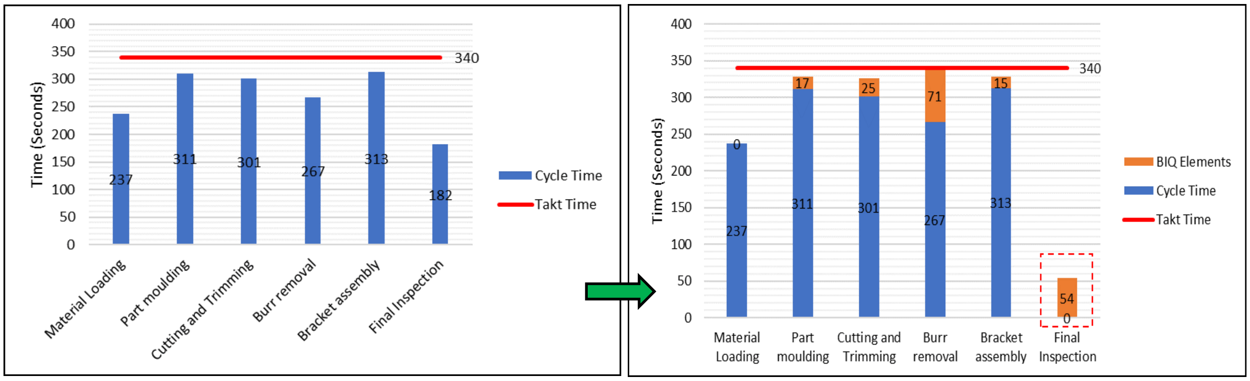


Figure 3. Time study and built-in-quality element distribution

5.5 Comparative analysis results

Based on the data collected from the comparative analysis experiment and statistical process control data, the study made a comparison between the conventional approach of using quality gates and built-in-quality in terms of process capability. From the characteristics that were measured, the process performance index (Ppk) results of the quality gate approach met the required standards on the statistical process control by obtaining a score greater that 1.67 across all measurables. The experiment on the built-in-quality approach met 80% of the capability score on the measurables and failed one measurable of torque specification. This was primarily driven by the process being new to the operators. From an aesthetic perspective, the quality gate process was able to prevent an outflow of defects by 80% while built-in-quality obtained 70% prevention. With this approach being relatively new to the line, the results were acceptable as training was ongoing and the process was able to get good results from the onset. Table 6 indicates the performance scores that were deduced form the Ppk capability calculations. Overall, the results indicated that the built-in-quality approach is capable of taking over from quality gates as an independent quality approach.

Table 6. Quality gate vs Built-in-quality capability study

Performance measurable		**Quality gate**					**Built-In-Quality**				
		Bright work gap	Frt to Rr bracket distance	Frt to Cntr bracket distance	Part weight	Torque spec	Bright work gap	Frt to Rr bracket distance	Frt to Cntr bracket distance	Part weight	Torque spec
Process performance	Pp	3.95	6.11	3.16	5.16	4.26	3.65	3.05	4.94	2.23	1.85
Pp Lower limit	PPL	2.21	10.3	1.74	6.71	5.78	1.91	4.26	4.84	2.53	2.32
Pp Upper limit	PPU	5.69	1.89	4.59	3.61	2.74	5.39	1.84	5.04	1.92	1.38
Process performance Index	Ppk	2.21	1.89	1.74	3.61	2.74	1.91	1.84	4.84	1.92	1.38
Results		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Fail
Ppk index criteria		**Ppk ≥ 1.67 = PASS**	**Ppk ≤ 1.67 = FAIL**				**Ppk ≥ 1.67 = PASS**		**Ppk ≤ 1.67 = FAIL**		

5.6 Strategic approach to implement built-in-quality in automotive component manufacturers.

Given the outcomes of the techniques used to develop a route towards unearthing constraints and possibilities of implementing built-in-quality, the study recommended Table 7 as a Plan-Do-Check-Act guideline approach to implement built-in-quality in automotive component manufacturers:

Table 7. Process improvement approach through built-in-quality

Process improvement approach through built-in-quality in automotive component manufacturers				
	Milestones	**Scope**	**Inputs**	**Output**
	Step 1 - Planning and preparation			
PLAN	Develop BIQ scope	Select the area and define the BIQ problems that are experienced in the manufacturing line or cell. Analyse the labor, cost, and profitability impact of the lack of BIQ.	Scrap percentages Cost of commodities Labor costs	Stratification Loss impact
	Establish sources of quality data collection	Collect quality defect data for the area select for the past 6 to 12 months. Establish the reliability of the information by comparing deferent data from different sources to ensure reliability.	Defect data Storage systems Historical reports	Data validation
	Step 2 - Execution and studies			
DO	Evaluate and conduct defect priority ranking	From the defect data that has been collected, the team must rank or stratify all the defects to develop focus. Decide on a ranking criteria e.g number of occurances, OEE percentage impact, customer complaints etc.	Pareto analysis Defect data Quality reports	Ranking Stratification Data validation
	Condut Root-Cause Analysis	From the stratified/ranked defects, define the quality problems, conduct root-cause analysis and develop countermeasures.	5why analysis Ishikawa diagrams Fault-Tree analysis	Defect root-causes
	Identify SOP gaps relative to quality defects	Conduct an SOP or Work Instruction study and verify if there is a correlation between defects and SOPs. Are SOPs driving defect prevention?	SOPs or Work Instructions	SOP or Work Instruction review
	Re-design SOPs to align with root-causes	If there is a gap between root-causes and SOPs, where possible, build the sustainability approaches to contain the defects into the SOPs of operators and not quality inspectors.		
	Identify opportunities to automate defect detection or implement Fool-Proof systems	Analyse all the quality elements and data storage of defect data and identify opportunities to convert them into digitalized systems or fool-proof systems.	Fool-proof systems study Information requirements Automation study	Defect detection systems Digital storage system Technology Investment opportunities

CHECK	**Step 3 - Cement the approach**			
	Conduct Training on new SOPs	Train manufacturing operators on the necessary in-process inspections required. Inspectors and shopfloor leadership need to lead the training.	Training plan Skills matrix Previous training records	Capable workforce
	Standardize BIQ elements and approach	Once training and implementation of fool-proof systems has been implemented, standardize the process and ensure ease of extraction of data.	SOPs or Work Instructions Quality Control Plan Defect reports	Updated procedures, reaction plans and quality data
	Compress and simplify quality gates elements	If there are elements still left with the quality gates, work towards simplifying them through automation to eventually enable process capability.	Work combination and Line balancing	Labor reduction Improved utilization Reduced reworks
ACT	**Step 4 - Drive stability**			
	Monitor customer quality impact of BIQ implementation	Continuosly monitor customer feedback on quality issues. Drive root-cause analysis with the involvement of the process owners associated with the defects.	Customer Quality Reports Customer Non Conformance Reports Customer Field Technical Reports	Continuous root-cause analysis and process capabilty improvements
	Drive continuous improvement	Channel Non-conformance reports and quality reports from customers down to the operators on the floor. Refrain from allocating inspection problems to inspectors. Drive process coaching and capability building.	Visual management and display of reports and Root-cause analysis conducted	Process BIQ capability building Awareness Root-cause analysis culture

5.7 Proposed improvements

- Move the weighing elements from the final inspector to the part moulding process to avoid assembling of brackets and brightworks on over/under weight parts. Cost saving can be realised on the part assemblies that are scrapped and time wasted on assembling an already out of spec part.
- Automation of the weighing process – a Pokayoke system to be linked to the scale such that if a part is put on the scale and is over/under weight, it can be rejected immediately and eliminate passing a defective part to the next process.
- Introduce torque wrenches that are Pokayoke controlled to eliminate the variations in torque specifications. The Pokayoke system must not allow a sidestep assembly jig to open unless it has cleared off the required torque specification.
- Introduce a feed ratio controller on the feeding system of the material to ensure accurate balancing of virgin and regrind material that is fed into the system to reduce appearance issues.
- Give operators authority and ownership of the parts they produce by allowing them to reject parts that are sub-standard. Quality responsibility to be on the shoulders of the entire operation as opposed to it lying with the inspector alone.

6. Conclusion

The study applied several lean manufacturing techniques to identify gaps in the implementation of built-in-quality in automotive component manufacturers and developed a subduing strategy. Automotive component manufacturers can follow the developed strategic approach that is centred around Deming's Plan-Do-Check-Act method. The study has shown to an extent that automotive component manufacturers need to invest in technology and empower employees to make decisions through coaching and training. automotive component manufacturers need to close the departmental gaps that are currently created during process design and enforce a unified multi-departmental approach towards designing their processes. Quality assurance must not be a departmental responsibility, but an organizational responsibility from the inception of processes. The employment of built-in-quality strategy brings into light hidden cost benefits of labour reduction, adequate utilization of resources and reduced process times especially in manufacturing lines where quality gates are in series with manufacturing processes. The first objective of the study was met through the development of a Pareto analysis, while the second objective was also met using a 5Why analysis technique which identified the root-causes of defects. The third objective of the study was also met through an experimental study of comparison. Gaps and opportunities that were identified using the various lean techniques led to the identification of technological advancements that can be employed to drive built-in-quality, which talks to the fourth objective. A detailed strategic approach was developed to aid automotive component manufacturers in implementing built-in-quality on their manufacturing lines. Further research into this area of study would be centred around the integration of shopfloor employees to fool-proof systems, defect detection technologies and comprehending digital product information to drive built-in-quality.

References

Bertagnolli, F., Perfection, in: Lean Management, pp. 117-127, Springer Books, Springer, Singapore, 2022.

Borkowski, S. and Knop, K., Challenges faced in modern quality inspection, Czestochowa, Poland, 2016.

Chen, K.S., Lai, Y.L., Huang, M.C. and Chang, T.C., Fuzzy judgement model for assessment of improvement effectiveness to performance of processing characteristics. *International Journal of Production Research*, vol. 61, no. 5, pp. 1591-1605, 2023.

Chiarini, A. and Kumar, M., What is Quality 4.0? An exploratory sequential mixed methods study of Italian manufacturing companies. *International Journal of Production Research*, vol. 60, no. 16, pp. 4890-4910, 2022.

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

Donada, C., Nogatchewsky, G. and Pezet, A., Understanding the relational dynamic capability-building process, *Strategic Organization*, vol. 14, no. 2, pp. 93-117, 2016.

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

Gupta, S., Holistic approach to quality management: A case study of the Indian industry, *IUP Journal of Business Strategy*, vol. 16, no. 1, pp. 7-26, 2019.

Hoe, L.C. and Mansori, S., The effects of product quality on customer satisfaction and loyalty: Evidence from Malaysian engineering industry, *International Journal of Industrial Marketing*, vol 3, no 1, pp. 20, 2018.

Hyun Park, S., Seon Shin, W., Hyun Park, Y. and Lee, Y., Building a new culture for quality management in the era of the Fourth Industrial Revolution, *Total Quality Management & Business Excellence*, vol. 28, no. 9-10, pp. 934-945, 2017.

Mohammed, S., Jidoka: The Toyota Principle of Building Quality into the Process, Cairo, Egypt, 2020.

Nomura, S., The Toyota Way of Dantotsu Radical Quality Improvement, CRC Press, 2021.

Palange, A. and Dhatrak, P., Lean manufacturing a vital tool to enhance productivity in manufacturing, Materials Today, *Proceedings*, vol. 46, pp. 729-736, 2021.

Psarommatis, F., May, G., Dreyfus, P.A. and Kiritsis, D., Zero defect manufacturing: state-of-the-art review, shortcomings, and future directions in research, *International journal of production research*, vol. 58, no. 1, pp. 1-17, 2020.

Pyzdek, T., Pareto Analysis, *In The Lean Healthcare Handbook*, pp. 157-164, Springer, Cham, 2021.

Reklitis, P., Sakas, D.P., Trivellas, P. and Tsoulfas, G.T., Performance implications of aligning supply chain with competitive advantage: Empirical evidence from the agri-food sector. *Sustainability*, vol. 13, no. 16, pp. 8734, 2021.

Serrat, O., The five whys technique, *In Knowledge solutions,* pp. 307-310, Springer, Singapore, 2017.

Singh, V.K., Kumar, R., Joshi, C.V. and Poddar, S., Improving operational performance with world class quality technique: A case in Indian automotive industry. *Materials Today: Proceedings*, vol. 72, pp.1561-1567, 2023.

Sisodia, R. and Villegas Forero, D., Quality 4.0–how to handle quality in the Industry 4.0 revolution, 2019.

Tinh, N.V., Husain, S.T. and Van Thanh, N., Application of Industrial Engineering Technique for Better Productivity in Garment Industry. *ARRUS Journal of Engineering and Technology*, vol. 1, no. 1, pp. 1-8, 2021.

Wahyu, P.T. and Sigit, M., The Effect of Service Quality and Product Innovation toward Competitive Advantage and Implications on Interest in Reference Customers" BRI" Bank in Bengkulu Province: Case Study in" BRI" Bank Bandar Bintuhan Branch. In *2019 International Conference on Organizational Innovation (ICOI 2019)*, pp. 249-253, 2019.

Biographies

Edward Makua is a masters student in the Department of Industrial Engineering at the Durban University of Technology in South Africa. He works for the automotive component manufacturing sector and has over six years of experience in the automotive sector. He has experience in production engineering, process engineering, production management, manufacturing excellence facilitation and is an expert in maintenance planning systems implementation. He completed his Bachelor of technology in industrial engineering at the Durban University of Technology and a Post graduate diploma in project management at the Management College of Southern Africa.

Dr Mendon Dewa Dr is a senior lecturer in the Department of Industrial Engineering at the Durban University of Technology in South Africa. He has presented at local and international conferences and has written several journal articles. He has also supervised master’s degree students and has a strong passion for optimisation of manufacturing systems and operations management.