DEPLOYING BUILT-IN QUALITY TO REDUCE SCRAP IN AN AUTOMOTIVE COMPONENT MANUFACTURER

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ABSTRACT

Automotive component manufacturers face global competitive challenges, and the paradigm has shifted from product price as the determining factor of competitiveness to the quality of the product. An automotive component manufacturer was struggling to manage the outflow of defects, and adding inspectors as quality gates to the rear-step bumper production line had severe cost implications. This study aimed to reduce the number of defects by deploying a strategic path of implementing built-in quality. Quality tools were used, and the study's results included significant manpower reduction, improved quality capability, and reduced scrap rates and reworks.

OPSOMMING

Motorkomponentvervaardigers staar wêreldwye mededingende uitdagings in die gesig, en die paradigma het verskuif van produkprys as die bepalende faktor van mededingendheid na die kwaliteit van die produk. 'n Vervaardiger van motoronderdele het gesukkel om die uitvloei van gebreke te bestuur, en die toevoeging van inspekteurs as kwaliteithekke na die agterbufferproduksielyn het ernstige koste-implikasies gehad. Hierdie studie het ten doel gehad om die aantal defekte te verminder deur 'n strategiese roete te implementeer om ingeboude kwaliteit te implementeer. Kwaliteitgereedskap is gebruik, en die studie se resultate het aansienlike vermindering van mannekrag, verbeterde kwaliteitvermoë en verminderde skroottariewe en herbewerkings ingesluit.

1. INTRODUCTION

Automotive component manufacturers are experiencing reduced profit margins owing to an influx of input resources to manufacture components. This is largely a result of not operating as lean as possible. The absence of a built-in quality (BIQ) principle takes the ownership of product quality away from manufacturing employees [1], thereby requiring additional manpower to inspect for quality. Once quality issues are picked up by 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. The researcher calculated the amount of scrap relative to output from one of the manufacturing line's scrap reports from January to July 2022, which indicated that, on average, the manufacturing line was making 16% scrap from its monthly output. This was 12% higher than the manufacturer's average monthly target of 4%. This indicated a huge gap in the prevention and appraisal of parts, which are the goals of implementing BIQ. Teli *et al*. [2] argue that 1% to 4% of scrap can be overcome through prevention and that 6% to 12% of scrap can be overcome through appraisal. Prevention and appraisal alone could drastically reduce the number of internal defects and the external outflow of defects to customers. Prevention ensures product quality before manufacturing, and appraisal ensures product quality during the conversion phase. The aim of this study is to address the problems that are faced on the rear-step bumper production line, outroot factors hindering BIQ in an automotive component manufacturer (ACM), and develop a strategic approach to implementing built-in quality for the rear-step bumper production line.

2. LITERATURE REVIEW

BIQ is a quality management practice that strives to apply continuous improvement initiatives to production processes in order to address quality issues before they cascade into large-scale problems. Diekmann *et al.* [3] outline the fundamental BIQ principle as driving proactivity to respond to defect occurrences, implementing fool-proof systems, measuring, and continually building an organisational culture that takes responsibility for quality in its entirety. The research indicates that the use of a quality gate to inspect for quality is the predominant approach to mitigating quality issues in ACMs. This is a traditional system that is being used to check components and assemblies to see whether they are either rejects or acceptable after being manufactured [4]. The process of establishing quality gates is driven by pre-determined criteria in which quality inspectors are expected to ensure adherence to those criteria or specifications. However, there are disadvantages to quality gates, such as that this approach makes it difficult to trace defects that are picked up at the end of the line in order to identify the causes of defects, thereby making it a passive and reactive process [5]. In addition, the approach reduces the responsibility and accountability for product quality to an inspector, and discourages the need for self-inspection and ownership [6].

The transition from conducting end-of-line inspections as the primary course for defect prevention to BIQ raises the art of building process capability. Manish and Manoj [7] describe 'process capability' as the degree in which a process can perform optimally and produce products that conform to specifications. Donada, Nogatchewsky and Pezet [8] expand the definition to describe a process of equipping manufacturing employees with the necessary skills and capabilities to execute their jobs with ease while adhering to good quality practices. One of the key difficulties in moving away from quality gates to BIQ is the introduction of employees to the innovations and different work methods that come with the BIQ approach. Helm and Graf [9] indicate in their study that skills upliftment and a knowledge-based integration of resources for innovation is critical to delivering to accurate customer standards.

According to Gupta [10], one of the main drivers of expanded quality responsibility across all departments of an organisation is the use of (Standard Operating Procedures) SOPs to drive quality systems. This holds true in manufacturing organisations, particularly in ACMs, because SOPs are the primary instructor and training tools for manufacturing processes. Esa *et al.* [11] describe SOPs as structured documents that are intended to outline the execution of processes sequentially and that hold the key to the successful execution of tasks. In the sphere of BIQ, SOPs have great significance, in that the integration of inspections into value-adding processes requires reviewing and revising the SOPs to contain inspection elements. Hollmann *et al.* [12] support this approach by arguing that SOPs have been used extensively by manufacturing companies to drive efficiencies and to meet quality standards by adhering to sequential elements of work. The SOP system encourages the periodic updating and review of methods of work that enable quality inspection elements to be incorporated into conversion processes.

According to Dias *et al.* [13], technological transformation for any organisation in the digital age is vital for competitiveness, monitoring systems' performance, and collecting real-time data. The replacement of manual processes with technology offers any company great efficiencies, superior quality products, and a competitive advantage. The key challenge in designing processes for BIQ is often to integrate resources and to expand the approach so that it becomes a multi-departmental effort with a single goal. The practices of departmental segregation and of building walls between departments are the root of process design weakness.

3. RESEARCH METHODS

The study employed a range of quality tools to gather and interpret statistical or numerical data. The techniques used in this study were Pareto analysis, SOP analysis, time studies, and a comparative analysis of quality gates and process BIQ. Table 1 summarises the types of data that were collected relative to the techniques that were used. Following the re-distribution of the elements in the time-study analysis, a comparative analysis was conducted to compare the quality results between using BIQ and the conventional approach of using quality gates. This was conducted in the form of an experimental study.

Table 1: Summary of quality tools and data sources

Technique	Primary source	Secondary source
Pareto analysis	Not applicable	Defect and scrap reports for the past 6 months
SOP study	Not applicable	SOPs and work instructions on the shopfloor
Time studies	Work observation and measurement using a stopwatch	Not applicable
Comparative analysis	Experiment on a controlled sample of parts while observing two different work methods	Quality reports from the customer for the controlled sample
Cost impact analysis	Not applicable	Labour hourly rates, material unit prices, product selling prices, and cost of scrap per unit
Process flow analysis	Work element observation and recording of process operations	SOPs and work instructions for validation of current standard cycle times
Ishikawa diagram	Process analysis for root causes	Defect and scrap reports for the past 6 months
Technological value analysis	Improvement of designs and recommendations	Already existing technologies and their respective designs

The analysis began by eliminating the quality gates for a controlled number of produced components. For that sample of parts, quality inspectors were not responsible for inspecting quality; rather, operators on the floor inspected their own work, and a sample of 30 parts was used. The second part of the experiment was to bring quality gates into the processes, produce a sample of 30 controlled parts where the dependence on quality gates was according to the normal process. Based on these runs for each of the lines, a quality report was obtained through the aid of quality engineers and statistical process control (SPC) specialists, detailing the overall outcome for each of the controlled parts. The SPC analysis and results were conducted using Minitab software, which is a Six Sigma tool. A comparative conclusion was then drawn between the two quality approaches.

4. RESULTS

4.1. Rear-step bumper process flow

The rear-step bumper assembly line is responsible for the production of rear-step bumpers. The first step in the process is the delivery of frames that go through a quality gate and then are assembled to form the primary structure of the bumper. This is done away from the production assembly line. The process then adds more components to the frame assembly, such as sensors, endcaps, step-pads, and towing bezels. At the completion state of the assembly, an automated roamer machine is responsible for parameter and tolerance checks on the finished product. A secondary final inspection is then conducted to check the aesthetics of the final product. Figure 1 indicates the layout of the process, and how quality gates are stationed on the production line to ensure adherence to quality standards.

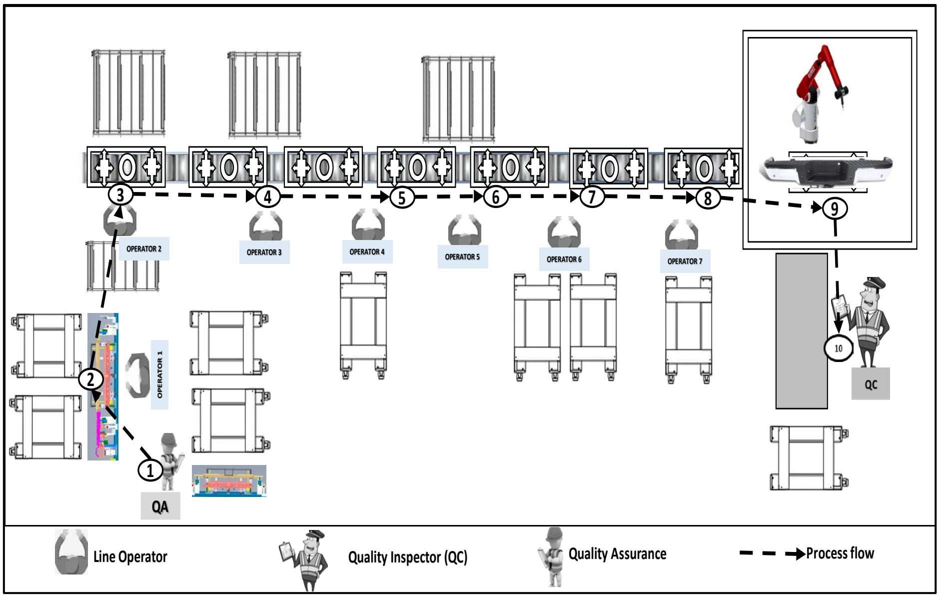

Figure 1: Rear-step bumper line process layout

Operation 1 – Quality gate: This operation is done by a quality assurer (QA), who is responsible for randomly inspecting incoming batch trollies containing frames, endcaps, and step-pads. The frames are randomly taken off the batch trolley and inserted into a checking fixture. The QA then measures the parameters of the frame, and gives approval for the parts to go into production, based on a random sampling method that is conducted twice a shift. Endcaps and step-pads are visually inspected for surface texture conformance (scratches and dents).

Operation 2: This operation is executed by operator 1, who is responsible for taking different pieces of the primary frame assembly and combining them through an assembly jig. The operator collects a centre frame, and places it on the assembly fixture, then collects a right hand and left-hand frame that support the endcap and aligns them to the centre frame on the fixture. The operator then collects the bolts and tightens the left and right frames on to the centre frame.

Operation 3: This operation is carried out by operator 2, who begins by collecting the frame assembly from the rack and placing the frame on to the assembly jig on the conveyor. The operator collects a step-pad from a trolley, loads it on to the frame assembly, and locates pins to lock it in place on the frame. The operator then connects a wire harness to the frame assembly for licence plate lighting. Last, the operator collects and places endcaps on the frame.

Operation 4: This operation is done by operator 3, who is responsible for tightening the left-hand and right-hand sides of the step-pad to the frame and tightening the endcaps with bolts. The operator collects bolts for the left-hand side endcap and then tightens it on to the frame. This is followed by collecting bolts to tighten the right-hand side endcap.

Operation 5: This operation is executed by operator 4 by assembling the left and right light bezels, which are assembled with the step-pad to light up the licence plate. The operator begins with a sub-assembly of the bezel and the light bulb, and fits it into the step-pad. The operator then connects the light assembly to the wire harness through a sensor connector.

Operation 6: This process is executed by operator 5, who is responsible for tightening the support brackets and trim brackets for both the left- and the right-hand sides of the bumper.

Operation 7: This operation is carried out by operator 6, who begins by picking tow covers for both the right- and the left-hand sides. The operator then collects pin-screws and secures the tow covers on the frame assembly with the pin-screws.

Operation 8: This is the last manual assembly operation on the production line, and is executed by operator 7. The operation begins with the collection of screws and side step-pads. Thereafter, the operator presses the side step-pads down on to the endcap frame assembly and tightens the left and right side step-pads on to the assembly.

Operation 9 – Quality gate: This is an automated operation that is activated by operator 7. The roamer arm is an automated laser inspection robot that is responsible for the inspection of tolerances on each assembled bumper. These tolerances range from gaps on the step-pad to the flushness of the bezels and gaps on the endcaps. The roamer arm rotates to key parameter inspection areas and sends data to a programmable logic controller (PLC), which transmits the data and displays it on a human-machine interface (HMI). The system indicates whether the bumper is within the correct specifications.

Operation 10 – Quality gate: This is the last process on the manufacturing line, and is done by the quality inspector, who is responsible for conducting a 360 degree check on the parts for conformance elements such as scratches on the surface, gaps on the endcap lining, and flush fitting of the light bezels, and for testing the sensors and light bezels. The inspector is also responsible for checking the data from the roamer arm to confirm whether all of the parameters from the roamer check are within specification. This is guided by the HMI display, whowing whether a bumper is good to go. If it is good to go, it proceeds to packaging; and if it is not good to go, it is directed for rework in the areas of concern. On completion of the cycle, the inspector puts identification stickers on the bumpers.

4.2. Value stream mapping

The value stream mapping (VSM) of the rear-step bumper line begins by acquiring the monthly forecast of production demands according to their respective derivatives. The information is then cascaded to three suppliers to deliver assembly components each week. The warehouse stock holding capacity in the plant can only hold stock for five days. The forecast is also inserted into a manufacturing plan and cascaded to the production supervisor, who then sends it to the production line operators daily. The inventory point carries 2 400 units, which is equivalent to a stock holding of five days. The production line runs 24 hours a day with a shift target delivery of 160 units. The total time that the components stay in the system from acquisition to finished product is five days. The processing lead time of the production line is 996 seconds – the time it takes for one bumper to be assembled from the initial random inspection operation to the final inspection. Deliveries by a truck with a carrying capacity of 40 units per delivery are made to the customer 12 times a day. Figure 2 illustrates the entire VSM of the manufacturing line and how the components flow through the system.

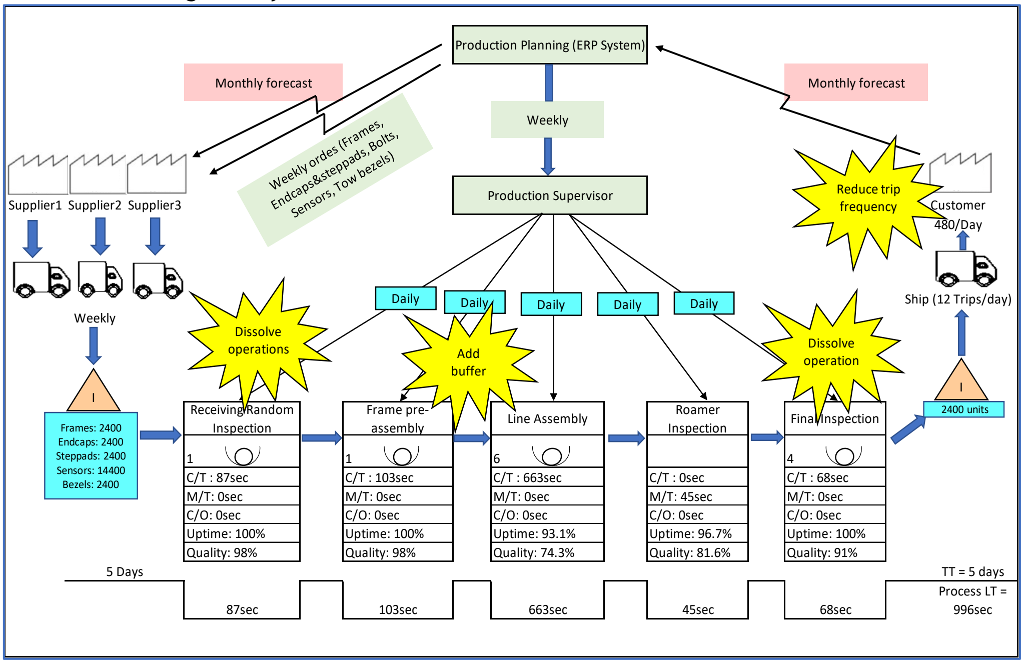

Figure 2: Rear-step bumper line VSM

The VSM of the production line has several value-adding operations. The only non-value adding operations are those associated with inspections. The overall stream presents several opportunities for improvement in order to optimise the line, as follows:

- The receiving inspection operation could be absorbed into the pre-assembly operation, given its frequency and requirements. At the beginning of the shift, the pre-assembly operator could randomly check a frame from the batch on a checking fixture before production begins. To cater for the time loss of the pre-assembly operator, a buffer of 10 units could be maintained between pre-assembly and assembly line to ensure that the line does not stop or have to wait for the random inspection conducted by the pre-assembly operator. This would lead to a reduction in the manpower needed and ultimately drive ownership.

- The roamer arm operation and the final inspection operations duplicate activities such as the inspection of gaps, which could be removed from the final inspection operation and be left to the automated roamer arm process. The inspection of surface textures could be fed back into the assembly operations to drive the principle of ensuring that they check their own work and do not pass on any defective work to the next process. The process of testing the bezel lights needs only power and visual confirmation; and those elements could be built into the last operator's SOP and station design.

- The activities associated with the identification of the bumpers could be moved to the collection and packing operation, which is outside of the VMS. External to the process is a logistics operation that takes the finished assemblies to the storage area. The parts are collected with a trolley in batches of four. With part identification, stickers are generated sequentially, and they could be placed on the parts during the part collection. This would allow the final inspection quality gate operation to be removed.

- There is an opportunity for improvement in the truck deliveries. The carrying capacity of the trucks could be increased by adding a trailer. By investing in a trailer with a carrying capacity equal to that of the truck, the number of trips to the customer could be reduced by 50%. The truck, together with the trailer, could make deliveries in batches of 80 units, which would reduce the number of deliveries from four per day to two. This could lead to benefits such as less traffic in the plant and savings in the operational and service costs of the trucks.

4.3. Pareto analysis

The results of the Pareto analysis indicated that the line was plagued by two defects that were ranked the highest. These were the wrong bliss sensor module, and poor bolt tightening. These two defects needed to be subject to a further root cause analysis approach in order to have a significant impact on the quality yield of the production line. The defects are highlighted in Figure 3 as those that fall within the 20% 'vital few' defects on the Pareto analysis graph. The remaining 15 defects fell within the 80% 'significant many'.

Defect description	Number of defects	Percentage	Cumulative %
Wrong bliss sensor	101	32.17%	32.17%
Poor bolt tightening	91	28.98%	61.15%
Scratches	64	20.38%	81.53%
Paint defect	12	3.82%	85.35%
Loose bolt	12	3.82%	89.17%
Loose nut	5	1.59%	90.76%
Gap step pad and end cap	5	1.59%	92.36%
Missing Nut	4	1.27%	93.63%
Wrong End cap	4	1.27%	94.90%
Dents	4	1.27%	96.18%
Missing bolt	3	0.96%	97.13%
harness not connected	3	0.96%	98.09%
Gap step pad and lower cover	2	0.64%	98.73%
loose components	2	0.64%	99.36%
uneven gap bezel	1	0.32%	99.68%
Loose connection	1	0.32%	100.00%
Wrong bumper	0	0.00%	100.00%
Other	0	0.00%	100.00%
TOTAL	314	100%	

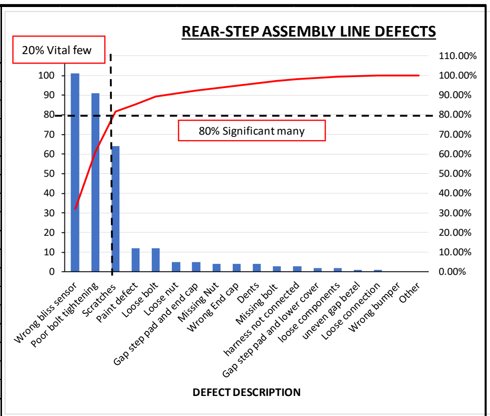

Figure 3: Rear-step bumper line Pareto analysis

4.4. Ishikawa diagrams

4.4.1. Wrong bliss sensor defect

The wrong bliss sensor module being fitted on the rear-step bumper was the highest ranked defect on the line, according to the Pareto analysis. The defect was subjected to the Ishikawa diagram technique to determine the possible root causes. Figure 4 illustrates the Ishikawa diagram that was completed for this defect.

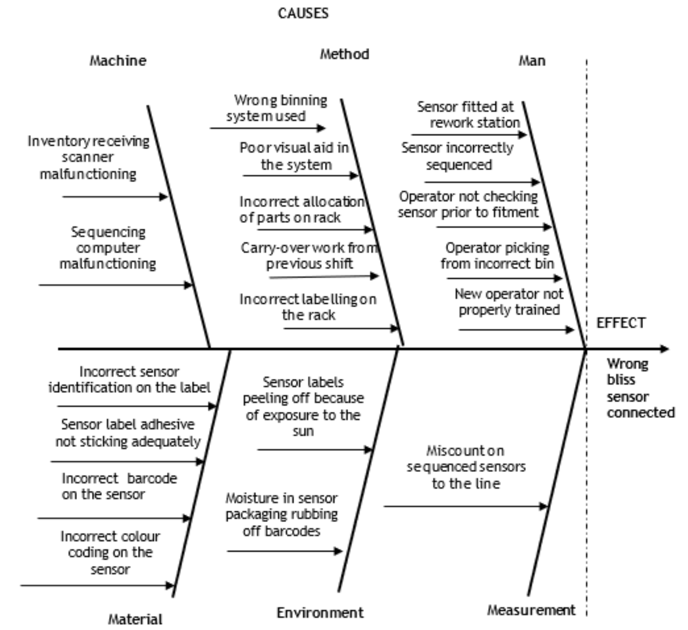

Figure 4: Ishikawa diagram: Wrong bliss sensor

The results of the Ishikawa diagram for the wrong bliss sensor indicated that there were four possible root causes for the defect. A further deduction from the diagram indicated that there were gaps in the operator training and self-inspection elements. Moreover, visual aids and shift handovers showed gaps that led to the occurrence of the defect. Table 2 summarises the root causes and the corrective actions that needed to be taken to drive BIQ in the manufacturing stream in order to curb the outflow of the wrong bliss sensor defect.

Table 2: Wrong bliss sensor: Corrective actions

Possible root cause	Category	Corrective action	Corrective action category
Operator not checking sensor prior to fitment	Man	Implement an automated picking indicator system through barcode scanning to aid the operator	Technological
Operator picking from incorrect bin	Man	Implement an automated picking indicator system through barcode scanning to aid the operator	Technological
Poor visual aid in the SOP	Method	Update visual aids and the new picking system on the operator SOPs	Operational
Carry-over work from previous shift	Method	Implement shift handover meetings	Operational

4.4.2. Poor bolt tightening defect

The second-highest ranked defect on the rear-step bumper line that fell within the boundary of the 20% vital few was poor bolt tightening. Figure 5 indicates the results of the Ishikawa diagram technique that was undertaken to determine the root causes of this defect.

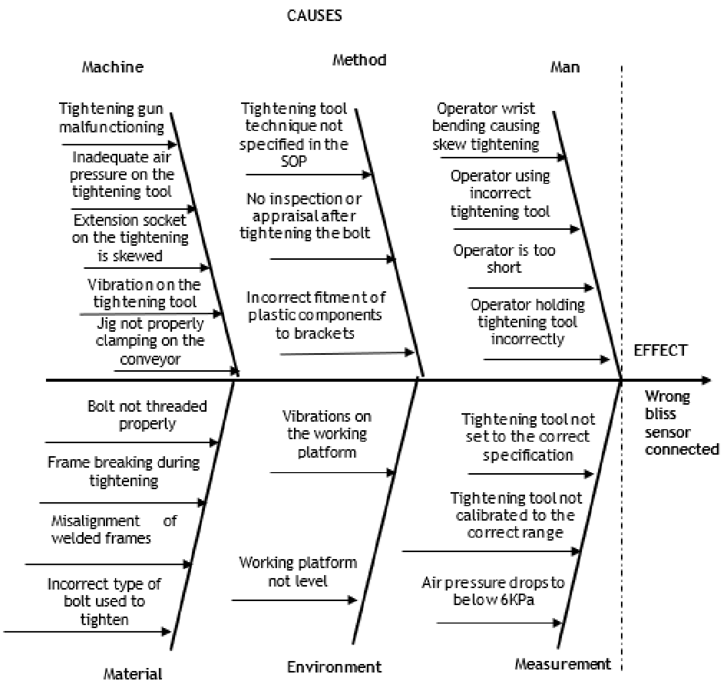

Figure 5: Ishikawa diagram: Poor bolt tightening

The results of the Ishikawa diagram for the poor bolt tightening defect indicated that there were five possible root causes to the defect. The root causes ranged from ergonomics, poor SOP construction, and misalignment of specifications for parts delivered on the line. The operational corrective actions of the root causes that needed to be implemented are outlined on Table 3. At the centre of the corrective actions, is the aim to drive BIQ in the manufacturing process.

Table 3: Poor bolt tightening: corrective actions

Possible root cause	Category	Corrective action
Operator wrist bending causing skew tightening (ergonomics)	Man	Develop a proper job-man specification for the operations, and where possible introduce platforms
Tightening tool technique not specified in the SOP	Method	Update SOPs to include elements that guide ease of tightening
No inspection or appraisal after tightening the bolt	Method	Update SOPs to include inspection or appraisal elelments after tightening the bolt
Frame breaking during tightening	Material	Update SOPs to include incoming part alignment inspections
Misalignment of welded frames	Material	Update SOPs to include incoming part alignment inspections

4.5. SOP analysis

The results of the rear-step bumper SOP analysis indicated that the line was sensitive to quality. Table 4 indicates that, across all of the value-adding operations, 14 out of 40 elements pointed to the prevention of occurring defects. The production process was reasonably on course to drive BIQ, as each of the operations contained an element of self-inspection. Only six elements were subjected to quality gates, and this was because of resource loading and layout constraints.

Table 4: Rear-step bumper line SOP analysis statistical results

Operation	SOP description	Number of steps in SOP	Number of self-inspection steps in SOP	Number of appraisal elements in SOP	Number of possible quality defects	Possible defects description
1	Quality assurance	7	2	1	3	Paint defect wrong end cap scratches
2	Frame assembly	17	4	0	7	Poor bolt tightening, missing bolt, loose components, loose nut, missing nut, paint defect
3	Step pad assembly	13	1	0	6	Wrong bliss sensor, dents, poor bolt tightening, wrong end cap, loose components, scratches, harness not connected, paint defect
4	End cap assembly	10	3	0	8	Wrong bliss sensor, dents, poor bolt tightening, wrong end cap, loose components, missing bolt, wrong bumper, gap on step pad and end cap
5	Bezel assembly	14	1	0	4	Poor bolt tightening, uneven gap bezel, scratches, loose bolt
6	Trim supports	11	1	0	5	Poor bolt tightening, missing bolt, loose components, scratches, loose bolt
7	Tow covers	10	2	0	6	Poor bolt tightening, missing bolt, loose components, scratches, loose bolt
8	Side steps	10	2	0	4	Poor bolt tightening, loose components, scratches, loose bolt
9	Quality check 1	11	4	2	3	Scratches, dents, wrong bumper
Total		**103**	**20**	**3**	**46**	

A percentage ratio summary table was developed for the overall results of the SOP analysis. The results indicated that the line had an overall self-inspection ratio of 35% and no appraisal elements. The lack of appraisal elements presented an opportunity for element execution verification, such as the tightening of bolts, screws, and nuts on the production line. These were elements that could be incorporated into the SOPs to drive BIQ. Given the lack of appraisal elements, the overall defect prevention ratio of the line was 35%. By updating the SOPs, a greater percentage of defect prevention in each operation could be realised. Table 5 summarises the overall defect prevention percentage ratio results of the SOPs on the rear-step bumper production line.

Table 5: Summary of rear-step bumper defect prevention

Operation	Quality assurance	Frame assembly	Step pad assembly	End cap assembly	Bezel assembly	Trim supports	Tow covers	Side steps	Quality check 1
Pareto defect ratio (%)	18%	41%	35%	47%	24%	29%	35%	24%	18%
SOP defect prevention element ratio	100%	57%	17%	38%	25%	20%	33%	50%	100%
Summary - Value-adding operations									
Measurables	Overall % of self-inspections to defects			Overall % of appraisal elements to defects			Overall % of process defect prevention		
Percentage value	35%			0%			35%		

4.6. Time studies

The results of the time study approach to quality gates on the rear-step bumper line are shown in Figure 6. The time study excluded the roaming inspection process, which was not fully commissioned at the time of the study. This reduced the total number of operations for the time study from 10 to nine. Basing the data on nine operations and a takt time of 120 seconds, the line was set up to take 1 080 seconds to assemble a rear-step bumper fully. In the case of this line, the quality assurance operation was included in the study, as it ensured full inspection of all of the parts going into the manufacturing line. Although it was called 'quality assurance', the operation worked like a receiving inspection quality gate. The formation ratio formula was used to determine the percentage loading of resources. Across all nine operations of the line, the formation ratio was 78.34%. This presented a 21.66% gap to load the resources further, either with elements from the quality gates or from operational and technological gaps identified in the SOP study.

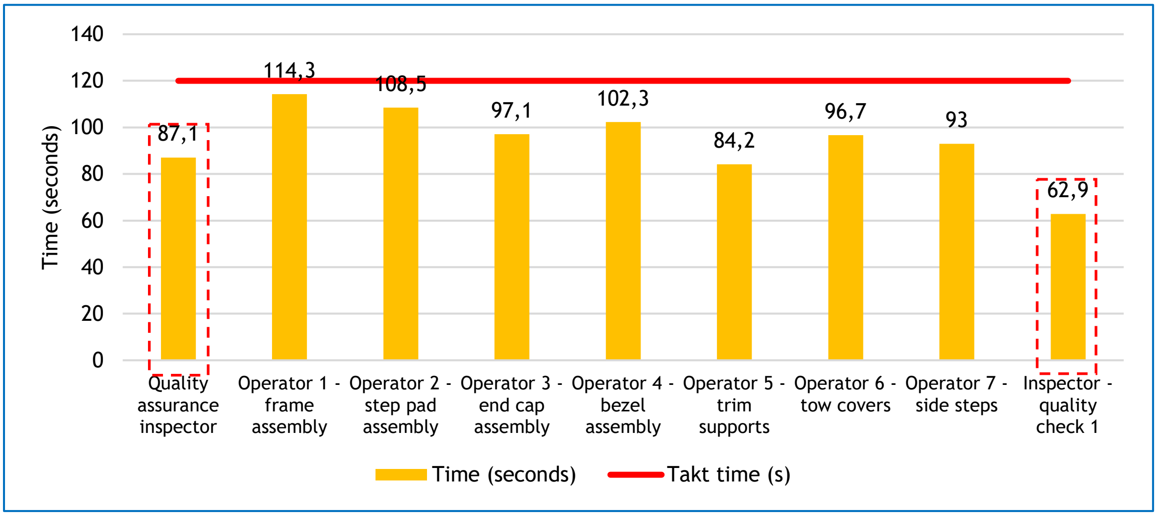

Figure 6: Time study of quality gate process

The results of the approach of the BIQ process for the rear-step bumper line are presented in Figure 7. The first quality assurance operation could not be removed because the preceding operations were loaded and the elements required fixing. This constrained the element distribution. The last inspection point also could not be removed owing to layout constraints. At the end of the process, a specialised testing jig did not allow for the elements to be distributed across the line. Taking these constraints into consideration, the line remained with nine operations and 1 080 seconds to assemble a bumper fully. The elements that could could be factored into the operations were the gaps identified in the SOP analysis and the technological improvement that was recommended by the technological value anlysis approach. With the addition of the self-inspection elements, and after training the operators on them, the formation ratio of the line improved from 78.34% to 87.69%. Further line balancing activities were still required to ensure that all of the operations did not exceed the takt line.

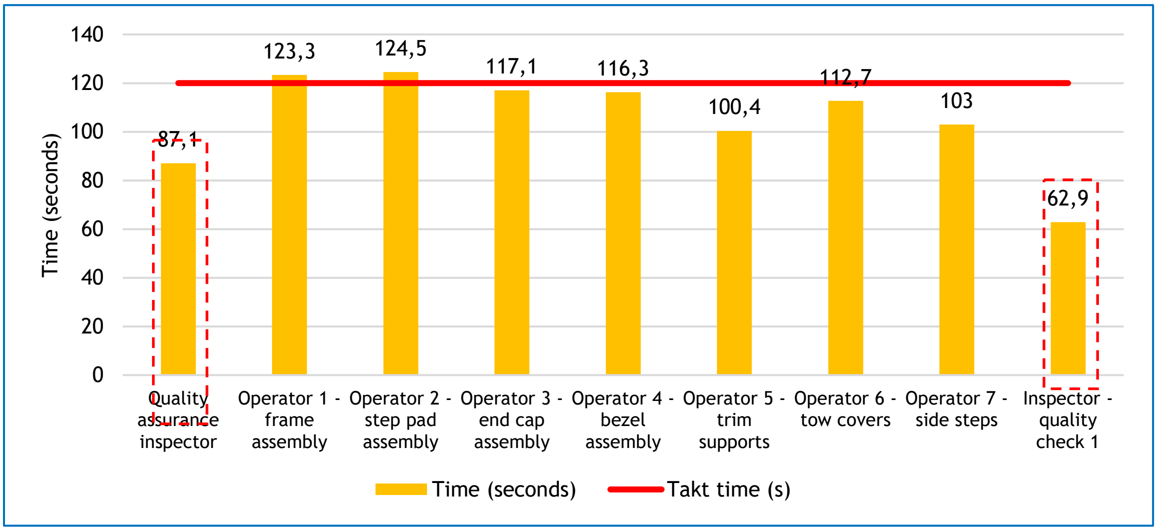

Figure 7: BIQ process time study

4.7. Technological intervention

The defect that required technological intervention on the rear-step bumper line was the wrong bliss sensor. The possible causes of the problem were wrong sensors being picked by operators and picking from an incorrect bin.

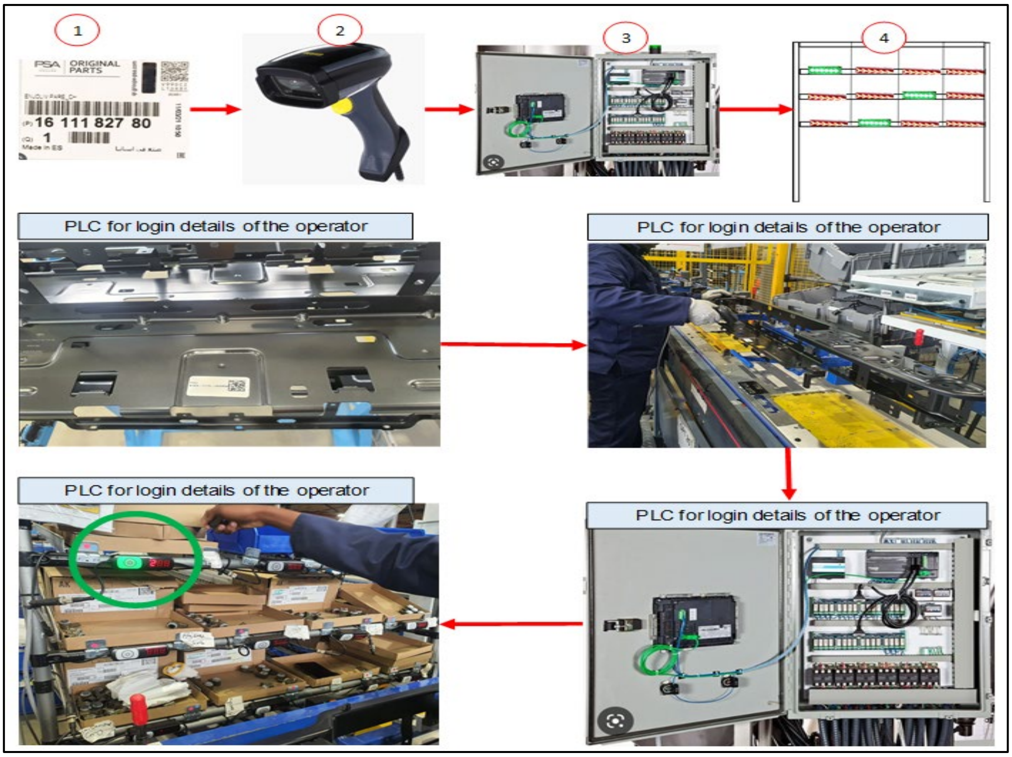

Figure 8: Automatic picking system indicator

The study suggested the implementation of an automatic picking system indicator as a corrective action at the root cause analysis stage. Figure 8 illustrates the picking indicator system that was integrated into the process to eliminate the defect of the wrong bliss sensor being fitted on to the bumper.

The recommendation of the automated picking system indicator was implemented to provide the process with a foolproof system that ensures that the operator never picks from the wrong bin. The process began with the main frames of the bumper being identified with a barcode sticker. The barcode was then scanned by the first operator. The scanner transmitted the identification information to the PLC. The PLC sent impulses to the rack where the lights were connected. Each of the lights represented a part and the quantity that was supposed to be picked. The lights on the rack lit up according to the derivatives after scanning was programmed into the PLC. The implementation of this automatic indicator ensured that operators did not become confused and pick the wrong sensors. Each sensor was picked according to the block lights on the rack, which was linked to the barcode identification of each bumper.

4.8. Experimental results on quality gates and BIQ approaches

The results of the rear-step bumper line only measured the statistical conformances of the 30 sampled parts. One example of the quality gates capability analysis is illustrated in Figure 9, showing the results of measuring SPC 4 gap tolerance. The following key deductions were made from the outcomes:

- 0% of the samples fell outside of the lower and upper boundary conformance.
- The Process performance index (Ppk) result indicated a measure of 1.27, which was less than the targeted 1.67.
- The process is expected to yield a 0.01% rejection rate against a target of 5%.
- For every million parts produced, 65 parts will be out of specification for SPC 4 gap measurement.

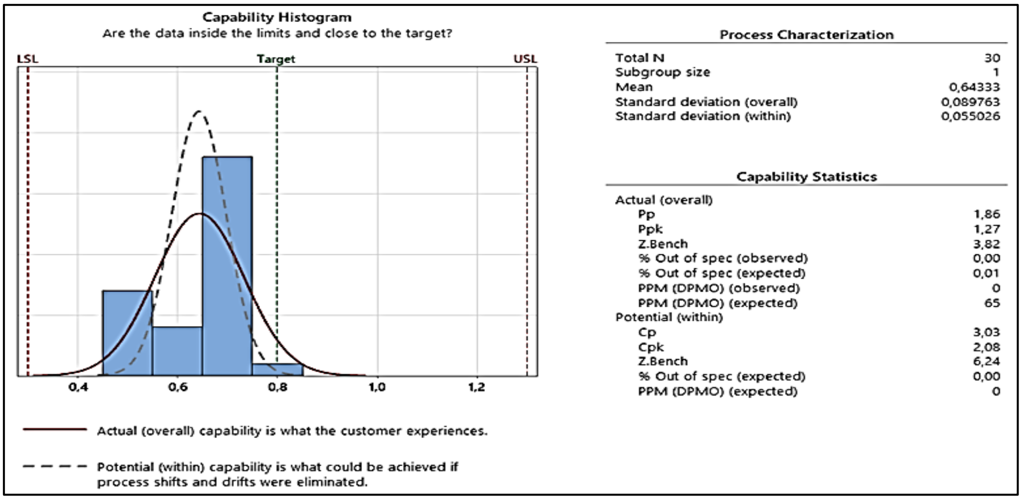

Figure 9: Quality gates capability analysis – SPC 4 RSB

One example of BIQ capability analysis is shown in Figure 10, which gives the results of measuring SPC 4 gap tolerance. The following key deductions were made from the outcomes:

- 0% of the samples fell outside of the lower and upper boundary conformance.
- The Ppk result indicated a measure of 1.62, which was less than the targeted 1.67.
- The process is expected to yield a 0% rejection rate against a target of 5%.

- For every million parts produced, only one part will be out of specification for SPC 4 gap measurement.

The BIQ approach indicated a greater degree of stability than the quality gates approach. The latter failed on two statistical specifications, while the BIQ approach indicated acceptable results for the same specifications. With the addition of BIQ SOP elements into the operations, the BIQ approach is more capable than the quality gates approach. The comparative analysis study indicated that the rear-step bumper line had to produce 0.01% more bumpers to offset scrap occurrences and meet the demands of the customer. The cost of the scrap was computed as:

Average scrap percentage (quality gates) x annual volume x bumper cost

= 0.01% x 120 000 x R2900 = R34 800

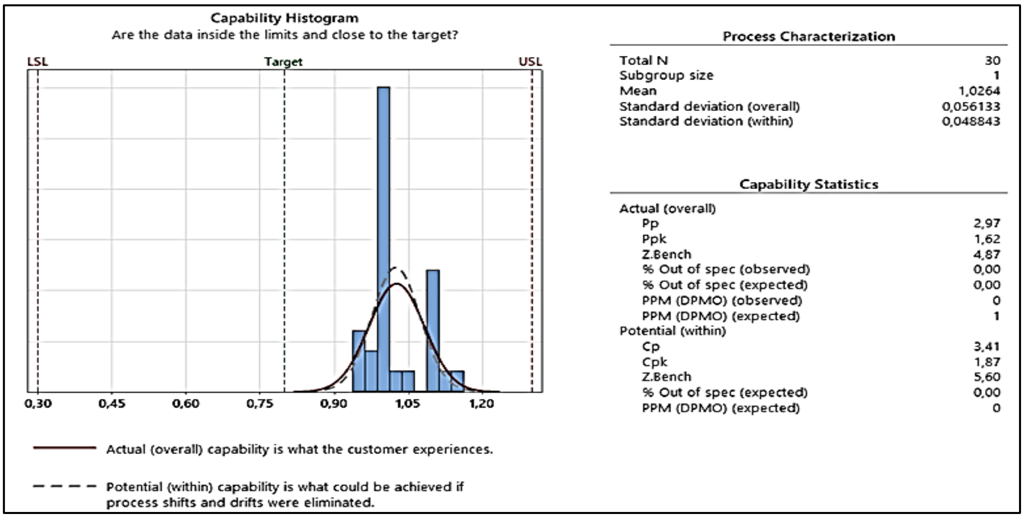

Figure 10: BIQ capability analysis – SPC 4 RSB

4.9. **Plan Do Check Act – Built-in quality** implementation

In line with the objective of developing a strategic approach to implementing BIQ, the key components of the building processes for BIQ needed to be evaluated from a planning, doing, checking, and actioning perspective. There was a need for the development of a strategic guideline for ACMs to implement BIQ in their manufacturing streams. It is important to highlight that BIQ starts at the design phase, where the quality management team specifies the quality objectives and sets the operational processes and resources to meet the quality objectives. As a continuous improvement initiative, Table 7 outlines the PDCA approach as a foundation for ACMs to implement BIQ.

Table 6: PDCA - BIQ implementation guide

PLAN
Step 1 - Define the scope of work
Step 2 - Develop the plan for BIQ implementation
Step 3 - Develop BIQ implementation team structure
Step 4 - Determine period of acceptable historical data
DO
Step 1 - Review process design - Ideal against current
Step 2 - Establish defects of high priority to narrow focus
Step 3 - Root-cause analysis
Step 4 - Conduct SOP analysis to identify gaps and opportunities
Step 5 - Revise SOPs or develop new operator check sheets to include Andon (line stop) systems
Step 6 - Review quality gates and process layout

Step 7 - Conduct re-distribution of elements to drive BIQ	
Step 8 - Conduct throughput impact on element distribution	
Step 9 - Identify opportunities for automation or pokayoke (fail-safe) systems	
Step 10 - Training execution	
CHECK	
Step 1 - Develop standards and cement the approach	
Step 2 - Compare improvement results	
ACT	
Step 1 - Monitoring and control	
Step 2 - Continuous improvement through standard work and repeating the loop	

5. DISCUSSION

Built-in quality is still relevant in this fourth industrial revolution era, in which high-quality standards and practices can be integrated into emerging technologies and processes. It is imperative that the ACM undergoes digital transformation and embraces technologies such as artificial intelligence (AI), the Internet of Things (IoT), and robotics to ensure successful implementation and operation [14]. Designing for quality should be embraced from the development phase, considering factors such as scalability, security, reliability, performance, fault tolerance, and redundancy planning. The ACM should also consider embracing digital twin technology so that it is able to simulate and optimise production processes, identify potential quality issues, and perform what-if scenarios to improve quality and efficiency.

Human–machine collaboration is also imperative during the fourth industrial revolution, and built-in quality could be enhanced by training and upskilling the workforce to collaborate effectively with AI-powered systems. The ACM could leverage advanced analytics and big data technologies to analyse vast amounts of prodution data. AI could enhance built-in quality by automating testing processes, predicting potential issues, monitoring systems in real time, detecting anomalies, and analysing user feedback – and it can offer intelligent assistance. The integration of IoT devices and sensors in automotive component manufacturing processes would enable real-time data collection and analysis, leading to enhanced quality management [15]. IoT devices could monitor various aspects of the production line, such as equipment performance, energy consumption, and environmental conditions, to identify potential quality issues. These capabilities wold enable the faster resolution of issues, improve system performance, enhance user satisfaction, and deliver overall higher built-in quality.

6. CONCLUSION

Transitioning from quality gates to BIQ comes with significant changes in manpower allocations that may raise industrial relations problems if not managed properly. The study recommends that the manpower that has been reduced on the lines be re-trained to fulfil other roles in the organization, as opposed to layoffs. The employment of quality gates has proven to be a vicious cycle for ACMs because that approach is set on catching defects rather than preventing their occurrence. The study recommends upskilling, development programmes, coaching, and capability building as the fundamentals that ACMs need to employ to drive BIQ effectively in their organisations. The results of the BIQ approach have proven to be effective in manufacturing processes that have already been implemented with quality gates. The BIQ principle presents vast opportunities for expanded research in the field of quality management; and a strategic approach to introducing manufacturing employees to new technologies to drive BIQ could be a topic of future exploration.

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