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Reducing the scrap rate in manufacturing SMEs through Lean Six Sigma methodology: an action research

ABSTRACT

The aim of this project was to investigate operational benefits of the Lean Six Sigma (LSS) methodology to reduce the scrap rate in the production line of a first tier supplier of automotive sector. This is an action research case study using LSS methodology in fully automated sub-process of the manufacturers. The implementation of LSS methodology had an effective and significant impact on the scrap rate reduction with increased First Run Yield (FRY) with significant financial impact at this scale. The research investigation needs to be fully controlled by the team in order to correctly gauge the effect of any changes made to the process. This action research can be replicated in other sub- processes of the production line and other processes of the company. This project addresses novelty about effectiveness of LSS methodology to reduce scrap rate and add value to automated processes in first-tier manufacturing SMEs supplying automotive sector. The project had greater saving than expected by the managers at £98k per annum. The approach of this research project combines proven statistical tools with some basic but effective lean tools to be applied in an original sequence in order to design robust product and match manufacturing capabilities.

Key Words – Lean Six Sigma, DMAIC, Manufacturing, SMEs, Waste Reduction, Scrap Rate

Article Classification:

Focus on practice

1. Introduction

Process improvement and operational cost reduction through quality improvement practices has been at the centre of attention for many businesses in different sizes and in a variety of sectors to gain a more competitive advantage. Lean Six Sigma (LSS) is an effective and

disciplined business transformation strategy and problem solving tool that has evolved through combination of Lean and Six Sigma. Both of these practices were recognised as leading Quality Management (QM) practices for performance improvement in organisations with a proper infrastructure built on leadership and change culture [1-11]. LSS has ability to foster process incremental and breakthrough innovation through its problem solving and continuous improvement approach [12]. The effective top-down methodology of LSS in both manufacturing and service Small to Medium – Sized Enterprises (SMEs) has been acknowledged by researchers and practitioners [13-17]. In fact, there have been many research studies available in relation to Six Sigma implementation in manufacturing SMEs with the focus on improving the quality of the product, customer satisfaction and financial enhancement [18-22]. The term SME for the purposes of this study uses the EU definition of any organisation with less than 250 employees [23]. The SMEs constitute the major economy and employment contributor and with the beginning of the new millennium, the degree of productivity demonstrated by SMEs will be vital to a continued economic surge [24].

However, despite of growing number of research studies and case studies in manufacturing SMEs, the LSS research and application with the purpose of waste reduction would need further attention by both researchers and SME practitioners [2, 25-27]. In particular, current research studies highlighted the scarce of action research in the format of LSS case studies to identify elements of waste in manufacturing SMEs and clear presentation of tangible outcomes such as financial benefits [24, 26-27]. This highlights the significant gap in both practice and research. Therefore, it was decided to focus on the integration of LSS implementation, SMEs and scrap rate reduction to present tangible benefits via case study.

The purpose of this project was to reduce the level of scrap rate in the sub-process of a vision inspection system as part of the fully automated process of “Overmould Line”. Although the company is practicing LSS as part of company establishment, this problem has been prioritised

at this stage due to being considered as a key measure for waste and cost reduction through LSS methodology. This problem may also be more serious in upcoming years due to expansion plans. This production line is used to produce a product known as the “Remote Acceleration Sensor (RAS)” that is used for air bags. The role of the vision inspection system (Figure 1) in the Overmould Line is to determine whether the dimensions of the pins inserted in the board are to the customers’ specifications before the unit is injection moulded.



Figure 1 – Vision Inspection Process

2. LSS in manufacturing SMEs

LSS research is growing rapidly, covering various disciplines and domains with a great focus on LSS tools and techniques. More emphasis on case study approach and growing gap between manufacturing- and service-focused articles imply return of LSS to manufacturing as its initial base [28]. LSS has evolved through the combination of Lean and Six Sigma, both recognised as leading QM tools for performance improvement in organisations [2-6,10, 29-30]. LSS is now regarded as one of the most effective and disciplined business transformation initiatives available in strategic operations management as well as an effective top-down methodology for improving quality in both the manufacturing and service SMEs and their larger counterparts [13-17,31-33]. The research findings have already recognised that the LSS framework has been

successfully implemented in automotive component manufacturing organizations and their supply chain, and non-value-adding activities and defects from assembly line have been reduced [34].

LSS is an appropriate approach in managing waste and variability to keep the operating expenditures to the minimum in synergy with other manufacturing dimensions such as consistent quality and high performance products [31,35-36]. It has been emphasised by researchers that focusing on low hanging fruits will have the best and most productive results in any LSS project [2,6], which perhaps could even be more appropriate for the SMEs due to being more restricted in resource availability. Although it has been suggested that LSS could be deployed in SMEs similar to their larger counterparts with consideration of specific resource management [22], it has also been argued that its application for SMEs could be considered in a different perspective [22,37]. This could be extended to different scales in financial gains.

LSS has been strongly suggested by a longitudinal study to promote a sustainable process improvement in manufacturing organisations including SMEs [5,22,32,38-39]. At an operational level within the manufacturing sector, the LSS model aims to clarify the process of identifying opportunities for non-value added activities, as well as reduce variability and improve the process cycle time and quality of the manufacturing process [25,40-44]. This will result in some strategic benefits such as customer satisfaction, financial enhancement, higher productivity and satisfaction of employees, and more efficiency in manufacturing processes [12,27,45-50]. Despite all of these benefits, “internal resistance”, “the availability of resources”, “changing business focus”, and “lack of leadership” have been suggested as the greatest impediments to implement LSS in any manufacturing SME [51].

Scrap rate is one of the common elements of the cost of poor quality, which may appear as the result of high defect and variability level in any manufacturing process. Scrap rate could potentially have negative impact on increasing the process cycle time and therefore generating

extra cost and uncertainty to supply the products [52]. It was evident from recent research studies that despite clear potential significant impact, LSS deployment in the automotive sector to reduce scrap rate suffers with neglect in both practice and research [53]. By utilising the LSS five-phased systematic methodology of DMAIC (Define, Measure, Analysis, Improve, Control) manufacturing SMEs can tackle any process variation and defect including scrap level [31,49,53-56]. This standard improvement model is extremely helpful for any organisation because of providing a systematic road map [5]. Nevertheless, it was argued that DMAIC is suitable for rather extensive problem solving tasks, requiring all of the components of problem definition, diagnosis and the design of remedies [33]. It was also highlighted that there are risks involved in this methodology deployment and sustainment in the project management perspective that need to be addressed [57]. In the light of above discussion, it was decided to investigate the extent of operational and strategic benefits of scrap rate reduction in a first-tier supplier of automotive sector. Therefore, this research question has been raised:

What are the operational and financial benefits of deploying LSS DMAIC methodology in a fully automated process of a manufacturing SME supplying automotive sector?

The next section presents the case study and methodology of this research project. A current qualitative research finding revealed that different levels of engagement of stakeholders in relation to informing, involving and influencing are required at different phases of DMAIC projects, and communication plays a big role [1].

3. Case Study and Research Methodology

Prior to discussing the research methodology and case study, it is crucial to leverage the LSS project with organisational structure and culture to strengthen the success rate of the project. Therefore, the critical success factors (CSFs) of any LSS project in organisations including SMEs are reminded here. Top Management Commitment, project selection, leadership,

continuous training, cultural change and a systematic road map have been recommended as CSFs for implementing LSS in any organisation [6,19,23,58-59]. Despite great deal of variation in introducing different CSFs for LSS implementation depending upon the size, type and region of organisations, top management commitment was almost unanimously suggested by scholars as the most crucial readiness factor for providing required resources, promoting and qualification polices, and a successful LSS implementation [6,19,58,60-61]. Nevertheless, a conceptual prioritisation analysis of many different LSS research articles revealed “Training” as the most referred success factors for LSS implementation in SMEs [24]. This is astonishing, since training cannot be fully accomplished without top management commitment.

The client is a first tier automotive supplier who specialises in sensor and safety electronics and has already been implementing some LSS projects. The company has hired one Black Belt (BB) with few Green Belts (GB) and this project has been conducted by a GB with the supervision of the BB. The managing director of the company has the power of approval and project tollgate review as the Champion. The approach taken to complete the scrap reduction of the Overmould line was that of inductive case study and action research. Action Research is viewed as a research strategy in which the researcher is working collaboratively with practitioners and directly involved in the organisational change [62,63]. We believe this could be the best possible research methodology for this study, since a production failure as a contemporary phenomenon will be investigated in a real life context. The data collection and data analysis methods of this study are in accordance with the LSS methodology of DMAIC. Throughout the use of Six Sigma in the literature there is a recurrence which is the use of the Minitab software [60,64-68]. Minitab is a statistical software package that enables the users to easily implement a statistical method with the data collected [64]. Minitab allows the use of any tool in the Six Sigma tool box from statistical tools such as hypothesis testing to softer

tools such as Cause and Effects diagrams. The next section presents the phases of this methodology that has been applied as part of a LSS project.

4. Case Study Analysis through LSS DMAIC Methodology

Define

Scrap reduction has been part of the corporate standard for quality for the client. The Overmould line scrap, which contributed to 18% of the total scrap level in the factory corresponding the cost of £130K within the course of three months investigation, has been nominated as a priority for the next LSS project. In order to reduce the scrap produced by the Overmould line, a cross functional team was assembled, which included a quality engineer (Green Belt), a manufacturing engineer, production staff, a Black Belt and a senior manager who acted as the sponsor of the project. Having developed a project charter, the project goal was established to reduce the level of scrap produced on the Overmould line from the current value of 3.52% of its own product sales down to 1.5% representing the FRY improvement from 98.4% to 99%. The customer need was identified as the “producing parts within specification” and the Critical-to-Quality (CTQ) measure that is a quantifiable metric of customer need was identified in the project charter as “correct dimensions”. The CTQ tree was depicted in figure 2. The SIPOC diagram (figure 3) that is a high level process map was created by brainstorming session to review the relationship between process, suppliers and customers [69].

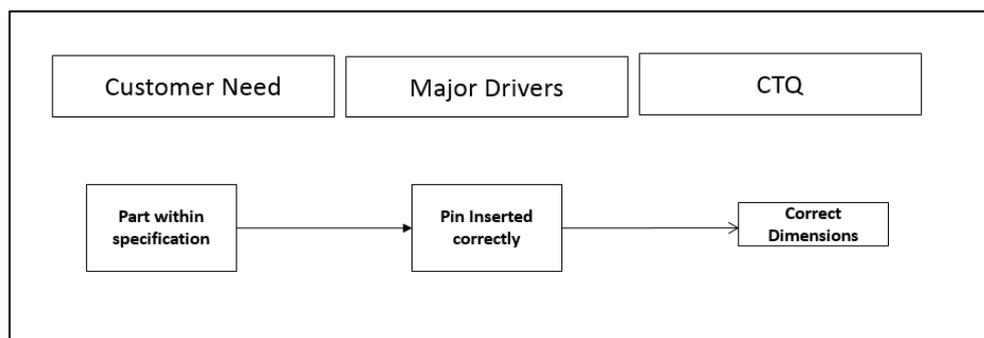


Figure 2- CTQ Tree

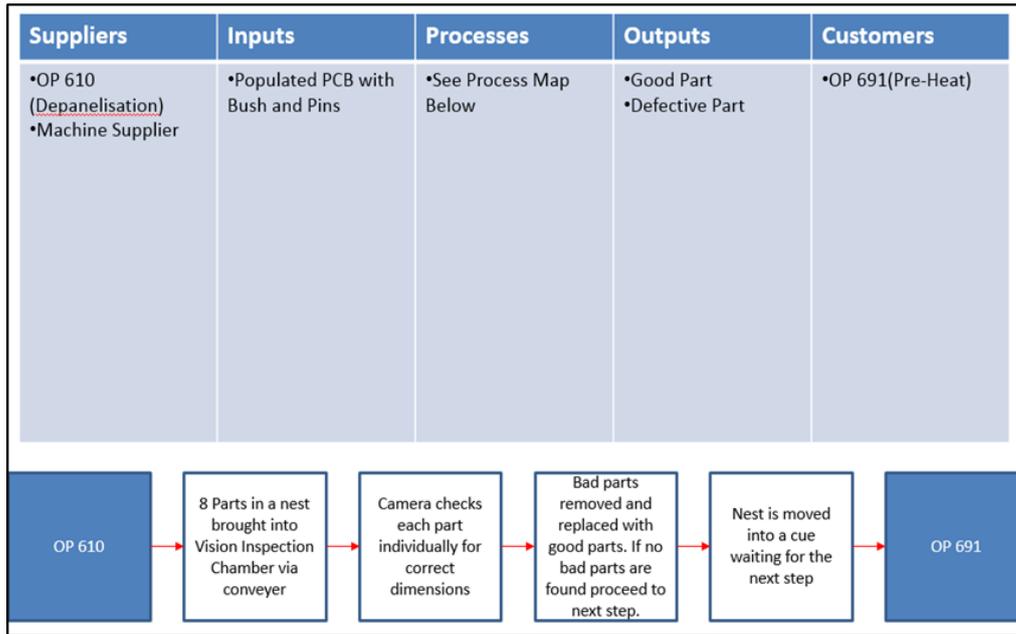


Figure 3 – SIPOC Diagram

A closer look at the data for the Overmould line through Pareto Analysis identified four main sub-processes contributing to the level of scrap (figure 4). The problem of the first stage Overmould process and its solution were already known by the process engineer and steps had been taken to resolve this. Therefore the second problem sub process was taken on, which was the vision inspection system.

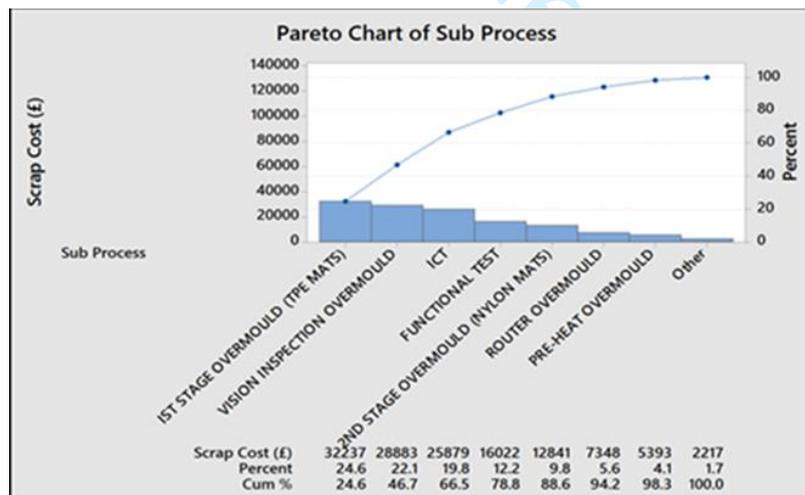


Figure 4 - Overmould Sub Processes Scrap cost Pareto Chart

The vision inspection system ensures that the part is compliant to the customer's specification by measuring seven different characteristics of the Printed Circuit Board (PCB) at that point in time. The tools used to fully outline the project to be completed were: High Level Process Map (Appendix A), and a Project Charter (Appendix B).

Measure

The system's ability to be measured has been approved through Measurement System Analysis (MSA). The baseline performance of the line was determined through the FRY data collected over the three months prior to the start of the project. The control chart in Figure 5 represents the average 98.4% FRY resulting in a sigma score of 3.65. The vision inspection system uses seven different parameters to determine whether the part is within specifications. When generating the process capability for the system, each of the seven parameters was treated individually with the results displayed in Table 1. The Normal Distribution for Parameter 2 has been provided in Appendix C as the sample.

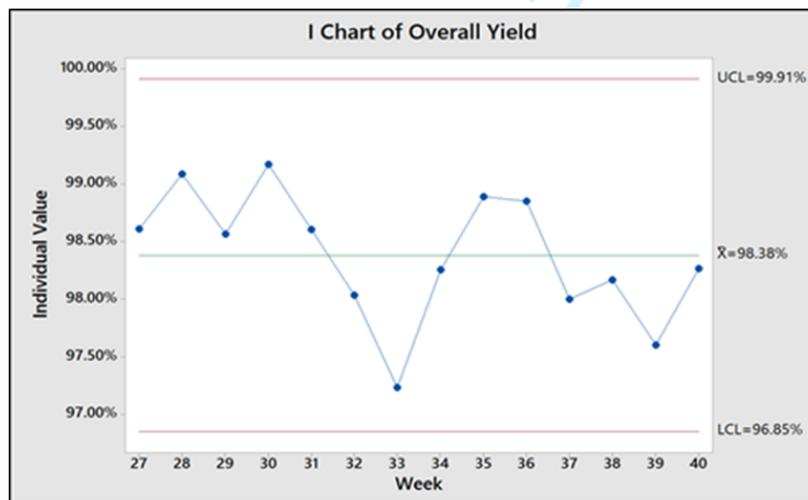


Figure 5– Baseline Performance Control Chart

Table 1 – Process Capability (Cpk) for all 7 parameter

Parameter	Specification	Process Capability/Cpk
1- Long to short pin (Vertical)	4mm \pm 0.5mm	1.62
2- Bottom of PCB to long pin	11.1mm \pm 0.5mm	0.8
3- Left right offset long	0mm \pm 0.6mm	0.88
4- Left right offset short	0mm \pm 0.6mm	1.63
5- Horizontal distance between pins	0mm \pm 0.6mm	2.08
6- angle between PCB border and pin	90 degrees \pm 3 degrees	1.66
7- long to short pin (Horizontal)	0mm \pm 0.8mm	0.32

Analysis

To start the analyse stage, a brainstorming session was held in order to identify the potential issues with Vision Inspection. The personnel involved with the brainstorming session were the Six Sigma team and the line operators. The results of the brainstorming session were displayed as a Root Cause and Effects Analysis diagram (Figure 6).

Root Cause and Effect Analysis is one of the most useful themes being used by practitioners around the globe and is continually being developed by the researchers and practitioners that can be bifurcated into two broad categories identification of the potential causes and validation to root cause [48]. The validity of these ideas was determined by the analysis of the data identified in the data collection plan. The review of process capability analysis revealed that parameters 2, 3 and 7 have Cpk of 0.8, 0.88 and 0.32 respectively. These values are much less than those expected for a capable line, which would be in the region of 1.33 by the Company's standard.

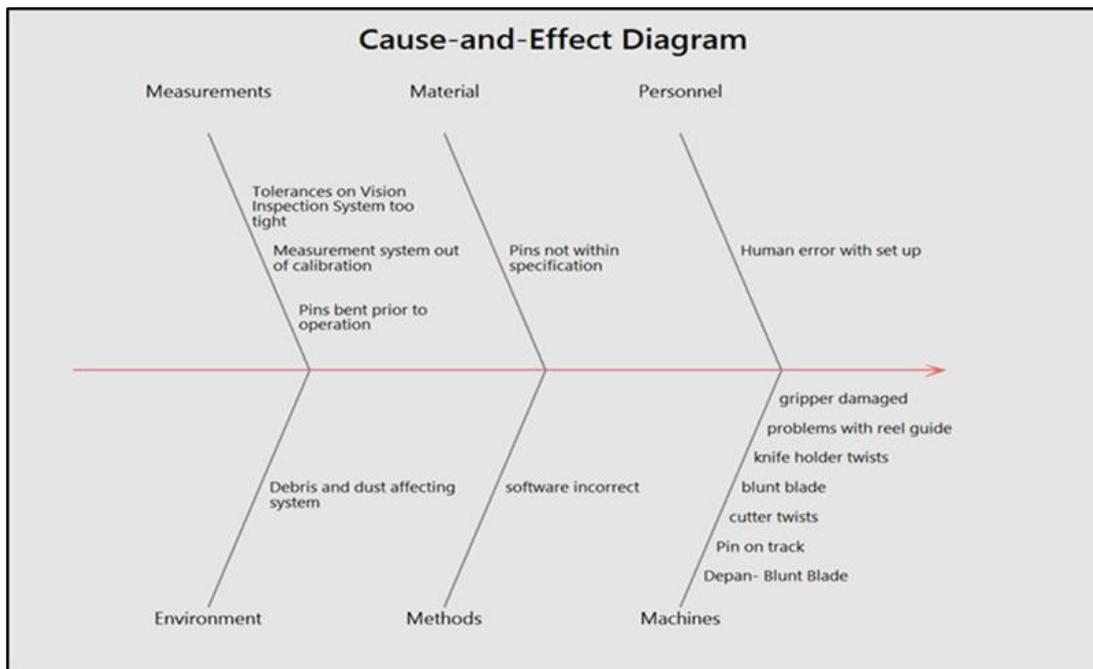


Figure 6– cause and Effect Diagram

A Gemba investigation has been set up in the production line and the first problem that has been identified was related to the cleanliness of the Vision Inspection system. A Gemba or Gemba Kaizen is a method which is meant to be a technique of line inspection in which obvious problems are able to be rectified in a short period of time [70,71]. The brighter parts identified by the circle in pictures taken by the camera (figure 7) show debris on the nest which can lead to an incorrect measurement of the thickness of the pins as the system will take the debris as the datum point rather than the edge of the pin. It was revealed that debris have been coming from previous process (De-panelisation).

The second problem was identified as the variation in programme set for the vision inspection system for different customers, despite of measurement against the same specification. This will result in slight shift of the measurement and also changeover time between different customer parts. The final note that has been taken as the result of Gemba investigation was related to the tight clamp on the first moulding cell, which will tighten the tolerance compared to customer specification (figure 8).

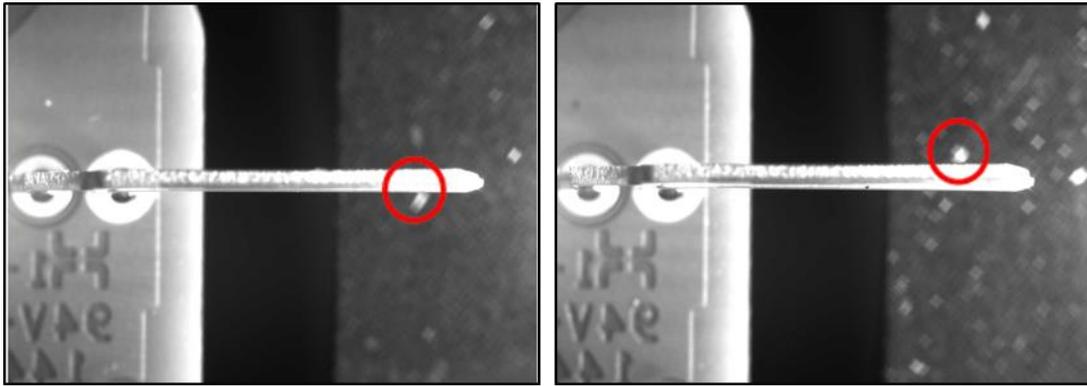


Figure 7– camera view of the debris on the nest



Figure 8 – First Moulding Pin Clamping Mechanism

Through a metrological analysis, the dimensional testing of 30 scrapped parts as samples against the engineering drawing by the use of a Co-ordinate Measuring Machine (CMM) confirmed that all parts were genuinely failed. In order to identify whether there is an issue with a particular gripper or PCB in the panel, an analysis of the failure rate to PCB slot position was conducted. This involved taking the scrap data from a 24 hour period worth of Vision Inspection failures (136 parts) and marking what their place was in the panel. The data was then placed in a Pareto chart (figure 9) to see whether there was a correlation between the two. This analysis shows that there is no particular slot positions with significant more counts of failure associated to them compared to other slots. Therefore, particular slot investigation was ruled out.

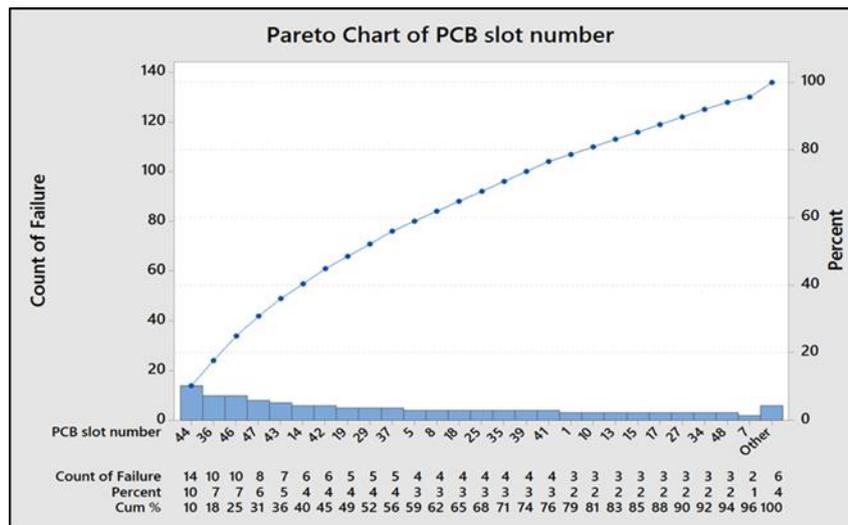


Figure 9 – Slot Position Vs failure count Pareto Chart

Improve

The objective of the “improve” phase is to generate a set of solutions for the issues identified previously and determine which of the solutions would be the best. The Analysis phase uncovered three issues as dust and debris on the PCB nests, the too tight tolerances and multiple Vision Inspection programmes. In order to generate a set of solutions for these problems a brainstorming session was conducted. The solution for debris on the nest has been agreed as having regular cleaning procedure for De-panelisation process in 8 hours intervals and also treating the Vision Inspection cell with Ioniser regularly to reduce the static electricity and remove the debris on the nest. An experiment was conducted with two different sets of tolerances as two trials setting applied to the Vision Inspection process of the first stage Overmould and Pin check (Table 2).

The first of tolerances includes an increase in the three parameters shown to be below the expected level of process capability while the second also increased the parameter relating to the angle of the pin in relation to the PCB. The DoE was not feasible at this stage due to time constraints limited to 4 hours to complete the trail to prevent any interfere and also nature of improvement strategies that would have minimum interactions with each other.

Table 2 – Trial Setting

Parameter Set	Parameter 2	Parameter 3	Parameter 6	Parameter 7
Standard Settings	11mm \pm 0.5	0 mm \pm 0.6	90° \pm 3	0 + 0.8
Trial 1	11 mm \pm 0.7	0 mm \pm 0.8	90° \pm 3	0 + 1.2
Trial 2	11 mm \pm 0.7	0 mm \pm 0.8	90° \pm 5	0 + 1.2

The results of the experiment revealed that both trial settings improve the process capabilities of the parameters examined with no failures at either the first stage Overmould or at Pin check (Table 3). To re-iterate the result, the Normal Distribution for Parameter 2 after the improvement has been provided in Appendix D to visualise the difference in productivity and process performance before and after the improvement.

Table 3- Trial Settings Cpk

Settings	Parameter 2	Parameter 3	Parameter 6	Parameter 7
Standard	0.8	0.88	1.66	0.32
Trial 1	1.51	1.59	1.87	2.27
Trial 2	1.58	1.78	4.61	2.19

A generic programme was developed and implemented two weeks after new settings for the system. The result presented in figure 10 shows the increase in yield from 98.81% to 99.03%, as the result of this generic programme meeting the target set out at the start of the project. It took the technicians four weeks to be able to find optimum programme and the best possible result.

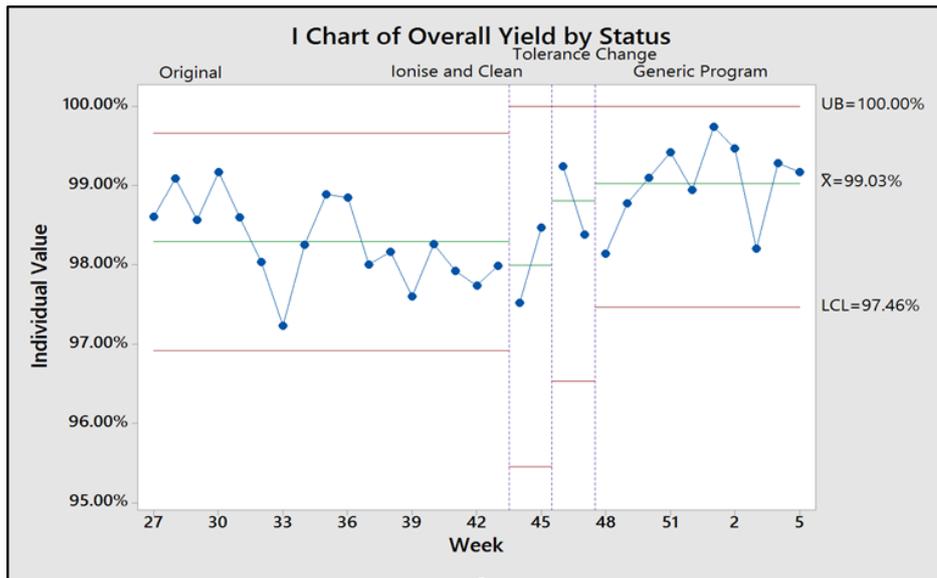


Figure 10 - Generic Vision Inspection Program Control Chart

Control

In order to control the process and retain the improvement in the FRY the clients' Failure Mode and Effect Analysis (FMEA) and control plans were updated with the changes made to the process. In addition to the FMEA and Control Plan, the control chart that was used through the previous four phases of DMAIC to identify the process performance has been upheld in order to be able to quickly identify any problems with the process.

5. Discussion and Conclusion Remarks

The main motivation behind using LSS methodology in this project was the existing LSS culture in the Company and also validity of the DMAIC methodology to reduce the variation and therefore scrap rate in the production line. The objective of the project has been attained, since the Vision Inspection process achieved an improvement in FRY from 98.3% to 99.03%, which exceeded the management target and represents sigma score from 3.65 to 3.85. Despite of small increase in the sigma value, the improvement of the FRY leads to a saving to the client of £98k annually, which was reported significant improvement by the management team in the company in this scale. The result of the project has been approved and was subjected to tollgate

review by the project Champion. The result of this project could also be even more significant for the management team who have been planning to expand the production line, and any process improvement in any scale would be critical for the managers. The saving could be greater in the future as the result of a possible plant expansion. The case study adds further evidence to the effectiveness of the LSS methodology in relation to waste reduction and cost saving in the manufacturing industry and in particular the electronics and automotive sections. This small but significant improvement in FRY within this process demonstrates a success story of LSS implementation. The LSS methodology of DMAIC can be replicated in other processes in this manufacturing SME with existing LSS infra-structure, capability and resources. This will significantly impact on the operation and satisfaction of their customers in their supply chain downstream that includes large car manufacturers due to the less chance of product failure, less non-adding value excessive over-processing (i.e. dealing with scrap rates), less interruption and reduced lead time in the supply chain.

The analysis of the potential increments of identified factors would have not been completed due to the lack of a Design of Experiment (DoE). Therefore the Cpk for all trials and FRY may have had slightly different results compared to when the DoE is used, which is recommended to be considered in the future work. There could also be a possibility of skewness in the improve phase due to possible regular alteration of settings by the Overmould technicians without any record. In addition to this, the LSS implementation in this Company could be extended to other processes rather than just design and production to be fully controlled by the team in order to correctly gauge the effect of any changes made to the process. It is also recommended that the project could be extended to other issues in the Overmould process that were identified in the Define stage as major contributors to the scrap level experienced.

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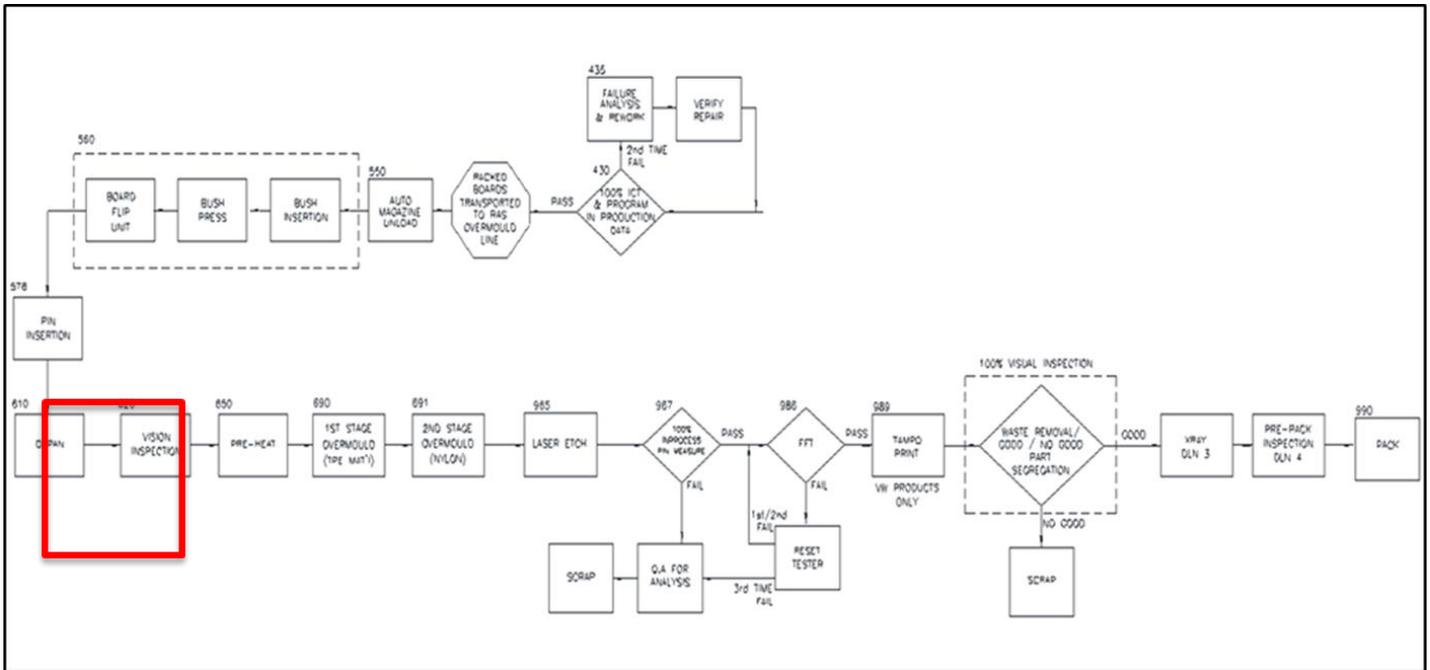
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Appendices

Appendix A



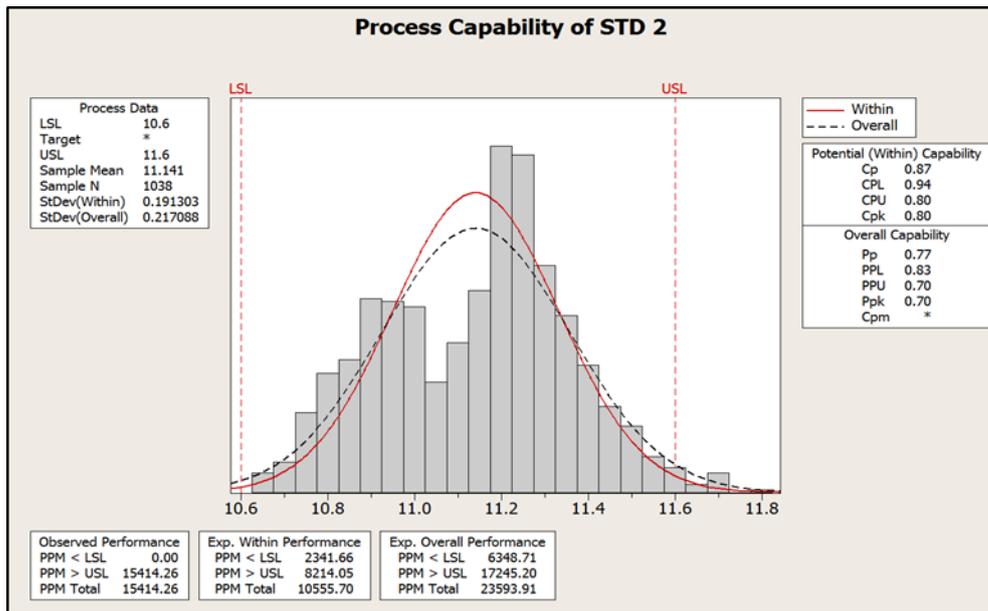
High Level Process Map

Appendix B

Project Details					
Scope	Start: Stop: Includes: Excludes:	OP 620 OP620 All Overmould Products Other Products			
Project Goals	Metric	Baseline	Current	Goal	Entitlement
FRY	%	98.4%	98.4%	99%	0
Process Sigma Score/ DPMO	Values	3.65/ 15884	3.65/ 15884	3.85/9461	0
Expected Business Results	Increased FRY, reduction in scrap.				
Expected Customer Benefits	Improved throughput				
Team members	Gareth Bradley Black Belt 2x Green Belt 1x Business Unit Leader 1x Process Owner				
Support Required	Engineering Department (RAS/DAS) Production				
Risks or Constraints	Line Time, Support from other departments.				

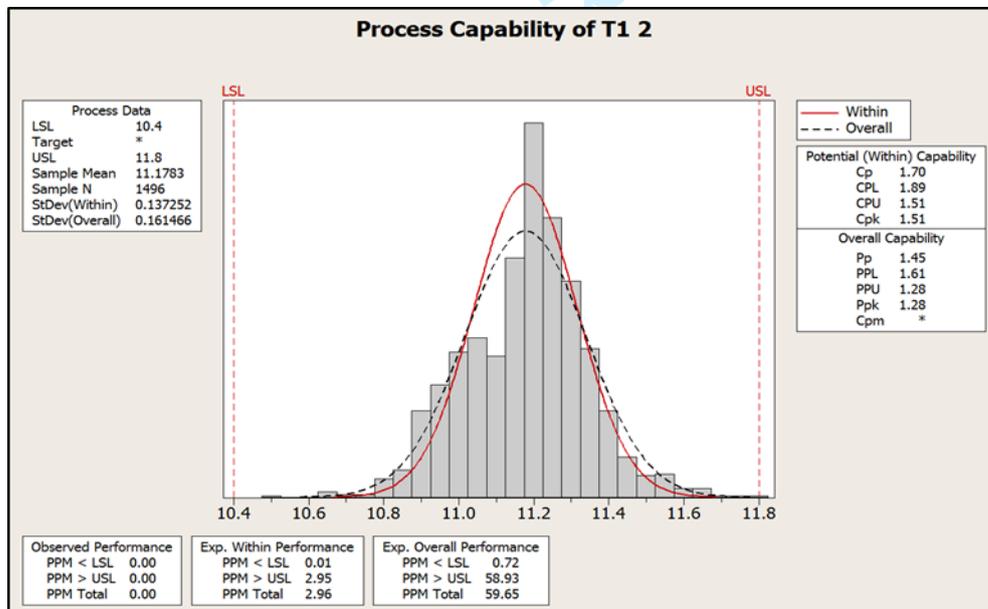
Project Charter Details

Appendix C



Parameter 2 Process Capability Normal Distribution

Appendix D



Trial 1 Parameter 2 Process Capability Normal Distribution