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A Framework for Six-Sigma Implementation in Rubber Manufacturing Industry – An Innovation between DMAIC Cycle and Quality Improvement Tools

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ABSTRACT

Quality improvement tools are commonly utilised by the industries to attain quality products and benefits like reduction in scrap cost and wastes. In order to achieve the proper implementation of quality tools, a theoretically developed framework inclusive of six-sigma DMAIC (Define, Measure, Analyse, Improve & Control) cycle is required. Also, the quality tools associated at each stage has thoroughly implemented on a case study which carries a real-time issue related to the quality products production. The issue has thoroughly resolved through the right application of quality tools like Failure Modes and effects analysis (FMEA) on the compression moulding technique utilised for the production of Rubber Valve Sleeve Liner (RVSL) under the umbrella of DMAIC cycle. The benefits achieved are 23.1% reduction in scrap rate, 63.8% reduction in Delivery on time (DOT) with savings gained almost RM26,880/month. The relationship between DMAIC cycle and quality tools for quality improvements under the platform of lean six sigma which is highly beneficial for academicians, practitioners and engineering managers working in this field with a limitation of implementation only in the rubber manufacturing industry. In future, the developed framework should be implemented in some other manufacturing industries.

Keywords: Lean Six Sigma; Rubber Manufacturing; DMAIC Cycle; Quality Improvement

INTRODUCTION

DMAIC stands for Define, Measure, Analyse, Improve, and Control. It is a sequential five-stage improvement cycle under six-sigma which is a measure of quality by striving towards the six standard deviations between the mean and the nearest specification limit in any process, and in order to achieve six sigma level, a process must not produce more than 3.4 defects per million opportunities (Lee & Ben-Natan 2002), in other words, a six sigma defect is defined as anything outside of customer specifications. There are series of quality tools and methods which six-sigma could offer under each of the DMAIC stages. When, Jirasukprasert et al. (2012) has presented a case study to reduce the defects in rubber gloves manufacturing process and utilised DMAIC and quality tools for each stage of the improvement cycle. But, it has been observed that there are series of quality problems or failure modes associated with the rubber compression moulding technique in rubber industry that requires the application of proper quality tools and also requires a proper conceptual framework for implementation.

Since, when Rafique et al. (2017) in their research study have introduced that the concept of utilising and interrelating two different parameters on one platform in their framework to attain successful implementation of lean through reducing barriers affecting lean (Rafique et al. 2016), then this concept of interrelation between two different aspects on one platform seems feasible. Moreover, in previous researches of Kumar et al. (2006), Vinodh et al. (2011) and Swarnakar et al. (2016), a trend of development of conceptual framework has been observed and following this trend the major aim and objective of this research study is the formation of conceptual framework in which an interrelationship between the DMAIC and quality tools has been achieved on one platform and its development will managed through its actual implementation on a case study in one of the rubber manufacturing industry, which is facing a series of quality problems regarding its compression moulding technique and requires urgent fixing. Therefore, in order to achieve this task regarding the development and implementation, the remainder of paper is structured as follows. Section 2 will explain about the previous literature, section 3 constitutes of the adopted methodology, section 4 discusses about the results and section 5 concludes the research with the explanation of limitation in Section 6.

LITERATURE REVIEW

LEAN SIX SIGMA AND QUALITY TOOLS

Six-sigma is because it is a proven methodology for business and organisation to improve their performance through having a sustainable programme to deliver continuous business benefits and value creation (Sujova et al. 2016). DMAIC (Define, Measure, Analyse, Improve and Control) is a sequential five-stage improvement cycle under six-sigma. The following is the details explanation for each of the DMAIC phases. As mentioned earlier, Jirasukprasert et al. (2012) has presented a case study to reduce the defects in rubber gloves manufacturing process and utilised DMAIC quality tools and methods for each stage of the improvement cycle. In the Define stage, Jirasukprasert et al. (2012) uses voice of customers (VOC) in order to understand and prioritise the customer's needs. Other quality tools which can be used are process mapping, SIPOC (Supplier, Input, Process, Output & Customer) chart, trend chart, root cause analysis, pareto analysis, business metrics, and critical to quality (CTQ) mapping (Chauhan & Belokar 2015). The outcome for this phase was the form a project charter that shows a complete project programme showing the cross-function project team formation, milestones, goals, target and project scope. The next stage of DMAIC is Measure. Jirasukprasert et al. (2012) utilised data collection sheets to collect the defect data efficiently that later will be analysed using the Pareto chart to determine the utmost occurring defects. The purpose of the second phase is to establish baseline performance through getting as much information as possible on the current process to fully understand both how it works and how well it works. The quality tools which can be used to achieve the purpose are check sheet for data collection, fishbone diagram and cause & effect (C&E) matrix to identify potential causes of problem, relation diagram, descriptive statistics like the use of histogram, affinity diagram, relations diagram, tree diagram, matrix diagram and even control charts like X-bar R chart to understand the process performance. The outcomes from this phase would be a list of potential causes which are called the potential X's which might have impacted the problem or called the 'Y' which helps to prioritise the most critical problem that is required in the next stage of DMAIC that is Analyse.

In the Analyse stage, the potential root causes will be identified. Ng et al. (2013) in a case study about reducing defects in the rubber latex dipping production have used fishbone diagram to reach the root causes of the quality problems. The fishbone diagram consists of five elements which are man, machine, material, method and measurement. The purpose of Analyse Phase is to identify potential root causes for the process problem and confirms about actual root causes with data. The quality tools associated with this Analyse Phase are Pareto chart, boxplot chart, histogram, hypothesis testing, relation diagram, linear regression and matrix data analysis diagram. The outcome from this phase would be the statistically validated root causes that are very important moving into the Improve Phase. The next stage of DMAIC is Improve that is to identify solutions to the problem. These tools or methods would be in use like brainstorming potential solutions, developing a countermeasure plan, developing the design of experiment (DOE) and developing pilot plan so that the selected solutions can be put to test and evaluating the results of the implemented solutions (Saad A & Javed 2015). The purpose of the Improve Phase is to identify solutions to the problem that the project aims to resolve. The quality tools which can be used are process decision programme chart (PDPC), brainstorming potential solutions, developing a countermeasure plan, developing the design of experiment (DOE) and developing verification plan and pilot plan so that the selected solutions can be put to test and evaluating the results of the implemented solutions. The outcome from this phase would be, for example the proposed solutions, proposed process parameter setting, pilot solutions, cost benefits analysis, and statistically validated results.

The last stage of DMAIC is Control that is to sustain the gains from the improvements, these quality tools and methods will be in use such as error proofing system, control chart, and visual display or controls (Idris 2015). Six sigma DMAIC is a problem solving method commonly used by the industries including the rubber manufacturing companies as the method has series of quality tools and techniques associated with each DMAIC stages to improve the processes which would deliver business benefits, for instance in reducing the defects and scrap costs. The purpose of the Control Phase is to make sure that the action item created in the Improve phase is well implemented and maintained hence the benefits can be sustained. The quality tools that can used are control chart to monitor and ensure variables are within the set limits. The outcome from this phase would be the creating or revision of the control plan, revision on the FMEA, creation of new SOP, update of existing SOP and training plan.

RESEARCH PROBLEMS IN RUBBER MANUFACTURING INDUSTRY

Compression moulding is basically a method of moulding in which the uncured rubber is loaded into an open, heated mould cavity and then the mould is closed, with certain pressure is applied to force the rubber into contact with all mould areas, while the heat and pressure are maintained until the rubber has cured following its curing time (Warrier 2015). There are series of quality problems or failure modes associated with the rubber compression moulding technique that require the application of quality tools like Failure Modes and effects analysis (FMEA) and methods like to address them. Some examples of the quality problems according to Walker (2017), could be in the form of over-curing of rubber compound that is due to excessive heat or time applied onto the rubber whilst being cured, excessive shrinkage which could adversely impact the rubber profile shape and dimensional measurement outcome, and poor storage and handling which could have a permanent deformation on the cured rubber profile. There is no "cure-all" for eliminating compression moulding quality problems. The most important thing is to make some reasonable adjustments, observe the results, determine the changes and keep tracks the responses by comparing the parts from before and after adjustment to determine if the effect is effective in addressing the quality problem (Plenco 2015). In attempting to resolve the compression moulding quality problem, a structured approach is taken that is DMAIC which is one of the several techniques used by the industries to improve wastes, defects, and quality problems (Sehgal & Kaushish 2013).

As mentioned earlier, Jirasukprasert et al. (2012) has presented a case study to reduce the defects in rubber gloves manufacturing process and utilised DMAIC and quality tools for each stage of the improvement cycle but lacks to provide proper framework for implementation of quality tools with DMAIC cycle and to understand the interrelation between them. In the previous researches of Kumar et al. (2006), Vinodh et al. (2011) and Swarnakar et al. (2016), have utilised conceptual framework for lean six sigma implementation. Rafique et al. (2017) in their research study have utilised the concept of interrelation between two different parameters on one platform in their framework. As it has been observed that there are series of quality problems or failure modes associated with the compression moulding technique of rubber manufacturing industry that require the application of quality tools and methods to address them (Jirasukprasert et al. 2012).

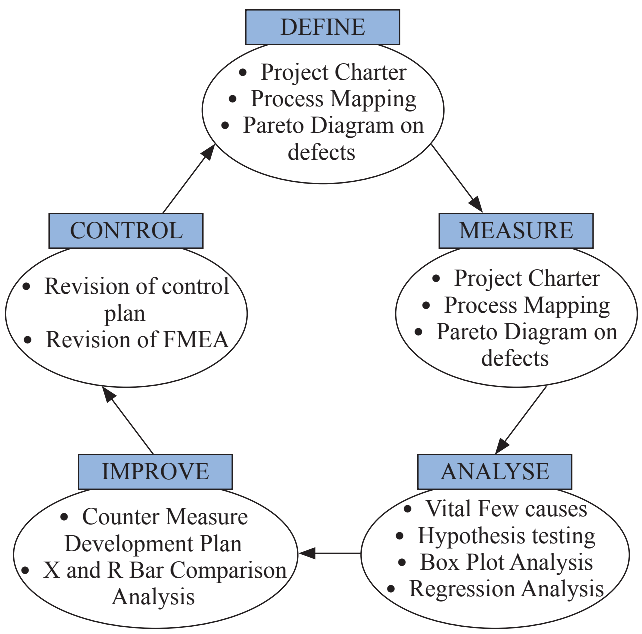

FIGURE 1. Proposed Conceptual Framework (Author Own Work)

So, in order to solve this (based on the discussion in Section 2.1) there are series of quality tools which six-sigma could offer under each of the DMAIC stages and the authors have designed a conceptual framework as mentioned in Figure 1 by utilising previous researches (Jirasukprasert et al. 2012, Sehgal & Kaushish 2013) which will be further implemented on the case study for development and validation by selecting one of the rubber manufacturing Industry.

METHODOLOGY

Case study is the organisation or company background for which the quality tools & methods application implemented and analysed (Rafique 2017; Sabbagh et al. 2016; Yin 2013; Rafique et al. 2017; Abdulmalek & Rajgopal 2007). The company is ABC manufacturers that is located at Bate Caves, Selangor. The company is indeed having a good business system and having certification in ISO 9001, OSHAS 18001, ISO 14001, PED 97/23/EC. The key business is the design and manufacture of natural rubber sheets of 9.25 meters long and 1.23 meters wide and of different thicknesses depending on the customers' demands. The main use of the rubber sheet is as the lining material in the mining industries processing equipment, for example for chute lining, tank lining and dewatering pipe lining which make the processing equipment last longer. The rubber sheets are being consumed by mines around the world like those at gold and platinum mines in Australia, South Africa and Europe. Besides the natural rubber sheets, the company as well designs and manufactures the synthetic type rubber sheets to cater the customer's needs.

Other key businesses by the company are the manufacture of engineering rubber moulded products, for instance Rubber Valve Sleeve Liner (RVSL) which used as the key product in the quality tools & methods implementation programme as explained in this assignment. The RVSL either assembled into a valve body and sold as a complete valve or just sold as spares depending on the customer's demands. As of May 2017, the total employees were 350. The business is headed by the Managing Director (MD) and supported by the leadership team, which form the top management. Each business function is led by a member of the top management and supported by the departmental managers, executives, officers, and team leaders. Most of the general workers at the departments are local.

ISSUE OF CURRENT CONDITION

There are various types of rubber-moulded products being produced by the company and after reviewing the average monthly for the past 6 months of production performance in term of the scrap cost and delivery on time (DOT), the Rubber Valve Sleeve Liner (RVSL) is having the highest scrap cost (RM26880) and lowest monthly DOT (34%). Having high scrap cost will definitely be adversely influencing the company business performance, for instance unable to deliver the product on time due to high delivery lead-time because of high reject rate. This condition has created a major concern to the company hence a systematic structured approach of quality improvement methodology with associated quality tools and methods are in need to address the Rubber Valve Sleeve Liner quality problem. The problem solving methodology adopted to resolve the quality issues is six-sigma that has 5 phases called DMAIC as illustrated in Figure 1. In define phase the first thing is to understand the quality problem in details of RSVL that at first requires the study of operations through the process mapping.

RUBBER VALVE SLEEVE LINER (RVSL) MANUFACTURING PROCESS MAPPING

The RVSL manufacturing process mapping is shown in Figure 2 below. The quality status of the RVSL determined during the inspection processes that cover the dimensional measurement, visual quality inspection and the mechanical property testing that is the hardness testing. All inspection and test results recorded in the QC record sheet that is very important for data collection and analysis. Whatever passed the inspection will be packed and sent to customer and those failed will be scrapped as nonconforming part cannot be reworked. The main quality problem in producing the RVSL is the inability of the existing process to produce consistent results in complying with the critical to quality (CTQ) that is the distance between flanges as mentioned in Table 1. The customer's view on the CTQ as defined by the design is reviewed by the project team in order to understand the significance of it. Table 2 shows the VOC summary which indicates the customer would have a major problem of leakage should the distance between flanges is not complying with the specification.

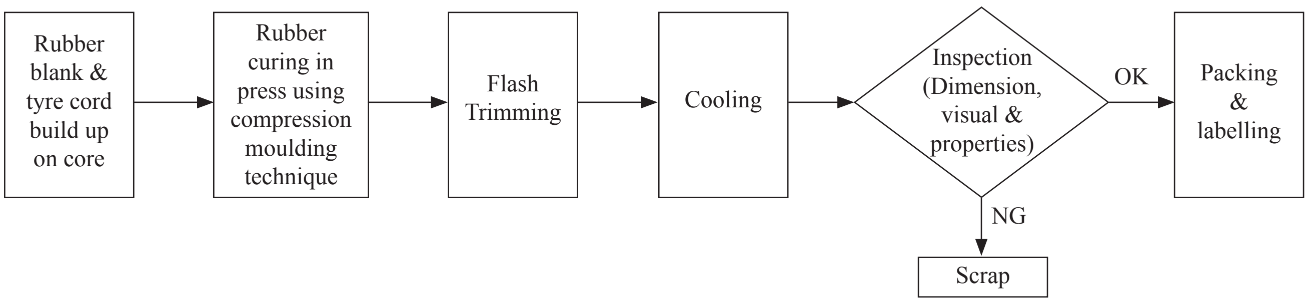

FIGURE 2. RVSL process mapping

TABLE 1: Results for distance between flanges

Day	1	2	3	4	5	6	7	8
1	154.82	154.94	154.90	154.80	153.79	153.75	154.80	155.90
2	155.12	154.84	154.11	154.73	154.79	154.87	154.73	154.69
3	154.82	154.80	154.56	154.88	154.76	154.94	154.88	154.92
4	153.21	155.15	155.02	154.81	154.19	154.88	154.81	155.01
5	155.13	154.88	154.89	154.92	154.88	155.00	154.92	153.75
6	154.75	155.15	154.76	154.81	155.24	154.80	154.81	154.87
7	155.15	154.71	155.09	154.93	154.83	154.73	154.93	154.94
8	153.50	155.02	154.69	154.90	154.91	154.88	154.90	154.88
9	154.90	154.89	154.92	154.11	154.13	154.82	154.11	155.09
10	154.88	154.76	155.01	154.76	154.99	154.80	154.56	154.69
11	154.81	155.09	153.75	154.82	154.94	154.73	155.02	154.92
12	154.93	154.69	155.02	155.12	154.84	154.88	154.89	155.01
13	154.90	154.92	154.89	154.82	154.80	154.81	154.76	153.75
14	154.11	155.01	154.76	153.21	155.15	154.92	155.09	155.02
15	154.56	153.75	155.24	155.13	154.88	154.81	154.69	154.89
16	154.69	154.87	154.83	154.75	155.15	154.93	154.92	154.76
17	154.92	154.94	154.91	155.15	154.71	154.90	155.01	154.79
18	155.01	154.88	154.13	153.50	155.02	154.11	153.75	154.76
19	153.75	155.00	154.99	154.90	154.89	154.56	155.02	154.19
20	154.87	154.80	153.79	154.88	154.76	154.69	154.89	154.88
21	154.94	154.73	154.79	155.02	155.12	154.92	154.76	155.24
22	154.88	154.88	154.76	154.89	154.82	155.01	155.09	154.83
23	155.15	154.81	154.19	154.76	153.21	153.75	154.69	154.91
24	154.88	154.92	154.88	155.09	155.13	154.87	154.92	154.13
25	155.15	154.81	155.24	154.69	154.75	154.94	155.01	154.99
26	154.71	154.93	154.83	154.92	155.15	154.88	153.75	154.94

TABLE 2. Voice of Customer (VOC)

Customer	Voice of customer	Customer Valves	Critical to quality
	RVS distance between flanges need to fit precisely with the valve metal body	If distance between the flanges is shorter or longer than spec then valve system will leak during operation	RVS distance between flanges to be within 154.75 to 155.25 mm
	RVS has to be in straight form, no shape deformation allowed	If shape not straight, very difficult to install rubber valve into valve metal body. Potential leak during valve operation	No shape deformation allowed. Sleeve must be in straight form

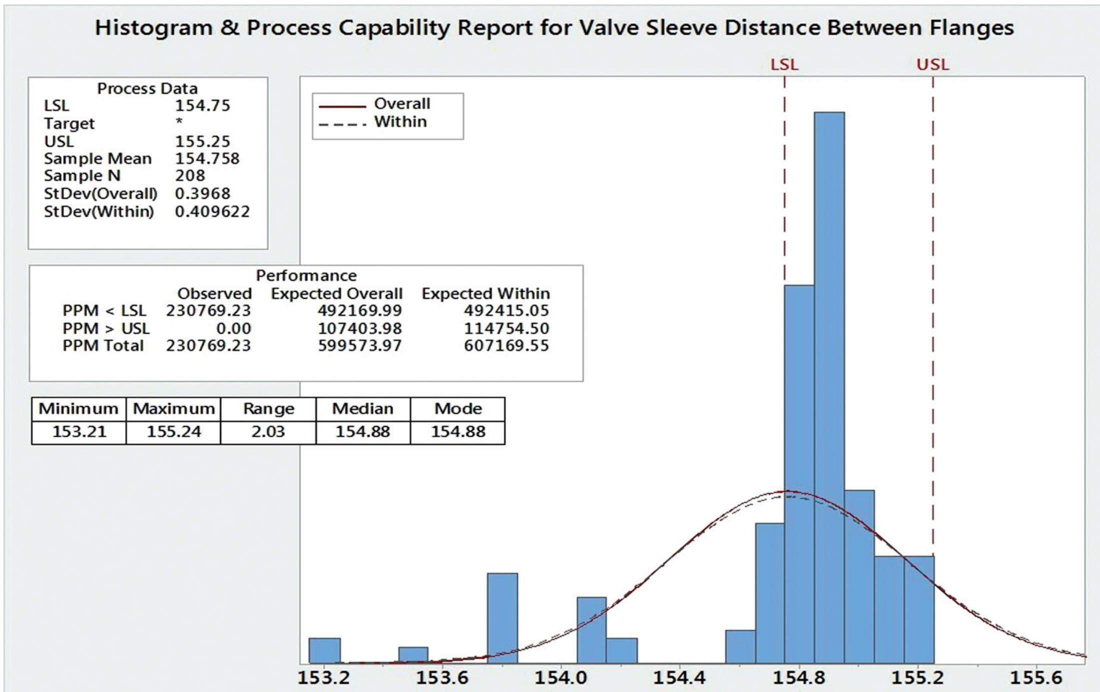

FIGURE 3. Histogram & Process Capability Report for VSD Between Flanges

DATA ANALYSIS

Using the descriptive statistics, all the measurements results are analysed as mentioned in Figure 3. Based on the descriptive statistics, central tendency of data distribution based on the mean, median and mode analysis, the distribution of the data set is skewed to the left as all values are lower than the centre limit of 155.00. As the mean is less than the median, there are many measurements results which would end up toward and passing the lower specification limit thus would drag the mean to the left. Hence, it can be said that the distance between flanges of the sleeve is mostly lower than the centre limit of 155.00 and passing the lower spec. limit and as of now the part per million (PPM) < LSL is observed at 230769.23 or 23.1%. It is observed that 48 pieces (23.1%) were rejected from the 208 pieces being sampled and all the rejected parts are having distance between flanges shorter than the LSL that is 154.75 mm. The current rejection rate is much higher than the target set by the management that is 0.1% maximum. There is no non-conformance observed above the USL.

The spread would indicate whether the calculated mean is representative for the data set. As the calculated one sigma is 0.397 (Overall) then in describing the data set, not only the mean but also the sigma has to be taken into consideration as there will potentially be large difference between individual measured values. The range (R) calculated at 2.03 as well indicates that the variability of the range among subgroups is too high. To understand this problem in details, all the rejected parts, 48 pieces in total. Pareto diagram is constructed per Figure 4 to separate the significant aspects of a problem from the trivial ones hence focus for improvement efforts can be directed effectively. Based on the pareto analysis, the dimensional issue that is the distance between flanges which is specified as critical to quality (CTQ) as shown in Figure 4, contributed significantly at 91.7% of the defect types. The second type of defect would be in the form of visual quality that contributed much lesser at 8.3% of the total defects. There is no defect recorded for the mechanical property.

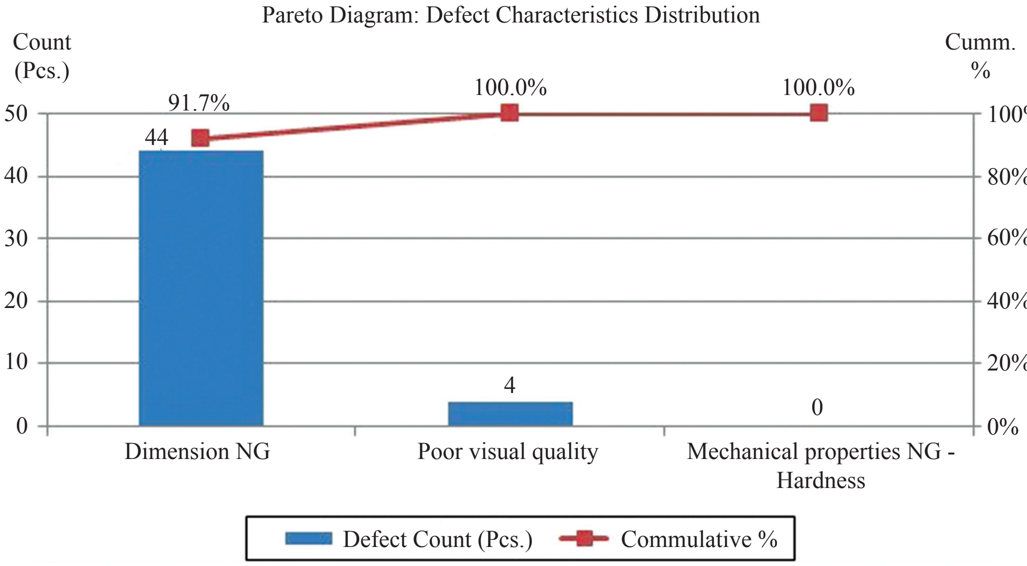

FIGURE 4. Pareto diagram for defect characteristics distribution

SUMMARY OF THE PROBLEM

The high rejection rate of 23.1% in producing the RVSL is caused mainly by the out-of-spec distance between flanges measurements that contributed 91.7% of the rejection rate. All (100%) of the out-of-spec valve sleeves are having measurement results shorter than the LSL which is 154.75 mm. Therefore, the focus of the team will be addressing all the factors that caused the out-of-spec distance between flanges of the valve sleeve.

RESULTS AND DISCUSSION

DEFINE PHASE

Based on the Define phase outcomes, the project team established a project charter as previously utilised by Jirasukprasert et al. (2012) for the purpose of setting the project direction, define the measures of success or project targets, the project boundaries, VOC, and aligns the goals with critical business needs. The project charter will be revisited as frequently by the project team whilst going through the rest of the six-sigma DMAIC phases so that the focus and activities are always aligned and

on track. The steps will be followed to identify and develop the potential solutions to address the quality problem of the RVSL. Through the six-sigma DMAIC trouble shooting methodology, the problem has been clearly defined at the Define phase hence the next step to be carried out is the Measure phase.

MEASURE PHASE

The aim for the team at this phase is to search for the potential causes or potential X's which might significantly impact the effect or the 'Y' that is the out of specification for distance between flanges for the Rubber Sleeve Liner. A Supplier-Input-Process-Output-Customer (SIPOC) to help the project team to understand the process elements and its interactions which later will be used in the brainstorming session. Later all the identified potential causes or the X's will be refined through the cause & effect (C&E) matrix process to prioritize the X's. Finally, the team will funnel all the prioritized X's into the existing FMEA so that the fully refined vital few X's could be developed effectively.

ANALYZE PHASE & FAILURE MODES & EFFECTS ANALYSIS (FMEA)

Taking the results from the C&E matrix as inputs, the team next conducted a failure modes and effect analysis (FMEA) to re-assess the potentials X's and the consequent risks associated with process and take steps to minimize the risk factors and prevent possible defects. All the identified potentials X's are funnelled into the FMEA (Figure 7) in order to attain the final vital few X's which more significantly impacting the distance between flanges of the Rubber Sleeve. To make the task easier the team defined the severity, occurrence and detection ratings. Using these criteria, an FMEA developed as shown in Figure 7. This Figure 7 shows potential failure modes, potential failure effects, potential failure causes and the current process control was used. From the FMEA, X's that appear to be important, as highlighted in yellow colour in Figure 7, are related to wrong measurement method (RPN = 567), moulding or curing temperature overshot (RPN = 405) and improper storage of rubber sleeve right away after de-moulding that is still hot (RPN = 243).

Note: RPN threshold is at 200 as there is significant gap noticed in the array of the RPN results in the FMEA (Figure 9). The FMEA process indicated that one variable that is the use of the old or scorch compound is insignificant (RPN = 81) hence dropped by the project team from being the vital few X's. The final vital few X's are associated with the process steps of moulding that includes curing and cooling, and the process of dimensional inspection by the QC.

In this phase, all the vital few X's will be tested through experiments and pilot runs through leveraging the Minitab statistical software tools like graphical analysis and hypothesis testing so that a statistically validated causes (X's) can be established from which the project team will pursue for the countermeasure plan in the Improve Phase. There is always a tendency of the flanges to deform slightly towards the centre of the valve body when cold down to room temperature, as illustrated in Figure 5 below. The project team wants to confirm how significance the slight deformation impacting the distance between the flanges on the Rubber Sleeve Liner.

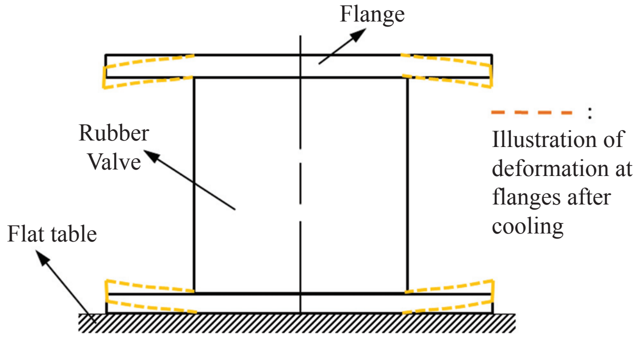

FIGURE 5. Illustration of flanges slight deformation

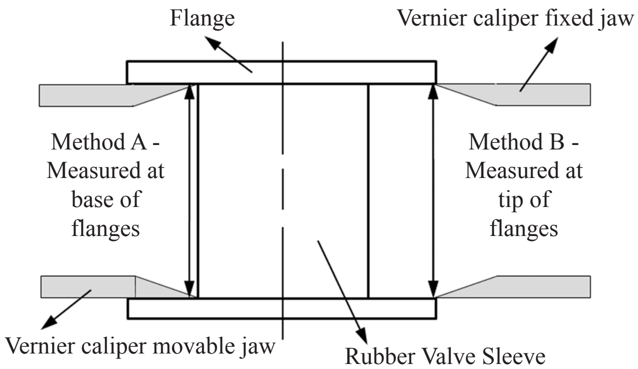

FIGURE 6. Measurement method for distance between flanges

To verify the significance of this variable, 10 samples of the valve sleeves are picked and the distance between flanges is measured. The measurement method utilised is as mentioned in Figure 6. The paired t-test is used to analyse the means from the 2 methods whether statistically significantly different. Using Minitab normality test with H_0 is that the data follow a specified distribution with significance level setting at p-value > 0.05 (Anderson-Darling method), both data set are normally distributed with p-value = 0.798 and 0.215 for method A and B respectively. The null hypothesis (H_0) assumes that the true mean difference (μ_d) is equal to zero and and having set the significance level at p-value > 0.05, the paired t-test analysis (Figure 8) with p-value < 0.001 suggests that the difference between the means is statistically significant for method A & B. Therefore, X_1 (Wrong measurement method) needs to be considered by the project team as one of the vital few variables in order to eliminate the distance between flanges problem. The project team believes that technically when the mould or curing temperature over shot above the parameter setting, the rubber will undergo excessive curing hence would produce an adverse impact to the rubber crosslinking which could be seen by the level of shrinkage when the rubber sleeve cold down to room temperature. Currently the way the distance between flanges is measured is by using a Vernier calliper. This variable subjected to trial by curing different rubber sleeves (Sample size is 3 pieces) at different temperatures. All the rubber sleeves were stored to cold down at the same condition that later the distance between flanges measured. The measurement results are shown in Table 3 below. The results are analysed using the boxplot and regression analysis to confirm whether significantly influencing the 'Y.' Through the boxplot analysis as shown in Figure 9, the means of the samples from different curing temperatures appear to differ thus to further confirm this, a regression analysis or fitted line plot analysis is carried out to verify whether the means difference is significant. The null hypothesis is that the coefficient is equal to zero (no effect) and having set the significance level at p-value > 0.05, the fitted line plot analysis suggests that the difference between the means is statistically significant as the actual p-value < 0.001 as shown in Figure 10 above. Therefore, X_2 (Mould temperature over shoot) needs to considered by the project team as one of the vital few variables in order to eliminate the distance between flanges problem.

TABLE 3. Mould temperature over shoot trials

(Curing Temperature)	Measurement results (mm)		
	Sample 1	Sample 2	Sample 3
100	154.99	155.21	155.10
120	155.16	155.21	155.07
140	154.49	154.33	154.78
160	152.71	152.33	152.21

The rubber valve sleeve believes to be deformed if right away after de-moulding and still very hot, stored or positioned in the manner as shown in Figure 11. However, the project team is unsure whether storing or positioning in that manner gives significant impact to the distance between flanges. In order to verify the significance of this variable, the project team ran a production trial of 20 pieces each following two different storing methods that are Method A & B as shown in Figure 11 below. After the Rubber Sleeve Liner has reached the room temperature, the distance between the flanges are measured. 2-sample t-test is used to check whether there is significant difference for the means from method A & B. Using Minitab normality test with H_0 is that the data follow a specified distribution with significance level setting at p-value > 0.05 (Anderson-Darling method), both data set are normally distributed with p-value = 0.921 and 0.062 for method A

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Item:	Rubber Valve Sleeve Liner	Responsibility:	Zamri Darus	FMEA Date (Orig):	19 April 2017
Item No.:	P050WD3-01	FMEA number:	P050-FMEA-127	FMEA Date (Latest Rev):	27 June 2017
Core Team:	Zamri, Jasmin, David, Jamelah, Vincent, Tajul, Rajah			Page:	1 of 1

te: Sev = Severity of Effect; Occ = Likelihood of Occurrence; Det = Ability to detect; RPN = Risk Priority Number (Sev X Occ X Det)

Process Function	Potential Failure Mode	Potential Effect(s) of Failure **(Y's)**	Sev	Potential Cause(s) of Failure **(X's)**	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results: Actions Taken	Sev	Occ	Det	RPN
Incoming inspection for rubber comppound & tyre cord	Failed raw materials passed through inspection	Poor visual quality on moulded rubber sleeve	5	Poor rubber mixing	3	10% sampling inspection for all rolls	3	45	None						
Rubber blank & tyre cord build up on core	Improper build up	Poor visual quality on moulded rubber sleeve	3	Lack of understan ding	3	SOP and supervision by team leader	1	9	None						
Moulding (Curing & cooling)	Under cured (Uncured) rubber sleeve	Distance between flanges out of spec.	9	Moulding temperatu re dropped	1	No current control	9	81	None						
	Excessive / over cured rubber sleeve	Distance between flanges out of spec.	9	Moulding temperatu re overshot	5	No current control	9	405	Implement preventive maintenance (PM) to ensure steam system is good with cut-off mechanism	MX	PM implemented. Steam line weekly inspected to ensure no blockage. Solenoid valve service & inspected weekly. No more recurrence of temperature over shot **Effective 23 May 2017**	9	3	1	27
	Rubber sleeve shape deformation	Distance between flanges out of spec.	9	Improper storage - Jumble up	9	No current control	3	243	Design a cooling jig to effectively cold down the sleeve temperature and avoid shape deformation. Work instruction developed to ensure understanding & compliance.	AY	All rubber valve sleeves are put onto the cooling jig right after de-moulding. Sleeves are able to be kept straight without any shape deformation. **Effective 31 May 2017**	9	1	1	9
	Rubber compound does not flow	Distance between flanges out of spec.	9	Use of old & scorch rubber compound	3	Rubber compound status identification	3	81	None						
Flash Trimming & finishing	Over trimmed	Poor visual quality on moulded rubber sleeve	3	Lack of understan ding	3	Limit samples are available	3	27	None						
Inspection (Dimension, visual & properties)	Ineffective inspection results (Good part could be considered NG)	Distance between flanges out of spec.	9	Wrong measurem ent method	9	SOP and inspection check sheet are available	7	567	Change the measurement method to measure at base of the flanges. Develop work instruction to ensure understanding & compliance	KAZ	Inspection method changed from measuring at the sleeve flange tip to flange base. Inspection report updated. **Effective 31 May 2017**	9	3	1	27
Labelling & packing	Wrong label on product	Send wrong part to customer	9	Lack of understan ding & product identificat ion	1	Tag ID pasted on product. Reference sample is available. SOP is available	3	27	None						
Deliver to customer	Delivery order (DO) & invoices details not match	Customer does not accept delivery	5	ERP (SAP) system error	1	Use of ERP (SAP) system for DO & invoice creation	1	5	None						

Update 27 June 2017

FIGURE 7. Failure Mode & Effect Analysis (FMEA)

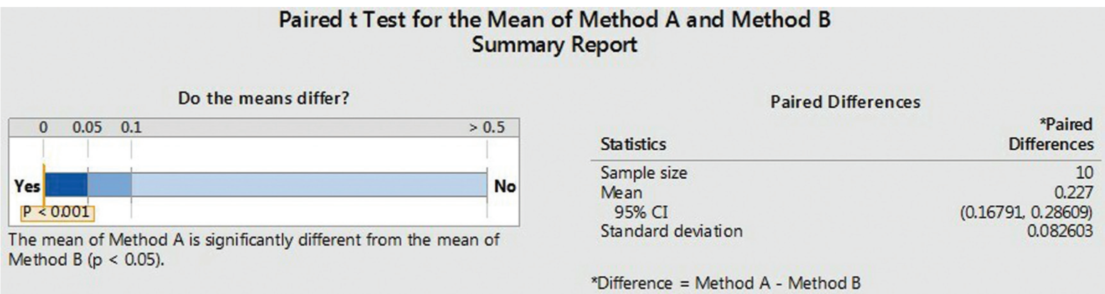

FIGURE 8. Paired t-test results for the Mean of Method A & Method B

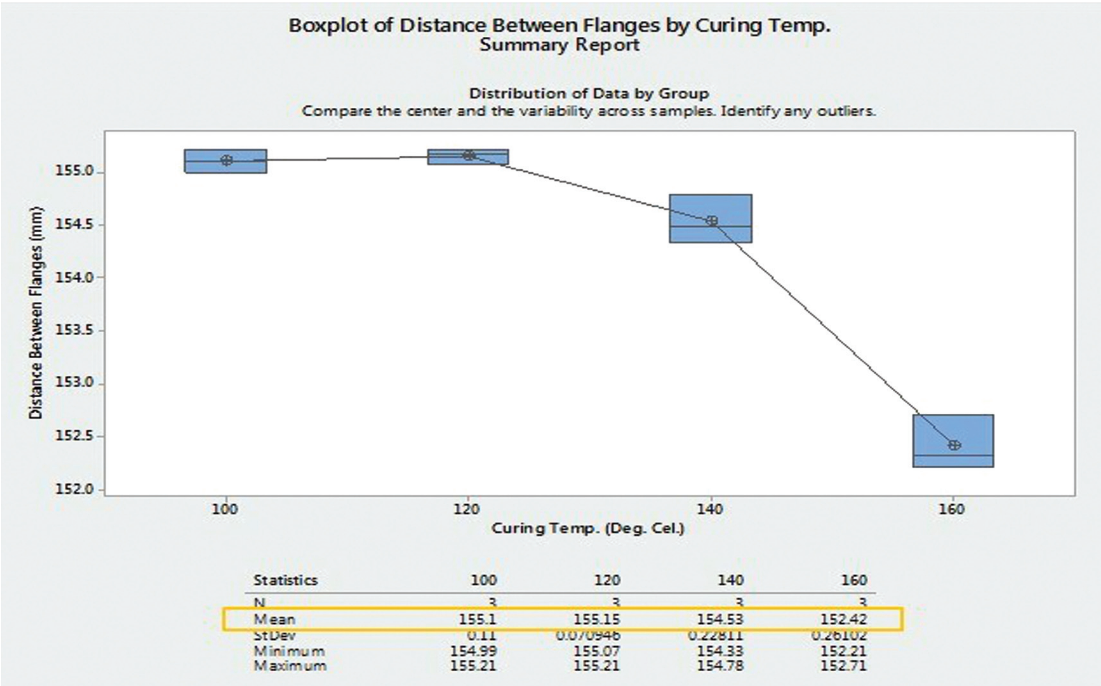

FIGURE 9. Boxplot analysis for trial result

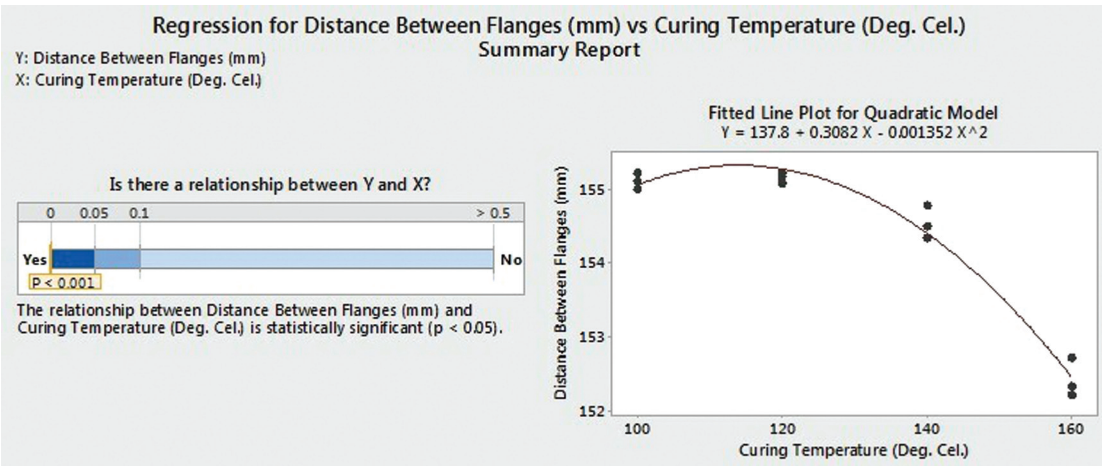

FIGURE 10. Regression analysis for Distance between Flanges Vs Curing Temperature

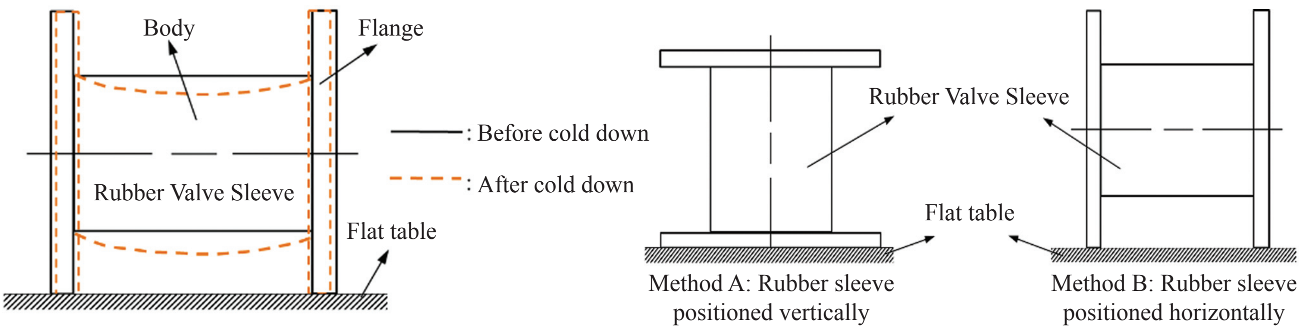

FIGURE 11. Illustration of rubber valve sleeve deformation and positioning storing methods after de-moulding

and B respectively. The null hypothesis (H_0) assumes that the true mean difference (μ_d) is equal to zero and having set the significance level at p-value > 0.05, the 2-sample t-test analysis, as shown in Figure 12, suggests that the difference between the means is statistically significant for method A & B as the actual p-value is 0.005.

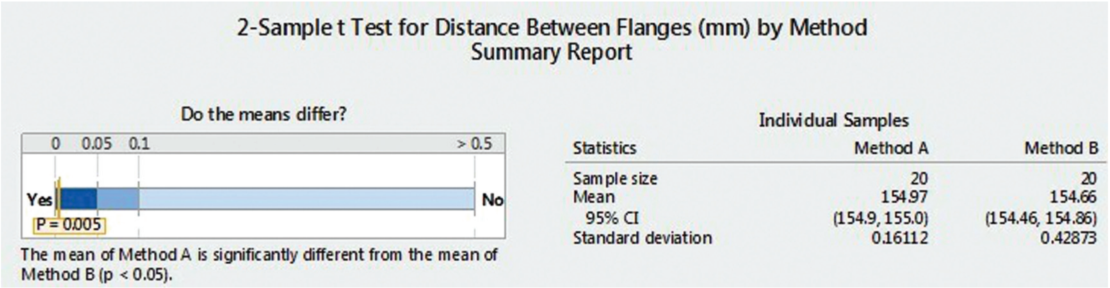

FIGURE 12. 2-sample t-test results for distance between Flanges

Therefore, X_3 (Improper storage condition after de-moulding) needs to be considered by the project team as one of the vital few variables in order to eliminate the distance between flanges problem.

After all the tests, the statistically validated vital few causes or X's are as shown in Table 4 and focus of improvements will be upon them. Y (Distance between flanges) = f (X_1, X_2, X_3).

TABLE 4. Vital few X's

X'$_S$	Variables
X1	Wrong measurement method
X2	Mould temperature over shoot
X3	Improper storage condition after de-molding

IMPROVE PHASE

In this Improve Phase, the project team brainstorms in order to identify the best solutions to address the vital few variables (X's) identified in the Analyse Phase previously. The countermeasures developed for each of the X's are now incorporated into the FMEA and the new RPN is calculated as shown in Figure 13. With much lower RPN now, the team believes all the risks associated with each of the X's have been addressed effectively. Note: In Figure 13, yellow denotes 'before RPN' and green denotes 'after RPN.' Once the actions stated in the countermeasure plan have been completed, the project team would again collect the data to assess the effectiveness in reducing the rejection/scrap rate due to the dimensional issue for distance between flanges.

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Item: Rubber Valve Sleeve — Responsibility: Zamri Darus — FMEA Date (Orig): 19 April 2017
Item No.: P050WD3-01 — FMEA number: P050-FMEA-127 — FMEA Date (Rev): 16 June 2017
Core Team: Zamri, Jasmin, David, Jamelah, Vincent, Tajul, Rajah — Page: 1 of 1

Note: Sev = Severity of Effect; Occ = Likelihood of Occurrence; Det = Ability to detect; RPN = Risk Priority Number (Sev X Occ X Det)

No	Process Function	Potential Failure Mode	Potential Effect(s) of Failure (Y's)	Sev	Potential Cause(s) of Failure (X's)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results: Actions Taken	Sev	Occ	Det	RPN
1	Moulding (Curing & cooling)	Excessive / over cured rubber sleeve	Distance between flanges out of spec.	9	Moulding temperature overshot	5	No current control	9	405	Install temperature sensitive detector for steam heat cut-off mechanism	MX	Sensitive heat cut-off system installed at machine & working well. **Effective 23 May 2017**	9	3	1	**27**
		Rubber sleeve shape deformation	Distance between flanges out of spec.	9	Improper storage condition after de-moulding - Jumble up while sleeve still hot	9	No current control	3	243	Fabricate cooling jig so that sleeve can be positioned straight	AY	Cooling jig fabricated and place next to the press worker. **Effective 31 May 2017**	9	1	1	**9**
2	Inspection (Dimension, visual & properties)	Ineffective inspection results (Good part could be considered NG)	Distance between flanges out of spec.	9	Wrong measurement method on flanges	9	SOP and inspection check sheet are available	7	567	Review inspection method and change to get reliable result	KAZ	Inspection method changed from measuring at the sleeve flange tip to flange base. **Effective 31 May 2017**	9	3	1	**27**

FIGURE 13. Updated FMEA with actions

DIMENSION MONITORING OF RUBBER SLEEVE DISTANCE BETWEEN FLANGES

Quality tool of X-bar and R- Bar chart will be implemented to plot the mean (X-bar) and range (R) of the distance between flanges measurement results. The purpose of implementing X-R bar chart is to assess the effectiveness of the countermeasures and stability of the process. The measurement results for distance between flanges are collected for both before and after countermeasures performance according to the X-bar & R-Bar chart control charts requirements. It is observed in the charts in Figure 14 that the range within subgroups is significantly closer and consistent each other. The range between the highest and lowest reading of the distance between flanges is significantly closer to each other. The range average is 0.22 that is within the maximum allowable variation of + 0.25 mm and much improved when compared with that before countermeasure that was calculated at 1.03. Moreover, increase in Delivery on time (DOT) from the baseline at 34% to 94% as mentioned in Figure 15.

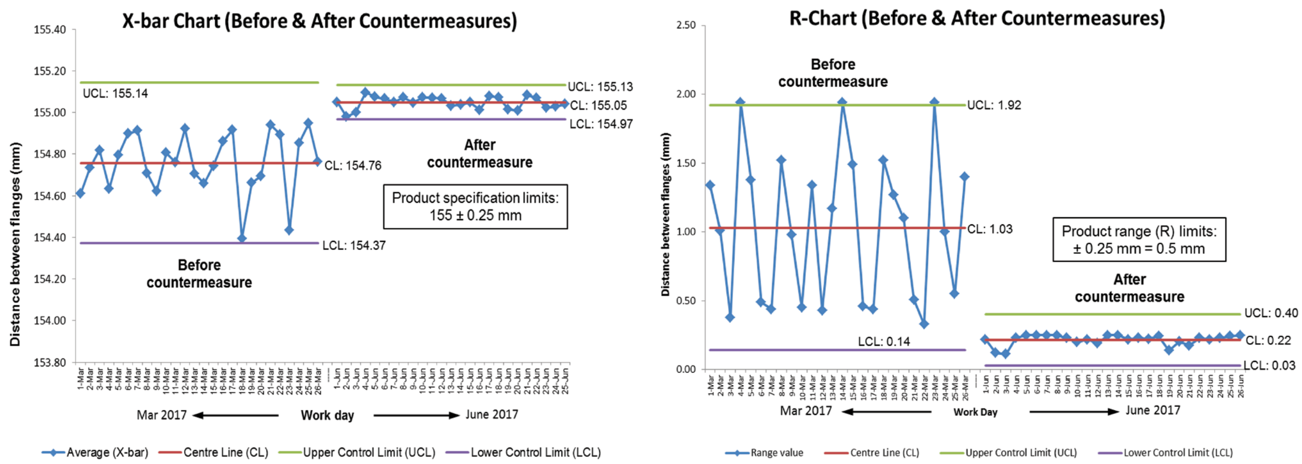

FIGURE 14. X and R bar chart for before and after countermeasures

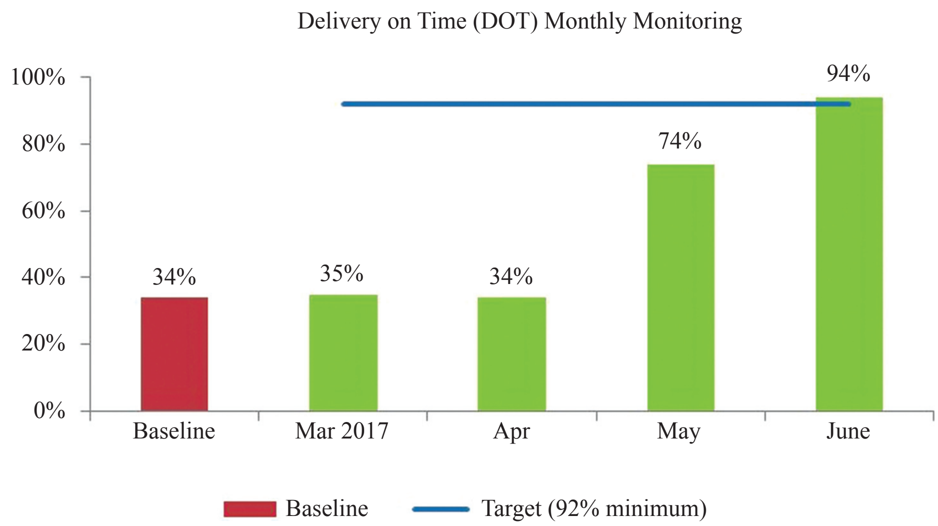

FIGURE 15. Scrap rate monthly monitoring

CONTROL PHASE

In order to ensure the action items created in the Improve Phase is well-implemented and benefits are sustained, the project team revised the control plan are as shown in Table 5 below. The control plan updated as to ensure the latest controls are documented and implemented so that consistent quality of production can be attained as mentioned in Figure 16.

CONCLUSION

There are series of benefits gained from the application of the quality tools and methods in resolving the quality issues and driving for quality improvement initiatives. Through the six-sigma DMAIC methodology, a framework has been developed associated with quality tools that worked as a structured problem-solving method in rubber manufacturing industry. Through the developed framework, critical causes or the vital

TABLE 5. Revision summary for control plan

X1	Wrong measurement method	Process step no. 50 (Distance between flanges): clearly states to be measured at the flange base. Classified control as CTQ. New SOP developed MP-QC-098-01
X2	Mould temperature over shoot	Process step no. 30 (Curing): Add temperature control at 120 ± 3 Cel. Classified control as CTQ. Mould temperature needs to be recorded every hourly at every curing. New SOP developed MP-WI-030-11
X3	Improper storage condition after de-moulding	Process step no. 30 (Cooling): The hot rubber sleeve needs to be put onto the cooling jig to avoid shape deformation. Classified control as CTQ. New SOP developed MP-WI-030-11

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Item:	Rubber Valve Sleeve Liner	Responsibility:	Zamri Darus	FMEA Date (Orig):	19 April 2017
Item No.:	P050WD3-01	FMEA number:	P050-FMEA-127	FMEA Date (Latest Rev):	27 June 2017
Core Team:	Zamri, Jasmin, David, Jamelah, Vincent, Tajul, Rajah			Page:	1 of 1

Note: Sev = Severity of Effect; Occ = Likelihood of Occurrence; Det = Ability to detect; RPN = Risk Priority Number (Sev X Occ X Det)

No	Process Function	Potential Failure Mode	Potential Effect(s) of Failure (Y's)	Sev	Potential Cause(s) of Failure (X's)	Occ	Current Process Controls	Det	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results: Actions Taken	Sev	Occ	Det	RPN
1	Incoming inspection for rubber comppound & tyre cord	Failed raw materials passed through inspection	Poor visual quality on moulded rubber sleeve	5	Poor rubber mixing	3	10% sampling inspection for all rolls	3	45	None						
2	Rubber blank & tyre cord build up on core	Improper build up	Poor visual quality on moulded rubber sleeve	3	Lack of understanding	3	SOP and supervision by team leader	1	9	None						
3	Moulding (Curing & cooling)	Under cured (Uncured) rubber sleeve	Distance between flanges out of spec.	9	Moulding temperature dropped	1	No current control	9	81	None						
		Excessive / over cured rubber sleeve	Distance between flanges out of spec.	9	Moulding temperature overshot	5	No current control	9	405	Implement preventive maintenance (PM) to ensure steam system is good with cut-off mechanism	MX	PM implemented. Steam line weekly inspected to ensure no blockage. Solenoid valve service & inspected weekly. No more recurrence of temperature over shot **Effective 23 May 2017** Update 27 June 2017	9	3	1	27
		Rubber sleeve shape deformation	Distance between flanges out of spec.	9	Improper storage - Jumble up	9	No current control	3	243	Design a cooling jig to effectively cold down the sleeve temperature and avoid shape deformation. Work instruction developed to ensure understanding & compliance.	AY	All rubber valve sleeves are put onto the cooling jig right after de-moulding. Sleeves are able to be kept straight without any shape deformation. **Effective 31 May 2017** Update 27 June 2017	9	1	1	9
		Rubber compound does not flow	Distance between flanges out of spec.	9	Use of old & scorch rubber compound	3	Rubber compound status identification	3	81	None						
4	Flash Trimming & finishing	Over trimmed	Poor visual quality on moulded rubber sleeve	3	Lack of understanding	3	Limit samples are available	3	27	None						
5	Inspection (Dimension, visual & properties)	Ineffective inspection results (Good part could be considered NG)	Distance between flanges out of spec.	9	Wrong measurement method	9	SOP and inspection check sheet are available	7	567	Change the measurement method to measure at base of the flanges. Develop work instruction to ensure understanding & compliance	KAZ	Inspection method changed from measuring at the sleeve flange tip to flange base. Inspection report updated. **Effective 31 May 2017** Update 27 June 2017	9	3	1	27
6	Labelling & packing	Wrong label on product	Send wrong part to customer	9	Lack of understanding & product identification	1	Tag ID pasted on product. Reference sample is available. SOP is available	3	27	None						
7	Deliver to customer	Delivery order (DO) & invoices details not match	Customer does not accept delivery	5	ERP (SAP) system error	1	Use of ERP (SAP) system for DO & invoice creation	1	5	None						

FIGURE 16. Revised FMEA Control

few X's identified and an effective improvement plan has been developed to solve the quality implementation problems. The benefits that has been attained by the company are reduction in Scrap rate from 23.1% to 0%, reduction in scarp cost from RM26,880/- to RM0/- (with saving gained almost RM26,880/ month and annually RM322,560) and increase in Delivery on time (DOT) from the baseline at 34% to 94%. Moreover, the leading benefit that has been attained through this framework by applying the quality tools like FMEA under six-sigma platform to reduce the quality problem in RVSL that confirmed the significance and excellence of developed framework. The developed framework is highly beneficial and new-liner for the practitioners and the managers that are working on the implementation of quality tools and focusing on the reduction of scrap rate. The most leading limitation of this research is its application only in the rubber manufacturing industry and the issue that has been addressed in this research is the specifically from the rubber manufacturing industry. Therefore, in future recommendations, the other manufacturing industries should be considered and DMAIC should be implemented on the other sectors.

REFERENCES

Abdulmalek, F.A. & Rajgopal, J. 2007. Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. *International Journal of Production Economics* 107(1): 223-236.

Chauhan, Y. & Belokar, R.M. 2015. Six sigma in project management for software companies. *SSRN Electronic Journal* 1-13.

Idris, F. 2011. Total quality management (TQM) and sustainable company performances: examining the relationship in malaysian firms. *International Journal of Business and Society* 12(1): 31-52.

Jirasukprasert, P., Garza-Reyes, J.A., Soriano-Meier, H. & Rocha-Lona, L. 2012. A Case study of defects reduction in a rubber gloves manufacturing process by applying six sigma principles and DMAIC problem solving methodology. *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management* 2012: 472-481.

Kumar, M., Antony, J., Singh, R.K., Tiwari, M.K. & Perry, D. 2006. Implementing the lean sigma framework in an indian sme: a case study. *Production Planning and Control* 17(4): 407-423.

Lee, J.K. & Ben-Natan, R. 2002. *Integrating Service Level Agreements: Optimizing Your Oss for Sla Delivery*. John Wiley & Sons.

Ng, C.K.M., Ab-Samad, H. & Kamaruddin, S. 2013. Reduction of defects in latex dipping production: a case study in a malaysian company for process improvement. *The International Journal of Engineering and Science* 2(6): 1-11.

Plenco. 2015. Philosophy Of Troubleshooting Compression Moulding Problems. Plastics Engineering Company, Sheboygan, Wisconsin, USA. [10 November 2015].

Rafique, M.Z. 2017. A Framework For Rfid Technology Combined Lean Implementation In Automotive Parts Manufacturing Industry. Phd Thesis UKM.

Rafique, M.Z., Rahman, M.N.A., Saibani, N. & Arsad, N. 2017. A systematic review of lean implementation approaches-a proposed technology combined lean implementation framework. *Total Quality Management and Business Excellence* 30(3-4): 386-421.

Rafique, M.Z., Rahman, M.N.A., Saibani, N., Arsad, N. & Saadat, W. 2016. Rfid impacts on barriers affecting lean manufacturing. *Industrial Management & Data Systems* 116(8): 1585-1616.

Saad, S. & Javed, K. 2015. Review on six sigma (DMAIC) methodology. *International Journal of Modern Engineering Research* 5(2): 2249-6645.

Sabbagh, O., Rahman, M.N.A., Ismail, W.R. & Wan, W.H.M.H. 2016. Methodology implications in automotive product–service systems: a systematic literature review. *Total Quality Management & Business Excellence* 28(13-14): 1632-1668.

Sehgal, S. & Kaushish, D. 2013. A State of art of review of dmaic approach. *International Journal of Science and Research* 4(8): 450-452.

Sujova, A., Simanova, L. & Marcinekova, K. 2016. Sustainable process performance by application of six sigma concepts: the research study of two industrial cases. *Sustainability* 8(3): 1-21.

Swarnakar, V. & Vinodh, S. 2016. Deploying lean six sigma framework in an automotive component manufacturing organization. *International Journal of Lean Six Sigma* 7(3): 267-293.

Vinodh, S., Gautham, S.G. & Ramiya, R.A. 2011. Implementing lean sigma framework in an indian automotive valves manufacturing organisation: a case study. *Production Planning & Control* 22(7): 708-722.

Walker, J. 2017. Elastomer Engineering Guide [Online]. Https://Www.Jameswalker.Biz/De/Pdf_Docs/148-Elastomer-Engineering-Guide [6 September 2017].

Warrier, P. 2015. A Step-By-Step Guide To Compression Moulding Rubber Machinery, Rubber Machinery World. Https://Rubbermachineryworld.Com/2015/06/02/A-Step-By-Step-Guide-To-Compression-Moulding-Rubber-Machinery/ [6 September 2017].

Yin, R.K. 2013. *Case Study Research: Design and Methods*. SAGE Publications.