Implementation of Statistical Process Control through PDCA Cycle to Improve Potential Capability Index of Drop Impact Resistance: A Case Study at Aluminum Beverage and Beer Cans Manufacturing Industry in Indonesia

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ABSTRACT

Purpose: The purposes of this study are first, to analyze why the *process capability index* (*Cpk*) for drop impact resistance (DIR) does not meet the specification or less than 1.33, and second, to find out what improvements should be made to make it meet the specification.

Methodology/Approach: The methodology used was Statistical Process Control (SPC) through the PDCA cycle, supporting with Cause and Effect Diagram (CED), Nominal Group Technique (NGT) and "why, what, where, when and how (5W1H)" method.

Findings: With the above methods, the result of the study was given a positive impact on the company. The average of DIR was increased from 20.40 cm to 25.76 cm, increased by 26.27% and the standard deviation was reduced from 1.80 to 1.48, and then the *Cpk* index was increased from 0.48 to 1.79 it means the process is in control and capable.

Research Limitation/implication: This research was limited only on the two-piece can aluminum cans manufacturing process, no for three-piece cans manufacturing. SPC through PDCA cycle is an interesting method for continuous improvement of process capability in the cans manufacturing industry.

Originality/Value of paper: This study highlights the area of future research SPC through the PDCA cycle to analyze and optimize process capability. Therefore, this research is considered to promote and adopt high-valued methodologies for supporting industry to achieve global competitive advantages.

Category: Case study

Keywords: drop impact resistance; SPC; *Cpk*; PDCA; 5W1H

1 INTRODUCTION

The Canmaker Magazine Vol 32: February 2019 reported that the beverages cans demand in the Southern East Asia region is about 7.2% from the total 335 billion of the global beverages cans demand. Aluminum cans have experienced many important developments throughout the years, if compared with other packaging aluminum cans having some advantages such as good in the stackable, easy opening by full the tab, hermetic sealing, environmental and economic (Mohamed, 2016).

With all these advantages and a good trend in the market, that condition redirects in progressively savage challenges to get each other's chances. Aluminum beverages cans manufacturing industry located in Jakarta is one of the packaging industry in Indonesia that has engaged with the challenge to become the cost leader and also to remain competitive in the global world packaging industry today, with slightly process changes in tooling geometry of punch sleeve and activated oven washer dryer zone 2 to achieve the minimum requirement of the potential capability to be able to produce the aluminum beverages cans with the new aluminum raw materials (Y1) without any reducing or degradation of the aluminum cans product quality.

The fact was with Y_1 material; from nine critical parameters, there is anyone of them the potential *capability index (Cpk)* does not meet the minimum requirement, the parameter is DIR with the *Cpk* index achievement was 0.48. The investigation intends to get the reasons for the faulty. Statistical Process Control (SPC) through the PDCA cycle and *Nominal Group Technique (NGT)* are combining in utilized to find out the root cause and the 5W1H method was used for improvement determinations. As one of the facts in the real industry that the defected of the products can be reduced effectively by the Integrating of nominal group technique, Shainin system, and DMAIC methods (Trimarjoko et al., 2019).

Quality improvement is becoming a critical issue in the highly competitive business environment nowadays, so the products are made need to be upgraded regularly (Dhounchak and Biban, 2017). Minimizing defects during the process is one thing that needed to maintain customer loyalty (Realyvásquez-Vargas et al., 2018). To make high-quality products proper planning and preparation are categorized as a vital factor (Chakraborty, 2016). The organization needs to maintain a process and keeping continuous improvement to make good product quality and minimize defects (Nugroho, Marwanto and Hasibuan, 2017). To reduce defects and minimize process variation can be used in the DMAIC method (Ani, Ishak and Shahrul, 2016). The investigation of a problem and the development of an appropriate solution to the quality improvement process could be able using quality tools (Nabiilah, Hamedon and Faiz, 2018). Many statistical tools are available to improve process; one of them is SPC (Statistical Process Control). SPC could be able to maintain process stability and capability (Saputra et al., 2019). The deviation or variation of the process can be eliminated, and also, the process capability can be increased by applying the DMAIC method (Sharma and Rao, 2013).

In the competitive business environment, the SPC method could be able to use to improve the process (Godina, Matias and Azevedo, 2016). Claim from customer need to be controlled well, SPC is one of the many tools it's effective in reducing claim (Solihudin and Kusumah, 2017). Quality could be able to increase by solving problem happened during the process, and the SPC method can be used as tools (Devani and Wahyuni, 2017). Product quality must be maintained; it can be implemented by building the team to aware of SPC (Mangesha, Singh and Amedie, 2013). Product quality control with the SPC method helps in reducing defects (Supriyadi, 2018). A process could be evaluated effectively by seeing the capability process index, which can be used as a managerial decision (Sagbas, 2009). Identifying the critical to the quality of a machining and prioritization corrective action are strongly needed for the improvement step, and the DMAIC method can be used to increase capability index level (Sharma, Rao and Babu, 2018). Quality satisfaction can be created through statistical tool implementations like SPC and FMEA (Rana, Zhang and Akher, 2018). Control chart standard deviation (S) and ($\bar{X}$)) are a statistical tool which can be used to a created quality products, and it could be able to upgrade to becoming a high-quality product with controlling the range and capability process coefficient as the indicator (Fazeli and Sharifi, 2011). To create a quality of the product are made has to be started from a small issue which was happened on the process or organization (Tuna, 2018). The quality is essential for the product that was made. It can be maintained with SPC implementation as robust tools (Bereman et al., 2014). Quality could be improved by emphasizing all the levels in the company to discipline to use statistical tools (Sokovi, 2009). The organization or company need to be aware to avoid mistake or wrong in doing an operation. QC with 7 tools is a switchable tool (Magar and Shinde, 2014). Also, in anticipating globalization, the product defect must be reduced, Kaizen and PDCA cycle are a famous tool to make it happened (Darmawan, Hasibuan and Hardi Purba, 2018). The organization or company that have many product types, a lot of checked quality parameter and also the materials came from many sources it recommended to implement the assessment process with monitoring stability and capability (Ramirez and Runger, 2006).

2 RESEARCH METHODOLOGY

The study aims to find out the factors were causing *potential capability index* (Cpk) of DIR for aluminum beverages cans does not meet the customer requirement or common industrial standard and constructing the steps of corrective to improve it in minimum 1.33. The conceptual frameworks for this matter are illustrated in Appendix 1 (Figure A1).

Based on research framework as in Figure 1, for getting *potential capability index* (*Cpk*) is meeting to the customer standard, SPC through PDCA cycle with the integration of NGT and 5WIH methods are used, supported with some of the statistical tools such as (X,) ̅R chart, histogram, and fishbone diagram.

3 RESULT AND DISCUSSION

Process improvements must be given high priority and documented. By using SPC through the PDCA cycle followed with CED and NGT to identify the root cause, then continued with 5W1H methods for determining improvements, the steps to achieve the above matter as in Figure 1.

Steps/cycle	**Activity**
Plan	Data collection, determine research priority and interview.
D0	Making a plan and do an improvement with the 5W1H method.
Check	Stability process *($\bar{X}$ – R Chart*) and *process capability (Cpk).*
Action	Making standardization.

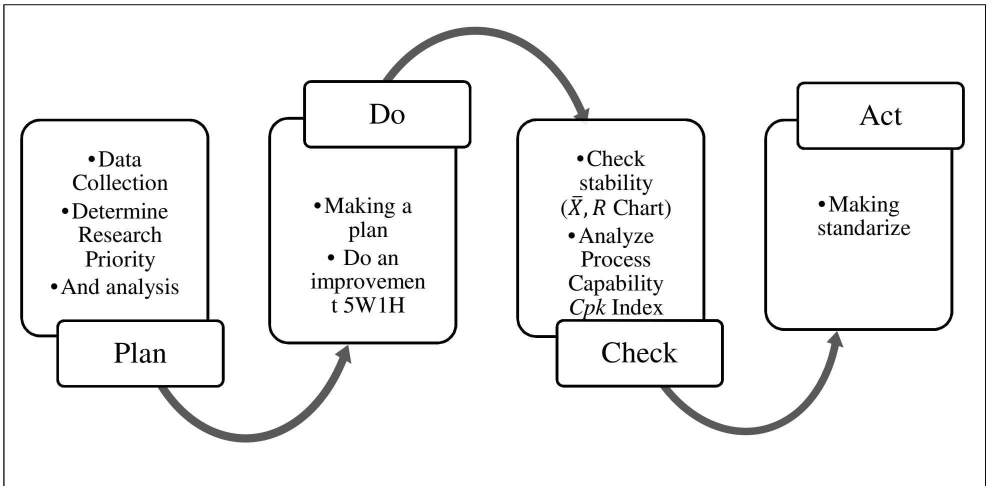

Figure 1 – Steps of the PDCA Cycle

3.1 Data Collections

Table 1 below is data of capability study for nine (9) critical quality parameters after any change on the input aluminum material for packaging aluminum beverages cans manufacture.

Table 1 – The Capability Study Data of Nine Critical Quality Parameters

Items	**Sample (n)**	**Average**	**Min**	**Max**	**Std dev.**	***Cp***	***Cpk***
1. Finish can height (mm)	180	146.02	145.87	146.15	0.05	3.04	2.24
2. Flange width (mm)	180	2.09	1.99	2.19	0.04	2.06	1.96
3. Plug Diameter (mm)	60	50.05	50.01	50.10	0.002	3.40	2.50
4. Axial Load (Lbs)	150	227.8	224	232	1.37	NA	12.60
5. Buckle Strength (Psi)	150	96.12	94.4	98.3	0.86	NA	2.35
6. Thin Wall Thickness (mm)	200	0.092	0.09	0.095	0.001	NA	2.01
7. Dome Depth (mm)	300	10.41	10.35	10.46	0.02	3.94	1.96
8. Reform Diameter (mm)	300	44.78	44.76	44.82	0.01	3.92	3.24
9. DIR (cm)	150	20.40	17.80	22.90	1.80	NA	0.48

3.2 Determining Improvement Priority

The capability study data, as in Table 1, concerning the *potential capability index* (*Cpk*), plotting to the trend chart to get easier in the analysis, as shown in Figure 2.

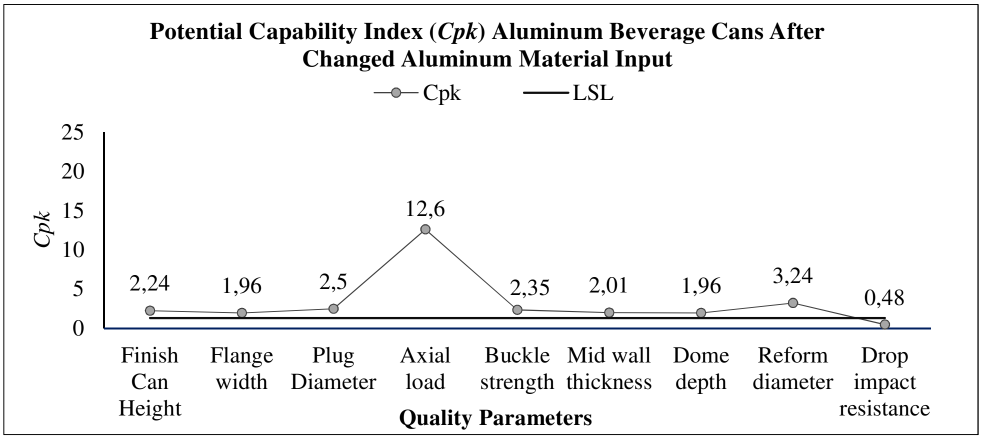

Figure 2 – Trend chart of Potential Capability Index (Cpk) Aluminum Beverages Cans With New Aluminum Raw Materials

Showing up Figure 2 above clearly that the DIR parameter is needed to be improved due to the achievement of the *potential capability index* (*Cpk*) was less than 1.33.

3.3 Discussion in Determining The Root Cause

The discussion was done with the staff of packaging aluminum beverage cans plant in Indonesia consisting of production, corporate production, and the Quality Assurance department. The aim of the discussion is for getting optimum results in solutions. Table 2 is describing the result of the discussion or brainstorming regarding the possibility of the root cause for the faulty drop impact resistance capability with the index less than 1.33.

Table 2 – The Brainstorming Data for the Possibility of the Root Cause for Drop Impact Resistance Aluminum Beverages Cans Faulty in Achievement Cpk Index > 1.33

No.	Causes	Causes Factor	Code
1	Annealing or softening of the aluminum materials	Material	CF1
2	Aluminum material thickness	Material	CF1
3	Washer oven dryer temperature	Machine	CF2
4	Temperature Feco oven decorator	Machine	CF2
5	Temperature oven IBO	Machine	CF2
6	Mat conveyor jam with full cans inside oven dryer washer, Feco oven deco or IBO oven with duration > 5 minutes	Machine	CF2
7	Domer process, the dome depth dimensions	Machine	CF2
8	The aluminum thickness of the dome area	Tooling	CF3
9	Profile / Geometry tooling of punch sleeve	Tooling	CF3
10	Bottom profil reformer, reform diameter dimensions	Machine	CF2
11	Air pressure that injected to inside the cans during testing DIR	Method	CF4
12	Base plate thickness for testing DIR	Method	CF4
13	Operator less knowledge	Man	CF5
14	Mistake or wrong in the measurement	Man	CF5
15	Lack of lighting	Environment	CF6
16	Body maker speed unstable	Machine	CF2
17	SOP not updated	Method	CF4

By observing Table 2, from 17 items of possibilities were causing for DIR does not meet to the customer specification in term of the *Cpk* achievement, to make clear in analysis the next table will be given classification information in more specific and details as stratification. Table 3 is describing the cause of the human (man) factor, the cause of the material factor as in Table 4, the cause of the method factor is in Table 5, the cause of machine factor is in Table 6, the cause of the tooling geometry factor is in Table 7, and the cause of the environment factor is in Table 8.

Table 3 – Cause of a Human (man) Factor

CF5	No.	Potential cause	Causes factor
	1	Operator less knowledge	Man
	2	Wrong in measurement	Man

Table 4 – Cause of Material Factor

CF1	No.	Potential cause	Cause factor
	1	Annealing or softening material aluminum deformation after Washer Dryer (Yield strength deformation)	Material
	2	Thickness of aluminum material	Material

Table 5 – Cause of Method Factor

CF4	No.	Potential cause	Cause Factor
	1	Air pressure was injected into the cans	Method
	2	The thickness of the DIR base plate fixture	Method
	3	SOP not update	Method

Table 6 – Cause of Machine Factor

CF2	No.	Potential cause	Cause Factor
	1	Body Maker speed	Machine
	2	Washer Dryer temperature setpoint	Machine
	3	Feco Oven Decorator temperature setpoint	Machine
	4	IBO Oven temperature setpoint	Machine
	5	Mat Conveyor Washer Oven Dryer, Pin Chain Feco Oven Decorator or Mat Conveyor IBO jam or stopped > 5 minutes.	Machine
	6	Doming Process	Machine
	7	Bottom Profile Reformer machine.	Machine

Table 7 – Cause of Tooling Factor

CF3	No.	Potential Factor	Cause Factor
	1	Punch sleeve tooling geometry	Tooling
	2	The aluminum thickness of the dome area	Tooling

Table 8 – Cause of Environment Factor

CF6	No.	Potential Factor	Cause Factor
	1	Lack of lighting	Environment

From the above stratification data in (Table 3-8), the next step is plotting into the cause and effect diagram (CED) with the aim to determining the root cause of why the potential capability index of drop impact resistance parameter for aluminum beverages cans does not meet to the customer requirement or common industry standard.

3.4 Creating the CED

CED to determining the possible root cause, as shown in Figure 3.

Analyzed CED as in Figure 3, there were ten (10) the possible root cause of the potential *capability index* (*Cpk*) does not meet to the customer requirement as can be seen on the rectangular box with dashed lines, details of the possible root cause are as follows:

(1) Man: The possibility of the operator did wrong or a mistake in measurement and lack of knowledge.

(2) Material: Yield strength and thickness

(3) Method: Air pressure that injected inside the cans and base plate thickness.

(4) Machine: Temperature Oven Washer Dryer; Conveyor Mat Washer Dryer, Feco Oven Deco or IBO Mat Conveyor jam or stopped > 5 minutes.

(5) Tooling: Punch sleeve tooling geometry and Aluminum thickness at dome area.

(6) Environment: Lack of light sources.

Based on the six factors above with ten findings cause were considered as the potential sources of the cause.

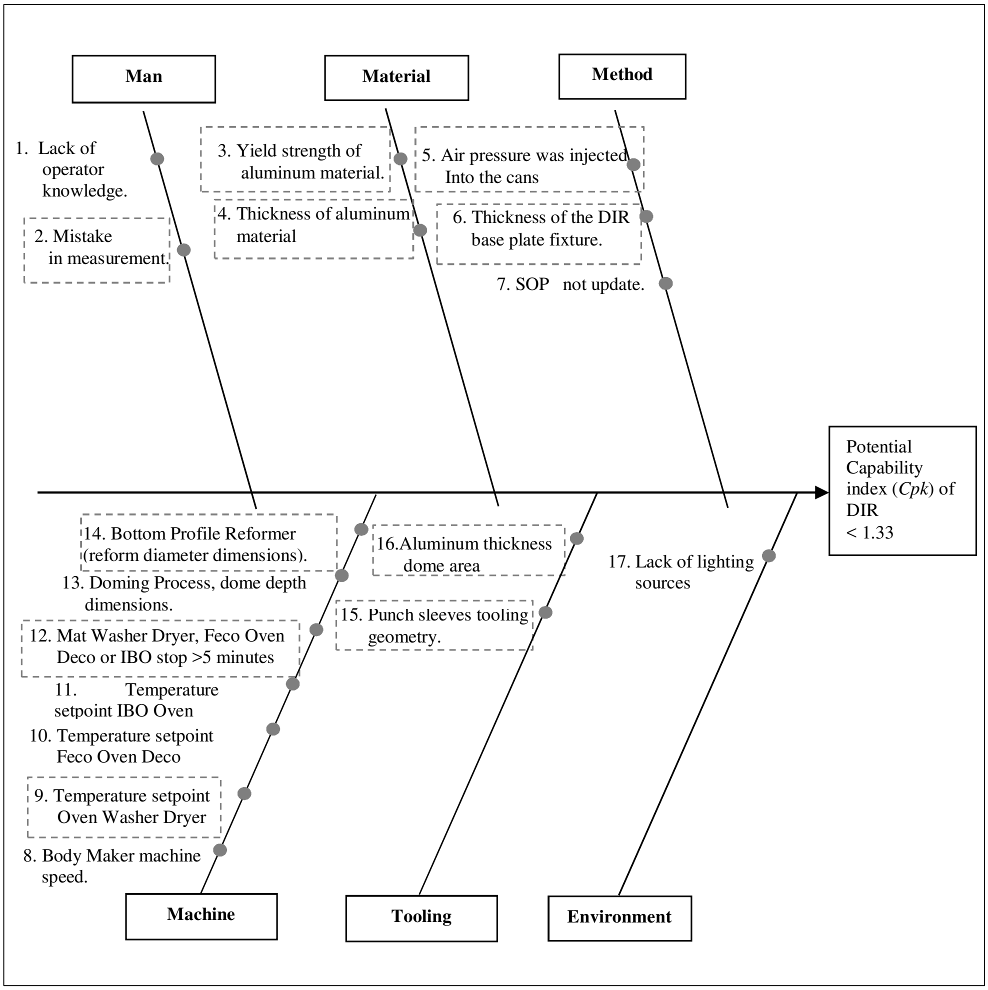

Figure 3 – CED or Fishbone Diagram for DIR Faulty

3.5 Creating the NGT

The next step is determining what the dominant cause for the issue. *NGT* method was used, the discussion group with eight members to involve in giving the score for *NGT*. All the members were coming from different backgrounds such as education, age, year of service, and current expertise. With these differences in the various background, it will be resulted in more accurate in giving the information, and finally, the correct decision is gotten. The concept of it is as in Table 9.

Table 9 – NGT Data Exposure Cause of Cpk below 1.33

No.	Variable Causes	Scorer								Total Score
		Scorer 1	*Scorer 2*	*Scorer 3*	*Scorer 4*	*Scorer 5*	*Scorer 6*	*Scorer 7*	*Scorer 8*	
1	V_1	4	5	5	4	5	6	5	5	39
2	V_2	5	4	6	5	5	5	5	5	40
3	V_3	5	4	5	4	5	5	6	5	39
4	V_4	7	8	7	6	5	8	7	8	56
5	V_5	5	5	4	6	4	5	5	6	40
6	V_6	7	5	5	6	6	7	7	8	51
7	V_7	5	5	5	5	4	5	6	5	40
8	V_8	5	4	5	4	5	6	5	5	39
9	V_9	8	7	8	6	7	8	7	7	58
10	V_{10}	5	5	4	5	5	5	6	5	40

Notes: V_1: Operator wrong measurement, V_2: Aluminum Yield Strength, V_3: Aluminum material thickness, V_4: Air pressure that injected inside the cans for test DIR high fluctuations. , V_5: Baseplate fixture drop impact resistance > 31 mm, V_6: Temperature oven washer dryer too high > 420oF. , V_7: Mat (oven dryer, IBO) and Feco Deco stopped for more than 5 minutes, V_8: Reform diameter dimensional, V_9: Tooling Geometry of punch sleeve and V_{10}: Aluminum thickness dome area.

The NGT calculated based on the below equasion:

$$\text{NGT} \geq \frac{1}{2}\ (\text{Total number of scorer} * \text{Caused Variable}) + 1 \qquad (1)$$

$$\text{NGT} \geq \frac{1}{2}\ (8 * 10) + 1\text{ , so NGT} \geq 41$$

Interpreted of Table 9 linked to the *NGT* value with using equasion (1) there are three (3) potential variable causes have *NGT* higher or the same 41, that became a dominant factor of the cause for the *Cpk* DIR achievement, namely: Air pressure injected to inside the cans, temperature of oven dryer and tooling geometry of punch sleeve.

3.6 Making Improvements

After the dominant cause or a vital factor is found, the next step is to determine the improvement steps.

3.6.1 Quality Improvement Plan (Plan)

By identifying the underlying causes, clarifying why they need to be improved, what improvements are being made, where or what areas are being corrected, when actions will be taken, who will improve them, and how to improve them, it will be more targeted. More details, improvement plans with the concept 5W1H are described as in Table 10.

Table 10 – Quality Improvement Plan and Action 5W1H

No	Cause	Why	What	Where	When	Who	How
1	Unstable air pressure, which was injected into inside the cans some time more than 60 Psi was observed.	Pressure gauge indicator was broken.	The pointer scale has not precise.	Regulator drop test fixture.	August, 2019	Hadi.P	Changed with the new one.
2.	The temperature setpoint of washer oven dryer too hight > 420°F.	Only using one zone for drying the cans.	Reducing the temperature to below 420°F.	Oven washer dryer.	July, 2019	Farid	Activated oven zone 2 to getting a temperature oven dryer below 420°F.
3	Profile or geometry tooling of Punch Sleeve.	The clearance needs to be adjusted in matching with new material.	Punch sleeve nose radius.	Punch Nose Radius R_1 dan R_2.	September 2019	Anton	Modifying punch nose radius, R_1 punch nose radius was changed from 0.05 inch to 0.06 inch, and R_2 punch nose was changed from 0.042 inches to 0.05 inch.

3.6.2 Implementation of Quality Improvement (Do)

Air pressure is injected inside the cans before the test of DIR

To avoid air pressure that injected inside the cans before test DIR, the pressure gauge indicator changed to the new one and doing the routine check for the function of pressure gauge with monthly bases and put on the calibration schedule.

Temperature oven washer dryer too high > 420°F

To make oven washer dryer temperature does not exceed 420°F the action has been done is activated oven dryer zone 2. Detail temperature with activated zone 2 is, as shown in Table 11.

Table 11 – Details of Oven Washer Dryer Temperature Setpoint

Aluminum Material Thickness	**Zone 1**	**Zone 2**	**Drying Time**
Current Thickness (Y_o)	430°F	Idle	1 minute and 26 seconds.
New Thickness (Y_1)	385°F	395°F	2 minutes and 52 seconds.

In line with the above data on Table 11, by activating two oven zones on the typical washer oven dryer, the oven temperature setpoint can be able to set to 395 °F for two minutes and fifty-two secs. The drying effectiveness has been still good and the particular big impact on the lightweight aluminum is getting safer to avoid annealing or softening if the machine stoppage or perhaps jam for a while. Figure 4 below is illustrated typical of oven washer dryer zone 1 and zone 2.

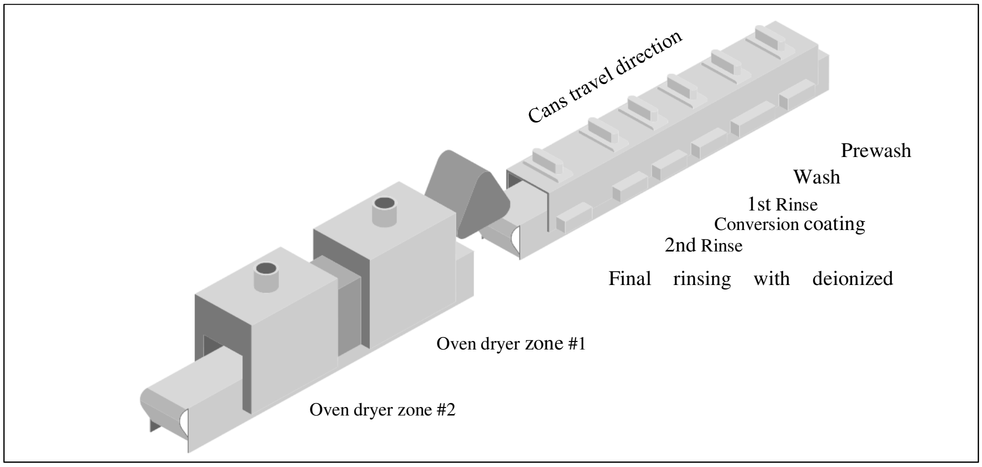

Figure 4 – Washer and Oven Dryer

Tooling Geometry or Profile Punch Sleeve

Stretching aluminum at dome area point 3 (p3), as shown in Figure 5 was reached 3.83% from the original thickness, it resulted in the drop impact resistance became weak.

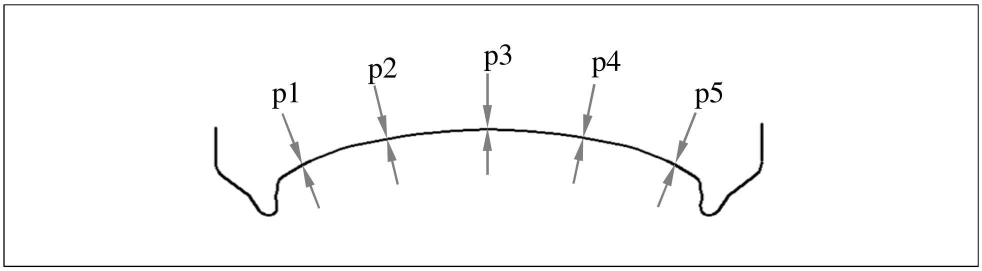

Figure 5 – Measurement Point for Aluminum Thickness Dome Area of Aluminum Beverage Cans

Figure 6 below is describing punch sleeve nose radius schematic radius 1 (R_1) and radius 2 (R_2).

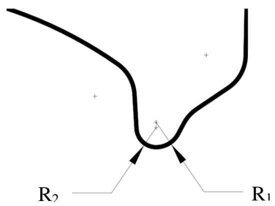

Figure 6 – Schematic of Dome Formation for Aluminum Beverages Cans: R_1: Radius 1, R_2: Radius 2

Changing details of punch sleeve tooling geometry or profile are as shown in Table 12.

Table 12 – The Information of Punch Sleeve Tooling Geometry or Profile Modification

Items	**Before**	**After**
R_1 (Inch)	0.050	0.060
R_2 (Inch)	0.042	0.050

3.7 Constructing $\overline{X}$ and R Chart

$\overline{X}$ and R Chart was used to control process stability with the final purposes is to minimize process variations. The below data as in Table 13 is capability study data for 5 hours running after improvement was done.

The sampling was carried out for 5 hours, from 08:15 a.m. to 12:15 p.m, followed by the DIR test with the air pressure were injected inside the cans continuously controlled at 60 Psi, the results of the test as shown in Table 13 above. From these data, we do the calculation to find the central point or *Center Line (CL), Upper Control Line (UCL),* the carry control point or *Lower Control Limit (LCL)* and its process capability index or *Index Capability Process (Cpk).*

Table 13 – Capability Study Data of DIR for 5 Hours Running on October 03, 2019 (cont's)

Date	Time	Machine	i	ii	iii	iv	v	vi	$\bar{X}$	R
03 Oct, 2019	08:15	1	27.94	25.40	25.40	25.40	27.94	25.40	26.25	2.54
		2	25.40	27.94	25.40	25.40	27.94	25.40	26.25	2.54
		3	27.94	25.40	22.86	25.40	25.40	25.40	25.40	5.08
		4	25.40	25.40	22.86	27.94	25.40	27.94	25.82	5.08
		5	25.40	25.40	25.40	25.40	27.94	27.94	26.25	2.54
	09:15	1	27.40	25.40	27.94	25.40	25.40	25.40	26.16	2.54
		2	25.40	25.40	22.86	25.40	27.94	25.40	25.40	5.08
		3	22.86	25.40	25.40	27.94	25.40	25.40	25.40	5.08
		4	27.94	25.40	25.40	22.86	27.94	25.40	25.82	5.08
		5	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
	10:15	1	25.40	27.40	25.40	27.94	25.40	25.40	26.16	2.54
		2	25.40	27.94	25.40	22.86	25.40	25.40	25.40	5.08
		3	25.40	25.40	25.40	25.40	27.94	25.40	25.82	2.54
		4	25.40	25.40	27.94	25.40	27.94	25.40	26.25	2.54
		5	22.86	25.40	25.40	25.40	27.94	25.40	25.40	5.08
	11:15	1	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
		2	25.40	27.94	22.86	25.40	25.40	25.40	25.40	5.08
		3	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
		4	25.40	25.40	25.40	27.94	22.86	25.40	25.40	5.08
		5	25.40	25.40	22.86	25.40	27.94	25.40	25.40	5.08
	12:15	1	27.94	25.40	25.40	25.40	25.40	25.40	25.82	2.54
		2	22.86	25.40	25.40	25.40	25.40	27.94	25.40	5.08
		3	25.40	25.40	25.40	25.40	27.94	25.40	25.82	2.54
		4	25.40	22.86	25.40	25.40	25.40	27.94	25.40	5.08
		5	27.94	25.40	25.40	25.40	27.94	25.40	26.25	2.54
									$\bar{\bar{X}}$ 25.765	$\bar{R}$ 3.759

3.7.1 The specification of DIR

The specification of DIR is minimum of 17.78 cm

3.7.2 Determining the Centre Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) for X-Chart

Centre Line (CL):

$$\mathrm{CL} = \bar{\bar{\mathrm{X}}} \tag{2}$$

$$= 25.765$$

Upper Control Limit (UCL):

$$\mathrm{UCL} = \bar{\bar{\mathrm{X}}} + \mathrm{A_2}\bar{\mathrm{R}} \tag{3}$$

$$= 25.765 + 0.483(3.759)$$

$$= 27.580$$

Lower Control Limit (LCL):

$$\mathrm{LCL} = \bar{\bar{\mathrm{X}}} - \mathrm{A_2}\bar{\mathrm{R}} \tag{4}$$

$$= 25.765 - 0.483(3.759)$$

$$= 23.9494$$

3.7.3 Determining control limit CL, LCL and UCL for $\bar{R}$-Chart

Centre Line (CL):

$$\mathrm{CL} = \bar{\mathrm{R}} \tag{5}$$

$$= 3.759$$

Upper Control Limit (UCL):

$$\mathrm{UCL} = \mathrm{D_4}\bar{R} \tag{6}$$

$$= 2.004(3.759)$$

$$= 7.533$$

Lower Control Limit (LCL):

$$\mathrm{LCL} = \mathrm{D_3}\bar{R} \tag{7}$$

$$= 0(3.759)$$

$$= 0$$

The constant for A2, D3 dan D4 for subgroup number 6 is as in Table 14.

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Table 14 – The Control Chart Constants

Sample Size = m	A2	A3	d2	D3	D4
2	1.880	2.659	1.128	0	3.267
3	1.023	1.952	1.693	0	2.574
4	0.729	1.628	2.059	0	2.282
5	0.577	1.427	2.326	0	2.114
6	0.483	1.287	2.534	0	2.004
7	0.419	1.182	2.704	0	1.924

The above calculation on Eq. (2), (3), (4), (5), (6), and (7) plotted to the chart using statistical software NWA Analysis v6.3 with the result as on Figure 7.

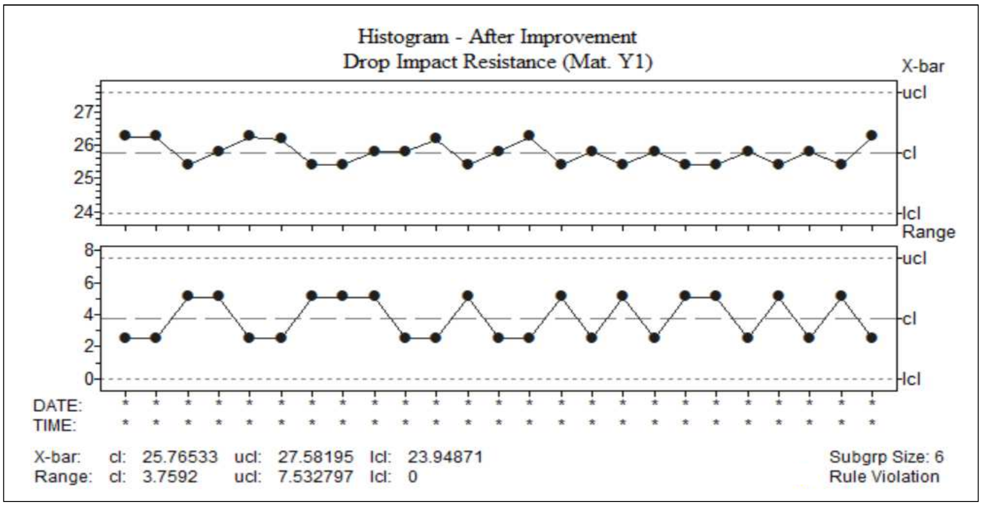


Figure 7 – $\bar{X}$-R Chart Drop Impact Resistance After Improvement of the 3 Dominants Factor

From the control chart in Figure 7, the process statistically was stable; the indication is there was no point is out from the control limit.

3.8 Calculating the Potential Capability Index (*Cpk*)

To calculate the potential capability index firstly need to know the standard deviation, due to the capability index, was decided using *Cpk* on this research so the standard deviation directly can be calculated as estimated standard deviation. The estimated standard deviation could be calculated using the below equation (8).

Determining the standard deviation (s):

$$S = \frac{\bar{R}}{d2} \tag{8}$$

DIR has only had one side specification (minimum specification), and the *Cpk = Minimum (Cpu, Cpl),* due to only one side specification so the *Cpk* will be the same with *Cpl* $(Cpk = Cpl)$. To determining the *Cpk*, the formula used as on (9).

$$Cpk = \frac{(\bar{\bar{X}} - \mathrm{LSL})}{3S} \tag{9}$$

$$Cpk = \frac{(25.765-17.78)}{3(\frac{\bar{R}}{d2})} = \frac{(25.765-17.78)}{3(\frac{3.759}{2.534})} = 1.79$$

The *Cpk* calculation based on the equation (9) is plotted to the histogram using statistical software NWA Analysis v6.3 with the result as in Figure 8.

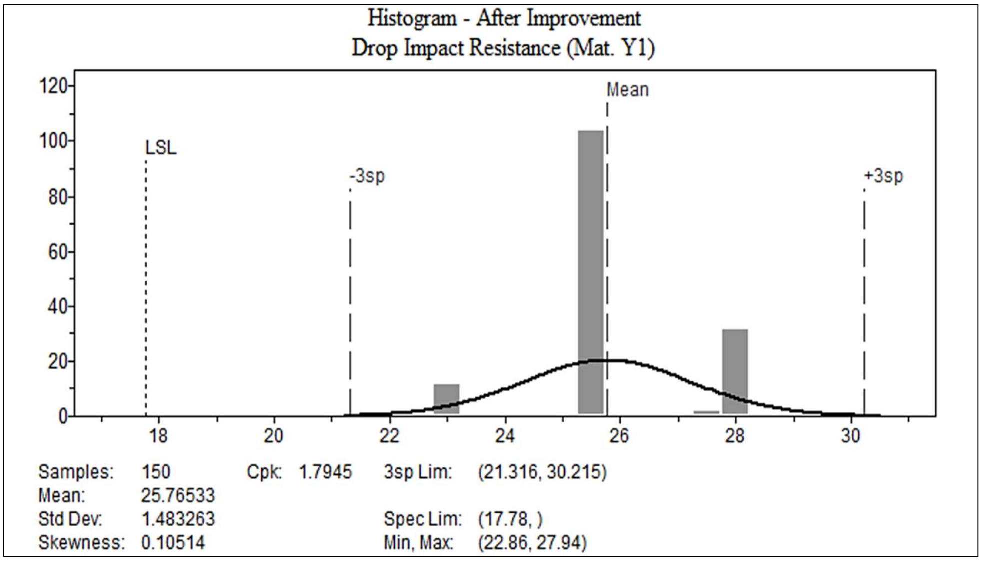


Figure 8 – Histogram of Drop Impact Resistance after Improvement

The histogram in Figure 8, given the information that the potential capability index of DIR after doing action on the three (3) factors that causing faulty in the potential index capability achievement, is positive with the *Cpk* index 1.79.

4 STANDARDIZATIONS

Looking at Figure 9 below we can learn that after improvement the average DIR was increased from 20.40 cm to 25.76 cm, and the potential *process capability index (Cpk)* increased from 0.48 to 1.79.

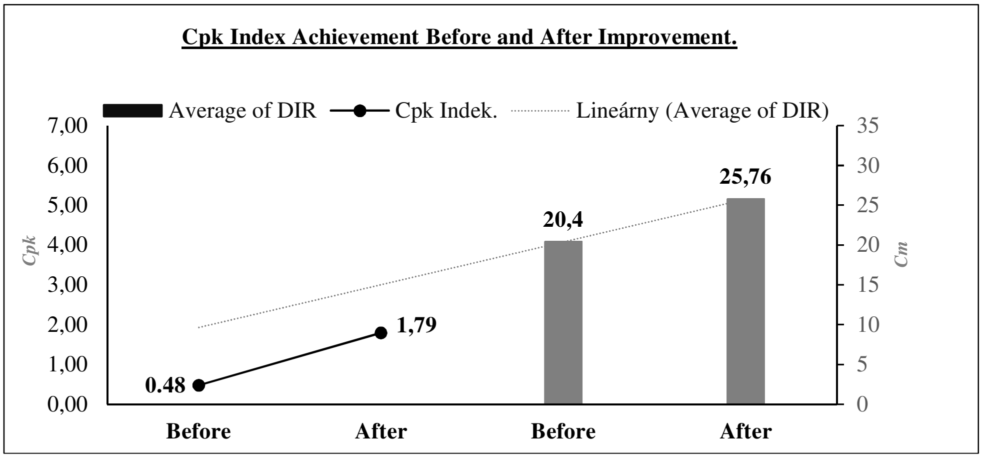


Figure 9 – The Achievement of Cpk and Average of DIR Test before Vs. after Improvement

The achievement as in Figure 9, then plotted into the distribution plot, as shown in Figure 10.

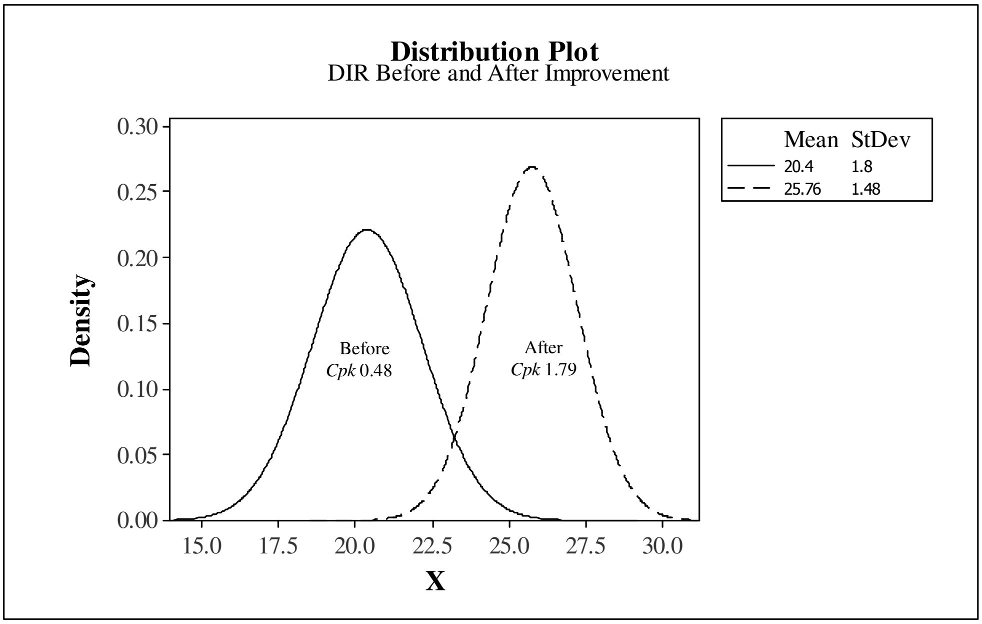


Figure 10 – Distribution Plot of DIR before and after Improvement

Based on Figure (7, 8, 9, and 10), the process stability and capability results for the DIR are ideal categorized, and it can be seen in the control and capable matrix in Figure 11.

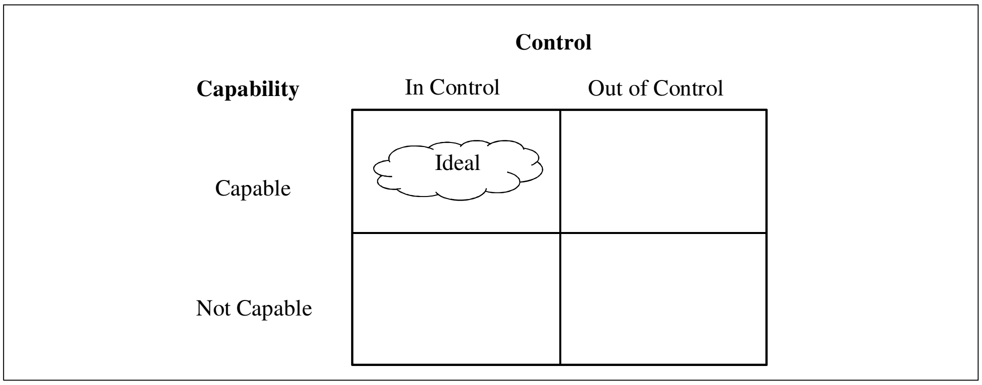
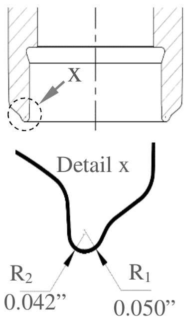
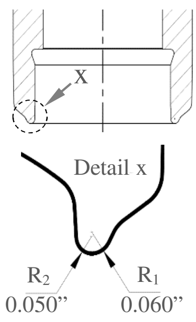


Figure 11 – Matrix in Control and Capable (IC &C) of the Process

After getting the improvement results, then determining the standardization to maintain the stability and the capability of the process, as shown in Table 14.

Table 14 – Data before and after Improvements as Standardization

No.	**Dominant Factors**	**Before**	**After**	**Standardization**
1	Air pressure was injected into the cans is fluctuated, so the DIR test results becoming unstable.	Unstable reading on the pressure gauge indicator.	Changing the pressure gauge indicator and put on the permanent mounting.	Pressure Gauge Indicator, put in calibration schedule to make well control.
2	Temperature oven dryer washer set point over then 420ºF.	Cans drying process was using one oven zone with setpoint temperature 430ºF with curing time 1 minute and 26 seconds.	Cans drying process is using two oven zones with setpoint zone 1: 385º F and zone 2: 395ºF, with curing time 2 minutes and 52 seconds.	Issue Oven Card, monthly bases, and verified by Engineering and Quality Assurance Manager.
3	*The tooling geometry* of the punch sleeve does not match for new aluminum thickness material (Y_1).	Punch Nose Radius R_1: 0.050 Inch R_2: 0.042 Inch 	Punch Nose Radius R_1: 0.060 Inch R_2: 0.050 Inch 	Revision Technical Drawing of Punch Sleeve. Documents: 0106384, Rev 1 (29-07-19).

5 CONCLUSION AND RECOMMENDATION

The study was implementing the SPC to analyze the data, PDCA to continuous improvement, CED to determine the root cause and *NGT* to determine the dominant cause factors, and then 5W1H method to manage the improvement. It's very useful and effective in creating and improves aluminum cans packaging product quality.

The fact is the average of DIR increased from 20.40 cm to 25.76 cm, the standard deviation was reduced from 1.80 to 1.48 and the potential *process capability index (Cpk)* increased from 0.48 to 1.79, it can be concluded that the process is stable and capable.

The significant impact for the company was the company to be able to use aluminum material Y_1 to produce aluminum cans packaging with high-quality standards.

To maintain the process stability and capability are always meet to the specification, it needs to be well controlled for the parameters i.e.: 1) Air pressure which is injected into the inside of the cans when doing the DIR test to make sure stables. 2) The washer-dryer oven machine the temperature setpoint needs to be controlled to do not exceed 420° F with two zones oven activation to avoid aluminum softening or annealing if any machine stops for a while. 3) To avoid the stretching during the doming process, which is caused by tooling geometry of the punch sleeve nose radius, it needed to do regular checks to maintain the clearance is match with the Y_1 materials.

At the end of this study, further discussion is needed to maintain what has been successfully achieved. The recommendations for future researchers to make it better is highly recommended to use the FMEA method because it has an RPN (Risk Potential Number) index, so it will be more accurate to make justifications establish the improvements.

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AUTHOR CONTRIBUTIONS

S.S. – conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing - original draft preparation; H.H.P. – writing - review and editing, visualization, supervision; S.H. – project administration, funding acquisition.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

APPENDIX 1

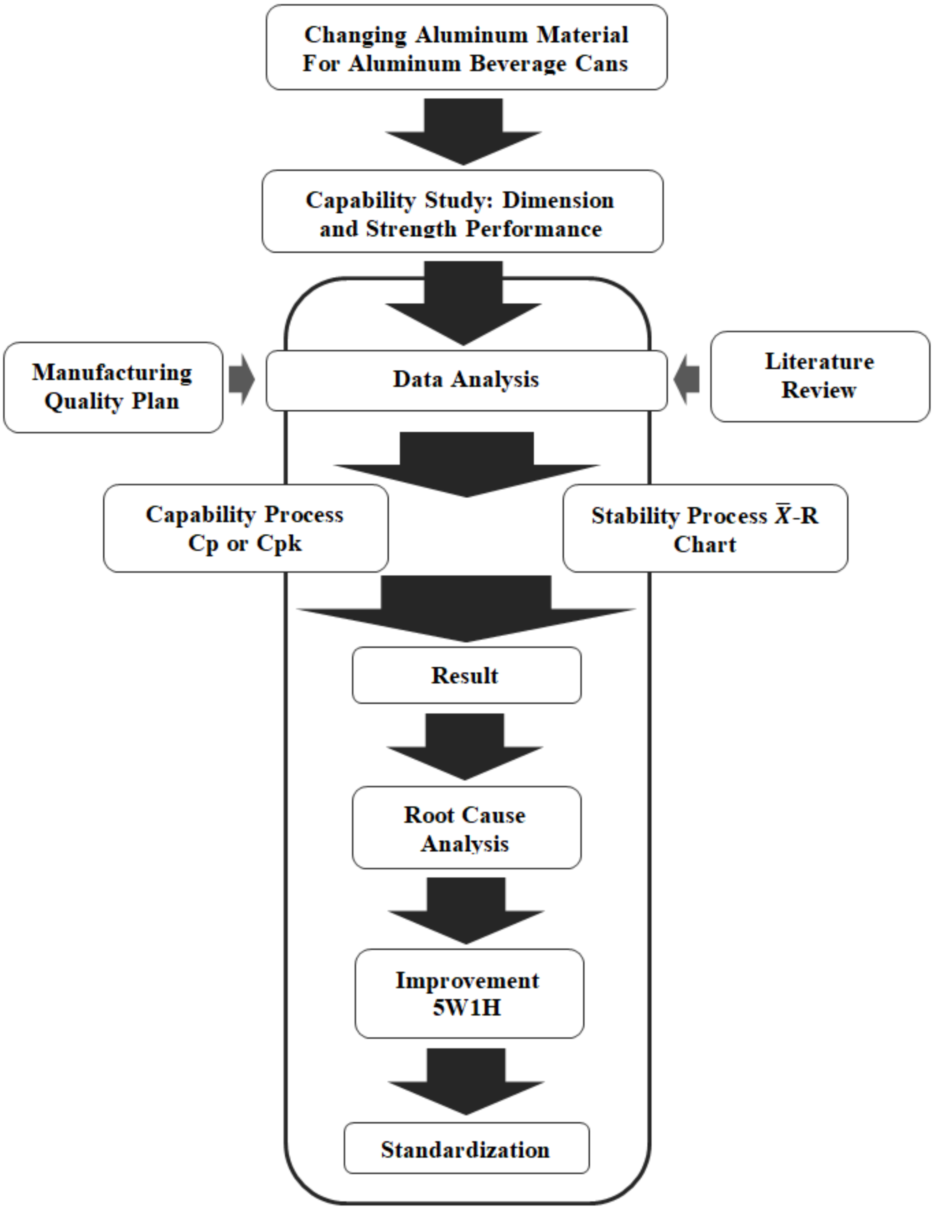

Figure A1 – Research Framework