Improving Material Efficiency on Calendering Process by Using Six Sigma and Define Measure Analyze Improve Control (DMAIC) Methods in Indonesian Leading Truck Bus Bias Tire Manufacturer

Albherd Ramadhan Putra
Master of Mechanical Engineering
Swiss German University
Tangerang City, Indonesia
albherd.putra@student.sgu.ac.id

Sumarsono Sudarto
Department of Industrial Engineering
Mercu Buana University
Jakarta Barat, Indonesia
sumarsono@elite-tutors.co.id

Aditya Tirta Pratama
Department of Industrial Engineering
Swiss German University
Tangerang City, Indonesia
aditya.pratama@sgu.ac.id

Abstract*—Companies continue to make efficiency efforts when running their business. Cost of Poor Quality (COPQ) is one of the company parameters in making efficiency. In order to suppress COPQ, increasing material efficiency needs to be done. This research aims to design a method to improve material efficiency in the calendering process of a tire manufacturing company. The method design is carried out by implementing Six Sigma and Define Measure Analyze Improve Control (DMAIC) as the main framework and several tools to support each stage. Increasing efficiency focuses on the problem of appearance treatment that is incompatible with the type of scrap that can be prevented. At the end of this study, the main factor of the nonconforming appearance of treatment is machine, method, and materials. The control to keep the improvement is by using work instructions and checksheet. Improvements to the root of the problem provide an increase in material efficiency by 23.07% in quantity and financial, and the sigma level there is shifting 0.089 to 4,178 in cord calendering process.

***Keywords*—scrap, calendering, efficiency, six sigma, DMAIC.**

I. Introduction

The export market's growth for bus-truck tires from Indonesia in the four years (2016 to 2019) grew by 58.84% (www.trademap.org, 2020). In 2016, the export tire was 19,011 pieces, and in 2019 the export was 30,198 pieces. This growth makes the tire industry, especially bus-truck tires, still attractive. Leading Truck Bus Bias Tire Manufacturer shows a fairly high gross profit margin of around 1%, surpassing the same industry at around 15%. However, the company in this case study is under pressure, so that the company's net profit margin is quite low at around 0.77%, while tire industry in general is at near 1.45%. In the midst of industrial competition, one of the steps to maintain and increase profits is making efficiency. The priority in carrying out efficiency in manufacturing companies can be done by looking at the performance of cost of poor quality. If the company is able to reduce the cost of poor quality, it means that the company is able to reduce defective products or those that do not meet quality standards that can harm the company [1]. The Cost of Poor Quality (COPQ) data in Fig. 1 has a downward trend from 2015 to 2019. However, the trend of scrap material costs has increased. This scrap of material is a lost opportunity for a case study company to maintain a profit.

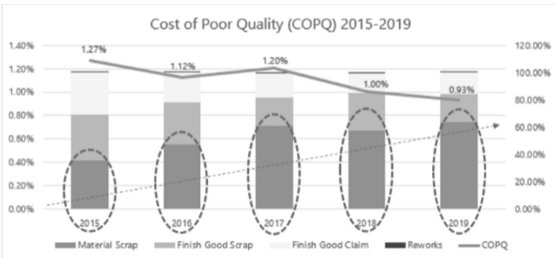

Fig. 1. Cost of poor quality trend in 2015 – 2019 (Source : Case Study Company, 2019)

Based on background and Fig. 1, the problems discussed in this paper are material scrap within calendering process scrap is around 40% of total material scrap by quantity in Fig. 2 and cost in Fig. 3.

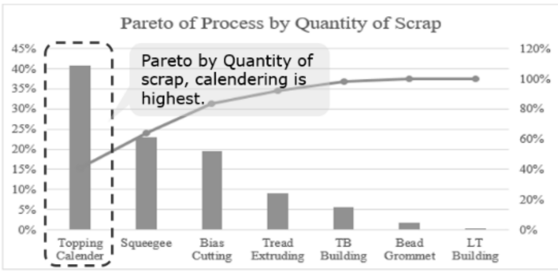

Fig. 2. Pareto process scrap by quantity in 2019 (Source : Case Study Company, 2019)

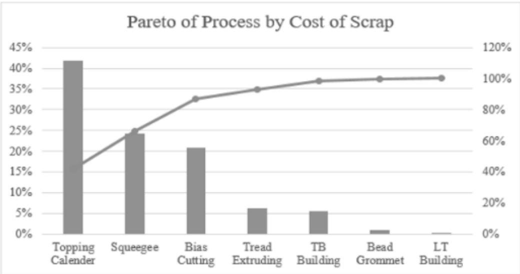

Fig. 3. Pareto process scrap by cost in 2019 (Source : Case Study Company, 2019)

Fig. 2 and Fig. 3 shows calendering is the highest contributor to material scrap in COPQ by the quantity of scrap and cost of scrap. The research problem focusses to improve the process contributed significantly to COPQ.

Interrelationship diagrams are used to illustrate the problems linkages between issues underlying this research can be seen in Fig. 4.

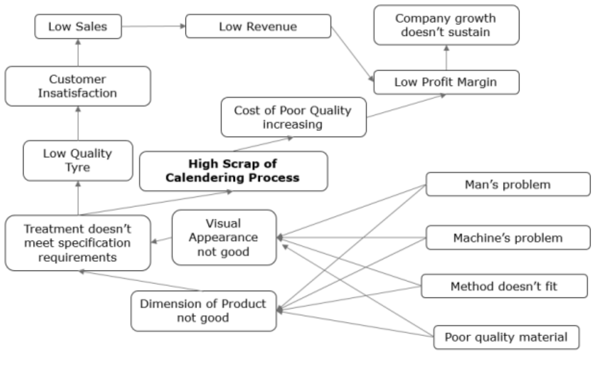

Fig. 4. Interrelationship diagram

The objective of this research is to set a design method to improve production process efficiency for reducing scrap material on the calendering process. This result's expected result is the design of a method to improve production process efficiency to reduce material scrap on Calendering Process. The expected result for academic is to provide a novel method for improving production process efficiency by reducing material scrap on the calendaring process in other manufacture, as literature for the development of related theories and provide direction and additional references for academics for further study and research on the same topic of problems. The expected finding of this research is the design of a method to improve production process efficiency could reduce material scrap on the calendering process; however, some condition should be applied.

II. LITERATURE REVIEW AND METHODS

A. Relevant Theories

Research mind map used to illustrate the linkages between item and theories underlying this research. Fig. 5 shows the research mind map of this paper.

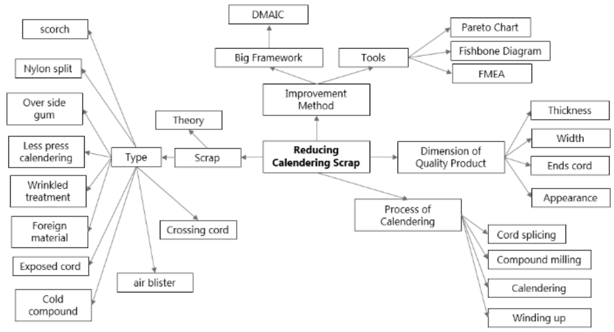

Fig. 5. Research mind map

Tires are a rubber product that is an essential component to support the automobile mechanism [2]. Tires can be divided into two types: bias Tires and radial Tires [3]. Bias Tires have body ply cords with an angle less than 90º to the tread centerline, extending from bead to bead. Belted Bias Tires are bias Tires with belts (breaker plies) added under the tread region. Radial Tires have body ply cords that are laid radially from bead to bead, nominally at 90º to the centerline of the tread [4]. Flow process of tire manufacture can be seen in Fig. 6 [5].

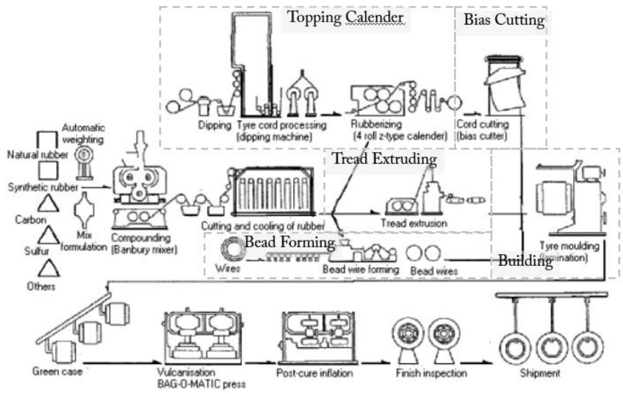

Fig. 6. Tire manufacturing flow process [5]

Calendering is one of the oldest rubber processing technologies. It is already known that coating of fabrics has been done for almost 200 years [6]. In calendaring, there is the wind-up process, and it is the process used in manufacturing industries, especially in the material storage process [7].

Six Sigma is a vision of improving quality towards the target of 3.4 defects per million opportunity (DPMO) for every product transaction (goods or services). There are efforts by enterprise toward excellence (zero defects) [8]. Six Sigma approach is organized around a five-step known as DMAIC, which stands for Define, Measure, Analyze, Improve, and Control [9]. Define how to terminates the quality problem of the process are identified. Measure the current state of the process before it is changed. Analyze the process to identify the root cause of the quality problem. Improve the process by using information obtained by analyzing phase. Control the process by confirmed and documented the improvement [10-11]. The six sigma method has proved to be very flexible and can be applied almost entirely by all industries, both large and small, and by all sectors such as manufacturing, health and laboratory services, home industry, construction, Etc. [12]. The DMAIC method is an excellent practice for improving process capability in the automotive industry [13].

In opportunity-based Measurement Concept, three variables that can be used to calculate and express defect probability-based measures, namely [14]:

- Defects per Unit (DPU)

Determine whether a process is good or not; it can be seen that the process contains defects.

$$DPU = \frac{\Sigma defect}{\Sigma Unit}\ x\ 100\ \% \tag{1}$$

- Defects per Opportunity (DPO)

The number of defects is adjusted to the chance of defects per unit. The development of the DPU concept is added with the opportunity variable.

$$DPO = \frac{\Sigma defect\ unit}{\text{Total unit x Opportunity}}\ x\ 100\ \% \tag{2}$$

- Defects per Million (DPMO)

The general formula for calculating DPMO is:

$$DPMO = DPO\ x\ 1{,}000{,}000 \tag{3}$$

- Sigma Level

The first thing to do to get the sigma level is to know the DPMO. These results can be converted to the sigma level through the sigma conversion table.

The *p*-chart is a control chart used to control the proportion of mismatches of items that do not meet the quality specification requirements or the proportion of defective products produced in a process [15].

FMEA can be classified as Process FMEA and Design FMEA. The Process FMEA is used to examine how the product or service's reliability and quality may be jeopardized the manufacturing and assembly processes [16]. The Risk Priority Number (RPN) is obtained from the multiplication of Severity, Occurrence, and Detection [17]. FMEA is one of the most effective and experienced methods to identify, classify, analyze failures, and assess risks resulting from them [18].

The Pareto principle, also known as the 80-20 rule, is based on the measurement of frequencies or occurrences that cause most problems. The rules state that 80 percent of the problems are caused by 20 percent of the causes [19]. The fishbone diagram, also called the Ishikawa diagram, is an extension of the technique used to determine the problem's root cause. It asks a series of questions to explore the relationship between cause and effect until the root cause is determined [19].

B. *Research Methodology*

In an effort to carry out this research, a structured and systematic process is needed. The steps for solving research problems can be seen in Fig. 7 as follows:

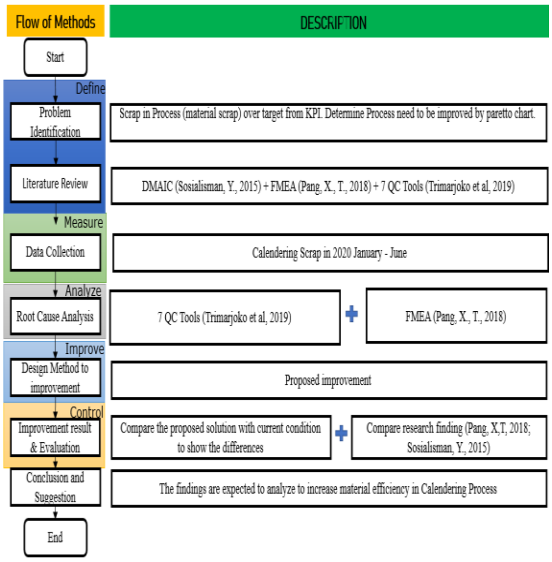

Fig. 7. Research methodology flow process

III. RESULT AND DISCUSSION

A. *Define Phase*

At this stage, the entire production process involved will be defined. How the existing process flow is identified, what inputs are needed in the preparation stage so that the process will run well will produce the outputs the company expected. The tools needed at this stage are process flow diagrams, and input process output diagrams can be seen in Table 1.

TABLE I
SIPOC IN CALENDERING PROCESS

Supplier	Input	Process	Output	Customer
Raw Material Warehouse	Nylon	Calendering	Treat-ment	Bias Cutting
Mixing	Compound			

The process flow for calendering can be seen in Fig. 8.

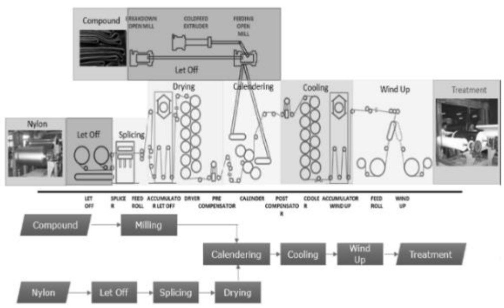

Fig. 8. Calendering flow process

Based on data collected from the company's secondary data, several categories of scrap that constituted deviations from appearance treatment can be seen in Fig. 9.

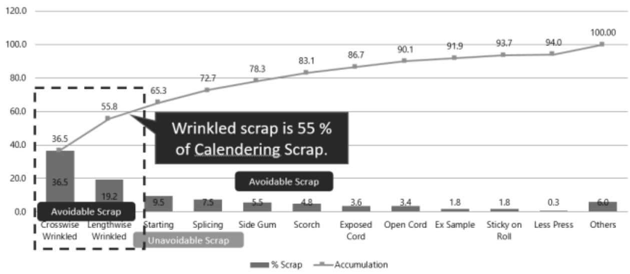

Fig. 9. Pareto of calendering scrap types/categories

Based on Fig. 9, the focus of the problem defined for analysis and improvement is included in 80% of the contributors in Pareto and is included in the category of avoidable scraps, such as wrinkled, side gum, and scorch. Starting and splicing are unavoidable scraps because the calendering technology at the beginning of the process and the joining cannot be changed, except by upgrading the existing calendering technology.

B. Measure Phase

Measure stage aims to measure the facts that will produce data and help focus on the steps for increasing quality and material efficiency. Pareto in Fig. 9 shows scrap treatment is caused because it is not visually pleasing. So that visual / appearance OK treatment becomes a Critical to Quality (CTQ) characteristic. This number of CTQs will be used to calculate the Defect per Million Opportunities (DPMO) uses (1), (2), (3). The sigma value can be seen in Table 2.

TABLE II
SIGMA LEVEL OF INDONESIAN LEADING TRUCK BUS BIAS TIRE MANUFACTURER

2020	Production (kg)	Defect / Scrap (kg)	DPO	DPMO	Sigma Value
January	2,864,440	15,510	0.005415	5,415	4.05
February	2,036,530	10,260	0.005038	5,038	4.07
March	2,519,950	12,850	0.005099	5,099	4.07
April	1,316,540	7,240	0.005499	5,499	4.04
May	504,060	2,830	0.005614	5,614	4.04
June	1,336,720	7,490	0.006503	5,603	4.04
Average	1,763,040	9,363.3	0.005311	5,311	4.05

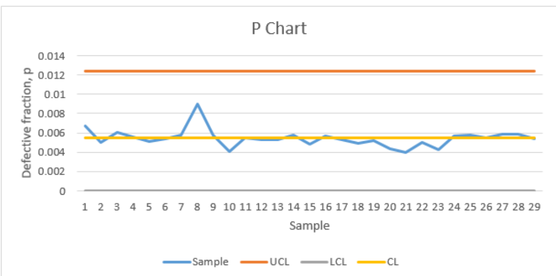

Fig. 10. *P*-Chart of calendering

After obtaining data of calendering scrap in January 2020 and determining the control limit for the *p*-chart, the data is plotted into the graph, as can be seen in Fig. 10. Based on the graph, it can be seen that defective fraction/scrap proportion is still within the control limit, and there is no special cause [8].

C. Analyze Phase

After doing the Define and Measure stage, the next stage is the analysis stage. This stage is a step to determine the main factors causing the defect that occur. The analysis uses Process Failure Mode Effect Analysis (PFMEA) and Ishikawa Diagram related to the man, machine, material, and method.

- Wrinkled Scrap

Supported by PFMEA of wrinkled treatment that available on Leading Truck Bus Bias Tire in Fig. 11, The Ishikawa diagram for wrinkled scrap was developed in Fig. 12.

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Clasification	Potential Cause(s) of Failure	Occurance	Current Process Controls Prevention	Current Process Controls Detection	Detection	RPN
Wrinkled treatment	- Blister between the plies (Blown Ply) - A portion of product to be scrapped	7		The beginning of liner winding is too short	5	The beginning of liner winding ± 45m and checked by sensor device (PIC : Prod dept)	Visual checking of the treatment appearance continuously (PIC : Prod dept)	5	175

Fig. 11. Snapshot of PFMEA for wrinkled treatment (source : Leading Truck Bus Tire Manufacturer)

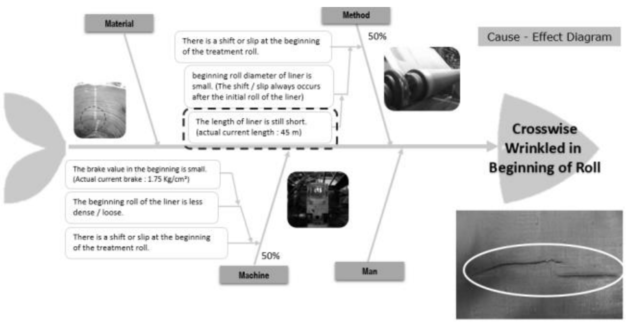

Fig. 12. Ishikawa diagram for wrinkled

The root cause of the method is the initial length of the liner is not long enough. For root cause of the machine is the brake value, in the beginning, is small where the actual current brake is 1.75 kg/cm^2.

- Side Gum Scrap

Supported by PFMEA of treatment side gum scrap that available on Leading Truck Bus Bias Tire in Fig. 13, the Ishikawa diagram for side gum scrap was developed in Fig. 14.

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Clasification	Potential Cause(s) of Failure	Occurance	Current Process Controls Prevention	Current Process Controls Detection	Detection	RPN
Treatment side gum (too many compound on the both side of treatment)	- Wrinkled Treatment on the bias cutting process. (Stucked on the cutter)	5		Side gum blade is dull	1	Sharpen the side gum blade every shift (PIC : Prod dept)	Visual checking of the treatment along the calendering process (PIC : Prod dept)	7	35
	- A portion of product to be repaired			The movement of side gum blade is less sensitive.	2	Check the movement before start. (PIC : Prod dept)	Visual checking of the treatment along the calendering process (PIC : Prod dept)	7	70

Fig. 13. Snapshot of PFMEA for side gum of treatment (source : Leading Truck Bus Tire Manufacturer)

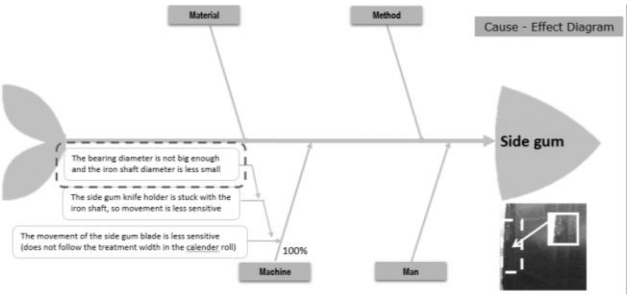

Fig. 14. Ishikawa diagram for side gum

The next root cause of the machine is the movement of the side gum blade which is less sensitive.

- Scorch Scrap

Supported by PFMEA of scorch scrap that available on Leading Truck Bus Bias Tire in Fig. 15, the Ishikawa diagram for scorch scrap was developed in Fig. 16.

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Clasification	Potential Cause(s) of Failure	Occurance	Current Process Controls Prevention	Current Process Controls Detection	Detection	RPN
Scorchy compound	- Scorchy treatment compound - A portion of product to be scrapped - Tire separation.	8		TCU of CFE 10" does not work normally.	1	Check the temperature of TCU of CFE 10" every month & after shutdown (PIC : Prod dept)	Visual checking of compound appearance continuously (PIC : Prod dept)	7	56
				Little spots compound scorch on calender roll.	2	Visual checking of the compound in open mill feeding. (PIC : Prod dept)	Visual checking of the treatment appearance (PIC : Prod dept)	7	112

Fig. 15. Snapshot of PFMEA for scorchy compound in treatment (source : Leading Truck Bus Tire Manufacturer)

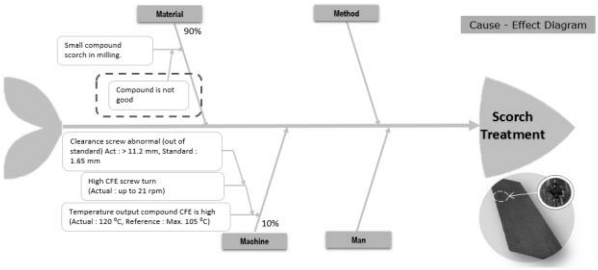

Fig. 16. Ishikawa diagram for scorch

The root cause of the material is compounded from the previous process (mixing) that is not good (NG).

D. Improve Phase

The improvement stage can be done since the analysis stage has been identified. Based on the research results, the improvements include modification to the beginning liner roll's standard length and change the brake pressure and PLC program for beginning roll, as shown in Fig. 17 and Fig. 18, respectively. Besides, modification of side gum blade holders can be seen in Fig. 19 for quarantining and returning the poor compound materials.

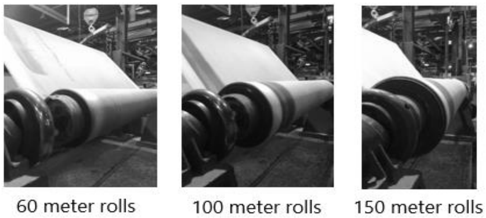

Fig. 17. Beginning liner length

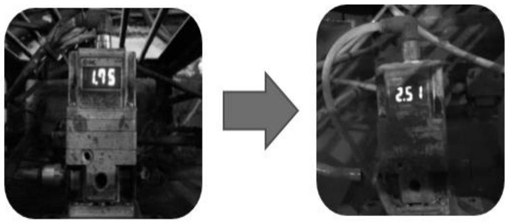

Fig. 18. Pressure brake in wind ip of calender

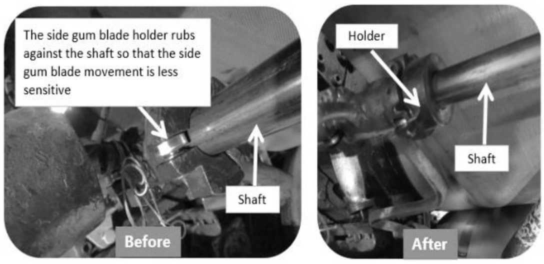

Fig. 19. Side gum blade holder improvement

Based on the calculation in Table 3 and Table 4, the cost reduction is directly proportional to the reduction in scrap, which is 23.07 %.

E. Control Phase

All attempts that can be made to keep the improvement of wrinkled scrap under control are revised in the Manufacturing Standard and prescribed into Visual Work Instruction. Control for the side gum improvement is the checksheet for the blade holder and the side gum blade condition. Also, all attempts that can be made to keep the improvement of scorch scrap under control are described in the Visual Work Instruction, especially the poor handling of the compound.

TABLE III
SUMMARY OF PERCENTAGE CALENDERING SCRAP COMPARISON

Item Scrap	Before (%)	After (%)	Change (%)
Crosswise Wrinkled	0.159	0.079	50.31
Lengthwise Wrinkled	0.093	0.093	-
Starting	0.046	0.046	-
Splicing	0.036	0.036	-
Side Gum	0.035	0.015	57.14
Scorch	0.030	0.019	36.66
Exposed Cord	0.017	0.017	-
Open Cord	0.016	0.016	-
Sticky on Roll	0.009	0.009	-
Ex Sample	0.009	0.009	-
Less Press	0.002	0.002	-
Others	0.029	0.029	-
Total	0.481	0.370	23.07

TABLE IV
SUMMARY OF CALENDERING SCRAP COMPARISON

Variables	Value	Description
Average crap Differences	0.111 %	After improvement scrap – Before improvement scrap
Percentage of Scrap Reduction	23.07 %	$\frac{Average\ Scrap\ Differences}{Before\ Improvement\ Scrap}$ x 100 %
Scrap cost before improvement	IDR 187,637,623	Average treatment production in a month (kg) x Before improvement scrap x cost of scrap per kilogram
Scrap cost after improvement	IDR 144,336,633	Average treatment production in a month (kg) x After improvement scrap x cost of scrap per kilogram
Initial investment for improvement	IDR 260,000	Based on Table 4.6
Payback Period	0.006 month (0.17 day)	$Payback\ Period = \frac{Initial\ Investment}{Total\ Benefit}$ (Using Equation 2.11)
Total Benefit	IDR 43,300,990	Total scrap cost before improvement - Total scrap cost after improvement
Percentage of Cost Reduction	23.07 %	$\frac{Average\ Scrap\ Differences}{Before\ Improvement\ Cost}$ x 100 %

IV. CONCLUSION AND RECOMMENDATION

A. Conclusion

Based on the research results, the calendering process's improvement with experiments and payback period calculation can be made by using Six Sigma and DMAIC method with combination of SIPOC, FMEA, Ishikawa Diagram, and p-chart.

The result summary shows the cost reduction is directly proportional to the reduction in scrap, which is 23.07 %. So, the improvement in calendaring process with six sigma and Define Measure Analyze Improve Control (DMAIC) can increase material efficiency by 23.07% in both quantity and financially. The sigma level also shifts to 0.089 at level 4.178 out of 6.

B. Recommendation

Recommendation and future direction from this paper :

- The company needs to make sure workers/operators follow the instruction and fills in the checksheet to control the improvement process.
- Future research may use different methodology such as the Taguchi method or Design of Experiment (DOE) to determine parameters that cause scrap categories. Besides, it can also use the Internet of Things and big data to maintain calenderings' process capability in real-time to control the improvements.

REFERENCES

[1] N. Kusmariyati, C. Sinuraya, and C. Verani, *Analisis Cost of Poor Quality Sebagai Alat Penilaian Kegiatan Perbaikan Kualitas*, 2, 2011.

[2] Y. Ishikawa, *Systematic Review of Tyre Technology*, 16, 137 2011. http://sts.kahaku.go.jp/diversity/document/system/pdf/066_e.pdf

[3] D. Beach, and J. Schroeder, "Overview of tire technology," *Rubber World*, 222 (6), pp. 44, 2000.

[4] J. G. Sommer, and J. G. Sommer, "Tires," *Engineered Rubber Products*, pp. 143–168, 2009.

[5] L. Stankevičiūtė, *Energy Use and Energy Management in Tyre Manufacturing : the Trelleborg 1 Case*, 1–45, 2000.

[6] G. Nijman, "A fundamental approach of the cord calendering process," *Rubber Chemistry and Technology*, 74 (4), pp. 715–728, 2001. https://doi.org/10.5254/1.3544969.

[7] Sugiyarto and W. Setiawan, "Analysis of motor speed effect on winding tension in the wind up calendering process," Proceeding of Conference on Management and Engineering in Industry (CMEI 2019), 1, pp. 8-13, 2019.

[8] V. Gaspersz, *Pedoman Implementasi Program Six Sigma Terintegrasi dengan ISO 9001:2000, MBNQA, dan HACCP*, Gramedia Pustaka Utama, 2002.

[9] D. Samson and P. J. Singh, *Operations management: An integrated approach. In Operations Management: An Integrated Approach*, 2008. https://doi.org/10.1017/CBO9781139150002.

[10] T. T. Allen, *Introduction to engineering statistics and lean six sigma: Statistical quality control and design of experiments and systems. In Introduction to Engineering Statistics and Lean Six Sigma: Statistical Quality Control and Design of Experiments and Systems*, 2018. https://doi.org/10.1007/978-1-4471-7420-2.

[11] Shankar, R. (2009). Process Improvement Using Six Sigma. https://books.google.ie/books?hl=en&lr=&id=pJFeNy9Z74IC&oi=fnd&pg=PR3&dq=DMAIC&ots=frlfPRwq0b&sig=pChD5SiFBpwZIgSOSMdOrdds6Mg&redir_esc=y#v=onepage&q=DMAIC&f=false.

[12] A. Trimarjoko, D. S. Saroso, H. H. Purba, S. Hasibuan, C. Jaqin, and S. Aisyah, "Integration of nominal group technique, Shainin system and DMAIC methods to reduce defective products: A case study of tire manufacturing industry in Indonesia," *Management Science Letters*, 9 (13), pp. 2421–2432, 2019.

[13] V. Gupta, R. Jain, M. L. Meena, and G. S. Dangayach, "Six-sigma application in tire-manufacturing company: a case study," *Journal of Industrial Engineering International*, 14(3), pp. 511–520, 2018.

[14] P. S. Pande, R. P. Neuman, and R. R. Cavanagh, *The Six Sigma Way - How GE, Motorola, and Other Top Companies are Honing Their Performance*, (1st ed.). McGraw-Hill, 2000.

[15] V. Gaspersz, *Statistical Process Control: Penerapan Teknik-Teknik Statistikal Dalam Manajemen Bisnis Total*, Gramedia Pustaka Utama, 1997.

[16] X. T. Pang, *Quality Improvement with PFMEA in A Manufacturing System*, 48, 2018.

[17] A. Y. Kristanto and R. Rumita, "Analisis Penyebab Cacat Kain Dengan Menggunakan Metode Failure Mode and Effect Analysis (Fmea) Dan Fault Tree Analysis (Fta)," 5 (1), pp. 1–8, 2016.

[18] M. J. Rezaee, A. Salimi, and S. Yousefi, "Identifying and managing failures in stone processing industry using cost-based FMEA," *International Journal of Advanced Manufacturing Technology*, 88(9–12), pp. 3329–3342, 2017.

[19] Boral, S. (2016). Ace the PMI-ACP® exam. In Ace the PMI-ACP® exam. https://doi.org/10.1007/978-1-4842-2526-4.