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Optimizing packaging process efficiency and quality control at a black carbon manufacturer through lean six sigma and design of experiment

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ABSTRACT

CI is a multinational company that involves manufacturing carbon black. The carbon black is packed in a 1250 kg jumbo bag and a 25 kg paper sack. Based on reject weight data for December 2019, 4.4% of paper sacks were rejected, with some caused by suboptimal packer machine settings. The study will use the design of experiment to determine critical quality factors for carbon black grade Sterling-V, identify waste in the packaging process, determine the sigma value in the packaging process, identify factors causing product defects, evaluate the risk priority number, and provide suggestions for optimal packaging machine conditions through factorial experiments. The reject weight of Sterling-V products due to reject weight was 123 out of the total production. The study results showed a sigma level of 2.205, with the engine factor being the main cause of reject weight (RPN 900). The optimal packaging machine conditions proposed for Sterling-V grade are Bulk Fill Cut Off (22.5 kg), High Pressure Air (7 bar), and Trim Final Cut Off (25 kg), which can reduce reject weight to 23 from total production.

1. Introduction

Product quality is fitness for use to meet customer needs and satisfaction [1]. Quality plays an important role in the process of product production to suit the needs of consumers. It states that quality control is a system of verifying and maintaining the desired level of product or process quality with careful planning, use of appropriate equipment, continuous inspection, and corrective action if necessary [2], [3].

CI is a multinational petrochemical company that produces carbon black that can be used in a variety of needs such as for household needs, infrastructure development, the tire industry, ink printing, reinforcing agents for the use of plastic, paper, and building materials. Carbon black is defined as a black material in the form of powder or granules formed through the combustion process of hydrocarbon fuels such as oil, gas, or acetylene with excess air supply [4].

CI produces 8 grades of carbon: Sterling-V, Sterling-SO, Vulcan-3, Vulcan-7H, Regal-300, Vulcan-6, Sterling-NS, and Spheron-SO. Carbon black that is produced through the production process after completion will be stored in SILO and then will go through the packaging process in the form of jumbo bags (1250 kg) and paper sacks (25 kg). The packaging process at CI is a line that should be highlighted by its performance. This is because in the paper sack packaging process, there were still around 4.4% of reject weight products (heavy incompatibility with company specifications is 25 ± 0.3) in December 2019, while the reject weight limit received by the company is only 1.8% of the product [5]. This is caused by one of them by the engine factor. Each carbon grade that will be packaged with a packer machine should have a different machine setting because it is related to the characteristics of each different carbon grade. However, currently only 1 packer engine setting is used for all carbon grades because the other engine settings are lost due to blackouts that occur due to power outages. As a result, many paper sacks lose weight due to mismatches to these settings, plus the age of the old machine which is around 25 years.

Based on these problems, in this research, a lean six sigma implementation is carried out to determine the sigma value of the process and to know the dominant causes of defects and process inefficiencies due to waste, which then these factors will be corrected in the improve stage with the design of experiment which can produce the proposed optimal conditions for the process.

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2. Material and method

In this study, the application of the DMAIC cycle (Define, Measure, Analyze, Improve, Control) is carried out. At the define stage, the problem is identified through the creation of a project charter, SIPOC diagram, packaging process flow, determination of Critical to Quality, waste identification, Value Stream Mapping Analysis Tools, Process Activity Mapping, and Big Picture Mapping [6], [7]. In the measure stage, calculations are performed using the data adequacy test, I-MR control chart, Revised I-MR control chart, process capability analysis, determination of sigma value, bar chart, and current state process activity mapping [8].

At the analyze stage, an analysis of the causes of the problem is conducted by creating a fishbone diagram and performing failure mode and effect analysis [9]. In the improve phase, improvements are made to the design of experiment method, process activity mapping, big picture mapping, and future stream mapping. Finally, in the control stage, a comparison is made between conditions before and after improvement using the I-MR control chart, process capability analysis, determination of sigma values, hypothesis testing, and standardization based on the best optimal conditions [10].

3. Results and discussions

3.1. Define

The define phase is the first operational step in the six-sigma implementation process, which involves identifying the problem at hand. The initial stage is the project charter, which outlines the research objectives and scope [11]. Based on the project charters created the problem in this study is related to performance packaging, where the number of rejects exceeds the company's allowable limit of 1.8%. In December, the number of rejects reached 4.4%. These rejects occur due to mismatches in weight size specifications, requiring rework in the form of adding or reducing carbon black, which is considered waste and reduces work efficiency.

To illustrate the flow of carbon black products, a SIPOC diagram is created, providing information about suppliers, inputs, processes, outputs, and customers [12]. Additionally, a packaging process flow is established to depict the packaging process line. Figures 1 and 2 show the SIPOC diagram and the packaging process flow, respectively. The grade to be examined is determined based on the highest number of rejects observed in December, specifically the sterling-v grade at 14.75%. The CTQ reject weight is then determined, including overfilling, underfilling, and rejection issues.

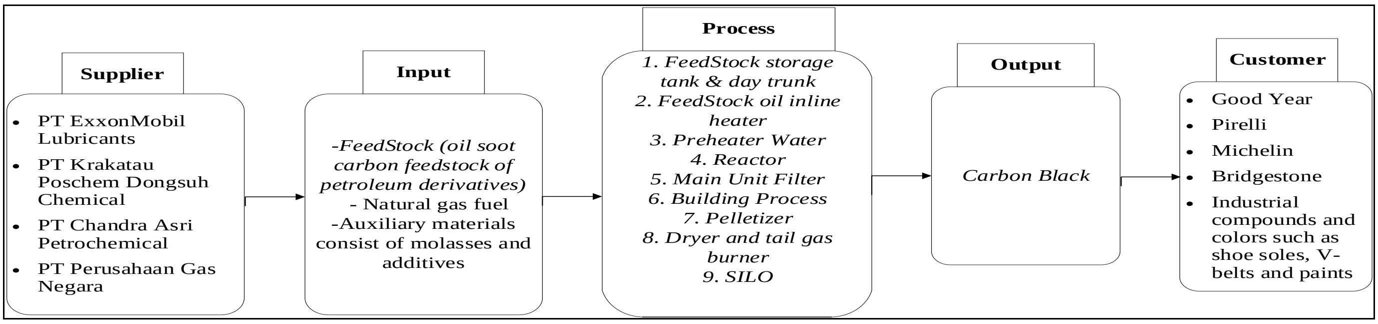

Figure 1. SIPOC diagram

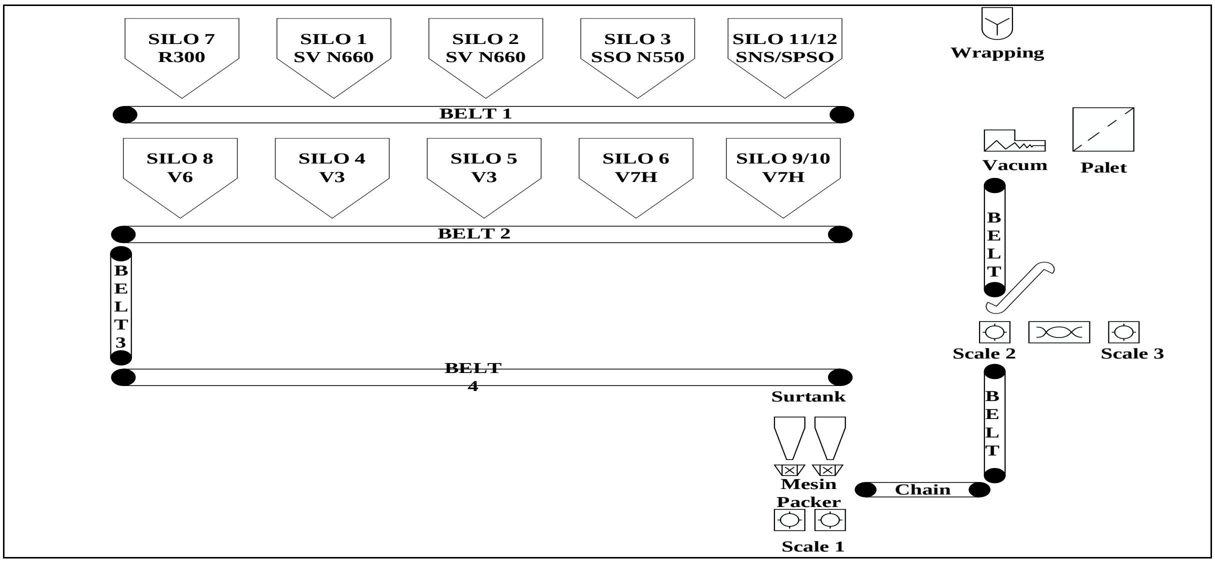

Figure 2. Flow process of packaging

Table 1.
Waste assessment

No	Waste Type	Score
1	Over Production	1
2	Excessive Transportation	4
3	Waiting	3
4	Inappropriate Processing	4
5	Unnecessary Inventory	1
6	Unnecessary Motion	3
7	Defect	4
	Total	20

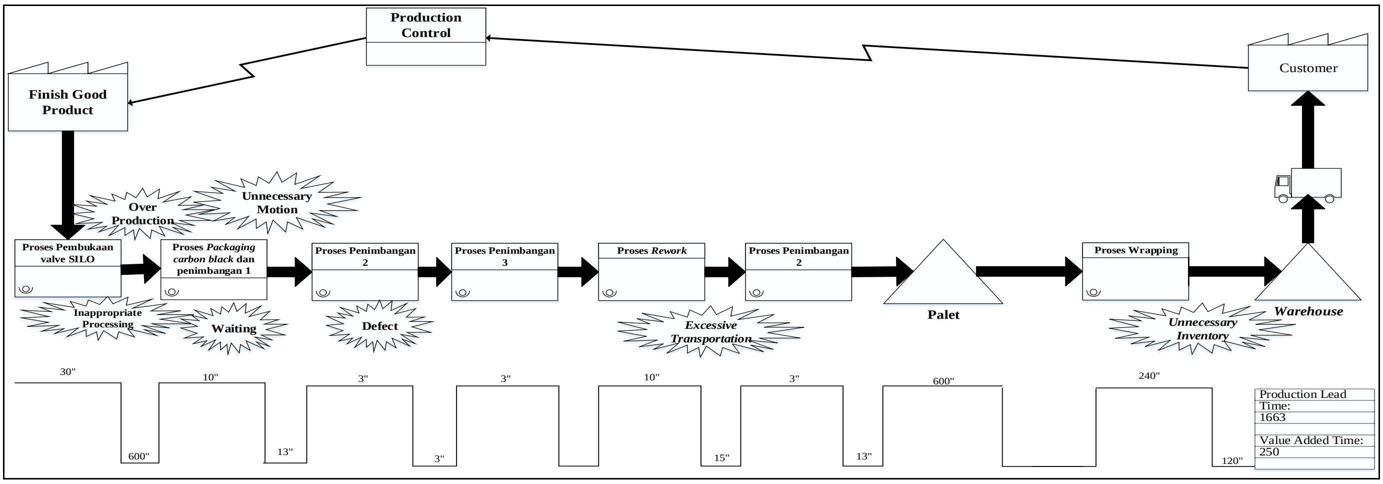

Figure 3. Current state mapping

The next step involves identifying waste to understand what is happening on the packaging line, using the concept of the 7 types of waste. The selection of the best mapping tools is based on the waste identification scores. In this study, process activity mapping obtained the highest score of 134.

Consequently, a process activity mapping is created to identify each activity on the packaging line as Value Added Activities (VA), Necessary but Non-Value-Added Activities (NNVA), or Non-Value-Added Activities (NVA). Table 1 presents the waste identification scores, and Table A1 (see Appendix) displays the process activity mapping.

3.2. Measure

At this stage, the following calculations are performed: the data adequacy test, the I-MR control chart, the revised I-MR control chart, process capability, sigma determination, bar charts, and current state mapping. Based on the results of the data adequacy test, it was declared that 100 samples taken were sufficient. To determine whether the process is statistically controlled or not, an I-MR control chart is created, and the results show that it is not yet under control. Therefore, it is necessary to create a revised I-MR control chart by removing out-of-control data points on the I-MR control map. Based on the results of the process capability analysis, it was found that the process has a Cp value of 0.59 and a Cpk of 0.37, which classifies it as a low process capability since Cp < 1. The sigma capability level is then determined using a formula for variable data, considering that the measurement is in kilograms. The resulting sigma value for the company is 2.205, which falls within the Indonesian industry average. It is observed that the percentage of CTQ (Critical to Quality) causing the highest reject weight product is lower by 5.2%, while it is higher by 1.8% for other factors and 0.8% for rejection issues. Lastly, based on the calculations for the current state mapping, the value-added ratio is determined to be 17.44%. Figure 3 depicts the current state mapping.

3.3. Analyze

At this stage, an analysis of the causes of the problem takes place, utilizing a fishbone diagram and failure mode and effects analysis (FMEA). Fishbone diagrams are employed to visually represent the cause-and-effect relationship of a failure across various factors [13], [14]. Fishbone diagram for unnecessary motion is presented in Figure 4. Subsequently, a failure mode ranking based on the RPN (Risk Priority Number) value in the failure mode and effects analysis is presented in Table A2. The results of the failure mode and effects analysis reveal that the engine factor exhibits the highest RPN value and therefore represents a failure mode that requires improvement.

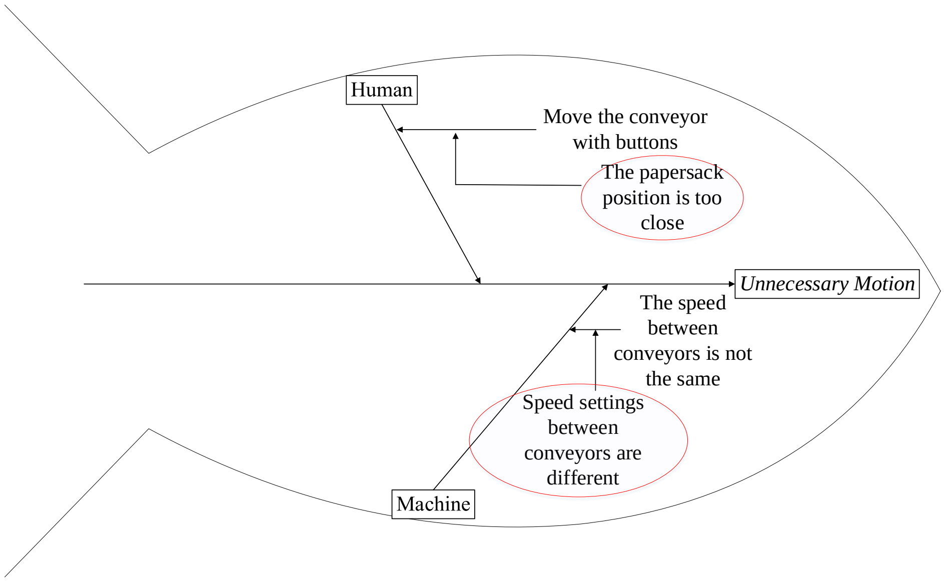

Figure 4. Fishbone fiagram for unnecessary motion

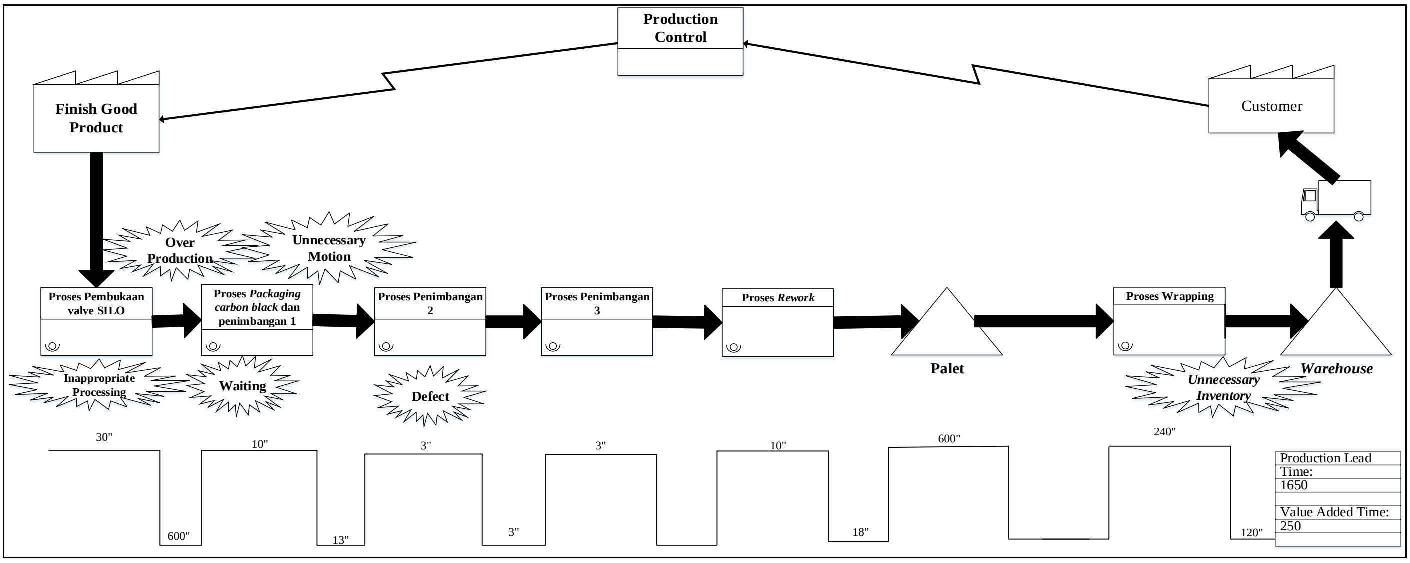

Figure 5. Future state mapping

3.4. Improve

Improvement is implemented after identifying the root cause of the problem, in the form of an action plan [15], [16]. In this research, the improvement takes the form of a design of experiment for machine factors and the creation of a future stream mapping.

Based on the FMEA results, the engine factor was identified as the area for improvement. The experimental factorial design used in this study was a 2^3 design, consisting of 3 factors with 2 levels, and it was replicated 4 times. The data table displaying the amount of reject weight for each treatment is presented in Table A3 (see Appendices). The data will be subjected to an ANOVA test to determine the impact of each treatment on the amount of reject. The ANOVA results are shown in Table A4 (see Appendices). Treatments that were found to have a significant effect will undergo further testing after the experiment to determine the optimal process conditions using the T-2 sample test and the least significant difference test. Based on the post-experiment test results, the optimal process conditions are achieved by setting a bulk fill cutoff of 22.5 kg, a trim/final cut off 25 kg, and a high-pressure water level of 0.7 bar.

The next step is the construction of future state mapping. At this stage the proposed process activity mapping is given as shown in Table A5 (see Appendices) and the results obtained in the calculation of future stream mapping can increase the value-added ratio to 17.58%. The future stream mapping is shown in Figures 5.

4. Conclusions

Critical to quality issues that arise in the packaging process at CI include Over Filling, Less Filling, and Rejection Issues. The waste occurring in the packaging process is categorized as follows: Waste Over Production (score of 1), Excessive Transportation (score of 4), Waiting (score of 3), Inappropriate Processing (score of 4), Unnecessary Inventory (score of 1), Unnecessary Motion (score of 3), and Defects (score of 4). The sigma value for the packaging process at CI is determined to be 2.205, which falls within the Indonesian industry average.

Factors contributing to product defects in the packaging process at CI are as follows: Human factor (operating the machine when the tank is empty and the operator chasing the target) material factor (carbon with numerous lumps), method factor (placing paper sacks too close), engine factor (instability in High-Pressure Air, inappropriate settings for carbon grade and errors in scales), environmental factor (carbon scattered in the scales container). The engine factor, specifically the failure mode of the receipt/setting of the machine not matching the carbon grade, has the highest Risk Priority Number with a value of 900.

The proposed optimal conditions for the packaging process to enhance the quality of CI involve using the settings of the packer machine with a bulk fill cut-off value of 22.5 kg, High Pressure Air set at 0.7 bar, and a Trim/Final Cut Off of 25 kg.

Declaration statement

Achmad Bahauddin: **Conceptualization, Methodology, Supervision**, **Software, Writing - Original Draft**. Dyah Lintang Trenggonowati, Atia Sonda, Vira Aleyda Yusuf: **Conceptualization, Resources.** Ade Irman Saeful Mutaqin: **Writing - Review & Editing, Data curation**. Ani Umyati: **Resources, Validation**, **Writing - Review & Editing.**

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The authors report there are no competing interests to declare.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

References

[1] F. Filardi, D. Berti, and V. Moreno, "Implementation Analysis of Lean Sigma in IT Applications. A Multinational Oil Company Experience in Brazil," *Procedia Computer Science*, vol. 55, pp. 1221–1230, Jan. 2015, doi: 10.1016/j.procs.2015.07.128.

[2] Y. Latief and R. P. Utami, "Penerapan Pendekatan Metode Six Sigma Dalam Penjagaan Kualitas Pada Proyek Konstruksi," MAKARA Technol. Ser., vol. 13, no. 2, pp. 67–72, 2010, doi: 10.7454/mst.v13i2.471.

[3] I. Panagopoulos, C. Atkin, and I. Sikora, "Developing a performance indicators lean-sigma framework for measuring aviation system's safety performance," *Transportation Research Procedia*, vol. 22, pp. 35-44, Jan. 2017, doi: 10.1016/j.trpro.2017.03.005.

[4] A. Ridwan, P. F. Ferdinant, and R. Aldiandru, "Perancangan perbaikan lean six sigma dalam proses produksi baja tulangan dengan integrasi value stream mapping dan design of experiment," *Journal Industrial Servicess*, vol. 3, no. 2, Mar. 2018, doi: 10.36055/jiss.v3i2.3169.

[5] S. Sandi, M. Ulfah, and Putro Ferro Ferdinant, "Usulan perbaikan kualitas produk pipa baja las spiral menggunakan metode six sigma berdasarkan design of experiment (DOE) di PT. XYZ," *Jurnal Teknik Industri Untirta*, vol. 5, no. 1, 2017, doi: 10.36055/jti.v0i0.1810.

[6] R. Kaban, "Pengendalian Kualitas Kemasan Plastik Pouch Menggunakan Statistical Procces Control (SPC) di PT Incasi Raya Padang," *J. Optimasi Sist. Ind.*, vol. 13, no. 1, pp. 518–547, 2014.

[7] M. G. Huddle, A. Tirabassi, L. Turner, E. M. Lee, K. Ries, and S. Y. Lin, "Application of Lean Sigma to the Audiology Clinic at a Large Academic Center," *Otolaryngology–Head and Neck Surgery*, vol. 154, no. 4, pp. 715–719, Feb. 2016, doi: 10.1177/0194599815627774.

[8] F. W. Breyfogle, *Implementing Six Sigma: Smarter Solutions Using Statistical Measures*. John Wiley & Sons, Inc.: New York, 1993.

[9] M. L. George, *Lean Six Sigma*. Dallas: George Group, 2002.

[10] M. N. K. Amrullah, "Penerapan Six Sigma Dalam Rancangan Percobaan Faktorial Untuk Menentukan Setting Mesin Produksi Air Mineral," *J. Gaussian*, vol. 5, no. 1, pp. 143–152, 2016.

[11] J. Jonny and J. Christyanti, "Improving the Quality of Asbestos Roofing at PT BBI using Six Sigma Methodology," *Procedia-Social and Behavioral Sciences*, vol. 65, pp. 306–312, Dec. 2012, doi: 10.1016/j.sbspro.2012.11.127.

[12] B. Santoso and M. Hastarina, "Pendistribusian Minyak Avtur Dengan Metode One Way Annova Di SPBU SMB II Palembang," *Integr. J. Ilm. Tek. Ind.*, vol. 3, no. 1, 2018.

[13] W. R. Dewi, "Implementasi Metode Lean Six Sigma sebagai Upaya Meminimasi Waste pada PT. Prime Line International," *J. Rekayasa dan Manaj. Sist. Ind.*, vol. 1, no. 1, pp. p47-56, 2013.

[14] N. Diwangkari, "Analisis Keragaman Pada Data Hilang Dalam Rancangan Kisi Seimbang," *J. Gaussian*, vol. 5, no. 1, pp. 153–162, 2016.

[15] A. S. Patel and K. M. Patel "Critical review of literature on Lean Six Sigma methodology," *International Journal of Lean Six Sigma*, vol. 12, no. 3, pp. 627–674, 2020, doi: 10.1108/IJLSS-04-2020-0043.

[16] J. M. Glasgow, J. R. Scott-Caziewell, and P. J. Kaboli, "Guiding Inpatient Quality Improvement: A Systematic Review of Lean and Six Sigma," *The Joint Commission Journal on Quality and Patient Safety*, vol. 36, no. 12, pp. 533-AP5, Dec. 2010, doi: 10.1016/s1553-7250(10)36081-8.

Appendices

Table A1.
Process activity mapping

No	Packaging Process Activities	Activity Type					Activity Properties			Machine/ Tools	Distance (m)	Time (s)
		O	T	I	S	D	VA	NNVA	NVA			
1	SILO valve opening process	✓					✓			SILO Valve	-	30
2	Transfer of carbon black from SILO via belt 1 or 2		✓					✓		*conveyor belt*	61,5	150
3	Transfer of carbon black from belt 1 or 2 to belt 3		✓					✓		*conveyor belt*	30	150
4	Transfer of carbon black from belt 3 to belt 4		✓					✓		*Conveyor*	45	150
5	Transfer of carbon black from belt 4 to sur-tanks 1 and 2		✓					✓		*Sur-tank*	10	150
6	The process of packing carbon black with a packer machine and weighing it with a scale 1	✓					✓			*packer machine*, scale	-	10
7	Transfer of scales 1 to scales 2 with a conveyor		✓					✓		*Conveyor*	5	13
8	The process of weighing carbon black use scales 2			✓				✓		scale 2	-	3
9	Transfer from scale 2 to scale 3		✓					✓		*Roll*	2,5	3
10	The process of weighing carbon black use scales 3			✓				✓		scale 3	-	3
11	*Rework* process	✓					✓			Shovel	-	10
12	Transfer from scale 3 to scale 2		✓					✓		Operator	4,5	15
13	The process of weighing carbon black returns use scales 2	✓						✓		scale 2	-	3
14	Transfer from second scale to pallet by conveyor		✓					✓		*Conveyor, vacuum*	15	13
15	Waiting for a full palette of 50 packs of carbon black					✓		✓		Palette	-	600
16	Palette *wrapping* process	✓					✓			*Wrapping tool*	-	240
17	Carbon black pallets are stored in the warehouse				✓			✓		*Forklift*	20	120

Table A2.
FMEA

No	Mode of Failure	Cause of Failure	Effect of Failure	Severity	Occurrence	Detection	RPN	Rank
1	Operate the machine when the sur-tank is empty	Error on the left lamp	Produce paper sack with less filling because it contains more dust and wind	8	4	6	192	6
	The operator does not fold the paper sack	Operator hit the target		5	7	3	105	8
2	Lots of carbon lumps	Humid Carbon	Produce paper sack with less filling because it contains more dust and wind	7	7	6	294	4
3	Produce paper sack with less filling because it contains more dust and wind	The process of packing by feeling	Two adjacent items reject over	8	6	5	240	5
		Conveyor speed is different						
4	Unstable HPA	There is only one compressor	Less/over reject goods due to unstable pressure	8	8	6	384	3
	error scale	Unstable weighing process	There is a rejection issue due to inaccurate scales, less/over due to differences in measurement results	9	9	9	729	2
	the paper sack position hangs on the scale holder	The scale buffer is too low	the measurement results are biased due to the position of the paper sack touching the support and not	3	8	6	144	7
	Receipt / machine settings do not match the carbon grade	The machine program does not record other receipts when they are blank out	It causes over/less because the receipts used do not match the density of carbon	10	10	9	900	1
	Scales 2 do not record data	The conveyor on the Toledo scale is tilted, the Toledo scale sensor sometimes doesn't turn on	data is not recorded to the system	7	5	2	70	10
5	Carbon splattered in the weighing pan	The weighing container has a hollow	Causing an error in calculating the scales 1	2	8	6	96	9

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Table A3.
Data reject weight

		Bulk Fill Cut Off (ai)				
		22,5		21,5		
		HPA (bj)		HPA (bj)		Total of k
		0,7	0,8	0,7	0,8	
Trim/Final Cut Off (ck)	25	2	14	4	8	
		10	12	8	25	
		2	17	5	19	
		3	18	6	18	
	Total	17	61	23	70	171
	24,5	4	15	12	7	
		3	8	10	3	
		5	11	8	4	
		7	13	13	6	
	Jumlah	19	47	43	20	129
	Total of ijk	36	108	66	90	300
	yijk2	216	1532	618	1484	3850

Table A4.
ANOVA result

Source	Degree of Freedom	Sum Square (SS)	Mean Square (MS)	F-calculated	F-table
Bulk Fill Cut Off(ai)	1	4,5	4,5	0,38	4,26
High Pressure Air (bj)	1	288	288	24,21	4,26
Trim/Final Cut Off (ck)	1	55,125	55,125	4,63	4,26
Bulk Fill Cut Off(ai) x HPA (bj)	1	72	72	6,05	4,26
Bulk fill Cut Off (ai) x Trim/Final Cut Off (ck)	1	10,125	10,125	0,85	4,26
HPA (bj) x Trim/Final Cut Off (ck)	1	231,125	231,125	19,43	4,26
Bulk Fill Cut Off (ai) x HPA (bj) x Trim/Final Cut Off (ck)	1	91,125	91,125	7,66	4,26
Error	24	285,5	11,9		
Total	31	1037,5			

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Table A5.
Proposed process activity mapping

No	Packaging Process Activities	Activity Type					Activity Properties			Machine/Tools	Distance (m)	Time (s)
		O	T	I	S	D	VA	NNVA	NVA			
1	SILO valve opening process	✓					✓			SILO Valve	-	30
2	Transfer of carbon black from SILO via belt 1 or 2		✓					✓		conveyor belt	61,5	150
3	Transfer of carbon black from belt 1 or 2 to belt 3		✓					✓		conveyor belt	30	150
4	Transfer of carbon black from belt 3 to belt 4		✓					✓		Conveyor	45	150
5	Transfer of carbon black from belt 4 to sur-tanks 1 and 2		✓					✓		Sur-tank	10	150
6	The process of packing carbon black with a packer machine and weighing it with a scale 1	✓					✓			Packer machine and scale 1	-	10
7	Transfer of scales 1 to scales 2 with a conveyor		✓					✓		Conveyor	5	13
8	The process of weighing carbon black use scales 2			✓				✓		scale 2	-	3
9	Transfer from scale 2 to scale 3		✓					✓		Roll	2,5	3
10	The process of weighing carbon black use scales 3			✓				✓		scale 3	-	3
11	Rework process	✓					✓			Shovel	-	10
12	Transfer from scale 3 to conveyor		✓					✓		Operator	1,5	5
13	Transfer from conveyor to palette		✓					✓		conveyor and vacuum	15	13
14	Waiting for a full palette of 50 packs of carbon black					✓		✓		Palette	-	600
15	Palette wrapping process	✓					✓			Wrapping tool	-	240
16	Carbon black pallets are stored in the warehouse				✓			✓		Forklift	20	120