

# The use of Lean Six Sigma to improve the quality of coconut shell briquette products



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**Abstract** Lean Six Sigma is a systematic and scientific operations management methodology aimed to improve the performance of their manufacturing processes through the elimination of waste. The objective of this paper is to analyse the problem of increasing demand of briquettes in BriqCo (Briquettes Coconut shell Charcoal) company. In this case, the company has a waste problem due to defective products amounting to 10.2% of the total production of 169,298 kg. The high defects cause the company to suffer losses profits due to the re-production process of defects and a decrease in selling because of the unsuitable quality. This study uses the Lean Six Sigma – Define, Measure, Analyze, Improve, Control (DMAIC) method. The define stages use the SIPOC diagram to determine the elements involved in the production process and Value Stream Mapping. Measure stages to determine the level of sigma based on production results. The analyze uses a fishbone diagram to determine the root cause problems. In improve, the application of the 5S Method and Standard Operating Procedures (SOP) proposed for a work improvement process that aims to improve the production process. In Control stage, the application of new SOP conducted to improve the production process in order to reduce defects. Based on the results, the initial sigma level reached 3.19. The causes of defects in briquette products consist of human, material, machine, method and environmental factors. With the application of 5S through SOP, it is expected that the level of disability will decrease by 50%.

**Keywords:** Lean six sigma, DMAIC, improve quality

## 1. Introduction

Every manufacturing company naturally struggles to hold a dominating market share and almost all market sectors fight to establish dominance. The primary objective of any company is to improve profits, which largely depends on the quality of its products or services. If a company endeavours to increase sales, it must first improve its pricing and the quality of its products and services (C.R and Thakkar 2019). The Six Sigma ( $6\sigma$ ) method is used by both the service and manufacturing industries (Muraleedharan et al 2017). After the success of the  $6\sigma$  method at Motorola®, its Define, Measure, Analyze, Improve, Control (DMAIC) method; a systematic technique that is used when routine checks fail to identify the flaws or root causes of a problem, rose in popularity among companies aiming to improve the quality of their products or services. The primary objective the  $6\sigma$  method is to decrease the number of defects per million opportunities (DPMO). Table 1 provides the DPMO limits of all six  $\sigma$  levels (Montgomery 2009).

**Table 1** DPMO per Sigma level increase.

$\sigma$ level	Specified Limits (%)	DPMO
1	30.23	697,700
2	69.13	608,700
3	93.32	66,810
4	99.379	6,210
5	99.9767	233
6	99.99966	3.4

As such, this present study used the DMAIC method to decrease the amount of waste that BriqCo Charcoal Indonesia (Briqco) produces during its coconut shell charcoal briquettes (CSCBs) production process. In the DMAIC method, a primary objective of the mechanism in question is conducted in the *Define* phase to identify the challenges that a company faces as well as waste- and defective product-related issues at every step, all of which increases a company's losses. Tools; such as the Supplier, Input, Processing, Output, Customer (SIPOC) and a Current State Value Stream Mapping (VSM) diagrams; are used to analyse the mechanism and identify opportunities to potentially decrease the number of errors. Data on the appropriate



variables and high-quality appearances are then collected during the *Measure* phase and used to calculate the  $\sigma$  level, which indicates the company's current level of performance. The data gathered in the Measure phase is analysed in the *Analysis* phase. Techniques; such as cause-and-effect diagrams and brainstorming; are used to identify the multiple different causes of the aberrations that occur during the production process and result in defective products. During the *Improvement* phase, methods of improving the company's performance are brainstormed and executed before a Future State VSM diagram is used to analyse the newly proposed improvements. Lastly, in the *Control* phase, the actions required to sustainably continue using the newly proposed improvements are added to the company's Standard Operating Procedure (SOP) manual as new standards.

## 2. Literature Review

In recent years, many organisations have adopted the DMAIC method to enhance the quality of their products and decrease the amount of waste generated during the production process. For instance, C. R. and Thakkar (2019) used the DMAIC method; a Lean 6 $\sigma$  process; to decrease the rejection rate when manufacturing door fittings for a telecommunication cabinet. Meanwhile, Ahmed (2019) used the DMAIC method to improve the performance of a healthcare company while Arafah (2015) used it to regularly execute lean manufacturing principles and practises to enhance the production process of a company that manufactures fire-resistant and safe metal windows, doors, and frames. Alkahtani et al (2016) used the DMAIC method to investigate increasing flour consumption during a company's wafer biscuit production process as it reduces profit and client satisfaction. Kaushik and Khanduja (2009) used the 6 $\sigma$  technique in the process industry to decrease the amount of water that thermal power plants require, which lowers cost. Prashar (2020) used the DMAIC method to resolve environmental issues in the process industry while Sharma et al (2018) used it to improve the quality of the anodising stage of the amplifier production process. Guo et al (2019) used a VSM diagram and the DMAIC method to develop a new model for concurrent Lean-Kaizen in the assembly line of the air-conditioning production process. Meanwhile, Gandhi et al (2019) used the DMAIC method to decrease the rejection rate when manufacturing cylinder blocks at a casting facility. Jamil et al (2020) suggested using a DMAIC-based method to develop a feasible VSM diagram of a sustainable manufacturing process. Rini (2021) has implemented the DMAIC concept using the A3 report as a form of applying lean thinking which has succeeded in providing good improvements to plastic injection companies. Mishra and Sharma (2014) developed a hybrid framework that combined the SIPOC diagram with the DMAIC method to improve the dimensions of the supply chain management process in a supply chain network. Upon reviewing extant studies, this present study used the the DMAIC method of Lean 6 $\sigma$  to decrease the rejection rate of CSCBs produced by Briqco and used VSM and SIPOC diagrams to investigate the issues that the company faces when attempting to increase CSCBs demand. The implementation of lean tools such as VSM and fishbone diagrams in solving this waste problem has been widely applied by researchers to deal with waste problems in companies and has proven to be successful as has been done by (Ishak et al 2022 and Khasanah et al 2021). Other tools that have proven to be applicable in the implementation of lean thinking are simulation and standardize work (Mohamad et al 2016 and Mohamad et al 2013). Therefore, the implementation of the tolls in this study was also practiced.

## 3. Materials and methods

The objective of this study was to improve the demand for Briqco's CSCBs by decreasing the amount of waste produced during the CSCBs production process. The data used in this present study was obtained by analysing the CSCBs production process on the shop floor. A thorough literature review was first conducted on the phases of the DMAIC method as well as the numerous tools that could be used at each stage of the 6 $\sigma$  method for small and medium-sized enterprises (SMEs). The DMAIC method is a sequential five-step model in which every stage has a defined purpose, requires inputs, and creates an output using the tools required according to the Plan-Do-Check-Act (PDCA) framework. The tools that were used at each stage of this present study were selected after analysing the literature review and brainstorming with the company owner and an academic expert. As seen in Figure 1, this present study used tools; such as a Pareto analysis, VSM diagram, SIPOC diagram, fishbone diagrams, and control charts to name a few; at the different stages of the DMAIC method.

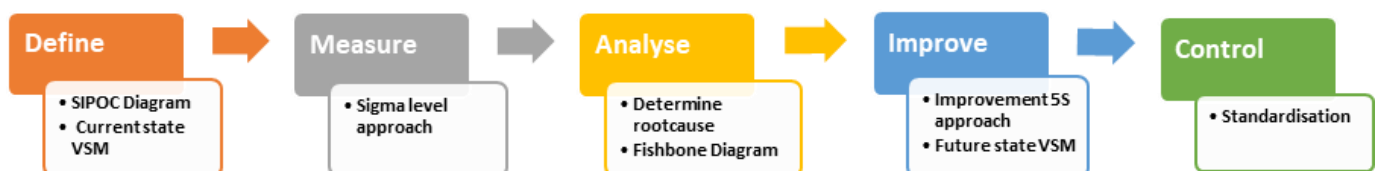


Figure 1 A Flow Chart of the methodology of this present study.

## 4. Case of study

This present study was executed in the briquette industry, which uses coconut shell charcoal as the raw material. The coconut shell charcoal briquettes (CSCBs) that BriqCo produces are primarily exported to multiple countries in the Middle

East, Africa, and Europe among others. During the production process, BriqCo uses the make-to-order system, wherein the company must satisfy buyer or customer needs, with a production target of 26 tonnes per month. However, the biggest challenge that the company faces is a high rate of defective products, with an average of 10.04% of defective products produced per month. This section discusses every step of the DMAIC method of 6σ that was used in a quality improvement programme to enhance the anodisation stage of CSCB production at BriqCo as well as the data analysis, findings, and discussion.

4.1. Define

The production process is observed in the Define phase of the DMAIC framework. As such, a SIPOC diagram was used to document and analyse the CSCB production process of BriqCo as well as their supplier(s) and customer(s) (Yeung 2009). Figure 2 provides a SIPOC diagram of the entire CSCB production process.

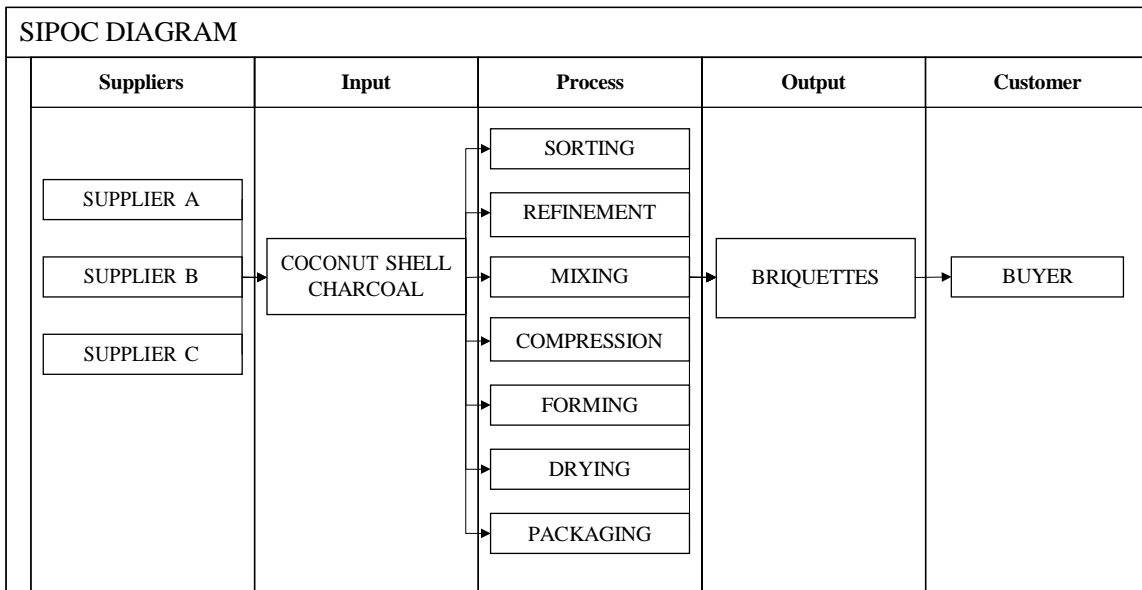


Figure 2 A SIPOC diagram of BriqCo's entire CSCB production process.

Figure 3 provides a Current Stage VSM diagram of the entire CSCB production process.

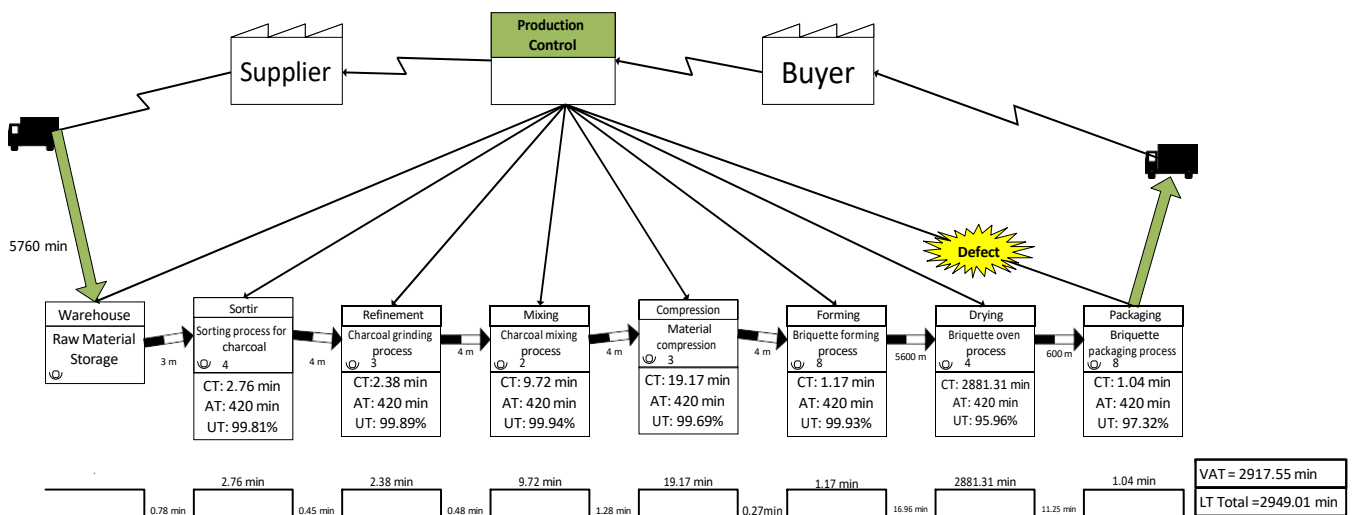


Figure 3 A current stage VSM diagram of BriqCo's entire CSCB production process.

Defect-based waste occurs when a product fails to satisfy the quality standards of a company. BriqCo exports 20 to 26 tonnes of CSCBs per month. An analysis of the company's production data between April to September 2020 indicated production-based losses as 16.998 kg (10.04%) of the total 169.298 kg of CSCBs produced were defective sub-quality.

4.2. Measure



Tables 2 and 3 depict the calculated  $\sigma$  level of defective products in the CSCBs production process at BriqCo.

**Table 2** Calculating of the  $\sigma$  level of defects.

Steps	Actions	Results
1	What process do you want to know	Briquette production
2	The number of products produced	30244
3	Number of failed products	2050
4	Calculate the failure rate	0.06778
5	The number of CTQ causes of failure	2
6	Chances of failure rate per CTQ characteristic	0.03389
7	Calculate the probability of failure per one million opportunities (DPMO)	33891.02
8	Convert DPMO into sigma value	3.33

Sigma ( $\sigma$ ) calculations conducted using the company's production data between April to September 2020 indicated a  $\sigma$  level of 3.17 and 51,188.84 DPMO. Table 3 presents the calculation of the  $\sigma$  defect level.

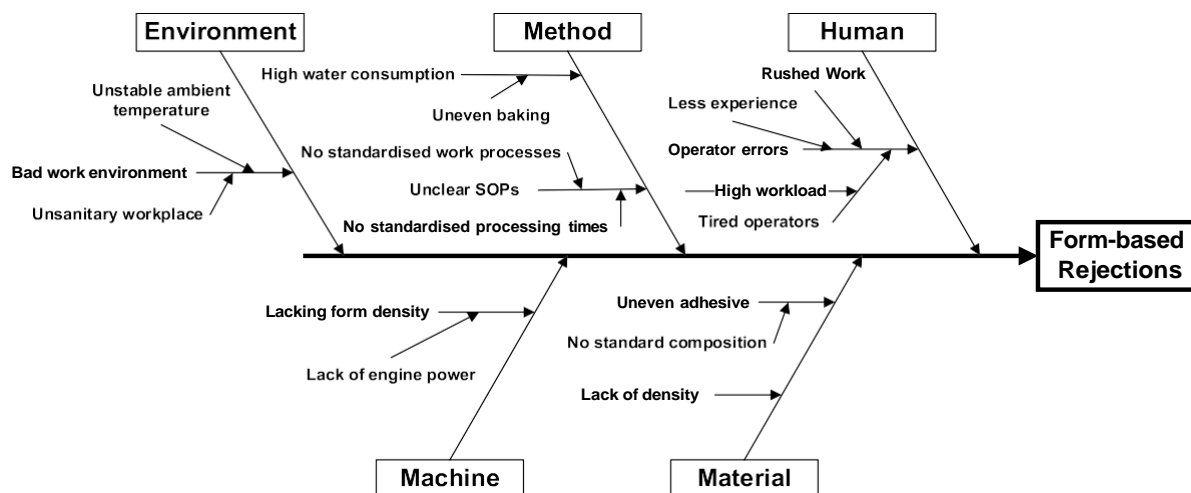
**Table 3** Calculation of Sigma Level of Defects.

Month	Output (Kg)	Reject		Total (Kg)	% Defect	CTQ	DPU	DPMO	Level Sigma
		Form	Color						
Apr-20	30244	1332	718	2050	6.8%	2	0.0678	33891.02	3.33
May-20	19009	756	554	1310	6.9%	2	0.0689	34457.36	3.32
Jun-20	34287	1423	794	2217	6.5%	2	0.065	32330.04	3.35
Jul-20	29430	2298	1128	3426	11.6%	2	0.116	58205.91	3.07
Aug-20	31217	1576	1229	2805	9.0%	2	0.0899	44927.44	3.20
Sep-20	25111	3874	1315	5189	20.7%	2	0.2067	103321.3	2.76
<b>Total</b>	169298	11259	5738	16997	61.4%	2	0.6143	307133	19.02
<b>Average</b>	28216.3	1876.5	956.33	2832.8	10.2%	2	0.1024	51188.84	3.17

4.3. Analyze

A fishbone diagram was used to determining the primary causes of waste generation at this stage (Figure 4).

a) Fishbone Diagram of Form-based rejections.



**Figure 4** A fishbone diagram of the causes of waste generation due to form errors.

An analysis of the causes of form-based product defects (Figure 4) revealed the following factors:

- Human errors, which include operator errors, that are caused by workers who are inexperienced, rushed, or exhausted due to large workloads.
- Material errors that are caused by uneven mixing, contamination, the presence of raw materials, and a lack of density.
- Machine errors that are caused by the lower density of the printing machine due to a lack of power in the printing press. The machines do not perform optimally as they are insufficiently maintained as there are only a few machines to satisfy the high production demand.



- Unconducive work environment as it is unsanitary and the ambient temperature of the shop floor fluctuates.
  - Method errors as the unstable oven temperature and non-standardised SOPs result in higher water consumption as well as non-standardised processing times and work processes.
- b) Fishbone of Color-based Rejection (Figure 5).

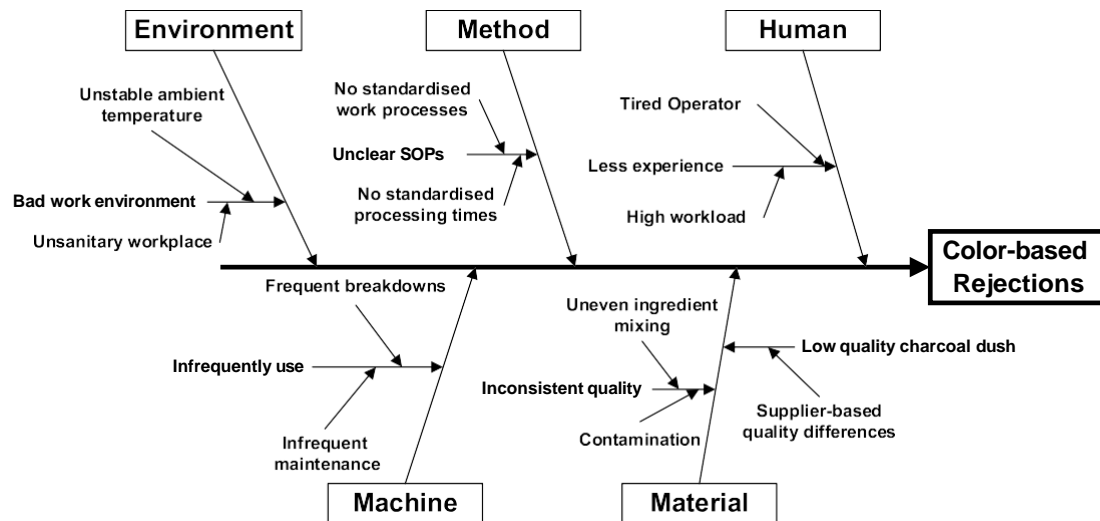


Figure 5 A fishbone diagram of the causes of waste generation due to color errors.

An analysis of the causes of colour-based product defects (Figure 5) revealed the following factors:

- Human errors, which include operator errors, that are caused by workers who are inexperienced, rushed, or exhausted due to large workloads.
- Material errors that are caused by uneven mixing, contamination, the presence of raw materials, and low-quality charcoal from multiple suppliers.
- Machine errors as the machines do not perform optimally as they are insufficiently maintained as there are only a few machines to satisfy the high production demand.
- Unconducive work environment as it is unsanitary and the ambient temperature of the shop floor fluctuates.
- Method errors as there are no standardised SOPs resulting in non-standardised processing times and work processes.

#### 4.4. Improve

A fishbone diagram was used to develop an alternative plan in the Improve stage using the factors identified in the Analyse stage.

a) The Sort, Straighten, Shine, Standardise, and Sustain (5S) method

- Seiri* (Sort): Identifying unnecessary tools or supplies at the sorting workstation as well as professionally separating the coconut shell charcoal (CSC) to ensure that it is sorted based on fitness for usage and only usable charcoal is used in the CSCB production process.
- Seiton* (Straighten): Storing tools or products in an organised and orderly manner so that they can be easily located when necessary and storing the raw charcoal according to their arrival time and labelling them according to the supplier.
- Seiso* (Shine): Maintaining a clean work environment and production tools by cleaning all the equipment after the production process to ensure that residue is not present.
- Seiketsu* (Standardise): Developing SOPs and establishing guidelines in the production process to ensure that the preceding 3s' are adhered to and operating smoothly.
- Shitsuke* (Sustain): Introducing and training staff and operators to adopt and apply the 5S culture in the workplace to improve the work environment. Once the employees are familiar and begin implementing the 5S culture, a monitoring system is required to ensure that the 5S culture is correctly applied.

b) Table 4 lists potential SOPs that BriqCo can implement during its CSCB production process to decrease the number of defective products.

**Table 4** Proposed SOP for the production process.

Work Station	Proposed Improvement
<b>Sorting</b>	<ol style="list-style-type: none"> <li>Sort the materials correctly</li> <li>Label the raw materials according to suppliers</li> </ol>
<b>Refinement</b>	<ol style="list-style-type: none"> <li>Make sure the crusher machine is in good condition before use</li> <li>Clean the remaining crushed charcoal</li> <li>Perform regular maintenance to ensure that the machine is in prime condition and is always ready for use</li> </ol>
<b>Mixing</b>	<ol style="list-style-type: none"> <li>Make sure the mixer machine is in good condition before use</li> <li>Using a machine that does not exceed the maximum capacity so that the machine can work properly</li> <li>Ensure that the dosage of the composition is appropriate between the raw material for coconut shell charcoal and other mixed ingredients</li> <li>Make sure the ingredients are evenly mixed before ending the mixing process by turning off the mixer machine</li> <li>Ensure that the floor where the mixing results are poured is clean so that it is not mixed with dirt or dust which can affect the quality of the product produced.</li> <li>Cleaning the mixer machine room after the mixing process so that the next mixing process is not contaminated with the rest of the previous mixing process.</li> <li>Perform regular maintenance by ensuring the condition of the machine is in good condition after use.</li> </ol>
<b>Compression</b>	<ol style="list-style-type: none"> <li>Ensure that the ulen machine is in good condition before use</li> <li>Perform cleaning of the ulen engine room after the compaction process so that the next compaction process is not contaminated with the remaining compaction of the previous process.</li> <li>Perform regular maintenance by ensuring the condition of the ulen machine is in good condition, namely that the output hole remains tight so that the materials resulting from the compaction process are properly adhered</li> </ol>
<b>Printing</b>	<ol style="list-style-type: none"> <li>Make sure the printer is in good condition before using it so that the printout is really solid</li> <li>Using a machine that does not exceed the maximum capacity so that the machine can work properly</li> <li>Perform cleaning of the printing machine room after the printing process so that the next printing process is not contaminated with the remaining printing from the previous process</li> <li>Make sure the cutting blades are sharp and suitable for size.</li> <li>Perform regular maintenance by ensuring the condition of both the printing press and the cutting machine is in good condition</li> <li>The process of placing the printout into a bin that does not exceed the capacity so that the printed briquette does not experience cracks due to the overlap of other briquettes on top and the air circulation runs well.</li> </ol>
<b>Drying</b>	<ol style="list-style-type: none"> <li>Ensure the condition of the oven room is in good condition</li> <li>Using firewood that is completely dry</li> <li>Ensure that the oven room temperature is stable +/- 100 degrees Celsius by using a thermometer</li> </ol>
<b>Packaging</b>	<ol style="list-style-type: none"> <li>Carry out the proper / inappropriate briquette sorting process carefully</li> <li>Carry out the process, namely packaging the briquettes according to company standards into available packaging boxes weighing 1kg / 72pcs.</li> </ol>

c) Future Value Stream Mapping (VSM) Diagram.

Implementing the proposed 5S-based improvements in the Improve phase is predicted to decrease the defect rate from 10.04% to 5%. The purpose of developing the Future VSM diagram is to compare the company's current state and its future state once the proposed improvements have been implemented, which is expected to decrease its defect rate to a target range. If the product defect rate decreases by 50%, the amount of time wasted producing defective products would decrease from 0.702 h to 0.351 h. These figures were obtained using the calculations seen in Tables 5 and 6:

**Table 5** Lost Time Before Improvement.

Total Products / Time	Per 6 months	monthly	daily	Per hours
Total Defects	16,997 kg	2,832.83 kg	118.03 kg	16.86 kg
Total Products	169,29 kg	28,216.33 kg	1,1175.68 kg	167.95 kg
Lost time		0.702 hours		

Time Wasted Pre-Process Improvements.



The time lost due to defective products was calculated using the company's production data between April to September 2020. Table 5 describes the total number of CSCBs produced and the total number of defective CSCBs produced.

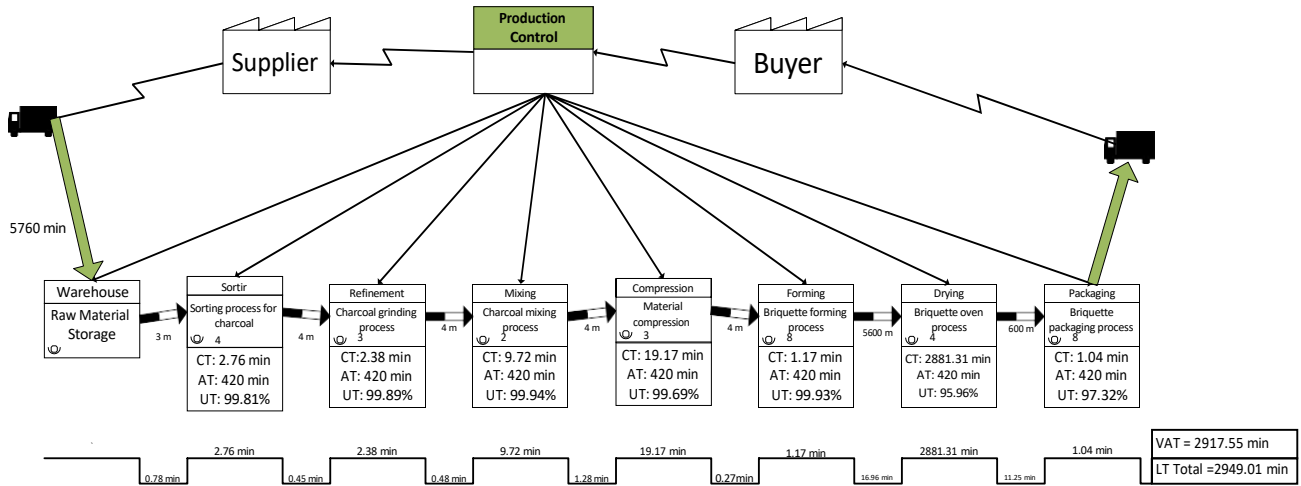
Time Wasted Post-Process Improvements.

Table 6 depicts the time lost by decreasing the defect rate by 50%.

**Table 6** Lost Time After Improvement.

Total Products / Time	Per 6 months	monthly	daily	Per hours
Total Defects	8,598.5 kg	1,416.42 kg	59.01 kg	8.43 kg
Total Products	169,298 kg	28,216.33 kg	1,1175.68 kg	167.95 kg
Lost time			0.351 hours	

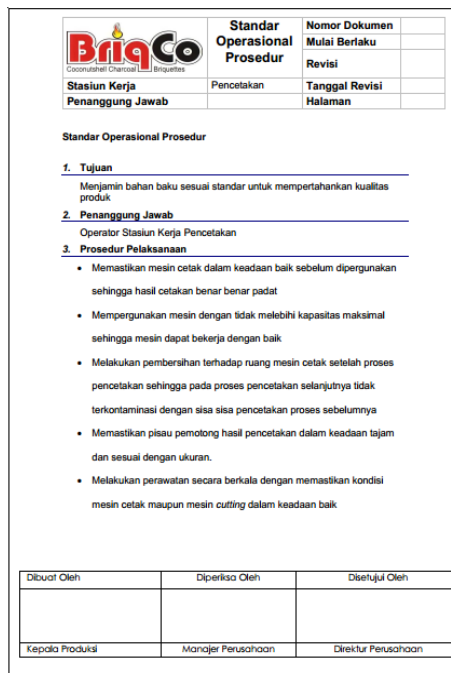
Figure 6 depicts the future VSM diagram of Briqco.



**Figure 6** Future VSM diagram of Briqco.

4.5. Control

In the *Control* phase, surveillance and monitoring are used to maintain all the improvements in the production process. The proposed improvements may be implemented as SOPs at a specific time so that it affects the production process positively. As seen in Figure 7, many SOPs were developed, especially SOPs for the sorting workstation.



**Figure 7** The SOPs developed for the sorting workstation.





## 5. Conclusions

This present study examined implementing the DMAIC method of 6 $\sigma$  at BriqCo; a CSCBs manufacturer, to increase consumer demands by minimising CSCB waste. Supplier, Input, Processing, Output, Customer (SIPOC) and current state VSM diagrams were used to analyse the issue and identify areas for improvement. Data was then collected over a six-month period before the  $\sigma$  levels were assessed to fulfil the target specifications. A fishbone diagram was then used to conduct a cause-and-effect analysis and identify root causes. A brainstorming session was also held with the owner of the company as well as an academic expert to develop effective solutions. According to the findings of this present study, BriqCo's primary  $\sigma$  level was 3.19. Multiple human-, machine-, environmental-, material-, and process-related issues were found to cause defects in the produced CSCBs. Using SOPs to implement the proposed 5S-based improvements is anticipated to decrease the level of disability by 50%. Therefore, future studies may examine combining the DMAIC method with additional quality tools as well as using the proposed method to solve issues related to other products.

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## Conflict of Interest

The authors declare there is no conflict interest.

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## References

- Ahmed S (2019) Integrating DMAIC approach of Lean Six Sigma and theory of constraints toward quality improvement in healthcare. *Reviews on Environmental Health* 9. DOI: 10.1515/reveh-2019-0003
- Alkahtani M, Kaid H, Nasr EA, Noman MA (2016) Six Sigma DMAIC phases application in Y company: a case study. *International Journal of Collaborative Enterprise* 5:181. DOI: 10.1504/ijcent.2016.10003185
- Arafeh M (2015) Combining Lean Concepts & Tools with the DMAIC Framework to Improve Processes and Reduce Waste. *American Journal of Operations Research* 5:209-211. DOI: 10.4236/ajor.2015.53017
- CR A, Thakkar JJ (2019) Application of Six Sigma DMAIC methodology to reduce the defects in a telecommunication cabinet door manufacturing process: A case study. *International Journal of Quality and Reliability Management* 36:1540–1555. DOI: 10.1108/IJQRM-12-2018-0344
- Gandhi SK, Sachdeva A, Gupta A (2019) Reduction of rejection of cylinder blocks in a casting unit: A six sigma DMAIC perspective. *Journal of Project Management* 4:81-96. DOI: 10.5267/j.jp.m.2019.1.002
- Guo W, Jiang P, Xu L, Peng G (2019) Integration of value stream mapping with DMAIC for concurrent Lean-Kaizen: A case study on an air-conditioner assembly line. *Advances in Mechanical Engineering* 11:1-17. DOI: 10.1177/1687814019827115
- Ishak A, Mohamad E, Sukarma L, Mahmood AR, Rahman MAA, Yahya SH, Salleh MS, Sulaiman MA (2022) Extended Value Stream Mapping for Enhancing the Sustainability of Lean Manufacturing. *Journal of Advanced Manufacturing Technology* 11:47-60.
- Jamil N, Gholami H, Saman MZM, Streimikiene D, Sharif S, Zakuan N (2020) DMAIC-based approach to sustainable value stream mapping: towards a sustainable manufacturing system. *Economic Research-Ekonomska Istrazivanja*. 33:331-360. DOI: 10.1080/1331677X.2020.1715236
- Kaushik P, Khanduja D (2009) Application of six sigma DMAIC methodology in thermal power plants: A case study. *Total Quality Management and Business Excellence* 20:197-207. DOI: 10.1080/14783360802622995
- Khasanah MN, Faishal M, Suharyanto TT (2021) Analisis Pengolahan Limbah Industri Rumah Tangga Konveksi dengan Prinsip Lean Manufacturing (Studi Kasus UKM Konveksi Kelurahan Kalitengah). *Jurnal Teknik Industri* 11:69-76.
- Mishra P, Sharma RK (2014) A hybrid framework based on SIPOC and Six Sigma DMAIC for improving process dimensions in supply chain network. *International Journal of Quality and Reliability Management* 31:522-546. DOI: 10.1108/IJQRM-06-2012-0089
- Mohamad E, Ibrahim MA, Shibghatullah AS, Rahman MAA, Sulaiman MA, Rahman AAA, Abdullah S, Salleh MR (2016) A simulation-based approach for Lean Manufacturing tools implementation: A review. *ARNP Journal of Engineering and Applied Sciences* 11:3400-3406.
- Mohamad E, Ito T, Yuniawan D (2013) Quantifying Benefits of Lean Manufacturing Tools Implementation. *Journal of Human Capital Development* 6:13–26.
- Montgomery DC (2009) *Introduction to statistical quality control* 6th ed. NJ: John Wiley & Sons Inc (6th ed.), In Hoboken.
- Muraleedharan P, Balamurugan S, Prakash R (2017) Six Sigma DMAIC in manufacturing industry: a literature review. *International Journal of Innovative Research in Science, Engineering and Technology* 6:18288-18293.
- Prashar A (2020) Adopting Six Sigma DMAIC for environmental considerations in process industry environment. *TQM Journal* 32:1241-1261. DOI: 10.1108/TQM-09-2019-0226
- Rini S (2021) Implementation of lean thinking through A3 report in plastic injection company. *International Journal of Industrial Optimization* 2:63. DOI: 10.12928/ijio.v2i1.3055



Sharma P, Malik SC, Gupta A, Jha PC (2018) A DMAIC Six Sigma approach to quality improvement in the anodising stage of the amplifier production process. *International Journal of Quality and Reliability Management* 35:1868-1880. DOI: 10.1108/IJQRM-08-2017-0155

