Lean Six Sigma and TRIZ to Reduce Non-Value-Added Activities of the Transformer Production Process

Adritho Zaifar[1] and Moses Laksono Singgih [1]
[1] Sepuluh Nopember Institute of Technology, Surabaya 60264, Indonesia
moseslsinggih@ie.its.ac.id

Abstract. Electronic Transformer Producer (ETP, a nickname) is electronic transformer manufacturing and distribution in Indonesia. The company has encountered challenges in meeting the escalating demands for both quantity and quality from its clientele. Concurrently, the company strives to curtail superfluous activities that do not contribute value within the production process. This study aims to pinpoint the key factors within the transformer production process to enhance the effectiveness and caliber of the electronic transformers yielded. In this research endeavor, Lean Six Sigma and Root Cause Analysis methodologies are employed to unearth inefficiencies within the production process that contribute to prolonged lead times and diminished quality benchmarks. Should contradictions arise as a consequence of implementing the Lean Six Sigma approach, the TRIZ methodology will be harnessed to bolster efforts toward process enhancement. Data to be utilized encompasses the entire production flow of electronic transformers, spanning from initiation to completion, alongside insights garnered from group discussions. The findings of this investigation underscore that by automating tasks lacking value-addition, ETP stands to reap substantial benefits. The investment funneled into these technological advancements proves lucrative, as evidenced by a positive net present value (NPV) of Rp. 43,181,818. Additionally, this automation endeavor will empower ETP to trim its workforce, culminating in a noteworthy 54% reduction in labor expenses, equivalent to a financial economy of Rp. 68,255,748.

Keywords: Electronic Transformer Producer (ETP), Lean Six Sigma, Net Present Value (NPV), Quality, Root Cause Analysis, TRIZ.

1 Introduction

An electronic transformer is an electrical device that can move and convert electricity from one or more electrical circuits to other electrical circuits using a magnetic coupling based on the induction electromagnet principle. The introduction should briefly explain the importance and objectives of this research. Support your arguments with references. You need to cite a few references from international journals in the Introduction section. No need to subdivide the Introduction section into multiple subsections. Electronic Transformer Producer (ETP) is a company in Surabaya that produces Trafo Kotak, an electronic transformer commonly used in home appliances. The

M. Hartono et al. (eds.), *Proceedings of the 4th International Conference on Informatics, Technology and Engineering 2023 (InCITE 2023)*, Atlantis Highlights in Engineering 21,
https://doi.org/10.2991/978-94-6463-288-0_21

company is one of the major producers of Trafo Kotak in Indonesia. ETP still struggles to minimize operational efficiencies and reduce non-value-added activities or costs. ETP has been unable to increase its net profit due to the considerably high number of product unit defects.

These production defects fall behind the company's Critical to Quality (CTQ) standards. These production defects resulting an extra production cost for the company and affect the company's ability to produce the number of products demanded by the customer and the level of quality that has been promised to the customer. Table 1, describes the percentage of transformers that Electronic Transformer Producer (ETP) produced with a defect rate during the production process. The percentage of production defects can still be categorized as high; on average, it reached around 7% defect rate from the monthly production, which is still far from the company target of achieving a 6 σ sigma yield of 99.99966% from the total products produced. Besides that, the re-work or product defect resulted in a substantial financial loss to the company.

Table 1. The Percentage of Reject in ETP as per 2022

Production	September	October	November
	15.500	21.000	13.300
Defect	1.005	1.491	917
Defect %	6.7%	7.1%	6.9%

Lean Six Sigma tool can be used to address these operational challenges. The Lean Six Sigma (L6σ) is a combination of two methodologies. Lean focuses on waste management, derived from the Toyota Production System (TPS). Six Sigma focuses on improving the quality of products or services by reducing defects. Six Sigma is a continuous improvement plan derived from Total Quality Management (TQM). Additionally, TRIZ is a problem-solving technique that identifies technical challenges and addresses non-routine problems, where the steps to find a solution may not be apparent [1]. TRIZ method will be applied when the improvement process recommended through the Lean Six Sigma method results in contradictions in the operational process.

2 Literature Review

Six Sigma plays a crucial role in enhancing processes, particularly in the manufacturing sector. Six Sigma effectively improves production processes, product quality, and productivity by employing the Define, Measure, Analyze, Improve, and Control (DMAIC) methodology [2]. Six Sigma used a statistical approach, methodology, and discipline. The Six Sigma tool aims to eliminate defects. Correspondingly, the references should be listed based on the alphabetical order of the first author’s last name. See examples at the end of these guidelines. While companies that operate under the guideline of Six Sigma typically only spend five percent of their revenue on fixing these

problems [3]. The Japanese developed the principles of Lean philosophy in the 1950s, and it was later globally known as the Toyota Production System. It is mainly used in manufacturing and has become a Lean Manufacturing or Lean Production concept. In the later years, the Lean philosophy expanded towards other areas like services, trade, and the public sector. The Value Stream Mapping will show diagrams showing the movements of information or products within the organization's internal processes [4] to identify the processes that cause wastage or the root cause of the wastage in the process itself.

The Five Whys problem-solving method is used to discover the leading cause or causes of the problem. The method is deemed effective in finding the leading root cause by asking the question Why? Moreover, the question will become the primary foundation for the next question [5]. Waste Assessment Model (WAM) is a model that makes identifying waste more accessible and straightforward. The Waste Assessment Model analysis within the manufacturing environment is much more complex than in the services industry. While for manufacturing, there are seven types of waste which are overproduction, inventory, defect, motion, waiting, transportation, and processing; there are 5 types of waste within the service industry, which are overproduction, waiting, overprocessing, design flaws, underutilization [6]. Operation Process Chart (OPC) is a chart that shows the end-to-end process of producing a particular product, starting from processing the raw materials until it becomes a finished product. This chart can also analyze production workflow, materials, and machinery [7]. The Ishikawa Diagram, named by Dr. Ishikawa in the 1940s, has a shape of a fish in which the qualitative characteristics of the problems are placed at the head of the fish while the causes of the problems are placed in the branches making a shape of a fish. FMEA is a systematic analysis of potential failure modes aimed at preventing failures. It is a tool that acts as a preventive action before a new product is developed or a new process is implemented. A practical FMEA usage is when it can take corrective actions to prevent product or service failures from reaching the final customer and to ensure the higher possible yield, quality, and reliability [8]. TRIZ is a methodology known for creating systematic innovation and improving its user design thinking process. TRIZ is a human-oriented, knowledge-based systematic methodology of creative problem-solving [9]. There are around 40 TRIZ principles and a methodology. TRIZ is a form of philosophy consisting of problem definition and problem-solving tools.

3 Methods

The study was conducted on ETP, which engages in the business of manufacturing electric transformers and the business has existed since the early 2000s and currently employs around 50 employees. The method used in this study is Lean Six Sigma and TRIZ with the following stages:

1. Analyzed the current operational process of ETP in manufacturing electronic transformers. A time study will be conducted so that Operations Process Chart (OPC) and Value Stream Mapping (VSM) can be drawn up. The data that is being

used for this is taken between December 2022 to January 2023. Waste Assessment Questionnaire is a method that is being used for this research.

Table 2. FMEA Criteria

Effect	Severity	Rating
Non-existent	No effect on the production process	1
Very Minor	It affects the production process, but the effects can be ignored	2
Minor	Affects the production process and potentiality cause a product defect	3
Very Low	It affects the production process and causes the product defects, but it can be ignored	4
Low	It affects the production process and can cause product defect In a month, there are <10% of product rework Causing financial loss of up to <5%	5
Medium	It affects production and causes product defect In 1 month's production process, 10 – 20% has rework Causing financial loss on a product of up to 5 – 10%	6
High	It affects the production process and causes the product defect In 1 month's production process, 20 – 30% product has to be reworked Can cause financial product loss of up to 10 – 20%	7
Very High	It affects the production process and causes the product defect In 1 month's production process, cause 30 – 50% of product rework Cause a financial loss to product up to 20 – 30%	8
Dangerous	It affects production and product defect In a month of the production process, >50% product re-worked Cause financial loss to product up to 30 – 50%	9
Very Dangerous	Has an effect on the production process and product defect In a month, all WIP has to go through rework Causing financial loss to a product >50%	10

2. Focus Group Discussion (FGD) is conducted with the Operations, Sales, and Engineering teams. The position of the interviewee varies from junior to mid/upper-

level positions within the company. The FGD is conducted to understand possible existing problems within the production process.

3. The existing problems are analyzed by Fishbone Diagram and 5 Whys Analysis to understand the possible root causes of the problem.
4. Then, Failure Mode and Analysis (FMEA) will be used to determine the Occurrence, Severity, and Detection to root out critical issues that frequently occur (Table 2). Issues with 240 will be prioritized for continuous improvement.
5. The improvements that are being suggested by the Lean Six Sigma method will be reviewed based on possible contradictions that it might produce. If the improvements suggested by Lean Six Sigma produced a contradiction then the TRIZ method will be used to counter the contradiction
6. Finally, Value Management will be used to choose the best alternative combination of the improvement suggested.

4 Result and Discussion

4.1 Analyze & Improvement

Based on the Risk Priority Number (RPN) value and Focus Group Discussion (FGD) results on the FMEA, the potential issues, and their root cause significantly affecting the production process are obtained. Following the results, improvement plans are drafted based on the issues and root causes that have been found. The issues highlighted and needing improvement are those RPN $\geq$ 240—the following recommendations have been made for the issues elaborated on in the FMEA.

Table 3. Summary of FMEA RPN

Waste	Sub-waste	RPN	Improvement
Defect	Mishandling of transformer by 3PL	240	Find a new 3PL vendor that has experience in transporting fragile products
	Transformer is damaged due to the absence of protective packaging	300	Putting foam packaging to protect the transformer
	Lack of product knowledge from the operator	240	Give training and guidelines to the operator who is in charge of the rolling activity
	Lack of differentiators between different types of coil	400	Give a differentiator label on the copper coil
	The soldering tool loses its sharpness over time	400	Preventive maintenance needs to be done on the soldering tool

Waste	Sub-waste	RPN	Improvement
	Manual documentation of sales orders and other essential documents	240	Implementing CRM software management technology
Waiting	Raw Materials is out of stock	210	Demand and supply planning systems need to be implemented
	WIP has not arrived yet from Jember Regency	240	A schedule for delivery from the Jember Regency needs to be created

4.2 Contradictions

The TRIZ Contradiction Matrix is being deployed to address the issues that ought to be addressed through TRIZ methods because the improvement strategies offered through Lean Six Sigma are not sufficient enough. First, to apply TRIZ methodology in this research, the improvements that have been suggested by Lean Six Sigma will go through a second screening for possible contradictions. If the improvement suggested contradicts with one or more of the 39 TRIZ characteristics, then 40 inventive principles of TRIZ will be applied. The suggested contradictions should be displayed as a TRIZ matrix (Figure 1). The

Worsening Feature > / Improving Feature V	Waste of Energy	Accuracy of Measurement	Energy Consumed by Fixed Object	Complexity of Device	Level of Automation	Productivity
	12	15	30	36	38	39
Waste of Energy						
Accuracy of Measurement	15, 16, 35					
Energy Consumed by Fixed Object						9, 20, 22, 26
Complexity of Device						
Level of Automation						
Productivity				34, 25, 24,16		

Fig. 1. TRIX Matrix

second stage of the TRIZ improvement method is by matching the possible contradictions found through TRIZ characteristics and improving it through the 40 inventive principles of TRIZ.

Through further analysis using the methods of the Focus Group Discussion (FGD), some of the improvement methods suggested in the previous section using the methodology of Lean Six Sigma contradicts some of the objectives that would like to be achieved by the company. The following are some of the improvements that will be addressed through TRIZ methods because it contradicts the company's objective.

1) Stockpiling of Raw Materials Based on Forecast

The idea of stockpiling raw materials might be useful to prevent the production process from being halted due to stock of raw materials. However, this might create an excess of unneeded inventory that could create loss to the company due to material deterioration over time. Therefore, the following contradiction is being solved through TRIZ shown in Table 4.

Table 4. Solving Contradiction through Stockpiling

Problems	Over/Lack of Supply of Raw Materials and Spare Parts
Contradictions	Wrong calculation resulting in either lack of supply of raw materials and spare parts or oversupply of unused materials used in the production of product X >< Time consumed waiting for important materials to be refilled or cost to store unused materials. (12) Waste of Energy >< (18) Accuracy of Measurement.
Contradiction Matrix	15, 16, 35
Solution	Based on the observation conducted on the condition of the factory and the issues that have been highlighted through the Ishikawa Diagram and 5 Whys Diagram, the following is the proposed solution: Therefore, based on the TRIZ methods that are being applied, ETP should implement a Lean Pull System in which the company will only procure raw materials based on the number of finished products requested by the company. This eventually will prevent the potential for excess inventory.

2) Relocation of WIP Processing Site from Jember Regency to Surabaya

The idea of relocating the WIP processing site from Jember Regency to Surabaya for efficiency, better monitoring, and cutting waiting time tends to be beneficial for the company. However, the company would like to maintain low-profile operations in the Surabaya location for the board management's private reasons. Therefore, the following contradiction is being solved through TRIZ shown in Table 5.

Table 5. Solving Contradiction through Relocation of WIP

Problems	Relocation of WIP Processing Site to Surabaya
Contradictions	The board management of the company would like to maintain low profile operations of the Surabaya's factory while keeping the production of WIP in Jember regency >< Lack of accountability of production associates in Jember regency to work on their responsibility in producing product X. (39) Productivity >< (30) Energy Consumed by Moving Object
Contradiction Matrix	9, 20, 22, 26
Solution	Based on the observation conducted on the condition of the factory and the issues that have been highlighted through the Ishikawa Diagram and 5 Whys Diagram, the following is the proposed solution: By placement of a Supervisor or Team Leader in the Jember Regency, the accountability of the production associates in the Jember Regency can be ensured. At the moment, ETP does not have an experienced supervisor or team leader placed in the Jember regency to supervise the work of the production associates located there. The supervisor has to correct the associates' work when they make potential errors in their work. With the placement of the supervisor, the number of product defects due to human error from the associates can be minimized.

3) Preventive Maintenance on Koker Cutting Paper Tool

Preventive maintenance aims to prevent some tools and machinery from breaking down. The Koker Cutting Paper Tool is one of the first tools being used in the production process of the electronic transformer. However, this tool is manually operated and can be replaced with an automated cutting machine. Therefore, the following contradiction is being solved through TRIZ shown in Table 6.

Table 6. Solving Contradiction through Preventive Maintenance

Problems	Preventive Maintenance of Koker Cutting Paper Tool
Contradictions	The company would like to minimize manual forms of work and replace the manual form of activity or outdated tools with automated machinery>< Prolonged cycle time in the production process and non-value added activity contributing to a higher workload for the staff (36) Complexity of Devices>< (39) Productivity
Contradiction Matrix	34, 25, 24,16
Solution	Based on the observation conducted on the condition of a factory and the issues that have been highlighted through the Ishikawa Diagram and 5 Whys Diagram, the following is the proposed solution:

	Principle 25 Self Service Replacing outdated and manually operated devices with automated machinery. In this case, the machinery will be the Die Cutting Paper Tool

5 Results

The calculation of the Net Present Value (NPV) is important to determine whether the machinery or tools that will be purchased by the company would bring a positive impact on the company not only in terms of processes but also bringing positive cash flow to the company in the long run. The company needs to purchase several types of machinery and assistance tools totaling around Rp. 1,775,000,000 while the expected monetary return for this is Rp. 2,000,000,000. The expected return rate from the NPV investment is around 10%. Therefore, the NPV calculation is as follows.

$$NPV = \left[\frac{Rp.\,2{,}000{,}000{,}000}{(1+0.1)^1}\right] - Rp.\,1{,}775{,}000{,}000$$
$$NPV = Rp.\,43{,}181{,}818$$

Based on the calculation above, it can be concluded that the investment that the company needs to make for this investment is profitable for the company in the long run. With the investment of these types of machinery, labor costs can be reduced. In case around 50% of the operations that are being operated manually are reduced as a result of the automation around 40% of the staff can be eliminated which results in 16 termination staff from 40 of the total staff. Considering that 15 of the Jember Regency production associates is reduced by 40%, it left the Jember Regency production team with only 6 staff. On the other hand, 25 of them from Surabaya's factory is reduced by 40%, the Surabaya's factory team will only consist of 15 staff. The following is the rough calculation of the new labor cost:

Cost Component :
$Labour\ Cost\ (Surabaya) = Rp.\,4.525.479{,}19/day/per\ staff$
$Labour\ Cost\ (Jember) = Rp.\,2.555.662{,}00/day/per\ staff$

Table 7. Manpower Cost After Automation

Production Line	Manpower	Manpower Cost
Surabaya Factory Staff (Surabaya)	15	Rp. 67,882,185
Production Associate (Jember)	6	Rp. 15,333,972
Total		Rp. 83,216,157

This can be compared with the labor cost before the reduction takes place which is the following:

Table 8. Manpower Cost Before Automation

Production Line	Manpower	Manpower Cost
Surabaya Factory Staff (Surabaya)	25	Rp. 113,136,975
Production Associate (Jember)	15	Rp. 38,334,930
Total		Rp. 151,471,905

$$Labour\ Cost\ Savings = Rp.151{,}471{,}905 - Rp.83{,}216{,}157$$
$$Labour\ Cost\ Savings = Rp.\ 68{,}255{,}748$$

$$Labour\ Cost\ Savings\ \% = \frac{Rp.\ 83{,}216{,}157}{Rp.151{,}471{,}905} \times 100\% = 54\%$$

From the above calculation, it can be concluded that the company will be able to save around 54% of its labor cost due to the automation process that is being put in place.

6 Conclusions

The following are some of the managerial implications from the research that has been conducted on the possible critical waste that exists in the production process ETP.

1) Based on the findings of this research, it is concluded that several operational processes can be automated starting from the rolling process, the koker paper-cutting process, and the packaging process. This automation will cost the company a total of Rp. 1,775,000,000 in investment for the types of machinery that will enable these processes to be automated.
2) The automation process will enable the company to reduce 40% of its total workforce. This will result in a potential cost saving of around Rp. 68,225,748 as a result of the lower headcount and reduction in wages-related costs. However, the company might quadruple its electricity-related spending due to the increased number of types of machinery being used in the production process. Therefore, with the estimation of the increased electricity usage the company will be spending an estimated Rp. 5,868,000 for electricity.
3) The use of 3PL services as a method of transportation of both WIP and finished products will reduce the lead time for delivery and enable the staff to concentrate on production-related tasks. However, the 3PL service cost per delivery can increase the selling price of the transformer to around 30%.
4) Since the management of ETP would like to keep the transformer WIP processing site in the Jember regency, the management needs to duplicate the automated rolling process that is already being implemented in Surabaya's factory to the Jember production team. As the automated rolling machine cost around Rp. 1,000,000 per unit. Considering that with the automation process being implemented, there will only be 6 production associates in the Jember regency. Hence, if the company

decides to give the 6 associates their automated rolling machine then the company will spend a total of Rp. 6,000,000 for the cost of 6 automated rolling machines.

5) The introduction of new pieces of machinery and operating systems such as the CRM will require the management team of ETP to conduct re-training of all the staff involved in the production process. If the management team decides to hire an external trainer to ensure that the operational team understands how to operate the new pieces of machinery or system being implemented, the company possibly needs to invest around Rp. 30,000,000 each year.

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