

Innovative Solution for Contradictions of Waste Handling in Disassembly Process Using TRIZ Method

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ABSTRAK

Proses pembongkaran dalam tahap remanufaktur saat ini memakan waktu rata-rata delapan hari, melampaui standar tujuh hari yang telah ditetapkan karena kegiatan non-nilai tambah atau pemborosan. Meskipun upaya telah dilakukan untuk mengatasi pemborosan, namun menghadirkan tantangan baru seperti pemborosan waktu dalam penyesuaian sistem. Oleh karena itu, penelitian ini bertujuan untuk menyelesaikan masalah tersebut dengan menerapkan metode TRIZ dan *Root Conflict Analysis* (RCA+) untuk mengidentifikasi kontradiksi dan memberikan solusi inovatif terhadap masalah pemborosan. Hasil penelitian menunjukkan adanya 25% kegiatan pemborosan, dengan kegiatan menunggu menyumbang sebanyak 19% dari total. Penelitian juga mengidentifikasi lima kontradiksi, di mana penanganannya dapat memberikan efek baik dan buruk pada proses pembongkaran. Solusi yang diusulkan untuk setiap kontradiksi melibatkan penggunaan *Magnetic Particle Testing* atau *Ultrasonic Testing*, penataan *box* secara bertingkat, penyediaan pemahaman dan pengawasan inspeksi kepada mekanik, penggabungan ukuran kunci pas yang beragam, dan pembuatan *checklist* untuk tahapan pembongkaran berdasarkan urutan komponen utama.

Kata Kunci:

Kontradiksi;
Pembongkaran; Root
Conflict Analysis; Metode
TRIZ; Penanganan
Pemborosan

Keywords :

*Contradictions; TRIZ
Method; Waste Handling;
Disassembly; Root Conflict
Analysis*

ABSTRACT

The disassembly phase in remanufacturing currently takes an average of 8 days, surpassing the standard of 7 days due to non-value-added activities, as known as waste. Although efforts to handle this issue have been made, they have introduced new challenges, particularly time waste in system adjustments. This study addresses the problem by employing TRIZ and Root Conflict Analysis (RCA+) methods to identify contradictions and propose innovative solutions to minimize waste. Findings reveal a 25% waste activity, with waiting activities contributing to 19% of the total. The research identifies 5 contradictions, each having both negative and positive impacts on the disassembly process. Proposed solutions involve implementing Magnetic Particle Testing or Ultrasonic Testing, organizing tiered boxes, offering understanding and inspection supervision to mechanics, utilizing a variety of wrench sizes, and developing a checklist for disassembly stages based on the sequence of main components.

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INTRODUCTION

Remanufacturing is the process of restoring the condition of used products by recapturing the added value that was initially provided when the product was first manufactured. In this process, used products are reconditioned to produce items that are as good as new, with performance specifications that are equal to or higher than those of the new products (Shu San et al., 2021). The remanufacturing production process for heavy equipment generally begins with receiving, followed by an inspection, disassembly of the heavy equipment, reassembly, testing, and finally wrapping (Suryaningtyas et al., 2017). Improved production outcomes do not necessarily indicate a company's ability to thrive in the competitive landscape, nor does it guarantee enhanced efficiency and effectiveness. The appropriate strategy to address this situation involves conducting measurements to enhance productivity (Sutiyono, 2012).

Production activities always yield outcomes in the form of goods and services, which can be linked to a company's productivity and can be influenced by the extent of Waste (Al Faritsy & Suseno, 2015) enhancement consists of several methods that can be implemented, namely 5S/Good Housekeeping, the 7 Wastes, Benchmarking, Green Productivity, and Kaizen. The objectives of these methods are to improve productivity that impacts products, processes, workers, and policies (Kalaw, 2015).

Waste is any resource used that does not add value to a product. Wastage that can occur in production activities includes overproduction, waiting, transportation of products, over-processing, inventory, motion or movement, and defects in products (El-Namrouty, 2013). The solution needed to reduce or eliminate Waste in the company is by identifying and minimizing the 7 types of Waste. Waste occurring in the remanufacturing industry needs to be eliminated as it affects company productivity (Kalaw, 2015), (Al Faritsy & Suseno, 2015)

The challenges of the remanufacturing process that have been identified contribute to the reduction of remanufacturing process lead time, where 83% to 99% of the total time is consumed by three unnecessary operations: inventory storage, waiting for spare parts, and waiting for information (Kurilova-Palisaitiene & Sundin, 2014). In research conducted by Catur Kurniawan et al., (2022) and Muqimuddin et al., (2021) using Lean Manufacturing approaches, remanufacturing lead time can be reduced by eliminating and minimizing non-value-added activities. However, while the elimination or reduction of non-value-added activities positively impacts lead time reduction, it also generates negative effects. Therefore, innovative solutions are required to optimize both the positive and negative impacts.

In this research, the TRIZ Method is proposed. The TRIZ Method (Theory of Inventive Problem Solving) is one of the approaches used to discover innovative solutions (Gadd, 2011)(Kandukuri et al., 2021) (Hartono et al., 2018) This method encompasses a contradiction matrix containing 40 innovative principles based on an analysis of 39 contradiction parameters (Altshuller Genrich, 1999). In identifying contradictions within a problem and establishing connections between the two, an additional tool that aids in utilizing the TRIZ Method is Root Conflict Analysis (RCA+). Root Cause Analysis, known as RCA+, is a relatively new tool or technique that depicts a tree-like structure with nodes providing information about impacts and consequences (Souchkov, 2011). The application of TRIZ has been used for various purposes such as defect reduction in products (Hanifuddin Hakim & Laksono Singgih, 2019), innovative Waste handling solutions (Indrawati et al., 2020; Purnomo & Lukman, 2020), and product development (Lin & Chen, 2021; Şen & Baykal, 2019). TRIZ implementation with a focus on the manufacturing industry has been carried out by Kandukuri et al., (2021) or improving the design of remanufactured products. Meanwhile, RCA+ has been applied by Souchkov, (2017) in the maritime industry, and Pratikno et al., (2023) in manufacturing companies. However, no research has yet utilized TRIZ and RCA+ with a specific focus on the Remanufacturing industry. Therefore, this study aims to discover innovative solutions in efforts to reduce the disassembly process lead time in a remanufacturing company.

RESEARCH METHODOLOGY

This research takes a case study approach in a heavy equipment remanufacturing company, focusing on hydraulic products, particularly in the disassembly process. To achieve its objectives, this study follows the flow as depicted in the following Figure 1:



Figure 1. Research Methodology

Problem Identification and Goal Setting

In the first stage, the research identifies problems from historical production data for the year 2022. As explained in the introduction, the year 2022 revealed that excessive completion time beyond the standard occurred frequently in the disassembly process. Hence, observations were conducted starting from the disassembly activities of heavy equipment until the completion of the disassembly process. These observations were coupled with a literature review, leading to the conclusion that the failure to meet the standard completion time was due to wastage in the disassembly process. Moreover, contradictions arose from the solutions previously applied by the company in their efforts to meet the standard disassembly completion time.

Identification and Classification of Waste

The identification of Waste will be conducted through observations starting from the beginning of the hydraulic disassembly process until completion. These observations will be accompanied by interviews with 14 mechanics involved in the disassembly process and with a supervisor. Interviews will help establish the workflow of the disassembly process, which will then inform the process mapping. Meanwhile, direct observations will be carried out to determine the types of Waste present during the disassembly process. Video recordings and Process Activity Mapping (PAM) will be used during these observations. The use of videos aims to provide detailed insights into activities and uncover less obvious sources of Waste, while PAM serves as a mapping tool for the sequence of heavy equipment disassembly activities performed by mechanics. The results of observations, PAM, and interviews, including identified Waste, will then be classified into the 7 types of Waste: overproduction, waiting, transportation activities, over-processing, inventory, motion or movement, and defects in products.

Prioritization of Waste

The prioritization of Waste will occur after the results of observations and interviews have been classified into the 7 Waste types. The prioritization process will employ a Pareto diagram, aiming to prioritize the most frequently occurring types of Waste. The data used in the Pareto diagram will consist of a histogram representing the frequency of each of the 7 Waste types in the disassembly process.

Identification of Causes and Contradictions of Waste

For the prioritized Waste types, the research will proceed to identify the causes of Waste occurrence as well as the contradictions present. The Root Conflict Analysis (RCA+) method will be used to identify the causes of Waste occurrence and the contradictions associated with it. RCA+ serves as a tool to identify the causes of Waste and contradictions related to products, systems, and components that can impact the performance of heavy equipment production and lead to Waste. In utilizing RCA+, data is required, obtained from interviews with mechanics and supervisors regarding the causes of Waste occurrence and past solutions. Once the causes and contradictions of Waste are identified, the issue of Waste is further addressed using the 39-contradiction matrix.

Determination of Waste Issue Solutions

The final stage of this research involves identifying ideal solutions based on contradictions. The formulation of ideal solutions is obtained through the use of the 39-contradiction matrix. The

results from this matrix will yield 40 innovative principles from the TRIZ method. The selected Innovative Principles will serve as the basis for determining solutions to the Waste issues. These principles will then be provided to the supervisor to find specific solutions.

RESULTS AND DISCUSSION

Identification and Classification of Waste

The process of Waste identification and classification aims to determine the 7 types of Waste that occur during the disassembly process of heavy equipment. The identification and classification process of Waste utilizes the Process Activity Mapping (PAM) method to aid in mapping the workflow in the heavy equipment disassembly area. The recapitulation of Process Activity Mapping (PAM) conducted for 6 products in the heavy equipment disassembly process can be seen in Table 1, with a total average time of 22.731 seconds or 6.3 hours for the disassembly of heavy equipment. This provides information that the Waste occurring during the process of disassembly heavy equipment includes waiting, transportation, over processing, and movement.

Table 1. Summary of Process Activity Mapping (PAM)

Product	Operation (s)	Over Production (s)	Waiting (s)	Transportation (s)	Over Processing (s)	Inventory (s)	Movement (s)	Defects (s)
1	36732	0	21967	1788	1075	0	2235	0
2	23496	0	1715	337	169	0	203	0
3	12138	0	62	0	67	0	472	0
4	17664	0	1491	0	135	0	546	0
5	3871	0	88	0	0	0	273	0
6	7972	0	452	78	0	0	1362	0
Mean	16978,8	0	4295,8	367,2	241	0	848,5	0

The comparison between the efficient heavy equipment disassembly activities and the Waste of time occurring during the process can be seen in Figure 2. The average disassembly activity takes around 6.3 hours. Disassembly activities consist of efficient operational activities (operation) accounting for 75%, with an average of 4.7 hours, and Waste occurring at 25%, with an average of 1.6 hours. The average Waste time does not align with the company's defined tolerance standard of 30 minutes. The 25% Waste percentage comprises 5 types of Waste: waiting (19%), transportation (2%), over-processing (1%), and movement (4%).

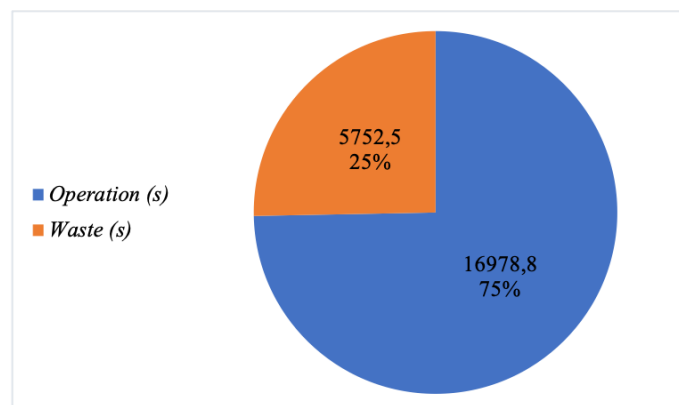


Figure 2. Comparison of Operation Time and Waste

Prioritization of Waste

The prioritization of Waste aims to identify the frequently occurring Waste among the 7 types, which can facilitate the search for Waste areas with potential for improvement. Prioritization of Waste is done using a Pareto diagram as shown in Figure 3. The most frequent Waste is waiting, with an average time of 4,295.8 seconds or 1.2 hours and a percentage of 75%. Following that, the most common Waste is related to movement (15%), transportation (6%), and

over-processing (4%). The Waste caused by waiting activities has the highest average time. Subsequent research will focus on activities that lead to waiting.

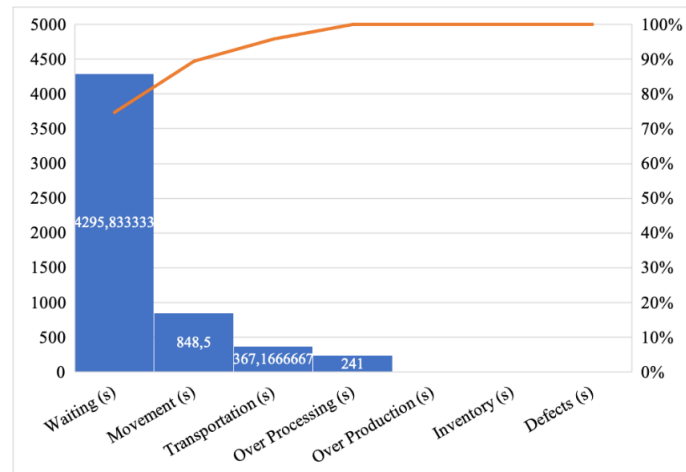


Figure 3. Pareto Diagram of the 7 Types of Waste

Identification of Causes and Contradictions of Waste

The identification of causes and contradictions arising from the waiting activities will be carried out using the Root Conflict Analysis (RCA+) method as depicted in Figure 4. The RCA+ diagram, focusing on the main issue of Waste due to waiting, reveals 8 root causes contributing to the Waste of time caused by waiting activities. These root causes include the unavailability of KPP documents and historical customer data, the need for the penetrant and developer process to be dry, the presence of only 1 unit for cleaning sub-assembly components, tool shortages, insufficient equipment maintenance activities, and the lack of regulations prohibiting off-topic discussions during working hours.

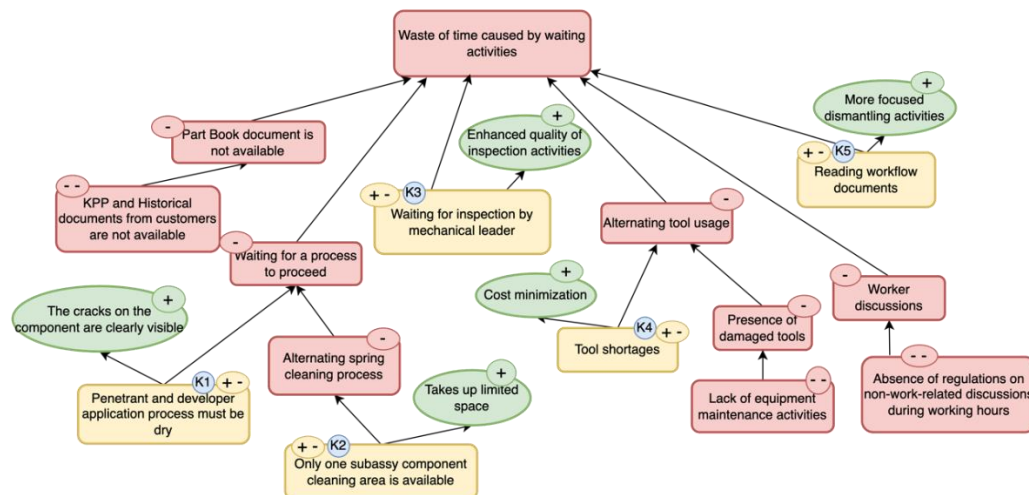


Figure 4. Root Conflict Analysis (RCA+) for Waiting Activity

The root causes of the problem, as determined through the RCA+ diagram, identified 5 root causes that have both negative and positive impacts or contradictions (+-). The root causes that exhibit contradictions are summarized in Table 2, which displays the innovative principles derived from the 39-parameter contradiction matrix. This considers the parameters that will be enhanced while considering the decrease in performance of other parameters.

Determination of Solutions

Having determined the contradiction parameters, the next step to find innovative principles is to use the contradiction matrix. The innovative principles obtained from the contradiction matrix need to be further adjusted to match the specific problem at hand. Discussion

on these 5 contradictions along with the corresponding innovative principles tailored to the issues is summarized in Table 3.

Table 2. Contradictions Results for Waiting Activity

No	Contradictions	Negative Impacts	Positive Impacts	Innovative Principles
1	Penetrant and developer application process must be dry	Waiting for a process to proceed (<i>Loss of time</i>)	The cracks on the component are clearly visible (<i>Manufacturing precision</i>)	<i>Mechanical vibration</i> <i>Intermediary</i> <i>Copying</i> <i>Mechanics substitution</i>
2	Only one subassembly component cleaning area is available	Alternating spring-cleaning process (<i>Loss of time</i>)	Takes up limited space (<i>Area of stationary object</i>)	<i>Asymmetry</i> <i>Preliminary action</i> <i>Another dimension</i> <i>Parameter changes</i>
3	Waiting for inspection by mechanical leader	Waste of time caused by waiting activities (<i>Loss of time</i>)	Enhanced quality of inspection activities (<i>Manufacturing precision</i>)	<i>Mechanical vibration</i> <i>Intermediary</i> <i>Copying</i> <i>Mechanics substitution</i>
4	Tool shortages	Alternating tool usage (<i>Quantity of substance / the matter</i>)	Cost minimization (<i>Difficulty of detecting and measuring</i>)	<i>Local quality</i> <i>Mechanical vibration</i> <i>Cheap short-living objects</i> <i>Pneumatics and hydraulics</i>
5	Reading workflow documents	Waste of time is caused by excessive document viewing (<i>Loss of time</i>)	More focused disassembly activities (<i>Ease of repair</i>)	<i>Segmentation</i> <i>Preliminary action</i> <i>Colour changes</i>

Table 3. Contradiction Parameters and Innovative Principles

No	Contradictions	Negative Impacts	Positive Impacts	Innovative Principles	Suggestions
1	Penetrant and developer application process must be dry	Waiting for a process to proceed	The cracks on the component are clearly visible	<i>Copying</i> (26) dan <i>Mechanics substitution</i> (28)	Replacing the crack inspection process with Magnetic Particle Testing (Magnetic Particle Testing Equipment) or Ultrasonic Testing (Generator).
2	Only one subassembly component cleaning area is available	Alternating spring-cleaning process	Takes up limited space	<i>Another dimension</i> (17)	Using stacked boxes.
3	Waiting for inspection by mechanical leader	Waste of time caused by waiting activities	Enhanced quality of inspection activities	<i>Copying</i> (26)	Providing understanding, training, detailed and clear inspection criteria to mechanics, and supervising during inspections.
4	Tool shortages	Alternating tool usage	Cost minimization	<i>Local quality</i> (3)	Combining various sizes of wrenches into an adjustable or universal wrench.
5	Reading workflow documents	Waste of time is caused by excessive document viewing	More focused disassembly activities	<i>Segmentation</i> (1) <i>Preliminary action</i> (10)	Creating a checklist of disassembly stages based on the sequence of major components. Mechanics need to read and understand the content of the provided documents beforehand.

Based on Table 3, Contradiction 1, which involves 'The process of applying penetrant and developer must be followed by waiting to see the results of heavy equipment damage,' is addressed with an applicable innovative principle involving the implementation of Non-Destructive Testing (NDT) inspection techniques such as Magnetic Particle Testing (Magnetic Particle Testing Equipment), Eddy Current Testing (Eddy Current Testing Equipment), Ultrasonic Testing (Generator), Coolant, Oscilloscope, Transducer). The suggested innovative solution will eliminate the waiting time for the drying of penetrant and developer fluids, facilitating the inspection process and crack detection in heavy equipment components.

Contradiction 2, 'The availability of only one unit for cleaning sub-assembly components,' is addressed with an innovative principle suggesting the addition of stackable boxes within the company's premises, not using the surrounding area. This solution involves organizing the boxes in a layered manner, with the lower box serving as a container for soaking components in solvent to minimize spillage risk, while the upper box is used for drying components after washing and brushing.

Contradiction 3, 'Waiting for inspections carried out by the mechanical leader,' is appropriately solved by applying the copying (26) innovative principle. This solution entails emphasizing the importance of inspection, providing training for technicians on inspection activities in line with existing procedures, developing detailed and clear inspection criteria or standards, and implementing supervision and evaluation during heavy equipment component inspections. This approach minimizes waiting time for mechanics during inspections and enhances the quality of inspection results.

Contradiction 4 involves a situation where 'Work cannot proceed smoothly due to a lack of tools.' The appropriate solution from the innovative principle Local quality (3) is to combine various sizes of wrenches into an adjustable wrench or a universal wrench that can adapt to different bolt or nut sizes. This solution not only reduces costs associated with purchasing multiple tools but also provides convenience to mechanics during the disassembly of heavy equipment components.

Contradiction 5, 'Repetitive reading of workflow documents,' is addressed using the innovative principle Segmentation (1), suggesting the creation of a checklist for the disassembly process based on the sequence of major components listed on a single thick sheet of paper. This simplifies mechanics' access to and examination of the disassembly procedure documents. Another solution based on the innovative principle Preliminary action (10) is for mechanics to read and comprehend the document's contents beforehand, then proceed with the disassembly or repair of heavy equipment. Additionally, providing training to mechanics can also be a viable solution.

CONCLUSIONS AND SUGGESTIONS

Conclusions

Conclusion drawn from the research on addressing Waste contradictions in the disassembly process reveals that the most frequent type of Waste is waiting, based on the average data collection, with an average time of 4,295.8 seconds or 1.2 hours, followed by movement at 848.5 seconds, transportation at 367.2 seconds, and process at 241 seconds.

The causes of Waste in waiting activities stem from the unavailability of part book documents, waiting for processes, worker discussions, waiting for inspections carried out by the mechanical leader, reading workflow documents, and alternating tool usage. Contradictions arise from the need for the penetrant and developer process to be dry, the presence of only one sub-assembly component cleaning area, inspections conducted by the mechanical leader, tool shortages, and repetitive reading of workflow documents.

Addressing the need for the penetrant and developer process to be dry can involve replacing the crack inspection process with methods like Magnetic Particle Testing (Magnetic Particle Testing Equipment) or Ultrasonic Testing (Generator). The limited sub-assembly component

cleaning area can be addressed by using stacked boxes. Waiting for inspections by the mechanical leader can be resolved through imparting understanding, training, detailed and clear inspection criteria to mechanics, and supervision during inspections. Tool shortages can be mitigated by combining various sizes of wrenches into an adjustable or universal wrench. Addressing repetitive reading of workflow documents involves creating a checklist based on the sequence of major components and ensuring mechanics read and understand the provided document content beforehand.

Suggestions

This research is perceived to still have shortcomings that need to be addressed in subsequent studies. The determination of the waste time needs to be more objectively defined with specific methods. If determined objectively, the prioritization of handled waste will be more accurate.

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