ENHANCING REMANUFACTURABILITY THROUGH TRIZ-BASED APPROACH

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Abstract

Design for remanufacturing aims to improve product designs to enhance remanufacturing operations' economic and environmental sustainability. Generating practical design ideas for remanufacturing requires a comprehensive understanding of the product manufacturing processes with constraints and applying a systematic approach to identifying feasible design changes. Theory of Inventive Problem-Solving (TRIZ) offers a systematic, knowledge-based problem-solving methodology, which could be used to address complex design challenges and generate alternative solutions for remanufacturing. Because TRIZ principles are derived through screening thousands of patents across diverse industries, these principles can be applied in a wide range of manufacturing systems. The design generation stage can be systematic and straightforward by utilizing the basic inventive problem-solving principles and considering the product- and manufacturing-specific constraints. This study focuses on the transmission control unit (TCU), which is responsible for controlling the calculation of when and how to change gears in automatic transmission vehicles. The current design needs improvement for disassembling the returned products, particularly in separating components, without the risk of damaging the printed circuit board (PCB) - a critical, economically valuable component. Consequently, design improvement focuses on easing the disassembly process without harming the reusable components. To achieve this, brainstorming sessions are conducted with the engineering team to define the problem in terms of technical contradictions within the TRIZ framework. Then, using the TRIZ matrix, feasible design changes to solve these contradictions are identified. Each design change is evaluated based on ease of applicability and compatibility with the current manufacturing setup. The entire idea generation process and resulting design improvement options are presented to inform remanufacturing practitioners about the usability of the TRIZ methodology in systematically enhancing design solutions.

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1. Introduction and Motivation

Remanufacturing is one of the most favorable product recovery strategies, offering significant savings in raw material and energy consumption. Therefore, there is a substantial research attempt to enhance the remanufacturability of the products. Within this context, design for remanufacturing (DfRem) focuses on improving the product design to facilitate various tasks involved in remanufacturing (Shu & Flowers, 1999). Nasr and Thurston define DfRem as engineering products and product strategies regarding remanufacturing needs (Nasr & Thurston, 2006). Similarly, Charter and Gray describe it as all the design processes intended to streamline remanufacturing (Charter & Gray, 2008). In those definitions, the emphasis is on enhancing the product design to remove barriers to remanufacturing. Remanufacturing includes many processes, including cleaning, disassembly, repair, and assembly, which require simultaneous consideration of many factors during the design stage. For instance, a joining that facilitates assembly may hinder the disassembly process, or the use of a non-durable material might break during repair (Ijomah et al., 2007a). From material selection to fastening methods, all the decisions made during design impact the efficiency of the remanufacturing in later stages. To address these challenges, DfRem should follow a systematic approach that integrates all these factors to increase the environmental and economic viability of remanufacturing.

Numerous design generation and analysis tools have been used to solve engineering design problems. Some notable examples are failure mode and effects analysis (FMEA), quality function deployment, and axiomatic design. However, the effectiveness of these techniques depends on domain-specific knowledge and experience. In contrast, Theories of Problem Inventive Solving (TRIZ) provides a systematic problem-solving methodology for users to find novel solutions to complex problems by leveraging the knowledge from past designs to generate creative solutions (Ilevbare et al., 2013). It helps capture the rationale behind the design solution and leverage it for similar new problems (Pham et al., 2009). Shirwaiker & Okudan (2006) demonstrated the successful use of TRIZ in product and manufacturing design problems. Furthermore, Spreafico (2021) demonstrated the effectiveness of TRIZ in developing eco-friendly products through case studies and life cycle assessments. Inspired by their research, this study investigates the use of TRIZ in DfRem. In TRIZ, any factor that impacts the system can be identified as a parameter, i.e., a feature. These parameters are interdependent, meaning that improving one parameter to have positive effects on the system may degrade another parameter to have harmful effects on the system, known as contradictions. For instance, increasing engine power obviously yields benefits in terms of performance but typically comes at the cost of increased size and weight, which can negatively impact the overall system. TRIZ aims to solve such contradictions by seeking solutions that improve system performance without compromising other parameters. The overall objective is to achieve the ideal state of the system where all the requirements are satisfied with no side effects, a.k.a., ideality concept. Because DfRem requires a holistic approach and thorough consideration of various parameters that might conflict, we adopt the TRIZ methodology in DfRem to enhance the ease of disassembly and, consequently, re-manufacturability of the product.

This paper applies TRIZ in DfRem to derive alternative design improvement solutions that facilitate remanufacturing. The effectiveness of the proposed solution is demonstrated through a case study. The case study discusses what design improvements are needed to enhance the transmission control unit's (TCU) ease of disassembly to make it remanufacturable. The current manufacturing process does not support disassembly and an alternative fastening method is required. Joining methods that prevent component detachment can cause harm during disassembly. DfRem has to consider ease of disassembly, with no damage to the product or its components. After identifying the technical constraints on TCU, the problem is defined in terms of contradictions, i.e., improving parameters vs. worsening parameters. Then, the TRIZ matrix provided generic solutions, a.k.a. TRIZ principles, to resolve these contradictions without tradeoffs. Next, with the engineering team, these generic solutions are tailored to the specific problem, i.e., TCU design improvement. A cantilever snap-fit solution is selected as the most effective solution that ensures secure sealing while improving both assembly/disassembly processes. The stages of deriving a cantilever snap-fit solution are detailed.

The paper is organized as follows. Section 2 overviews the literature for DfRem and TRIZ applications in engineering design problems. Section 3 presents the proposed methodology and tailors the solution to the considered case study. Section 4 presents the results. Finally, Section 5 concludes the paper while discussing potential future research avenues.

2. Review of Related Work

The research under DfRem can be broadly categorized into two main streams based on the methods used in product design or improvement: i) developing new DfRem guidelines and ii) adapting existing methods to address the

problems in remanufacturing. Under the first research stream, Ijomah (2009) provided high-level remanufacturing guidelines derived from existing literature, workshops, and case studies. According to the guideline, the factors that need to be considered related to joining methods include i) using similar or compatible materials as a fastener, ii) employing assembly methods that avoid damage to components, iii) designing components to facilitate disassembly, iv) standardizing fasteners, and v) ensuring easy access to joints. Similarly, Russo et al., (2014) proposed the "iTree" tool/matrix, which suggests guidelines for designing eco-friendly products. The tool uses life cycle assessment to identify critical areas of the product and recommends how to reduce mass, volume, waste, and energy. Another research in this stream was performed by Schlesinger et al. (2023). Their study defined design rules to integrate additive manufacturing in remanufacturing. The design guidelines evaluated the production of a part using additive manufacturing, which could then be used in remanufacturing, and provided suggestions for optimizing the part design to ensure additive manufacturing compatibility.

Under the second research stream, existing techniques such as FMEA, quality function deployment, TRIZ, and different optimization approaches, either individually or in combination, were used to enhance product remanufacturability. These techniques were applied through product- or industry-specific case studies. For instance, . (Behtash et al. (2024) developed a joint optimization of product design changes and remanufacturing actions, such as basic cleaning, machining, and additive manufacturing, to minimize economic and environmental impacts. The study was applied to hydraulic manifolds. First, an FMEA was performed to capture failure modes, and then, the effectiveness of the proposed method was shown by reductions in costs, energy consumption, and CO_2 emissions. In another study, Nemani et al. (2021) proposed a reliability-informed framework to analyze cost and energy consumption across multiple remanufacturing cycles of the hydraulic manifolds. The framework used a branched power-law model to characterize the uncertainty in reuse rates and provided insights to guide decisions on reuse and replacement.

Given the substantial use of existing approaches in DfRem, we overviewed studies that are most relevant to our problem here. Kremer et al. (2012) used axiomatic design, TRIZ, and mixed integer programming to solve the locomotive ballast arrangement problem, which determines material combinations, quantities, and allocation of the limited cavities to minimize cost. Axiomatic design was used to decompose the problem into smaller mutually independent subproblems, TRIZ generated feasible design concepts, and last, the mixed integer programming model selected the best locomotive ballast arrangement that minimized total material costs. Yang et al. (2024) combined Latent Dirichlet Allocation, TRIZ, and Kansei Engineering to design an eco-friendly coffee maker based on online product reviews. Latent Dirichlet Allocation extracted customer requirements from online reviews. Then, these requirements were incorporated into sustainable and emotional design concepts. Next, TRIZ was used to generate solutions that meet customer requirements. Last, Kansei Engineering and an interactive genetic algorithm were applied to generate the final design. To expand additive manufacturing applications in remanufacturing, Kandukuri et al. (2021) proposed an enhanced TRIZ matrix that overcomes design-related contradictions in remanufacturing. They compiled a list of design guidelines from the literature and tailored them for using additive manufacturing in remanufacturing processes. Hameed et al. (2022) used FMEA, environmentally conscious quality function deployment, TRIZ, and fuzzy version of the technique for order of preference by similarity to ideal solution (TOPSIS) for designing eco-friendly pressure relief valve, which is prevalent in boilers, pressure vessels, and pipelines. Critical failure modes were defined by FMEA; then, design options were evaluated based on environmentally conscious quality function deployment. TRIZ resolved conflicts between engineering parameters. Last, fuzzy TOPSIS was used to select the final design.

As seen in the above-mentioned studies, TRIZ is effectively incorporated into the design stage to address customer requirements and solve contradictions in engineering parameters. However, Kandukuri (Kandukuri et al., 2021), to the best of our knowledge, is the only study considered TRIZ in DfRem to develop design guidelines. There is a gap in demonstrating how TRIZ can support DfRem in practical implementations. Addressing this gap, our study applies TRIZ in DfRem through an industry case study and highlights its effectiveness in design improvement.

3. Technical Approach

The general flow of the TRIZ methodology to enhance the remanufacturability of the products is outlined in Figure 1. The first stage is the identification of the problem. Here, the problem at hand is clearly defined with the associated constraints. For our case study, the working conditions of the TCU and the limitations on the design improvement were collected from our industry partner. The second stage is the identification of the technical contradictions, which involves reidentifying the problem in terms of technical contradictions. Therefore, the specific problem was analyzed and translated into a generic problem by redefining the conflicts between engineering parameters. In TRIZ, there are 39 engineering parameters combined into a 39×39 TRIZ matrix, where rows present the improving parameters, and

the columns present the worsening parameters. TRIZ matrix serves as a tool to guide designers in solving the contradictions and generating innovative solutions.

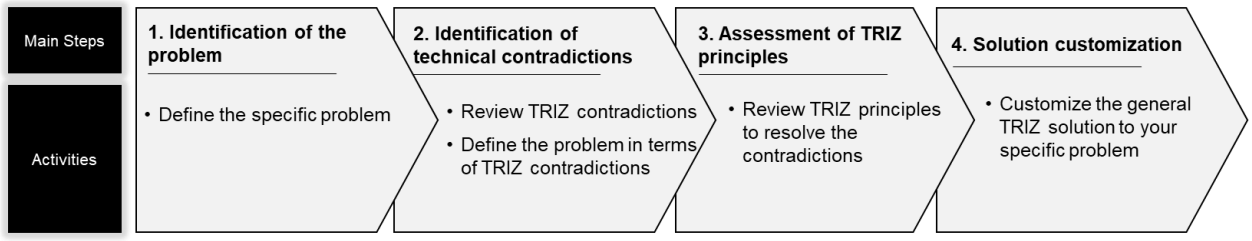


Figure 1. Overview of TRIZ procedure

The third step is the assessment of TRIZ principles. These TRIZ principles suggest a generic solution to solve the contradiction and are located in the cells of the TRIZ matrix. Each cell located in the intersection of the contradictions (e.g., improving parameter × worsening parameter) presents the TRIZ principles suggested for solving the specific contradiction. By applying these principles, it is possible to develop a solution without compromising any parameters. For example, as presented in Figure 2, the conflict is defined as improving the strength of the object (improving parameter) increases the weight of an object (worsening parameter). The suggested principles to solve this contradiction are 01-Segmentation, 26-Copying, 27-Cheap short living, and 40-Composites. Because these principles provide generic guidance, the final step in our methodology involves carefully interpreting their definitions and selecting the most appropriate one for customization to meet the specific needs of the problem.

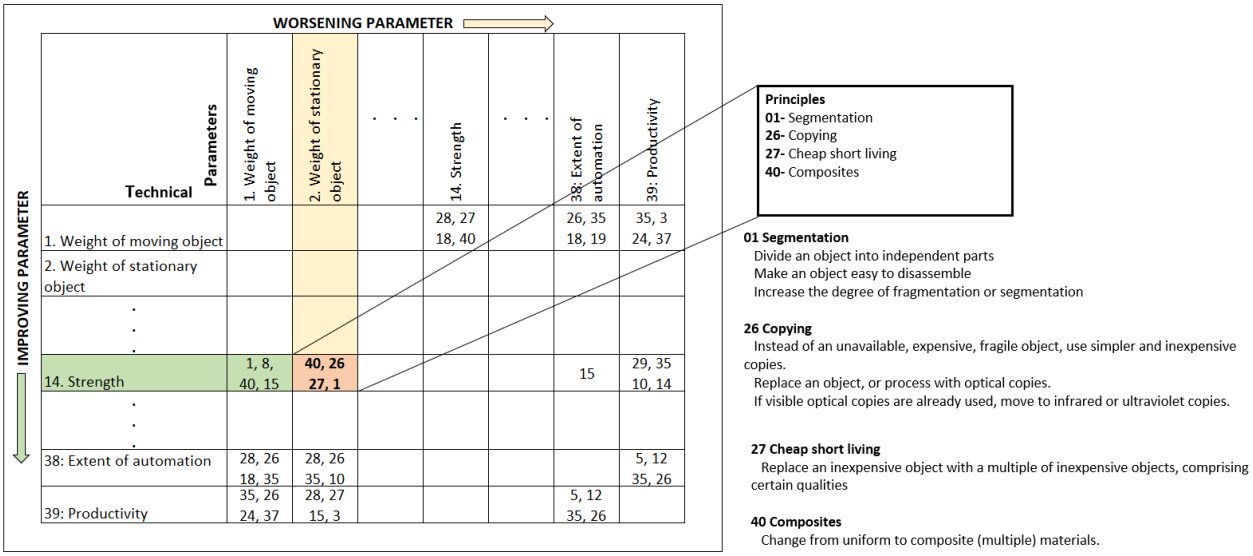


Figure 2. TRIZ parameters with the principles (adapted from (Gadd, 2025))

4. TCU Case Study

4.1. Identification of the problem

TCU, a.k.a. a transmission control module or gearbox control unit, is an automotive engine control unit that controls electronic automatic transmissions. Using sensor data and electronic automatic transmissions, TCU calculates when and how to change gears (Gogoi, 2022). An example of TCU is presented in Figure 2. TCU has an aluminum housing at its base, where the printed circuit board (PCB) is mounted. The top of this aluminum housing is sealed with a plastic cover to protect the PCB from external contaminations, such as water, oil, or dirt. Glue is commonly used to seal the

plastic cover to the aluminum housing since it offers a secure seal and is easy to apply. However, gluing poses a challenge for remanufacturing. During the disassembly stage, removing the glued plastic cover from the aluminum housing requires high force, which increases the risk of damaging the PCB. Given the economic value of PCB and aluminum housing, design improvement is required to ease the detachment of the plastic cover and aluminum housing and reduce the risk of potential harm to PCB.

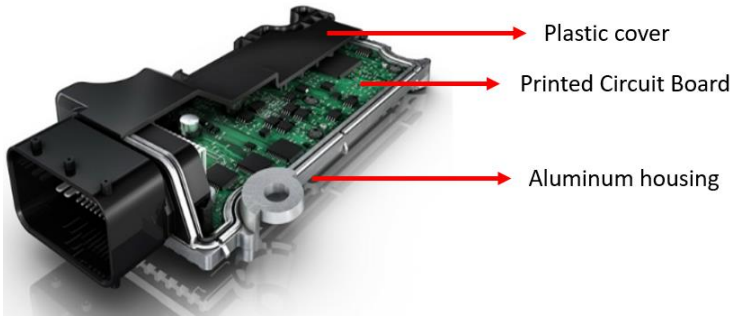


Figure 2. An example of TCU (photo courtesy: ZF group)

4.2. Identification of technical contradictions

In this step, the TRIZ contradiction matrix redefines the problem regarding technical contradictions, which involves identifying conflicting engineering parameters. Accordingly, first, the problem is examined to reveal potential areas for improvement. These improvements are then mapped to specific TRIZ parameters. To do so, we refer to the original definitions of the TRIZ parameters (Altshuller & Shulyak, 2002; Orloff, 2006) and select the parameters that have the highest match with the required improvement on the TCU parameter. To understand the problem thoroughly, all technical contradictions are identified as improving and worsening parameters. In our problem, the primary constraint is easing the disassembly process and eliminating the risk of potential harm to the PCB while having secure sealing (strength between the plastic cover and the aluminum housing). Accordingly, we identified three improvable engineering parameters that conflict with the strength parameter, as shown in the contradiction matrix Table 1.

Table 1. Contradiction matrix with TRIZ principles

Improving vs Worsening parameter	**TRIZ Principles**
Object-generated harm vs Strength	15 Dynamics; 35 Parameter changes; 22 Blessing in disguise; 2 Taking out
Ease of manufacture vs Strength	1 Segmentation; 3 Local quality;10 Preliminary action; 32 Color changes
Ease of operation vs Strength	32 Color changes; 40 Composite materials; 3 Local quality; 28 Mechanics substitution
Loss of time vs Strength	29 Pneumatics and hydraulics; 3 Local quality; 28 Mechanics substitution;18 Mechanical vibration
Force vs Strength	35 Parameter changes; 10 Preliminary action; 14 Spheroidality – Curvature; 27 Cheap short-living objects
Device complexity vs Strength	2 Taking out;13 The other way round; 28 Mechanics substitution

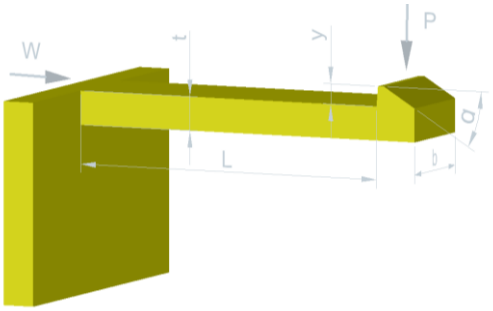
4.3. Assessment of TRIZ principles

This subsection discusses how to use the suggested TRIZ principles in design improvement. By analyzing Table 1, three principles, “28 Mechanics substitution,” “3 Local quality,” and “10 Preliminary actions,” emerged as the most repeated principles regarding design improvements. Mechanics substitution proposes replacing mechanical with sensory means and switching stationary to moving fields (Pham et al., 2009). Local quality emphasizes customization and suggests changing the structure from uniform to non-uniform (if it is uniform) or changing parts to provide different functions. Finally, the preliminary action principle suggests proactive actions that simplify the processes,

which could incorporate additional mechanisms to streamline sealing and assembly (Gazem, 2014). It is worth mentioning that the interpretation of these principles is not straightforward and can vary among designers (Pham et al., 2009). However, they provide a starting point for design improvements. Combining the suggestions from three principles, the design team focused on three points in their improvement: i) substitute traditional processes with more streamlined and intuitive alternatives, ii) avoid replacing complex mechanical solutions, and iii) modify uniform design to non-uniform that enhances connection and simplify assembly/disassembly. Accordingly, the team decided on two possible design improvements: i) using screws or ii) adopting a snap-fit solution. Although screws provide secure sealing, they are usually time-consuming (Ijomah et al., 2007b). Therefore, the team put efforts into developing a snap-fit solution that eliminates harm to the PCB and accomplishes secure sealing while saving time during assembly and disassembly.

4.4 Solution customization

This stage focuses on developing a snap-fit solution based on the suggested TRIZ principles. Snap-fits are practical and time-efficient solutions for assembly and disassembly since they eliminate the need for tools to join parts together. A snap-fit consists of a flexible element that deflects during the assembly and locks into the mating component. Among several snap-fit designs, cantilever, torsional, and annular snap-fits are widely used (Amaya et al., 2019). In this study considering the design simplicity, ease of assembly and disassembly, strength, and stress concentration of the snap-fit solutions, the team decided to develop a cantilever snap-fit solution. To assure functionality and allow for ease of assembly and disassembly, the snap-fit design must follow the design guidelines, which define the relationships between dimensions. Figure 3 presents a cantilever snap-fit with design guidelines. According to the design guidelines (Amaya et al., 2019; BASF, 2007), the snap-fit should be designed based on the following constraints. Equation (1) states that the beam length L needs to be 5 to 10 times the beam thickness t. Equation (2) states that the beam width b should be less than half the beam length. Equation (3) states that the height of the retention mechanism y should be determined based on the beam length and thickness ratio, L/t. If L/t ratio is around 5, y should be less than the beam thickness. However, if L/t ratio is close to 10, y should be equal to the beam thickness. The retention mechanism ensures the connection between the beam and the mating remains secure once assembled. This height defines the maximum deflection of the snap-fit joint during assembly or disassembly motions. Equation (4) states that the mounting angle α should be within the range of 25º to 30º. Lastly, Equation (5) states that the dismounting angle β for a non-releasing joint should be above 80º, while it should be determined based on the retention force for the releasing joints.



L: Beam length	$5t < L < 10t$	(1)
b: Beam width	$b < 0.5L$	(2)
y: Height of retention mechanism	$If\ L/t \cong 5,\ y < t$ $If\ L/t \cong 10,\ y = t$	(3)
α: Mounting angle	$\alpha = 25°\sim30°$	(4)
β: Dismounting angle	$\beta > 80$, for non-releasing joint $\beta = f(retention)$, for releasing joint	(5)

Figure 3. An example cantilever snap-fit design with guidelines

Based on the design guidelines, the dimensions of the snap-fit feature are as follows: the beam length is L =9 mm, the beam thickness and width are t = 1.5 mm and b = 4 mm, respectively. The height of the deflection y is 0.75 mm while the mounting and dismounting angle are 30º and 85º, respectively. To ensure secure sealing, a plastic gasket is placed between the plastic cover and aluminum housing. The design of the snap-fit is shown in Figure 4. Even though a single snap-fit design is presented in Figure 4, a total of eight snap-fit mechanisms are located along TCU sides.
The strain level of the snap-fit feature is calculated as in Equation (6). In Equation (6), Q refers to the deflection magnification factor, which is 1.8 for the considered snap-fit design.

$$\varepsilon = 1.5\frac{t \cdot y}{L^2 Q} \quad (6)$$

The strain level of the design, ε_{design} =1.1%, is less than the material strain limit (Ultradur B4300 G3 (PTB) $\varepsilon_{material}$ =2.5%). This indicates that the snap-fit design is within acceptable limits.

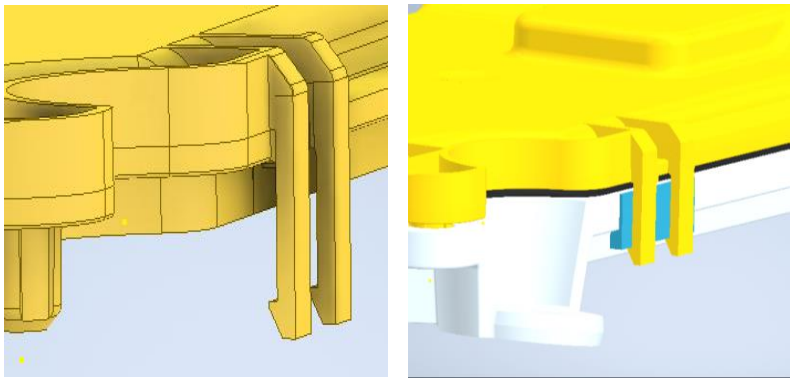


Figure 4. Proposed snap-fit design

The proposed solution will facilitate the disassembly process without harm to PCB, which has the most economic value. By doing so, the developed solution will not only provide cost benefits but also contribute to the circular economy. However, quantification of these benefits will be the focus of another research.

5. Conclusion

This paper explores the use of TRIZ in DfRem to address challenges in the disassembly and remanufacturability of TCU. TRIZ provided a step-by-step solution framework for generating design alternatives to enhance remanufacturing. The problem was first identified in terms of technical contradictions, and the suggested generic solutions were reviewed by the engineering team. Given TRIZ suggestions, the team developed a snap-fit design solution for the current TCU, which eliminates harm to components, ensures secure sealing, and facilitates both the assembly and disassembly process. Even though the effective use of TRIZ in DfRem was demonstrated through a TCU case study, the methodology can be applied across industries that benefit from remanufacturing. It is important to mention that the primary focus of the study was the application of TRIZ in DfRem, rather than quantifying economic and environmental benefits. In future research, those benefits will be calculated and the contribution of the proposed solution to the circular economy will be presented. Furthermore, we will incorporate the ergonomic factors, such as assembly and disassembly forces needed, before finalizing the proposed solution. This might involve slight changes in the dimensions to further enhance the ease of assembly and disassembly process.

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DISCLAIMER

the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

References

Altshuller, G., & Shulyak, L., 40 Principles TRIZ Keys to Technical Innovation (1st ed., Vol. 1). Technical Innovation Center, Worchester, MA, 2002.

Amaya, J. L., Ramírez, E. A., Maldonado, G. F., & Hurel, J., Detailed design process and assembly considerations for snap-fit joints using additive manufacturing. Procedia CIRP, 84, 680–687, 2019. https://doi.org/10.1016/j.procir.2019.04.271

BASF, Snap-Fit Design Manual, 2007.

Behtash, M., Liu, X., Davied, M., Thompson, T., Burjes, R., Lee, M., Wang, P., & Hu, C., Reman Co-Design: A Combined Design and Remanufacturing Optimization Framework for the Sustainable Design of High-Value Components. Journal of Mechanical Design, 146, 2, 2024. https://doi.org/10.1115/1.4063660

Charter, M., & Gray, C., Remanufacturing and product design. International Journal of Product Development, 6, 3-4, 375-392, 2008. https://doi.org/10.1504/IJPD.2008.020406

Gadd, K., Oxford TRIZ Innovation Tools. Https://Www.Triz.Co.Uk, 2025.

Gazem, N. and Rahman, A. A., Interpretation of TRIZ principles in a service related context. Asian Social Science, 10, 3, 108–130, 2014.

Gogoi, M. B., A study on transmission unit (Automatic Transmission). South Asion Academic Research Journals, 12, 2, 93–108, 2022.

Hameed, A. Z., Kandasamy, J., Aravind Raj, S., Baghdadi, M. A., & Shahzad, M. A., Sustainable Product Development Using FMEA ECQFD TRIZ and Fuzzy TOPSIS. Sustainability, 14, 21, 14345, 2022. https://doi.org/10.3390/su142114345

Ijomah, W. L., Addressing decision making for remanufacturing operations and design-for-remanufacture. International Journal of Sustainable Engineering, 2, 2, 91–102, 2009. https://doi.org/10.1080/19397030902953080

Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T., Development of design for remanufacturing guidelines to support sustainable manufacturing. Robotics and Computer-Integrated Manufacturing, 23, 6, 712–719, 2007a. https://doi.org/10.1016/j.rcim.2007.02.017

Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T., Development of robust design-for-remanufacturing guidelines to further the aims of sustainable development. International Journal of Production Research, 45, 18–19, 4513–4536, 2007b. https://doi.org/10.1080/00207540701450138

Ilevbare, I. M., Probert, D., & Phaal, R., A review of TRIZ, and its benefits and challenges in practice. Technovation, 33, 2–3, 30–37, 2013. https://doi.org/10.1016/j.technovation.2012.11.003

Kandukuri, S., Günay, E. E., Al-Araidah, O., & Okudan Kremer, G. E., Inventive solutions for remanufacturing using additive manufacturing: ETRIZ. Journal of Cleaner Production, 305, 126992, 2021. https://doi.org/10.1016/j.jclepro.2021.126992

Kremer, G. O., Chiu, M.-C., Lin, C.-Y., Gupta, S., Claudio, D., & Thevenot, H., Application of axiomatic design, TRIZ, and mixed integer programming to develop innovative designs: a locomotive ballast arrangement case study. The International Journal of Advanced Manufacturing Technology, 61, 5–8, 827–842, 2012. https://doi.org/10.1007/s00170-011-3752-1

Nasr, N., & Thurston, M., Remanufacturing: A Key Enabler to Sustainable Product Systems, 23, 2006.

Nemani, V. P., Liu, J., Ahmed, N., Cartwright, A., Kremer, G. E., & Hu, C., Reliability-Informed Economic and Energy Evaluation for Design for Remanufacturing: A Case Study on a Hydraulic Manifold. Volume 3B: 47th Design Automation Conference (DAC), 2021, August 17. https://doi.org/10.1115/DETC2021-67996

Orloff, M. A., Inventive Thinking through TRIZ a Practical Guide (2nd ed.). Springer Berlin Heidelberg New York, 2006.

Pham, D. T., Ng, K. W., & Ang, M. C., Applying TRIZ to Support Designers in a Descriptive Design Framework. Volume 2: 29th Computers and Information in Engineering Conference, Parts A and B, 871–880, 2009. https://doi.org/10.1115/DETC2009-87455

Russo, D., Rizzi, C., & Montelisciani, G., Inventive guidelines for a TRIZ-based eco-design matrix. Journal of Cleaner Production, 76, 95–105, 2014. https://doi.org/10.1016/j.jclepro.2014.04.057

Schlesinger, L., Koller, J., Pagels, M., & Döpper, F., Alignment of design rules for additive manufacturing and remanufacturing. Journal of Remanufacturing, 13, 2, 99–119, 2023. https://doi.org/10.1007/s13243-022-00122-9

Shirwaiker, R., & Okudan, G., TRIZ and Axiomatic Design: A Review of Manufacturing Case-Studies&Their Compatibility. Technology Management for the Global Future - PICMET 2006 Conference, 2510–2520, 2006. https://doi.org/10.1109/PICMET.2006.296848

Shu, L. H., & Flowers, W. C., Application of a design-for-remanufacture framework to the selection of product life-cycle fastening and joining methods. Robotics and Computer-Integrated Manufacturing, 15(3), 179–190, 1999. https://doi.org/10.1016/S0736-5845(98)00032-5

Spreafico, C., Quantifying the advantages of TRIZ in sustainability through life cycle assessment. Journal of Cleaner Production, 303, 2021.126955. https://doi.org/10.1016/j.jclepro.2021.126955

Yang, C., Xu, T., & Ye, J., Applying TRIZ and Kansei engineering to the eco-innovative product design towards waste recycling with latent Dirichlet allocation topic model analysis. Engineering Applications of Artificial Intelligence, 133, 107962, 2024. https://doi.org/10.1016/j.engappai.2024.107962

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