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Optimization of Cone Lifter Components in C2L Machine for Highway Concession Operation Using TRIZ Method

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Keywords

Theory of inventive problem solving (TRIZ), engineering contradiction, cone collecting and laying, functional analysis model (FAM)

Abstract

This study aims to enhance cone laying and picking (C2L) machines used in highway concession operations through the application of TRIZ methodology. The study identified engineering contradictions within the C2L machine and proposed solutions to address them systematically. TRIZ tools were utilized to identify areas for improvement in the assembly and disassembly processes of cone lifters, leading to the redesign and fabrication of C2L machines. Testing of C2L machines demonstrated the effectiveness of the new design in handling cone lifters. Results showed that by increasing the weight capacity and gripping force of the cone lifter improved lifting efficiency and reduced cone slippage. However, it also introduced challenges such as stress on structural components and potential cone deformation. Through the TRIZ methodology, these contradictions were addressed, leading to a redesigned cone lifter with improved durability and performance. TRIZ tools, including the Function Analysis Model, were employed to attribute functions to each component of the C2L system. Additionally, a framework for assessing C2L machine effectiveness in highway concession operations was proposed. The redesign and fabrication of C2L machines, along with various tests demonstrated the success of the new design in handling cone lifters. The findings highlight the importance of TRIZ methodology as a valuable tool for resolving technical contradictions and optimizing C2L machine designs, contributing to a more efficient and sustainable future in transportation infrastructure management.

1. Introduction

Within modern transportation infrastructure management, prioritizing the safety of both workers and commuters on expressways is of utmost importance, especially within highway concession operations. Expressway

maintenance is very important to ensure road user's safety and comfort while they are traveling from one place to another [1]. Highway concession operations, such as those managed by PLUS Malaysia Berhad (PMB), require meticulous maintenance to uphold road user safety and comfort [2]. However, traditional methods of expressway maintenance, particularly the manual handling of safety cones, pose significant safety risks to workers due to potential collisions with live traffic and accidents involving reversing vehicles. Thus, the C2L machine was created as a semi-automated solution to address this issue and replace the labor-intensive manual process of gathering and placing safety cones (Fig. 1).

As such, it aims to minimize or eliminate workers' exposure to live traffic, thereby enhancing their safety. Currently, workers receive cones from a colleague behind a moving lorry and place them on the pavement, while the cones are collected by passing them back to a colleague on a reversing lorry. These manual processes produce a greater risk of accidents occurring for highway workers. TRIZ method was utilized to identify areas for improvement in the assembly and disassembly processes of the cone lifter, which is one of the main components of the C2L machine that leads to the redesign and fabrication of C2L machines. The objective is to improve the efficiency of the C2L process, thereby reducing safety risks to workers and establishing a new standard in highway maintenance practices.

Cone lifters are designed to efficiently collect cones from the ground. The use of cone lifters improves the operation time as compared to manual collection methods. Importantly, cone lifters improve safety by minimizing the need for workers to bend or manually handle heavy cones. Besides reducing the physical strain on workers, particularly during repetitive or labor-intensive tasks, this can lead to improved worker efficiency. The need for manpower to perform labor can be reduced and the overall operation time can be improved. The C2L machine faced a significant issue when a crack occurred in the cone lifter weld joint after about 25 hours and 16 minutes of operation as shown in Fig. 2. These cracks, possibly due to the fatigue failure, caused the machine operation to become risky and potentially dangerous. It is found that the repeated impacts and prolonged heavy cone handling have subjected the cone lifter to excessive stress, leading to the formation of cracks. Thus, TRIZ is used as an improvement solution to ensure that the cone lifter can be used longer and more effectively.

(a) **(b)**

Fig. 1 *Type of testing (a) Testing in the laboratory; (b) Testing in the field*

2. Methodology

The TRIZ methodology was selected for this study because it is known for solving difficult and complex problems that demand users to think outside the box [3-4]. In this research, TRIZ tools were utilized. Firstly, the framework was generated and followed by conducting a Function Analysis Model (FAM) to attribute a function to each component of the system. Then, it was continued by examining the C2L Engineering contradiction. The subsequent step is to facilitate the systematic resolution of engineering contradictions. The overall experimental approach adhering to the TRIZ principles is summarized in Fig. 3.

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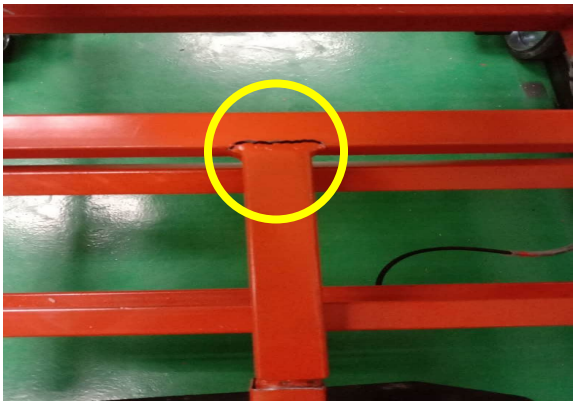

Fig. 2 *Crack welded joint at cone lifter*

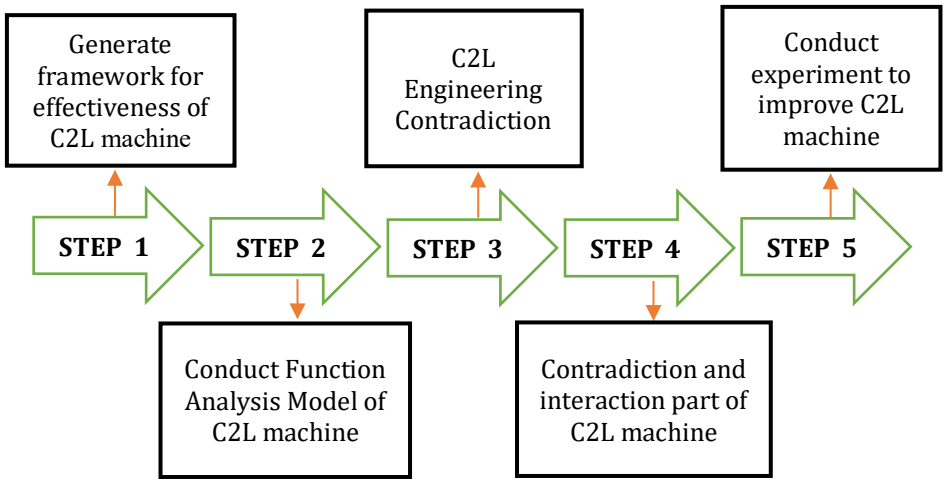

Fig. 3 *Flow chart of research methodology and experiment of research*

2.1 Framework Design for The Effectiveness of C2L Machine

Fig. 4 shows the framework for the effectiveness of C2L machine used by the Malaysia Highway Concession. Variables were categorized into time awareness and vehicle operation. These variables represent the outcome and are influenced by the independent variables. The study employs a mediation analysis framework to examine how the independent variables affect the dependent variables, both directly and indirectly through the mediators (TRIZ). This analysis will provide insights into the mediating role of TRIZ implementation and employee skills in the relationship between time awareness, vehicle operation, and the dependent variable.

The cone lifter mechanism in the C2L machine is designed to operate with high speed, consistency, and efficiency to minimize the time required for placing and collecting cones. Automating and optimizing the cone handling process enables the lifter to swiftly and consistently manipulate cones at a rate significantly surpassing the manual methods. The cone lifter allows the entire C2L task to be completed in a fraction of the time compared to traditional manual approaches. This time-saving capability directly enhances productivity and operational efficiency. Furthermore, the lifter's automated and self-regulated functioning reduces the need for worker involvement, thus decreasing personnel exposure to hazardous roadside environments with live traffic.

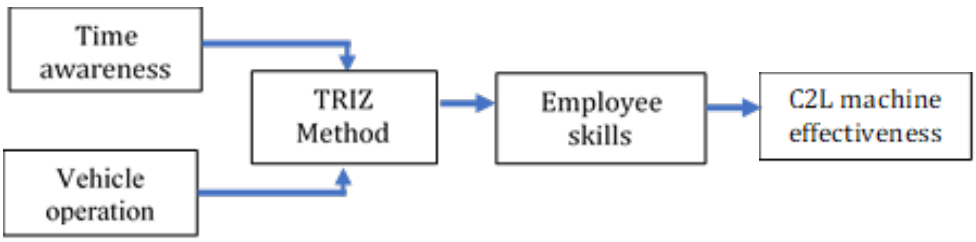

Fig. 4 *A framework for effectiveness of C2L machine in Malaysia Highway Concession*

2.2 Utilizing FAM of C2L to Identify Improvement Option

The Functional Analysis Model (FAM) serves as a framework for analyzing the functions of an artifact. It uses simple keywords and line types to provide clues about functions and relationships between components. In this study, the main product is C2L machine. The system principles of the FAM are divided into three types:

- System: It is designed to accomplish a specific task in a specific work environment [5-6].
- Subsystem: This refers to a group of interconnected and interacting parts that together perform an important task as part of a larger system, as outlined by [7-8].
- Super-system: It comprises the system under consideration as a subsystem. When simplifying a system, the use of a super-system is essential from the outset [9].

The FAM diagram for the C2L machine, is a tool aimed at providing a conceptual description of a product or process [10]. This diagram helps in understanding the function of each component and facilitating the generation of ideas to optimize the components' functionality. In addition, FAM 'strives to analyze the process, execute comparisons, and rank the functions performed by different operations [11]. Fig. 5 illustrates the connections and relationships between components and equipment, showing how they work together to operate a C2L machine. Control and power distribution are clearly illustrated, along with the critical functions of each functional part of the overall system. It also highlights the critical role of each component in the overall functionality of the system.

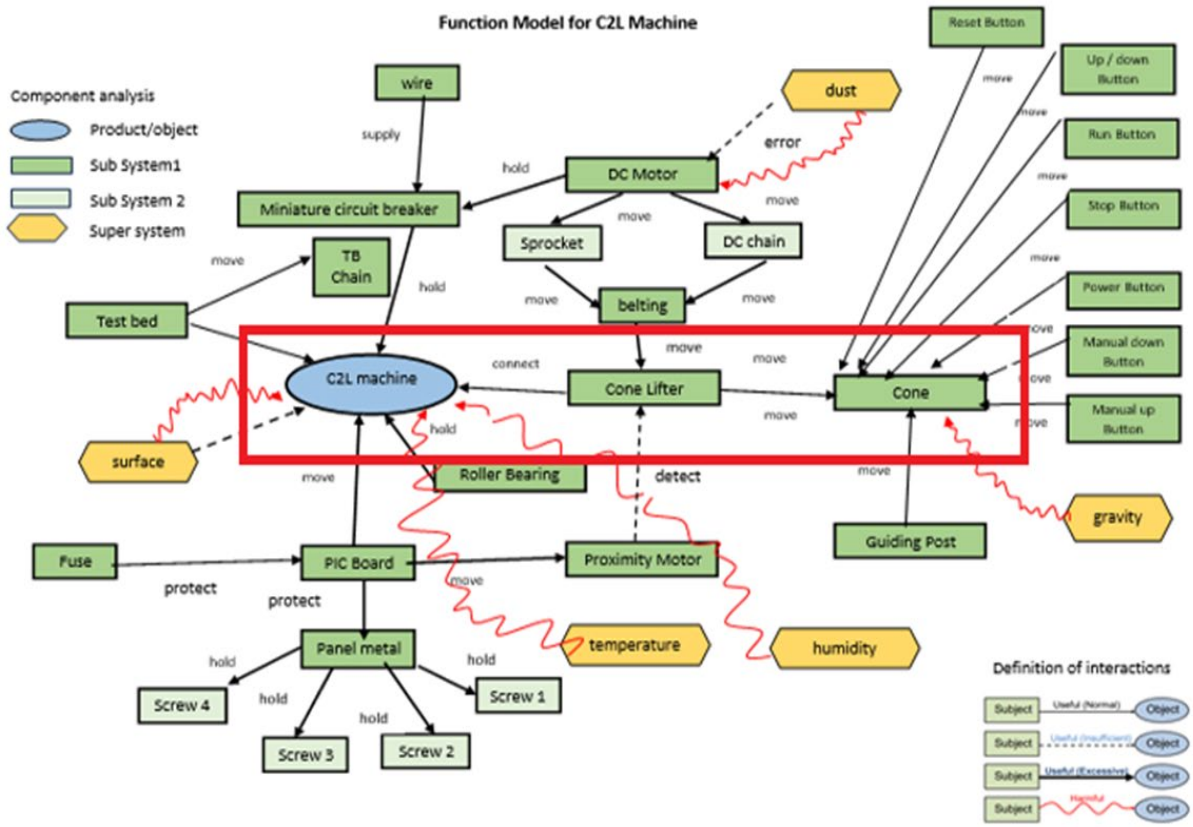

Fig. 5 *The function analysis model (FAM) of C2L machine*

2.3 Construction of References

The "If...Then...But..." approach emphasizes a proactive stance through maintenance, monitoring, redundancy, and safety features. It aims to optimize the performance of each component, ensuring that the machine operates smoothly under normal conditions and is resilient to unexpected challenges. Applying this method to every component and variable in the C2L machine and its subsystems will result in a thorough study that is solution-focused and supports the machine's efficacy, safety, and dependability. The goal is to identify and address contradictions systematically, that leads to improvement.

Through this approach, TRIZ enables systematic resolution of engineering contradictions, facilitating innovative problem-solving and design optimization. Moreover, Table 2 illustrates the contradiction and

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interaction function components within the Function Analysis Model (FAM) for the C2L machine. The contradiction from the FAM is as below:

(a) **If** the tension in the belt system is increased, **then it** improves the reliability of the belt system in terms of durability and wear resistance, **but** the increased tension in the belt system leads to higher friction and wear on other components such as rollers and bearings.
(b) **If** the size or load capacity of the roller bearings used in the C2L machine is increased, **then** the smoothness and efficiency of cone transport may improve, but the overall size and weight of roller bearings may increase.
(c) **If** the rigidity of the test rig is increased, **then** the accuracy of testing and validation of the C2L machine's functions and performance could increase, **but** the cost and complexity of the test rig could increase significantly.
(d) **If** the sensitivity or range of the proximity motor used for cone detection and lifting is increased, **then** the efficiency of cone detection and lifting improves, **but** can also lead to more false positives or unintended cone detections.
(e) **If** the processing speed of the PIC board in the C2L machine is increased, **then** the overall efficiency and speed of the C2L process improve significantly **but** it requires more energy from the power supply to support the advanced functionality of the PIC board.
(f) **If** the guiding post height is increased to accommodate taller cones, **then** the stability and alignment of taller cones during the laying process improve, **but** the increased height may introduce additional vibrations or instability, leading to a higher risk of cones toppling over during the collection or laying process.
(g) **If** the lifting capacity of the cone lifter is increased, **then** the efficiency of cone pick-up and placement improves, **but** the speed of the process decreases, resulting in a lower overall throughput or a shorter cycle time efficiency.
(h) **If** the MCB's sensitivity to current fluctuations increases, **then** it improves the safety of the electrical system within the C2L machine, **but** the increased sensitivity of the MCB can cause it to trip frequently even with minor fluctuations, causing interruptions in the operation of the machine and reducing overall efficiency.

Table 1 *Contradiction and interaction function parts within the FAM for the C2L machine*

Component Analysis	Each Part	Contradiction
Subsystem 1	Miniature Circuit Breaker, Wire, Test Bed, Fused, PIC Board, Panel Metal, Proximity Motor, Roller Bearing, Cone Lifter, Belting, DC Motor, Button, Cone, Guiding Post	Each component, can analyze potential contradictions using the Contradiction Matrix. For example, improving the strength of a material may contradict its flexibility.
Subsystem 2	DC Chain, Sprocket, Screw	Each component in Subsystem 2 can be analyzed for contradictions. For instance, improving the speed of a mechanism may contradict its precision.
Super System	Dust, Surface, Humidity, Temperature, Gravity	External conditions may present contradictions. For instance, improving protection against dust may contradict the need for efficient heat dissipation.

3. Result and Discussion

3.1 Conceptual Design and Fabrication of C2L Machine

The current design of the cone lifter is shown in Fig. 6. The function of the cone lifter in conjunction with cones involves securely gripping, lifting, and transporting the cones to designated locations during the laying and collecting process. The application of the TRIZ method in optimizing the design of the C2L machine leads to promising results. These solutions ranged from technological advancements to operational adjustments, highlighting the importance of creative problem-solving approaches.

Designing an experimental setup to measure the total time for repair and total operating time provides valuable insight into assessing the reliability, maintainability, and performance of the C2L machine. Mean Time to Failure (MTTF) is defined as the duration a device or product is anticipated to function before encountering a

failure. It represents the average duration, over extended periods of operation, of the random variable known as 'time to failure' [12]. The mean time between failures (MTBF) is the mean (average) time between failures of a system, which can be restarted after a failure occurs and therefore is considered as a repairable system. [13]. The mean time to recovery (MTTR) is the average time required to repair a failed component or device." [14]. In this experiment, reliability metrics such as MTTF, MTTR, and MTBF were employed to assess and quantify the reliability of both the individual C2L component and the system as a whole. Since each metric represents a time-based function, it was imperative to observe and gather data to gain deeper insights into the behavior of the C2L components.

Fig. 6 *The current cone lifter design*

Fig. 7 (a) shows the results indicate significant differences in the performance and maintenance requirements among the components evaluated in the C2L machine. The highest recorded time for repair is PLC after undergoing a total operating time of 208 hours. Fig. 7 (b) shows the results underscore the importance of regular maintenance and potential replacement of components, particularly the PLC, to ensure the reliability and efficiency of the C2L machine. The findings indicate a need for diligent maintenance, particularly regarding the PLC board, to ensure consistent operation and prevent downtime. Furthermore, attention to critical areas such as welded junctions within the machine's structure is imperative to prevent recurring issues and maintain optimal functionality.

These three metrics provide valuable insights into the reliability characteristics of components, systems and assets. MTTF estimates non-repairable life, MTBF tracks the frequency of failures for repairable systems, and MTTR quantifies recovery efficiency. Altogether, they support maintenance planning, sparing strategies, and overall asset management.

3.2 Cone Lifter Engineering Contradiction

The application of TRIZ Engineering Contradiction in designing the cone lifter for the C2L machine produces the result as shown below:

- **If** the weight of the cone increases to accommodate heavier loads, **then** the lifting capacity and efficiency of the cone lifter improve, **but** the stress on the lifter's structural components also escalates, potentially leading to premature wear and fatigue failure.
- **If** the cone lifter exerts greater gripping force to securely hold cones during lifting and transportation, **then** the likelihood of cone slippage or damage decreases, **but** the increased gripping force may also crush or deform the cones, leading to potential damage or deformation.
- **If** the cone lifter exerts a higher gripping force on the belting to ensure secure cone transportation, **then** the belting experiences reduced slippage, ensuring more stable cone movement, **but** the increased gripping force may also lead to excessive wear and tear on the belting.
- The TRIZ Engineering Contradiction analysis shows that there are inherent trade-offs in the design of the cone lifter for the C2L machine. While increasing the weight capacity and gripping force improves lifting efficiency and reduces the risk of cone slippage or damage, it also introduces challenges such as increased stress on structural components and the potential for crushing or deforming the cones. These contradictions highlight the need for a redesigned and fabricated cone lifter for the C2L machine. The

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result indicates that when the weight of the cone increases to handle heavier loads, the lifting capacity and efficiency of the cone lifter improve, yet this also escalates stress on the lifter's structural components, potentially causing premature wear and fatigue failure. Similarly, if the cone lifter applies greater gripping force to securely hold cones during lifting and transportation, it reduces the likelihood of cone slippage or damage, yet the increased force may also crush or deform the cones.

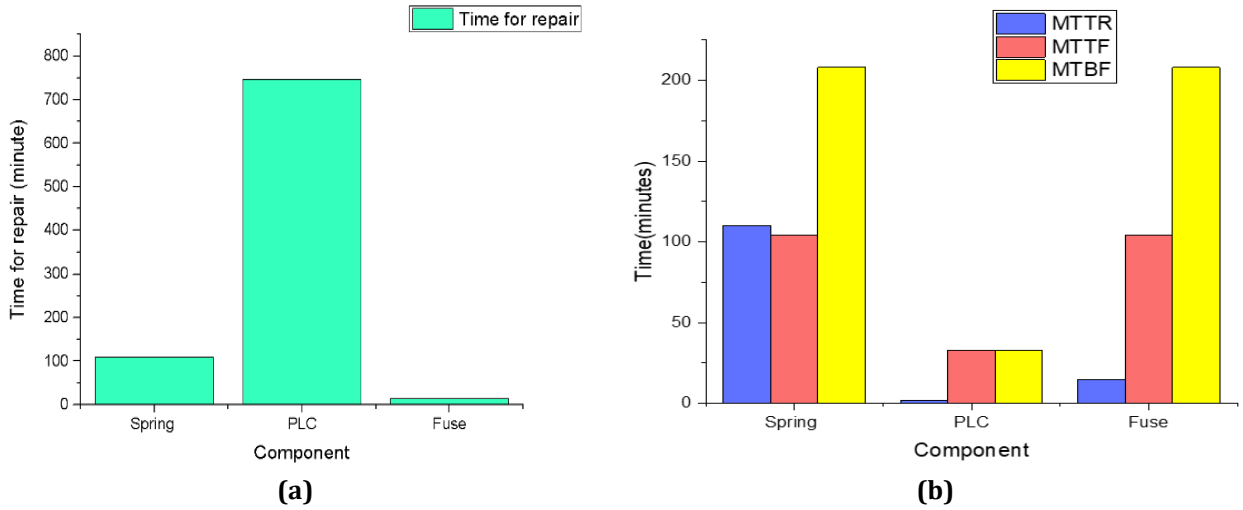

Fig. 7 *The reliability experiment of C2L (a) The Graph of test motion B; (b) The graph of reliability for test motion B*

4. Conclusion

Through the systematic application of TRIZ tools, including the Functional Analysis Model (FAM) and engineering contradiction analysis, potential areas for improvement in the assembly and disassembly processes of the cone lifter were identified, and innovative solutions were proposed. TRIZ proved to be a valuable tool in guiding the redesign and optimization process of the C2L machine. It facilitated the identification of innovative solutions to complex engineering challenges. Through the application of TRIZ principles, contradictions within the C2L machine design were addressed, leading to improvements in efficiency, safety, and reliability. The redesigned cone lifter balanced lifting capacity and structural integrity, as well as gripping force and cone integrity. Through iterative testing and refinement, the new design demonstrated improved reliability and performance, ensuring safer and more efficient expressway maintenance operations. Moving forward, continued utilization of TRIZ methodologies can support ongoing optimization and enhancement efforts for the C2L machine and other engineering projects.

Additionally, a framework for assessing the effectiveness of the C2L machine in highway concession operations was proposed, offering valuable insights for future research and development endeavors. This research highlights the significance of TRIZ methodology as a valuable tool for promoting creativity, problem-solving, and innovation in transportation infrastructure management, ultimately contributing to safer, more efficient, and sustainable highway operations. Through collaborative efforts and a commitment to innovative thinking, the study sets the stage for continued advancements in cone-handling equipment and the broader field of transportation engineering.

In conclusion, TRIZ served as a catalyst for innovation in the assembly and disassembly processes of the cone lifter, leading to the successful redesign and fabrication of the C2L machine. By leveraging TRIZ principles, highway maintenance practices can be elevated to new standards by, prioritizing worker safety and operational efficiency. This study has effectively demonstrated the effectiveness of applying TRIZ methodology in addressing engineering contradictions and improving the design of C2L machines for highway concession operations.

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Conflict of Interest

The Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm the contribution to the paper as follows: ***study conception and design:*** *Azilah Ismail, Mohd Azli Salim;* ***data collection****: Azilah Ismail, Sitinor Wardatulaina;* ***analysis and interpretation of results****: Adzni Md. Saad, Azilah Ismail, Chew Kit Wayne;* ***draft manuscript preparation****: Azilah Ismail, Mohd Azli Salim. All authors reviewed the results and approved the final version of the manuscript.*

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