# IMPROVING THE EFFICIENCY AND RELIABILITY OF CONE LAYING AND COLLECTING (C2L) MACHINE USING TRIZ METHOD



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**DEDICATION**

This thesis in wholeheartedly dedicated to my wife, Aisyatul Badriah binti Abdul Ghani for her endless support and confidence in my journey, for believing in me at every turn. Her patience, understanding, and countless sacrifices made this achievement possible. I also dedicate this thesis to my children, Nur Iman Raihanah and Hamzah Aziz, who are my constant source of inspiration and joy. I hope that my journey inspires you to dream big and always work hard towards your dreams.

# ABSTRACT

PLUS Berhad (PLUS) executes the temporary signing procedure when maintenance or repair works needs to be done along the highway. Setting up cones around the work area would inform incoming traffic of the lane closure, thus helping the drivers to steer into open lanes. Manually handling the cones impacts the health of the workers while also exposes the workers to the potential of being hit by live traffic and other safety hazards as well. The Cone Laying and Collecting (C2L) semi-automated machine was then developed to address the health and safety issues faced by the workers. The machine's features enable it to lay and collect cones as per PLUS requirements. However, the machine has not yet been tested on its reliability and operational efficiency when under actual working condition, which is a crucial requirement for it to replace the manual cone handling procedure. In this thesis, the C2L machine was tested under several parameters. During the laboratory test, the C2L machine was tested on a test rig to determine the impact of road surface condition on the machine's operation. The operational efficiency of the machine and the mechanical failures that occurred during the test were analysed. TRIZ methodologies were then used on redesigning the machine to address the mechanical failures and further improve the machine's efficiency and reliability. The improved C2L machine was then tested under the field test to determine if it can lay and collect cones according to PLUS requirement. The result from the Laboratory Test showed that the operational efficiency of the C2L machine was consistent on both smooth (Test Motion A) and uneven surface (Test Motion B), suggesting that the efficiency of the C2L machine is not impacted by the road condition. For Test Motion A, the mean of the Total distance traveled on the test rig per minute was 9.43 (m/min), while the median was 9.81 (m/min). For Test Motion B, the mean was 9.54 (m/min), and the median was 10.34 (m/min). Next, the mean of the Total actual distance travelled per minute under Test Motion A was 77.25 (m/min) while the median was 81.63 (m/min). The mean under Test Motion B was 76.17 (m/min) while the median was 82.59 (m/min). The third operational data that was analysed was the Total laying and collecting movements per minute. For Test Motion A, the mean was 7.73 (count/min) while the median was 8.13 (count/min). For Test Motion B, the mean was 7.62 (count/min) while the median was 8.26 (count/min). In terms of reliability analysis, three failed components were redesigned using TRIZ methodologies. The welded joint had a high MTTR (1:00:00), as did the hook spring (1:50:00), while the PLC had low MTTF (0:10:12) and MTBF (0:12:16). These results indicate that these three components may severely affect the reliability of the C2L machine. The redesigned C2L 02 machine was then tested under several Field Test parameters. Overall, the results showed that the machine could lay and collect cones as per PLUS requirements. The time to lay and collect 10 sets of safety cones and 10 sets of super cones during Field Test 1 was consistently 5 minutes across two days. For Field Test 2, the time lay and collect 20 sets of cones in a straight and tapered orientation remained at 10 minutes on both days. These positive results suggested that the C2L 02 machine is reliable and operationally efficient to execute the cone laying and cone collecting activities along PLUS highway. It enhances safety and efficiency in highway maintenance by reducing worker risks and physical strain, leading to fewer injuries and better operational continuity.

***PENINGKATAN KECEKAPAN DAN KEBOLEHPERCAYAAN MESIN CONE LAYING AND COLLECTING (C2L) MENGGUNAKAN KAEDAH TRIZ***

***ABSTRAK***

*PLUS Berhad (PLUS) melaksanakan prosedur penutupan jalan setiap kali kerja penyelenggaraan dilakukan di sepanjang lebuh raya. Kon di lokasi kerja bertindak sebagai amaran awal untuk memberitahu pengguna tentang penutupan lorong agar pemandu dapat beralih ke lorong yang terbuka. Pengendalian kon secara manual ini didapati memberi kesan buruk kepada kesihatan pekerja, mendedahkan pekerja kepada potensi dilanggar oleh kenderaan dan risiko keselamatan lain. Mesin "Cone Collecting and Laying" (C2L) telah dibangunkan untuk mengatasi isu-isu ini. Walaupun ciri-ciri mesin ini membolehkannya meletak dan mengangkat kon, namun mesin ini belum diuji dari segi kebolehpercayaan dan kecekapan operasinya di bawah kondisi kerja sebenar, yang merupakan keperluan penting untuk mesin ini dibolehkan untuk mengganti prosedur pengendalian kon secara manual. Dalam tesis ini, mesin C2L telah diuji pada rig ujian untuk menentukan kesan keadaan permukaan jalan terhadap operasi mesin. Kecekapan operasi mesin kemudian dianalisis menggunakan analisis deskriptif. Kegagalan mekanikal dan komponen yang berlaku semasa ujian juga dianalisis. Mesin C2L yang baru tersebut kemudian diuji di bawah ujian lapangan. Ujian ini akan menentukan jika mesin C2L yang telah diperbaharui dapat melaksanakan prosedur meletak dan mengangkat kon di sepanjang jalan lurus dan rata mengikut keperluan PLUS. Hasil dari ujian makmal menunjukkan bahawa kecekapan operasi mesin C2L adalah konsisten apabila diuji di atas permukaan yang licin dan permukaan tidak rata, yang menunjukkan bahawa kecekapan mesin itu tidak dipengaruhi oleh keadaan jalan. Berdasarkan analisis kebolehpercayaan, tiga komponen yang gagal ketika ujian makmal telah direka semula menggunakan metodologi TRIZ, bagi meningkatkan kebolehpercayaan mesin C2L. Apabila mesin C2L 02, iaitu mesin yang telah diperbaharui, diuji di bawah parameter ujian lapangan, mesin tersebut telah menunjukkan yang ianya berupaya untuk meletak dan mengangkat kon tanpa gagal. Hasil positif ini menunjukkan bahawa mesin ini berpotensi melaksanakan aktiviti meletak dan mengumpul kon di sepanjang lebuh raya PLUS dan menggantikan prosedur manual yang sedia ada. Penggunaan mesin ini berpotensi untuk meningkatkan keselamatan dan kecekapan dalam penyelenggaraan lebuh raya. Ia secara signifikan mengurangkan risiko keselamatan pekerja dan tekanan fizikal dalam pengendalian kon, disamping mengurangkan kes kecederaan berkaitan kerja, sekaligus meningkatkan imej PLUS sebagai organisasi yang memberi fokus kepada keselamatan. Penggunaan C2L juga akan membuka jalan untuk kajian inovatif baru dijalankan oleh PLUS. Dari segi akademik, proses pembangunan mesin C2L menawarkan templat komprehensif untuk penyelidikan teknologi baru. Model penyelidikan ini meliputi kajian terhadap keselamatan dan reka bentuk kejuruteraan kebolehpercayaan operasi. Penyelidikan ini boleh menjadi panduan untuk kajian yang bertujuan untuk menukar sesuatu proses manual ke sistem separa automatik dengan menawarkan panduan untuk menangani masalah kompleks dari pelbagai aspek.*

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In the Name of Allah, the Most Gracious, the Most Merciful. First and foremost, I would like to take this opportunity to express my sincere gratitude to my supervisors, Assoc. Prof. Ir. Ts. Dr. Mohd Azli bin Salim and Assoc. Prof. Dr. Nor Azmmi bin Masripan. Their expertise and continuous guidance were instrumental in shaping this thesis. Also, their confidence in my own ability to execute and complete this research had fuelled my motivation to complete my studies. I am also grateful to Ts. Dr. Norbazlan bin Mohd. Yusof, the Head of Unit of Innovation and Centre of Excellence Department, PLUS Berhad for providing insights on the highway maintenance procedures which strengthen this research. Finally, I would like to express my appreciation to PLUS Berhad for providing access to their internal resources and operational data which became the foundation for this work.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AiCl | - | Advanced Academia Industry Collaboration Laboratory |
| AC | - | Alternating Design |
| AD | - | Axiomatic Design |
| BKE | - | Butterworth-Kulim Expressway |
| C2L | - | Cone Collecting and Laying |
| CECA | - | Cause and Effect Chain Analysis |
| CFD | - | Computational Fluid Dynamics |
| CCR | - | Cutter Changing Robot |
| DC | - | Direct Current |
| DLS | - | The Dynamic Lift System |
| ELITE | - | Expressway Lingkaran Tengah Sdn. Bhd |
| FM | - | Function Model |
| FTME | - | Faculty of Technology and Mechanical Engineering |
| IFR | - | Ideal Final Result |
| Linkedua | - | Linkedua (Malaysia) Berhad |
| LBP | - | Low Back Pain |
| MCB | - | Miniature Circuit Breaker |
| MHA | - | Malaysian Highway Authority |
| MTBF | - | Mean Time Before Failure |
| MTTF | - | Mean Time to Failure |
| MTTR | - | Mean Time to Repair |
| NKVE | - | New Klang Valley Expressway |
| NRF | - | Non-repairable Failures |

| | | |
|---|---|---|
| $NSECL$ | - | The North-South Expressway Central Link |
| $PBSM$ | - | Penang Bridge Sdn Bhd |
| $PEB$ | - | PLUS Expressways Berhad |
| $PMB$ | - | PLUS Malaysia Berhad |
| $PLC$ | - | Programmable Logic Control |
| $PLUS$ | - | Projek Lebuhraya Usahasama Berhad |
| $PLUS\ Berhad$ | - | Projek Lebuhraya Utara-Selatan Berhad |
| $QFD$ | - | Quality Function Deployment |
| $RAMD$ | - | Reliability, Availability, Maintainability, and Dependability |
| $RF$ | - | Repairable Failures |
| $SPDH$ | - | Seremban-Port Dickson Highway |
| $SRB$ | - | Spherical roller bearings |
| $TRIZ$ | - | The Theory of Inventive Problem Solving |
| $USSR$ | - | Union of Soviet Socialist Republics |
| $UTeM$ | - | Universiti Teknikal Malaysia Melaka |
| $WMDs$ | - | Work-related musculoskeletal disorder |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| $F$ | - | Force |
| $k$ | - | Spring constant |
| $x$ | - | Change in length |

# LIST OF APPENDICES

## LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

M. Reza, M. A. Salim, N. A. Masripan, N. M. Yusof and M. R. A. Prunomo, 2023. Improving the efficiency of operating the Cone Laying and Collecting Machine (C2L) using TRIZ Method. *Journal of Advanced Manufacturing Technology*, vol. 17, no.3, 2023.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

PLUS Malaysia Berhad (PMB) was originally founded as Highway Concessionnaires Berhad on June 1986 before changing its name to Projek Lebuhraya Utara Selatan Berhad on May 1988. PMB was incorporated on November 2010 (PLUS, 2023). A year after that, Projek Lebuhraya Usahasama Berhad (PLUS) was born. As of 2023, the PLUS highway is still the largest toll expressway operator in Malaysia. It consist of the North-South Expressway (NSE), New Klang Valley Expressway (NKVE), Seremban-Port Dickson Highway (SPDH), North-South Expressway Central Link (NSECL), Linkedua, Butterworth-Kulim Expressway (BKE) and the Penang Bridge, which stretches to approximately 945km.

Projek Lebuhraya Usahasama Berhad (PLUS) was established on 2011 following the incorporation of PLUS Malaysia Berhad (PMB) a year before (PLUS, 2023). Currently, PLUS is the biggest toll highway operator in Malaysia, managing several highways including the North-South Expressway (NSE) and New Klang Valley Expressway (NKVE), which covers a total distance of about 946.5km.

The daily traffic volume along PLUS highway is approximately 1.5 million vehicles. Hence, proper maintenance and repair work are constantly conducted so that the highway assets are maintained to the highest standard. This will ensure that the highway users can experience a smooth and safe driving along their journey.

Everytime a maintenance or repair work needs to be done, it needs to be preceeded with the temporary signing procedure. The temporary signing procedure refers to the action of closing several affected lanes. Proper signages and cones are set up on areas leading to and around the location where maintenance work will be done. By doing so, incoming traffic will be alerted about the work done on the roads ahead. The drivers can then carefully steer their vehicles into the lanes that are not closed, maintaining the fluidity of the traffic movement along the highway.

When a driver reaches closer to the area where the temporary signing procedure is being executed, the first area that the driver will see is the Advance Warning Zone. There will be a series of signages arranged within the zone to provide early warning to incoming vehicles of the lane closure ahead. After the driver passes the Advance Warning Zone, the driver will reach the Transition Zone. By aranging several super cones and arrows in a tapered orientation, the drivers are guided to move into open lanes. The Buffer Zone comes next to the Transition Zone, which is an area that provides a safety buffer area for both workers and driver. This area is free from equipments and vehicles, but safety cones are used to enclose this area. The most impotart area is the Work Zone, which is the area where the maintenance work and repair work happens. The length of the Work Zone depends on the type of the work that needs to be conducted. Safety cones are arranged parallel along the zones to separate the work area with live traffic. The bright coloured cones would also alert the drivers to be careful when driving along the Work Zone. The Termination Zone is at the end, also enclosed by safety cones and a signboard, which is a small area that helps traffic to merge back into the normal traffic lanes.