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Lead Time and Cost Reduction in Reach Stacker Repair: A Lean Six Sigma Case Study

Rio Wahyu Prasojo[1], Abduh Ghani Amrullah[1], Didik Wahjudi[2]*, Samuel Trinata Winnyarto[3], Muhammad Razzaq Multazam[4], Leon Jonathan[1]

[1] SPIL University
Jl. Kalianak No. 51F, Surabaya 60183, Indonesia
[2]Department of Mechanical Engineering, Petra Christian University
Jl. Siwalankerto 121-131, Surabaya 60236, Indonesia
[3]Department of Industrial Engineering and Management, National Taiwan University of Science and Technology
No. 43號, Section 4, Keelung Rd, Da'an District, Taipei City, Taiwan 106
[4]Faculty of Advanced Technology and Multidiscipline, Industrial Engineering Dept., Universitas Airlangga
Jl. Dr. Ir. H. Soekarno, Surabaya 60115, Indonesia
*Corresponding author; E-mail: dwahjudi@petra.ac.id

ABSTRACT

This study examines the application of the Lean Six Sigma DMAIC methodology to reduce repair times and operational costs in the maintenance of reach stackers at P. T. X, a container shipping company in Indonesia. It identifies the prolonged repair process, often extending to 14 days, primarily due to dependency on original equipment manufacturer suppliers and aging systems, as significant obstacles. The research emphasizes the development of an internally fabricated control system to mitigate these challenges, leading to enhanced operational independence and efficiency. The implementation of DMAIC methodology reduced repair lead time from 14 days to 3 days, achieving a cost reduction of over 90% related to previous downtime expenses caused by Kalmar control system failures. Through detailed analysis, the study highlighted factors contributing to inefficiencies, such as non-interchangeable components linked to identical stock keeping unit numbers, which exacerbated delays. The improved process involved creating tailored control systems, stockpiling essential components, and establishing standard operating procedure for maintenance. Furthermore, training programs for the maintenance team ensured competency in managing the new systems. The results indicate that integrating Lean Six Sigma methodologies with innovation in system development can greatly enhance reliability and efficiency in logistics operations. While this research primarily focused on Kalmar DRD and DRF types, it suggests potential for extending the approach to other reach stacker types. Future studies could investigate the integration of predictive maintenance technologies to improve reliability and reduce downtime in varied operational settings.

Keywords: lean six sigma, DMAIC methodology, reach stacker, control system, operational efficiency, repair times.

INTRODUCTION

Transportation and logistics play a crucial role in supply chains by connecting manufacturers, suppliers, and customers through the physical movement of goods, where any disruptions can significantly impact overall operations [1]-[4]. In the container terminal industry, operational efficiency is essential to reduce costs, increase throughput, enhance customer satisfaction, and optimize supply chain performance while improving safety, minimizing environmental impact, and ensuring adaptability in a dynamic and competitive market [5, 6]. The efficient operation of container terminals facilitates the seamless flow of goods across borders, ensuring continuous container handling processes in ports, warehouses, and distribution centers. Among the various equipment used in such settings, RS play a key role in lifting and moving containers in high-density storage facilities [7]-[9]. Seamless RS operation is indispensable for sustaining supply chain efficiency, minimizing operations disruptions, and optimal utilization of resources [10]. However, mechanical failures in RS units are a serious operational issue, leading to extended downtimes, increased maintenance costs, and reduced logistics efficiency [11],[12].

P.T. X is a company operating in the container shipping sector, managing an extensive logistics network that spans over 38 ports across Indonesia. Considering the scale and complexity of its operations, any disruption involving critical handling equipment, such as RSs, could significantly affect its operational performance and service reliability. At P.T. X, one of the main challenges in RS maintenance was the long repair time, which directly affected the machine's availability and disrupted operations. Each RS unit consists of several essential components in its control system, such as Kalmar distributed unit (KDU), Kalmar cab unit (KCU), Kalmar information terminal (KIT), Kalmar information display (KID), and advanced process control (APC) transmission that keep the system running smoothly. When any of these parts fail, the repair process becomes a long and complicated journey, involving diagnosis, ordering spare parts, waiting for shipments, installation, and system calibration. The repair process of an RS unit at P.T. X could take up to 14 days, leading to severe operational delays. The extended downtime slowed logistics hub service and led to significant financial losses, often forcing companies to rent expensive third-party equipment to keep their operations moving.

Several key factors contributed to the long RS repair times at P.T. X. One of the biggest challenges was the heavy reliance on original equipment manufacturer (OEM) suppliers for spare parts, often leading to unpredictable procurement delays. Additionally, many RS units at P.T. X were aging, and their outdated control systems posed a significant obstacle to their repairs because the program within these systems cannot be accessed, making direct repairs impossible. As spare parts of these older systems were not always readily available, OEMs had to produce them first or source the components from subcontractors.

Previous research explored various strategies to improve product quality, enhance equipment maintenance, and reduce downtime. Raharjo et al. focused on minimizing downtime frequency in the pellet sifter machine at P.T. Charoen Pokphand Indonesia Feedmill Balaraja [13]. Their research applied the define, measure, improve, and control (DMAIC) methodology within the Six Sigma framework to identify significant causes of downtime, such as weak screening fabric and overly tight installation. Applying corrective measures such as a fabric replacement checklist led to a significant reduction in downtime and generated cost savings of approximately Rp. 194 million for pellets and Rp. 193 million for packing, with total implementation costs estimated at only Rp. 262,778. Another study conducted by Santoso and Adi applied DMAIC methodology to reduce defects such as torn packaging, inadequate packaging, coarse salt, and short package lengths [14]. Their research identified key root causes, including dull cutting blades, high cutting pressure, improper sieve installation, and conveyor belt issues. After implementing targeted improvements like blade sharpening and equipment replacement, they found a significant decrease in defects and enhanced process capability, demonstrating the effectiveness of Six Sigma tools for quality improvement.

Rahmadsyah and Sarfin [15] utilized the DMAIC approach to investigate machine downtime in injection molding at P.T. XYZ. The research findings indicated that the "hot runner mold" was the primary cause of downtime, accounting for 27% of total downtime from March to May 2023. Through the systematic application of the DMAIC methodology, the study effectively identified the main issues, analyzed their root causes, and developed actionable solutions. The successful implementation of these strategies led to increased production efficiency, reduced downtime, and improved mold quality, illustrating the effectiveness of the DMAIC approach in addressing complex manufacturing challenges. Ponidi and Makhfud [16] examined the implementation of predictive maintenance on RSs, specifically the Kalmar type DRD 450, to minimize repair delays. The research emphasized the advantages of real-time monitoring and automation in maintenance processes. By utilizing predictive maintenance strategies, companies could forecast potential failures, allowing for timely corrective actions that significantly reduce downtime costs and enhance system reliability.

While prior studies have successfully implemented DMAIC methodology in general manufacturing and maintenance contexts, e.g., pellet sifters, injection molding machines, packaging, these studies rarely focus on container terminal equipment, particularly RS units, which are critical to port logistics. This paper presents a unique challenge of obsolete proprietary control systems in aging

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RS units, especially the issue of non-interchangeable OEM components with embedded SKU numbers, which leads to prolonged downtime. To systematically address the long repair time of RS units at P.T. X, this study applies the DMAIC methodology to analyze the root causes and implement improvement solutions. The Lean principles are also incorporated to enhance maintenance efficiency by minimizing waste, optimizing workflows, and ensuring continuous process improvement [17]-[19]. By applying Lean principles, unnecessary delays in spare part procurement, excessive waiting times, and non-value-adding repair steps can be eliminated, resulting in a more streamlined and cost-effective maintenance process [20],[21].

METHODS

This study applies the DMAIC methodology from the Lean Six Sigma framework to reduce the repair time and cut the operational costs related to failures in the Kalmar control system of RSs. The DMAIC implementation aims to identify inefficiencies, analyze their causes, and implement targeted improvements, as shown in Figure 1. This study gathered data on repair times in the past three years, primary delay factors, spare part procurement information, rental costs, component costs, and research expenses from historical maintenance records, technician interviews, brainstorming sessions, and operational analysis. Tools such as the Five Whys analysis were used to identify root causes. By implementing the DMAIC approach, a structured strategy is developed to enhance the efficiency and cost-effectiveness of the repair process.

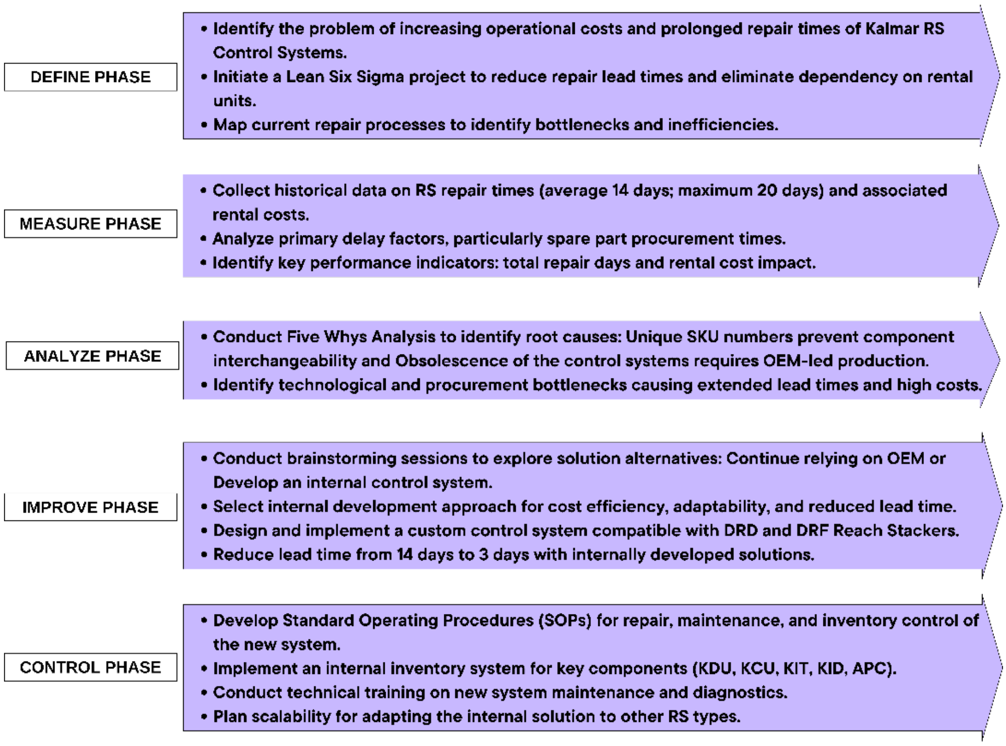

Figure 1. DMAIC framework applied to RS repair at PT X

Define Phase

The problem to be solved was the increasing operational costs at the container depot due to the prolonged repair time of the Kalmar control system on RS units. A Lean Six Sigma project was initiated to reduce the repair time and eliminate the need to rent replacement RS units. The target benefit of the project is to reduce repair lead times and lower operational costs by improving the repair process efficiency. The project team consisted of a continuous improvement (CI) coach, a CI sponsor, a CI champion, a CI leader, and some team members from the heavy equipment (HVE) department, i.e., the electrical staff as the research executor and the mechanical staff responsible for system installation. An initial analysis was conducted by mapping the current repair process to identify existing bottlenecks and potential areas for improvement.

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Measure Phase

In the measure phase, the team collected historical data on repair time from the last three years and the associated costs caused by delays. It was found that the average repair time could reach up to 14 days, with the longest repair duration extending to 20 days. Most of the delay was caused by the time required to procure control system components from the original equipment manufacturer (OEM). During these delays, the company often had to rent third-party RS units to maintain operational continuity, which resulted in additional costs. The key performance indicators examined were the total days required to complete repairs and the rental expenses incurred during the downtime.

Analyze Phase

In the analyze phase, the Five Whys analysis was employed to identify the root causes of the prolonged repair durations. The result of the Five Whys analysis is presented in Figure 2. Findings revealed that each control system component—KDU, KCU, KIT, KID, and APC—was embedded with a unique SKU Number, resulting in non-interchangeability. This technological constraint, exacerbated by the system's obsolescence, significantly reduced repair agility and contributed to increased maintenance costs. This analysis uncovered two primary root causes:

i. Every system had an identical SKU Number embedded in each of its components.
ii. The RS owned by the company was relatively old, resulting in the control system type no longer being available in the market, thus requiring the OEM to prepare the system in advance and perform complex system construction.

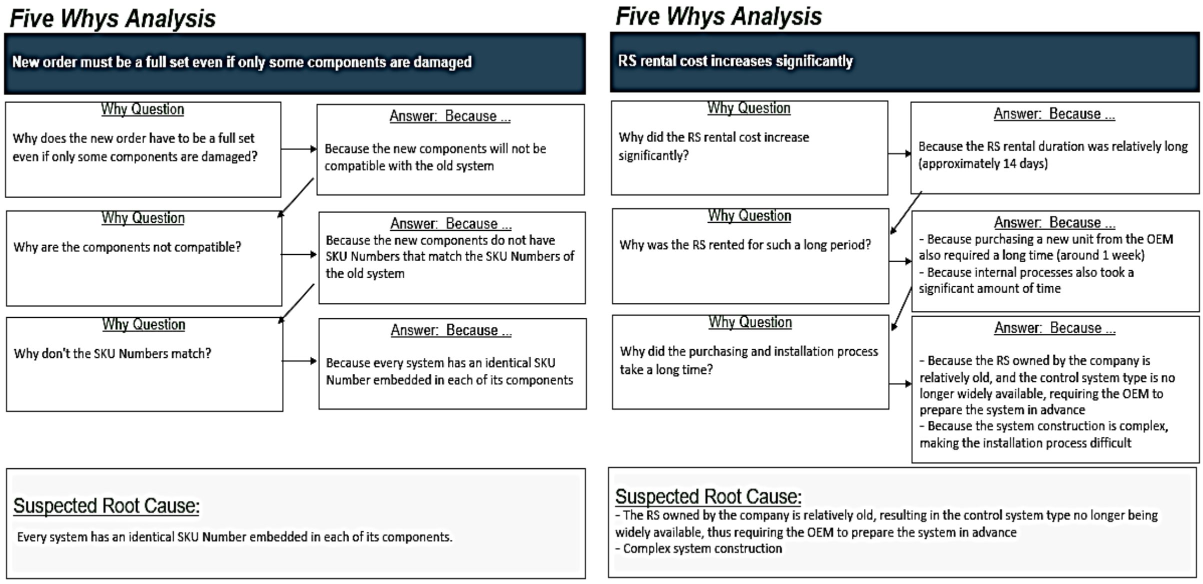

Figure 2. Five Whys Analysis

Improve Phase

The improve phase was initiated in response to the root causes identified during the analyze phase, i.e. the uniqueness of every RS control system and the unavailability of the aging (RS) control system in the market. Because the two root causes were related, the team came up with an idea develop a modified version of the Kalmar control system, allowing the company to reduce its dependence on the OEM. The Electrical Team designed and built custom control systems tailored to match the operational requirements of specific RS units, prioritizing those frequently used or with a history of repeated control system failures. Several modified control systems were pre-produced and kept in stock to enable immediate replacement when a failure occurred. This proactive approach eliminated the need to wait for OEM components and significantly shortened repair time. After undergoing multiple rounds of testing to ensure functionality and compatibility, the new control units were installed on the RS units of Kalmar Type DRD and Type DRF.

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Control Phase

The company developed a new set of Standard Operating Procedures (SOPs) in the control phase to keep the repair time short. These SOPs included clear guidelines for inventory management to ensure the availability of critical control system components and standardized repair procedures to minimize operational downtime. Key components such as the KDU, KCU, KIT, KID, and APC could now be produced and repaired internally, enhancing operational independence and efficiency. Quality audit mechanisms, including routine monitoring and standardized documentation, were also implemented to ensure that each inspection and repair process met the established standards. To support long-term sustainability, the company began evaluating the feasibility of applying the same modification and repair approach to other types of RS units. The evaluation assessed compatibility, identified high-risk units, and proactively prepared corresponding replacement systems.

RESULTS AND DISCUSSIONS

Applying the DMAIC methodology in this study led to significant reduction in repair time and operational costs associated with failures in the Kalmar control system of RS units. Several solution alternatives were generated through structured brainstorming sessions conducted during the planning stage. These alternatives included continued reliance on OEM support and the internal development of the control system. Each option was systematically evaluated based on feasibility, cost, and long-term sustainability criteria. After thorough analysis, the team developed the control system internally due to its clear advantages: lower operational costs, reduced repair lead time, and improved system adaptability. Although this approach required an initial investment in system design and testing, the long-term benefits outweighed the risks associated with continued dependence on the OEM.

In response to the suspected root causes, the electrical staff developed a modified control system that was entirely fabricated internally, as shown in Figure 3. The development process began with an in-depth observation of the existing system's operation, followed by a detailed electrical configuration and components analysis. A new electrical design and customized firmware were developed to ensure compatibility with the current RS infrastructure. After iterative prototyping and testing, a finalized solution was deployed.

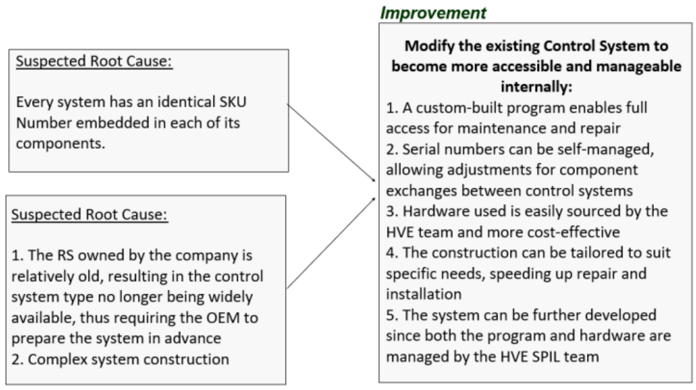

Figure 3. Proposed solution for the root causes

The system developed for DRD and DRF-type RS units enabled complete independence from the OEM. The proposed solution featured a custom-built software program for maintenance and diagnostics, management of serial numbers for component interchangeability, and use of locally sourced and cost-effective hardware. In addition, its construction allowed faster installation and flexible adaptations based on specific operational needs. Since the internal team developed both the hardware and software, further enhancements could be implemented without dependency on the OEM. As a result, the lead time for system replacement and installation was significantly reduced from 14 days with the OEM-dependent supply to just 3 days using the internally developed solution. This solution effectively eliminated downtime, reduced operational costs, and cut over 90 percent of the additional expenses incurred during Kalmar Control System failures in RS units.

In the control phase, the focus was on ensuring the long-term sustainability of the improvements made during the Improve phase. The company established standard operating procedures (SOPs) to control the inspection, maintenance, and repair of the modified Kalmar control systems in the RS units. These SOPs standardized the process flow for handling system failures, inventory control, and internal component production to prevent regression to previous inefficiencies. The other approach was developing an internal inventory management system, which ensured that essential components such as the KDU, KCU, KIT, KID, and APC were always in stock. These components were manufactured in-house, eliminating the previous dependency on long lead times associated with OEM supply. The inventory system was also integrated with preventive maintenance schedules, allowing the technical team to anticipate needs and prepare parts. Furthermore, training programs were conducted to improve the maintenance team's knowledge of the new control system design, troubleshooting techniques, and usage of custom-developed diagnostic software. This capacity-building initiative ensured that the internal teams could handle future issues without external assistance. To support the solution's scalability, the company began a feasibility study to expand the internal modification approach to other RS unit types beyond DRD and DRF models. This study identified units most at risk for control system failure, assessed component compatibility, and pre-produced tailored replacement systems for future implementation.

The implementation of the proposed solution can reduce repair times from 14 to 3 days and enhanced operational independence. In addition, new repair strategy reduces more than 90 per cent of the previously incurred costs due to Kalmar Control System failures. While several studies argue that up to 70 per cent of LSS projects have failed [22, 23], this study identifies the positive results of Lean Six Sigma implementation like the above mentioned studies [13-16], which can encourage practitioners to apply the Lean Six Sigma framework.

CONCLUSION

This study applied the Lean Six Sigma DMAIC methodology to significantly reduce RS' repair time from 14 to 3 days by developing an internally fabricated control system. In addition, the new solution reduced over 90 percent of the additional costs previously incurred during Kalmar Control System failures. By addressing the dependency on OEM supply, P.T. X achieved greater operational independence, lowered costs, and improved maintenance efficiency. The results demonstrate the effectiveness of Lean Six Sigma methodology to improve operational efficiency and provide a sustainable competitiveness beyond manufacturing and service sectors, a relatively underexplored field. In addition, this study provides a replicable framework how logistics companies can reduce repair time and cost by developing internal engineering capabilities instead of relying on OEM suppliers.

The research limitation of this study is on the nature of the case study. The case study was conducted on Kalmar DRD and DRF RS units and focused primarily on control system failures. The capability of the internal development team is really essential to the success of the project. Additionally, while the internally developed control systems significantly reduce repair time, long-term reliability data and performance under varied operational conditions have yet to be fully evaluated. Furthermore, financial analysis was also based on direct cost savings compared to procuring the control systems from the OEM. The financial analysis does not take into account potential risks, such as unforeseen system integration issues, and the initial development cost of the control systems. Recommendations for future research include the possibility to use smart sensors to monitor the condition of the RSs, further reduction of the repair time, and conducting comprehensive financial analysis on the project.

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