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Design thinking as a driver of fuel efficiency in motorcycle engine testing operations

Aris Risdiyanto*, Aditya Tirta Pratama, Gembong Baskoro

* Master of Mechanical Engineering, Faculty of Engineering and Information Technology, Swiss German University, Tangerang, Indonesia

*Correspondence email: aris.risdiyanto@student.sgu.ac.id

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ABSTRACT

Fuel consumption inefficiency in motorcycle engine testing remains a critical issue in manufacturing operations. This study aims to improve fuel efficiency by applying a human-centered Design Thinking approach that integrates ergonomic and behavioral factors, which are often overlooked in conventional optimization methods. A controlled before–after experimental design was conducted over four weeks involving 22,400 units. The intervention consisted of implementing an ergonomic fuel nozzle and a standardized testing procedure. The results show a significant reduction in fuel consumption from 318.5 ± 12 ml/unit to 200 ± 8 ml/unit, representing a 37.2% decrease, with a large effect size (Cohen's d ≈ 2.8). Additionally, daily fuel usage decreased substantially, leading to considerable annual cost savings. In conclusion, this study demonstrates that integrating Design Thinking into manufacturing processes can effectively enhance operational efficiency and sustainability, while offering a scalable and replicable framework for fuel optimization.

Keywords: Design Thinking; fuel optimization; motorcycle manufacturing; industrial efficiency; sustainability.

1. Introduction

Motorcycle manufacturing operates at high production volumes, where even minor inefficiencies can lead to significant operational costs and environmental impacts [1]. One critical yet underexplored process is engine unit testing, which requires substantial fuel consumption to verify ignition performance and product quality [2]. In a typical Indonesian production line, fuel consumption during testing can reach approximately 1,433 liters per day for around 4,500 units, equivalent to more than 500,000 liters annually, highlighting a considerable opportunity for efficiency improvement.

Previous studies have applied conventional approaches such as Lean Manufacturing and Six Sigma to improve production efficiency by focusing on waste reduction and process stability [3]. However, these approaches predominantly emphasize system-level optimization and often overlook human-related inefficiencies, including operator fatigue, inconsistent work practices, and ergonomic constraints [4]. As a result, fuel inefficiency in engine testing processes remains insufficiently addressed, particularly from a human-centered perspective [5].

Despite existing optimization efforts, there is a lack of research that integrates human factors and behavioral aspects into fuel consumption reduction strategies in manufacturing environments [6]. Moreover, the application of Design Thinking as an innovation-driven, user-centered approach has rarely been explored in the context of production efficiency, especially in engine testing operations [7].

To address this gap, this study proposes a novel approach by applying Design Thinking to optimize fuel consumption in motorcycle engine testing [8]. The novelty of this study lies in the integration of ergonomic product redesign (ergonomic fuel nozzle) and procedural standardization (testing script) within a human-centered innovation framework [9]. This combined approach enables the simultaneous improvement of technical performance and operator behavior, supported by quantitative experimental validation [10].

2. Method

This study employed a before–after experimental design conducted in a motorcycle engine testing line over a four-week period, involving a total of 22,400 units. The experiment was designed to evaluate the effectiveness of a Design Thinking-based intervention in reducing fuel consumption during engine testing operations. To ensure experimental consistency, several variables were controlled, including motorcycle model, testing cycle, and operator assignment across shifts. Fuel consumption was measured using calibrated instruments with an accuracy of ±1 ml, with calibration performed at the beginning of each shift to maintain measurement reliability. Fuel consumption per unit was defined as the volume of fuel used for each tested motorcycle, while idle time referred to engine running duration without active testing.

Data analysis was conducted using descriptive statistics, expressed as mean ± standard deviation, to compare fuel consumption before and after the intervention. In addition, effect size was calculated using Cohen’s d to assess the magnitude of the intervention impact, following established practices in manufacturing experiments [11]. The intervention was developed and implemented using the Design Thinking framework, which consists of five iterative stages: empathize, define, ideate, prototype, and test [12]. The empathize stage involved direct observation and interviews with operators to identify practical challenges. In the define stage, root causes of fuel inefficiency were determined. The ideate stage generated potential solutions, which were then translated into prototypes, including an ergonomic fuel nozzle and a standardized testing procedure. Finally, the test stage involved validating the proposed solutions under real production conditions. The overall Design Thinking workflow applied in this study is illustrated in Figure 1, highlighting the sequential and iterative nature of the intervention process.

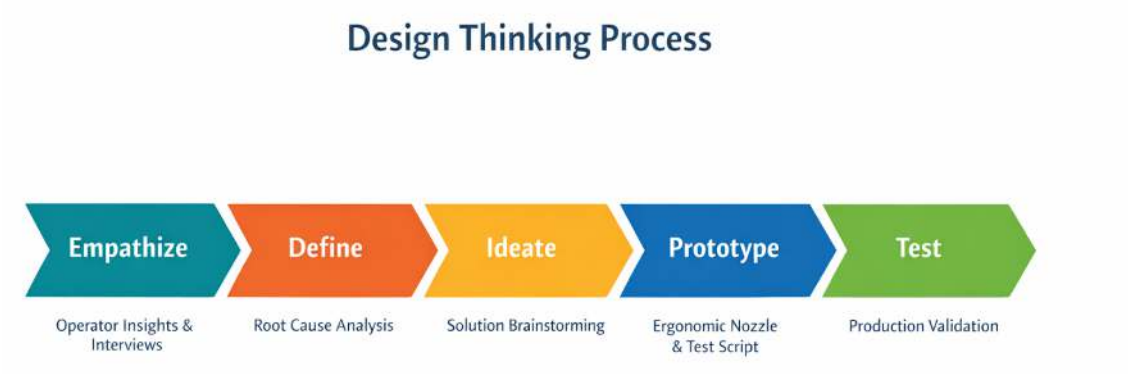

Figure 1. Design thinking workflow for fuel optimization in engine testing operations.

3. Results and Discussion

The root cause analysis revealed that fuel inefficiency in engine testing was primarily influenced by human and procedural factors, particularly inconsistent fuel dispensing techniques, prolonged idle time, and the absence of standardized testing procedures. Technical factors, such as fuel delivery system design, also contributed but to a lesser extent. These findings are summarized in the fishbone diagram presented in Figure 2, which illustrates the key sources of variability in the testing process.

Following the identification of these root causes, targeted interventions were implemented focusing on ergonomic improvement and procedural standardization. The results demonstrate a substantial reduction in fuel consumption from 318.5 ± 12 ml/unit to 200 ± 8 ml/unit, representing a 37.2% decrease. The magnitude of the intervention effect was large, with a calculated Cohen’s d of approximately 2.8, indicating a strong practical impact. In addition, the reduction in standard deviation suggests improved consistency in fuel usage across operators, reflecting enhanced process stability after the intervention.

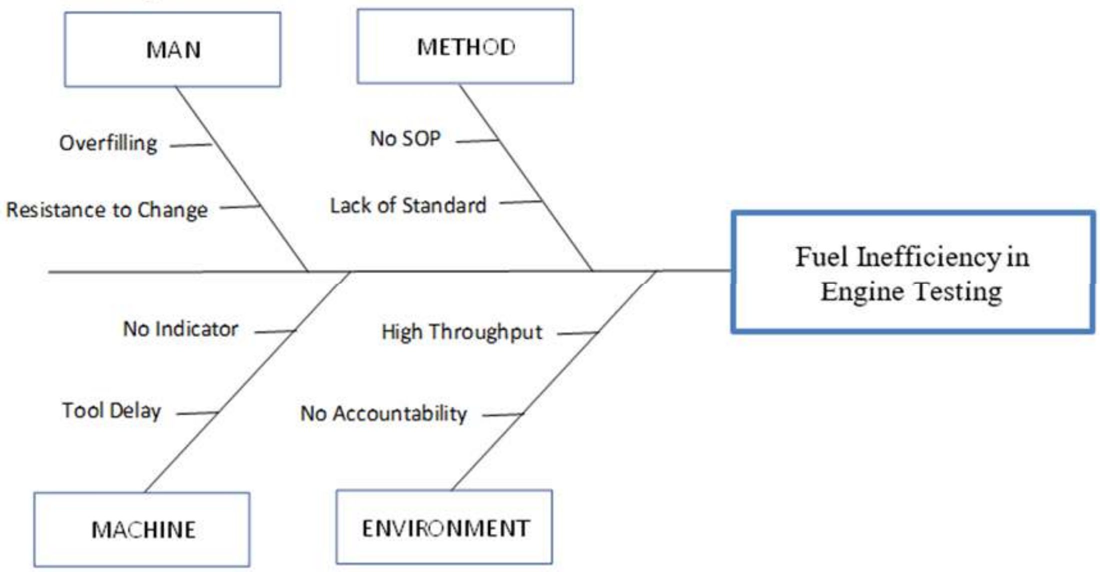

Figure 2. Fishbone diagram of root causes of fuel inefficiency in engine testing.

Discussion

The findings of this study demonstrate that fuel inefficiency in engine testing is predominantly driven by human-related factors, particularly operator behavior and ergonomic limitations. This can be explained by the direct interaction between operators and the fuel delivery process, where inconsistent handling techniques and non-standardized procedures lead to excessive fuel usage and increased variability. By addressing these factors, the intervention was able to simultaneously improve both efficiency and process consistency.

The results are in line with previous studies on manufacturing efficiency and energy optimization, which emphasize the importance of process improvement in reducing resource consumption [13]. However, unlike prior approaches that primarily focus on system-level optimization, this study highlights the critical role of human-centered factors in influencing operational performance. In this context, the integration of Design Thinking provides a distinct advantage by enabling a deeper exploration of user behavior and practical constraints in real production settings [14].

The substantial effect size observed in this study (Cohen's d $\approx$ 2.8) further supports the effectiveness of combining ergonomic redesign with procedural standardization. This finding suggests that addressing both technical and behavioral dimensions can produce synergistic improvements, which are often not achieved through conventional methods such as Lean Manufacturing or Six Sigma alone.

From a practical perspective, the proposed approach offers a scalable and low-cost solution for fuel optimization in high-volume manufacturing environments. From a theoretical standpoint, this study extends the application of Design Thinking beyond product development into the domain of manufacturing efficiency, thereby contributing to the growing body of research on human-centered innovation in industrial systems [15].

Nevertheless, this study has several limitations. The experiment was conducted in a single production facility, which may limit the generalizability of the findings. In addition, other potential influencing factors, such as machine variability and environmental conditions, were not explicitly analyzed. Future research should validate the proposed approach across multiple manufacturing contexts and incorporate additional variables to provide a more comprehensive understanding of fuel efficiency optimization.

This study has several limitations that should be considered when interpreting the results. First, the experiment was conducted in a single motorcycle production facility, which may limit the applicability of the findings to different manufacturing environments with varying production scales, technologies, and operator characteristics. Second, the ergonomic assessment partially relied on self-reported data, which may introduce subjective bias and affect the accuracy of evaluating operator behavior and comfort. Third, fuel consumption measurements were based on calibrated manual instruments, and the absence of real-time digital monitoring systems may restrict the granularity and continuity of the collected data.

Future research should address these limitations by incorporating advanced monitoring technologies, such as IoT-based fuel measurement systems, to enable real-time and high-resolution data acquisition. In addition, multi-site studies across different manufacturing settings are necessary to validate the robustness and generalizability of the proposed approach. Longitudinal studies are also recommended to assess the sustainability of the observed improvements and to examine potential behavioral adaptation effects over time. Furthermore, future work may explore the integration of Design Thinking with data-driven optimization methods, such as machine learning or predictive analytics, to enhance decision-making in manufacturing systems. This could provide a more comprehensive framework that combines human-centered innovation with intelligent process optimization.

4. Conclusion

This study aimed to evaluate the effectiveness of a Design Thinking-based intervention in improving fuel efficiency in motorcycle engine testing operations. Using a controlled before–after experimental design, the results demonstrate that integrating ergonomic redesign and procedural standardization within a human-centered framework significantly reduced fuel consumption by 37.2% while maintaining process reliability. These findings confirm that human-related factors play a critical role in operational inefficiency and that addressing both technical and behavioral dimensions can produce substantial performance improvements. The novelty of this study lies in the application of Design Thinking as an integrated approach to manufacturing efficiency, combining user-centered insights with engineering optimization. From a practical perspective, the proposed approach offers a scalable and cost-effective model for industrial energy optimization. From a theoretical standpoint, this study provides empirical evidence that extending human-centered innovation into manufacturing processes can deliver measurable and sustainable efficiency gains.

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