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Improving Tire Lifespan Using the Six Sigma Approach: A Case Study in a Coal-Hauling Company

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Abstract
In the mining industry, the use and maintenance of equipment are associated with significant operational costs. One of the issues in this case is tire wear, as tires account for a major part of the operating costs of rubber-tired equipment. This paper aims to improve the tire life span of hauling dump truck tires using the Six Sigma approach. The case study was conducted at a medium-sized coal-hauling contractor company. The root causes were identified through a cause-effect diagram, which improved operations by increasing tire life by 27% from 56.065 kilometers to 73.093 kilometers.

Keywords
Tire, life, lean, six, sigma, improvement.

Introduction

Dump trucks are widely used as transportation equipment in surface mining operations. Using and maintaining such heavy equipment incurs significant operational costs (Li et al., 2012a). Such a high cost has been a main concern for coal-hauling contractors due to its substantial contribution to total operational costs. For example, the Indonesian coal-hauling company under investigation bears a maintenance cost of about 14% of the total revenue. Among equipment parts requiring maintenance, the tire incurs a large portion of the total cost. Therefore, the company aims to reduce tire costs to minimize overall operational costs. One way to achieve this is by increasing the tire lifespan, which will reduce tire usage. Using this coal-hauling company as a case study, the current study examines the improvement of tire lifespan using the Six Sigma approach.

The Six Sigma approach consists of five steps: define, measure, analyze, improve, and control (DMAIC). This approach has been widely used to improve performance in various businesses (Brady & Allen, 2006; Chaurasia et al., 2019; Herlambang, 2020) and has been proven to improve process performance, including in the service sectors (Patel, 2017; Gutierrez et al., 2016; Kumar et al., 2018; Zhang, 2017; Tay & Aw, 2021; Bloj et al., 2020). Hauling businesses fall under the category of transportation or logistic services. Therefore, the Six Sigma approach is suitable to apply in coal-hauling companies. By adopting a case study method, the authors observed the operational situations in real time and collected the existing tire lifespan, analyzing it and improving it.

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Literature Review

Tire wear is a significant concern for companies, as tires constitute a major portion of operating costs. To mitigate this, companies seek strategies to extend tire lifespan and reduce consumption. The most effective method for achieving this while ensuring safety is proper tire maintenance (Weissman et al., 2003), which can be done by either replacing the existing tire with a new model with a longer lifespan or improving the existing lifespan. Since the former will incur even higher costs, the latter seems to be the most viable solution.

The foundation of this approach is to prioritize service quality and safety. Studies indicate that certain operating conditions influence tire lifespan Weissman et al., 2003; Vimal, 2012; Abdullah et al., 2013), which include tire maintenance, road pavement conditions, and driving practices. Yong Li et al. (2012b) stated that tire lifespan depends on tire structure and properties, environment, and operating conditions. The study also revealed that overloading leads to early tire retirement, so it must be avoided. The study also concluded that optimum tire pressure can reduce tire wear; thus, maintaining tire pressure is important during operations. Abdulaev et al., (2019) agree that tire pressure plays a significant role in tire life. Likewise, Lindeque (2016) mention that tires should be properly inflated and maintained at the correct pressure. Proper inflation can help prolong tire lifespan, as shown in a past study by Bell (2016). Considering the previous research on tire lifespan extension as outlined above, this study aims to improve tire longevity by optimizing operating conditions rather than introducing new models or structures.

Materials and Methods

To address the tire issue, the company employed the Six Sigma DMAIC method. The first stage is the define phase, where a main problem is identified: the high maintenance costs of hauling dump trucks due to excessive tire wear. In this case, the solution is to extend the tires' lifespan. The second stage is the measure phase, where data on total tire consumption in one year, including tire lifespan, is collected. The third step is the analysis stage; in this stage, where a cause-effect analysis is employed to find the actual root cause. The fourth stage is the improve phase, where actionable plans are devised and executed according to the timeline. The final step is the control, where the result and potential savings from the improvement are calculated, including recommendations to sustain the achievement. These stages are summarized in Figure 1.

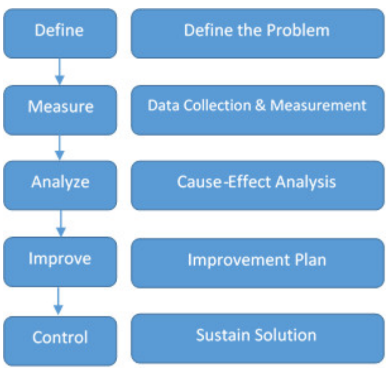

Fig. 1. Research method

The case study was conducted in a medium-sized coal-hauling contractor in Indonesia. The company uses trucks to transport coal from pits to ports. The trucks use off-the-road radial tires with size 11.00R20 dump truck series. The cross-section view of the radial tire can be seen in Figure 2. The truck capacity is about 24–25 metric tons, and each truck is equipped with ten tires. Minitab statistical software was utilized to analyze the data.

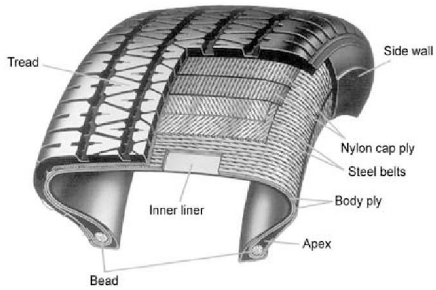

Fig. 2. Cross-section view of tire radial. Source: Ghoreishy & Hamid (2020)

Results and Discussion

Define Phase

In this stage, the team defined 'tire lifespan' in measurable terms, such as the number of kilometers a tire can travel before replacement or the rate at which the tread wears down. The basic data on the current tire lifespan was collected over one year, and the average lifespan was calculated. In one year, the company used 64 tires with an average of 56.065-kilometer (km) lifespan. The data on the tire lifespan for the whole year is presented in Figure 3. The company aims to improve the lifespan to 65.000 km per year to minimize operational costs.

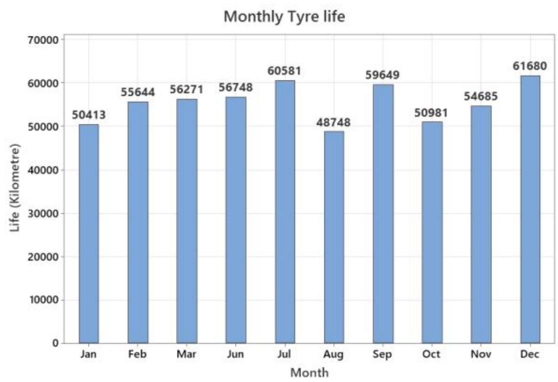

Fig. 3. Tire lifespan data before improvement

Measure Phase

In the measure phase, the improvement team analyzed the data in detail using statistical tools with Minitab software. Key metrics, such as the tire life's mean, median, and standard deviation, were calculated. This analysis helps to understand the current performance situation and pinpoint variability in the tire lifespan. The data is presented in Figure 4, where the mean is 56.065 km, the median is 57.122 km, the standard deviation is 11.013 km, and the maximum tire lifespan is 72.809 km.

Analyze Phase

In the analysis phase, the team identified the root cause of the problem. To visualize potential factors affecting the tire lifespan, such as materials, methods, machines, manpower, measurements, and the environment, the team used cause-and-effect diagrams, as shown in Figure 5. The process began with brainstorming potential causes and validating the root causes. During the session, the team identified several factors, including road conditions, which caused impact forces on the tire when the truck encountered bumpy roads. Other causes included the lack of a tire maintenance schedule, low driver awareness, and the absence of calibration for the pressure gauge. To validate the root causes, the team used a Genba investigation, which means a direct field investigation in Japanese. The root cause validation is described in Table 1.

To validate driver awareness, the team interviewed the drivers about their tendency to drive at high speeds on bumpy roads. Most drivers cited concerns about cycle time, with little regard for tire life or potential damage.

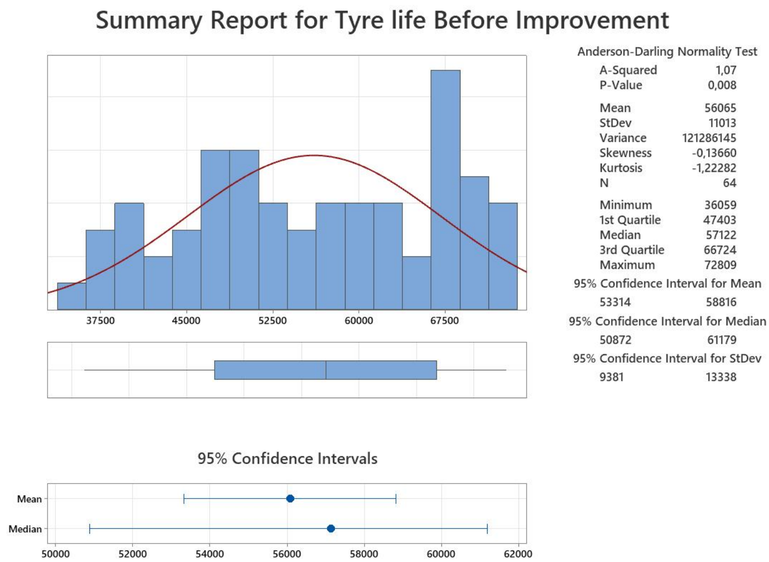

Fig. 4. Tire lifespan histogram before improvement

Table 1
Root cause validation

No	Root Cause	Validation	Result
1	Lack of driver awareness	Driver interview	The driver did not understand the correlation between tire lifespan and high-speed driving on bumpy roads (Valid)
2	No tire maintenance schedule	Genba observation	There was no regular tire maintenance schedule (Valid)
3	Road damage	Genba observation	Several road segments were damaged, especially after the rain (Valid)
4	Lack of measurement system	Measurement System Analysis (MSA) Study	Gage repeatability and reproducibility (Gage R&R) meets the standard (Not Valid)
5	No standard for tire repair	Genba observation	The company has a standard operation procedure for tire repair (Not Valid)

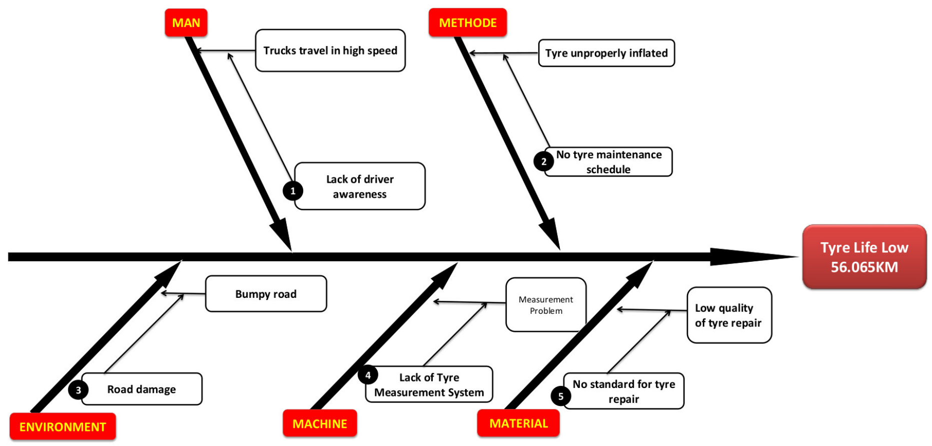

Fig. 5. Cause-effect analysis

The company also lacked a regular tire maintenance schedule, and tire pressure was only measured during new installations or repairs. During direct observation of the hauling road, the team identified several damaged segments in need of maintenance. The company already had a tire repair procedure in place, which was followed when the tire technician performed repairs.

Meanwhile, to validate the tire pressure measurement system, the team used a Measurement System Analysis (MSA) study. This was done to validate any errors in the measurement system, which is crucial, as the literature indicates that tire inflation significantly impacts tire lifespan (Bell, 2016). The MSA was carried out using the MSA standard consisting of two ANOVA methods: two inspectors, ten parts, and three repetitions (Patyal et al., 2021). Lastly, Gage repeatability and reproducibility (Gage R&R) were used to evaluate the tire pressure measurement system, as described in Figure 5. The results were satisfactory, as the Gage R&R was 18.16%, indicating that only 18.16% of the variation was due to the measurement system.

According to automotive standards, the Gage R&R should fall between 10% and 30%, indicating that the measurement system may be acceptable for certain applications (Down et al., 2010). The results of the MSA study, as described in Figure 6, are acceptable, which means the measurement system has followed the standard MSA. The lack of a measurement system

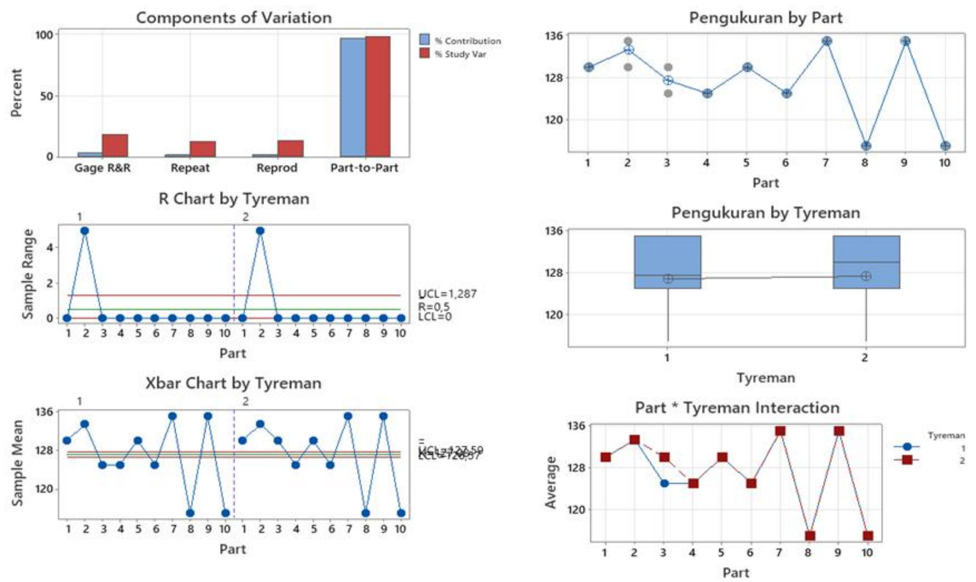

Fig. 6. Gage R&R tire pressure

is not a valid root cause.

Improve Phase

After finalizing and validating the root cause, the team set up an improvement plan, as shown in Table 2. There are three improvement initiatives to improve tire lifespan. The first is to raise drivers' awareness of the impact high speeds have on tires. By providing knowledge on how traveling at high speeds can increase the impact force when encountering bumpy roads, drivers can better understand the consequences. The second is establishing a tire maintenance schedule every two weeks, where the tire technician checks and records all tire pressures in the tire maintenance record. The third initiative is to improve road conditions and conduct regular maintenance to minimize or eliminate bumpy roads. The team put more effort into tire maintenance, as the company had 15 trucks, each equipped with 10 tires. Every two weeks, the tire technician was responsible for checking the tire pressure and addressing any instances where the pressure was below standard. The standard for tire pressure is 130 Psi.

Table 2
Improvement Plan

No	Root Cause	Improvement Plan
1	Lack of driver awareness	Training the drivers
2	No tire maintenance schedule	Establishing a tire maintenance and pressure check schedule (every two weeks)
3	Poor road quality due to damages	Improving road conditions and conducting regular maintenance

Control Phase

The control phase was when the team evaluated the improvement results after implementing the improvement plan. After the improvement was carried out, the team collected data for one year following implementation. The total tire consumption in one year after the implementation was 109 pieces. Compared to the total consumption before implementation, which was 64 pieces, the truck required more tires due to the significant increase in production volume.

However, looking into the details, the tire lifespan has improved significantly from a mean of 56.065 km to 73.093 km, which is about 27%. The detailed statistical metric can be seen in Figure 7. Since a longer tire life improves tire performance and reduces the cost per kilometer, comparing the maximum tire life before and after the improvement became important.

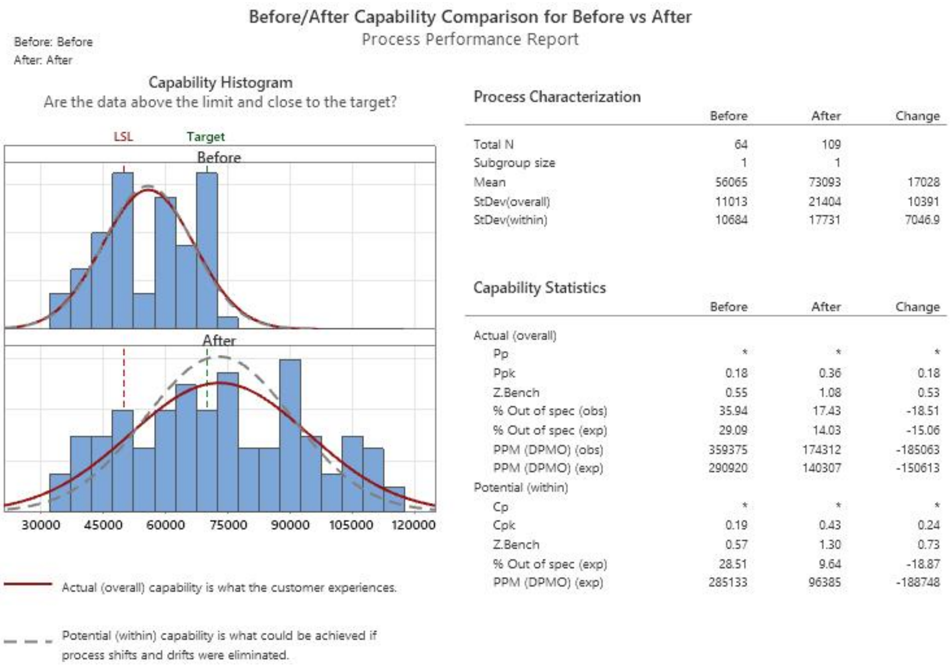

Fig. 7. Statistical analysis before and after improvement

The maximum tire life before the improvement was 72.809 km, and after the improvement, 109.626 km.

After the improvement, the data distribution became wider, reflecting a higher standard deviation. This is because more tires now have a longer lifespan, leading to more data points exceeding the target value, which is beneficial for tire life. The target value given by the management was 65.000 km. The process capability index (Cpk) before the improvement was 0.19, while after the improvement, it increased to 1.3. To ensure timely monitoring of tire performance, the team established a control chart, as shown in Figure 8. The chart indicates that, after the improvement, the mean has increased, reflecting the improved tire lifespan.

A hypothesis test was performed to confirm that the improvement results are significant using two Sample t-tests and the p-value 0,000 means that the improvement is significant. There is a significant difference in mean after improvement. The visual boxplots before and after improvement can be seen in Figure 9.

Conclusions

This study has shown how tire life improvement was achieved using the Six Sigma approach. Enhancements in operating conditions, such as tire maintenance, road pavement quality, and driving habits, have led to a significant increase in tire lifespan. The data shows that tire lifespan increases by 27% from its

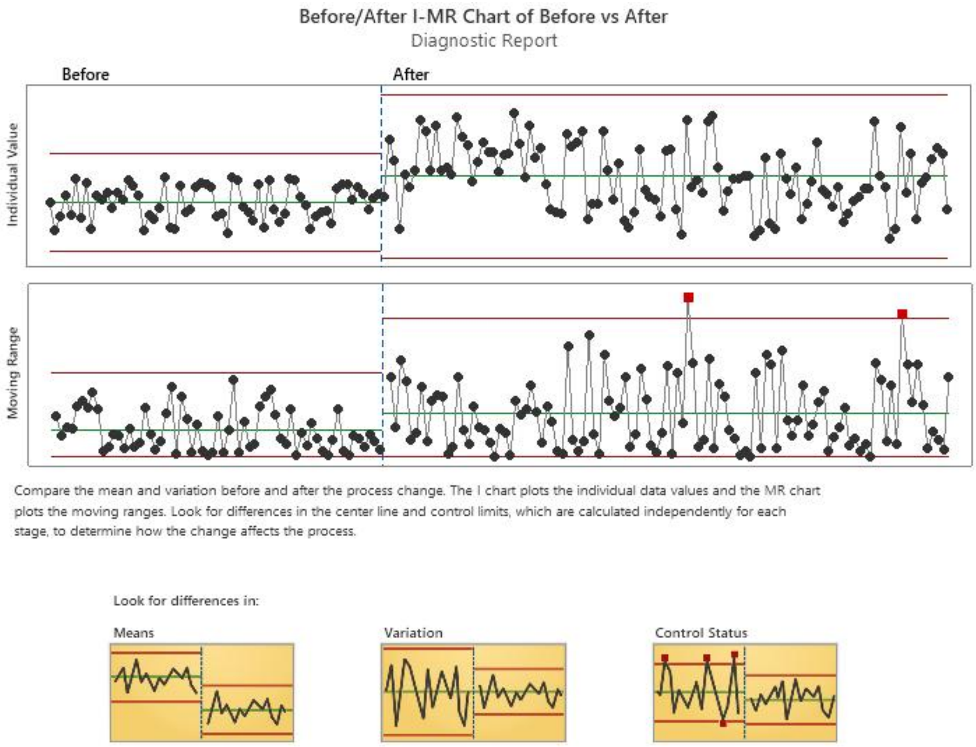

Fig. 8. Control chart before and after the improvement

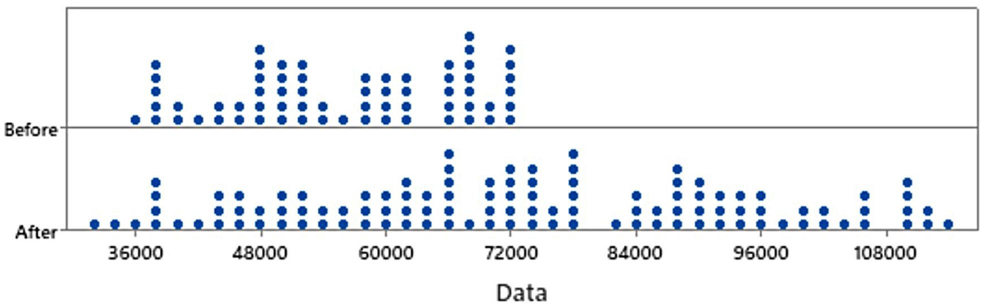

Fig. 9. Visual box plots of the data distribution after the improvement

previous conditions. This finding confirms past studies stating that tire life depends on the environment and operating conditions (Li et al., 2012b), which include road conditions and tire pressure. The findings in the study also confirm that tire pressure plays a significant role in tire lifespan (Abdulaev et al., 2019; Bell, 2016; Lindeque, 2016).

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