REDUCING COAL MINING SHOVEL BREAKDOWN TIME USING DMAIC APPROACH

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***Abstract*—**The reduction of shovel breakdown time in coal mining is crucial for maintaining operational efficiency and minimizing production losses. This study aims to address shovel breakdown issues by applying the DMAIC (Define, Measure, Analyze, Improve, Control) approach, a structured Six Sigma methodology designed to optimize processes and eliminate inefficiencies. Through the DMAIC framework, key factors contributing to shovel breakdowns were identified and analyzed. The Define phase involved understanding operational challenges and setting goals for reducing downtime. In the Measure phase, historical breakdown data were collected and performance baselines established. Root causes of shovel failures were identified during the Analyze phase using tools like Pareto charts, failure mode analysis, and cause-and-effect diagrams. Solutions were then developed and implemented in the Improve phase, focusing on preventive maintenance schedules, training programs, and equipment upgrades. Finally, the Control phase ensured sustained improvements through continuous monitoring and the implementation of standard operating procedures (SOPs). Results indicated a significant reduction in breakdown time, leading to improved operational efficiency and cost savings. This research demonstrates the effectiveness of the DMAIC approach in enhancing equipment reliability and can serve as a model for other industries facing similar challenges.

Keywords: Coal mining, Shovel breakdown, DMAIC, shovel, Preventive maintenance, Pareto Analysis.

INTRODUCTION

In the coal mining industry, shovels are critical pieces of equipment used to handle and move large volumes of material. The efficiency and reliability of these shovels directly influence production output and operational costs. However, frequent breakdowns and unplanned maintenance can lead to significant downtime, reduced productivity, and increased operational expenses. Ensuring the optimal performance of shovels is essential for maintaining a smooth workflow and minimizing disruptions. Addressing the issue of shovel breakdowns requires a systematic approach to identify, analyze, and eliminate the underlying causes. The DMAIC (Define, Measure, Analyze, Improve, Control) methodology, a cornerstone of the Six Sigma framework, provides a structured and data-driven process improvement strategy. Widely used in various industries to enhance operational efficiency, DMAIC enables organizations to identify inefficiencies, reduce variability, and implement sustainable solutions.
In this research, the DMAIC approach is applied to reduce shovel breakdown time in coal mining operations. The study begins with defining the problem, followed by measuring current performance, analyzing root causes, and identifying potential solutions. Improvements are then implemented to address the identified issues, and a control plan is developed to sustain the benefits achieved.

This thesis focuses on enhancing the reliability of shovels by targeting preventive maintenance, operator training, and process optimization. By implementing the DMAIC methodology, the goal is to achieve a measurable reduction in breakdown time, leading to improved productivity and cost savings in coal mining operations. This research not only contributes to the practical improvement of mining equipment reliability but also demonstrates the value of data-driven process management approaches in industrial contexts.

Machine Breakdown Time is the time which the machine is out of order and cannot add value to a process or product. Minimizing breakdown time is important because it saves us valuable production hours. When your machines break down often, it means you're unable to meet customer’s orders on time. If it requires a lot of time get it back up and running, the problem gets worse because every minute spent fixing a broken machine means a minute of lost production. If you have calculated your cost per minute (CPM) then you might know how much you are suffering from these down times. Ultimately, this leads to significant financial losses, potentially costing hundreds or even thousands of dollars to fix the broken equipment. If these down times are not considered as risk and not addressed on time. Then the machine can never be restored to its best condition unless a huge amount of money is spent on it. [1] [2] There are many Non-Productive time (NPT) which contains Planned and unplanned down times. A planned down time refers to scheduled time when machines and equipment’s are taken offline for the purpose to improve machine health and reduce sudden breakdowns. This downtime is planned carefully in order to minimize the disruption in production so that the process can be done efficiently. Unplanned Breakdown Time refers to the down time which occurs unexpected and unscheduled. When a machine or equipment unexpectedly fails and experience issue that requires sudden addressing. [3] Both planned and unplanned breakdown time can have significant impacts on productivity, effectiveness and efficiency. Minimizing both types of downtime is crucial to maximize operational uptime and reduce the negative effects on production and overall business performance.[4] To avoid these breakdown times implementing preventive, corrective and scheduled based maintenance. It must inspect and maintain machines to identify potential issues before they turn into breakdowns. For that purpose, organizations have maintenance departments whose job description is to develop maintenance schedule and then following it carefully. [5] Machine Breakdown Time not only affects our production and quality, but it also affects us financially. Most of the time to get the machine up and running it is must either repair the part or replace it with a new part which costs us too. [6]

The implementation of a strategy based on measurement focuses on process improvement and variation reduction which is the Fundamental objective of the Six Sigma methodology. This can be achieved by systematically using Six Sigma methodology which is DMAIC (Define-Measure- Analyze-improve-Control). Vehicle turnaround time is the time taken by the vehicle to complete all the operations of loading the product starting from the entry to exist from the industry [7]. Higher Vehicle turnaround time increases traffic inside plant which causes delays and results in decreased efficiency of the plant. It also increases the number of vehicles present in the plant which raises the safety issues especially in oil industries [8]. In a heavy oil industry where number of vehicles delivered are huge on the daily basis vehicle turnaround time plays a vital role in ensuring high productivity of the plant. Vehicle turnaround is calculated by considering the meantime taken by the vehicle from its arrival to the departure from the plant.

AIM AND OBJECTIVE

The primary aim of this research is to reduce the shovel breakdowns in a coal mining environment using the DMAIC approach, and consequently, to increase coal production. To achieve this aim, the research will focus on the following objectives:

1. Define the key performance indicators (KPIs) related to shovel performance.
2. Measure the frequency and duration of shovel breakdowns and their impact on coal production.
3. Analyze the root causes of hydraulic system failures using data-driven techniques and failure mode analysis.
4. Improve the reliability of the hydraulic system by implementing targeted maintenance practices and system enhancements.
5. Control the effectiveness of these improvements through continuous monitoring and process control to ensure long-term sustainability.

LITERATURE REVIEW

Ms. Su Nandar Hlaing, et al. (2023) Defect Reduction in Selected Sewing Lines of a Garment Factory with DMAIC Methodology of Six Sigma. The defect rate decreased by 69% after implementing the DMAIC methodology. The rejected percentage improved by 17% after implementing the DMAIC methodology. The overall quality percentage improved by 7% after implementing the DMAIC methodology. The contribution of this research is how to use the DMAIC methodology for the increased quality of the apparel production line. The paper will discover experimental answers to the good quality manufacturing problems of some manufacturing lines of a garment factory because of the quality increase. [1]

Suneel Kumar (2023) The application of DMAIC approach for increasing the quality of yarn manufacturing: a case study of textile industry. The researchers used the DMAIC approach of Six Sigma to identify and reduce defects in the yarn manufacturing process, with the goal of improving efficiency, productivity, and quality. The DMAIC approach helped identify the winding machine during the evening shift as the main source of defective products, and the researchers then implemented improvements to address these issues. - The implementation of the DMAIC approach led to the manufacturing process being brought under control, reducing defects in the winding machine and improving the overall effectiveness, efficiency, quality, and productivity of the yarn manufacturing system. In the future, we are looking to design the overall yarn manufacturing process to increase the effectiveness and efficiency. We are looking to use various techniques to minimize the possible defects in different stations and compare with the TPM technique. In the future analysis more advanced and automated industries will be researched to analyze their pros and cons. [2]

Muhammad Mustafa Ibrahim (2023) Reducing machine breakdown time using DMAIC approach in a garment industry. The article offers insights into effective tactics like preventative maintenance, condition-based monitoring, and efficient scheduling, and data-driven approaches using machine learning algorithms and real-time monitoring. The research paper also includes a case study of how the DMAIC methodology was used in the real-world textile industry to drastically minimize downtime. Lowering machine breakdown times is essential for success in the clothing sector. Industries can successfully address the underlying causes of machine malfunctions by prioritizing training, adopting preventative maintenance, and developing control systems.[3]

Nejc Novak Et al. (2023) Degradation of Hydraulic System due to Wear Particles or Medium Test Dust. Contamination in hydraulic systems is the cause of 70% of failures. This study highlights the performance degradation caused by solid particle contamination of hydraulic components: hydraulic gear pump, 4/3 valve, and orbital motor. Experimental durability tests of components with wear particles and test dust are used to investigate the effects of accelerated wear caused by these two types of contaminants. Results show that oil contaminated with wear particles reduces the volumetric efficiency of the gear pump by 18% and the hydraulic valve by only 0.8%, while oil contaminated with test dust reduces the efficiency of the pump by 76% and the hydraulic valve by 0.9%. This research provides insights for accelerating hydraulic component testing to improve system reliability and longevity.[4]

Harcourt David Onwuchekwa (2022) Plant maintenance and organizational productivity of first aluminum plc, port. 1. Lack of research on the relationship between plant maintenance and organizational productivity, especially in the context of First Aluminum Plc. 2. The role of employee empowerment in plant maintenance and its impact on organizational productivity. Run to Breakdown (RTB) as a plant maintenance strategy enhances the safety of First Aluminum Plc in Port Harcourt. Preventive maintenance as a plant maintenance strategy significantly impacts the increased reliability of First Aluminum Plc in Port Harcourt. Condition Based Maintenance (CBM) strategy as a plant maintenance significantly impacts the low operation cost of First Aluminum Plc in Port Harcourt.[5]

Er. Sanket Manohar Nawghare Et al. (2022) Analysis of Breakdowns and Implementing Optimal Maintenance of Engine Cylinder Block Machines for Improving Operational Availability. There is less research on long-term maintenance strategies to prevent breakdowns. - Most previous research has focused on short-term remedies for breakdowns, rather than long-term maintenance actions. The findings underscore the importance of a structured maintenance management approach in reducing machine breakdowns and enhancing operational efficiency. -machine availability/uptime, Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), production rate. [6]

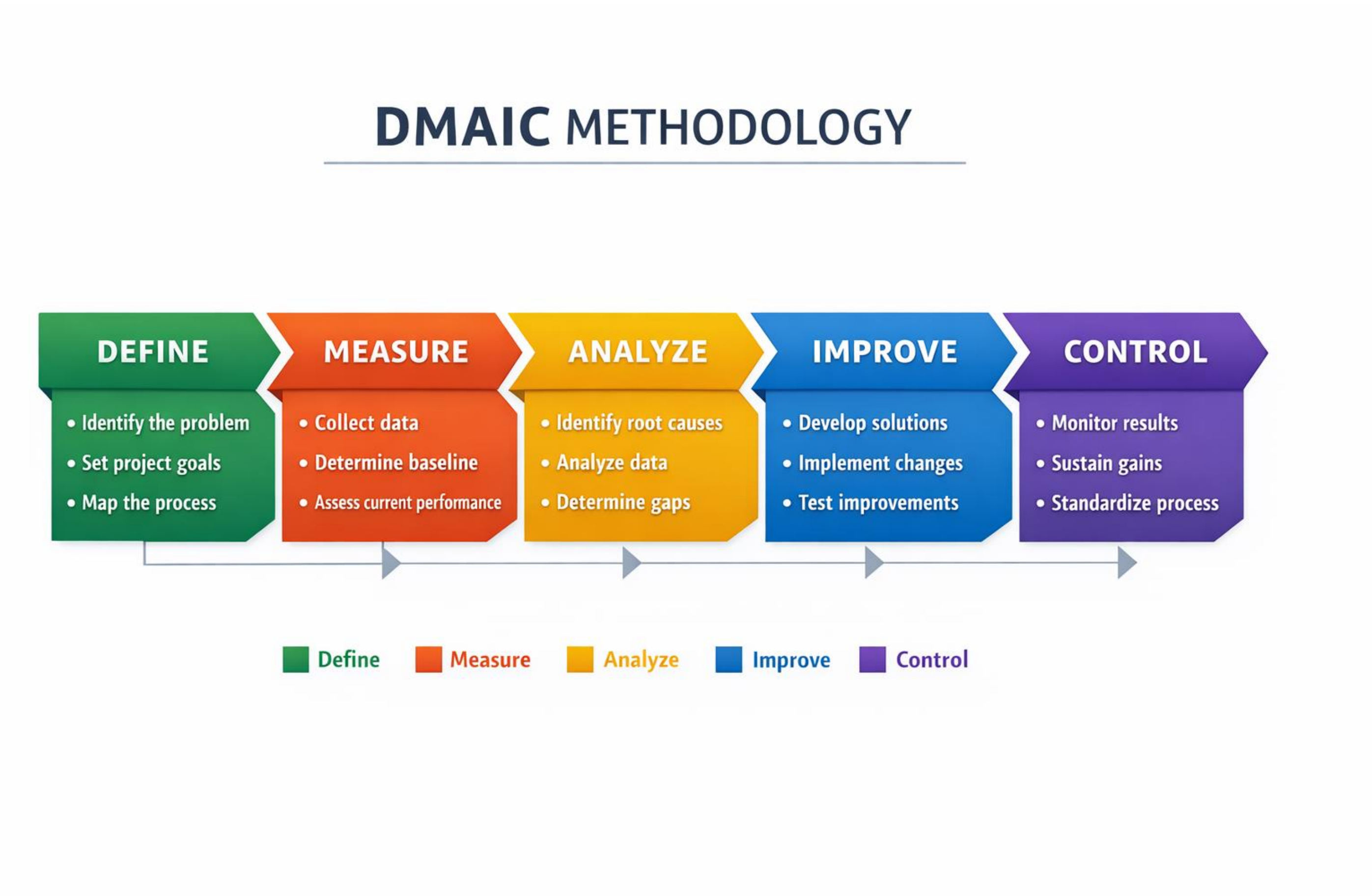
Ahmad Bahrudin et al. (2021) Analysis of Preventive Maintenance and Breakdown Maintenance on Production Achievement in the Food Seasoning Industry. Future research to deepen by analyzing the indicators of each of these variables using Structural Equation Modelling (SEM) based on covariance or Partial Least Square (PLS). Variables preventive maintenance and breakdown maintenance simultaneously have a significant effect on the achievement of production. This means that these two variables together affect the increase in production output. [7]

Pranav Bharara, et al. (2018) Implementation of DMAIC Methodology for reduction of weighted defects in a vehicle assembly process. The Six Sigma DMAIC methodology implemented in this study led to an improvement in the sigma level from 2.76 to 3.12. Achieving the Six Sigma target of 3.4 DPMO requires rigorous and sustained implementation across all levels and areas of the organization, which takes significant time and effort. Embracing Six Sigma and a continuous improvement culture is key to realizing benefits like cost savings, quality improvements, and customer satisfaction. [8]

Suhas N Karajgar, et al. (2018) Reducing the Vehicle Turnaround Time inside the Oil Industry using Six Sigma DMAIC Approach. the process improvement six sigma DMAIC tool can be effectively applied on the existing business processes. Six sigma DMAIC tool provides statistical support to each and every action thus helping making decisions more efficient. Thus, Six Sigma DMAIC is completely an industry-oriented methodology of process improvement. Implementation of six sigma DMAIC tool in an oil industry resulted in reduction of vehicle turnaround time by 20%. [9]

METHODOLOGY

The research will adopt the DMAIC methodology as the primary framework for identifying, analyzing, and addressing the root causes of shovel breakdowns. This structured approach will involve the following steps:



Define phase

In the define phase identify challenges and the project objective. In this study, we want to use the Six Sigma tool to reduce downtime. In this phase, the specific problem areas related to the shovel's breakdown will be clearly defined. KPIs such as Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and shovel availability will be established. The scope of the problem and its impact on coal production will be outlined, and the goals for improvement will be set. Daily operational hour for one shovel is 8 hours, and monthly Shovel Breakdown days can be seen in the below.

Sr. No	Problem Description	Breakdown Occurrence
1	Hydraulic hoses failure	137
2	Bucket teeth damage	44
3	Hydraulic cylinders failure	32
4	Hydraulic cylinders failure	16
5	Brake jam	9
6	Hydraulic controller failure	7
7	EPC valves fail	6
8	Gear shifting trouble	4
9	Swing drive & motor failure	3
10	Track chain damage	3
11	Engine failure	3
12	Undercarriage Roller damage	1
	Total	265

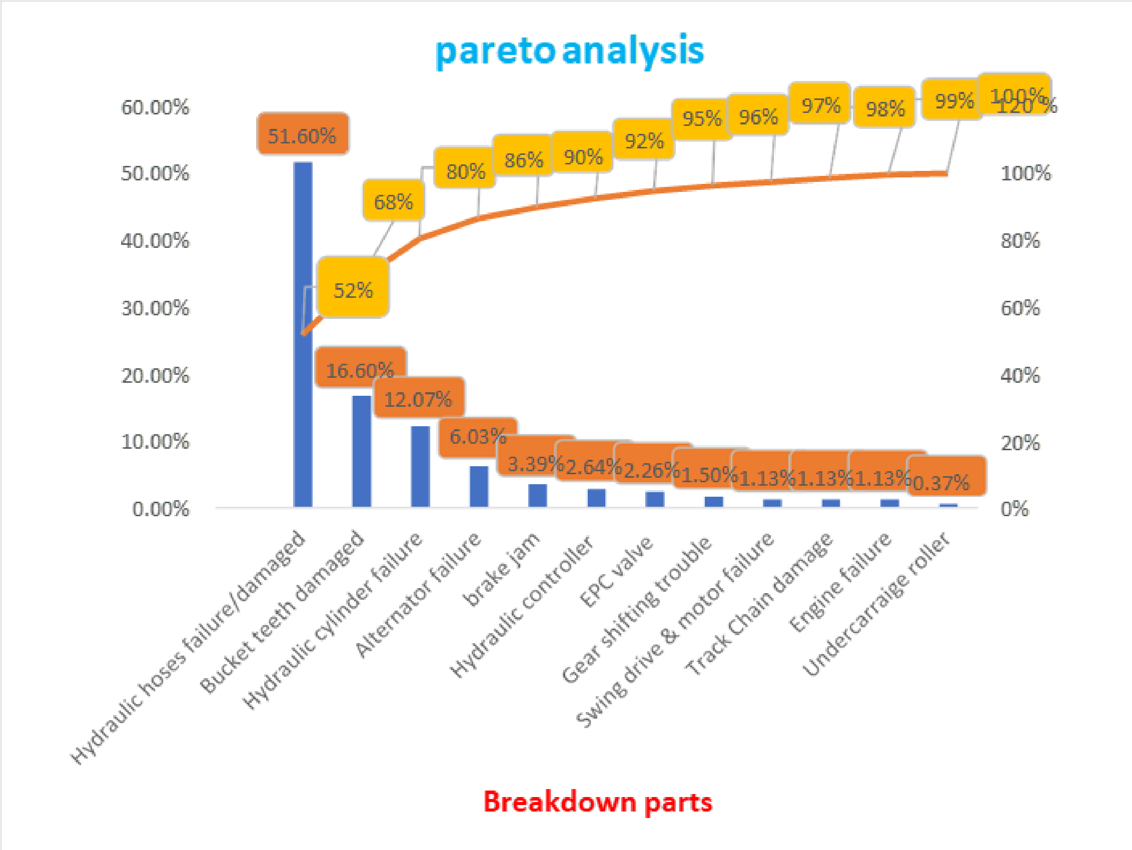
Table 1: Breakdown parts and breakdown occurrence number in 4 shovels from January 2024 to July 2024.

Measure Phase

Data collection and process status measurement are the main objectives of the second phase. To comprehend the performance of the process, data is gathered and key process metrics are determined. This stage aids in creating a baseline and offers a precise grasp of the scope and effects of the issue.
In measure phase Pareto analysis is a tool based on the 80/20 rule, which states that roughly 80% of the problems are caused by 20% of the causes. In this paper, we can use Pareto analysis to determine which breakdown issues are responsible for the majority of occurrences, helping to focus on the most significant issues.

Problem description	**Contribution%**	**Cumulative%**
Hydraulic hoses failure	51.60%	52%
Bucket teeth damaged	16.60%	68%
Hydraulic cylinder failure	12.07%	80%
Alternator failure	6.03%	86%
brake jam	3.39%	90%
Hydraulic controller	2.64%	92%
EPC valve	2.26%	95%
Gear shifting trouble	1.50%	96%
Swing drive & motor failure	1.13%	97%
Track Chain damage	1.13%	98%
Engine failure	1.13%	99%
Undercarriage roller	0.37%	100%

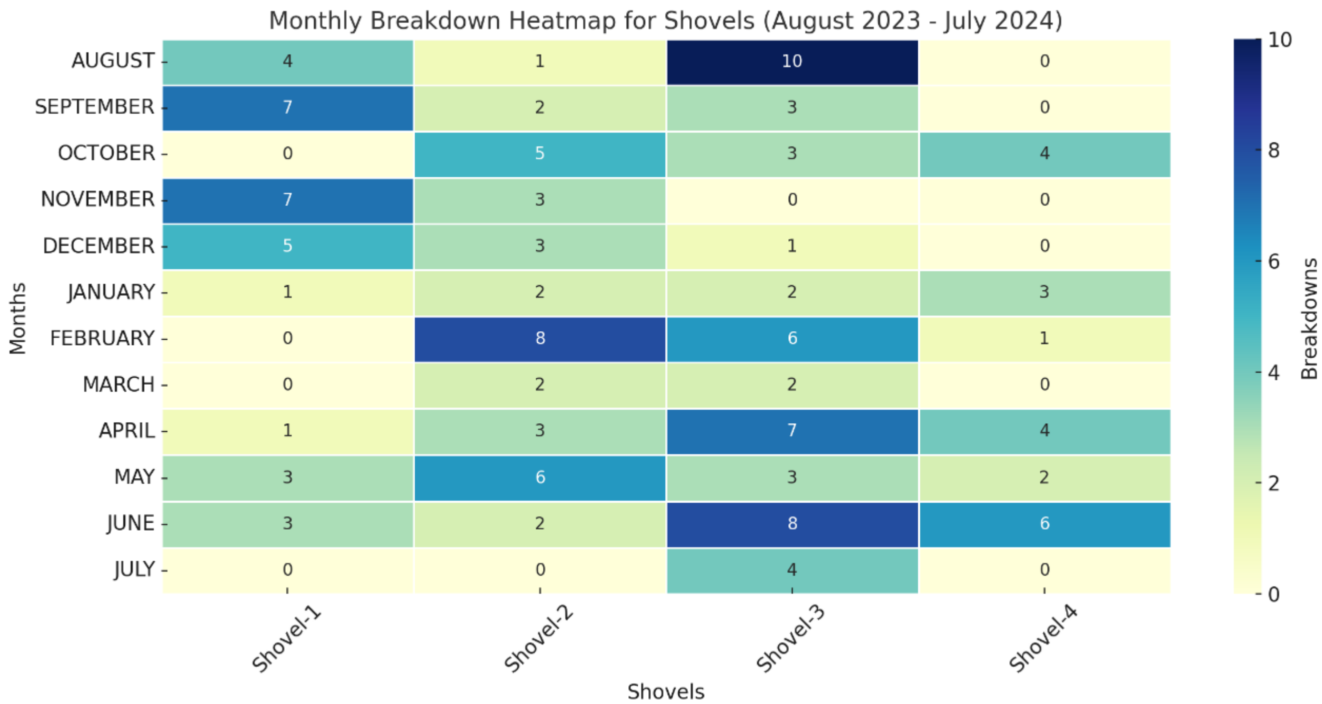
Table 2 : problem description and contribution percentage of 4 shovels.



From the table, following information obtained:
Hydraulic hose damage/failure, bucket teeth damage, and Hydraulic cylinder failure account for 78% of all breakdown occurrences. This means that focusing on fixing or preventing these three issues can potentially solve the majority of breakdown problems.

Analyze Phase

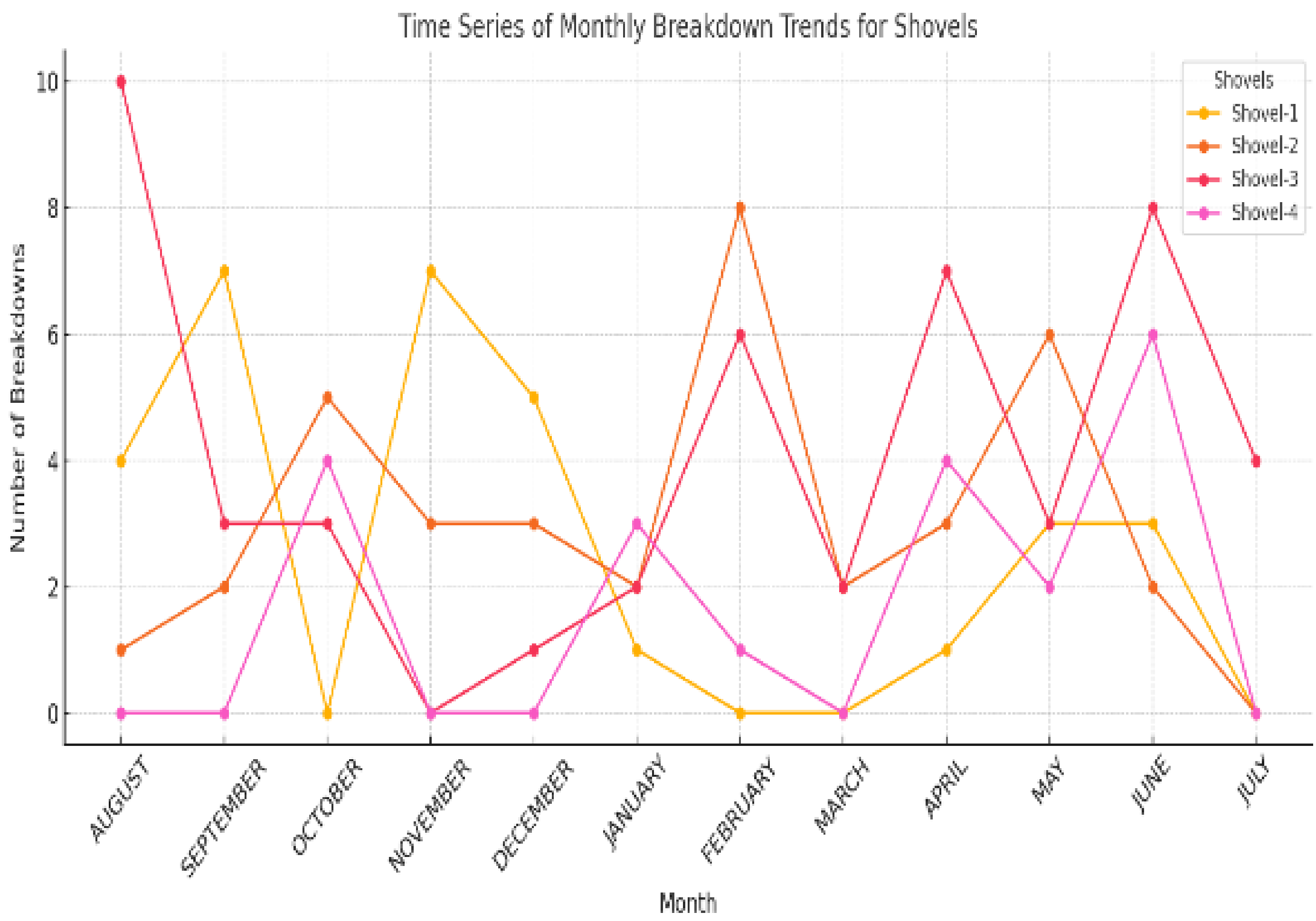
The failure of hoses in coal mining shovels can be a critical issue, leading to significant downtime and maintenance costs. Hoses are an integral part of the hydraulic systems in shovels, and their failure can result from various causes.



The heatmap above visualizes the monthly breakdown data for each shovel over the year August 2023 to July 2024.
Key Insights:

- High Breakdown Periods: Shovel-3 shows consistently high breakdowns, especially in August, April, and June.
- Shovel-2 peaks in February and May.
- Low Breakdown Periods: Shovel-4 has minimal issues, except for spikes in April and June.

- Shovel-1 experienced relatively low breakdowns, with peaks in September and November.
- Critical Focus Areas: Shovel-3 and Shovel-2 are clear priorities due to frequent issues.
- Peak months: February, April, and June warrant further analysis.



The time series chart above illustrates the monthly breakdown trends for each shovel over the year.

Key Observations:

- **Shovel-3:** Consistently high breakdowns throughout the year, peaking in August, April, and June.
- Requires urgent attention, likely due to operational or maintenance issues.
- **Shovel-2:** Noticeable spikes in February and May, suggesting potential seasonality or specific workload issues during these months.
- **Shovel-1:** Moderate breakdowns, with notable peaks in September and November.
- **Shovel-4:** Minimal breakdowns overall, with occasional spikes in April and June.

Improve Phase:

Based on the insights gained from the analysis phase, targeted improvements will be implemented. These may include changes in maintenance practices, the introduction of preventive maintenance techniques, the upgrading of components, or modifications to the operating procedures of the shovel. The improvements will be tested and evaluated to ensure they lead to a measurable reduction in shovel breakdowns.

The improvement phase is concerned with developing and implementing solutions to address the issues that have been identified as the primary causes. Potential solutions are developed, evaluated, and tested through the use of simulations or experiments. The best option is selected and implemented. We can go for kaizen to keep our machine breakdown time more. Appropriate training ought to be provided. Proactive maintenance is the process of keeping machinery, equipment, or systems free from malfunctions, breakdowns, or performance issues. To ensure that assets are in optimal operating condition, it involves planning regular inspections, repairs, cleanings, and maintenance. The goals of preventive maintenance are to minimize unscheduled downtime, lengthen the lifespan of equipment, reduce repair costs, and guarantee dependable operation.

Recommended SOP for coal mining hose maintenance:

Here's an outline for a process chart for the Hydraulic Hose Maintenance SOP for Coal Mining Shovels. This flowchart will visually represent each step, from daily inspections to emergency replacements. Let's break it down into sections:

1. Daily Inspection Process

- Daily Visual Inspection ➔Inspect for visible wear, cracks, or leaks?
- Yes: - Record in Inspection Log ➔Proceed to Repair/Replacement Process
- No: -No Issues ➔Proceed with Normal Operations

2. Scheduled Preventive Maintenance Process

Weekly/Monthly Maintenance ➔Check hose fittings, pressure ratings, connections

- (Issues Detected): Log Issues ➔Schedule Replacement ➔Proceed to Replacement Process
- (No Issues): No Replacement Needed ➔Document & Continue Operations

3. Hose Replacement Process (Routine or Emergency)

- Pressure Relief ➔Shut down system & activate lock-out/tag-out (LOTO)
- Remove Damaged Hose ➔Dispose of properly
- Select Correct Hose & Fittings ➔Follow hose specifications
- Install New Hose ➔Follow torque specs & secure clamps
- Check Connections ➔Ensure correct pressure rating, avoid twisting/bending
- Test System ➔Observe for any leaks or irregularities
- Log Replacement ➔Complete documentation & restart operations

4. Emergency Procedure for Breakdown

- Breakdown Detected ➔Shut down machine ➔Activate LOTO
- Follow Replacement Process ➔See Hose Replacement Process steps
- Test System ➔Ensure system is fully operational
- Resume Operations ➔Document in breakdown log

Control Phase:

Once improvements are in place, control mechanisms will be established to monitor the performance of the Shovel continuously. Control charts and other statistical tools will be used to ensure that the improvements are sustained over time. Maintenance schedules and operational practices will be adjusted as necessary to maintain the gains achieved.

The primary objective of the final phase of DMAIC is to ensure that the improvements are sustained over time. Control measures are implemented to monitor the process and ensure that the enhancements achieved during the improvement phase are maintained. Statistical process control (SPC) methods are often used to monitor and regulate the process, preventing it from reverting to its original state. To drive improvements, it's beneficial to hold daily and weekly meetings with the maintenance team. This allows everyone to report on their progress and discuss areas for improvement. Maintaining this routine can significantly reduce downtime over time.

RESULT AND DISCUSSION

The primary aim of this study was to reduce shovel machine downtime in the coal mines. Machine breakdown time refers to the duration when machines are non-operational, leading to lost production and potential financial setbacks. The research highlighted the importance of minimizing downtime to meet coal production target and avoid unnecessary costs.

Using the DMAIC (Define, Measure, Analyse, Improve, and Control) methodology, the study identified key causes of hose failures. A Pareto analysis revealed that hose accounted for a significant portion of the breakdowns. Through root cause analysis, the study further explored the factors behind hose problems and stressed the importance of training workers to replace hose independently.

The study emphasized preventive maintenance as a solution to these issues, aiming to improve equipment reliability. It recommended that the maintenance team develop standard operating procedures (SOPs) to ensure regular inspections, adjustments, and cleaning of hoses. To ensure sustained improvement, the implementation of control measures, such as daily and weekly meetings with the maintenance team, was also suggested complexity in hose maintenance.

The findings of this research highlight the critical role of worker training, preventive maintenance, and continuous improvement initiatives in reducing machine downtime within the coal mines. By adopting these strategies, companies can boost productivity, meet coal production target efficiently, and minimize the financial impact caused by shovel downtime.

Machine breakdowns pose a significant challenge for the coal mines companies, as they hinder efficiency, disrupt production schedules, and incur costs. Reducing equipment downtime is crucial for meeting coal production target, maximizing operational uptime, and improving overall business performance. The DMAIC method (Define, Measure, Analyse, Improve, and Control) has proven to be an effective strategy for addressing this issue.

In this study, the primary causes of machine downtime in a coal mining company were identified using the DMAIC approach, with shovel hose issues being the leading factor. Root cause analysis revealed that empowering and training workers and simple design of hoses could significantly reduce these hose-related problems. To enhance equipment reliability, it was recommended to implement preventive maintenance, which entails regular inspections and adjustments. To sustain the improvements achieved, the maintenance team was encouraged to adopt standard operating procedures (SOPs) and implement control mechanisms, such as daily and weekly meetings. These measures ensure ongoing monitoring, continuous improvement, and the prevention of reverting to previous issues. By utilizing the DMAIC approach and applying the suggested strategies, the coal mining companies can significantly reduce machine downtime, resulting in increased production, timely order fulfilment, and minimized financial losses.

CONCLUSION

Reducing machine breakdown time is crucial for success in the coal mining sector. By focusing on training, implementing preventive maintenance, and establishing control systems, industries can effectively tackle the root causes of machine failures. The adoption of the DMAIC methodology fosters continuous improvement and ensures long-term success. By implementing these strategies, the coal mining companies can enhance operational efficiency, meet customer demands, and improve profitability.

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