The principles of mobile asset maintenance management strategy (a fundamental approach)

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Abstract

The fundamental aim of an asset maintenance practise is to enhance asset performance, minimize downtime, prolong the lifespan of assets, and manage maintenance expenses. While this objective can differ across various industries, this extensive research experience indicates that it remains a common goal.

Developing a maintenance plan suitable for organizations ranging from small businesses to large enterprises can be quite challenging. This process encompasses multiple components and methodologies, along with diverse approaches, all aimed at ensuring the thorough and efficient upkeep of assets, which include equipment, machinery, facilities, and infrastructure.

While some of these assets may not be the expensive, they are crucial for producing production achievable or services, highlighting their importance in operational workflows. The failure of these essential assets can initiate a chain reaction that disrupts the entire production operations and may even lead to a complete halt in organisational operations. To guarantee that vital assets operate at peak efficiency consistently, it is essential to establish a maintenance management practise that is both effective and dependable. This meticulously designed strategy plays a pivotal role in maintaining the ongoing performance of such assets, resulting in fewer operational failures, minimizing errors or quality issues, and significantly reducing the need for constant oversight or monitoring.

Keywords- Maintenance, computerised maintenance management system (CMMS), equipment, Failure Mode and Effects Analysis (FMEA), criticality analysis, Plan Do Check Act (PDCA), preventative maintenance, predictive maintenance, Asset life cycle, safety.

Introduction

Asset lifecycle optimization is a principle that aims to enhance the longevity and performance of an asset throughout its various stages, ranging from acquisition to disposal. An effective maintenance strategy that integrates predictive, preventive, and, when necessary, reactive methods tailored to asset criticality is crucial for maximizing uptime, ensuring safety, and extending operational lifespan. A customized proactive approach helps lower long-term expenses, while insights derived from data enhance decision-making processes. This shift transforms maintenance from merely a cost center into a source of competitive advantage.

This article presents a summary of the existing literature concerning asset management within multi-unit systems, focusing particularly on mobile assets such as mining equipment. As these asset systems grow increasingly complex, researchers have adopted various terminologies to address their unique challenges. Given the current position of maintenance, the framework used in this paper also suggests the strategic direction to progress for long-term effectiveness. It helps in stimulating practising managers to manage maintenance with a strategic thinking and mindset. It also helps them to visualize the capabilities of maintenance in enhancing the competitive advantage of a company.

Together, maintenance and reliability foster a proactive strategy that decreases downtime, reduces expenses, and enhances the lifecycle value of essential assets.

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literature review

Asset management is currently a young and growing, yet still a fragmented industry. Asset maintenance management strategy literature focuses on transitioning from reactive to proactive, data-driven approaches—specifically condition-based (CBM) and predictive maintenance (PdM)—to optimize asset life, uptime, and cost. One of the contributing factors to this fragmentation is that the asset management industry is witnessing a proliferation of software tools [1]. Furthermore, each of these software tools is providing standalone solutions to a multitude of problem areas, such as asset inventory, condition assessment and strategic planning. The term asset management has been widely used since the International Organisation for Standardisation (ISO) established its definition in ISO 55000 [2]. An organization requires a framework to prioritize assets within a system, particularly when their contributions to overall value are uneven. Given limited resources, asset managers must focus on the most critical assets to ensure that necessary intervention activities are implemented effectively. [3] conducted an analysis cantered on criticality with a particular focus on maintenance management. The authors highlighted the importance of prioritizing assets and created a model that ranks them based on their associated risks (frequency levels) and impacts on business objectives (severity of functional loss). In a recent study by [4], the authors examined a portfolio system where both the risk profile and the consequences of asset failure evolve over time.

Asset maintenance management is increasingly becoming a prominent area of research, particularly with the adoption of methodologies like Reliability-Centered Maintenance, Reliability, Availability and Maintainability (RAM) analyses, and various optimization strategies aimed at reducing maintenance expenses and improving scheduling. These methodologies are also applicable for assessing the remaining useful life of essential components by incorporating stochastic processes and degradation models that utilize sensor data, which are then refined using posterior information within a Bayesian analysis framework [5.6]

Key to maintenance principles are parameters such as safety stock and reordering points, which must be considered to assess spare part movement effectively and optimize inventory levels [7.8] Routine physical inspections of equipment involve creating work orders for maintenance tasks that are documented within a Computerized Maintenance Management System (CMMS). This system facilitates effective management of work order backlogs as well as the routing and scheduling of resources aligned with maintenance activities [8.9].

Asset Maintenance strategy

Principles of computerised asset maintenance management system (CMMS)

In the current competitive industrial environment, a robust maintenance strategy is vital for maintaining operational efficiency, optimizing asset lifecycles, and effectively managing costs. Achieving desired objectives and striving for superior production performance requires viewing maintenance as a fundamental component of a successful strategy. This article delves into the essential aspects of creating and developing an effective maintenance strategy that aligns with production operations' overarching vision.

1.Asset register

A Fixed Asset Register **(FAR)** is a comprehensive list of fixed assets owned by an organization. The primary function of a fixed asset register is to monitor the book value of assets and facilitate the calculation and recording of depreciation for both management oversight and maintenance planning. At minimum, an effective fixed asset register should encompass details like asset ID or tag number, description, category/class of the asset, acquisition date, original cost, vendor/supplier information, location, department or cost centre designation, responsible custodian details, useful life estimates, depreciation method employed, salvage value assessment.

Table 1: Asset register sample (Source:[10])

Asset ID	Description	Category	Acq. Date	Cost	Method	Life	Accum. Depr.	NBV	Location
P001	Heavy Equipment	Excavator	15/02/2024	$620,000	Cash	15 Years	$100,000	$520,000	Mining
P002	Heavy Equipment	Bull Dozer	10/06/2023	$420,000	Cash	20 Years	$80,000	$340,000	Mining
P003	Light Vehicle	Double cab	25/04/2023	$20,000	Cash	5 Years	$900,00	$19,100	Admin
P005	Heavy Vehicle	Fuel Truck	10/01/2023	$200,000	Cash	7 Years	$8,000	$192,000	Operations
P006	Heavy Equipment	Loader	22/10/2022	$350,000	Cash	10 Years	$12,000	$338,000	Operations

The register is crucial for maintenance strategy, acting as the "single source of truth" for asset data, including location, condition, and maintenance history. It supports proactive maintenance scheduling, reduces reactive catastrophic failures and assists with lifecycle management (repairs, depreciation, and disposal). A sample of the details required in the asset register are illustrated in table 1 above.

Key Asset Register Role in Maintenance Strategy

- Preventive & Predictive Maintenance: By detailing asset specifications, maintenance history, and warranty info, it enables scheduling, reducing breakdown costs and improving maintenance efficiency.
- Proactive Planning: It assists in tracking asset condition and expected useful life, allowing for budgeting and replacement planning before failure occurs.
- Operational Visibility: Provides technicians access to documentation, including location, through CMMS or asset management software, reducing time spent searching for assets.
- Cost Management: Assists in identifying over-serviced or poorly performing assets to optimize repair costs.

Best Practises for Asset Maintenance Register

- Tag Assets at the Point of Receipt: The most common source of FAR errors is the gap between purchasing and tagging. When an asset is received, unpacked, and put into service without being tagged and entered into the register, it becomes invisible to the accounting system
- Regular Updates: Review the register at least annually and update whenever significant repairs, upgrades, or maintenance actions are completed.
- Maintain an Audit Trail for Every Change: Every modification to a FAR record should be logged with a timestamp, user ID, and reason. This includes acquisitions, disposals, transfers between locations, changes to depreciation parameters, impairment adjustments, and revaluations.
- Digital Integration: Use software (like CAFM or CMMS) to link the register to maintenance work orders.
- Assign Clear Ownership and Accountability: Every asset in the register should have an assigned custodian — the person responsible for the asset's physical safekeeping and condition.
- Staff Training: Train staff on updating maintenance records to ensure the register is a reliable data source

2 Risk assessment

Assets Failure Mode and Effects Analysis and Criticality analysis

Failure Mode and Effects Analysis (FMEA) is a systematic approach aimed at recognizing and addressing possible issues or failures along with their impacts on a system or process prior to any negative occurrences. For new initiatives, it highlights potential bottlenecks or unforeseen consequences before implementation. Additionally, it aids in evaluating an existing system or process to comprehend how suggested modifications will affect the overall operation. After identifying necessary changes in the process or system, the subsequent steps align with those employed in any type of Process Improvement Plan (PIP).

FMEA represents a structured, proactive technique for identifying possible failures, evaluating their effects, and prioritizing corrective measures to enhance the reliability of products or processes. Within asset management, Failure Modes and Effects Analysis (FMEA) serve as a forward-thinking method that identifies, ranks, and mitigates potential equipment failures before they lead to downtime, safety hazards, or substantial repair expenses. This process involves analysing the causes and consequences of failure modes, assigning a Risk Priority Number (RPN), and formulating customized maintenance strategies [11]. A stronger risk assessment leads to the relevant formulation of a reliable asset's maintenance procedure. Mobile assets identified in the asset register (table 1), will now be critically analysed and maintenance need will be rated and prioritised after the risk assessment has been completed as indicated in table 2 below.

Table 2 : Failure mode effect analysis (Source : [11])

Asset/Item	Potential FailureMode	Potential Failure Effects	Severity	Causes	Occurance	Current Controls	Detection	RPN	Recommended actions
ID Number	System Potential Failure	Related consequencies		All contributing factors		Prevention Detection			Steps to reduce severity
P001	Engine failure	Production loss	5	maintenance	5	inspections	3	6	Preventative
P002	Transmission	Loss of traction	4	low oil	4	Oil Analysis	4	4	Cond Mont
P003	Brake failure	Accident	4	worn brakes	5	ramp test	3	4	Predictive
P004	Noisy pins	Component fail	5	no lubrication	4	Cond Monit	3	3	Inspections
P005	loss of power	Slow functioning	5	filter blokage	4	clean out	3	3	Preventative
Severity	Rates impact of failure on a scale from 1-10. Higher score indicates more asset serious effects								
Occurance	Measures how frequently a failure happens on a scale of 1-10								
Detection	Assesses the likelyhood that existing controls will catch the failure on a scale of 1-10								

There are three primary ways in which maintenance teams can implement a failure mode and effects analysis (FMEA):

- Establish a preventive maintenance schedule that minimizes the risk of asset failure while maximizing resource efficiency.

- Prepare for emergency maintenance to ensure assets can be swiftly repaired, thus reducing downtime.
- Prioritize corrective maintenance and manage the maintenance backlog.

Three key applications of FMEAs in developing a top-tier preventive maintenance strategy include:

- Developing new preventive maintenance tasks
- Prioritizing existing preventive maintenance efforts
- Enhancing the overall effectiveness of preventive maintenance

The initial phase in formulating an asset preventive maintenance program involves identifying potential failures and their frequency. An asset FMEA provides this critical information. For instance, when designing a new asset, an FMEA helps determine necessary preventive measures to avert possible failure modes and establishes their required frequency. This process enables you to outline essential inputs for creating new preventive measures, such as assigning personnel, identifying triggers for action, estimating costs, and determining timeframes needed for completion.

3 Structured maintenance strategy

All functioning assets accumulate operating hours; its expected failure rate increases. The P-F curve maintenance principle offers a way for you to see the health of equipment over time. It's an essential tool in developing effective maintenance strategies, as it can be used to predict the optimal balance between planned and corrective maintenance procedures.

The P-F curve, or Prevention-Failure curve, is a graph used to identify asset reliability and performance over time as shown in Diagram 1 below. It plots the interval between an asset's potential failure (P) and functional failure (F), which allows you to identify when preventive maintenance measures should be taken. In this article, it will be illustrated why the P-F curve is an incredibly useful tool for helping with maintenance planning and execution activities by allowing maintainers to plan your maintenance strategy more effectively and reduce downtime due to equipment breakdowns

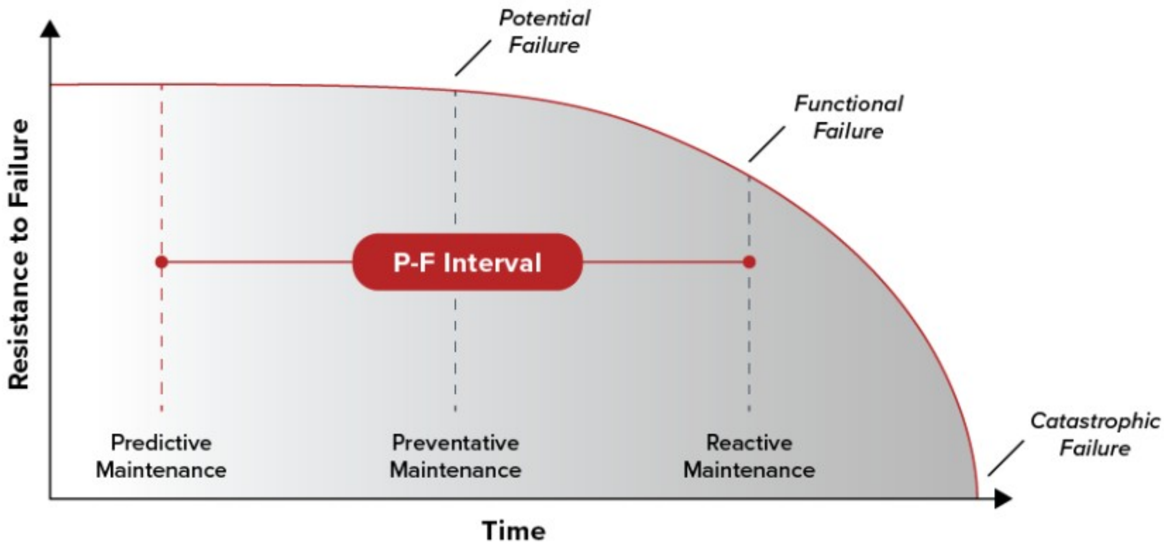

Diagram 1: The asset P-F Curve (Source [13])

The P-F Curve illustrates the lifecycle of an asset from potential failure (P) to functional failure (F), helping predict equipment breakdowns and formulation of the maintenance strategy and the implementation of repair activities, (execution) as listed below:

- **P-F Interval**: The time between potential failure and functional failure, critical for performing preventive maintenance.
- **Point P**: Marks the start of a defect or failure mode, where early detection can prevent further degradation.
- **Point F**: Represents the point where the asset can no longer function, leading to downtime and costly repairs.
- **Expanding the P-F Interval**: Techniques like predictive maintenance, condition monitoring, and inspections can extend this interval.
- **Creating the P-F Curve**: Requires historical data, failure records, and condition monitoring technologies to map asset degradation.

Table 3 : Asset maintenance strategy (Source : [12])

STRATEGY	FREAUENCY	MAINTENANCE DESCRIPTION-TASKS	RESPONSIBLE	PRIORITY	LOCATION
Preventative Maintenance	Daily, Weekly,	Scheduled maintenance tasks at regular intervals to prevent issues, including time-based, usage-based, and predictive approaches.Inspections, Backlog/Work order creations, Lubrication/greasing, PM Services	Workshop Planning, Supervisors, Mechanics	High, Equipment with predictable wear and tear	Workshop Based, Field based
Predictive Maintenance	Weekly, Monthly	A more advanced form of preventive maintenance that uses data and analytics to predict when maintenance should be performed based on equipment condition.	Workshop Planning, Supervisors, Mechanics	Critical machinery where downtime is costly	Workshop Based, Field based
Condition Based Maintenance	Weekly, Monthly	Monitors real-time conditions (e.g., vibration, pressure) to determine when maintenance is needed, triggering action when predefined thresholds are crossed.	Workshop Planning, Supervisors, Mechanics	Assets with fluctuating performance	Workshop Based, Field based
Corrective Maintenance	Daily, Unplanned	Repair equipment only after failure/ breakdown	Workshop Planning, Supervisors, Mechanics	Non-critical equipment where downtime isn't a major issue.	Workshop Based, Field based
Parts Components Change Out/Midlife Maintenance	Planned yearly	It is proactive, scheduled replacement of worn, aging, or critical major machine components.It is an advanced form of preventive maintenance designed to maximize equipment lifespan and prevent unexpected downtime	Workshop Planning, Supervisors, Mechanics, Welders	Critical prime movers,long term perfomers	Workshop Based,
Reliability Centred Maintenance	Planned Daily, weekly,monthly	Focuses on optimizing maintenance for critical assets based on reliability analysis, often a combination of preventive and predictive methods.	Workshop Planning, Supervisors, Mechanics	High-value, mission-critical assets	Workshop Based, Field based

By making room for the P-F Curve into the asset management and maintenance strategies and practices as shown in Table 3 above, organisations can proactively manage equipment lifecycles, lower unexpected downtime, and strengthen operational efficiency. This approach offers a clear path from detecting early signs of potential failure to ensuring that the assets perform optimally on a continuous basis.

Choosing a strategy depends on asset criticality, safety requirements, cost constraints, and available technology. A blend of strategies is common, using predictive maintenance on key machines and preventive maintenance on others to optimize resources. The success of any maintenance plan relies heavily on the skills and expertise of the maintenance personnel responsible for its execution. Staff members must be trained in relevant methodologies, technology usage, troubleshooting techniques, safety protocols, etc., ensuring they possess both hands-on experience and theoretical knowledge.

4.Assets spare parts strategy

Spare parts maintenance management optimizes inventory, reduces downtime, and cuts costs by strategically sourcing, storing, and tracking components. Spare parts management is the strategic and operational process of identifying, sourcing, storing, and distributing spare parts to ensure uninterrupted equipment functionality. It involves cataloging parts, defining stock levels, classifying criticality, managing suppliers, and integrating with maintenance and procurement workflows. The process must balance availability with cost efficiency, using tools like CMMS, ERP systems, and data analysis to ensure parts are where and when they're needed — without overstocking or running short.

Key Components of Spare Parts Management

- Criticality Analysis: Prioritize parts based on equipment criticality (e.g., VED - Vital, Essential, Desirable) to ensure high-stakes items are always in stock.
- Inventory Segmentation: Categorize parts by usage frequency (fast/slow-moving) and cost (high/low) to apply appropriate stocking strategies.
- Optimal Stock Levels: Define minimum and maximum stock levels, using re-order points to automatically trigger procurement.
- Data Integrity (CMMS/EAM): Use computerized systems to maintain 95%+ inventory accuracy, ensuring that digital records match physical stock.
- Vendor Management**:** Establish reliable supplier partnerships and rapid supply agreements for critical or high-lead-time components

Strategies for Optimization

- Preventive Maintenance Alignment: Align spare parts inventory with PM schedules to ensure parts are available for scheduled work, reducing reactive, emergency orders.
- Standardization: Standardize parts across machinery to reduce the total variety of components stocked.
- Kitting: Assemble all required parts for specific maintenance jobs beforehand to improve efficiency.

5. Maintenance Strategy Skills

A vital skill for maintenance teams is the ability to nurture talent, fostering an environment of continuous learning and improvement. Prioritizing the long-term career development of team members contributes to a highly efficient, productive, and motivated maintenance workforce.
Effective maintenance strategies necessitate a combination of technical knowledge, data-informed decision-making, and strong leadership to enhance asset reliability while lowering costs. Essential competencies include strategic planning, optimizing preventive and predictive maintenance, conducting root cause analysis, and expertise in CMMS software, as outlined in the Maintenance Management document. Additionally, robust leadership and effective communication are crucial for promoting team efficiency and ensuring safety.

Regularly facilitating knowledge transfers allows team members to exchange information, ideas, and experiences. Organise work orders strategically so that seasoned team members can mentor those with less experience. Furthermore, having well-trained and capable maintenance team enables swift internal promotions when senior roles become available. It is also important to recognize potential maintenance leaders within the team by providing them with opportunities for advancement whenever possible.

- **Strategic Planning & Reliability Analysis:** Ability to shift from reactive to proactive maintenance, using methods like Total Productive Maintenance (TPM) or Reliability-Centered Maintenance (RCM) to optimize asset life.
- **Data Analysis & Technical Knowledge:** Using data from CMMS or condition monitoring to make informed decisions, analyze equipment history, and solve complex technical problems.
- **Planning & Scheduling:** Creating structured workflows, setting priorities for repairs, and managing resources (time, parts, labor) efficiently to reduce downtime.
- **Leadership & Change Management:** Mentoring, motivating teams, and leading, as detailed in this LinkedIn post on Maintenance Manager leadership, for building a strong safety culture and fostering adaptability to new technologies.
- **Root Cause Analysis (RCA):** Identifying the root cause of failures, rather than treating symptoms, to prevent reoccurrence.
- **Financial Acumen:** Balancing maintenance needs with budget constraints, understanding cost-benefit analyses for equipment repairs versus replacements.

The concluding phase of the strategic management process involves evaluation and control. This entails overseeing the execution of strategies, evaluating organizational performance, and making adjustments to those strategies as needed.

Conclusion

In summary, the significance of crafting an effective maintenance strategy and roadmap should not be underestimated in attaining sustainable results for both maintenance and production. By concentrating on key success factors and employing a systematic approach, organizations can efficiently plan, execute, and refine their strategies. An efficient maintenance strategy ensures daily productivity while also enhancing the long-term competitiveness of equipment operations. Additionally, the paper pointed out the limitations of current modelling techniques. The benefits of maintenance include extending the useful life of assets, reducing downtime due to unexpected failures and enhancing overall efficiency; however, maintenance challenges can arise when selecting the optimal strategy that aligns with an organization's goals. By using tools such as Artificial intelligence AI-powered predictive analytics and internet of things, it helps organisations reduce downtime, enhance decision-making, and maximize asset performance. An organization's asset management strategy should not remain static; it should evolve continuously based on new insights gleaned from monitoring processes or technological advances.

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