Ports bulk material handling equipment maintenance practices (trends and perspectives)

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Abstract

Guinea has established itself as a pivotal player in the global bauxite market, with a significant increase in ore export volumes over the last five years. This surge in demand is primarily influenced by the expanding production of electric vehicles and solar panels, both of which rely on bauxite for aluminium manufacturing. The escalating need for bauxite within China's aluminium sector has not gone unnoticed by Guinea. Since 2020, the volume of seaborne bauxite exports from Guinea has more than doubled, reaching 178 million tons by 2025, based on data from Ocean bolt information [1]. This swift growth in the bauxite trade has positively impacted dry bulk shipping, as vessels—primarily Capesizes undertake lengthy journeys from Guinea to China laden with bauxite [2]. The prolonged sailing durations, coupled with slow loading times, have notably contributed to the rise in freight rates. The maintenance management of ports bulk material handling equipment (MHE) is a challenge for ports managers as they must sustain the continuous operations with maintenance activities. An effective port material handling system is crucial for a nation's trade framework. Developing countries that seek to be self-sustaining and to be competitive in global mineral ore export markets must acknowledge the significance of well-operated ports. When key material handling equipment is constantly breaking down, spare parts are inaccessible, or the port's capacity fails to meet the timely needs of shipping operators, the cargo that passes through will inevitably incur higher costs and experience prolonged delays upon reaching its markets. Regardless of a port's size, substantial investments in mechanical equipment and infrastructure necessitate ongoing maintenance and protection.

This report examines the challenges that port operators, port authorities, and managers face in making equipment maintenance safe, reliable, and efficient. It also outlines practical maintenance strategies to improve the reliability of port material handling systems.

Keywords: material handling equipment (MHE), Guinea, Bauxite, Aluminium, maintenance, failure mode effects analysis (FMEA), root cause analysis (RCA), Predictive maintenance (PdM).

Introduction

There has been limited research conducted on port equipment, primarily because various ports handle different types of products and employ distinct machinery. In this paper, literature review and practical ports experience will be used to formulate a comprehensive maintenance strategy to improve the safety and the reliability of the port's bulk material handling equipment. Maintenance at the port should encompass a comprehensive approach from planning, scheduling, and execution that includes all activities essential for the effective organization, oversight, and finally to the documentation of all maintenance work performed

Ports use a mix of preventive, predictive, and corrective maintenance strategies to maximize equipment uptime, protect capital investments, and ensure safety. Because port material handling equipment (MHE) operates in harsh environments, operators increasingly rely on data-driven approaches rather than reactive, run-to-failure methods. Ports maintenance management process includes the regular maintenance of piers and docks includes checking for corrosion, cracks, or any physical damage that might jeopardize their ability to support large vessels. In this article, the author discusses the principles, architecture, and implementation of predictive maintenance for port equipment, the advantages of AI-based diagnostics, and the strategic roles of digital twins, virtual replicas of physical assets, and edge computing, which processes data near the source of generation.

This document will highlight the importance of heavy machinery and equipment in ports for the processes of loading, unloading, and transporting cargo. Maintaining this equipment effectively is crucial for the seamless and efficient management of goods, as it helps to decrease downtime and lower operational expenses. It is clear from the extensive experience of ports over the years that certain activities exhibit maintenance shortcomings. The purpose of this document is to assess and offer support for the overall strategies related to the maintenance of port material handling systems.

Literature review

Ports' material handling machinery—such as front-end loaders, barge loaders, feeders, conveyors, and lifting devices—constitutes the essential operational framework for transshipment activities, marine facilities, and transportation centres globally. However, in the absence of systematic maintenance protocols, even the most dependable equipment can be prone to unexpected malfunctions, safety issues, and compliance deficiencies that can hinder operations and increase expenses.

Predictive maintenance (PdM) is a methodology that employs data analysis tools and techniques to identify irregularities and foresee equipment malfunctions. This process is fueled by Artificial Intelligence (AI) and sophisticated sensor analytics, fundamentally changing how ports manage their essential assets [3]. The Internet of Things (IoT), which encompasses a network of connected devices that exchange sensor information, along with machine learning and extensive data analytics, facilitates real-time monitoring of the status of cranes, conveyors, and other port machinery. Predictive maintenance (PdM) is a methodology that employs data analysis tools and techniques to identify irregularities and foresee equipment malfunctions. This process is fuelled by Artificial Intelligence (AI) and sophisticated sensor analytics, fundamentally changing how ports manage their essential assets. The Internet of Things (IoT), which encompasses a network of connected devices that exchange sensor information, along with machine learning and extensive data analytics, facilitates real-time monitoring of the status of cranes, conveyors, and other port machinery [4][5].

The theory on automated material handling system demonstrates that predictive maintenance (PdM) utilizing AI, driven by precise sensor data from cranes, conveyors, dry-dock machinery, and port vehicles, greatly enhances equipment reliability and reduces total ownership costs. Models trained on multi-modal time series data—encompassing vibration, temperature, electrical metrics, hydraulic pressure, and operational logs—provided early warning indicators of mechanical deterioration that preceded noticeable failures. This led to the primary hypothesis that sensor information, augmented by machine learning techniques, can effectively forecast failure modes with actionable lead times [6][7]. Reduction of unexpected downtime and a decline in emergency repair expenses during pilot implementations align with findings from existing literature regarding ensemble and deep learning techniques for industrial predictive maintenance [8]. Importantly, the data indicates not just enhanced detection capabilities but also improved scheduling for maintenance, transitioning interventions from a predictive approach to a reactive one. This shift increases lifecycle advantages by prolonging component lifespan and reducing the reliance on spare parts [9].

<u>Basic ports material handling equipment</u>

Bauxite is a dense, abrasive bulk material that requires robust, high-capacity material handling equipment at ports. Facilities must seamlessly manage the continuous chain from truck unloading to storage and barge loading, minimizing dust, spillage, as shown in Figure 1 below,

Figure 1: Bon Ami Bauxite Handling Port, Guinea (Source : [10])

Equipment includes:

Apron & Belt Feeders: Heavy-duty feeders that regulate the flow of raw ore out of hoppers onto the main conveyor systems

Long-Distance Overland & Jetty Conveyors: High-capacity, wide belt systems designed to move thousands of tons per hour from the receiving area to the port stockpile.

Dozer Traps: Bulldozers push bauxite into specialized hoppers that feed the jetty conveyors, acting as an alternative or backup to automated reclaimers

Ship loaders: Articulated, luffing, and shuttling boom conveyors placed on the jetty. They pour bauxite directly into the holds, Panamax, or Capesize bulk carriers.

Hydraulic Material Handlers: Front loaders equipped with large buckets transfer bauxite directly into dozer traps

Automation & Control: manage these high-capacity, multi-stage processes safely and efficiently, ports utilize advanced automation. Electronic instrumentation provides automation systems like Siemens S7 PLC and Profibus communication linked to control room to monitor and control equipment, manage alarms, and integrate electrical systems seamlessly across bulk terminals

Maintenance methodologies

Selecting a competitive strategy is a process grounded in analysis rather than mere speculation. It requires a thorough examination of the surrounding environment, the organization's capabilities, and its objectives. According to Porter's Generic Strategy framework, companies can achieve above-average profits by either minimizing costs or providing distinctive features. By integrating these two advantages with the range of activities—whether targeting a broad or narrow market—three fundamental strategies emerge: cost leadership, differentiation, and focus [11]. Maintenance strategies are a critical aspect of asset management, by which companies attempt to manage everything contributing to their operations and the production of their goods. A strong effective maintenance strategy tools encompass software applications, hardware components, and methodologies aimed at enhancing equipment reliability, decreasing downtime, and lowering expenses. The subsequent tools implement the fundamental approaches of Reactive, Preventive, Predictive, and Reliability-Centered Maintenance (RCM) as shown in table 1 below. This table provides a clear overview of the different approaches and helps to select the right strategy depending on company requirements and capacities.

Table 1: Maintenance strategy overview (Source:[12])

Strategy type	Definition of	Advantages	Disadvantages
Reactive maintenance(Breakdown Maintenance)	Reaction to failures when they occur.	Low initial costs.	Higher long-term costs, risk of downtime.
Preventive maintenance	Scheduled maintenance based on predefined intervals.	Prevents unplanned breakdowns, longer service life.	Potential over-maintenance, unnecessary costs.
Predictive maintenance	Use of real-time data to predict failures.	Optimal use of the systems, cost reduction.	Higher initial investment, requires data analysis.
Condition-based maintenance	Use of sensors for continuous condition monitoring.	Maintenance only when required, efficient use of resources.	Complexity in data interpretation, initial costs.

<u>Material handling equipment daily pre and post inspections</u>

Daily pre- and post-shift inspections of port material handling equipment (MHE)—like loaders, conveyor belt system, barge loader, dozer traps, drive gear boxes and transfer towers —are crucial for regulatory compliance, preventing costly breakdowns, and ensuring workplace safety. These quick, standardized walk-arounds and functional tests help identify mechanical faults before they lead to severe accidents.

Table 2: Ports conveyor belt system inspection checklist (Source:[10])

Inspector Name: **Inventory#:**
Meter Reading:
Model/Year:

Belt conveyors Inspection and Maintenance Checklist

Task Description	Pass	Fail	NA	Comments
Installation and Commissioning				
- Verify proper installation of conveyor components				
- Check for proper alignment and tensioning of the belt				
- Test and calibrate controls and safety devices				
- Ensure proper lubrication of moving parts				
- Document installation details and commissioning results				
Routine Maintenance (Daily/Weekly)				
- Visually inspect the conveyor belt for wear, damage, or tracking issues				
- Check for any unusual noise or vibration during operation				
- Clean the conveyor belt and surrounding area				
- Ensure proper functioning of safety devices and emergency stops				
- Document all maintenance tasks performed				
Periodic Maintenance (Monthly/Quarterly)				
- Perform a thorough inspection of the entire conveyor system				
- Check and adjust belt alignment and tensioning as needed				
- Lubricate bearings, pulleys, and other moving parts				
- Inspect and replace worn or damaged rollers, idlers, and pulleys				
- Check and tighten all fasteners and hardware				
- Test and calibrate sensors, switches, and control devices				
- Document all maintenance tasks performed				
Annual Maintenance				
- Perform all periodic maintenance tasks				
- Conduct a detailed inspection of the conveyor structure and supports				
- Check and replace worn or damaged belting as needed				
- Inspect and service the drive system, including motors, gearboxes, and couplings				

As with any significant physical asset, it is essential to conduct routine maintenance on conveyors. It is suggested that implementing a computerised maintenance management system to guarantee that all preventive maintenance tasks are executed timely and meet the necessary standards. These checklists must be used as a foundation for development. When establishing a preventive maintenance strategy for the conveyor systems, consider factors such as age, condition, and operating environment. This approach facilitates planning and scheduling of regular work, maintaining an appropriate inventory of spare conveyor components, consolidating all maintenance records in one easily accessible location, among other benefits.

Barge loader/Stacker maintenance strategy

A barge loader like the Telestack TB/TS 58 is a heavy-duty mobile telescopic conveyor heavily utilized in port and terminal operations as shown in the diagram below (Figure 2). Its maintenance strategy must combine Preventive (PM), Predictive (PdM), and Corrective measures to handle abrasive bulk materials and prevent catastrophic downtime during critical vessel-loading windows.

Figure 2: Barge loader/Tele stacker (Source [13])

A structured maintenance framework for this equipment incorporates the following critical elements:

1. Preventive Maintenance (PM)

PM focuses on routine, scheduled checks to ensure continuous reliability.

- Daily / Pre-Shift: Visual inspections of conveyor belts for fraying, check engine oil and fuel levels, inspect hydraulic/pneumatic lines for leaks, and verify the safety of emergency rope-brake systems.
- Weekly / 50-Hour: Clean material spillage around the feed-in point and tail end. Grease all bearings (head, tail, and telescopic boom pulleys).
- Monthly / 250-Hour: Inspect and adjust the tension of the telescopic boom wire ropes and winches. Check scraper and skirting rubber wear, and test tracking/steering mechanisms

2. Predictive Maintenance (PdM)

This approach utilizes sensor data and non-destructive testing to anticipate failures before they occur. [1]

- Condition Monitoring: Utilize infrared thermography on electrical panels and drive motors to detect abnormal heat buildup before an electrical failure.
- Oil & Grease Analysis: Sample hydraulic oil to monitor viscosity, detect contaminants (like water from port environments or metal wear particles), and prevent hydraulic pump failure.

- Ultrasonic Thickness Testing: Routinely gauge the wear of impact plates, hardened steel liners, and transfer chutes to plan replacements during scheduled maintenance windows.

3. Structural & Mechanical Strategy

- Wire Rope & Winch Health: Because the TB58 relies on a heavy-duty wire rope and winch system to extend and retract the telescopic boom, rope degradation is a major safety and operational risk. Regular visual inspections and scheduled replacements are non-negotiable.
- Conveyor Belt Tracking: Uneven loading of abrasive materials (such as woodchips, coal, or aggregates) can cause belt misalignment, which quickly damages the belt edges. Daily visual checks and proper tensioning are required.
- Dust Suppression & Containment: Inspect and replace integrated dust extraction components (if equipped), rubber dust flaps, and seals at transfer points to maintain environmental compliance and prevent dust from infiltrating moving parts

Dozer trap and mobile loading equipment

Figure 3: Front end loader feeding dozer trap (Source:[10])

A dozer trap converts accumulated material into a consistent supply using front-end loaders or trucks. It operates by pushing material directly into the hopper/grizzle, which then transfers it onto a feeder, ensuring the plant runs efficiently with fewer operators while continuously supplying the main belt that feeds into the barge loader. It is best to empty out the feeder at the end of the day. However, during operation, it is a good practice to leave a little material in the pan between dumps. In this way, the next load of dumped material will land on stone – not the pan. This cushions the impact and reduces wear.

End of shift/daily maintenance plan:

Prevent reduced scalping capability and damage to the grizzly bar section, by inspecting the grizzly bars daily for any stone that is wedged between the bars.

Liners are proven to deliver a healthy payback in reduced maintenance costs. Feeder pans are typically lined with abrasion-resistant steel that are either welded or bolted in place. As the liner wears thin, it may buckle or warp, indicating it is time to replace the liner.

Clear out the bars after every shift. Also, grizzly bar caps should be repaired or completely replaced if sufficiently worn. Worn or bent bars are far more likely to have material hang up creating a daily problem.

Lastly, while breaker hammers are commonly used at the primary, avoid breaking stone on the grizzly bar section as hammering can cause damage to the bars and the bar support.

Weekly maintenance plan:

To minimise spring breakage, remove any stone or dust build-up appearing around the base of the spring. Material can wear or scratch the spring, creating a stress point that may ultimately lead to cracking and failure

Commonly used with a grizzly feeder, variable speed drives maximise production and handle wide variances of feed. It is strongly recommended that a limit be set on the drive so that it cannot exceed the feeders maximum rated speed

Monthly maintenance plan:

Inspect the liners monthly and replace them as needed. In extremely abrasive or sticky applications, specially formulated rubber liners, as well as rubber-capped grizzly bars may be used. These liners are heavier and thicker than steel liners, impacting the live weight and requiring more depth in the pan. Allowance for these types of liners should be incorporated into the feeder design and discussed at the time the feeder is purchased.

Mobile equipment maintenance plan

A front-end loader is a robust and adaptable earthmoving vehicle equipped with a broad bucket positioned at the front, supported by two hydraulic arms. Its main functions include the scooping, lifting, transporting, and dumping of loose materials such as mineral ore and debris. The bathtub curve illustrates the failure rate of a system over time, offering a data-centric approach to foresee potential issues prior to their emergence. By analysing an front end loader position on this curve, ports maintenance teams can forecast upcoming performance, enhance maintenance planning, and confidently decide whether to repair or replace equipment.

This article delves into the mechanics of the machine bathtub curve, clarifying the significance of each phase for loader maintenance strategies and demonstrating how to leverage this information for informed decision-making that enhances asset longevity, minimizes downtime, and manages expenses effectively.

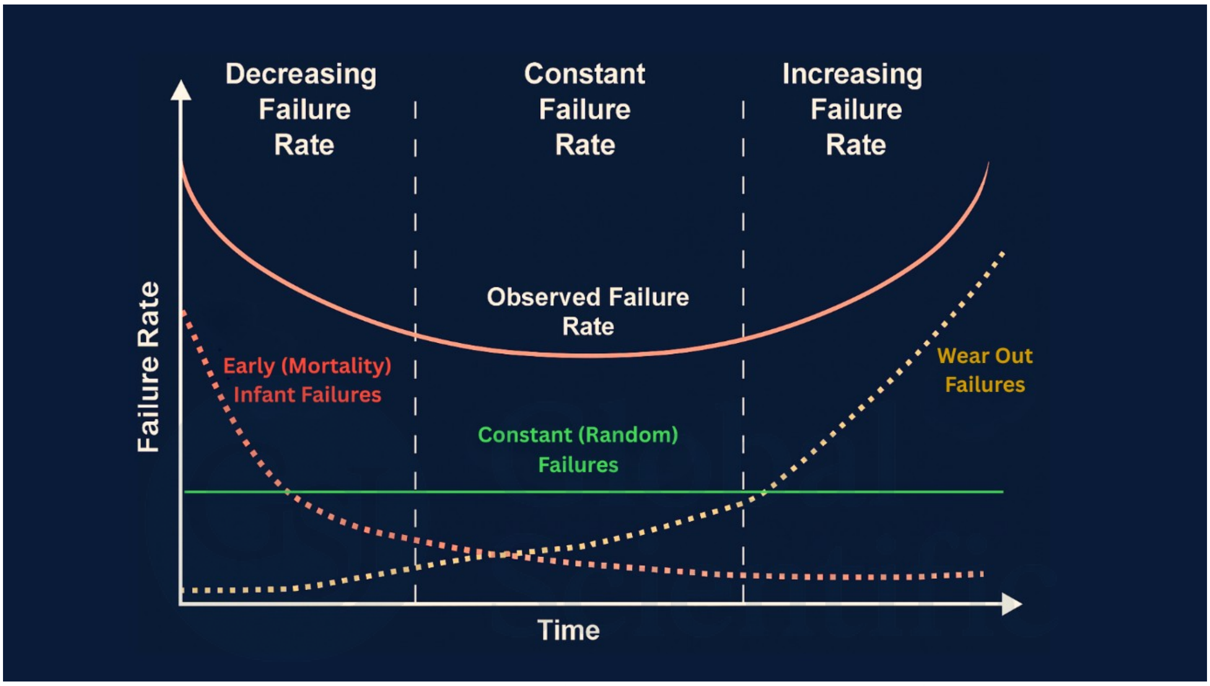

Figure 4: Bathtub analysis curve (Source: [13])

Determining a machine's phase involves reviewing its age, failure history, and performance trends. The organisation can use tools such as historical failure logs, trend analysis, condition monitoring, and diagnostic reports to help reveal whether the loader is in the early, stable, or wear-out stage of its lifecycle.

Phase-Based loader maintenance guideline

In Phase 1 (infant mortality), repair is usually best unless the defect is systemic.

In Phase 2 (everyday life), repairs remain optimal as long as maintenance costs are proportional to performance.

In Phase 3 (wear-out), replacement becomes more cost-effective as failure frequency rises.

Before starting the loader, conduct a thorough wheel loader maintenance check. A walkaround inspection before starting will help determine if there are any damaged, loose, or worn parts, fluid leaks, or other problems.

The loader planned maintenance system uses a four-tier structure as shown in table — PM1 through PM4 — based on engine operating hours: 250, 500, 1,000, and 2,000 hours. Each tier is cumulative: PM2 includes everything from PM1 plus additional tasks, PM3 includes PM1 + PM2 plus deeper service, and PM4 is the most comprehensive. The exact contents depend on your machine model and engine configuration, but the tier structure applies to every wheel loader, dozer and motor grader in production.

Table 3: Loader maintenance schedule (Source:[13])

Service Task	PM1 (250hr)	PM2 (500hr)	PM3 (1,000hr)	PM4 (2,000hr)
Engine oil and filter	Change	Change	Change	Change
Grease – bucket, Z-bar, steering, axle pivots	All points	All points	All points	All points
Fuel filter / water separator	Drain	Replace	Replace	Replace
Air filter primary element	Check	Check	Clean/Replace	Replace
Hydraulic return filter	–	Replace	Replace	Replace
Hydraulic oil sample / change	–	–	Sample	Change
Transmission oil and filter	Level check	Filter replace	Sample + filter	Change all
Axle oil (front and rear)	Level check	Level check	Sample	Change
Differential oil	–	–	Check	Change
Tire condition / inflation	Check	Check	Check	Check
Brake system inspection	Function test	Inspect pads	Measure	Comprehensive
Articulation joint / steering pins	Grease	Grease + check	Measure play	Replace if worn
Coolant test / flush	Level check	Test SCA	Test SCA	Flush/Replace

Conveyor belt electrical maintenance

A conveyor belt safety and monitoring system is an integrated network of sensors, cameras, and software designed to protect workers and prevent catastrophic equipment failure. It tracks structural health, operational anomalies (misalignment, slippage), and surface damage, initiating automatic shutdowns when hazardous conditions arise.

These electro-mechanical and digital tools are primarily responsible for preventing workplace injuries and stopping the belt in emergencies:

1. Pull Cord Switches: Emergency stop cables running the entire length of the conveyor. Workers can pull the cable to immediately halt the belt if an accident occurs.
2. Belt Misalignment Switches: Sensors placed on the sides of the belt that trip an alarm or shut down the motor if the belt drifts too far off-centre, preventing spills and equipment damage.
3. Belt Rip Detection Systems: Contact wires or inductive sensors placed under the belt. If the belt rips or tears, the wire pulls free, triggering an immediate emergency stop.
4. Overspeed / Under speed Switches: Monitors designed to detect if the belt is moving too fast or suffering from slippage (running too slowly), which can cause fires or severe friction damage.

Condition Monitoring Systems (Predictive Maintenance)

These act as a digital watchdog, constantly assessing the "health" of the belt to prevent surprise breakdowns and costly production halts: [

1. Machine Vision & AI: Uses high-definition cameras and deep-learning algorithms to detect surface cracks, splice deterioration, and carry-back (stuck material) in real-time.
2. Belt Thickness Monitoring (BTM): Uses ultrasonic waves or RFID tags to track rubber wear down to the millimeter, predicting exactly when a belt needs replacement.
3. Steel Cord Monitoring (SCM): Uses X-ray, dynamic radiography, or magnetic sensors to peer inside the rubber and detect internal steel cord corrosion or breaks.
4. Laser Scanning: Scans the surface of the belt continually to look for volume anomalies and tears while the system is running.

Modern systems integrate these safety and health monitors with Programmable Logic Controllers (PLCs) and cloud-based IoT gateways to give control room operators a total picture of the line.

Conclusion

The study of ports equipment failure affect operations in bulk dry material handling terminals is particularly noteworthy because of its considerable economic consequences. Maintaining a port involves various intricate tasks that demand meticulous attention, strategic planning, and efficient resource utilization. Porter's generic strategies is a powerful tool for strategic planning, but they are not rigid formulas. Cost leadership works when you can produce efficiently and maintain quality. The responsibilities range from infrastructure maintenance and machinery servicing to managing environmental concerns, adhering to safety regulations, and overseeing financial operations. This multifaceted process is essential for the seamless functioning and long-term viability of a port. Given that ports serve as crucial centres for international trade, their upkeep has significant implications for the economy, the environment, and the safety of all parties involved.

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