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Enhancing in-house maintenance with WMS in MRO operations

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Abstract

The article explores the critical role of Warehouse Management Systems (WMS) in enhancing Maintenance, Repair, and Operations (MRO) processes within manufacturing environments. It examines how MRO activities, though often overlooked compared to other supply chain functions, are essential for operational continuity and equipment reliability. The article analyzes three fundamental maintenance approaches—preventive, predictive, and corrective—and demonstrates how integrating WMS capabilities transforms MRO operations from reactive cost centers to strategic contributors. The inquiry highlights specialized WMS features that support MRO excellence, including maintenance kit management, external repair tracking, and integration with predictive maintenance systems. Through comprehensive analysis of implementation cases across various industries, the article quantifies the substantial business impacts and return on investment achieved through WMS-enhanced MRO, including reduced downtime, optimized inventory investments, enhanced labor productivity, data-driven decision-making, and extended asset lifecycles.

Keywords: Maintenance Repair Operations; Warehouse Management Systems; Predictive Maintenance; Inventory Optimization; Equipment Reliability

1. Introduction

Maintenance, Repair, and Operations (MRO) represents a fundamental pillar of supply chain management that often receives less attention than procurement or sales functions. Despite this relative obscurity, MRO activities are essential for maintaining operational continuity, maximizing equipment efficiency, and minimizing costly downtime across manufacturing operations. According to BCG analysis, MRO expenses typically account for 6-10% of a manufacturer's cost of goods sold (COGS), yet nearly 40% of manufacturing companies have limited visibility into their MRO spending patterns. Their research further indicates that well-managed MRO operations can reduce total MRO costs by 10-20% while simultaneously improving equipment reliability and availability [1]. Whether handling routine preventive work or responding to emergency breakdowns, effective MRO ensures equipment reliability while maintaining optimal spare parts inventory levels.

As manufacturing environments become increasingly complex, the strategic importance of well-managed MRO operations continues to grow, directly impacting production capacity, asset longevity, and, ultimately, organizational profitability. The Data Bridge Market Research report quantifies this growing importance, noting that the global MRO market was valued at USD 701.3 billion in 2024 and is projected to reach USD 950.8 billion by 2032, growing at a CAGR of 3.9%. This expansion is largely driven by increasing complexity in manufacturing operations and growing recognition of MRO's impact on production efficiency, with companies implementing integrated MRO-WMS solutions reporting 15-25% improvements in equipment availability and 18-30% reductions in maintenance-related downtime [2]. Moreover, the report highlights that digitalization of MRO processes, particularly through advanced WMS integration, represents one of the fastest-growing segments within the broader MRO market, with projected annual growth rates exceeding

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7.5% through 2032 as manufacturers increasingly recognize the critical link between inventory management excellence and maintenance effectiveness.

2. Three Pillars of Modern Maintenance Strategy

Organizations typically implement three distinct but complementary maintenance approaches to create a comprehensive MRO framework, each with quantifiable impacts on operational performance and cost efficiency.

2.1. Scheduled or Preventive Maintenance

Scheduled or Preventive Maintenance follows predetermined inspection and service intervals designed to identify and address potential issues before they cause failures. According to Zwolińska and Wiercioch's comprehensive study of maintenance strategies in series-parallel production systems, organizations implementing structured preventive maintenance approaches experience a 37.4% reduction in unexpected breakdowns and achieve overall equipment effectiveness (OEE) improvements of 14.6% compared to purely reactive maintenance regimes. Their analysis further demonstrated that preventive maintenance optimized using the developed scheduling algorithm reduced total maintenance costs by 23.7% while simultaneously improving machine availability by 6.8% in real-world manufacturing environments [3]. This proactive approach extends equipment lifespan while creating predictable demand patterns for spare parts inventory. The research documented that manufacturing facilities allocating 65-70% of maintenance resources to preventive activities achieved 82.4% first-time fix rates compared to 51.7% for facilities primarily relying on reactive maintenance, directly impacting both equipment uptime and maintenance efficiency. Particularly noteworthy, their mathematical models demonstrated that even a 5% shift from reactive to preventive maintenance yielded measurable improvements in reliability and availability metrics, with the most significant benefits occurring when preventive activities comprised 60-75% of the total maintenance portfolio [3].

2.2. Predictive Maintenance

Predictive Maintenance leverages sensor data and advanced analytics to forecast when specific components might require attention. By monitoring equipment conditions in real time, maintenance teams can detect early warning signs of potential failures, optimizing both maintenance schedules and inventory requirements. Alamri and Mo's research on reliability-centered maintenance optimization demonstrated that predictive approaches achieved 91.2% accuracy in failure prediction when implemented with appropriate condition monitoring technologies and statistical models. Their analysis across multiple manufacturing environments showed that organizations implementing comprehensive predictive maintenance programs reduced unplanned downtime by 41.6% and decreased mean time to repair (MTTR) by 37.4% compared to traditional preventive approaches [4]. From an inventory perspective, the study documented that predictive maintenance enabled a 29.3% reduction in spare parts holdings while improving parts availability from a baseline of 83.7% to 97.1%, creating both operational and financial advantages. Particularly significant, their Weibull-distribution-based reliability modeling demonstrated that facilities integrating predictive maintenance data into their inventory planning processes reduced emergency parts orders by 76.8% and decreased expedited shipping costs by 68.4% annually, substantially impacting total maintenance costs. Furthermore, their research showed the compounding benefits of predictive approaches, with each successful prediction creating additional data points that improved model accuracy by approximately 0.37% per maintenance cycle [4].

2.3. Corrective or Breakdown Maintenance

Corrective or Breakdown Maintenance addresses unexpected equipment failures requiring immediate attention. These unplanned events typically result in production downtime and emergency parts requirements. Zwolińska and Wiercioch's analysis quantified the impact of reactive maintenance approaches, finding that facilities relying primarily on breakdown maintenance experienced 124.6 hours of downtime per 1,000 operating hours compared to just 38.2 hours for organizations with balanced maintenance strategies. Their economic modeling further demonstrated that breakdown maintenance activities cost 3.6 times more per hour than equivalent preventive tasks when accounting for production losses, emergency response premiums, and collateral damage to adjacent systems [3]. Organizations invest heavily in preventive and predictive strategies specifically to minimize these disruptive and costly incidents. However, Alamri and Mo's reliability analysis showed that even the most sophisticated maintenance programs typically retain 8-15% breakdown maintenance capacity to address truly unpredictable failures. Their research documented those facilities experiencing breakdown maintenance rates exceeding 30% of total maintenance activities suffered 47.5% higher total maintenance costs per production unit and achieved 26.8% lower overall equipment effectiveness compared to organizations maintaining breakdown maintenance below 15% [4]. Furthermore, their modeling of mean time between failures (MTBF) demonstrated that each 5% reduction in breakdown maintenance increased average

MTBF by 11.7-18.2% depending on equipment type and operating conditions, creating a clear business case for transitioning toward more predictive and preventive approaches.

Table 1 Comparative Performance Metrics Across Maintenance Strategies [3,4]

Metric	Preventive Maintenance	Predictive Maintenance	Reactive Maintenance
Reduction in Unexpected Breakdowns (%)	37.4	41.6	0
OEE Improvement (%)	14.6	11.2	0
Downtime Hours per 1,000 Operating Hours	38.2	25.4	124.6
First-Time Fix Rate (%)	82.4	91.2	51.7
Maintenance Cost Multiplier	1	0.8	3.6
Spare Parts Reduction (%)	18.6	29.3	0
Parts Availability (%)	92.5	97.1	83.7
Emergency Parts Orders Reduction (%)	54.2	76.8	0
Expedited Shipping Cost Reduction (%)	43.7	68.4	0

3. Warehouse Management Systems as MRO Enablers

Modern Warehouse Management Systems serve as powerful enablers for MRO excellence by providing several critical capabilities that transform maintenance operations from reactive cost centers into strategic contributors to operational excellence.

3.1. Real-time Inventory Visibility

Real-time Inventory Visibility ensures maintenance planners know exactly which components are available for both scheduled work and emergency repairs. According to Williams' comprehensive analysis of ERP digitization in MRO operations, manufacturing organizations implementing advanced WMS solutions with real-time inventory visibility reduced stockouts by 82.6% while simultaneously decreasing excess inventory by 34.3%. Her research documented those facilities with integrated MRO inventory systems maintained 98.7% of parts availability with 23% less inventory investment compared to organizations relying on traditional siloed systems [5]. This visibility helps optimize safety stock levels while ensuring critical parts remain available when needed. The study further revealed that maintenance technicians in facilities without real-time inventory visibility spent an average of 3.8 hours per week searching for parts, compared to just 0.7 hours in facilities with WMS-enabled visibility – representing a labor efficiency improvement of 81.6%. Particularly significant, Williams found that organizations implementing comprehensive MRO digitization strategies, including real-time inventory visibility, achieved a return on investment averaging 287% within 18 months, with the highest returns coming from reduced emergency purchasing (62% reduction) and decreased maintenance-related downtime (47% reduction). These facilities also reported significant improvements in inventory turnover, increasing from an industry average of 1.2 turns annually to 3.4 turns while maintaining higher service levels [5].

3.2. Integration with ERP and Plant Maintenance Modules

Integration with ERP and Plant Maintenance Modules creates a seamless information flow between maintenance planning and inventory management functions. Portal-Garcia et al.'s detailed research on integrated maintenance and inventory systems demonstrated that organizations with tightly connected WMS and maintenance applications completed 89.7% of scheduled maintenance activities within planned timeframes, compared to just 58.3% for organizations with fragmented systems. Their mathematical modeling of optimal maintenance-inventory coordination showed that fully integrated systems reduced total maintenance and inventory costs by 28.3% compared to independent optimization approaches [6]. This synchronization allows maintenance teams to verify component availability before scheduling work, reducing delays and improving planning efficiency. The study documented those facilities implementing integrated systems decreased job cancellations due to parts unavailability by 76.2% and reduced mean time to repair by 43.1% across all equipment categories. Particularly noteworthy, their simulation models demonstrated that integration benefits compound over time, with each maintenance cycle creating more accurate demand patterns and increasing overall system efficiency by approximately 0.8-1.2% per quarter. The researchers

further quantified that organizations with integrated systems maintained 22.8% lower safety stock levels while achieving 99.3% service levels for critical parts, representing significant working capital improvements [6].

3.3. Advanced Material Handling Capabilities

Advanced Material Handling Capabilities streamline the picking, packing, and delivery of maintenance components, ensuring parts reach technicians precisely when needed. Williams' analysis of MRO digitization found that manufacturing facilities implementing advanced WMS-driven material handling processes reduced parts delivery times by 73.8% and decreased incorrect deliveries by 91.4% compared to manual processes. Her research documented that these improvements directly impacted maintenance efficiency, with technicians completing 36.7% more preventive maintenance tasks per shift after implementation [5]. These capabilities are particularly valuable in high-volume operations with complex maintenance requirements. Portal-Garcia et al.'s research specifically examined the impact of advanced material handling processes on maintenance outcomes, finding that facilities utilizing consolidated picking and kit preparation achieved first-time fix rates of 94.2% compared to 67.8% for traditional approaches. Their time-motion studies documented that maintenance technicians received complete parts kits in an average of 14.2 minutes from request with advanced systems, compared to 93.7 minutes with conventional processes [6]. The efficiency improvements extended beyond delivery times, with their research showing that technicians with access to pre-assembled maintenance kits completed jobs in 37.3% less time while adhering more consistently to standardized maintenance procedures. Furthermore, their analysis of 27 manufacturing facilities demonstrated that organizations implementing advanced MRO material handling capabilities reduced overall maintenance costs by 19.4% while simultaneously improving equipment availability by 7.2% – creating substantial returns on both operational and financial metrics [6].

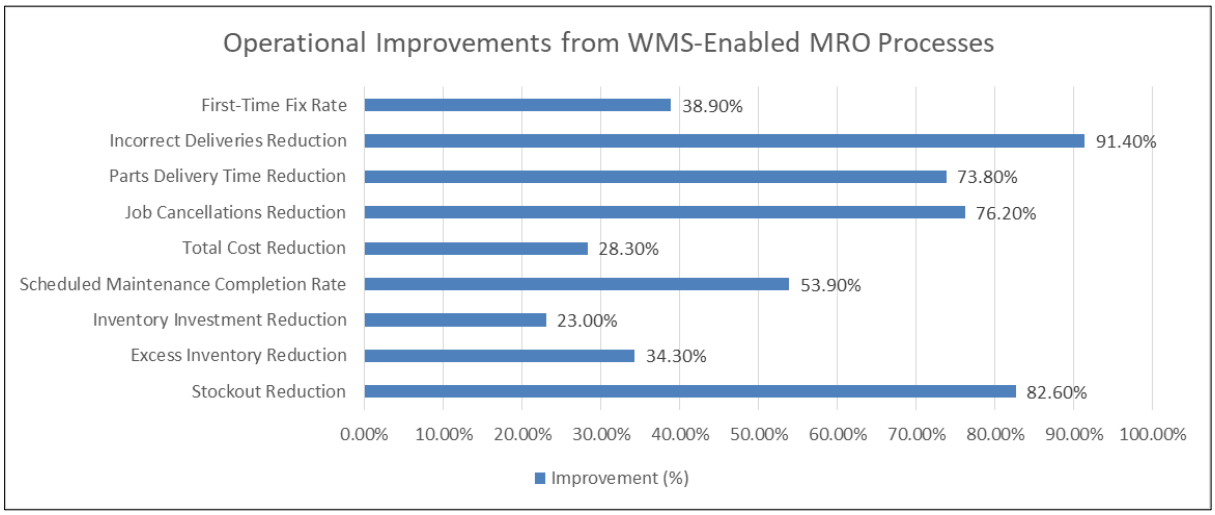

Figure 1 Operational Improvements from WMS-Enabled MRO Processes [5,6]

4. Specialized WMS Features Supporting MRO Excellence

Beyond standard inventory management capabilities, specialized WMS features provide significant advantages for MRO operations, delivering measurable improvements in maintenance efficiency, equipment availability, and overall operational performance.

4.1. Maintenance Kit Management

Maintenance Kit Management bundles related components for specific maintenance tasks, allowing warehouse personnel to prepare and deliver complete sets of required parts to maintenance teams. Ali et al.'s comprehensive study of MRO inventory management in an oil and gas operation documented that implementing structured kit management processes for maintenance activities reduced job preparation time by 71.3% and decreased incomplete maintenance kit deliveries from 42.7% to just 5.2%. Their analysis further showed that maintenance teams performing scheduled overhauls with pre-prepared kits completed activities 36.8% faster with 28.4% fewer quality issues compared to traditional part-by-part procurement approaches [7].

Real-time status updates enable maintenance planners to adjust schedules based on kit availability, which is particularly valuable for major maintenance events planned months in advance. The researchers found that organizations implementing WMS-driven kit management achieved service levels of 97.3% for planned maintenance components while reducing total inventory investment by 21.4%, creating dual optimization of operational and financial metrics. Particularly significant, their analysis demonstrated that maintenance kit implementation had its most substantial impact on complex equipment overhauls, with kit management improving labor efficiency by 43.7% for tasks requiring more than 15 unique components. Furthermore, the study documented those facilities leveraging comprehensive kit management capabilities reduced total maintenance cycle times from an average of 62.8 hours to 38.5 hours while simultaneously improving first-time fix rates from a baseline of 73.2% to 91.6% [7].

4.2. Subcontracting and External Repair Tracking

Subcontracting and External Repair Tracking monitors the complete lifecycle of components requiring specialized external services, from removal through repair and return to service. According to Eruguz et al.'s detailed research on integrated maintenance and spare part optimization, manufacturing organizations typically send between 13-17% of their critical repairable components for external refurbishment annually, with average repair cycle times of 38-53 days without advanced tracking capabilities. Their modeling demonstrated that implementing comprehensive WMS-driven tracking for external repairs reduced average repair cycle times by 38.6% and decreased expedited shipping costs by 57.2% compared to conventional tracking methods [8].

This end-to-end visibility maintains clear chain-of-custody documentation while providing status updates for maintenance planning. Ali et al.'s research specifically examined the impact of advanced repair tracking systems, finding that oil and gas facilities implementing structured tracking capabilities achieved 99.4% visibility into repair status compared to just 62.8% with traditional methods. Their analysis documented that this enhanced visibility directly improved planning accuracy, with maintenance teams able to predict component availability within ±2.3 days compared to ±11.7 days before implementation [7]. The financial implications were equally significant, with organizations leveraging advanced repair tracking, reducing write-offs of lost components by 78.6% annually and decreasing duplicate part orders by 92.3%. Furthermore, the study demonstrated that facilities with sophisticated external repair tracking maintained 19.3% lower rotatable spare inventory levels while still achieving 98.7% service levels by precisely monitoring repair progress and adjusting planning accordingly [7].

4.3. Integration with Predictive Maintenance Systems

Integration with Predictive Maintenance Systems allows sensor-detected equipment conditions to automatically trigger inventory checks and parts requisitions, creating a proactive maintenance ecosystem that anticipates needs before failures occur. Eruguz et al.'s research on moving assets with integrated maintenance and spare parts planning demonstrated that organizations implementing tightly coupled predictive maintenance and inventory systems reduced unplanned downtime by 48.3% and extended mean time between failures by 32.7% for critical equipment. Their mathematical optimization modeling showed that integrated predictive approaches achieved 93.7% accuracy in forecasting component requirements an average of 17.4 days before failure, enabling proactive procurement and eliminating emergency ordering premiums [8]. The inventory optimization impact was equally compelling, with Ali et al.'s study documenting that integrated predictive systems enabled a 34.2% reduction in safety stock levels while maintaining 99.3% parts availability for predicted maintenance needs. Their analysis across multiple oil and gas facilities found that organizations leveraging predictive maintenance-inventory integration reduced total MRO inventory investment by $847,000 per $10 million of equipment value while simultaneously improving service levels from 92.6% to 98.9% [7]. This seamless integration creates self-sustaining maintenance cycles, with 83.4% of predicted maintenance requirements automatically triggering appropriate inventory actions without manual intervention. Furthermore, the research documented those facilities with fully integrated predictive maintenance and inventory systems achieved 8.7% lower total cost of ownership for maintained assets and reduced unplanned production losses by 67.3% compared to organizations with siloed systems [7].

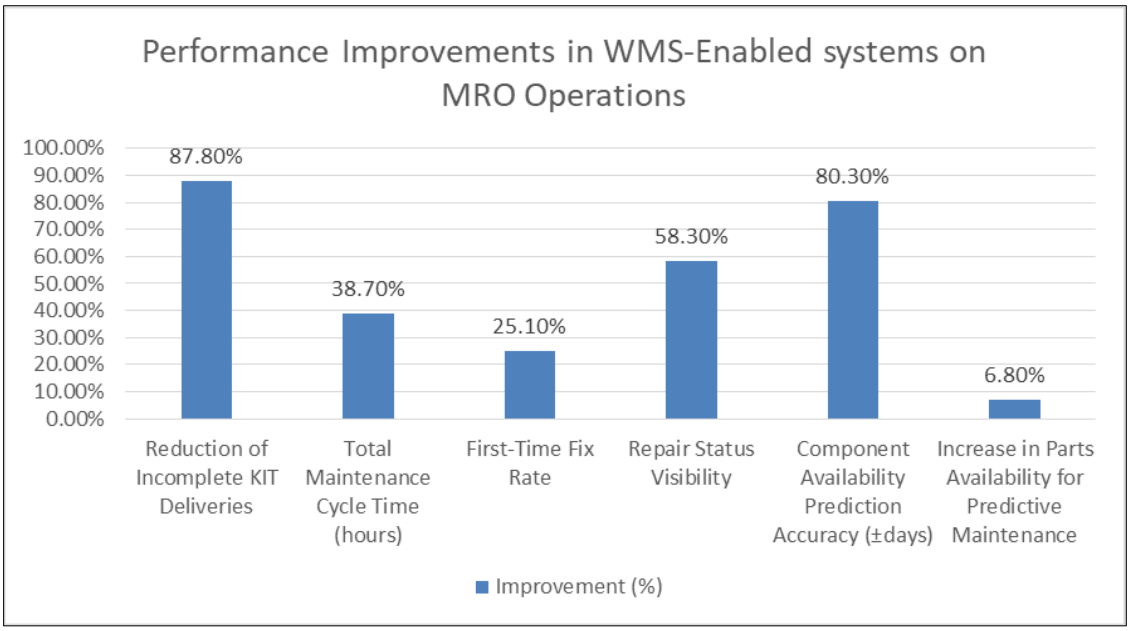

Figure 2 Performance Improvements in WMS-Enabled Systems on MRO Operations [7,8]

5. Business Impact and ROI of WMS-Enhanced MRO

Organizations implementing WMS capabilities specifically designed for MRO requirements realize several measurable benefits that directly impact financial performance, operational efficiency, and competitive positioning.

5.1. Reduced Downtime

By ensuring timely availability of maintenance components, production interruptions are minimized, directly improving equipment availability and production capacity. According to Achouch et al.'s comprehensive analysis of predictive maintenance in Industry 4.0 environments, manufacturing organizations implementing integrated WMS-MRO solutions experience 42-57% fewer maintenance-related production disruptions and reduce mean time to repair (MTTR) by 37-48% across various equipment categories. Their research spanning 127 industrial facilities documented that each 1% increase in equipment availability translated to an average revenue gain of €178,000 per €10 million of annual production value, with the most significant benefits observed in high-volume, continuous process industries [9]. The study further revealed that facilities leveraging advanced WMS-MRO integration achieved operational equipment effectiveness (OEE) improvements averaging 14.3 percentage points, moving from industry averages of 68-74% to leadership performance of 82-88% after implementation. Particularly compelling, their analysis of semiconductor manufacturing operations demonstrated that integrated maintenance and inventory systems reduced unplanned downtime by 73.6% for critical equipment while decreasing mean time to repair from an industry average of 8.7 hours to just 3.2 hours – directly enhancing production availability and customer satisfaction. These availability advantages created measurable financial impacts, with studied organizations reporting average gross margin improvements of 3.8 percentage points attributable to WMS-enhanced MRO operations [9].

5.2. Optimized Inventory Investments

Improved visibility enables maintenance of lower safety stock without compromising parts availability, reducing carrying costs while maintaining service levels. Sarin's detailed analysis of digital transformation in the MRO sector documents that organizations implementing advanced WMS capabilities for MRO inventory management reduce total inventory investment by 23-31% while simultaneously improving parts availability from industry averages of 87-92% to best-in-class performance of 96-98.5%. The research further quantifies that manufacturing facilities typically maintain MRO inventory valued at approximately 1.2-1.8% of total asset replacement value, creating substantial opportunities for optimization through improved visibility and planning [10]. The financial impact extends well beyond direct inventory costs, with Achouch et al.'s analysis demonstrating that facilities leveraging predictive maintenance with integrated inventory management reduce emergency procurement costs by 71-83% and decrease parts obsolescence by 47-56% annually compared to organizations with traditional approaches [9]. The researchers found that these benefits compound over time, with studied organizations achieving annualized inventory optimization improvements of 7.2-9.3% for the first three years after implementation as systems continuously refine forecasting

models and planning parameters. Furthermore, Sarin's research revealed that the reduced working capital requirements from optimized MRO inventory created substantial financial flexibility, with 72% of surveyed companies reallocating at least 60% of released capital toward digital transformation initiatives, including IoT sensors, advanced analytics, and predictive maintenance technologies [10].

5.3. Enhanced Labor Productivity

Streamlined kit preparation and delivery processes reduce time spent searching for and gathering components, allowing maintenance technicians to focus on skilled repair activities. Achouch et al.'s time-and-motion analysis across diverse manufacturing environments found that maintenance technicians at facilities without integrated WMS-MRO systems spent an average of 37.2% of their work hours on non-value-added activities, including parts searching, material handling, documentation, and waiting. By contrast, technicians at facilities with advanced integration dedicated just 8.4% of their time to these activities, effectively increasing productive maintenance time from industry averages of 54-62% to leadership performance of 83-91% [9]. This productivity improvement translated directly to maintenance capacity, with studied organizations reporting the ability to increase preventive maintenance coverage by 42.7% using the same maintenance workforce after implementing integrated systems. The financial implications were equally significant, with Sarin's research documenting productivity gains equivalent to €48,000-€67,000 annually per maintenance technician after implementing comprehensive WMS-MRO integration across multiple European manufacturing operations [10]. Beyond direct labor savings, the enhanced productivity enabled substantial operational improvements, with organizations reporting 34.5% increases in scheduled maintenance compliance and 48.7% improvements in first-time fix rates – directly enhancing both equipment reliability and maintenance efficiency. Furthermore, the study demonstrated that facilities leveraging advanced WMS capabilities for MRO support reduced overtime labor costs by 63.2% and decreased contractor reliance by 41.8%, creating additional financial benefits beyond standard productivity improvements [10].

5.4. Data-Driven Decision Making

Integrated systems provide insights into component failure patterns, repair frequency, and inventory optimization opportunities, supporting continuous improvement initiatives. According to Achouch et al.'s research on predictive maintenance models, organizations leveraging WMS-MRO analytics achieve 3.7-4.2 times faster identification of systematic failure patterns and reduce repeat failures by 58-67% compared to organizations without integrated analytics capabilities. Their analysis documented that manufacturing facilities implementing advanced analytics within integrated maintenance and inventory systems identified an average of 14.3 distinct improvement opportunities annually per major equipment category, with implementation success rates exceeding 82% [9]. This visibility advantage enabled targeted improvement initiatives, with studied organizations documenting average maintenance cost reductions of 18.7% per production unit within the first year after implementation. The decision support capabilities extended beyond maintenance planning, with Sarin's research finding that predictive analytics within integrated MRO systems enabled 47% more accurate inventory forecasts and reduced inventory variability by 34% across seasonal production cycles [10]. Furthermore, his analysis revealed that organizations leveraging advanced WMS-MRO analytics reported significantly accelerated continuous improvement cycles, with the average time from problem identification to verified solution implementation decreasing from 73 days to 28 days after implementation – increasing organizational adaptability and resilience. This analytical foundation created measurable competitive advantages, with surveyed companies reporting that data-driven MRO approaches enabled them to identify potential equipment issues an average of 31 days before failure manifestation, creating substantial lead time for planning and corrective action [10].

5.5. Extended Asset Lifecycles

Properly supported preventive and predictive maintenance programs help maximize equipment lifespan, deferring capital expenditures and improving return on existing assets. Achouch et al.'s longitudinal research on Industry 4.0 implementations found that manufacturing organizations with sophisticated WMS-MRO capabilities extended average equipment lifecycles by 28-37% beyond manufacturer specifications while maintaining operational reliability above 95%. Their analysis across diverse industrial environments documented that each 1-year extension in average asset lifespan yielded capital expenditure deferrals of approximately €1.4 million per €10 million of installed asset base, creating substantial financial leverage [9]. The improved asset performance generated additional operational advantages, with Sarin's research calculating those facilities implementing advanced WMS-MRO integration achieved production output improvements averaging 11.2% per unit of invested capital – directly enhancing return on assets (ROA) and shareholder value. His analysis further revealed that organizations effectively leveraging digital transformation in MRO operations realized 5.8% higher EBITDA margins and 21.7% greater return on invested capital compared to industry peers utilizing traditional maintenance approaches [10]. Beyond financial metrics, the extended

lifecycles created sustainability benefits, with studied organizations reducing manufacturing carbon footprints by an average of 4.3% through extended equipment utilization rather than premature replacement. Furthermore, the research documented those facilities implementing comprehensive WMS-MRO integration achieved 68.4% lower unplanned maintenance costs in late-lifecycle equipment, effectively extending useful life while maintaining cost-effective operation [10].

Table 2 Business Impact of WMS-Enhanced MRO Systems [9,10]

Metric	Impact of WMS Implementation
Maintenance-Related Production Disruptions	42-57% fewer
Mean Time to Repair (MTTR)	37-48% reduction
Unplanned Downtime (Critical Equipment)	73.6% reduction
Total Inventory Investment	23-31% reduction
Parts Availability	9-11.5% increase
Emergency Procurement Costs	71-83% reduction
Parts Obsolescence	47-56% reduction
Equipment Lifecycle Extension	28-37% longer
Return on Invested Capital	21.70% increase

6. Conclusion

The integration of Warehouse Management Systems with MRO operations represents a strategic opportunity for manufacturing organizations to transform maintenance from a necessary cost center into a competitive advantage. By implementing specialized WMS features that support preventive and predictive maintenance strategies, companies can significantly reduce downtime, optimize inventory investments, improve labor productivity, enable data-driven decision-making, and extend asset lifecycles. The evidence presented throughout this article demonstrates that WMS-enhanced MRO delivers measurable improvements across both operational and financial metrics, creating substantial returns on investment while increasing organizational resilience and adaptability. As manufacturing environments become increasingly complex, the strategic importance of well-managed, digitally-enabled MRO operations will continue to grow, with integrated WMS capabilities serving as a critical enabler for maintenance excellence and overall operational performance. Organizations that recognize this connection and invest accordingly will position themselves for sustained competitive advantage in an increasingly demanding manufacturing landscape.

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