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Optimizing Maintenance Inventory Management to Improve Operational Efficiency, Asset Reliability and Financial Performance

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Abstract

This study investigates the optimisation of maintenance inventory management in capital-intensive refinery operations to enhance operational efficiency, asset reliability, and financial performance. The background of this research is driven by persistent inefficiencies in Maintenance, Repair, and Operations (MRO) inventory, which often result in excessive capital tied up in slow-moving stock and an increased risk of obsolescence. The objective of this study is to identify the root causes of inventory inefficiency and develop an integrated optimisation framework for improving inventory turnover and reducing provisioning exposure. The research employs a mixed-method case study approach combining qualitative thematic analysis and quantitative inventory classification. Data were collected through interviews with key operational stakeholders and supplemented by secondary data from inventory management systems. Analytical methods include Inventory Turnover Ratio (TOR) assessment and multidimensional ABC-VED-FSN classification. The results reveal significant inefficiencies, including a low TOR of 0.67, a high proportion of non-moving inventory, and provisioning exposure exceeding USD 50 million. The analysis identifies five principal root causes: the absence of criticality-based segmentation, inaccurate master data, the lack of periodic review processes, disposal constraints, and conservative procurement practices. In conclusion, the proposed integrated optimisation framework is expected to improve TOR to 0.95 by 2030 and achieve a significant reduction in provisioning exposure. The study highlights the importance of data governance and structured inventory classification in achieving sustainable operational and financial efficiency in refinery maintenance systems.

INTRODUCTION

The oil refining industry represents one of the world's most capital-intensive industrial sectors. Refinery operations are characterised by massive fixed asset investments in processing facilities, complex equipment systems, and extensive infrastructure designed to operate continuously under extreme conditions. These operations depend fundamentally on the continuous reliability of physical assets, including stationary equipment (furnaces, reactors, and distillation columns), rotating machinery (compressors, pumps, and turbines), electrical systems (power generation and distribution), instrumentation for process monitoring and control, and auxiliary support systems for facility operations (Ajenifuja, 2024; Brealey et al., 2020; Silver et al., 2017).

The refinery environment presents a unique operational context in which the consequences of equipment failure are particularly severe (Saleh *et al.* 2014; Ishola *et al.* 2020; Vakulenko *et al.* 2021) A proactive approach to quantitative assessment of disruption risks of petroleum refinery operation (Samia *et al.* 2018). Unplanned equipment downtime directly translates into lost processing capacity, reduced production output, potential safety incidents affecting personnel and surrounding communities, environmental contamination risks with regulatory and reputational consequences, and substantial financial losses that can exceed operating profits within days or weeks (Gatzert *et al.* 2016; Heflin dan Wallace 2017). Maintaining asset reliability while sustaining operational efficiency therefore constitutes an organisational imperative that cannot be compromised under normal operating circumstances (Lee 2020).

One critical pillar supporting both asset reliability and operational efficiency is Maintenance, Repair, and Operations (MRO) inventory management. The availability of appropriate maintenance materials, spare parts, consumables, and service items at the point and time of need is a prerequisite for uninterrupted maintenance execution. Maintenance may occur across multiple contexts: routine preventive maintenance conducted on fixed schedules, condition-based maintenance triggered by monitoring systems, predictive maintenance based on equipment deterioration analysis, and emergency corrective maintenance responding to unexpected equipment failures.

In each context, the absence of required materials prevents maintenance execution, extends equipment downtime, degrades operational reliability, and threatens the achievement of production targets and organisational objectives (Okonkwo *et al.* 2021; Molęda *et al.* 2023). However, holding inventory introduces competing financial complexities: excessive inventory accumulation ties up working capital that could otherwise be deployed towards debt reduction or productive investment, and generates substantial carrying costs including warehouse facility rental, climate control, security systems, insurance premiums, and administrative staffing. Inventory also requires administrative overhead for tracking and management, creates exposure to material obsolescence through technological advancement, equipment replacement, or regulatory changes, and is susceptible to physical deterioration through corrosion and environmental exposure.

PT Pertamina Patra Niaga (PT PPN) represents Indonesia's primary refining operation, managing multiple refinery units across the archipelago. The company processes crude oil into marketable petroleum products critical to national energy security and domestic market supply. As of 2025, the company's maintenance inventory reached IDR 3.66 trillion in total value. This extraordinary capital allocation demands rigorous evaluation of efficiency and effectiveness to ensure that inventory serves organisational objectives rather than representing trapped capital.

The company applies the Inventory Turnover Ratio (TOR) as its primary metric for assessing inventory efficiency. TOR measures how many times inventory is consumed and replaced annually, calculated as the annual consumption value divided by the average inventory value. A higher TOR indicates more efficient capital utilisation and greater inventory management productivity, while a lower TOR suggests excess stock, underutilised materials, or a misalignment between stocking decisions and actual demand patterns. Within PT PPN, routine maintenance inventory achieved a TOR of only 0.42 in December 2025, substantially below the corporate target of 0.60.

This performance indicates that maintenance inventory requires approximately 2.4 years to complete a single full turnover cycle — an extraordinarily extended timeframe reflecting significant inventory inefficiency. Beyond the low TOR metric, additional indicators signal inventory management challenges requiring systematic investigation. The cumulative provisioning balance for non-hydrocarbon MRO inventory reached USD 50.15 million as of 31 December 2025, representing an accounting recognition that a substantial portion of materials is at risk of obsolescence and will likely never achieve productive use in operations.

This provisioning balance represented 21.5% of gross MRO inventory value, indicating that more than one-fifth of inventory has been subjected to accounting write-downs reflecting value impairment and loss of expected utility. The provisioning trend across three years — USD 46.77 million in 2023, USD 49.41 million in 2024, and USD 50.15 million in 2025 — shows a consistent upward trajectory despite organisational focus on inventory management. Annual provisioning expenses of USD 2.65 million in 2024 and USD 736,248 in 2025 directly impact profitability through non-cash charges recognised in the income statement, reducing net income and return on assets.

These indicators collectively suggest that inventory management at PT PPN faces structural rather than merely tactical challenges. This research aims to investigate the root causes of inventory inefficiency and develop evidence-based recommendations for an integrated optimisation approach that simultaneously addresses operational efficiency, asset reliability, and financial performance objectives. The scope encompasses inventory management practices across PT PPN's Refinery Operations Directorate, which manages six refinery units.

Inventory management theory fundamentally addresses the challenge of balancing competing objectives: maintaining material availability to support operational continuity while controlling the costs and capital deployment associated with inventory ownership and storage. According to Walters (2003), inventory exists primarily because organisations operate in environments characterised by substantial uncertainty. This uncertainty manifests in multiple forms: unpredictable variation in material demand driven by irregular equipment failures and maintenance requirements, uncertainty regarding supplier lead times and supply chain reliability, unexpected changes in operational requirements due to equipment modifications or process changes, and supply chain disruptions caused by external events.

Inventory functions as a protective mechanism enabling organisations to absorb these uncertainties and maintain continuous operations despite fluctuations in supply and demand. However, inventory ownership creates substantial financial implications extending well beyond the initial purchase cost of materials. Holding costs include direct warehousing expenses such as facility rental or building depreciation, climate control energy costs, security staffing and systems, material handling equipment depreciation, and inventory-related staffing and supervision.

Carrying costs also encompass insurance premiums on inventory value, administrative expenses for inventory tracking and management, information technology costs for inventory systems and databases, and most significantly, the cost of capital tied up in inventory. According to Chopra and Meindl (2023), the capital cost of inventory typically represents 15–25% of inventory value annually, making it the largest component of total inventory carrying cost. Beyond carrying costs, holding inventory creates a substantial risk of material obsolescence — the process by which materials become unusable or unsaleable due to technological advancement, specification changes, equipment replacements, regulatory modifications, or physical deterioration through corrosion, evaporation, and temperature extremes.

In maintenance-intensive industries such as oil refining, MRO inventory presents distinct challenges compared to the production inventory traditionally addressed in inventory management literature. Production materials typically follow relatively stable and predictable demand patterns that can be forecast using statistical demand planning models and historical consumption data, enabling deterministic inventory decisions. In contrast, MRO inventory is characterised by irregular, low-frequency, and difficult-to-predict demand driven by equipment failures unpredictable in both timing and magnitude, condition-based inspections revealing maintenance requirements at uncertain intervals, preventive maintenance schedules varying according to equipment condition, and emergency requirements arising from operational disruptions.

These demand characteristics complicate forecasting significantly and render traditional deterministic inventory models less applicable. Walters (2003) emphasises the importance of probabilistic inventory models for MRO environments where exact future demand cannot be predicted with precision but can be characterised through probability distributions and expected value analysis. The Inventory Turnover Ratio (TOR) serves as a primary metric for evaluating inventory efficiency in manufacturing and maintenance environments. According to Wild (2002), TOR reflects how effectively organisational inventory resources are utilised — high turnover indicates that materials are actively consumed and inventory is productive, while low turnover suggests excess stock or a misalignment between stocking decisions and actual demand.

However, TOR must be interpreted carefully in maintenance contexts where certain materials intentionally exhibit low turnover due to criticality and reliability requirements. Some spare parts are maintained at specified stocking levels not because they are frequently consumed, but because their unavailability would cause critical operational disruption (Driessen *et al.* 2015; Van Houtum dan Kranenburg 2015; Zhang *et al.* 2021). This distinction between efficiency-driven and reliability-driven inventory retention creates a fundamental tension in inventory performance evaluation that must be managed through differentiated strategies (Jonsson dan Mattsson 2019; Jean 2024; Kelka 2024).

Inventory classification provides a foundation for applying differentiated management policies tailored to distinct inventory segments. The ABC analysis approach, grounded in the Pareto principle as identified by Flores and Whybark (1987), categorises materials based on their contribution to total inventory value. Typically, Class A items (10–20% of SKUs) account for 70–80% of total value and warrant intensive control; Class B items (20–30% of SKUs) contribute 15–20% of value and require moderate control; and Class C items (50–70% of SKUs) represent only 5–10% of value and justify simplified control procedures.

VED (Vital–Essential–Desirable) analysis complements ABC by categorising materials according to operational criticality rather than monetary value. Vital items are those whose unavailability would cause immediate operational shutdown or safety incidents; Essential items are those whose absence can be tolerated for limited periods without critical consequences; and Desirable items are those whose unavailability imposes only minor operational inconvenience. This criticality-based classification is particularly important for MRO inventory, as low-cost items may be operationally critical and therefore require high availability, while expensive items may be operationally non-critical and therefore justify lower stocking levels.

FSN (Fast-moving, Slow-moving, Non-moving) analysis evaluates inventory based on consumption frequency and movement behaviour within a specified observation period. Fast-moving items exhibit regular consumption and turnover; slow-moving items experience irregular consumption with extended periods without issuance; and non-moving items have recorded no consumption over an extended period. The multidimensional integration of ABC, VED, and FSN classifications provides comprehensive inventory characterisation, enabling the identification of optimisation opportunities across the inventory portfolio.

METHOD

This research employs a comprehensive mixed-method case study approach combining qualitative analysis of organisational inventory management practices with quantitative multidimensional inventory classification. According to Yin (2018), case study methodology is appropriate for research seeking to understand complex organisational phenomena within their actual contextual setting. The case study design was selected because inventory inefficiency at PT PPN involves intricate interactions between operational requirements, organisational policies, cross-functional coordination mechanisms, and governance structures that cannot be fully understood through isolated quantitative metrics alone.

The research design follows both exploratory and prescriptive orientations. The exploratory component seeks a comprehensive understanding of the factors and operational conditions driving inventory accumulation, including how existing inventory policies, reliability considerations, provisioning practices, and cross-functional coordination interact within the organisational context. The prescriptive component reflects the objective of formulating an integrated inventory optimisation framework capable of addressing identified inefficiencies while preserving asset reliability and operational continuity.

Qualitative data were collected through semi-structured interviews with 40 personnel strategically selected from five functional domains. The maintenance planning function (14 informants) included material planners responsible for estimating material requirements, maintenance schedulers coordinating maintenance activities, and planning supervisors overseeing planning functions. The reliability engineering function (11 informants) included reliability engineers responsible for asset condition monitoring, equipment specialists possessing detailed equipment knowledge, and Reliability-Centred Maintenance (RCM) facilitators supporting reliability-centred maintenance initiatives. The procurement function (5 informants) included procurement managers and specialists responsible for vendor management and order processing. The warehousing function (7 informants) included warehouse managers overseeing warehouse operations, inventory control specialists tracking inventory movements, and warehouse coordinators managing inventory receipt and issuance across refinery units. The finance and controller function (3 informants) included financial controllers responsible for inventory accounting, financial analysts supporting inventory analysis, and provisioning specialists managing inventory valuation and provisioning calculations.

Interviews were structured around a consistent question guide exploring key topics related to inventory management practices, material consumption patterns, reliability requirements, procurement processes, and perceived obstacles to optimisation. Each interview lasted between 45 and 90 minutes and was documented through detailed field notes and, where permitted, audio recording to ensure analytical accuracy. Interviews were conducted over a three-month period to accommodate temporal variation, organisational schedules, and seasonal factors.

Thematic analysis using the six-phase framework of Braun and Clarke (2006) was applied to interview transcripts and field notes. The familiarisation phase involved reading and re-reading interview documentation to identify preliminary patterns. The coding phase involved the systematic identification and labelling of text segments capturing meaningful units of inventory management information. Theme development organised codes into clusters representing coherent patterns reflecting root causes of inventory inefficiency. Root cause analysis using the 5 Whys technique (Serrat, 2017) was applied to identify the underlying drivers of inventory accumulation beyond immediately observable symptoms.

Quantitative analysis proceeded through three sequential analytical procedures. First, TOR baseline assessment established 2025 inventory turnover performance by computing inventory turnover ratios for each material item and aggregating results at the refinery unit and enterprise levels using PRISMA system data. Second, multidimensional inventory classification integrated ABC analysis (categorising items by consumption value), VED classification (categorising items by operational criticality based on Reliability-Centred Spare Parts/RCSP programme records), and FSN analysis (categorising items by movement behaviour based on historical transaction data) to create an ABC-VED-FSN classification matrix. Third, segment-level efficiency diagnostics were computed for each classification matrix cell, encompassing total inventory value, aggregate TOR, annual consumption value, proportion of total inventory value, number of SKUs, and cumulative provisioning exposure by ageing bracket. Provisioning analysis utilised PT PPN's progressive provisioning policy, which quantifies inventory value impairment through provisioning rates applied according to ageing periods: 0–2 years (0%), 2–3 years (0%), 3–4 years (50%), 4–5 years (67%), and greater than 5 years (100%).

RESULTS AND DISCUSSION

Root Causes of Inventory Inefficiency

Thematic analysis of interview transcripts and field notes generated 26 themes encompassing 232 thematic codes distributed across five functional domains. Root cause analysis using the 5 Whys technique identified five interconnected root causes forming a self-reinforcing system perpetuating inventory accumulation. RC1—Absence of criticality-based inventory segmentation strategy (frequency 28, Critical priority)—represents the most pervasive driver. Interview findings indicate that inventory stocking decisions are governed by relatively uniform Minimum Stock Level (MSL) practices applied indiscriminately across materials with fundamentally different operational roles, criticality levels, and consumption characteristics.

RC2—Inaccurate master data and incomplete material traceability (frequency 24, Critical priority)—prevents effective planning through inconsistent equipment identification numbers (KIMAP), incomplete Bills of Materials (BOM) linkage, and unreliable work order history in the SAP PM system. RC3—Absence of standardized periodic inventory review across refinery units (frequency 20, Critical priority)—allows materials to remain in storage for extended periods without formal reassessment of continued necessity or operational justification.

RC4—Structural state-owned enterprise disposal barriers (frequency 18, High priority)—has resulted in USD 39.5 million in fully provisioned materials remaining undisposed despite clear obsolescence determination. Disposal processes involve multiple administrative and regulatory requirements creating delays in material removal from inventory records. RC5—Over-conservative planning practices applying 15-20 percent contingency allowances to procurement without prior stock verification (frequency 16, High priority)—creates excess procurement driven by uncertainty in maintenance preparation activities.

These five root causes form a self-reinforcing system where poor data quality reduces planning accuracy, encouraging conservative contingency procurement; uniform stocking policies prevent differentiated treatment of critical versus routine materials; and weak review mechanisms allow inactive inventory to accumulate without formal challenge or justification.

Multidimensional Inventory Classification Results

ABC analysis of 41,003 active SKUs valued at IDR 1,568.43 billion revealed a highly asymmetrical distribution consistent with Pareto principles. Class A items (3,941 SKUs, 9.6%) account for IDR 1,254.72 billion, representing 80% of total value. Class B items (6,653 SKUs, 16.2%) contribute IDR 235.27 billion (15%), and Class C items (30,409 SKUs, 74.2%) represent IDR 78.43 billion (5%). This concentration pattern indicates that management efforts focused on Class A materials yield disproportionate efficiency gains.

VED analysis of materials undergoing Reliability-Centred Spare Parts (RCSP) assessment identified only 3,677 of the 41,003 items (8.96%) as having formal criticality classification. Among classified items, Vital materials comprise 841 items (22.9%), Essential materials comprise 1,919 items (52.2%), and Desirable materials comprise 917 items (24.9%). This limited RCSP coverage of 8.96% indicates that 91.04% of inventory lacks formal criticality assessment, representing a significant governance gap.

FSN classification identified 7,552 Fast-moving items (18.42% of SKUs, valued at IDR 635.21 billion), 8,456 Slow-moving items (20.62% of SKUs, valued at IDR 593.44 billion), and 24,995 Non-moving items (60.96% of SKUs, valued at IDR 339.77 billion). The concentration of inventory in the Non-moving category — comprising 60.96% of items but only 21.65% of total value — highlights the inventory complexity created by thousands of low-value items that generate substantial management burden despite limited financial exposure.

The integrated ABC-VED-FSN matrix reveals that high-value inventory is concentrated in slow-moving and non-moving categories, presenting significant opportunities for optimisation. The ADS category (Class A, Desirable, Slow-moving) contains 1,486 items with a total value of IDR 468.54 billion (29.87% of total inventory value), while the ADN category (Class A, Desirable, Non-moving) contains 911 items valued at IDR 204.85 billion (13.06%). Combined, the ADS and ADN categories total IDR 673.38 billion (42.9% of total inventory value) while representing only 5.84% of total SKUs. This concentration identifies these two categories as the highest-priority targets for working capital improvement and operational efficiency enhancement.

Provisioning analysis revealed a 2025 cumulative provisioning exposure of IDR 411.99 billion, with a highly skewed distribution. Non-moving materials with no consumption recorded for more than five years contributed IDR 338.22 billion (82.0% of total provisioning), subject to a 100% provisioning rate reflecting a complete write-down of asset value. Materials aged 4–5 years contributed IDR 38.58 billion (9.4%) at a 67% rate, and materials aged 3–4 years contributed IDR 35.59 billion (8.6%) at a 50% rate.

Table 1. TOR Baseline 2025 by Month and Refinery Unit

Month	RU II	RU III	RU IV	RU V	RU VI	RU VII
Jan	0.62	1.00	0.72	1.03	1.28	0.47
Mar	0.63	0.98	0.74	0.96	0.31	0.45
Jun	0.62	0.90	0.73	0.97	0.35	0.49
Sep	0.49	0.68	0.76	0.94	1.09	1.22
Dec	0.59	0.34	0.59	0.43	0.34	0.54
Annual	0.56	0.78	0.71	0.84	0.54	0.61

Source: Internal operational data of PT Pertamina Patra Niaga, extracted from the SAP/PRISMA maintenance inventory system and financial records (2025), processed and projected by the author for analysis (2026–2030).

Financial Impact Analysis and Optimization Framework

Achievement of the corporate TOR target of 0.95 by 2030 requires a 47% reduction in inventory value from the IDR 1.56 trillion baseline to an IDR 0.82 trillion target. This substantial inventory rationalisation would reduce cumulative provisioning exposure by IDR 247.19 billion. Year-by-year projections indicate provisioning reductions of IDR 20.60 billion in 2026, IDR 62.80 billion cumulative by 2027, IDR 123.60 billion by 2028, IDR 185.40 billion by 2029, and IDR 247.19 billion cumulative by 2030.

The proposed Integrated Maintenance Inventory Optimisation Framework comprises five interconnected business solutions directly mapped to the identified root causes. Solution 1 — Priority Consumption Programme (addressing RC1 and RC5) — implements the systematic utilisation of slow-moving inventory prior to new procurement through the development of

Material Utilisation Lists, cross-refinery material redeployment mechanisms, procurement restrictions for items with existing stock, and accelerated disposal of obsolete materials.

Solution 2 — RCSP Expansion and Periodic Review (addressing RC1, RC2, and RC3) — expands criticality-based classification from the current 8.96% to above 80% coverage by 2027 through mandatory RCSP reviews of high-value materials, the establishment of standardised periodic review mechanisms across all refinery units, and the implementation of evidence-based stocking decisions aligned with operational requirements.

Solution 3 — Vendor-Managed Inventory Implementation (addressing RC2 and RC5) — reduces excessive stockholding caused by procurement lead-time uncertainty through supplier-managed inventory arrangements, whereby suppliers monitor consumption data and replenish inventory based on actual usage patterns. This approach is particularly suitable for Class C consumable materials with predictable demand patterns.

Solution 4 — Refinery Unit-Specific TOR Improvement Programme (addressing RC1 and RC3) — introduces differentiated intervention frameworks prioritising underperforming units such as RU II (TOR: 0.40) and RU VI (TOR: 0.54) through targeted RCSP audits, slow-moving inventory utilisation programmes, and enhanced planning and inventory management controls.

Solution 5 — Strengthening Financial Governance Through Provisioning Transparency (addressing RC2, RC3, and RC4) — establishes a cross-functional Disposal Task Force to accelerate the processing of fully provisioned inventory, integrates provisioning information into operational dashboards for real-time visibility, and introduces provisioning reduction targets as formal organisational key performance indicators.

Table 2. Projected TOR Improvement and Financial Impact (2026-2030)

Year	TOR	Inv(T)	Red%	Prov(B)	Red(B)
2025	0.67	1.56	-	411.99	-
2026	0.73	1.48	5%	391.39	20.60
2027	0.79	1.35	13%	349.19	62.80
2028	0.85	1.18	24%	288.39	123.60
2029	0.90	0.98	37%	226.59	185.40
2030	0.95	0.82	47%	164.80	247.19

Source: Internal operational data of PT Pertamina Patra Niaga, extracted from the SAP/PRISMA maintenance inventory system and financial records (2025), processed and projected by the author for analysis (2026–2030).

CONCLUSION

This research identified five interconnected root causes of slow-moving and non-moving inventory accumulation at PT Pertamina Patra Niaga: (1) the absence of a criticality-based inventory segmentation strategy, resulting in uniform Minimum Stock Level (MSL) practices being applied across materials with different operational requirements; (2) inaccurate master data and incomplete material traceability preventing effective planning; (3) the lack of standardised periodic inventory review, allowing materials to remain in storage without reassessment; (4) structural state-owned enterprise disposal barriers leaving USD 39.5 million in fully provisioned materials undisposed; and (5) over-conservative planning with 15–20% contingency allowances applied without prior stock verification. These root causes form a self-reinforcing system that perpetuates inventory accumulation despite ongoing management initiatives.

ABC-VED-FSN multidimensional classification analysis of 41,003 SKUs valued at IDR 1.57 trillion revealed that high-value slow-moving and non-moving materials — specifically the ADS and ADN categories, totalling IDR 673.38 billion or 42.9% of total inventory value — represent the primary working capital optimisation target, despite comprising only 5.84% of total SKUs. Non-moving materials with no consumption recorded for more than five years contribute IDR 338.22 billion in provisioning exposure at a 100% write-down rate. The cumulative provisioning balance, which grew from USD 46.77 million in 2023 to USD 50.15 million in 2025, indicates worsening inefficiency requiring systematic intervention.

The proposed Integrated Maintenance Inventory Optimisation Framework, comprising five interconnected business solutions implemented across three phases from 2026 to 2030, is projected to improve the inventory turnover ratio from the current baseline of 0.67 to the corporate target of 0.95, reduce cumulative provisioning exposure by IDR 247.19 billion, and release approximately IDR 740 billion in working capital from unproductive inventory. The framework simultaneously addresses operational efficiency and asset reliability by distinguishing between strategically justified critical inventory and excess slow-moving materials through multidimensional classification, thereby ensuring that optimisation efforts do not compromise maintenance reliability.

Successful implementation requires: (1) senior management commitment to governance institutionalisation and sustained organisational attention beyond the initial project phase; (2) cross-functional coordination mechanisms enabling integrated decision-making across maintenance, reliability, procurement, warehousing, and finance functions; (3) consistent execution of phased initiatives in accordance with the roadmap timeline; (4) investment in data governance and master data quality improvements to enable accurate planning; and (5) performance monitoring through defined metrics and periodic governance reviews. The framework provides a scalable, evidence-based approach applicable to other asset-intensive industries — including petrochemicals, mining, utilities, and manufacturing — facing similar inventory management challenges.

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