Available *online* at: https://newjournal.lppmunindra.ac.id/index.php/JOTI

Jurnal Optimasi Teknik Industri

| ISSN (Print) 2656-3789 | ISSN (Online) 2657-0181 |

FMEA-Based Risk Analysis to Improve Material Planning Effectiveness at PLN Indonesia Power UBP Saguling

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ARTICLE INFORMATION

Received : 13 Februari 2026
Revised : 02 Maret 2026
Accepted : 24 Maret 2026
Available online : 31 Maret 2026

KATA KUNCI

Continuous improvement;
Failure Mode and Effect Analysis;
Inventory Control;
Material Planning;
Risk Management

ABSTRACT

Effective material planning is essential to ensure uninterrupted operations in the energy sector, where supply delays may affect system reliability and maintenance schedules. PT PLN Indonesia Power UBP Saguling continues to experience recurring warehouse management challenges, particularly overstock that increases storage costs and stockout that disrupts preventive maintenance activities. This study aims to analyze risks associated with material planning and propose implementable improvement strategies. A descriptive case study approach was employed, focusing on warehouse operations at PT PLN Indonesia Power UBP Saguling. Primary data were collected through direct observation and semi-structured interviews with warehouse staff and planners, while secondary data included material planning documents, inventory records, and material usage effectiveness from January to June 2025. The analysis integrated Failure Mode and Effect Analysis (FMEA) to prioritize risks based on Risk Priority Numbers, the Fishbone Diagram to identify root causes, and the 5W+1H framework to formulate corrective actions. The findings indicate that inaccurate demand forecasting and weak inventory control were the most critical risks, with the highest priority score of 270. Recommended improvements include enhancing planning accuracy, implementing real-time monitoring through enterprise resource planning systems, and formalizing vendor coordination via Service Level Agreements. This study contributes by proposing an integrated risk-based framework for improving material planning effectiveness in the power sector.

I. INTRODUCTION

Procurement within supply chain operations is foundational to maintaining operational reliability in power generation, as it ensures timely access to essential materials and parts needed for continuous operation [1]. Indonesia's electricity demand is projected to rise steadily by around 4.7% to 5.3% per year over the next decade, as reported in national electricity planning documents and recent academic studies, thereby requiring power plants to strengthen operational reliability and supply security [2] [3]. In this context, studies in power plant operations demonstrate that delays or mismatches in spare parts availability can lead to costly downtime, rising operational expenses, and interruptions to maintenance activities, thereby emphasizing the need for effective material planning and inventory control [4] [5]. For PT PLN Indonesia Power, one of the largest power generation subsidiaries in Indonesia, inefficiencies in material procurement and planning not only risk financial losses but also affect national energy supply stability. Therefore, the urgency of

https://doi.org/10.30998/joti.v8.i1.2189

addressing material planning risks in power plants is both a corporate and national priority.

Inaccurate inventory management often leads to two extreme conditions: overstock, which increases storage and opportunity costs, and stockout, which creates delays in maintenance and potentially forces unplanned outages [4]. Previous research has shown that in the energy sector, planning inaccuracies frequently stem from limited forecasting accuracy, poor supplier lead-time estimation, and weak interdepartmental coordination [6] [7]. Furthermore, emergency demand for materials that is not included in annual or monthly planning cycles often disrupts resource allocation and raises operational expenditures [8]. While many organizations rely on Enterprise Resource Planning (ERP) and related digital platforms, these systems have not eliminated inefficiencies. For example, ERP-based inventory systems in energy operations improved data accuracy but still required complementary risk-management methods to handle sudden demand variation [9].

To mitigate such risks, scholars have increasingly emphasized the importance of integrating modern inventory strategies with risk-analysis tools. Recent studies confirmed that data-driven planning, which integrates real-time monitoring, predictive analytics, and demand-sensing capabilities, enhances forecasting accuracy and reduces mismatches between supply and demand [10] [11]. These approaches have been applied successfully in perishable goods industries and automotive sectors, where variability in demand is high, demonstrating their potential relevance to energy operations as well. Similarly, studies demonstrated the significance of adopting classical inventory models such as Safety Stock, Reorder Point (ROP), and Economic Order Quantity (EOQ) to minimize imbalances and prevent disruptions in production and maintenance activities [12] [13]. However, despite their proven value, evidence from Indonesian power plants shows recurring inefficiencies and persistent material shortages [7]. This suggests that technical models alone are insufficient, particularly when organizational culture, vendor performance, and interdepartmental coordination remain weak. Therefore, it is necessary to complement quantitative models with structured risk-management perspectives to address systemic challenges that affect material planning reliability.

Recent literature also highlights the relevance of structured risk-assessment methodologies such as Failure Mode and Effect Analysis (FMEA) in overcoming these limitations. FMEA enables practitioners to identify potential points of failure in the planning process and to prioritize corrective actions based on calculated Risk Priority Numbers (RPN). This structured prioritization allows companies to focus resources on the most critical risks, improving efficiency in both planning and execution. For example, recent studies have shown that the application of FMEA-based models significantly enhances supply chain resilience in manufacturing contexts by identifying and prioritizing failure modes, thereby reducing disruptions, improving delivery reliability, and enabling more responsive risk mitigation [14] [15] [16]. Complementary to FMEA, visual diagnostic tools such as the Fishbone Diagram help organizations uncover multi-dimensional root causes across categories including human factors, machinery, methods, materials, measurement, and environmental conditions [17]. In addition, Continuous improvement frameworks, such 5W+1H methods, are recognized for their effectiveness in transforming complex risk factors into structured and actionable solutions, improving operational performance and decision-making processes [18] [19]. Although these methods are well established in other industries, their combined application within Indonesia's energy sector is rarely documented, creating opportunities for contextual adaptation.

From this review, it is evident that earlier studies have contributed valuable insights into both inventory optimization and risk management; however, most have focused on technical forecasting methods or digital solutions without fully addressing the interplay between systemic risks and day-to-day operational practices in the energy sector. For instance, while ERP systems have been shown to improve transparency and accuracy [9] [20], they often fail to capture the complexity of sudden demand shocks, vendor lead-time variability, and cross-departmental misalignments. Similarly, the use of inventory models like EOQ or ROP helps stabilize procurement decisions [12] [13], but does not sufficiently integrate qualitative factors such as organizational coordination or regulatory requirements that often influence material availability in public utilities. Moreover, even though risk-based tools like FMEA and Fishbone have been validated in manufacturing and service industries [17] [21] , there is limited empirical evidence of their integration into Indonesian power plant operations. This gap underlines the need for studies that combine risk-identification methods with improvement frameworks, tailored specifically to the realities of energy companies operating in emerging economies.

Accordingly, this study positions itself to address the gap by analysing risks in material planning within the warehouse of PT PLN Indonesia Power UBP Saguling, a strategic facility that supplies critical components for power generation and maintenance. The research focuses not only on identifying the most critical risks but also on tracing their underlying causes and designing implementable solutions. To achieve this, the study integrates Failure Mode and Effect Analysis to quantify and prioritize risks, Fishbone Diagrams to map root causes across technical and organizational dimensions, and 5W+1H framework to propose operational strategies that are both practical and replicable. By adopting this integrative methodology, the study seeks to produce a comprehensive risk-analysis framework that strengthens planning accuracy, minimizes overstock and stockout conditions, and enhances the overall effectiveness of material management. Ultimately, the findings are expected to contribute not only to PT PLN Indonesia Power but also to the broader discourse on supply-chain risk management in the energy sector, particularly in the context of state-owned enterprises in developing countries.

II. METHOD

1. Research Design

This study employed a descriptive research design with a case study approach, focusing on the warehouse operations of PT PLN Indonesia Power UBP Saguling. The topic was selected because effective material planning is a critical component of supply chain management in power plants, directly affecting operational continuity, maintenance schedules, and overall system reliability. Frequent discrepancies between planned and actual material usage, as well as overstock and stockout incidents, pose substantial financial and operational risks. By focusing on this specific warehouse and its material planning processes, the study aims to identify operational gaps, understand the causes of inefficiencies, and develop actionable solutions that can be generalized to similar facilities. This approach allows a detailed, contextualized analysis, combining theoretical insights from literature with empirical observations from the field, which is essential to produce meaningful and implementable recommendations.

2. Data Sources

This study began by defining the scope of analysis along the planning–procurement–warehouse execution chain, motivated by observed fluctuations in Effectiveness of Material Usage (EPM), recurring overstock/stockout conditions, and inconsistencies between planned procurement and realized consumption. Data were collected from both primary and secondary sources. Primary data were obtained through direct observation of warehouse and planning activities and semi-structured interviews with personnel from the Rendal Har Division and warehouse staff involved in inventory handling, issuing, and monitoring. Secondary data were gathered from material planning documents, inventory records, historical usage logs, and ERP/IP-ProInventory outputs. The EPM dataset (January–June 2025) was compiled as the key quantitative indicator to describe alignment between planned and actual material usage. Triangulation was applied by cross-checking field narratives against documentary and system-based evidence to strengthen the validity of findings.

3. Risk Identification and Prioritization Using FMEA

After the data were consolidated, Failure Mode and Effect Analysis (FMEA) was applied to systematically identify potential failure modes in the material planning process. Failure modes were defined as recurring conditions that contribute to mismatches between planned and realized inventory, including planning-document inconsistencies, schedule changes, unexpected demand, vendor lead-time variability, and inaccurate replenishment parameters. Each failure mode was evaluated using three FMEA dimensions: Severity (S), Occurrence (O), and Detection (D). The Risk Priority Number (RPN) was calculated as [22], following the formulation used in[20],[23]:

$$RPN = S\ x\ O\ x\ D \tag{1}$$

where S = Severity, O = Occurrence, and D = Detection. The RPN results were used to rank risks and determine which issues require earlier corrective action. This stage provides a transparent prioritization logic: rather than treating all problems equally, the study focuses improvement efforts on risks with the highest combined likelihood, impact, and detectability weakness. The prioritization approach is consistent with risk management principles emphasizing the evaluation of risk events through likelihood–impact assessment to set mitigation priorities [24].

4. Root Cause Analysis Using Fishbone Diagram

To avoid treating symptoms as root causes, the high-priority risks from FMEA Stage were further analyzed using a Fishbone Diagram. This tool maps potential causes into the 5M1E framework—man, machine, method, material, measurement, and environment—so that failures can be traced across both technical and organizational dimensions [17]. The analysis examined (i) human-related contributors such as planning skill gaps, data entry errors, and cross-functional coordination; (ii) system-related contributors such as ERP limitations and suboptimal utilization of IP-ProInventory; (iii) procedural contributors such as inconsistency of working practices and the absence of standardized workflows; (iv) material-related contributors such as inaccurate requirement estimation; (v) measurement-related contributors such as unreliable EPM reporting; and (vi) environment-related contributors such as location constraints and weather-related disruptions. By structuring root causes in this way, the study provides a comprehensive explanation of why specific failure modes occur and clarifies which causes are controllable through managerial, procedural, or technological interventions.

5. Improvement Strategy Development Using 5W+1H Framework

Based on the prioritized risks and the mapped root causes, improvement strategies were developed using the 5W+1H framework (What, Why, Where, When, Who, How). This step converts analytical findings into implementable actions and ensures that recommendations are operationally feasible rather than purely conceptual. the operationalization of improvement strategies through the 5W+1H framework reinforces the study's integrative approach, ensuring that risk prioritization results are systematically translated into structured, accountable, and implementable management actions. The output of this stage is a structured implementation plan that aligns recommendations with actual workflow conditions and coordination practices observed in the field, thereby strengthening practicality, accountability, and sustainability of the proposed improvements.

III. RESULTS AND DISCUSSION

1. Effectiveness of Material Usage (EPM)

The analysis of material usage effectiveness (EPM) from January to June 2025 reveals considerable fluctuations, indicating weaknesses in the current planning system. EPM performance in January and February was close to 100%, reflecting alignment between planned and actual material usage. However, in March, it dropped sharply to below 50%, suggesting a significant mismatch between forecasted demand and actual requirements. Performance improved in April and June, with realized values approaching or exceeding targets (Fig. 1). These inconsistent trends indicate that the material planning process has not fully anticipated demand variability and supplier lead-time uncertainty. Notably, the simultaneous occurrence of overstock (112% receipt) and stockout (114% usage) in June, with a closing balance of 98%, reflects persistent inefficiencies in balancing supply and demand. These findings resonate with Stevenson[25] and Heizer[26], who highlight that weak planning accuracy leads to excessive holding costs and shortages. If not addressed, such instability may increase operational costs and disrupt preventive maintenance schedules, potentially affecting power plant reliability. Therefore, strengthening demand forecasting accuracy and integrating predictive analytics into ERP systems are critical to stabilizing EPM performance and minimizing inventory mismatches.

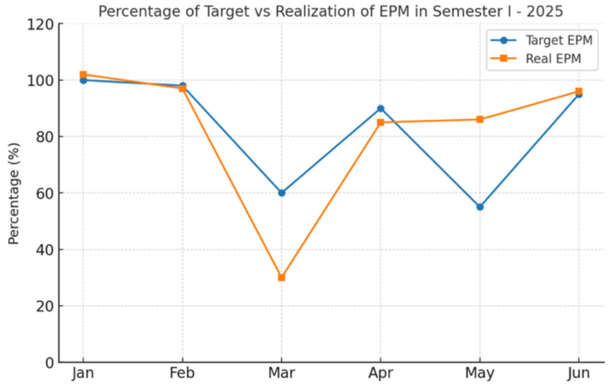

Figure 1 Comparison of EPM Targets and Realization (January–June 2025)

2. Risk Analysis Using FMEA

Risk analysis through the Failure Mode and Effect Analysis (FMEA) identified five major failure modes, as shown in Table 1.

Table 1 FMEA Risk Assessment Results

Failure Mode	Cause of Failure	Effect of Failure	Severity	Occurrence	Detection	RPN
			(Score 1-10)	(Score 1-10)	(Score 1-10)	
Discrepancy in TUG9 issuance	Invalid planning	Overstock	9	6	5	270
Change in work schedule	Postponed unit overhaul	Overstock, disrupted maintenance	8	7	2	112
Sudden demand outside planning	Equipment failure outside overhaul schedule	No stock available	3	4	9	108
Supplier schedule mismatch	Inaccurate vendors lead time	Late material delivery, delayed project	10	9	1	90
Inaccurate order quantity	Mis-calculated EOQ/ROP	Idle stock or shortage	7	2	5	70

As presented in Table 1, the most critical issue was the discrepancy in the issuance of material usage forms (TUG9), which recorded the highest Risk Priority Number (RPN = 270). This indicates a substantial gap between planning documentation and actual consumption that can trigger inventory

https://doi.org/10.30998/joti.v8.i1.2189

imbalances. Other prominent risks included changes in work schedules (RPN = 112), typically associated with postponed or rescheduled unit overhauls, and sudden demand outside the planning cycle (RPN = 108) driven by unexpected equipment failures. Supplier schedule mismatches (RPN = 90) also emerged as a notable risk due to inaccurate vendor lead-time estimation, while miscalculations in EOQ/ROP (RPN = 70) contributed to idle stock or shortages. Overall, the RPN ranking suggests that weaknesses in planning and coordination remain the dominant sources of material planning risk.

The risk prioritization results in Table 1 provide the basis for formulating targeted improvement actions, which are summarized in Table 2.

Table 2 Prioritized Corrective Actions

Rank	*Failure Mode*	*RPN*	*Proposed Corrective Action*
1	Discrepancy in TUG9 issuance	270	System integration between planner & warehouse; routine reconciliation
2	Change in work schedule	112	Flexible scheduling + contingency plan
3	Sudden demand outside planning	108	Critical buffer stock + emergency notification system
4	Supplier schedule mismatch	90	SLA with vendor + active communication
5	Inaccurate order quantity	70	Re-evaluate EOQ & ROP with validated historical data

Based on the prioritized RPN values in Table 2, corrective actions were developed to address the highest-risk failure modes. For the TUG9 discrepancy, system integration between planning and warehouse functions, supported by routine reconciliation, was proposed to reduce deviations between planned and actual usage. Flexible scheduling and contingency planning were recommended to mitigate procurement mismatches caused by overhaul changes, while critical buffer stock and an emergency notification mechanism were suggested to respond to unexpected demand. In addition, formalizing vendor coordination through Service Level Agreements (SLA) and recalibrating EOQ/ROP parameters using validated historical data were identified as essential measures to strengthen inventory control. These findings are consistent with prior FMEA-based studies showing that weaknesses at the planning stage amplify failure risk and degrade system reliability[27] [28], reinforcing the need for both technical recalibration and stronger cross-functional integration.

3. *Root Cause Analysis with Fishbone Diagram*

The Fishbone Diagram (Fig. 2) illustrates that the root causes of ineffective material usage in PT PLN Indonesia Power UBP Saguling extend across multiple dimensions within the 5M1E framework, emphasizing that inefficiencies are both technical and organizational. From the material perspective, problems arise due to inaccurate estimation of requirements and the unavailability of critical materials when urgently needed, which directly contributes to risks of stockouts and overstock. In terms of measurement, inaccuracies in EPM data reduce the reliability of planning outputs, leading to poor alignment between forecasted and actual usage. On the machine side, systemic weaknesses are observed, as the ERP system lacks real-time capability and the IP-ProInventory application is not optimally utilized, thereby limiting the accuracy of monitoring and reporting. Human factors (man) also play a major role, where insufficient training on planning, human error during data entry, and lack of coordination between inventory and warehouse departments lead to fragmented communication and operational delays. The method dimension highlights inconsistencies caused by differences in working practices among teams, which reduce standardization and efficiency. Finally, the environmental factors, such as the warehouse's distance from operational units and weather-related disruptions, exacerbate delays in material availability. These findings align with Djuhana and Gozali [17], who emphasized that categorizing risks using the 5M1E framework provides a structured approach to analyzing inefficiencies in material planning. Similarly, Quan et al. [8] confirmed that weaknesses in ERP-based monitoring systems often result in delayed distribution, underscoring the urgent need to improve real-time logistics integration. Overall, the diagram demonstrates that the problem of ineffective material usage is multifactorial, requiring comprehensive interventions that combine digital system optimization, human resource development, and structural process redesign.

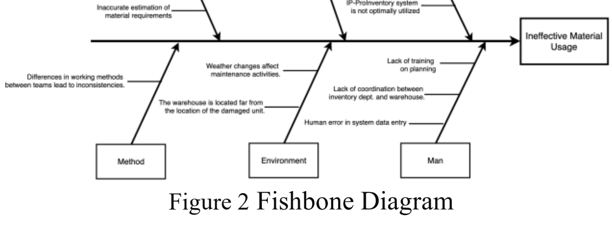

Figure 2 Fishbone Diagram

4. *Improvement Strategies Using 5W+1H*

The improvement strategies derived from the FMEA and Fishbone analyses were further operationalized using the 5W+1H framework, which transforms broad risk factors into structured and actionable solutions. This framework allowed the research team to translate each identified weakness into practical interventions that address the *What, Why, Where, When, Who,* and *How* of corrective action. For instance, in the material dimension, the establishment of buffer stock for critical components is necessary to ensure uninterrupted supply during maintenance periods, especially when unexpected failures occur. Similarly, in the measurement category, routine validation of Effectiveness of Material Usage (EPM) data at the end of each month is essential to align planning with actual consumption and reduce discrepancies that may lead to inefficiencies. In terms of machines, optimizing ERP and IP-ProInventory systems through gradual upgrades and training ensures more accurate, real-time monitoring of inventory data, which has been shown in prior studies to reduce mismatch and improve supply-chain responsiveness[29] [8].

The method factor underscores the need to standardize SOPs across planning and warehouse divisions to reduce procedural inconsistencies and improve coordination. Environmental risks—such as weather disruptions and long distances between warehouses and units—can be reduced through layout redesign and protective facilities that maintain material accessibility. The man dimension highlights the human element of planning: quarterly training can reduce ERP input errors and strengthen coordination among HR, inventory, and warehouse teams, ensuring shared procedural understanding and better planning accuracy. These interventions align with inventory management best practices that integrate Safety Stock, Reorder Point (ROP), and EOQ models with organizational and technological improvements[12] [13].

The structured summary of these recommendations is presented in Table 3 and Table 4, which consolidates the improvement strategies into clear, implementable actions based on the 5W+1H framework. This tabular format enables practitioners to quickly identify responsibilities, timing, and execution methods for each intervention, thereby ensuring that the proposed solutions are not only theoretically sound but also practically applicable to the operational context of PT PLN Indonesia Power UBP Saguling. By integrating quantitative risk assessments with qualitative improvement tools, this study underscores the significance of combining analytical rigor with actionable strategies, offering a replicable framework for enhancing material planning effectiveness in the energy sector.

Table 3 Strategic Action Plan Based on 5W+1H

Factor	What (Action)	Why (Reason)
Material	Provide buffer stock for critical items	Ensure availability of critical materials
Measurement	Periodically validate EPM data	Improve demand data accuracy
Machine	Optimize ERP & IP-ProInventory systems	Enhance real-time integration
Method	Standardize SOPs	Reduce procedural discrepancies
Environment	Reassess warehouse layout	Minimize disruption risks
Man	Conduct regular technical training	Reduce human error & strengthen coordination

Table 4 Implementation Plan

Factor	Where	When	Who	How
Material	Main warehouse	Before maintenance	Planning & warehouse team	Safety stock calculation
Measurement	EPM system	Monthly	Planning team	Planned vs actual comparison
Machine	ERP server	Gradual	IT & inventory	System upgrade + training
Method	Warehouse areas	Annual cycle	Managers	SOP drafting & socialization
Environment	Storage unit	Before restructuring	Logistics team	Layout redesign
Man	Training room	Quarterly	HR & inventory	Technical refresh training

IV. CONCLUSION

This study has demonstrated that material planning at PT PLN Indonesia Power UBP Saguling continues to face significant risks that directly affect operational reliability. The analysis of Effectiveness of Material Usage (EPM) from January to June 2025 revealed inconsistent performance, with sharp declines in certain months that highlighted weaknesses in forecasting accuracy and supplier lead-time management. Through the application of Failure Mode and Effect Analysis (FMEA), five critical failure modes were identified, with discrepancies in material usage documentation (TUG9) producing the highest Risk Priority Number (RPN) of 270. The Fishbone Diagram further revealed that these problems originate from a combination of technical and organizational factors, including human error, fragmented coordination, underutilized ERP systems, and external environmental disruptions. The study also confirmed that these systemic issues result in simultaneous risks of overstock and stockout, conditions that not only raise storage and operational costs but also delay preventive maintenance schedules. By systematically combining EPM evaluation with risk identification and root cause analysis, the findings emphasize the urgent need to strengthen planning accuracy, improve digital monitoring systems, and enhance coordination across divisions and with vendors to ensure material availability aligns with operational requirements.

Conceptually and methodologically, this study advances an integrated framework that connects quantitative risk prioritization through FMEA with qualitative root cause analysis via the Fishbone Diagram and the structured design of improvement strategies using the 5W+1H approach. This integration provides not only a theoretical contribution to supply-chain risk management but also a practice-ready model for power-generation contexts. By operationalizing continuous improvement principles, the framework clarifies accountability across organizational roles, synchronizes planning governance with digital platforms such as ERP, and translates complex risks into actionable strategies. In practical terms, the recommendations deliver short-term improvements, including routine validation of material usage data, standardization of SOPs, and targeted training for warehouse and planning staff, while also preparing organizations for medium-term enhancements such as ERP real-time integration, warehouse layout redesign, and vendor SLA formalization. Nevertheless, the research is not without limitations. The single-unit case study design and six-month observation period restrict generalizability, and the reliance on expert judgment in FMEA scoring introduces subjectivity into the prioritization process. Moreover, the absence of post-implementation validation means that the financial and operational impacts of the recommendations remain untested. Future studies should therefore extend this framework to multiple power plants, apply it over longer time horizons, and incorporate advanced techniques such as fuzzy-FMEA, multi-criteria decision-making, or data-driven forecasting with machine learning to enhance robustness and scalability.

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