Intelligent Material Code Deduplication and Governance Using Tokenization-Based Fuzzy Matching for Industrial Group Collaboration

Chunyan Yu[1], Xingyan Zhou[1], Jianjia He[1,2], Han Xia[1]
[1]*Business School, University of Shanghai for Science and Technology, Shanghai, China*
[2]*Center for Super Networks Research, University of Shanghai for Science and Technology, Shanghai China*

Abstract: Ensuring the uniqueness of material codes in group-level material management is essential for integrating business and finance across an industrial supply chain. This study proposes an intelligent deduplication and governance approach by incorporating a fuzzy matching algorithm based on tokenization matrices. The method enhances material management efficiency by computing the similarity between newly applied material codes and historical records, ensuring precise duplication detection. The algorithm tokenizes material names, specifications, and models to construct a tokenization matrix, enabling accurate similarity calculations. It is applied to key approval processes in the aluminum industry, including material code application, deactivation, activation, and merging. Empirical results from a large aluminum industry group demonstrate that the algorithm significantly reduces duplicate codes, improving data accuracy and management efficiency. The findings show that this approach optimizes inventory balancing, minimizes overstocking, and reduces capital occupation, contributing to cost control and operational efficiency. Moreover, it supports cross-subsidiary material sharing, reinforcing data standardization across departments and systems. The proposed method offers a scalable and effective solution for intelligent material governance in industrial groups, highlighting its broad applicability and high promotional value in enterprise-wide material management.

Keywords: Supply Chain Management; Material Coding; Inventory Optimization; Fuzzy Matching

1. Introduction

In large-scale aluminum industry group enterprises, issues such as multiple codes for the same material and multiple materials sharing a single code impact the accuracy of material demand reporting, inventory balancing, procurement, usage, and stocktaking at varying degrees[1]. The phenomenon of multiple codes for the same material significantly affects the accuracy and timeliness of material information statistics, posing severe challenges to material management[2]. According to the Guidelines for Improving the Supply Chain Management Level of Manufacturing Enterprises (Trial) jointly issued by the Ministry of Industry and Information Technology and other departments in 2024, enterprises are encouraged to standardize material coding in collaboration with upstream and downstream supply chain partners and participate in the development of general, key technology, and industry application standards[3]. This policy directive provides clear guidance for material code management in manufacturing enterprises, enhancing supply chain efficiency, reducing inconsistencies due to non-unified coding, and promoting effective collaboration within the supply chain[4]. Leveraging digital technology for intelligent material code deduplication and governance can optimize the allocation of technological, human, informational, and industrial resources, making them more rational and efficient[5]. Given the backdrop of excessive inventory tying up corporate cash flow and the policy-driven push for digitization, promoting intelligent material coding deduplication and governance offers an information-based, industrialized, and systematized solution for material management in aluminum industry groups. This initiative facilitates the standardization and unification of material coding, addressing long-standing issues such as decentralized material coding, inconsistent classification standards across multi-tier supply chains, and redundant or misclassified codes. Consequently, it helps reduce communication and transaction costs across different segments of the industrial chain.

The intelligent material coding deduplication and governance system is designed to standardize material classification by employing structured standards and predefined rules[6], enabling rapid retrieval and in-depth analysis of essential material information and their interrelations. This approach establishes a methodological foundation for improving material management efficiency and accuracy.

In recent years, intelligent technologies have been widely explored for material coding analysis and supply chain optimization, particularly in areas such as material demand planning, procurement, warehousing, and stocktaking[7-8]. The application of intelligent material coding systems has proven effective in logistics allocation, inventory control, and centralized procurement by reducing redundant coding and ensuring data consistency across different operational units[9-10].

Despite advancements in information classification and coding, challenges remain in the implementation of standardized material coding frameworks. Many enterprises lack strategic planning in this domain, leading to inconsistencies that hinder operational efficiency. The issue is particularly prevalent in small and medium-sized enterprises, where the absence of specialized coding teams and standardized implementation processes results in fragmented and uncoordinated material coding efforts. Such inconsistencies obstruct information sharing and create inefficiencies in inventory management, procurement, and logistics operations. While progress has been made in establishing national standards for information classification and material coding, the actual implementation varies significantly among enterprises. Cost considerations, legacy systems, and entrenched practices often lead organizations to deviate from established standards, thereby diminishing the intended benefits of standardized material management.

With the increasing adoption of digitalization and artificial intelligence in supply chain management, intelligent material coding systems play a crucial role in enhancing efficiency, ensuring regulatory compliance, and supporting sustainable development. By integrating digital technologies, enterprises can improve environmental sustainability, enhance corporate social responsibility, and optimize economic performance[11]. The relationship between warehouse logistics distribution and material coding is particularly significant, as standardized coding enables more accurate inventory tracking, minimizes sorting errors, and optimizes logistics routes[12]. Non-standardized coding, on the other hand, contributes to high sorting error rates and inefficiencies in storage and transportation.

Given these insights, the adoption of intelligent material coding deduplication and governance systems is essential for large-scale enterprises seeking to streamline supply chain operations. By leveraging these technologies, organizations can enhance material coding accuracy, provide a robust data foundation for industrial chain collaboration, and improve overall operational efficiency. This approach reduces inventory costs, minimizes communication barriers, and supports data-driven decision-making, ultimately leading to a more agile and responsive supply chain. Costs. Additionally, studies on intelligent material coding deduplication and governance have traditionally focused on machine learning and natural language processing techniques to build comprehensive, standardized, and unique material coding management systems[13]. These efforts have significantly improved the accuracy of material data in centralized procurement. However, the potential of advanced artificial intelligence technologies, such as large language models, in enhancing material coding deduplication and governance remains underexplored.

In response to this gap, this study utilizes A Groups supply chain management relationship data, along with regulatory documents, case studies, and academic literature in the supply chain field, to extract key factors across different industrial chain scenarios. It proposes a construction method for intelligent material coding deduplication and governance, tailored for large-scale aluminum industry groups, and explores its application through information retrieval and fuzzy matching algorithms. The study aims to resolve supply chain challenges such as inconsistent material names, specifications, classifications, and measurement units, which contribute to duplicate coding issues. By addressing these challenges at the industrial chain level, the study provides a standardized and accurate data foundation for material management while offering a new perspective on the digital and intelligent transformation of supply chain management. Ensuring the uniqueness and standardization of group material codes, the proposed intelligent material coding deduplication and governance framework integrates artificial intelligence, big data, and the Internet of Things (IoT) to enable full lifecycle management of materials. This includes tracking information from demand initiation, procurement monitoring, warehouse acceptance, issuance, return, maintenance, and disposal. Additionally, it facilitates group-wide material sharing and centralized procurement, enhancing operational transparency and efficiency.

Table 1. Material Coding for Post Responsibility Plaques

No.	Name	Specification (mm)	Material Composition	Unit
1	Post Description Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
2	Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
3	Roasting & Packaging Area Inspection Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
4	Roasting & Packaging Area Supervisor Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Sheet
5	Roasting & Packaging Area Director and Deputy Director Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
6	Decomposition & Evaporation Area Inspection Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
7	Decomposition & Evaporation Area Supervisor Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Sheet
8	Decomposition & Evaporation Area Deputy Director Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Unit
9	Decomposition & Evaporation Area Director Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
10	Alumina Safety & Production Department Planning Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
11	Alumina Safety & Production Department Technician Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
12	Alumina Safety & Production Department Dispatcher Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
13	Alumina Safety & Production Department Minister Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
14	Red Mud Filtration Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Square Meter
15	Pre-Desilication & High-Pressure Pump Room Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
16	Dissolution & Sedimentation Area Inspection and Supervisor Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
17	Dissolution & Sedimentation Area Deputy Director Post Responsibility Plaque (2)	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
18	Dissolution & Sedimentation Area Deputy Director Post Responsibility Plaque (1)	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
19	Dissolution & Sedimentation Area Director Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
20	Raw Material Area Inspection & Supervisor Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
21	Raw Material Area Primary & Secondary Operator Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece

22	Raw Material Area Ore Conveying System Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Square Meter
23	Raw Material Area Grinding System Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
24	Raw Material Area Director and Deputy Director Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
25	Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
26	Post Regulation Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
27	Post Identification Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece
28	High-Pressure Dissolution & Dilution Post Responsibility Plaque	800 × 500	Aluminum-Plastic Board + Vinyl Decal	Piece

2. Analysis of Duplicate Material Coding in Group-Level Management

To investigate the causes of duplicate material coding, this study examines a commonly used identification plaque in Company A as a case study. The plaque, referred to as the "Post Responsibility Plaque," has a standard specification of 0.8m *0.5m and is measured in units. A fuzzy search within the enterprise's material management system revealed 28 different material codes assigned to this same item.

A detailed analysis of Table 1 highlights several key inconsistencies contributing to the issue. First, the lack of a standardized naming convention results in variations in item descriptions, making it difficult to accurately classify and retrieve materials. Second, identical physical dimensions are expressed using different measurement units, including meters (m), centimeters (cm), and millimeters (mm), leading to unnecessary variations in coding. Third, the same material is assigned different measurement units such as units, sheets, and square meters, further complicating material identification. These inconsistencies directly impact procurement, inventory balancing, stocktaking, and overall coding standardization. The manual deduplication of material codes is an extremely time-consuming process, resulting in low efficiency and high operational costs. To address these issues, the fuzzy matching mechanism for mandatory material attributes and the intelligent material coding deduplication and governance system were introduced. Before the implementation of these mechanisms, the group-level material coding process followed the workflow illustrated in Figure 1.

The root causes of these issues lie in the absence of a unified material coding framework and the independent deployment of multiple material management systems across different subsidiaries. Without a standardized approach, inconsistencies naturally arise, leading to duplicate entries and misclassified materials. Furthermore, the material code application process lacks scientific rigor, allowing redundant codes to be generated without a structured approval mechanism. These factors collectively hinder material traceability and disrupt supply chain coordination.

To address these inefficiencies, the fuzzy matching mechanism for mandatory material attributes and the intelligent material coding deduplication and governance system were introduced. Before the implementation of these mechanisms, material coding within the group followed a manual process. Technical personnel in the requesting department provided key material information, including material name, specifications, measurement units, and material standards, based on supplier records or historical databases. Material planners in each department then conducted manual searches in the material management system to determine if an existing material code was available. If no matching code was found, a new material coding application was initiated. Once submitted, material administrators in subsidiaries manually cross-checked their respective local material management systems before approving a new code. If no exact match was identified, the system generated a new material code automatically.

The reliance on manual querying at multiple stages of the process introduces significant inefficiencies. Both applicants and approvers must conduct duplicate searches twice, making the accuracy and efficiency of deduplication highly dependent on personnel experience and familiarity with the coding system. Moreover, the material management system currently only supports exact searches, meaning that minor discrepancies in input formatting prevent duplicate codes from being detected. Since the system is deployed using a Client/Server (C/S) architecture on local networks, its search scope, speed, and accuracy are limited. For instance, when searching for "B-Type Metal Wound Gasket" and "(B-Type) Metal Wound Gasket," the presence of parentheses prevents the system from recognizing them as duplicates, leading to incorrect search outcomes. Manual deduplication alone is insufficient to ensure accurate and efficient material code governance.

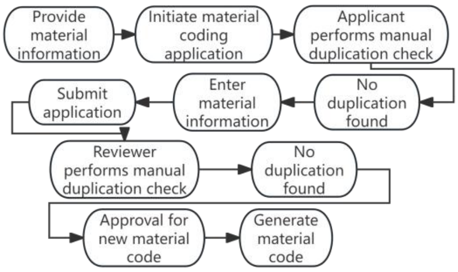

Figure 1. Original Group's New Material Code Generation Process

These challenges underscore the necessity of an intelligent material coding deduplication system that integrates fuzzy matching algorithms and automated material classification techniques. By optimizing search mechanisms and standardizing coding structures, the implementation of such a system can significantly enhance material management efficiency, reduce procurement costs, and improve overall supply chain coordination.

3. Optimization of Material Code Deduplication Mechanism

Enhancing the efficiency and accuracy of material information retrieval in aluminum industry groups is crucial for preventing duplicate material codes. Leveraging natural language processing (NLP) and segmentation-based matching algorithms enables intelligent text deduplication. By analyzing textual similarities, the algorithm identifies overlapping segments among multiple entries and quantifies their relative contribution within each text. This study applies a segmentation matrix-based fuzzy matching algorithm to material queries and optimizes the material code management system and approval workflow, achieving intelligent material code deduplication at the group level. To improve the efficiency of the deduplication algorithm, it is necessary to establish mandatory material attributes and verification rules.

Each material entry must include essential attributes such as name, specification and model, measurement unit, material standard, manufacturer, and technical parameters. Standardized input management and mandatory validation are implemented for different material categories to ensure data consistency. During the deduplication process, searches are confined to the same material category to enhance computational efficiency. Classification-based deduplication rules are established according to supplier requirements, assisting both code applicants and approvers in decision-making. The current material classification system supports four distinct types of deduplication rules, each subjected to mandatory validation to establish a solid foundation for material coding standardization. The distribution of different deduplication rules is illustrated in Figure 2.

Figure 2. Distribution of Duplication Check Rules for Different Elements

Since some material attributes require additional auxiliary information for similarity calculation, the four deduplication rules assign different weights based on input characteristics to compute an overall similarity score. During this process, materials with similar names, specifications, and material standards are initially flagged as potential duplicates. If uncertainty remains, additional attributes such as material category and measurement unit are incorporated into the similarity assessment. The methodology follows a hierarchical approach: if two material entries share similar names and specifications but remain indistinguishable, the system evaluates material standard similarity. If differentiation is still unclear, the system further considers category and measurement unit attributes. Measurement units are particularly crucial; if two materials have different units, they are more likely to be distinct, whereas identical units increase the probability of being the same material. The system integrates historical data and expert knowledge to refine weight assignments, ensuring an optimal deduplication framework. The final comprehensive similarity weight configuration is presented in Table 2.

Table 2. Comprehensive Similarity Weight of Different Types of Duplication Check Rules

Material Element	Name Uniqueness	Specification Uniqueness	Material Standard Uniqueness	Measurement Unit Uniqueness
Filling Condition	All Fields Filled	Name Only	Specification Only	All Fields Filled
Weight	20	0	100	80

The technical parameters of material data are stored in an Oracle relational database, allowing flexible management of complex technical specifications. This approach offers high readability, scalability, and structured data representation, supporting various formats such as objects, arrays, strings, and numeric values. By applying predefined deduplication rules, material attributes undergo segmentation-based matching, and materials with high similarity scores are displayed for further validation. The deduplication logic follows a structured workflow:

Implementation of the Fuzzy Matching Algorithm for Material Code Deduplication

To implement intelligent material deduplication, a segmentation-based similarity matching algorithm is integrated into the system. The algorithm leverages the TF-IDF (Term Frequency-Inverse Document Frequency) vectorization and cosine similarity calculation to identify duplicate materials based on text segmentation. The workflow consists of the following steps:

Data Preprocessing – The algorithm extracts material names and specifications from the dataset and tokenizes them using the Jieba segmentation tool to handle variations in wording and format.

Feature Vectorization – The TF-IDF model transforms tokenized text into numerical vectors, quantifying the importance of each token in relation to the dataset.

Similarity Computation – The cosine similarity algorithm calculates the degree of overlap between vectorized material entries, identifying those exceeding a predefined threshold as potential duplicates.

Grouping and Deduplication – The system clusters highly similar materials, reducing redundancy while maintaining data integrity.

Final Verification – The system generates a deduplication report, allowing manual validation for borderline cases where algorithmic confidence is low.

The Python script implementing this fuzzy matching algorithm is as follows:

```
#!/usr/bin/env python3
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.metrics.pairwise import cosine_similarity
import pandas as pd
import jieba
import time
import csv
def similarity(cut, score):
  vectorizer = TfidfVectorizer(token_pattern=r'(?u)\w+|\.+')
   tfidf_matrix = vectorizer.fit_transform(cut)
   cosine_sim_matrix = cosine_similarity(tfidf_matrix)
   similarity_df = pd.DataFrame(cosine_sim_matrix, index=cut.index, columns=cut.index)
   # Identify material pairs with similarity above threshold
   high_similarity_pairs = similarity_df.where(similarity_df > score).stack().dropna()
   similar_pairs_indices = high_similarity_pairs.index.tolist()
   # Group similar materials
   groups = {}
   for pair in similar_pairs_indices:
      if not any(pair[1] in group for group in groups.values()):
         for item in pair:
            if item not in groups:
               groups[item] = {item}
            else:
               groups[item]. add(pair[1])
   return {key: group for key, group in groups.items() if len(group) > 1}
# Load dataset
wl = pd.read_csv('materials_data.csv', low_memory=False)
wl['MATERIAL_NAME'] = wl['MATERIAL_NAME'].astype(str)
```

```
wl['SPEC_MODEL_NUMBER'] = wl['SPEC_MODEL_NUMBER'].astype(str)
# Tokenization
wl['NAME_CUT'] = wl['MATERIAL_NAME'].apply(lambda name: " ".join(jieba.cut(name)))
wl['SPEC_CUT'] = wl['SPEC_MODEL_NUMBER'].apply(lambda spec: " ".join(jieba.cut(spec)))
# Compute similarity scores
non_singleton_groups = similarity(wl['NAME_CUT'], 0.5)
wl_new = wl.loc[[item for subset in non_singleton_groups.values() for item in subset]]
# Save results
wl_new.to_csv('deduplicated_results.csv', index=False, quoting=csv.QUOTE_ALL, encoding='utf-8-sig')
```

With this algorithm embedded into the material management system, the deduplication workflow follows Figure 3. The system first receives material coding requests, enforces input standardization, and applies predefined deduplication rules. The system then conducts a segmentation-based similarity check, comparing material names, specifications, material standards, and measurement units. Finally, similarity scores are computed based on weighted criteria, and the system generates a deduplication report to assist in material code assignment.

The implementation of this system significantly improves material deduplication efficiency, eliminating the need for time-consuming manual searches and enhancing overall data accuracy. By leveraging machine learning and natural language processing, the solution ensures consistent, standardized material coding across the group, reducing procurement costs and optimizing supply chain operations.

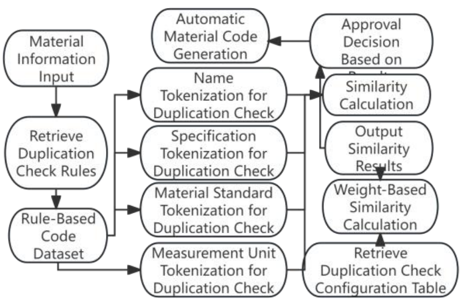

Figure 3. Material Code Generation Process After Embedding Tokenization-Based Fuzzy Matching Duplication Check

4. Implementation and Application

Li et al. proposed a segmentation matrix-based fuzzy matching deduplication algorithm, achieving an accuracy rate of 90.37%, with no false-positive matches observed. Although this method is computationally intensive compared to traditional algorithms, its efficiency can be improved by executing similarity calculations in the server backend before submitting results to the application layer. Since the group's material management system does not natively support embedding such an algorithm, a B/S (Browser/Server) architecture-based management system was developed to facilitate the application and approval of new material codes. Concurrently, the algorithm was used to detect and consolidate redundant codes within the existing material database, ensuring standardized material coding across the group.

Before the implementation of the intelligent material coding deduplication and governance system, the company had accumulated approximately 528 material categories over several years, with a total of 268,000 material codes. Among these, 313 subcategories contained over 50 material codes each, accounting for 219,000 material codes, with turnover materials representing 81.72% of the total material classification and covering 78% of the material codes.

To ensure accurate deduplication, data preprocessing and enrichment were performed before running the algorithm. Standardized material classification data was manually curated and fed into the algorithm's interface, computing the comprehensive similarity between each material code and others within its respective category. Based on the deduplication results, redundant codes were merged, reducing the total number of group-level material codes to 103,000, achieving a 61.57% consolidation rate. Some material categories reached a 70% consolidation rate, demonstrating significant optimization.

For newly added material codes, a group-wide material coding management system based on the B/S architecture was implemented. Upon submission of a new material coding request, the system automatically runs a deduplication check in the background. After processing, the applicant can review the similarity results and decide whether to proceed with the request.

Similarly, approval officers can update deduplication results and determine whether to approve or reject the application. The deduplication results for different types of materials are summarized in Table 3.

By integrating the deduplication mechanism into the application and approval processes, the system has significantly reduced the time spent by applicants and approvers on manual material code searches, while improving the accuracy of coding requests. During system development, additional duplicate code merging functionalities and an annual similarity assessment of material categories were incorporated to support continuous optimization of material coding governance. Since the system’s deployment, the total approval process time has been reduced by approximately 52%, with the average time from request submission to final code generation decreasing to 0.8 days. Additionally, 24% fewer duplicate material codes were submitted for approval, further enhancing coding accuracy.

Table 3. Example of Similarity Calculation Results Using the Duplication Check Algorithm in Material Coding

Specification and Model	Similar Material Specification	Similar Material Description	Similarity (%)
Z962Y-P54 140V DN225	Z962Y-P54 - 140V DN220	Bolt Grade 8.8	91
Z962Y-P54 140V DN250	Z962Y-P54 - 140V DN200	Gland Bolt Grade 4.8	95
Z962Y-P54 140V DN275	Z962Y-P54 - 140V - DN275	Packing Gland Bolt Grade 4.8	90
	Z962Y-P54 - 140V- DN275	Packing Gland Bolt Grade 8.8	100

5. Conclusion

This study applies a segmentation matrix-based fuzzy matching algorithm to address key challenges in group-level material management, including one material with multiple names, multiple categories, multiple measurement units, and multiple materials under one code. By achieving unified material coding, significant improvements were observed in procurement efficiency, inventory optimization, and data traceability. The intelligent deduplication system facilitated material allocation and sharing across the group, reducing inventory costs and enhancing overall operational efficiency. Within one year of implementation, the system enabled 169 material reallocation events, covering 217 material types, and reduced inventory occupation by 3.13 million RMB, demonstrating substantial cost savings.

The integration of fuzzy matching deduplication algorithms into material management enhances standardization, uniqueness, and scalability. The principle of one material, one code serves as the foundation for future material optimization strategies, including digital warehouses and intelligent storage systems. Additionally, it supports the interconnection of material management with equipment maintenance and overhauls, enabling automated stock replenishment and the establishment of strategic safety stock levels. By ensuring effective full lifecycle management of materials, the system provides enterprises with timely and accurate data to support strategic decision-making and drive digital transformation in material management.

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