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Classification of Electrical Distribution Materials Based on Weight and Volume for Warehouse and Transportation Capacity Planning

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Abstract

Electricity distribution logistics involves highly heterogeneous materials with different physical characteristics, creating challenges for warehouse capacity and transportation planning. Conventional material classification approaches mainly focus on economic value, demand frequency, or criticality, while physical logistics burdens generated by material weight and volume remain insufficiently represented. This study develops a weight–volume-based classification framework for electricity distribution materials to support physical logistics planning. A quantitative descriptive approach was applied using material master data and historical demand records from electricity distribution facilities in Central Java and the Special Region of Yogyakarta, Indonesia. Materials were classified into representative categories based on material characteristics, unit weight, and unit volume. Historical demand was then converted into total physical loads expressed in kilograms and cubic meters and aggregated by logistics location. The results identified 24 representative material categories with unit weights ranging from 0.50 to 3,300 kg and unit volumes from less than 0.01 to 4.40 m³. The highest physical demand was observed at UP3 Jogja, reaching 59.30 million kg and 120,221.83 m³. The findings demonstrate that material quantity alone is insufficient to represent logistics requirements in heterogeneous electricity distribution systems. The proposed weight–volume classification provides a practical basis for warehouse capacity evaluation, material handling planning, and transportation resource allocation.

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1. Introduction

Electricity distribution systems require reliable logistics operations to ensure the availability of materials for network construction, maintenance activities, customer connections, and disturbance recovery. Distribution warehouses play an important role in managing material storage, inventory availability, and material flows within the electricity supply chain [1], [2], [3]. However, electricity distribution logistics involves highly heterogeneous materials, ranging from small electrical accessories and meters to large components such as poles, cubicles, and distribution transformers [4], [5], [6]. These differences in physical characteristics create different requirements for warehouse space, material handling resources, and transportation capacity.

Material classification has been widely applied in supply chain and inventory management to simplify complex material systems and support operational decision-making. Conventional classification approaches generally consider economic value, demand frequency, movement characteristics, or operational importance, such as ABC analysis and other inventory segmentation methods [7], [8]. Product grouping based on similar characteristics can reduce analytical complexity and improve resource allocation decisions. Furthermore, warehouse design and logistics planning are strongly influenced by product characteristics, storage requirements, and material flow patterns[9], [10], [11].

Despite these developments, existing material classification approaches primarily focus on inventory control, purchasing priorities, and service-level management. These approaches do not explicitly represent the physical burden generated by heterogeneous materials on warehouse and transportation resources. A material with high economic value may require limited storage space, whereas a relatively lower-value material with large dimensions or high weight may create significant requirements for storage capacity, handling equipment, and transportation capability[12], [13], [14]. Therefore, material quantity, inventory value, or movement frequency alone may not sufficiently represent actual physical logistics demand.

Weight and volume are important physical parameters because they directly influence logistics capacity requirements. Weight represents payload requirements, handling constraints, and equipment limitations, while volume represents storage-space utilization and cargo-space requirements[3], [5]. However, the application of weight and volume as integrated parameters for classifying electricity distribution materials remains limited. Existing studies have not sufficiently addressed how heterogeneous electricity materials can be transformed into measurable physical logistics loads that support warehouse and transportation capacity planning.

Electricity distribution networks manage a large number of material codes with different technical specifications and physical characteristics. Analyzing each material individually may increase managerial complexity and reduce the efficiency of logistics planning. Appropriate aggregation methods can simplify supply chain analysis while maintaining characteristics relevant to decision-making [15], [16]. Therefore, a classification framework that groups materials based on physical characteristics while preserving weight and volume information is required to support logistics capacity analysis.

This study was conducted at an Indonesian state-owned electricity utility, focusing on distribution logistics facilities in Central Java and the Special Region of Yogyakarta. The operational environment involves multiple warehouse locations with different material flows, storage conditions, and demand characteristics. These variations indicate that uniform assumptions regarding logistics capacity may not accurately represent the actual physical workload generated by material demand. The novelty of this study lies in developing a weight–volume-based classification framework that transforms heterogeneous electricity distribution material demand into measurable physical logistics loads. Unlike conventional classification methods that mainly emphasize economic value, demand characteristics, or criticality, the proposed approach represents material demand using total weight (kg) and volume (m^3), enabling direct evaluation of warehouse capacity, material handling requirements, and transportation resources.

Accordingly, this study aims to develop a classification framework for electricity distribution materials based on weight and volume characteristics and to analyze the physical logistics demand generated across distribution warehouse locations. The research addresses two questions: (1) how heterogeneous electricity distribution materials can be grouped into representative categories while maintaining relevant physical characteristics, and (2) how the conversion of historical material demand into weight and volume reveals differences in logistics capacity requirements among warehouse locations. The results are expected to provide a practical analytical basis for improving warehouse capacity planning, material handling strategies, and transportation resource allocation in electricity distribution logistics systems.

2. Methods

2.1 Research Design and Data Source

This study employed a quantitative descriptive approach to develop a weight–volume-based classification framework for electricity distribution materials and evaluate its implications for warehouse and transportation capacity planning. The research was conducted within the electricity distribution logistics system of an Indonesian state-owned electricity utility in Central Java and the Special Region of Yogyakarta.

The research area consists of multiple UP3 (distribution service units) and ULP (service units) warehouses that manage various electricity network materials. These warehouses serve as intermediate distribution points connecting suppliers, central distribution units, operational units, contractors, and customers. The distribution flow of electricity materials is illustrated in Figure 1.

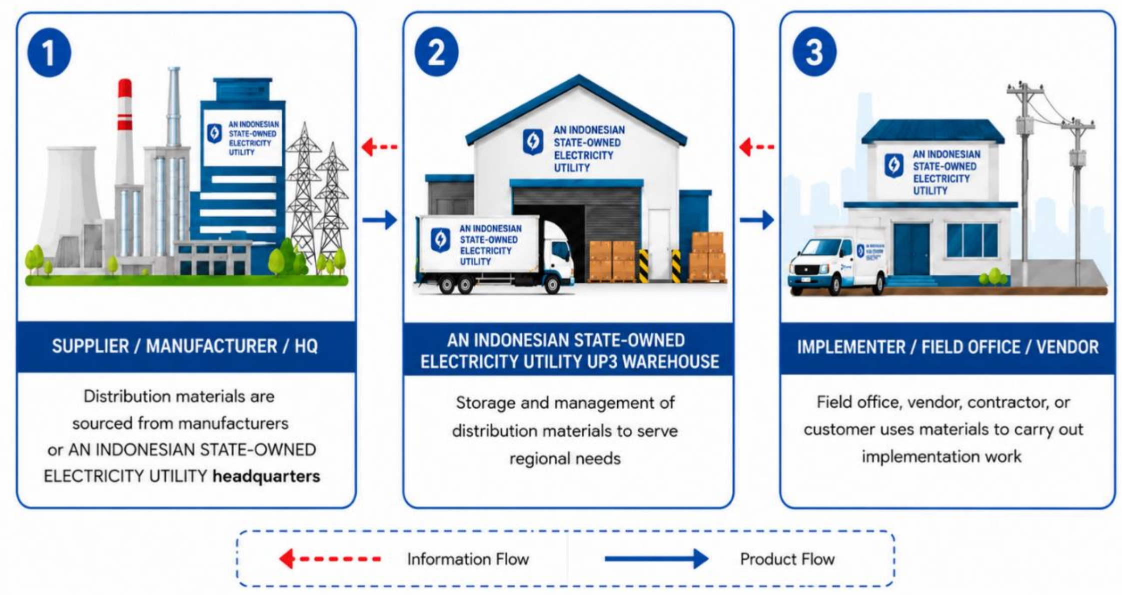

Figure 1. Distribution Network of Electricity Distribution Materials

The observed logistics network consists of warehouses with different material flows, storage conditions, and operational characteristics. These differences indicate that material demand generates different physical logistics requirements among locations. The general characteristics of the observed warehouses are summarized in Table 1.

2.2 Data Collection and Material Classification

The study utilized material master data and historical demand records from the electricity distribution logistics system. The collected data consisted of material descriptions, technical specifications, demand quantities, unit weights, and unit volumes. Due to the large diversity of electricity distribution materials, a rule-based classification approach was applied. Materials were grouped based on similarities in material type, technical specifications, and physical characteristics. The classification process aimed to reduce material complexity while maintaining physical information relevant to logistics planning.

The classification resulted in 24 representative material categories. Each category was assigned a representative unit weight and unit volume, which were subsequently used for physical demand conversion.

Table 1. Electrical Distribution Material Warehouses under An Indonesian State-Owned Electricity Utility Central Java and D.I. Yogyakarta Distribution Unit

No	UP3/UP2D Warehouse	Incoming Material Volume	Outgoing Material Volume	Area Occupancy (%)	Demand Points Served	ITO (%)	DOI (%)	Warehouse Condition
1	Kudus–Senenan	2,392,495	2,357,971	4	9	77.9	54.4	Severely underutilized
2	Surakarta–Jajar	1,866,292	1,673,998	25	7	68.5	47.8	Underutilized
3	Surakarta–Sumberlawang	0	0	5	7	68.5	47.8	ATTB warehouse
4	Yogyakarta–Sedayu	2,748,917	2,590,581	15	20	68.9	48.1	Underutilized
5	Magelang–Tegalrejo	1,507,147	1,423,611	24	8	54.6	38.1	Underutilized
6	Purwokerto–Sokaraja	1,897,391	1,883,663	14	8	59.9	41.8	Underutilized
7	Purwokerto–Wangon	13,416	13,416	8	8	59.9	41.8	Severely underutilized
8	Tegal–Eks Texin	2,468,378	2,457,396	25	11	77	53.8	Underutilized
9	Semarang–Kalisari	27,992	27,992	45	7	64.9	45.3	Moderate utilization
10	Semarang–Krapyak	2,336,303	2,239,245	3	8	64.9	45.3	Severely underutilized
11	Semarang–Randugarut	0	0	11	7	64.9	45.3	ATTB warehouse
12	Salatiga–Bawen	1,035,436	881,302	18	5	57.1	39.8	Underutilized
13	Klaten–Tulung	1,289,125	1,136,436	93	7	73.1	51	Overcapacity
14	Pekalongan–Medono	1,521,652	1,391,710	71	6	85.1	59.4	Optimal utilization
15	Cilacap–Swadaya	1,749,749	1,657,339	12	8	75.9	53	Underutilized
16	Grobogan	1,345,122	1,221,239	100	6	67.8	47.3	Overcapacity
17	Grobogan–Jogoloyo	0	0	–	6	–	–	ATTB warehouse
18	Sukoharjo–Jatisrono	1,210,021	1,124,694	7	7	60.9	42.5	Severely underutilized
19	Semarang UP2D–Mangkang	63,026	44,708	17	14	88.2	61.6	Underutilized

2.3 Conversion of Material Demand into Weight and Volume

Historical material demand was transformed from quantity-based demand into physical logistics demand by calculating total weight and total volume for each logistics location.

The total weight and total volume were calculated using the following equations:

$$W_l = \sum_{i=1}^{n} Q_{il} \, w_i \tag{1}$$

$$V_l = \sum_{i=1}^{n} Q_{il}\, v_i \tag{2}$$

where:

- W_l= total weight of material demand at location l(kg);
- V_l= total volume of material demand at location l(m³);
- Q_{il}= quantity of material category $i$demanded at location l;
- w_i= representative unit weight of material category i(kg/unit);
- v_i= representative unit volume of material category i(m³/unit);
- i= material category index;
- l= logistics location index.

The calculated weight and volume values were aggregated at UP3 and ULP levels to identify differences in physical logistics demand among locations.

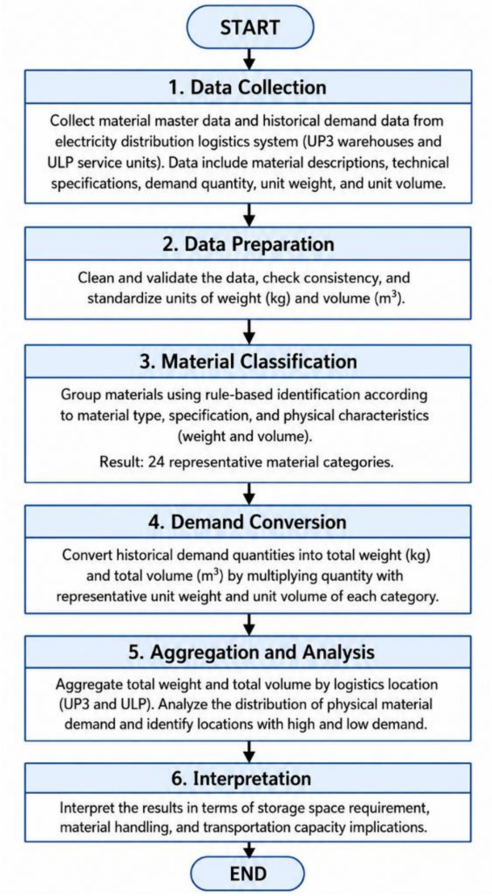

Figure 2. Research Flow Diagram

2.4 Data Analysis Procedure

The analysis consisted of four main stages:

1. Data preparation Material descriptions, specifications, weight, volume, and historical demand data were verified and standardized.
2. Material classification Materials were grouped into representative categories based on physical characteristics.

3. Demand conversion and aggregation Material quantities were converted into total weight and volume and aggregated by logistics location.
4. Logistics implication analysis The resulting weight–volume profiles were analyzed to evaluate implications for warehouse capacity, material handling, and transportation planning.

The overall research procedure is presented in **Figure 2**.

3.Results and Discussion

3.1 Weight–Volume-Based Material Classification

The classification process identified 24 representative categories of electricity distribution materials based on material type, unit weight, and unit volume. The classification was developed to simplify heterogeneous material data while maintaining physical characteristics relevant to logistics planning.

The classification results show substantial variation in physical characteristics among materials. Distribution transformers represent the highest weight and volume categories, with unit weights ranging from 450 to 3,300 kg and unit volumes from 0.90 to 4.40 m³. In contrast, meters, protection devices, and network accessories have considerably lower physical requirements. **Figure 3** presents the Pareto distribution of representative unit weight among the 24 categories.

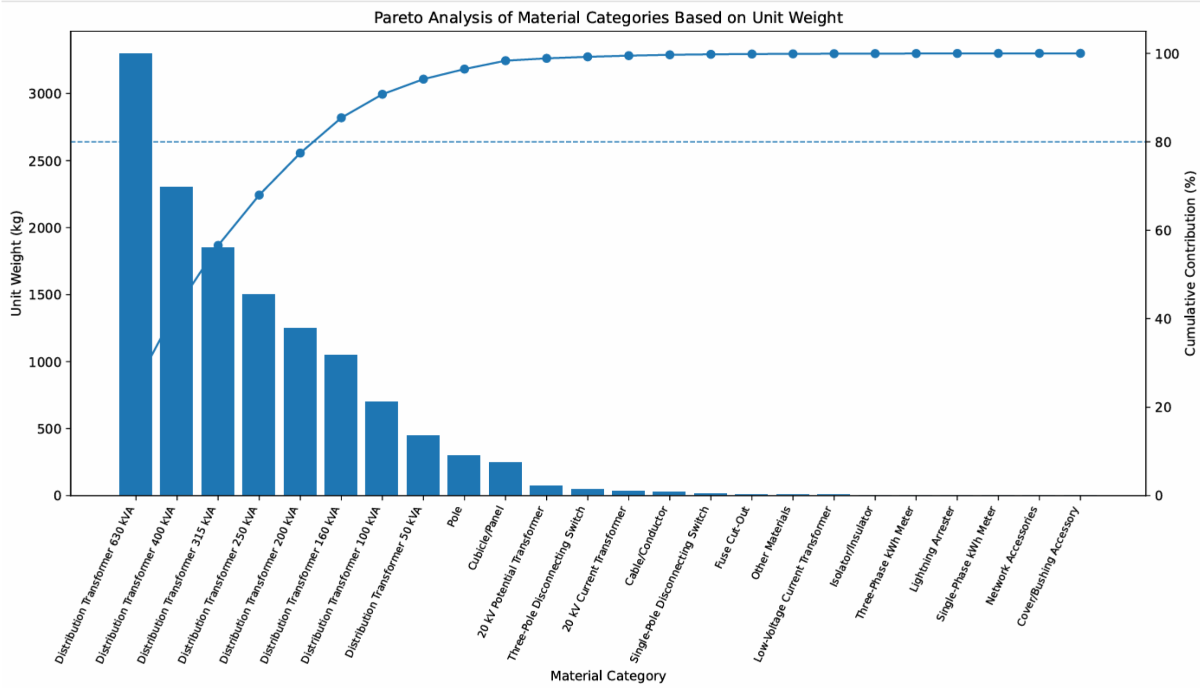

Figure 3. Pareto Based on Unit Weight of 24 Material Categories

The Pareto analysis indicates that transformer categories dominate the physical weight profile. The six largest transformer categories contribute approximately 85.43% of the representative unit-weight distribution. This finding demonstrates that material quantity alone cannot adequately represent logistics workload because different materials generate substantially different handling and storage requirements.

Table 2. Classification of Electricity Distribution Materials Based on Weight and Volume

No.	Material Category	Identification Criteria	Unit Weight (kg)	Unit Volume (m³)
1	Distribution Transformer 50 kVA	TRF/TRAFO + 50 kVA	450	0.9
2	Distribution Transformer 100 kVA	TRF/TRAFO + 100 kVA	700	1.2
3	Distribution Transformer 160 kVA	TRF/TRAFO + 160 kVA	1,050.00	1.6
4	Distribution Transformer 200 kVA	TRF/TRAFO + 200 kVA	1,250.00	1.8
5	Distribution Transformer 250 kVA	TRF/TRAFO + 250 kVA	1,500.00	2.15
6	Distribution Transformer 315 kVA	TRF/TRAFO + 315 kVA	1,850.00	2.6
7	Distribution Transformer 400 kVA	TRF/TRAFO + 400 kVA	2,300.00	3.2
8	Distribution Transformer 630 kVA	TRF/TRAFO + 630 kVA	3,300.00	4.4
9	Single-Phase kWh Meter	MTR/kWh without 3P	1.2	0
10	Three-Phase kWh Meter	MTR/kWh + 3P/4W	2.5	0.01
11	Lightning Arrester	LA/ARRESTER	2.5	0.01
12	Single-Pole Disconnecting Switch	DS 1P	15	0.06
13	Three-Pole Disconnecting Switch	DS 3P/ABSW	45	0.18
14	20 kV Current Transformer	CT + 20 kV/24 kV	35	0.06
15	Low-Voltage Current Transformer	LV CT	5	0.02
16	20 kV Potential Transformer	PT + 20 kV	70	0.1
17	Cubicle/Panel	CUB/PANEL/RMU	250	0.8
18	Fuse Cut-Out	FCO/CUT OUT	8	0.03
19	Isolator/Insulator	ISOLATOR/INSUL	3	0.01
20	Cover/Bushing Accessory	COVER/BUSHING	0.5	0.001
21	Cable/Conductor	KBL/KABEL/CABLE/AAAC/NFA2X	25	0.05
22	Network Accessories	CLAMP/CONN/JOINT/SKUN/TERMINAL/ACC	1	0.01
23	Pole	TIANG/POLE	300	0.5
24	Other Materials	Materials outside Categories 1–23	5	0.02

3.2 Conversion of Material Demand into Physical Logistics Demand

Historical demand data were converted from material quantities into total weight and volume to represent physical logistics demand. The conversion provides two complementary perspectives: weight reflects payload and handling requirements, while volume represents storage and cargo-space requirements.

The conversion results demonstrate that identical material quantities may generate substantially different logistics requirements. For example, 100 units of 630 kVA transformers generate approximately 330,000 kg and 440 m³, while 100 units of lightweight network accessories generate only approximately 100 kg and 1 m³. This difference confirms that unit quantity is insufficient as a standalone indicator of logistics capacity requirements. The aggregated demand analysis shows significant variation among logistics locations.

Table 3. Representation of Material Demand

Demand Measure	Unit	Logistics Interpretation
Material quantity	Unit	Number of materials demanded
Total weight	kg	Handling and transportation load
Total volume	m^3	Storage and cargo-space requirement
Weight–volume profile	kg and m^3	Physical logistics demand

UP3 Jogja recorded the highest physical demand with 59.30 million kg and 120,221.83 m^3, followed by UP3 Tegal and UP3 Kudus–Senenan. At the ULP level, Jogja Kota showed the highest physical demand with 6.32 million kg and 12,869.59 m^3. These differences indicate that logistics workload is not evenly distributed across locations. Locations with high weight and volume demand require greater warehouse capacity, handling capability, and transportation resources. Figure 4 illustrates the relationship between aggregate weight and volume demand.

Table 4. Selected Locations With High Physical Material Demand

Logistics Location	Weight (kg)	Volume (m^3)
UP3 Jogja	59,300,433.50	120,221.83
UP3 Tegal	58,424,120.80	118,129.10
UP3 Kudus–Senenan	57,265,119.90	117,545.31
ULP Jogja Kota	6,317,285.20	12,869.59
ULP Semarang Timur	6,026,927.90	12,305.76
ULP Pati	5,856,764.50	11,791.44

The analysis shows a strong positive relationship between weight and volume demand (Pearson's $r = 0.9998$). However, both parameters remain complementary because weight represents payload constraints, while volume represents spatial constraints.

3.3 Logistics Implications of Weight–Volume Classification

The weight–volume classification provides practical implications for warehouse and transportation planning. First, warehouse capacity planning can be improved by considering physical material characteristics. Heavy and bulky materials, particularly distribution transformers, require dedicated storage areas and mechanical handling equipment. Conversely, lightweight materials may require efficient identification and picking systems due to higher transaction frequency.

Second, transportation planning can benefit from physical demand information. Materials with high weight require vehicles with sufficient payload capacity, whereas bulky materials require adequate cargo space. Therefore, shipment planning based only on material quantity may underestimate actual transportation requirements.

Third, the classification enables differentiation of logistics requirements among locations. High-demand locations such as UP3 Jogja, UP3 Tegal, and UP3 Kudus–Senenan require greater logistics capacity compared with locations generating lower physical demand.

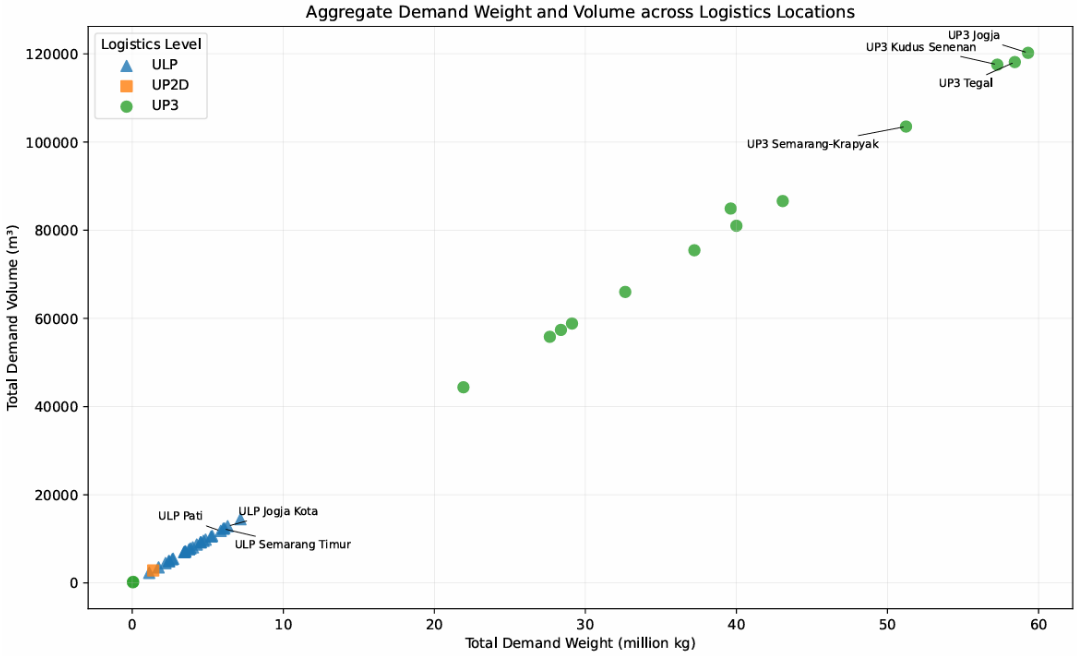

Figure 4. Scatter Plot of Aggregate Demand Weight and Volume Across UP3 and ULP Logistics Locations

The proposed framework complements conventional inventory classification approaches. Unlike value-based or demand-frequency classifications that support inventory control decisions [14], [15], the weight–volume approach provides additional information regarding physical logistics burden. Therefore, it can be used as an intermediate analytical framework between individual material codes and aggregated logistics planning.

4. Conclusion

This study developed a weight–volume-based classification framework for heterogeneous electricity distribution materials to support physical logistics planning. The results identified 24 representative material categories based on material characteristics, unit weight, and unit volume. The conversion of historical material demand into total weight and volume demonstrated that material quantity alone is insufficient to represent actual logistics requirements, as materials with similar quantities may generate substantially different storage, handling, and transportation demands.

The proposed approach provides a physical representation of logistics demand through weight (kg) and volume (m^3), enabling more accurate evaluation of warehouse capacity, material handling requirements, and transportation resource allocation. The findings indicate that high-demand locations require differentiated logistics strategies based on their physical material load rather than unit-based demand alone. Therefore, weight–volume-based classification can complement conventional inventory classification methods by incorporating physical characteristics relevant to operational capacity planning.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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