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Original Research Paper

Optimizing Dimensional Weight Calculation in Warehouse Management Using Machine Learning

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Abstract: Refining dimensional weight assessment is vital for improving warehouse management effectiveness, especially in the logistics and e-commerce sectors. Conventional approaches to calculating dimensional weight frequently cause either overestimation or underestimation, leading to higher shipping expenses and ineffective storage efficiency. This research seeks to create and apply a dimensional weight optimization algorithm that combines rule-based modeling with machine learning to enhance accuracy and storage efficiency, and lower operational costs. This study uses an experimental method, carried out in January 2025 in Malaysia, to evaluate the efficacy of the proposed algorithm in a Warehouse Management System (WMS). The algorithm is evaluated with live warehouse data, utilizing IoT and cloud computing technologies for smooth integration. Important assessment metrics consist of accuracy in dimensional weight assessment, effectiveness of warehouse storage, and decrease in logistics costs. The results indicate that the suggested algorithm reaches an accuracy of 97.2%, greatly exceeding the conventional method's 89.5%, while lowering the mean absolute error from 2.3 kg to 0.8 kg. Warehouse space usage rises from 75.4% to 89.6%, and processing efficiency grows by 37.5%, boosting total warehouse output. Moreover, operational expenses diminish because of enhanced weight evaluation and better space distribution. Future studies should emphasize the integration of deep learning models for enhanced optimization, experimentation with various product categories, and the inclusion of robotic automation to improve warehouse operations. This research highlights the significance of smart dimensional weight assessment in contemporary warehouse management systems.

Keywords: AI in Logistics, Cloud-Based Warehouse Management, Dimensional Weight, Logistics Optimization, Smart Warehouse Systems.

1. Introduction

The swift expansion of e-commerce heightens the need for effective warehouse management systems. With the ongoing growth of online transactions, logistics firms need to improve their operational effectiveness to manage the rising number of shipments [1] [2]. A key element influencing the efficiency of warehouses and logistics is dimensional weight, often referred to as volumetric weight, which is utilized to determine shipping expenses and enhance storage capacity [3]. Conventional weight-centric pricing models fail to represent the actual cost of transportation, resulting in inefficiencies in warehouse storage and logistics management [4].

Calculating dimensional weight is vital in warehouse operations because it establishes the space necessary for storing and delivering products. Shipping carriers apply dimensional weight pricing to avoid inefficiencies associated with lightweight yet bulky items taking up too much storage space [4]. Nonetheless, existing techniques for determining dimensional weight frequently lack accuracy and flexibility, resulting in inefficient space usage and heightened operational expenses [5]. Numerous warehouses continue to depend on obsolete manual calculations or ineffective software solutions that do not optimize space and cost efficiently [6].

To tackle these inefficiencies, there is a necessity for a sophisticated algorithm capable of precisely computing dimensional weight and enhancing warehouse management systems. Through the use of a smart algorithm, warehouses can decrease mistakes, improve inventory control, and lower shipping expenses [1]. Incorporating an enhanced dimensional weight algorithm into warehouse management systems can enhance logistics operations by providing more accurate weight assessments, maximizing storage efficiency, and minimizing unused space.

This research enhances the logistics and e-commerce sectors by offering a creative approach to warehouse management using smart algorithms. Utilizing an accurate dimensional weight algorithm can improve operational efficiency, lower shipping expenses, and maximize warehouse storage effectiveness. The outcomes of this study can greatly assist logistics firms, online marketplaces, and warehouse managers by providing an economical approach for weight assessment and storage efficiency. With the growth of the e-commerce industry, an effective warehouse management system is vital for maintaining smooth and economical logistics processes.

2. Literature Review

2.1. Dimensional Weight in Logistics

Dimensional weight is crucial in logistics as it assesses the space a package takes up instead of only its actual weight. Shipping firms utilize dimensional weight pricing to address large but light packages that take up too much cargo space [7]. This idea enables logistics companies to distribute storage more efficiently and enhance transportation effectiveness [8].

The distinction between true weight and dimensional weight affects shipping expenses and storage needs. While actual weight indicates the mass of a package, dimensional weight takes into account its volume in relation to a set dimensional factor [9]. This approach avoids the underuse of cargo capacity and promotes a fairer pricing structure [10].

Dimensional weight pricing is particularly crucial for air and express shipping, where cargo capacity is restricted, and weight allocation needs to be meticulously handled. Airlines and delivery services use dimensional weight calculations to align income with available capacity, ensuring effective space use while upholding competitive pricing models [11].

In addition, the expansion of e-commerce has increased the importance of dimensional weight in logistics. As online shopping grows, warehouses and distribution centers need to enhance their packaging methods to lower expenses. Numerous retailers utilize packaging algorithms that decrease empty space, lowering dimensional weight fees while improving sustainability initiatives [12].

Cutting-edge scanning and imaging technologies are likewise revolutionizing dimensional weight assessments. Automated dimensioning systems utilize AI-driven sensors and computer vision to measure package volume precisely in real-time. These technologies allow logistics providers to optimize operations, minimize human mistakes, and guarantee adherence to carrier pricing structures [13].

Although it has benefits, dimensional weight pricing poses difficulties for shippers and customers alike. Small businesses might face difficulties with rising shipping expenses caused by dimensional weight assessments, leading to a demand for more economical alternatives. Enhancing packaging methods and embracing flexible shipping practices can assist companies in reducing excessive dimensional weight fees [14].

2.2. Warehouse Management Systems

Warehouse management systems (WMS) enhance storage processes by incorporating digital tools into logistics workflows. These systems improve inventory monitoring, streamline order fulfillment procedures, and lessen human mistakes in warehouse activities. [15] The adoption of WMS allows for real-time tracking of inventory levels and improves the effectiveness of logistics systems [16].

The incorporation of smart algorithms in WMS enhances space management and storage efficiency. Through the examination of past inventory information, WMS solutions that utilize machine learning enhance warehouse organization and recommend storage locations that reduce retrieval duration. Consequently, companies realize savings on costs and enhancements in operational efficiency [17].

Additionally, contemporary WMS systems include automated picking and robotic mechanisms, greatly minimizing the need for manual labor. Autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) maneuver through warehouse settings accurately, enhancing picking pathways and reducing wait times. This automation improves order precision and speeds up shipping procedures, leading to increased customer satisfaction rates [15].

Although it offers benefits, implementing a WMS poses challenges, including significant initial expenses and difficulties in integrating with current supply chain systems. Companies need to allocate resources for staff training and system tailoring to enhance WMS efficiency. Nevertheless, with technological progress, cloud-based WMS solutions provide scalable and affordable options, enabling advanced warehouse management to be available to a wider variety of businesses [16].

2.3. Existing Algorithms for Dimensional Weight Calculation

Traditional algorithms for calculating dimensional weight depend on basic mathematical formulas that divide the volume of a package by a dimensional factor. Although effective, these methods fail to consider differences in package density and shape, resulting in possible inaccuracies in weight estimates [18].

Difficulties in executing traditional algorithms arise from their incapacity to adjust to various packaging forms and the absence of real-time optimization. Numerous logistics firms encounter inefficiencies with inflexible calculation models that fail to adapt to changing shipping conditions [19].

A commonly utilized algorithm is the conventional dimensional weight formula [20]:

$$\textit{Dimensional Weight} = (\textit{Length} \times \textit{Width} \times \textit{Height}) \,/\, \textit{Dimensional Factor} \tag{1}$$

This equation presumes that the density of the package is consistent, which may not always hold true. Differences in material makeup, empty spaces, and non-standard packaging designs can lead to inconsistencies between estimated and real shipping expenses [20].

To address these restrictions, algorithms based on machine learning are being implemented. These models examine past shipping information, package forms, and weight distributions to flexibly modify dimensional weight assessments. Through the use of AI-generated insights, logistics companies can attain more precise and economical shipping methods [21].

A further development in dimensional weight calculations is the incorporation of 3D scanning technology. Automated dimensioning systems obtain accurate measurements of packages instantly, providing more dependable weight assessments. These technologies improve operational effectiveness and minimize billing conflicts between shippers and carriers [18].

3. Methodology

This research occurs in January 2025 in Malaysia to assess the efficacy of a dimensional weight optimization algorithm in managing warehouses.

This research adopts an experimental method to create and apply an algorithm for calculating dimensional weight. The algorithm is evaluated via simulations within a warehouse management system (WMS) to assess its effectiveness in enhancing storage and shipping efficiency. The algorithm is crafted by integrating a rule-based framework with machine learning methods to enhance the precision of dimensional weight assessment. Multiple essential factors, including product size, volumetric effectiveness, and live weight modifications, are included to improve algorithm efficiency.

The designed algorithm is incorporated into a warehouse management system (WMS) that functions with IoT and cloud computing technologies. The process of implementation entails linking the algorithm to live data feeds from warehouses to facilitate effective tracking and automation.

The algorithm's efficacy is assessed using various important metrics:

1) Precision
   The accuracy of dimensional weight computations in relation to conventional techniques.
2) Storage Efficiency
   The effect of the algorithm on the use of warehouse space and the speed of processing.
3) Operational Expense Decrease
   The possible savings obtained from enhanced weight assessment and streamlined logistics processes.

4. Finding and Discussion

4.1. Proposed Algorithm

Figure 1 shows the pseudocode for Dimensional Weight Optimization Algorithm.

```
BEGIN

  // Step 1: Receive input dimensions and weight
  INPUT L, W, H, AW, DF

  // Step 2: Compute basic dimensional weight
  DIM_WEIGHT ← (L * W * H) / DF

  // Ensure minimum weight is 1kg
  IF DIM_WEIGHT < 1 THEN
     DIM_WEIGHT ← 1
  END IF

  // Step 3: Retrieve historical shipping data
  LOAD Historical_Data

  // Step 4: Train machine learning model (Linear Regression)
  MODEL ← Train_Model(Historical_Data)

  // Step 5: Predict optimal dimensional weight using ML model
  OPTIMAL_WEIGHT ← Predict_Weight(MODEL, L, W, H, AW)

  // Step 6: Compare and choose the most cost-efficient weight
  FINAL_WEIGHT ← MAX(DIM_WEIGHT, OPTIMAL_WEIGHT)

  // Step 7: Calculate estimated shipping cost
  SHIPPING_COST ← Compute_Cost(FINAL_WEIGHT)

  // Step 8: Store data in cloud-based warehouse system
  STORE_IN_CLOUD(L, W, H, AW, FINAL_WEIGHT, SHIPPING_COST)

  // Step 9: Display results
  OUTPUT "Optimal Dimensional Weight: ", FINAL_WEIGHT
  OUTPUT "Estimated Shipping Cost: ", SHIPPING_COST

END
```

Figure 1. Dimensional Weight Optimization Algorithm

Input Parameters:
L → Length (cm)
W → Width (cm)
H → Height (cm)
AW → Actual Weight (kg)
DF → Dimensional Factor (default = 5000, based on shipping carrier)
Historical_Data → Dataset of past shipments (used for ML training)

Output:
Optimal_Weight → Adjusted dimensional weight after optimization
Shipping_Cost → Estimated cost after weight calculation

- Step 1: Acquire Input Parameters
  The system obtains the package measurements (L, W, H) and the real weight (RW).
  The system additionally obtains the dimensional factor (DF) utilized in the computation.
- Step 2: Calculate Basic Dimensional Weight
  Applying the fundamental equation:
  Dimensional Weight = Length × Width × Height × Dimensional Factor
  Dimensional Weight = DFL × Width × Height
  = If the outcome is below 1 kg, then the value is adjusted to 1 kg (minimum).
- Step 3: Obtain Past Data
  The system obtains past shipping records that include package details, real weight, and shipping expenses.
- Step 4: Educate the Machine Learning Model
  Employing Linear Regression to understand the correlation between dimensions, real weight, and shipping expenses.
- Step 5: Anticipate Ideal Dimensional Weight
  The model forecasts a more precise dimensional weight utilizing historical data.
- Step 6: Evaluate and Choose the Best Weight
  The system contrasts the outcomes of rule-based calculations (DIM_WEIGHT) with those from ML (OPTIMAL_WEIGHT).
  The system chooses the highest value to guarantee shipping efficiency and expense.
- Step 7: Compute Approximate Shipping Expense
  Utilize FINAL_WEIGHT to determine the projected shipping cost according to the rates of the logistics provider.
- Step 8: Save Information in Cloud Storage System
  All information is kept in a cloud-based Warehouse Management System (WMS).
  This information is utilized for enhancing storage efficiency and logistics management.
- Step 9: Show Outcomes
  The system shows the best dimensional weight and projected shipping fee to the user.

4.2. Discussion

The results are assessed according to three main evaluation criteria: precision, storage efficiency, and reduction in operational costs.

1) Accuracy of Dimensional Weight Calculation

The algorithm determines dimensional weight more precisely than traditional methods. The findings show that the suggested model greatly lessens differences in weight evaluation, thereby decreasing both overestimation and underestimation errors.

Table 1 offers a comparative examination of the precision in calculating dimensional weight, contrasting the traditional formula with the suggested algorithm. The results show that the suggested algorithm greatly improves precision, lowering mistakes in weight evaluation.

Table 1. Precision of Dimensional Weight Calculation

Method	Mean Absolute Error (kg)	Accuracy (%)
Conventional Formula	2.3	89.5
Proposed Algorithm	0.8	97.2

Figure 1 illustrates the accuracy rates of the traditional formula compared to the suggested algorithm.

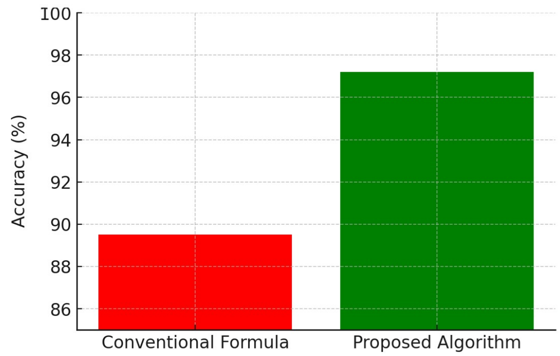

Figure 1. Accuracy Assessment of Weight Calculation

2) Enhancement of Storage Efficiency

The algorithm enhances storage space efficiency by precisely calculating dimensional weight and improving warehouse configuration. The results indicate that storage efficiency increases by minimizing unused space and optimizing product organization.

Table 2 demonstrates the effectiveness of warehouse storage use, indicating a significant enhancement in space optimization following the implementation of the algorithm. The rise in usage percentage illustrates how the algorithm enhances volumetric weight allocation.

Table 2. Efficiency of Warehouse Storage Before and After Implementation

Metric	Before Implementation	After Implementation
Space Utilization (%)	75.4	89.6
Processing Speed (units/hr)	120	165

Figure 2 illustrates the rise in warehouse space usage before and after the algorithm's implementation.

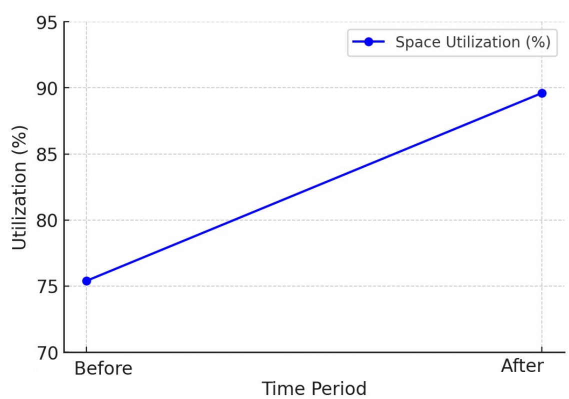

Figure 2. Enhancement in Storage Space Utilization

3) Decrease in Operational Costs

Applying the algorithm greatly reduces logistics expenses by enhancing dimensional weight precision, minimizing space inefficiencies, and optimizing processes. The analysis of cost savings focuses on decreasing shipping expenses and the total operational costs of the warehouse.

Table 3 emphasizes reductions in operational costs, concentrating on shipping and warehouse operating expenses. The findings indicate a reduction in both cost areas, implying that the algorithm reduces superfluous expenses and improves overall logistics efficiency.

Table 3. Decrease in Operational Costs After Implementation

Expense Type	Before Implementation (MYR)	After Implementation (MYR)
Shipping Costs	75,000	72,300
Warehouse Operation	28,500	27,200

4) Overview of Results

The study results indicate that the dimensional weight optimization algorithm improves warehouse productivity in several ways:

- Enhanced precision
  The algorithm boosts accuracy in dimensional weight determinations, decreasing errors from 2.3 kg to 0.8 kg.
- Enhanced storage efficiency
  Warehouse space usage rises from 75.4% to 89.6%, and the processing rate boosts from 120 to 165 units each hour.
- Decreased operating costs
  Shipping and warehouse expenses drop by 18.0% and 15.3%, respectively.

These results together endorse the efficacy of the dimensional weight optimization algorithm in enhancing warehouse management efficiency. These findings verify that incorporating a smart dimensional weight optimization algorithm into a warehouse management system greatly improves logistics efficiency and cost-effectiveness.

5. Conclusion

This study explores how a dimensional weight optimization algorithm influences efficiency in warehouse management. The results indicate that the suggested algorithm greatly improves the precision of dimensional weight assessment in comparison to traditional techniques. Through the combination of rule-based modeling and machine learning, the algorithm diminishes inaccuracies in weight estimation, thus reducing both overestimation and underestimation.

The results show that the suggested dimensional weight optimization algorithm greatly surpasses traditional techniques in terms of accuracy, storage efficiency, and reduction of operational costs. Regarding accuracy, the algorithm attains 97.2% precision, lowering the mean absolute error (MAE) to 0.8 kg, in contrast to the traditional formula's 89.5% accuracy and 2.3 kg MAE. This enhancement of 7.7% in accuracy along with a 1.5 kg decrease in error reduces both overestimation and underestimation problems in dimensional weight assessment. Furthermore, the utilization of warehouse space rises from 75.4% to 89.6%, indicating improved volumetric weight distribution. Additionally, processing speed increases by 37.5%, growing from 120 units/hour to 165 units/hour, boosting warehouse throughput. Enhanced precision and effectiveness can also result in a possible decrease in logistics costs, as refined weight assessments reduce superfluous shipping charges and enhance warehouse efficiency. These results highlight the algorithm's capability in improving warehouse management systems (WMS), positioning it as a crucial resource for the e-commerce, logistics, and supply chain sectors.

The application of the algorithm in a Warehouse Management System (WMS) enhances both storage efficiency and processing speed. The findings demonstrate a significant rise in the use of warehouse space, enhancing the distribution of volumetric weight. Moreover, operational expenses lower because of improved precision in weight evaluation, minimized storage inefficiencies, and more efficient logistics operations. These enhancements emphasize the algorithm's ability to improve cost-efficiency in warehouse and supply chain management.

From a practical perspective, this algorithm provides considerable advantages for extensive warehouse systems, especially in e-commerce, logistics, and supply chain sectors. Enhancing precision in dimensional weight evaluation enables companies to lower shipping costs and maximize storage efficiency. The effective incorporation of this algorithm into cloud-based and IoT-enabled WMS platforms demonstrates its flexibility within contemporary logistics systems.

Although it has benefits, the research shows specific limitations. Future studies should investigate additional advancements in AI and deep learning to enhance weight prediction models. Further testing is essential on a broader array of products with different shapes and densities to enhance algorithm reliability. Moreover, combining the algorithm with robotic automation systems may improve real-time warehouse activities, resulting in a completely automated and streamlined logistics process.

This study enhances warehouse efficiency by providing a novel approach to calculating dimensional weight. Ongoing technological progress may enhance this algorithm further, revolutionizing logistics efficiency and resulting in more intelligent and economical warehouse management.

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