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Warehouse Optimization for Sustainability: A Case of a Company Supplying Renewable Energy Components

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Abstract

Warehousing plays a significant role in the storage, control, and maintenance of renewable energy systems that require sizable volumes of specialized, bulky, fragile, and high value equipment. Furthermore, these components are imported from countries such as India and China, thus necessitating proper warehousing to prevent supply delays due to disruptions. Now, the adoption of sustainable warehousing practices requires the assessment of the current practices to identify areas of improvement. This study analysed the warehouse operations of Company X Engineering within the renewable energy sector, which faces challenges of managing large volumes of materials while optimizing logistical and environmental practices, which can lead to wastage thereby impacting sustainability. The focus was on the use of technology for data capturing, stock volumes, cost, routes for transportation and fuel consumption. A descriptive analysis of quantitative data was adopted to provide insights on the current situation and assist in making proposals for future solutions. Through data analysis, areas of improvement such as fuel consumption, and inventory management were identified to serve as a basis for adoption of sustainable solutions. For example, the implementation of ABC classification system helped in reducing stockout risks. This study sets an agenda for further discussions and development in the field of warehousing, and data analysis for improvement and sustainability.

Keywords
Warehouse Optimization, Sustainability, ABC Classification, Inventory Management, Renewable Energy

1. Introduction
Warehouses are critical features of supply chain processes providing storage, control, and management of products in centralized locations. Companies in this industry are constantly seeking ways to streamline operations, reduce costs, and minimize their environmental footprint. This focus on operational excellence is shaped by regulatory pressures, customer expectations, and the global push toward a greener economy. However, managing large volumes of materials in warehouses, while integrating sustainable practices, presents significant challenges that companies must navigate to meet these goals. In warehouse management, various challenges such as inventory inaccuracies, labour shortages, and supply chain disruptions require innovative solutions, including advanced technologies, process improvements, and strategic planning. Bagaskara et al. (2020) spotlight the consequence of ineffective route planning that increases travel distances for workers, leading to slower operations and a higher error rate. These inefficiencies not only impact financial outcomes but also compromise customer satisfaction, underscoring the urgency for strategic layout redesign to bolster warehouse operations. Additionally, Wang and Ke (2019) identify problems like poor space utilization and unclear functional area delineation, which can cause congestion and logistical bottlenecks, thereby escalating operational costs and impeding the warehouse's capacity to efficiently fulfil customer demands. The purpose of warehouse solutions is to address shortcomings in inventory management and inefficiencies warehouse practices, thereby reducing costs, averting stockouts, and optimizing quality of service (Elorrieta-Ordoñez and Guevara-Cardozo, 2024). Despite this, research on sustainable warehouses is still in its early stages. Now, sustainable innovative technologies help to reduce energy consumption and greenhouse gas emissions from warehouse operations, and that sustainable innovative technologies provide solutions to reduce the environmental and social impacts of

warehouse operations (Al-Saad, et al., 2023). In case of warehouses for renewable energy components, there are challenges associated with traits of renewable energy parts causing complex inventory management. Figure 1. below presents the traits of renewable energy parts causing complex inventory management adapted from text provided in (Lapide, 2023).

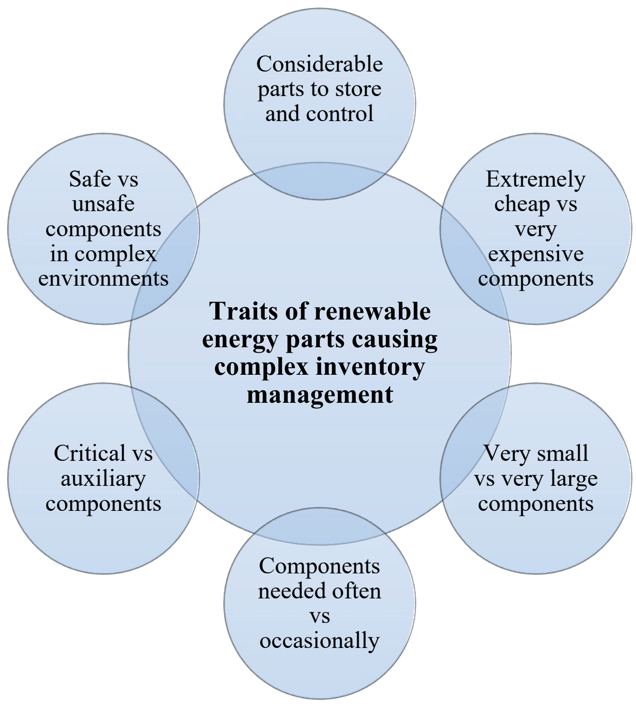

Figure 1. Traits of renewable energy parts causing complex inventory management (Adapted from: Lapide, 2023)

There is a need to address these challenges and enhance warehousing specifically for renewable energy components as the world embarks on the journey towards sustainability.

1.1 Objectives

The aim of the study was to analyse current practices and propose solutions for warehouse optimization using use a case Company X Engineering. This aim involved the following objectives:

- To analyse the existing warehouse operations to identify areas that can be optimized for improved material flow and inventory management.
- To identify and discuss areas for enhancing sustainable warehousing.
- To propose and implement solutions for warehouse optimization in terms of logistics, fuel consumption through delivery routes. through delivery routes.

This study makes contributions to sustainable practices within the warehousing of renewable components. It sets the agenda for research and further development leading to optimised warehouses.

2. Literature Review

2.1 Sustainable Warehouse Practices

Sustainable warehouse practices aim to minimize environmental impact by implementing eco-friendly initiatives such as energy-efficient lighting, waste reduction programs, and the use of renewable materials in warehouse construction and operations. These practices encapsulate a vision that goes beyond immediate economic benefits, integrating long-term environmental and social considerations into the heart of warehouse and supply chain operations. According to Tahboub and Salhieh (2019), efforts to reduce waste in warehouse activities have a significant positive impact on warehouse operation performance, leading to improvements in overall business performance. Additionally, Carli et al. (2020) highlights the importance of sustainability in warehouse management, particularly in energy management, to minimize environmental impact and enhance economic competitiveness. Their research emphasizes the adoption of scheduling strategies that minimize electricity costs and reduce carbon emissions, aligning economic advantages with sustainable practices.

2.2 Technology in Warehouse Management
Technology plays a crucial role in modern warehouse management, enabling automation, real- time tracking, and integration with supply chain systems to optimize processes and enhance operational visibility. Barcode and RFID technology have emerged as essential tools for inventory tracking and management, providing accurate and efficient identification of items throughout the warehouse. According to Thanapal, Prabhu, and Jakhar (2017), implementing tracking systems from initial to final stages reduces human error and increases work efficiency. Dhaliwal (2020) predicts substantial revenue growth in the global warehouse robotics market, highlighting the increasing adoption of robotics in modern logistics. Additionally, Internet of Things (IoT) sensors play a vital role in monitoring environmental conditions within warehouses, ensuring optimal storage conditions for sensitive products. Such technological evolutions not only contribute to lowering operational costs but also promote better ergonomics and efficient space use, reinforcing the pivotal role of technology in the pursuit of sustainability and operational excellence in warehouse management.

2.3 Data Analytics in Warehousing
Data analytics plays a pivotal role in modern warehouse management, providing valuable insights that drive informed decision-making and optimize operations. By leveraging data analytics tools and techniques, warehouses can analyse vast amounts of data related to inventory levels, order volumes, customer preferences, and operational performance. This enables warehouses to forecast demand more accurately, optimize inventory levels, and improve resource allocation and to make better-informed decisions. Research indicates that the logistics industry has grown increasingly complex due to globalization and evolving market and consumer behaviors, making it essential for businesses to not only leverage advanced IT-based warehouse management systems (WMS) to collect accurate data, but also to thoroughly analyze and optimize their logistics networks to remain competitive (Andiyappillai, 2019). Data analytics in warehouse management is emerging as a valuable tool for extracting insights from vast data sets, improving performance, and reducing operational costs (Ghaouta et al., 2018).

2.4 Inventory Management and Material Handling
Efficient control of inventory and careful handling of materials are essential for keeping stock at ideal levels, reducing the risk of shortages, and fulfilling orders with precision. The evolving complexity of modern global supply chains calls for innovative approaches to effectively address challenges in demand forecasting and inventory optimization (Nwenje and Taiwo, 2025). For example, some companies implement inventory management techniques such as Economic Order Quantity (EOQ) and Safety Stock that have been proven to be instrumental in enhancing warehouse performance. Kurniawan et al. (2024) highlight the significance of such practices in their study, emphasizing their role in improving warehouse efficiency and productivity. Furthermore, by adhering to EOQ and Safety Stock guidelines companies can mitigate risks associated with stockouts and overstock situations, ultimately leading to improved customer satisfaction and timely delivery. In their study, Andrada and Biscocho (2019) advocate for ABC inventory analysis to categorize materials based on picking frequency, facilitating efficient item retrieval and placement. Coupled with a "U" flow layout, such strategies aim to reduce delays and cut travel distances, enhancing overall operational efficiency.

3. Methodology
This study used an exemplary case study research methodology of a Company X Engineering. It focussed on the warehouse and logistics operations such as inventory management, fuel consumption, and routes for transportation. The quantitative data, such as stock quantities, stockout risks, costs per item, and fuel consumption, was analysed to optimize inventory and logistics processes. The data provided spanned from the 1st of June 2024 and spans for three months until the 31st of august 2024, including 738 job numbers for the components that the company sold. Additionally, qualitative insights were gathered through observations of overall warehouse operations, which are perceived to be running smoothly and efficiently. The data was collected via access to data dumps provided by the head of operations using a cloud-based management software program called eazycontracting. This software supports

with gathering of easy to use and reliable data, formalization of workflows, management of inventory, and displays for making informed decisions.
The data dumps included details on stock levels, stockout days, fuel consumption, and logistics information. The raw data was refined using Excel, where it was organized and prepared for analysis. All data is securely stored in go.eazycontracting.com.
Beyond data used to develop tables, the following equations were also used for data analysis:

$$\textbf{Number of bakkies based on weight} = \frac{\textbf{Total Weight (kg)}}{\textbf{Bakkie Weight Capacity (1,000 kg)}}$$
Eq.1

$$\textbf{Number of bakkies based on volume} = \frac{\textbf{Total volume (m}^3\textbf{)}}{\textbf{Bakkie volume Capacity (1,2 m}^3\textbf{)}}$$
Eq.2

$$\textbf{Fuel cost per job} = \frac{\textbf{Total distance} \times \textbf{Number of Bakkies}}{\textbf{8,33km/l}} \times \textbf{Fuel price per liter} \qquad \text{Eq.3}$$

Notes: Average fuel efficiency with carrying approximately 1000kg. The figure 8,33km/l was taken from data given by Company X Engineering, the low figure is due to the heavy weight in the back of the bakkie.

5. Results and Discussion

The study is conducted at Company X Engineering focusing on the warehouse and logistics operations. The current state of the warehouse is perceived to be running efficiently, with well-organized processes in place for inventory management and logistics coordination. Inventory levels are regularly monitored, and replenishment schedules are aligned with demand. Overall, the system is viewed as functioning smoothly, with no major operational issues.

5.1 Item Weight and Volume

Table 1 below presents the average weights and volumes of the renewable energy components in the warehouse.

Table 1. Average weights and volume for each renewable component

Item Category	Average Weight (kg)	Average Volume (m^3)
Inverters	50	0,1
Battery	30	0,03
Solar Panels	20	0,15
Distribution Boards	15	0,05
Circuit Breakers/Fuses	1,5	0,003
Miscellaneous	1	0,01
Cable Routing (per meter)	0,5	0,002
Cables (per meter)	0,3	0,0005
Panel Mounting (per unit)	0,3	0,001
Consumables (per item)	0,05	0,0001
Lugs (per lug)	0,05	0,00005

Inverters have the highest weight (50 kg) and volume (0,1 m^3), which could have a significant impact on logistics and storage. Whereas solar panels are also bulky and heavy, with an average weight of 20 kg and volume of 0,15 m^3. Furthermore, smaller items like Circuit Breakers/Fuses and Lugs have much lower weights and volumes, making them easier to handle and store. The information on weight and volume helps when developing layouts, storage capacity, and transportation.

5.2 Total Quantity and Cost

The total quantity of renewable components is exhibited in Figure 2 below.

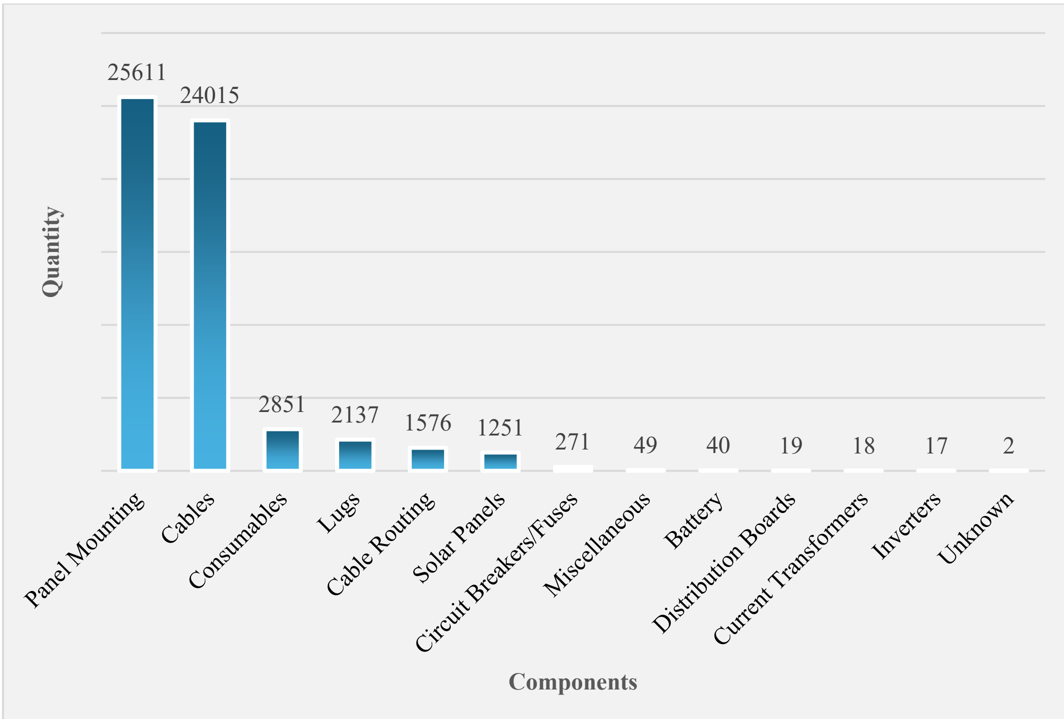

Figure 2. Quantity of renewable energy parts

Warehousing cost per component was recorded and the results are s presented in Figure 3 below.

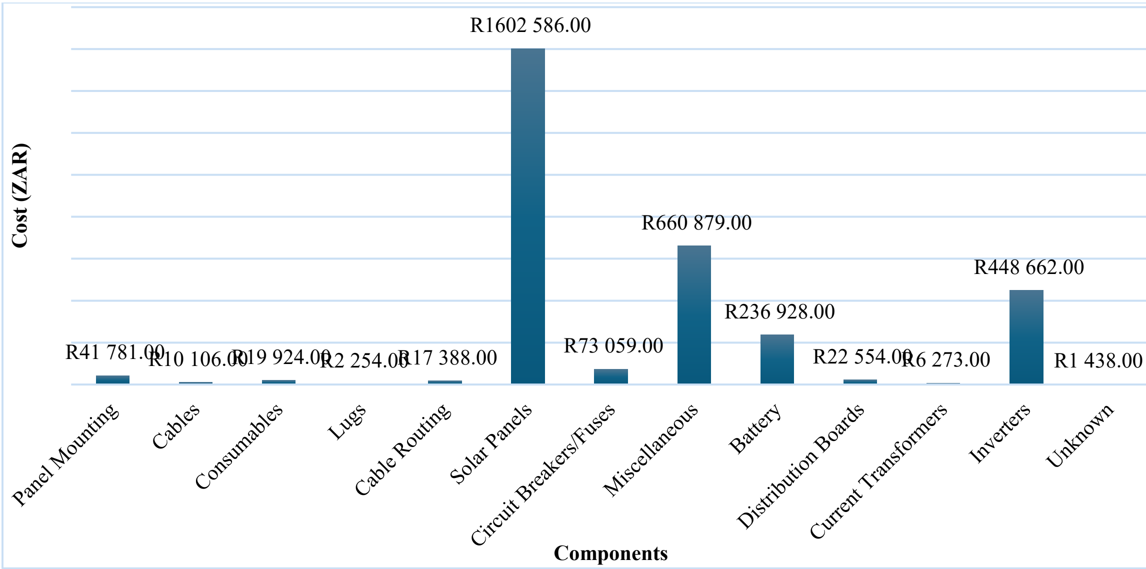

Figure 3. Warehousing cost for the group of items

Panel mounting (25611 units) and Cables (24015 units) make up the largest quantities, indicating their high demand in operations. On the other hand, solar panels have only 1251 units but contribute significantly to the total cost (51%), reflecting their high unit price. Furthermore, miscellaneous items, despite having only 49 units, account for 21% of the cost, likely due to their specialized or high-value nature. Inverters and Batteries have small quantities but also contribute notably to overall costs, emphasizing their value in the system.
Now, the knowledge of weight, volume, and quantity can be used to improve facility layouts and integrity of warehouse structures as they are key in defining the storage units (Saderova et al., 2021). Furthermore, it can assist in re-designing the racks for cost-effectiveness. It was also expected that managing fewer solar panels generally has a higher cost per panel compared to the cost associated with mounting systems. This is because even the manufacturing of solar panels involves complex processes and materials that are more expensive and sensitive than the materials and labour of mounting.

5.3 Logistic Summary and Fuel Cost per Job

The fuel cost represented in South African rands (ZAR) associated with the transportation of components to different sites was analysed as presented in Figure 4 below.

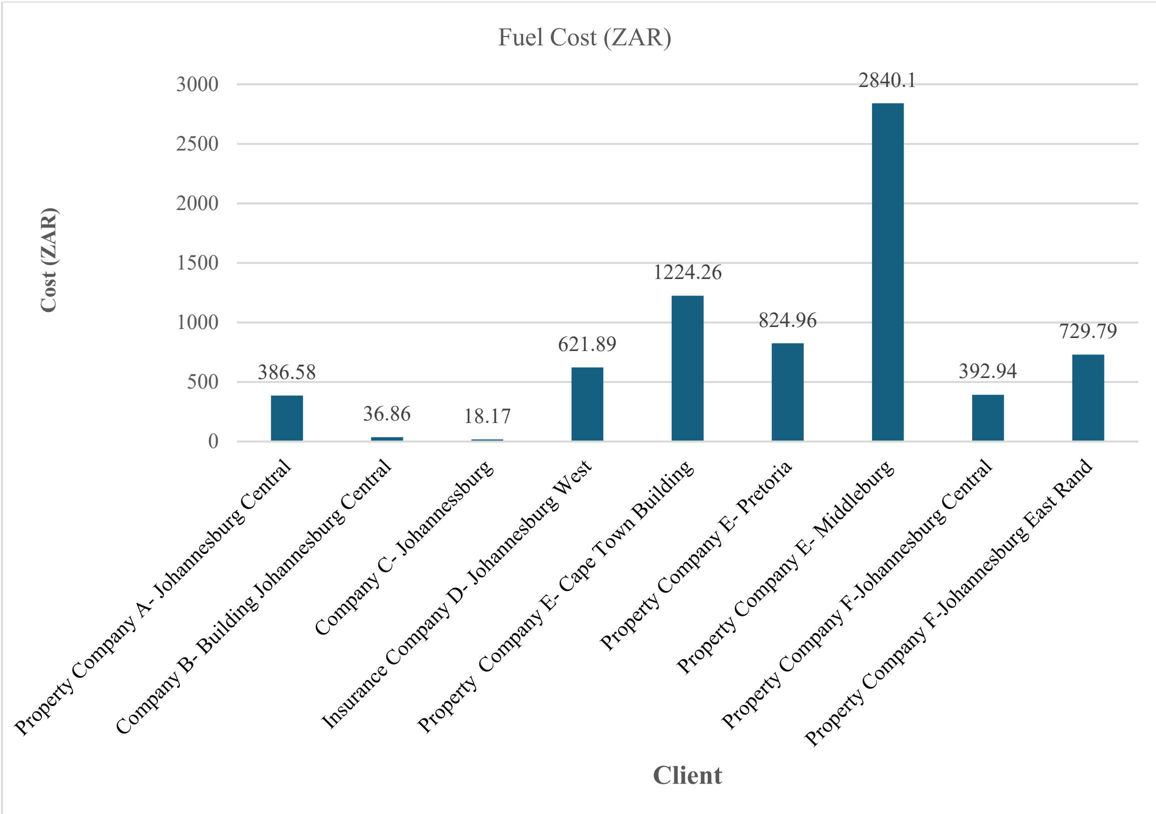

Figure 4. Fuel cost for transportation of equipment to sites

The fuel cost and travel distance were also evaluated, and results are presented in Figure 5 below.

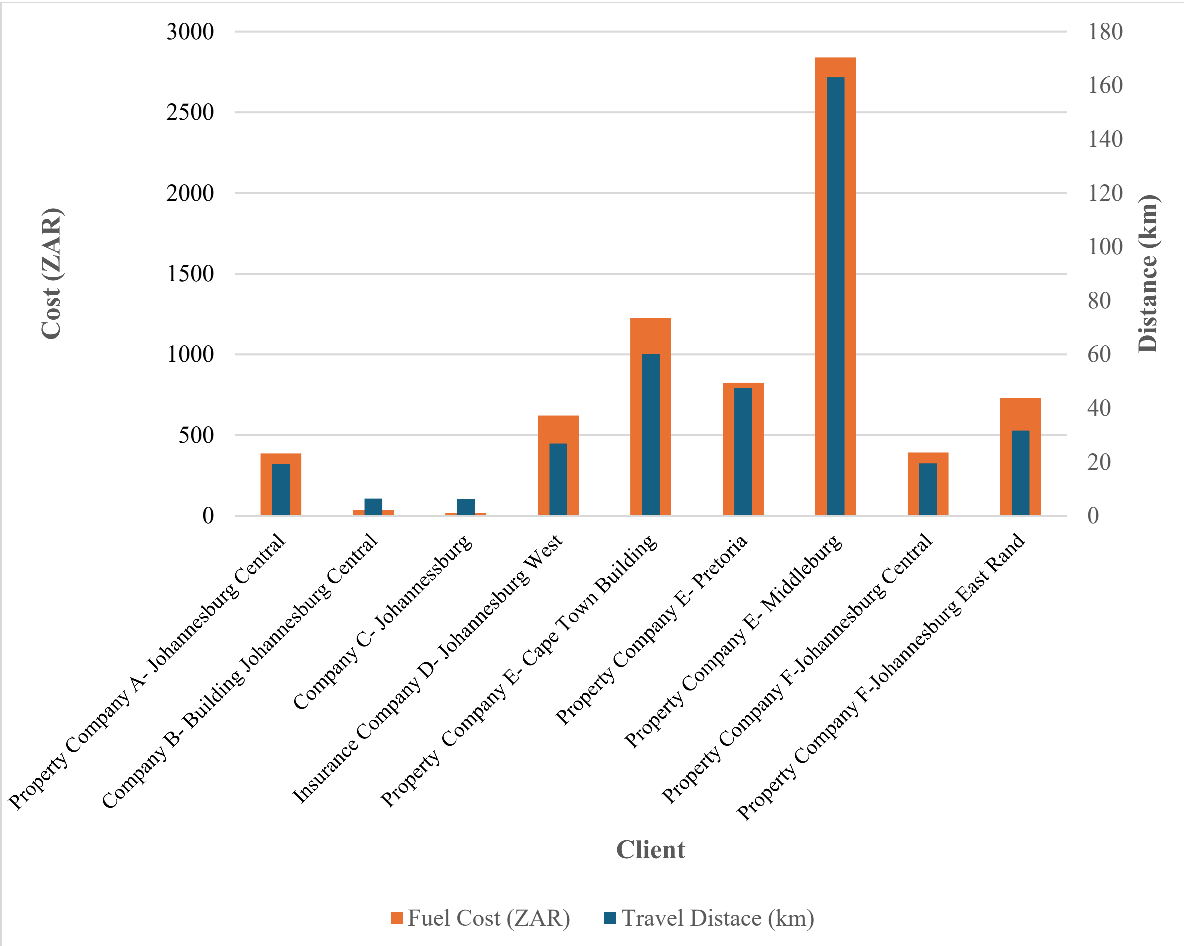

Figure 5. Logistics summary in terms of fuel cost and travel distance

Resource Usage Across Clients: Property Company E – Middleburg Station requires the most resources, with 6 bakkies and the highest fuel cost at ZAR 2,840.10. The long travel distance and heavier loads contribute to this, making it the most resource-intensive client. Fuel efficiency for smaller jobs such as Company B – Building Johannesburg Central and Company C - Johannesburg demonstrate much lower resource needs, requiring only 1 or 2 bakkies and incurring minimal fuel costs (R 18,17 and R 36,86 respectively). These jobs reflect higher fuel efficiency due to shorter travel distances and lighter loads. High-cost jobs and logistics planning such as Property Company E – Pretoria and Insurance Company D – Johannesburg West, also involve significant fuel costs. These costs correlate with the number of bakkies used and the distance travelled. By optimizing routes or grouping deliveries, it's possible to reduce the logistical costs associated with these jobs. Opportunity for Cost Optimization: The variation in fuel costs across clients highlights potential areas for improving logistics planning. Reducing the number of trips for distant projects or combining deliveries could significantly cut down fuel expenses. The results on cost and travel can be used to determine emissions of greenhouse gases and the detection of areas with unusually high fuel usage as supported by (Huertas et al., 2022).

5.4 Stockout Risk and ABC Classification

This section presents the results of stockout risk, cost per item, and days until stockout using ABC Classification. Figure 6 below presents of the results of stockout quantity.

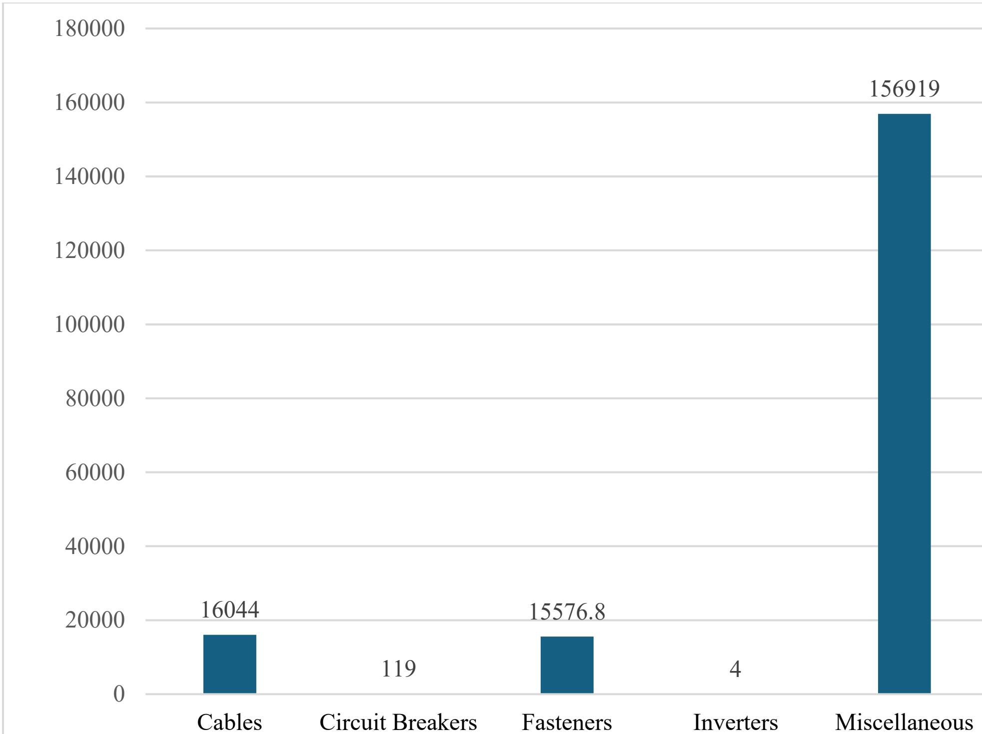

Figure 6. Quantity of stock until stockout

Results of cost per item in South African Rands (ZAR) are presented in Figure 7 below.

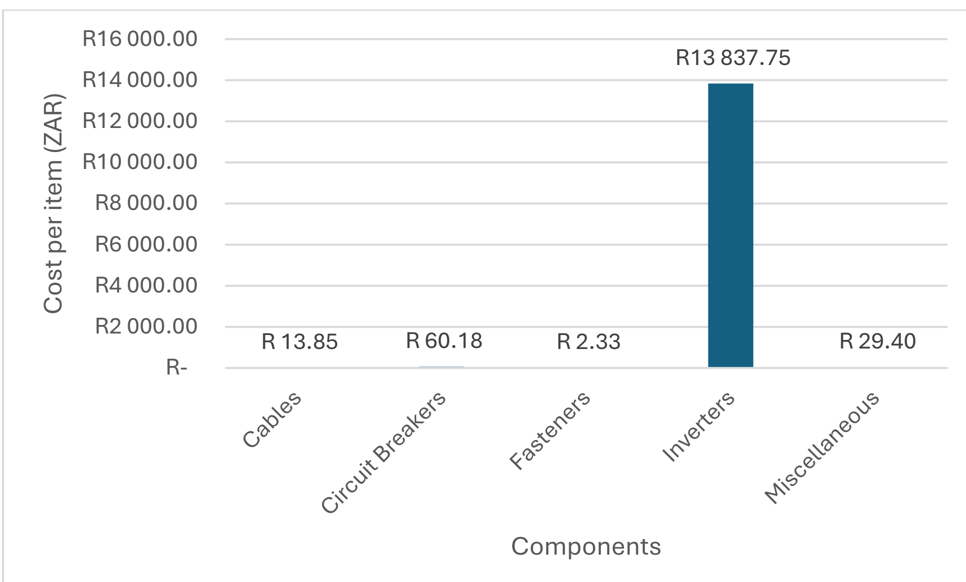

Figure 7. Cost per item

The results for days until stockout are presented in Figure 8 below.

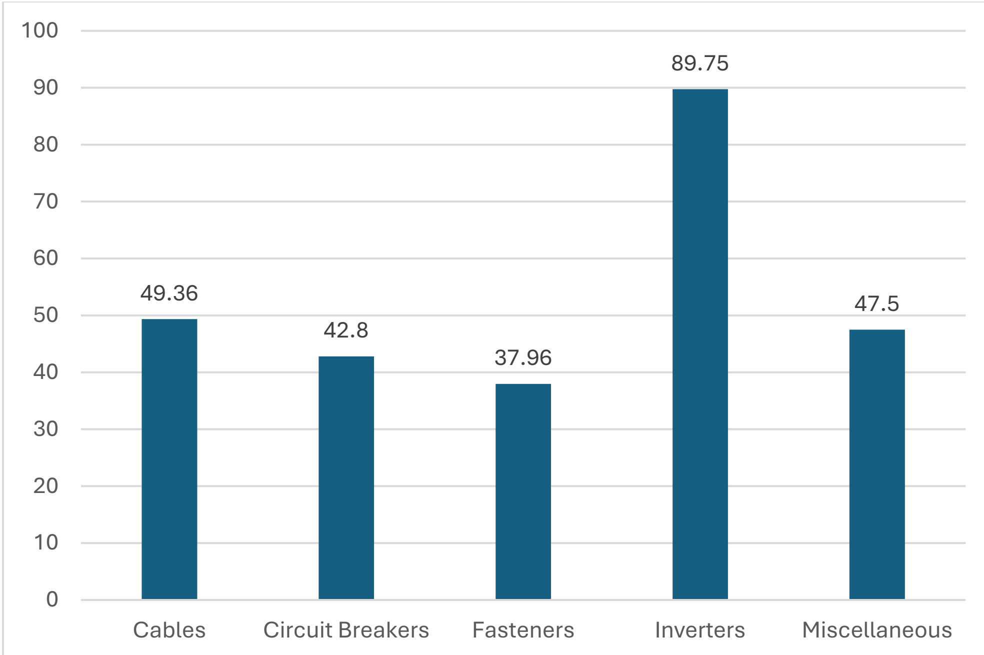

Figure 8. Days until stock out

The following are apparent based on the figures provided above:

- A-Items (Inverters): High value, low quantity, and low stockout risk, but careful management is required.
- B-Items (Miscellaneous, Circuit Breakers): Moderate value and stockout risk; routine monitoring needed.
- C-Items (Cables, Fasteners): Low value but high quantity; fasteners have the highest stockout risk, requiring frequent restocking.

Inverters have the longest stockout period (89,75 days), indicating a lower risk of running out soon. Fasteners have the shortest stockout period (37,96 days), suggesting the highest urgency for replenishment. Cables, Circuit Breakers, and Miscellaneous fall in the middle, with moderate stockout risks, requiring regular monitoring. Inverters stand out with the highest cost per item (R 13,837.75), far exceeding the other categories, making them high-value, low-quantity items that need careful stock management.Circuit Breakers have a moderate cost per item (R 60,18), while Fasteners and Cables are much lower in value (R 2,33 and R 13,85 respectively), suggesting they are high-volume, low-value items. Miscellaneous items have a mid-range cost per item (R 29,40), indicating their significant impact on overall inventory value. The data on the stockout can help the organization place orders on time before replenishing. It can also help with in planning for optimal inbound quantity for the next intervals due to new arrivals having the tendency to pose a heavy burden (Huang et al., 2023).

6. Solution Design

6.1 Concept Generation

The design process for Company X Engineering's inventory management system addressed key challenges identified in the data analysis, focusing on stockout risks, logistics inefficiencies, and sustainability goals.

6.1.1 Challenges Identified

- Stockout Risks: Inverters (high-value, low-quantity) needed careful monitoring due to their financial impact, while fasteners (low-value, high-volume) required frequent restocking to avoid production delays. Cables and miscellaneous items presented moderate stockout risks, needing regular inventory checks to avoid overstocking.
- Logistics and Fuel Costs: Large discrepancies in fuel costs between clients (e.g., Property Company E – Middleburg with high costs vs. smaller, fuel-efficient jobs like Company B – Building Johannesburg Central) highlighted the need for more efficient route planning and vehicle allocation.

- Sustainability: The project aimed to minimize environmental impact by optimizing fuel usage and reducing energy consumption within the warehouse.

6.1.2 Initial Ideas

- Fully Automated System:
  Pros: Reduces human error and enables real-time tracking.
  Cons: Expensive implementation, not suitable for mid-sized operations.
- JIT System with ABC Classification:
  Pros: Optimises stock levels and reduces excess inventory.
  Cons: Requires precise forecasting and supplier reliability
- Manual Tracking with Inventory Classification:
  Pros: Cost-effective solution for managing low-value items.
  Cons: Lack of real-time accuracy and prone to human error.

6.1.3 Sustainability Considerations

- Fuel Efficiency: Improved delivery routes and grouping were effective strategies for reducing fuel consumption and carbon emissions.
- Energy Use: Optimised item placement reduces energy consumption in warehouses, particularly for frequently used items like fasteners and cables.

6.2 Concept Generation

After developing multiple concepts to address Company X Engineering's inventory management and logistical challenges, each concept was evaluated using key criteria such as efficiency, sustainability, cost, and technological feasibility. The evaluation process helped to determine the best solution for warehouse operations.

6.2.1 Evaluation Criteria

- Efficiency: Each concept was evaluated based on its ability to reduce stockouts, improve order fulfilment, and improve inventory management. The goal was to find a solution that would ensure critical items, such as inverters, were available when needed while minimising overstocking of lower-value items like fasteners and cables.
- Sustainability: Each concept was evaluated for its ability to reduce carbon emissions and energy consumption. The chosen solution had to support Company X Engineering's sustainability objectives, specifically by reducing fuel consumption during deliveries and optimising warehouse operations.
- Cost: The implementation and maintenance costs were significant factors. The solution had to be cost-effective, weighing short-term setup costs against long-term operational savings. Concepts that required large initial investments with little long-term return were less appealing.
- Technological Feasibility: Company X Engineering prioritised integrating the system with existing technology. The ideal solution had to be compatible with existing warehouse management systems and simple enough to implement without requiring significant technological changes.

6.2.2 Comparison of Concepts

- Fully Automated System:
  Pros: Provides real-time tracking while reducing human error.
  Cons: High implementation costs and complexity make it impractical for a mid-sized company like Company X Engineering.
- JIT System with ABC Classification:
  Pros: Optimises inventory levels and increases turnover.
  Cons: Requires accurate demand forecasting, which increases complexity and costs while also increasing the risk of stockouts if supply chains are disrupted.
- Manual Tracking with Inventory Classification:
  Pros: Low cost and simple to implement.
  Cons: Inadequate real-time accuracy, prone to human error, and inefficient for managing high-value items and large-scale operations.

6.2.3 Selection of ABC Classification

After evaluating the various concepts, the ABC Classification System was selected as the most suitable solution for Company X Engineering due to the following reasons:

- Balance Between Efficiency and Cost-Effectiveness: The ABC Classification System provided a structured way to manage inventory, ensuring critical items (A-items) like inverters are always available while reducing the risks of overstocking lower-priority items (B- and C-items). It achieved this without the high costs associated with full automation or the complexities of a Just-In-Time system.
- Sustainability Alignment: By optimizing stock levels and reducing unnecessary replenishments, the ABC system helped minimize fuel consumption and carbon emissions. Grouping deliveries for C-items and prioritizing critical A-items also contributed to a more sustainable logistics model.
- Ease of Integration: The ABC system was easily integrated with the existing processes and technologies at Company X Engineering. It required minimal disruption to current workflows and could be implemented with relatively low costs compared to more complex solutions like full automation.
- Directly Addresses the Key Challenges: The ABC system specifically tackled the stockout risks for high-value items and helped manage the inventory turnover for frequently used low-cost items. This system balanced operational efficiency with ease of implementation and sustainability, making it the ideal choice for the warehouse's needs.

6.2.4 Detailed Design Solution

The final design solution for Company X Engineering involves the ABC Classification System, customized to meet the warehouse's operational and sustainability needs. This system categorizes inventory into A-, B-, and C-items based on value and usage frequency, optimizing resource allocation to reduce stockouts and streamline replenishment.

- A-items: High-value, low-volume items like inverters (R 13,837.75 per unit) will be stored in easily accessible locations for immediate retrieval. Regular checks will be conducted to prevent stockouts, ensuring continuous availability and minimizing downtime.
- B-items: Mid-value, moderate-frequency items like circuit breakers and cables will require routine restocking at scheduled intervals. This approach prevents both overstocking and stockouts, maintaining balanced inventory levels.
- C-items: Low-value, high-volume items like fasteners (R 2.33 per unit) will be stored in bulk in less accessible areas. Frequent restocking will be implemented to avoid operational delays due to their high consumption rates.

The customized application of the ABC system will ensure efficient inventory management, addressing Company X Engineering's specific challenges in stock monitoring and replenishment.

6.2.5 Sustainability Integration

Sustainability was a key consideration in the design of the ABC Classification System for Company X Engineering. The following measures should be integrated to reduce environmental impact:

- Fuel Consumption Reduction: By prioritizing deliveries for A-items and optimizing delivery routes, the system reduced the number of trips required for restocking high-priority components. This will lead to a reduction in fuel consumption, contributing to the company’s overall sustainability goals.
- Space-Saving Measures: The efficient placement of items, particularly C-items that were stored in bulk, allowed for better space utilization. This will reduce the need for excessive warehouse heating, cooling, and lighting, which in turn minimized energy usage and operational costs.

6.2.6 Sustainability Integration

The ABC Classification System was designed to integrate seamlessly with existing warehouse technologies at Company X Engineering. Key integrations should include:

- Real-Time Tracking with RFID: RFID technology should be introduced to enable real-time tracking of A-items and B-items, providing immediate visibility into stock levels. This will allow the system to automatically trigger replenishments before stockouts occurred.
- Warehouse Management Software: The system should be integrated as well into the warehouse management software, enabling data analysis and reporting on stock levels, consumption rates, and restocking efficiency. This data-driven approach will enhance the overall performance of the ABC system by ensuring timely restocking and reducing manual intervention.

7. Conclusions and Recommendations

This research aimed to analyse and optimize warehouse operations using a case Company X Engineering, to propose solutions for operational efficiency and sustainability. The primary objectives included assessing the current warehouse operations for improved space utilization and material flow, implementing sustainable practices in logistics operations, and enhancing inventory management through the adoption of an ABC classification system. An analysis of the existing warehouse operations identified key areas for optimization, particularly regarding space utilization and material handling processes. The findings indicated that implementing sustainable practices could significantly reduce fuel consumption and enhance overall logistical efficiency. Furthermore, the adoption of the ABC classification system showed promise in improving inventory management, ensuring the availability of critical components, and minimizing stockouts.

Key results from the analysis highlighted the importance of efficient warehouse operations in promoting both economic and environmental sustainability. The integration of these practices not only supports operational excellence but also aligns with the broader goals of the renewable energy sector. These findings underline the critical role that optimized warehouse operations play in enhancing productivity and reducing environmental impact. By building on the insights gained from this research, Company X Engineering can continue to improve its warehouse operations, contributing to a more sustainable and efficient future. While this research aims to provide valuable insights, several weaknesses should be noted. First, the reliance on data from a single case study (Company X Engineering) may limit the generalizability of the findings to other organizations in the renewable energy sector. To address this, future research could include multiple case studies across different companies to validate the results and enhance applicability.

Second, the focus on existing data may overlook real-time operational challenges that staff encounter daily. Incorporating qualitative methods, such as interviews or observations with warehouse personnel, could provide additional insights into practical difficulties and user perspectives, thereby enriching the analysis. In terms of future work, it is recommended to conduct a longitudinal study to assess the long-term impacts of the implemented strategies on warehouse performance. Additionally, exploring advanced technological solutions such as warehouse management systems (WMS) and automation could further enhance operational efficiency. Continuous stakeholder engagement is also vital to ensure that the strategies remain relevant and effective in addressing evolving warehouse challenges. The study makes contributions to supply chain research specifically warehousing by providing valuable insights on wights, cost, inventory management, fuel consumption, and solutions to logistical complexities to the research debate, practical application and continuous learning for improvement.

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