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# Application of Lean Six Sigma in Inventory Optimization at a Water and Electricity Company

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## Abstract

This paper outlines the application of Lean Six Sigma principles in enhancing inventory management at a water and electricity distribution company. Employing the DMAIC (Define, Measure, Analyse, Improve, Control) methodology, the project targeted critical inefficiencies in the inventory systems, particularly focusing on electrical and mechanical equipment. Key achievements included a significant reduction in lead times from 13.08 days to 3.08 days, considerable cost savings, and enhanced operational efficiency. The integration of tools like Value Stream Mapping, Refurbishment operations, and advanced forecasting models facilitated these improvements, demonstrating the effectiveness of Lean Six Sigma in optimizing complex inventory systems.

## 1. Introduction

This study presents a comprehensive application of Lean Six Sigma to optimize inventory management within a water and electricity company. The project was driven by the need to address inefficiencies caused by prolonged inventory lead times and demand variability, which impacted service delivery and operational costs. By adopting the DMAIC methodology, the project aimed to streamline inventory processes, enhance forecasting accuracy, and reduce operational waste. This approach not only aligned with organizational strategic goals but also ensured a structured pathway toward achieving significant improvements in inventory management.

## 2. Literature review

Six Sigma is a statistical approach used to reduce variation within processes. It is primarily a project-focused approach that uses statistical tools to guide improvements through different stages. Six Sigma adopts the DMAIC (Define-Measure-Analysis-Improve-Control) methodology to guide improvement teams through the stages of an improvement project (Antony and Scheumann 2022). Lean (also known as Lean Manufacturing) is another process improvement methodology that focuses on identifying stakeholder value throughout the value stream and 5 reducing forms of waste by creating value flow (Womack and Jones 1997).

Lean is a well-known quality management philosophy that requires involvement and commitment from the organization, client, and suppliers. Lean Six Sigma (LSS) is a combination of both Lean and Six Sigma that forms a much more complete business strategy and philosophy that guides waste elimination and continuous process improvements (Zhang and Irfan 2012). Inventory management systems and techniques are used by businesses and companies of all sizes to monitor inventory levels, forecast demand, and place orders from suppliers. Among the frequently used inventory management systems are Just in Time (JIT), Economic Order Quantity (EOQ), and Materials Requirement Planning (MRP). The best system for a particular business will depend on several factors, such as the type of products the business sells, the size of the business, and the business's budget (Strack 2010).

In sectors like water and electricity distribution, companies hold particular significance for inventory management due to the provision of essential services to customers (Becerra and Mula 2022.). These industries must ensure a consistent resource supply to meet demand, even during unexpected disruptions. However, managing inventory in these sectors comes with distinct challenges, including high associated costs, the need for reliable suppliers, and the necessity of precise inventory level control to prevent costly overstocking and service-disrupting stockouts (Chan et al. 2018).

Implementing Lean Six Sigma in the inventory management system of a water and electricity distribution company faced several challenges, including tight time constraints, bureaucratic delays, significant initial investments for new tools, and data limitations. Additionally, limited stakeholder availability and data sharing issues posed risks to progress and decision-making. Despite these challenges, the team succeeded through persistent effort, comprehensive training, and iterative refinements, achieving notable improvements in efficiency and cost savings.

To overcome the challenges of inventory management, companies look for ways to eliminate waste and optimize their resources. Tracking and visibility over the entire inventory is a critical component for inventory optimization (Trunick, 2007). A useful lean tool that can help managers visualize the entire process and spot inefficiencies in the process is Value Stream Mapping (VSM) (Alahmad et al., 2024). VSM is a special mapping tool that shows the flow of material and information across the entire process. It starts by mapping the current state of the entire system to visualize and identify inefficiencies. Once managers have identified wastes in the process, a future VSM can be created to represent an improved iteration of the process (Shou and Wang 2017). Other waste elimination methods, such as 5S, can also be used (Singh and Rastogi 2014).

## 4. Define

In the Define Phase of their DMAIC process, the team refined the project's scope and objectives to tackle inventory management deficiencies at the company. The team utilized SIPOC and Process Flow tools to outline the inventory process, identifying key components and stakeholders. Moreover, a project charter was developed to guide management and align with organizational goals. According to the VOC (voice-of-customer) analysis, the main objective, as addressed by the project champion, is to have all forecast errors less than 20%. Furthermore, sub-objectives regarding extended lead times and excessive returned items were also labeled as critical. These sub-objectives were raised as many capital projects have been delayed due to extended lead times. Moreover, most returned items are excess safety stock from projects that are returned in poor conditions. These excess items are rarely ever repurposed and end up being discarded as scrap for 10% of their original value. A Pareto analysis, presented in Figure 1, underscored electrical and mechanical inventories as critical focus areas due to their substantial impact on operations.

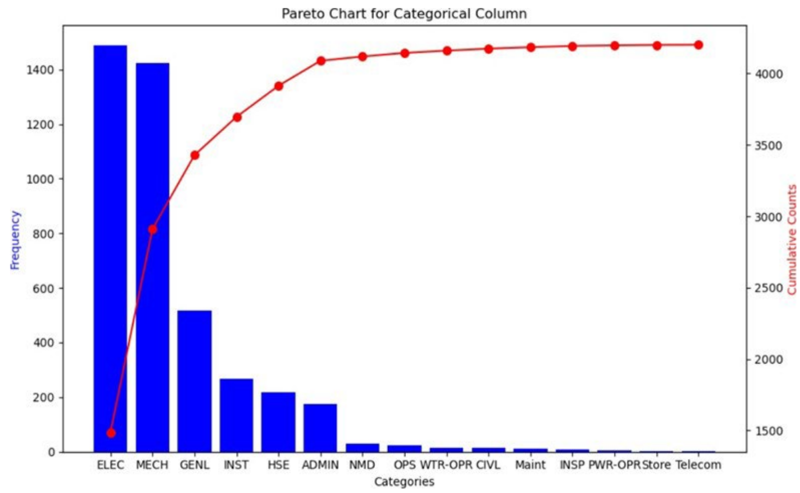


Figure 1. Pareto Chart for Item Categories

## 5. Measure

During the Measure phase of the DMAIC Six Sigma process, the team homed in on improving inventory management by focusing on warehousing operations and forecast metrics. Procurement operations were not considered as they have been addressed by another recent Six Sigma project. The team developed a systematic approach to quantitatively analyse the variance between forecasted and actual inventory demands, aiming to reduce this gap and avoid stockouts. Key strategies included employing data collection aligned with Critical to quality (CTQ) parameters using tools like process capability measurements, control charts, and value stream mapping to identify bottlenecks and non-value-added activities. The data collection effort concentrated on defect rates, order completion times, and detailed inventory tracking, using the company's database to pull data on electrical and mechanical equipment. This structured approach not only provided insights into inventory usage patterns but also supported the enhancement of the warehousing and replenishment process, helping to streamline operations and improve efficiency across the board.

**Current State Value Stream Map**

The following current state map represents the warehousing operations within the warehouse management process. The current state map will serve as the baseline for visualizing and streamlining the warehousing process (Figure 2).

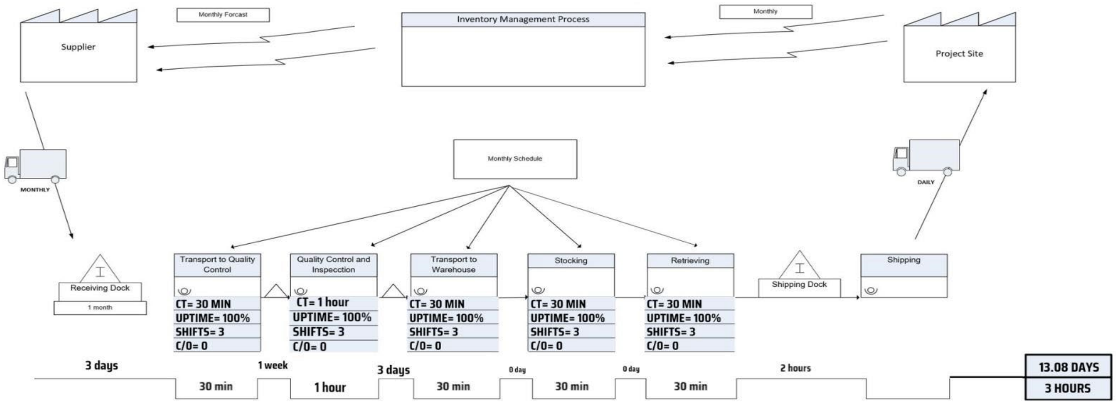


Figure 2. current state map of warehousing operations

**Process Capability**

The process capability analysis for average forecast error by item type for 2022 and 2023 using 2-parameter Exponential non-normal distribution revealed poor performance, with Ppk (index of performance) values of -0.05 and -0.01 respectively, indicating the process's incapability of meeting specifications. A Ppk below 1.0 signifies statistical incapacity. The lower specification limit (LSL) was set at 0 and the upper specification limit (USL) at 20, aiming for a maximum 20% error margin from the relative zero percentage error. Corresponding sigma levels were 1.18 for 2022 and 1.30 for 2023, significantly below the Six Sigma goal of 6, suggesting a high number of defects and confirming the need for process improvements to reduce variation and align the process mean closer to target limits. This poor performance is also highlighted by high parts per million (PPM) values exceeding the upper specification limit, emphasizing the urgent need for process optimization (Figure 3).

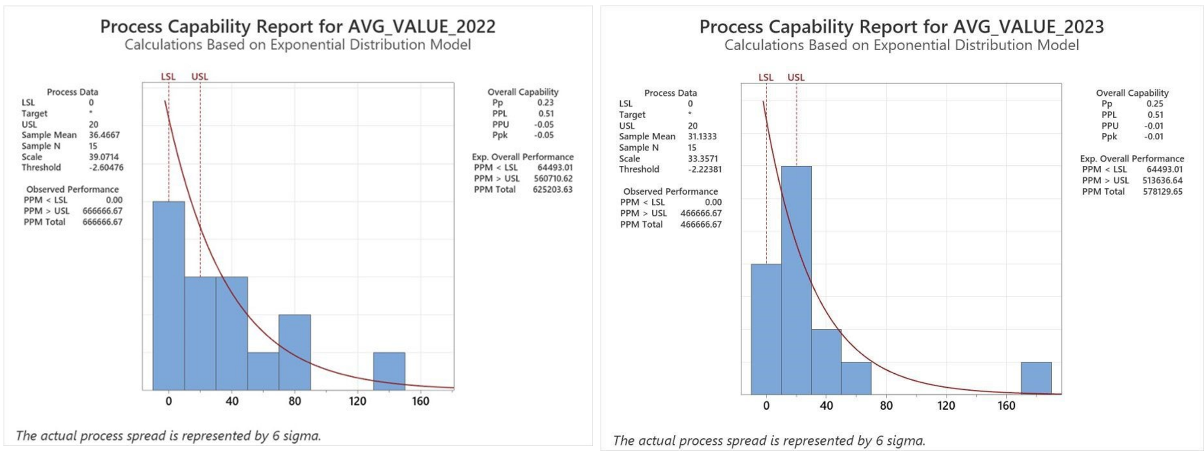


Figure 3. Process capability report for 2022 and 2023

## 6. Analyse

In the *Analyse* phase of the DMAIC Six Sigma methodology, the team examined the root causes of process variation affecting inventory levels of electrical and mechanical items. Qualitative tools like Fishbone Diagrams and 5 Whys, alongside quantitative tools like correlation analysis, pie charts, and histograms, were used to identify and address factors causing inventory issues systematically (Figure 4).

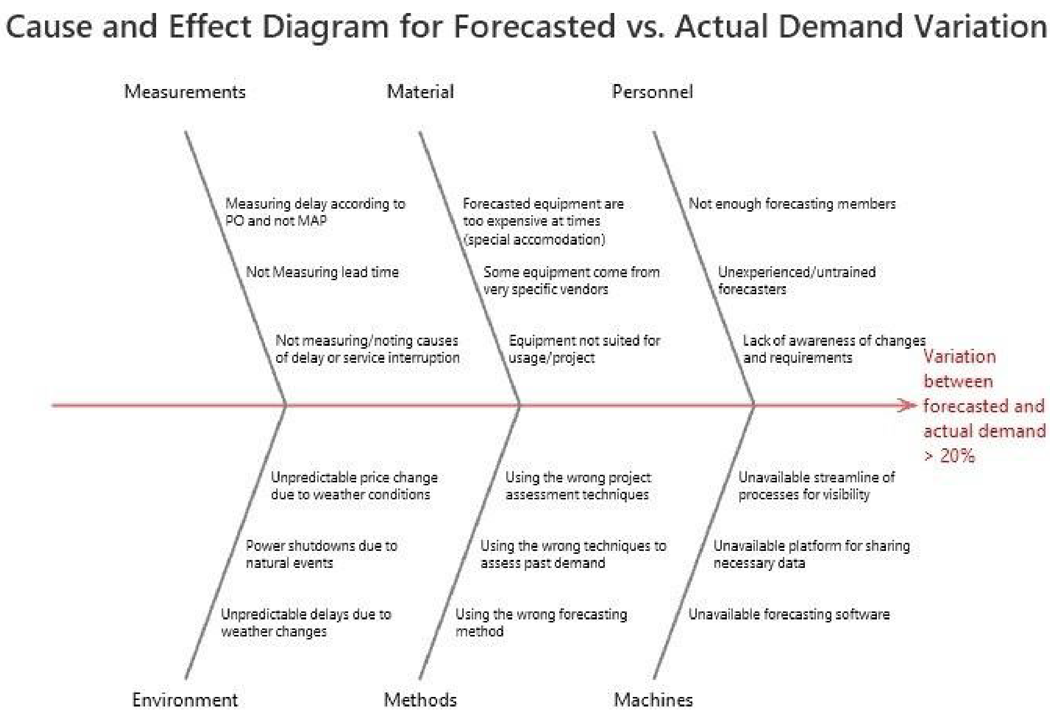


Figure 4. Cause and Effect Diagram

The Ishikawa diagram above highlighted some of the possible root causes of the large variation between the forecasted and actual demand. A key takeaway from this analysis was that some factors can easily be controlled and improved, such as methods and measurements, while other factors are much more difficult to control and improve. The team focused on improving those factors within control while trying to mitigate any drawbacks from factors beyond control (Figure 5).

**Root Cause Analysis**

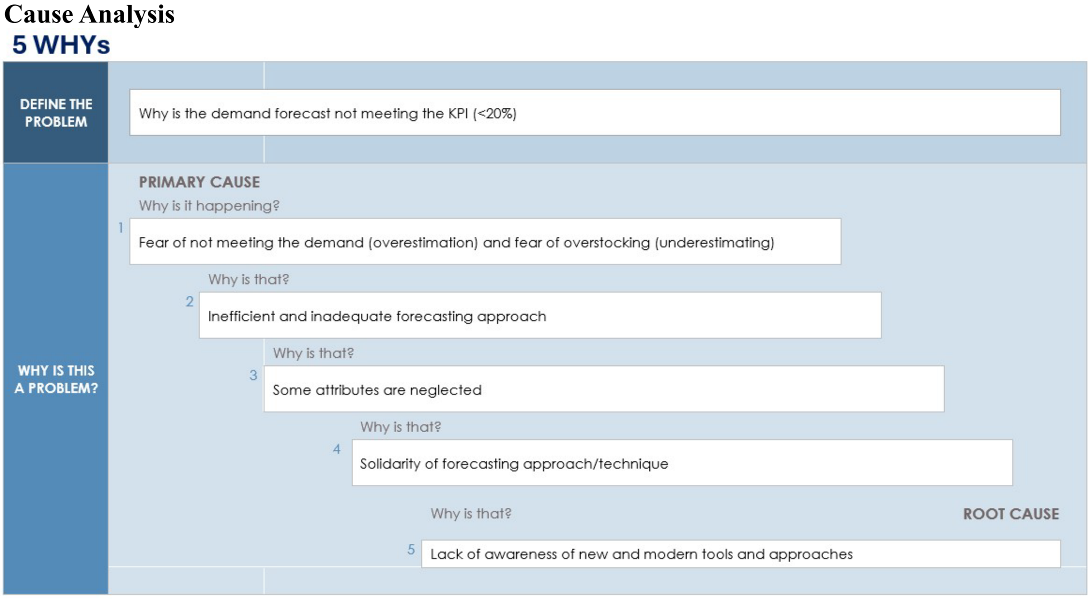


Figure 5. 5 Whys

After conducting a proper RCA with the stakeholders, the team concludes that the lack of awareness of modern forecasting tools is the root cause for inaccurate demand forecasts that do not meet the target KPI (<20%) (Figure 6).

**Quantitative Analysis**

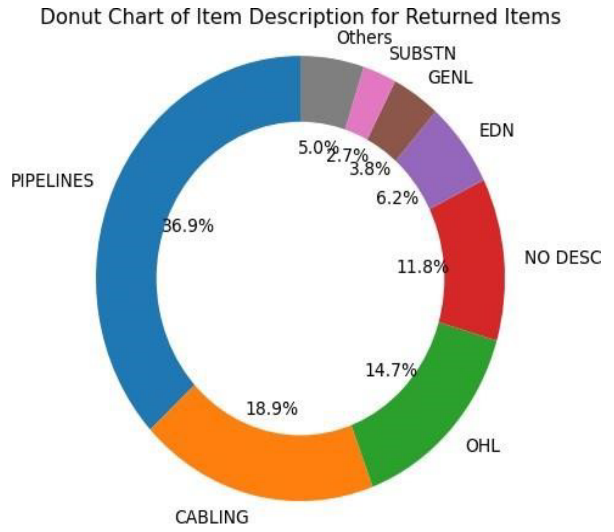


Figure 6. Donut chart of item descriptions for returned items

Addressing the issue of returned items, the doughnut chart presented in Figure 6 indicates that most returned items are pipelines, cablings, and OHL (over-headlines) (Figure 7).

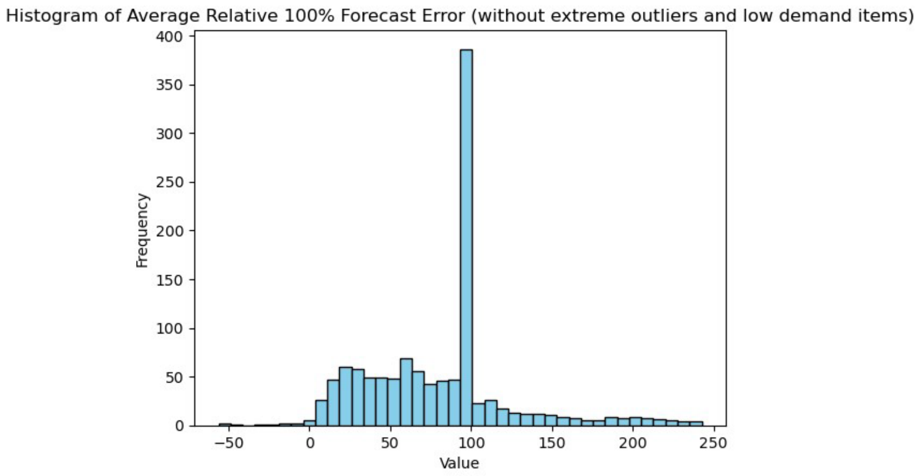


Figure 7. Histogram of average Relative 100% Forecast Error

The histogram in Figure 7 above shows the Average Relative 100% Error, excluding outliers and low-demand items. The histogram indicates that although many items meet the acceptable range of the forecast error, many items are spread around the target range. Although more items are underestimated, overestimated forecasts are usually much more extreme.

**Process Stability**

To minimize forecasting errors in their material acquisition plan, the team analyzed process stability using a U Chart control chart, categorizing data into 15 sample sizes from various organizational disciplines. The variable used for the analysis is the average forecast error percentage. This analysis method provided a visual and statistical overview of process trends, shifts, and outliers over time, revealing significant improvements and insights for targeted improvements in specific departments like Electrical, which improved from an average value of 59 in 2022 to 36 in 2023. The collected data highlighted defects per unit and identified out-of-control processes across multiple departments, necessitating focused process improvements (Figure 8 and Figure 9).

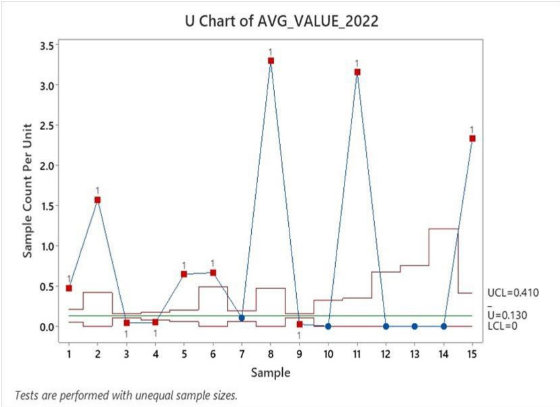


Figure 8. U chart of average forecast error value 2022

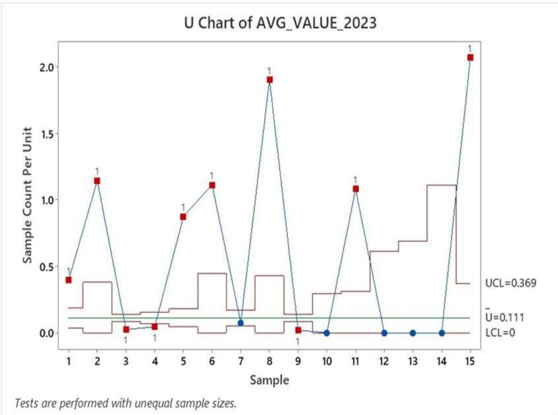


Figure 9. U chart of average forecast error value 2023

## 7. Improve

During the *Improve* phase of their DMAIC process, the team focused on refining project objectives to enhance the efficiency of inventory management for electrical and mechanical equipment, aiming to develop and implement a framework to accurately monitor and reduce the discrepancy between expected and actual inventory demand. Using the insights gained from the previous phases, the team developed several possible solutions to address the project objectives. Decision-making processes led to the exclusion of cross-training and new ERP software in favor of enhancing current practices with lean supermarket tools and a modern forecasting framework. The team proceeded to implement these solutions along with establishing a refurbishment centre to further reduce inventory variations, concluding with the development of a new facility layout plan.

**Process and Lean metrics**

Although lean tools and principles are applied in manufacturing settings, recent applications continue to prove their effectiveness in other operations, such as maintenance (Alahmad and Aljaberi 2024) operations. The following lean applications will focus on warehousing operations (Table 1).

Table 1. Process metrics and lean calculations

| Item Description | Issue Unit | Item Discipline | Demand Value Group | Lead Time | Available Time | Customer Demand | Takt Time | Trigger Point |
|---|---|---|---|---|---|---|---|---|
| Sleeve | Each | Genl Ohl | Value <1000 | 1.15 | 0.5 | 1.5 | 0.33 | 3 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Joint | Each | Elec Ohl | 1000<Value<5000 | 0.84 | 0.5 | 6.5 | 0.08 | 11 |
| Valve | Each | Mech Pipelines | 5000<Value<10000 | 1.21 | 0.5 | 3.5 | 0.14 | 8 |
| Ring Main Unit | Each | Elec Edn | 10000<Value<100000 | 1.08 | 0.5 | 1 | 0.5 | 2 |
| Meter | Each | Elec | 100000<Value<1000000 | 1.03 | 0.5 | 503 | 0.001 | 10391 |
| Substation Package Unit | Set | Elec Substn | 1000000<Value | 1.61 | 0.5 | 0.5 | 1 | 2 |

This table details lean management calculations, mostly focusing on electrical and mechanical items with extended lead times. It provides metrics like item description, discipline, demand value, and trigger points derived from the comparison of lead time to takt time. This analysis helps pinpoint bottlenecks and determines when to replenish stock to meet customer demand efficiently (Table 2).
* All times are converted to years for consistency in calculations*

Table 2. Stock metrics

| **Item Description** | **Issue Unit** | **Item Discipline** | **Demand Value Group** | **Cycle Stock** | **Buffer Stock** | **Safety Stock** | **Total Stock** |
|---|---|---|---|---|---|---|---|
| Nut | Each | Mech Plnt Deasl | Value <1000 | 966 | 193.2 | 232 | 1391 |
| Battery | Each | Admin Genl | 1000<Value<5000 | 909 | 181.8 | 218 | 1308 |
| Seal | Each | Insp | 5000<Value<10000 | 16000 | 3200 | 3840 | 23040 |
| Chemical | Kg | Ops Plnt Water | 10000<Value<100000 | 31587 | 6317 | 7581 | 45485 |
| Conductor | Meter | Elec Ohl | 100000<Value<1000000 | 20527 | 4105 | 4927 | 29559 |
| Cable | Meter | Elec | 1000000<Value | 257863 | 51573 | 6188 | 371323 |

This table outlines inventory calculations for high-demand items, including cycle stock, buffer stock, and safety stock. It categorizes items by demand value and totals the stocks to ensure sufficient inventory levels that cover regular demand, accommodate variability, and mitigate unexpected shortages. This structured inventory approach aims to enhance operational stability and efficiency.

**Future Value Stream Map**
To implement the future state map, a cell was created containing transportation, quality assurance, and stocking operations. Moreover, a supermarket system which utilizes the previously calculated stock levels and reorder levels is implemented. The new supermarkets will utilize the kanban system to initiate replenishment. The resulting improvement is a reduction in lead time from 13.08 days to 3.08 days (Figure 10).

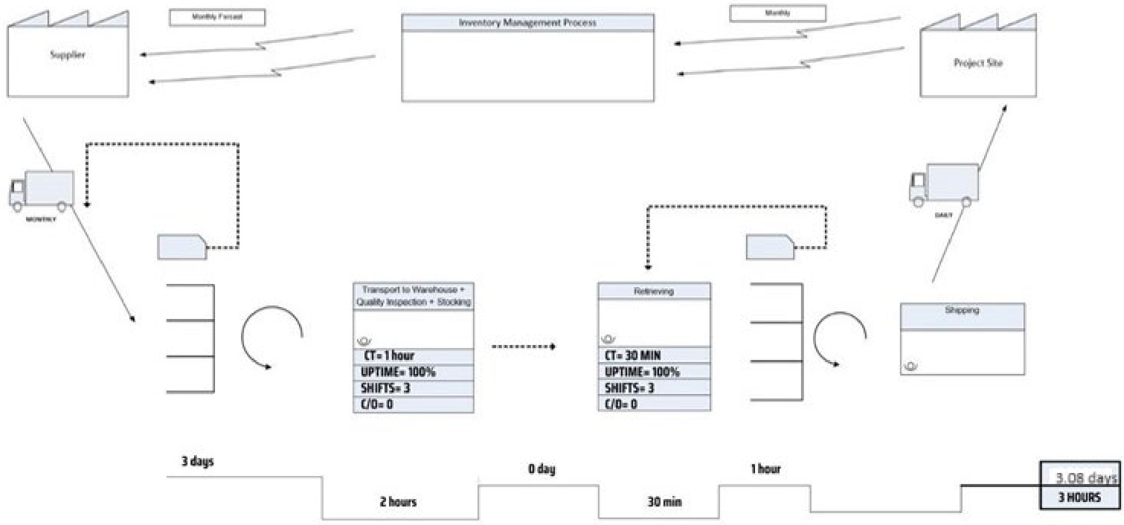


Figure 10. future state map of the warehousing operations

**New Refurbishment Centre**
A new refurbishment center is created to repurpose returned items that can be salvaged for future use instead of being sold as scrap for 10% of their original value. The refurbishment center will focus on the items that are most returned. **F**acility **L**ayout **P**rogram (FLAP) software solves facility layout design problems using the following inputs: total bay space, required space bay for each department, and affinity importance (represented in an affinity diagram). FLAP software was used to design the new Refurbishment center (Table 3).

Table 3. Affinity diagram

| | Inspection/QC | Cabling refurb. | Pipelines refurb. | OHL refurb. | Racks |
|---|---|---|---|---|---|
| Inspection/QC | - | A | E | E | U |
| Cabling refurb. | | - | U | U | E |
| Pipelines refurb | - | | - | U | E |
| OHL refurb. | - | - | - | - | O |
| Racks | - | - | - | - | - |

A: 50 trips; E: 40 trips ;I: 30 trips ;O:20 trips ;U:10 trips

The standard size of bays in the warehouse is 18 meters * 30 meters . for easier generation of evaluation using the software, the bay area will be represented in a 6*10 grid (actual area will be divided by 9 to match the scale) . All departments in the new facility and their details are represented in Table 4:

Table 4. Refurbishment center department details

| Department | Description | Area calculation | Grid calculation | Number of cells required |
|---|---|---|---|---|
| 1.Inspection/QC | A critical area where materials are examined and tested to ensure they meet quality standards. | inspection and evaluation station (4*10) + Cleaning station (5*5) + Sorting Area (2*5) = 75 meters^2 | 75/9 = 8.33 | 8 |
| 2.Cabling Refurbishment | Various cabling components undergo refurbishing to restore them to their optimal functional state | 2 tote pan trays (2*1) + Vacuum Pump (3*7) + Work Station (8*10) = 105 meter^2 | 105/9 =11.67 | 12 |
| 3.Pipelines Refurbishment | This zone is dedicated to the restoration of pipeline materials. | Tote pan tray (2*1) + Hydrostatic Testing Equipment (1*2) + Hydraulic Press (2*5) + Pipe Bending Machines (5*10) + Work area (10*10= 164 meter^2 | 164/9 = 18.22 | 18 |
| 4.OHL refurbishment | Overhead line materials are refurbished, ensuring the reliability of reusing the material. | Tote pan tray (2*1) + Hydraulic Press (3*5) + Wire Stripper Machine (3*4) + PCB Repair Station (2*1) + Ultrasonic Cleaner (3*4) + work station (5*10) = 93 meter^2 Planning facility layout: | 93/9 = 10.33 | 10 |
| 5.Racks | This section is organized for the storage and easy access to materials required across the refurbishment process. | 2 Racks (3*10) = 60 meters^2 | 60/9 = 6.67 | 7 |

According to FLAP, the best layout is presented below in Figure 11 and Figure 12:

| | | | | | |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 2 | 2 | 2 |
| 1 | 1 | 1 | 2 | 2 | 2 |
| 1 | 1 | 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 | 3 | 2 |
| 3 | 3 | 3 | 3 | 3 | 2 |
| 3 | 3 | 3 | 3 | 3 | 3 |
| 3 | 5 | 5 | 4 | 4 | 4 |
| 3 | 5 | 5 | 4 | 4 | 4 |
| 5 | 5 | 5 | 4 | 4 | 4 |
| 0 | 0 | 0 | 0 | 0 | 4 |

Figure 11. FLAP Layout

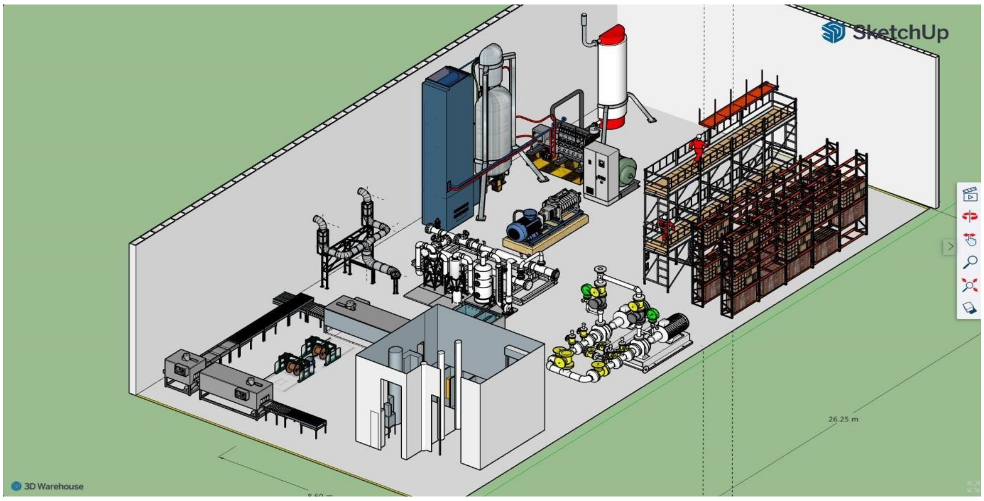


Figure 12. Final Refurbishment Centre Layout

Expanding on the operational aspects of the refurbishment centre, the facility was meticulously designed to streamline the refurbishment process for various components, including cabling, pipelines, and overhead line materials. Advanced testing tools such as ultrasonic testing, radiography, and hydrostatic testing ensure high-quality standards. The centre is equipped with state-of-the-art machinery, including automated stripping machines, hydraulic pipe benders, and ultrasonic cleaners, tailored to restore items to optimal functionality. The cabling section focuses on cable cleaning, re-insulation, and splicing, while the pipeline zone emphasizes cleaning, welding, and coating operations. The overhead line refurbishment includes conductor testing, insulator replacement, and PCB repair. This comprehensive setup not only extends the lifespan of critical components but also significantly reduces waste and operational costs.

*Return on Investment (ROI) analysis for the new refurbishment centre*

Evaluating the ROI of the new refurbishment center is an excellent assessment of the risk associated with such a project. The Pareto chart below represents the available value of returned items. These values could be used to estimate the total savings from this project (Figure 13 and Table 5).

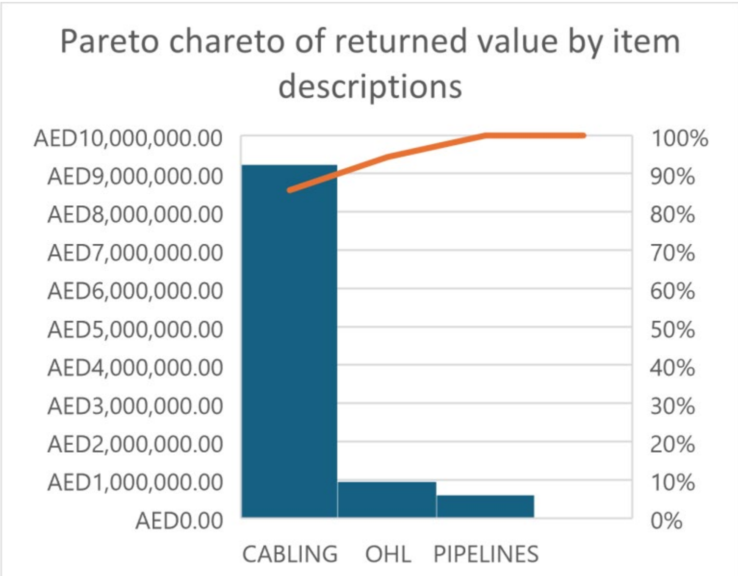


Figure 13. Pareto chart of returned items by value

Table 5. ROI calculations

| Cost of investment | Total savings (assuming 50% of items can be saved- Naïve estimation) | Net benefit | Return on investment (ROI) |
|---|---|---|---|
| AED 325,000 | AED4,852,683.95 | AED4,527,683.95 | (AED4,527,683.95 / AED 325,000) * 100 = 1393.13% |

The ROI for this project is estimated to be just under 1400%, indicating the enormous financial benefit for this project and making it clear that this new facility projects low financial risk.

### New Forecasting Framework
A new forecasting framework has been created to address the lack of awareness of modern forecasting tools and to guide stakeholders in making more accurate forecasts by choosing the most suitable method/technique. The proposed framework is inspired by a sales forecasting framework from (Chern, C.-C., Ao Ieong, K. I., 2009.)

<u>Building the Forecasting Framework</u>
The team proposes a forecasting framework using decision trees to select the optimal forecasting techniques for each SKU based on comprehensive historical data, including demand trends and economic indicators. The approach involves 1) Collecting detailed data, 2) Developing and testing various models from simple averages to complex AI, 3) Identifying the top three methods per SKU, and 4) Using decision trees to finalize the best method for each SKU. This structured method enhances decision-making clarity and accuracy in forecasting by providing transparent, logical reasoning for each choice.

<u>Using the Forecasting Framework</u>
After successfully building the learning platform using decision trees, the platform can be incorporated into the framework, and the framework is ready for use. A Figure 14 showing the design of the framework is presented below:

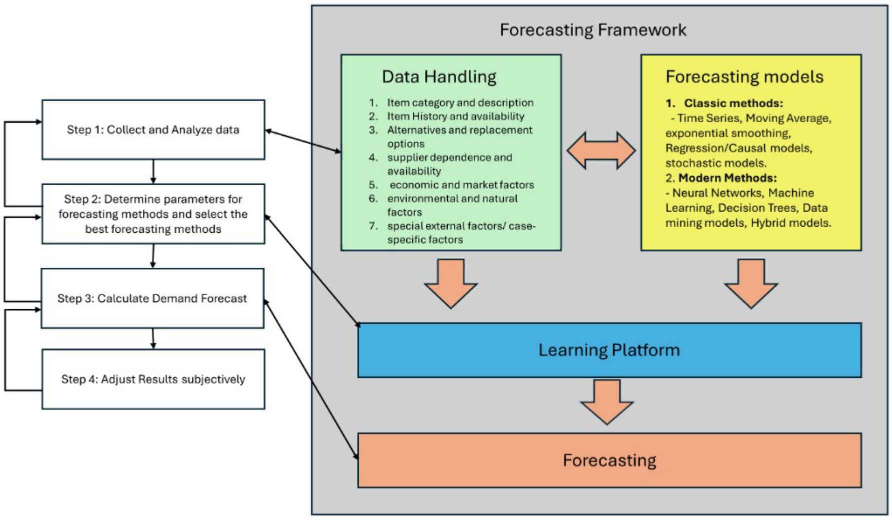


Figure 14. Forecasting Framework

The forecasting framework includes: 1) **Data Collection and Analysis:** Gather and analyze relevant data such as last year's demand and population growth to detect impactful trends; 2) **Model Selection:** Use a decision tree to determine the top three forecasting models for each SKU; 3) **Demand Forecasting:** Employ the suggested models to forecast next year's demand, optionally using multiple models for a comprehensive analysis; 4) **Results Adjustment:** Apply expert judgment to refine and possibly combine forecasts for accuracy. This iterative framework promotes continuous improvement and updates based on annual performance evaluations to enhance forecasting precision over time.

## 8. Control
In the Control phase of the DMAIC Six Sigma project at a water and electricity company, the team concentrated on cementing the improvements made in inventory management, particularly for electrical and mechanical inventory, to ensure sustained efficiency and cost reduction. Key actions included implementing robust control mechanisms and

new work standards to maintain optimization gains, particularly through lean practices like regular stock reviews, dynamic buffer adjustments, and continuous monitoring of inventory processes. The new forecasting framework was standardized to enhance accuracy and efficiency, emphasizing documentation, KPI monitoring, response strategies for discrepancies, ongoing system audits, and user training. Moreover, the establishment of a Refurbishment Centre focused on quality control, sustainable practices, continuous monitoring, and performance metrics to ensure the integrity and efficiency of the refurbishment processes. Furthermore, adopting appropriate and customized storage and order policies will impact process performance (Al Jaberi, A., Amer, S. 2024). Overall, the Control phase aimed to solidify the advancements made, ensuring these systems not only meet but exceed operational expectations through continuous improvement and adaptation to changing demands.

## 10. Conclusions

The implementation of Lean Six Sigma methodologies within the utility company's inventory management processes has demonstrated substantial improvements across various metrics. Notably, the project has achieved significant reductions in lead times and operational costs, alongside improved customer satisfaction through more reliable service delivery. The successful application of tools such as Value Stream Mapping, various quality tools, and sophisticated forecasting techniques has set a precedent for continuous improvement within the company. Future initiatives will focus on further refining these processes and extending similar methodologies to other operational areas to sustain and enhance the gains achieved. This continuous improvement effort will ensure that the inventory management system remains robust and adaptable to changing demands and operational challenges (Gonzalez et al. 2016).

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## Biographies

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