**Analyzing and Forecasting Product Demand for Strategic Inventory Management**

Abstract

This research focuses on improving inventory management through precise demand forecasting and anomaly identification. Using a quadratic exponential smoothing approach, we forecast monthly sales and examine historical product demand data from 2014 to 2019. Effective demand forecasting is the foundation of inventory management, affecting production planning, inventory levels, and overall business operations. We handle missing and inaccurate data, rectify negative demand numbers, and aggregate order demand to assure data integrity. Key visualizations show the main product categories and demand trends, while forecasting models exhibit the capacity to accurately estimate future demand. Seasonal decomposition divides demand patterns into observable, trend, seasonal, and residual components, while anomaly detection detects odd departures.

This complete method offers firms significant insights into optimizing inventory management, lowering expenses, and improving strategic planning.

Literature Survey

The study focuses on enhancing inventory management through accurate demand forecasting, utilizing a quadratic exponential smoothing method to predict monthly sales for product A in 2013. Effective demand forecasting forms the foundation of inventory management, as it influences inventory planning and business operations. The research emphasizes the importance of systematic demand forecasting for large-scale businesses, noting that accurate predictions allow for efficient production planning and inventory management, thus improving overall competitiveness. By proposing the ABC classification management method based on demand forecasts, the study aims to address inventory management issues, demonstrating significant implications for enterprises seeking to optimize their inventory levels and reduce costs. *(Xi & Sha, 2014)*

Management must continually negotiate a dynamic environment that necessitates quick decisions and business planning. Forecasts that are trustworthy and accurate are essential for enhancing the outcomes of these operations. Even though management has long struggled with prediction, advancements in advanced computing technology have enabled the examination and implementation of previously unattainable complex forecasting methods. *(Thomopoulos, 1970)*

**Data Overview**

The dataset contains historical product demand data for a manufacturing company, spanning from 2014 to 2019, with over a million entries. This data is critical for analyzing demand patterns, predicting future demand, and optimizing inventory management.

|  |  |  |
| --- | --- | --- |
| **Columns** | **Description** | **Details** |
| Product\_Code | Unique identifier for each product. | Ranges from Product\_0001 to Product\_2172 |
| Warehouse | Identifier for the warehouse. | Includes Brampton, Oshawa, Surrey, and St John's |
| Product\_Category | Category of the product. | Ranges from Category\_001 to Category\_033 |
| Date | Date when the order was placed. | Spans from the year 2014 to 2019, contains missing values |
| Order\_Demand | Demand quantity for the product. | Numerical values representing the demand for the product |

**Data Preprocessing for Time Series Analysis**

To ensure the integrity and correctness of our time series analysis, we ran numerous critical preprocessing processes on the dataset.

Handling Missing Dates:  
The Date column of the dataset has 11,239 missing values, which was crucial for chronological ordering and trend identification. To remedy this, we chose to remove the rows with missing dates. This step was required to ensure a comprehensive and accurate timeline, which is critical for good time series analysis.

Adjusting Invalid Dates:  
Invalid dates, such as "2015-02-29" and "2019-02-29" (because 2015 and 2019 are not leap years), were converted into valid dates. These dates were corrected before being converted into the appropriate format, ensuring the dataset's chronological order and accuracy.

Handling Negative Demand Values:  
The Order\_Demand column has 5,997 negative values, most likely owing to data entry errors. Because demand cannot be negative, these figures were converted to their positive counterparts. This change was critical to ensuring that the dataset accurately reflected actual demand without errors.

Grouping and Summarizing Order Demand:

To avoid duplicates and assure reliable analysis, we aggregated and totaled order demand for each unique combination of date, product code, product category, and warehouse. This aggregation process produced a clear and structured dataset, which is critical for analyzing demand trends and inventory requirements. It also improves regression analysis by providing a cleaner dataset for modeling and prediction.

**Visualization and Analysis:**

1. Top Product Categories by Demand:
   * We used the aggregated data to identify the top 10 product categories based on total order demand. The investigation revealed important insights into demand distribution across product categories, allowing for smarter inventory management and resource allocation.  
       
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Fig 1. Top 10 Product Categories by Demand

1. Annual Demand Trends for Top 5 Product Categories:
   * The demand trends study for the top five product categories reveals that Category\_019 has the strongest increasing trend and the highest demand. The yearly demand patterns represented in the graphic highlight the growing importance of Category\_019 and the varied trends for the remaining top categories. This knowledge assists firms in optimizing inventory management, strategic planning, and resource allocation to line with changing market demands.

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Fig 2. Annual Demand Trends for Top 5 Product Categories

1. Analysis of Top 5 Products by Demand in 2014 and Their Trends Over Time:

* The bar chart highlights the top 5 products based on total demand in 2014. It shows each product's demand level for the year, clearly illustrating which products were most popular and in highest demand.

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Fig 3. Top 5 Products by Demand in 2014

* The line chart depicts the demand trends for the top five products in 2014. Product\_0033 displays a constant upward trend, reflecting rising demand over time. Product\_1245 and Product\_1431, on the other hand, follow similar trends, fluctuating at first and then decreasing with time. Product\_0366 has had a consistent demand level over the years. This analysis focuses on varying demand behaviors and trends for important products.

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Fig 4. Demand Trends Over the Years for Top 5 Products in 2014

1. Demand Forecast for Top Product in the Highest Demand Category of 2019:

To predict the demand for the top product in 2019 (product\_1359), we filtered the data to identify the most in-demand product, used dates as the index for time-series analysis, resampled the data to a monthly frequency, and divided it into training and test sets. We used an Exponential Smoothing model to forecast demand for both 2019 and 2020, and the findings were displayed with a plot contrasting actual and forecasted figures. A comparison of actual and predicted demand for 2019 demonstrates that the model produced accurate results.

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Fig 5. Demand Trends Over the Years for Top 5 Products in 2014

This strategy enables firms to make informed inventory management decisions, optimize stock levels, and plan strategically by matching resources with projected demand trends. The successful projection for 2019 and 2020 indicates the model's usefulness while also revealing predicted variations and a declining trend for the product. These insights are critical for future inventory management and strategic planning, allowing organizations to reduce stockouts while increasing overall operational efficiency.

1. Seasonal Decomposition and Anomaly Detection in the Highest Demand Category of 2019:
   * Seasonal Decomposition Analysis:  
     This technique entails dividing the monthly demand data into four categories: observed, trend, seasonal, and residual. This breakdown is achieved using the seasonal decomposition technique, which provides a better understanding of the underlying trends in demand data.

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Fig 6. Seasonal Decomposition Analysis

Visualizing each of these components yields significant insights. The observed data plot depicts actual demand, but the trend plot illustrates the overall direction of demand. The seasonal plot aids in understanding recurring trends, whereas the residual plot identifies any anomalies or irregularities. This detailed analysis helps organizations better estimate demand, manage inventory, and plan strategically by allowing them to isolate and analyze the various components that influence demand.

* A comparison of the original data and the estimated trend with the seasonal component:

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Fig 7. Comparison of Original Data and Estimated Trend with Seasonal Component

This figure compares the original monthly demand data to the predicted demand based on the trend and seasonal components. It visually shows how effectively the combined trend and seasonal components represent the original data patterns, shedding light on the trend and seasonal corrections' accuracy.

* Anomaly Detection:

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Fig 8. Anomaly Detection in residual

This graphic depicts the residuals from the decomposition process, showing anomalies by darkening the area between the calculated upper and lower bounds using Empirical rule (between 3 standard deviation). The shaded area depicts the range of normal residual values, with deviations from this range indicating potential anomalies.

The following graph shows monthly demand data with yearly markers, indicating noteworthy anomalies. On January 31, 2019, a significant anomaly is detected, presenting a clear picture of anomalous demand patterns in the context of annual averages. Conducting an event analysis on this specific day can help pinpoint the causes of the spike, allowing for a more in-depth knowledge of the elements that contributed to the anomaly. This information is extremely useful for enhancing demand forecasts and strategic planning.

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Fig 9. Monthly Data with Yearly Markers and Anomalies

**Conclusion:**

This study highlights the value and efficacy of accurate demand forecasting and anomaly detection in inventory management. We effectively anticipated demand for top products using a quadratic exponential smoothing method, resulting in a clear grasp of demand trends and improved inventory planning. The analysis provided vital insights into demand distribution across product categories, as well as notable trends identified through seasonal decomposition. Anomalies, such as the noteworthy rise discovered on January 31, 2019, were noticed and examined to better understand their causes, allowing for more informed decision making.

Our method of addressing data inconsistencies, aggregating order demand, and applying advanced forecasting models proved successful in projecting future demand and aligning resources with expected needs. The findings highlight the necessity of systematic demand forecasting for large-scale firms, which enables more efficient production planning, optimum inventory levels, and increased overall competitiveness. Businesses that use these data into strategic planning can reduce stockouts, manage inventory more effectively, and increase operational efficiency.

**References:**

Thomopoulos, N. T. (1970, January 1). *Demand forecasting for inventory control*. SpringerLink. <https://link.springer.com/chapter/10.1007/978-3-319-11976-2_1#citeas>

Xi, J., & Sha, P. B. (2014, November 27). *Research on optimization of inventory management based on Demand Forecasting*. Applied Mechanics and Materials. <https://www.scientific.net/AMM.687-691.4828>