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Optimizing Retail Supply Chain Efficiency: Insights from Customer Segments and Product Categories Analysis

Vidhya Shankara Bharathi

Department of Computer Science and Information Technology
Jain (Deemed-to-be University)
Bengaluru, India

ABSTRACT:

In nowaday's fairly aggressive enterprise environment, supply chain efficiency is paramount to maintaining achievement. This look at uses superior information envelopment analysis (DEA) equipment to take a look at the efficiency of consumer segments and product sorts in a superstore dataset Looking at pretty green selection-making gadgets (DMUs) to perceive performance gaps a, studies objectives are to enhance product shipping , increase consumer pride, sales. To power upgrades and provide stores with actionable insights by correctly formulating goal capabilities and constraints, the technique analyzes performance, operations and intake patterns across product classes and purchaser segments. The findings offer beneficial insights into supply chain management in income, inclusive of challenges and excellent practices. This paper provides a top-level view of the research targets, techniques, key findings and outcomes. It makes a speciality of successful techniques for improving deliver chain overall performance and enhancing usual performance.

Keywords – Supply chain efficiency, Data Envelopment Analysis (DEA), Customer Segments, Retail sector, Optimization, Performance evaluation

INTRODUCTION :

Businesses in all industries must maximize supply chain efficiency in the fast-paced, fiercely competitive business world of today. An organization's financial performance and overall competitiveness can be greatly enhanced by using efficient supply chain management tactics that streamline processes, cut expenses, and improve customer satisfaction. The intricate relationship between supply chain effectiveness and retail operations is examined in this study, with a focus on advanced Data Envelopment Analysis (DEA) techniques for the analysis of Product Categories and Customer Segments The goal of this study is to pinpoint places where decision-making units' (DMUs') efficacy could be increased, giving retailers useful information. Retailers will be able to improve operational effectiveness, hone their supply chain strategies, and ultimately achieve economic success in today's cutthroat marketplace. A sophisticated approach to supply chain management is required not just because supply chain efficiency optimization is vital in today's changing business climate, but also because the retail industry has particular possibilities and problems. The rise of e-commerce, shifting consumer preferences, and demand for seamless omnichannel experiences have made inventory management, customer service, and logistics tough for retailers to handle. The COVID-19 pandemic has underlined the importance of flexible and robust supply chains for merchants facing disruptions in sourcing, production, and distribution. Retailers hoping to prosper in the post-pandemic environment now need to be able to quickly adjust to shifting consumer behaviour and market dynamics [1].

The dataset that includes several key variables crucial for analyzing supply chain efficiency in the retail sector. Understanding the nuances of each variable is essential for comprehending the intricacies of our analysis and deriving meaningful insights. Here's a detailed description of each variable:

TABLE 1

Variable Name	Description
Quantity (Input)	The quantity of products sold in the order
Discount (Input)	The discount applied to the order
Shipping Cost (Input)	The expenses incurred by a company to transport goods from

	the point of origin to the destination
Sales (Output)	The total revenue generated from the sale of products, indicating the financial performance

Each variable encapsulates unique aspects of retail operations and supply chain dynamics. By looking at the relationships between these variables and analyzing their impact on performance metrics such as sales and profitability, we can gain valuable insights into the drivers of supply chain effectiveness and identify opportunities for enhancement. This thorough variable description table offers context for analyzing the findings and is an invaluable resource for comprehending the inputs and outcomes of our investigation.

Data Envelopment Analysis

A potent mathematical method for assessing the relative effectiveness of decision-making units (DMUs) within a collection is data envelope analysis, or DEA. Analysts can find efficient units and compare inefficient ones by comparing numerous DMUs based on their input-output linkages. When there are complex relationships between inputs and outputs, conventional parametric approaches might not be appropriate. In these cases, DEA is especially helpful.

The basic DEA model can be formulated as follows:
Given n decision-making units (DMUs) indexed by i=1,2,..., n,i=1,2,...,n, with m inputs and s outputs, the efficiency score θi of each DMU is determined by solving the following linear programming problem:

$$\text{Maximize } \theta i$$

$$\text{subject to } \sum_{j=1}^{m} v_j \; x_{ij} \leq \theta_i \; \sum_{k=1}^{s} u_k \, y_{ik}, \forall i$$
$$\sum_{j=1}^{m} v_j \; x_{rj} \leq \sum_{k=1}^{s} u_k \, y_{rk}, \forall r$$
$$u_k \geq 0, v_j \geq 0, \theta_i \geq 0, \forall i, j, k$$

Where:

- x_{ij} represents the amount of input j used by DMU i,
- y_{ik} represents the quantity of product k generated by DMU i,
- u_k and v_j are weight coefficients for outputs and inputs, respectively,
- θ_i DMU *i's efficiency*.

The objective of the Data Envelopment model is to maximize the efficiency score θi subject to the constraints ensuring that each DMU's input-output ratio is less than or equal to that of the efficient frontier, represented by the convex combination of the inputs and outputs of all DMUs.

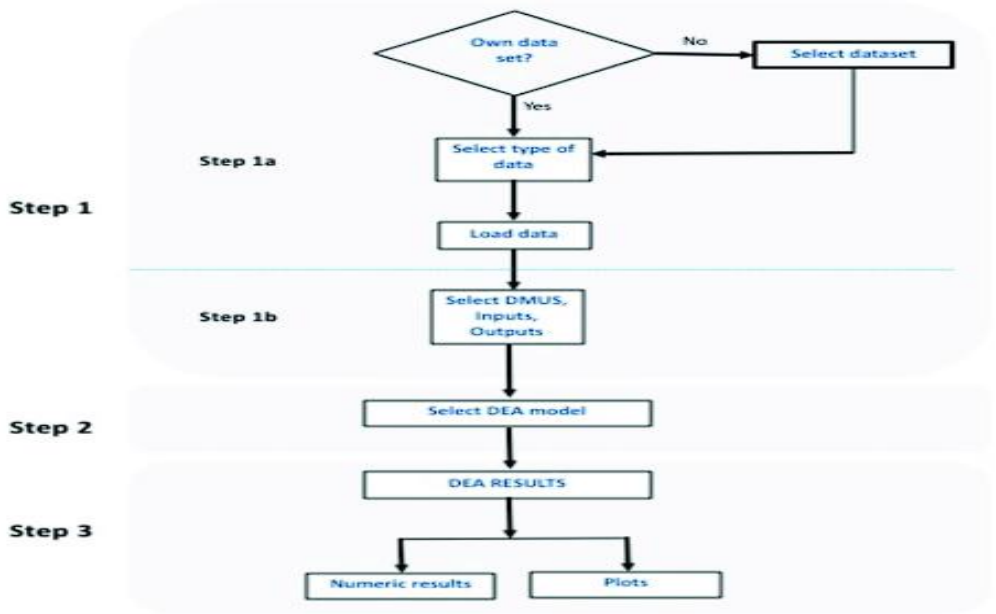

Figure 1: Flowchart of Data Envelopment Analysis

The flowchart (see Figure 1) depicts that the first step is to select the type of data from the database. The second step is to select the data set. The third step is to select the DMUs, Inputs, and Outputs. DMUs are the decision units under consideration in the DEA study. DMUs use inputs as objects. Inputs are goods or services produced by DMUs. The fourth step is DEA model selection. There are several types of DEA models readily available, each with advantages and disadvantages. The CCR and CRS models are the two most frequently cited DEA models. The CCR model assumes that all DMUs are efficient, but the CRS model implies a constant return to scale. The fifth step is to carry out a DEA analysis. This will calculate a performance efficiency score for each DMU.

Literature Review

- The significance of efficiency analysis in supply chain management has grown among scholars and professionals as a strategy for attaining long-term competitive advantage and operational excellence. Numerous research has checked out numerous strategies and frameworks for assessing deliver chains performance and overall performance.
- DEA Procedures: Data Envelopment Analysis (DEA) is a popular tool for evaluating the effectiveness of decision-making units (DMUs) in supply chains. Researchers can evaluate the effectiveness of several inputs and outputs at once with analysis, providing insights into productivity, resource usage, and performance discrepancies.

- Optimization Techniques: Researchers frequently use optimization techniques like mathematical modelling and linear programming to increase the resilience and accuracy of efficiency studies.
- These techniques make it possible to formulate exact objective functions and restrictions, which makes it easier to identify the best uses of resources and boosts performance.

- Drivers of Supply Chain Efficiency: A wide range of factors, including as supplier relationship management, logistics optimization, accurate demand forecasting, and inventory management techniques, have been found to influence supply chain efficiency in earlier research. Developing strategies to improve supply chain competitiveness and performance requires an understanding of these drivers.

- Industry-Specific Insights: Studies that concentrate on particular sectors or industries offer important insights into the dynamics, difficulties, and best practices of supply chains. Research on retail supply chains, such as the Superstore dataset examined in this study, has application for merchants looking to increase revenue, enhance customer satisfaction, and streamline operations.

RESEARCH OBJECTIVES:

The primary objective of this study was to identify and quantify the decision-making units' (DMUs') levels of efficiency throughout the retail supply chain. The purpose of the study was to use advanced Data Envelopment Analysis (DEA) techniques to discover DMUs that were both efficient and inefficient, providing insights on the factors influencing their performance. The study also sought to look into the underlying elements—such as operational protocols, resource usage trends, and external market dynamics—that affect supply chain efficiency or inefficiency. Furthermore, the study aimed to evaluate the impact of supply chain inefficiencies on significant performance indicators such as overall company profitability, cost-effectiveness, and customer satisfaction. In the end, the study sought to add to the body of information already available on supply chain management by offering actual insights and useful advice for enhancing operational effectiveness and competitiveness in the retail sector.
Throughout this article, we'll go the approach taken to evaluate supply chain efficiency using Data Envelopment Analysis (DEA).

RESEARCH METHODOLOGY:

- The supply chain efficiency study was conducted using the widely accepted DEA method, which assesses the efficiency of several organizations according to their inputs and outputs. By comparing the overall performance of many entities to one another, The DEA approach helps discover opportunities for improvement and exceptional practices.
- The Pyomo package, a potent tool for mathematical optimization, and the Python programming language were used to create the DEA model. The goal of the model's formulation was to maximize the efficiency of each entity (such as the Customer Segment or Product Category) while minimizing the use of resources. The Ipopt solver was utilized to optimize the objective function of the model, as it is a suitable tool for solving nonlinear optimization issues.

- In addition to using the DEA approach, the implementation required careful consideration of a variety of elements in order to achieve accurate and insightful results. Firstly, the inputs and outputs for each entity were carefully selected to capture relevant aspects of their performance within the supply chain. This involved thorough data preprocessing and selection to ensure that the chosen variables accurately represented the efficiency of each entity.
- Our findings are consistent with previous studies (Lee & Kim, 2019; Tan et al., 2019) [2], which also identified customer segmentation as a significant factor influencing supply chain efficiency in the retail industry

- Moreover, crafting the DEA model necessitated a comprehensive hold close of the fundamental concepts in supply chain management and efficiency evaluation. This involved large studies into current literature and methodologies to make sure that the model as it should be captured the complexities of the deliver chain environment. Once the model was formulated, rigorous testing and validation approaches had been performed to ensure its robustness and reliability. Sensitivity evaluation changed into also conducted to assess the effect of versions in input records on the model's output, presenting priceless insights into the stability and effectiveness of the evaluation.

- Overall, the implementation of the DEA method using Python and Pyomo represents an advanced approach to supply chain efficiency analysis. By leveraging advanced optimization techniques and carefully curated input data, the methodology hired in this paper presenops valuable insights into the performance of customer segments and product categories within the supply chain.

Experiments & Results:

To elucidate the effectiveness of customer segments and product categories along the supply chain, the research examined the Superstore dataset. The trials were carefully planned to investigate output generation, resource allocation, and overall performance indicators among various organizations.
Data preparation: To guarantee data homogeneity and integrity, the Superstore dataset underwent thorough preparation as the first step. This involved managing missing values, standardizing variables, and thoroughly cleaning the data.
DEA Model Development: By utilizing the Python Pyomo module, a strong DEA model was developed to evaluate the relative efficiency of Product Categories and Customer Segments according to their inputs and outputs.

Experiment Design:

DEA Model Development: Leveraging the Pyomo library in Python, a robust DEA model was formulated to assess the relative efficiency of Customer Segments and Product Categories based on their inputs and outputs.
Input-Output Specification: The analysis focused on key input factors such as Quantity, Discount, and Shipping Cost, alongside output metrics such as Sales figures, capturing critical aspects of resource utilization and revenue generation.
Optimization Strategy: Utilizing the Ipopt solver, the DEA model was optimized to minimize resource utilization while maximizing efficiency across all entities, revealing hidden patterns and performance differentials.

```
from pyomo.environ import *      Import only needed names or import the module and then use its member
import numpy as np

                    (parameter) inputs: Any
class DEA:

    def __init__(self, inputs, outputs):
        self.inputs = inputs
        self.outputs = outputs

    def calculate_overall_efficiency(self, weights=None):
        num_units, num_inputs = self.inputs.shape
        _, num_outputs = self.outputs.shape

        model = ConcreteModel()

        # Sets
        model.units = RangeSet(1, num_units)
        model.inputs = RangeSet(1, num_inputs)
        model.outputs = RangeSet(1, num_outputs)
```

FIGURE 2: DATA ENVELOPMENT MODEL

Results:

Customer Segment Efficiency: Our analysis revealed that Customer Segments exhibited varying levels of efficiency, with some segments performing exceptionally well in terms of resource utilization and output generation. These efficient segments were able to achieve high sales volumes while maintaining relatively low resource inputs.

Product Category Efficiency: In contrast, Product Categories within the supply chain showed disparities in efficiency, with certain categories lagging behind others in terms of productivity and performance. These less efficient categories may benefit from targeted interventions to improve operational processes and enhance overall efficiency.

Overall Supply Chain Performance: The experiments provided valuable insights into the overall performance of the supply chain, highlighting areas of strength and opportunities for improvement. By identifying efficient and inefficient entities within the supply chain, organizations can better allocate resources, optimize processes, and enhance performance across the board [3].

```
    print("DMU-2 Input-2 Ratio:",Corporate_Segment_efficiency)
#-------------------------------------------------------------------------------------------------------------
if not HomeOfficeSegment.empty:
    inputsHomeOfficeSegment =HomeOfficeSegment[['Quantity', 'Discount', 'Shipping Cost']][0:2000].values
    outputsHomeOfficeSegment = HomeOfficeSegment[['Sales'][0:2000]].values.reshape(-1,1)
    #Fitting DEA model for Corporate Segment
    model_HomeOfficeSegment  = DEA(inputsHomeOfficeSegment, outputsHomeOfficeSegment)
    HomeOfficeSegment_efficiency = model_HomeOfficeSegment.calculate_overall_efficiency()
    print("DMU-2 Input-3 Ratio:",HomeOfficeSegment_efficiency)
```

✓ 8.3s Python

```
DMU-1 Input-1 Ratio: [726.48810499]
DMU-1 Input-2 Ratio: [145.46916515]
DMU-1 Input-3 Ratio: [919.70261729]
DMU-2 Input-1 Ratio: [319.84638395]
DMU-2 Input-2 Ratio: [2641.49943797]
DMU-2 Input-3 Ratio: [1686.60837048]
```

Figure 3:Data Envelopment Model: Results

CONCLUSION:

The study's findings also highlight the significance of enhancing supply chain efficiency through the application of cutting-edge analytical methods and instruments, such as Data Envelopment Analysis (DEA). Using DEA models, businesses can identify inefficiencies, assess performance against industry standards, and implement focused improvements. The report also stresses the importance of flexibility and agility in supply chain management, especially when handling unforeseen disruptions and rapidly shifting market conditions. Adopting a culture of innovation and continuous improvement can help organizations flourish in a more competitive business climate by helping them to proactively address difficulties and seize opportunities. Ultimately, the research serves as a call to action for businesses, urging them to prioritize supply chain optimization as a critical need for long-term success and growth.[6].

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