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Construction Hardware Store Warehouse Layout Optimization Using Market Basket Analysis

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Abstract. The layout of a retail establishment has an essential part in attracting and maintaining clients, thereby influencing sales. This study focuses on the issue of customers in hardware stores seeking assistance as a result of insufficient organization. By utilizing purchase history and doing market basket research, a data-driven method is suggested to enhance the store design. Market basket analysis is a technique that derives association rules from consumer purchasing data, facilitating the identification of products that are connected with each other. The objective is to minimize the distance to get the items in the hardware store which will increase customer satisfaction by reorganizing the store layout using consumer transaction data.

Keywords: construction hardware store · warehouse · purchase history · market basket analysis.

1 Introduction

A retail store's layout is an important aspect in drawing customers. The use of a suitable retail layout increases the store's sales. Purchase history can be used to predict customer preferences and as a tool for building a more efficient store layout. Market basket analysis is used to extract insights from transaction data. Market basket analysis (MBA) helps in the extraction of numerous association rules from shopper purchasing data. A client can select different things that are associated with the items that the person has just placed in his or her shopping basket or cart, so establishing an association rule. The extraction of such criteria can help in the right product placement in the store based on the preferences of the shopper. [4]

Warehouse management involves the coordination of activities and the efficient utilization of space within a warehouse to facilitate the processes of

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receiving, storing, and distributing products. Most research is conducted on enhancing warehouse operations for multiple case study organizations. Most individuals prefer utilizing the ABC analysis approach to categorize things according to their price and quantity. [7]

A research study was conducted to improve the placement of fresh food and optimize the departing process for warehouses in the Market Basket Analysis storage system. It has been discovered that this format is suitable for organizations seeking to store linked products. The notion of proximity, which involves storing things near the delivery location, is crucial and can enhance staff efficiency. However, no research has been conducted on the inventory management of a building material store that employs warehousing techniques using Market Basket Analysis. [8]

Hardware stores are retail establishments that provide various necessary equipment, construction materials, and renovation items. These contain many elements, such as steel poles, fasteners, paint, plumbing fittings, and other materials. An existing problem in the current store arrangement is customers' need for help finding requested items due to inadequate organization. The lack of organization raises the probability that buyers may overlook other things they may require, as the positioning of objects could be more precise. In order to tackle this issue, it is crucial to rearrange the design according to consumer transaction data.

Thus, this paper proposed the strategy utilizes a data-driven methodology that leverages market basket analysis, a type of data mining that detects correlations between matched products commonly bought together and identifies co-occurrence patterns. The goal is to develop a highly efficient analytical approach to minimizing the distance to get each item by managing the arrangement of the hardware shop. On the basis of the market basket analysis results, we devise a store layout in which products with high correlations are positioned in close proximity to one another. By reducing the walking distance, the store's overall efficacy is increased. To achieve this objective, we conducted an experiment that assessed the impact of various layouts on travel distances. By focusing on the relationships between items, the analysis provided actionable insights into how to rearrange items to reduce travel time effectively.

This work's findings underscore the potential for market basket analysis to be a valuable tool in warehouse management. Additionally, it opens the door for future research into integrating more indicators or alternative methods to further improve warehouse optimization.

2 Related Works

The shopping experience has evolved from little corner businesses in the 1900s to contemporary superstores. The changeover brought about a new era of global rivalry and corporate prospects. Presently, consumers have an extensive range of choices available to them across many sectors concurrently. Furthermore, consumers have the option to select from a diverse range of products within the same industry, regardless of the time of year or any other commitments. [1]

Since 1980, searches for hidden data in the database of a supermarket have been extremely popular. The rapid growth of supermarkets, consequently, has generated a greater degree of consumer interest in the area of search method development and research. Retail owners attempt to "remind" consumers of essential products in order to attract their interest towards newly arrived items. A prevalent strategy for boosting sales is to arrange frequently purchased items in close proximity on adjacent shelves or stands. [6]

Association rules, commonly known as Market Basket Analysis, are a data mining approach used to identify customer buying patterns. Association rule mining is a data analysis technique that tries to identify frequent co-occurrences of things. Association encompasses multiple algorithms that facilitate data mining tasks, including Apriori, ECLAT, FP-Growth, and Hash-Based. There was a study comparing Fp-Growth with Apriori and concluded that the Fp-Growth Algorithm shows a far greater level of accuracy, specifically 217%, compared to the Apriori Algorithm, which only achieves 46%. The Fp-Growth algorithm has a significantly shorter runtime of 6 seconds compared to the Apriori algorithm, which necessitates a runtime of 30 seconds. The Fp-Growth Algorithm yields over 19 association rules, but the Apriori Algorithm generates only 6 rules. [2] The RDA Hijab has utilized this idea to obtain recommendations for business promotion techniques by analyzing the sales transaction data possessed by the firm. The outcomes derived from the established guidelines can provide as a suggestion for building novel business promotion methods for RDA Hijab. One method involves implementing promotions through the provision of bonuses for unsold products to consumers who purchase specific product packages. Based on the conducted re-search, it is advised to utilize 16 different types of product packaging. [5]

Association rules not only discover customers' buying behavioral patterns, but they can also enhance shelf productivity. In 2021, a study demonstrated the utilization of data mining methods to enhance sales. It is the initial analysis of transaction data from a single store, covering a full year of regular operations, within the context of a market basket analysis. Over 60 association rules delineate consumer behavior. These regulations are employed to achieve the most suitable arrangement of the sales area. The optimum spatial arrangement impact is achieved by devising promotional. methods that enhance the distance customers walk throughout the business. [3]

3 Methodology

The research paper consists of three primary sections: Data collection and preprocessing, Market Basket Analysis, and Store layout optimization. The overview of the research methodology is illustrated in Fig. 1. The data used to determine the warehouse layout optimization is the real-life sales transaction data in a hardware retail shop from January 2022 to December 2023 with 43 features, which are partially illustrated in Fig 2.

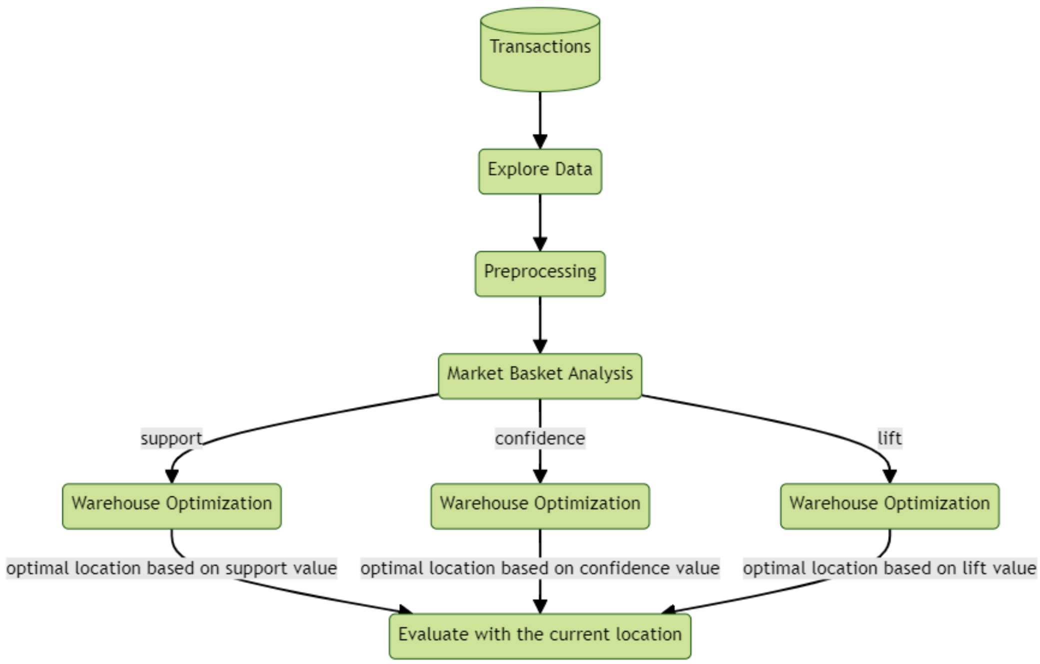

Fig. 1. Research Framework

3.1 Data Collection and Pre-processing

Before utilizing the raw sales transaction, it is necessary to eliminate a significant number of unused features. TRANNO, TRANDATE, and ITEMNAME are the features that are utilized; these three are the only features required to uncover association rules. With the objective of improving the operational efficiency of the warehouse, we have initiated an extensive investigation of 30510 transactions comprising transactional data, which serves as the basis for our market basket analysis. Three specific data elements—Transaction Number (TRANNO), Transaction Date (TRANDATE), and Item Name—are essential to this analysis. Every individual data column in this dataset is essential for revealing purchasing patterns, which subsequently guide our choices regarding product placement and inventory management. The Transaction Number functions as a distinct identifier for every purchase made by a consumer. This identifier is critical because

```
Data columns (total 43 columns):
 #   Column                       Non-Null Count   Dtype
---  ------                       --------------   -----
 0   SYSWAREHOUSEID               121457 non-null  int64
 1   TRANDATE                     121457 non-null  datetime64[ns]
 2   TRANNO                       121457 non-null  object
 3   REFERENCENO1                 2410 non-null    object
 4   SYSVOUCHERID                 121457 non-null  int64
 5   SYSSALEID                    121457 non-null  int64
 6   TOTAL                        121457 non-null  float64
 7   TOTALVAT                     121457 non-null  float64
 8   GRANDTOTAL                   121457 non-null  float64
 9   FCANCEL                      121457 non-null  int64
 10  TAXRATE                      121457 non-null  int64
 11  SYSPERSONID                  121457 non-null  int64
 12  SYSBRANCHID                  121457 non-null  int64
 13  ORDINARY                     121173 non-null  float64
 14  FPROCESS                     121173 non-null  float64
 15  SCANCODE                     121173 non-null  object
 16  TAXTYPE                      121173 non-null  object
 17  ITEMNAME                     121173 non-null  object
 18  SYSUNITID                    121173 non-null  float64
 19  BASEQUANTITY                 121173 non-null  float64
 20  QUANTITY                     121173 non-null  float64
 21  SYSITEMID                    121173 non-null  float64
 22  PRICE                        121173 non-null  float64
 23  AMOUNT                       121173 non-null  float64
 24  DETAILNO                     121173 non-null  float64
 25  ITEMID                       121173 non-null  object
 26  ITEMNAME.1                   121173 non-null  object
 27  TOTALTRADDISCHAVEVAT         121457 non-null  float64
 28  TOTALTRADDISCNONEVAT         121457 non-null  float64
 29  FSTOCKMAIN                   121457 non-null  int64
 30  FMLDISCOUNTITEM              1642 non-null    object
 31  FMLDISCOUNTROW               559 non-null     object
 32  DISCOUNTPROMOTION            121173 non-null  float64
 33  NAME                         121457 non-null  object
 34  EMPID                        121457 non-null  object
 35  CF_UNITNAME                  121173 non-null  object
 36  CF_COMPANY                   121457 non-null  object
 37  FNAME                        121457 non-null  object
 38  CF_TRANEXTRAINFO_PRENAME     99130 non-null   object
 39  CF_TRANEXTRAINFO_FNAME       121457 non-null  object
 40  CF_TRANEXTRAINFO_LNAME       11 non-null      object
 41  CF_TRANEXTRAINFO_DIS         121457 non-null  float64
 42  CF_TRANDATE                  121457 non-null  object
```

Fig. 2. Raw Data

it consolidates all items collected during a single transaction, allowing us to determine which products are frequently purchased in combination. These insights are crucial in identifying product relationships, which in turn can inform the strategic arrangement of the store to improve employee efficiency.

Through the strategic arrangement of related products according to their co-purchase history, it is possible to substantially augment cross-selling prospects and reduce the employee's spending time. Moreover, the inclusion of the Transaction Date in our data analysis introduces a temporal aspect, enabling us to monitor the evolution of purchasing patterns. This knowledge is essential for identifying seasonal trends and the influence of promotional activities on consumer purchasing behavior. Prepared with this understanding, we can adapt our inventory and store design to meet predicted peaks in demand during designated time periods, which ensures availability for customer influxes while improving stock management efficacy to avert instances of scarcity or surplus.

Finally, the Item Name offers a direct insight into consumer purchasing decisions, revealing the most frequently purchased items and the ways in which they are grouped together in the warehouse. This data not only facilitates the optimization of the warehouse layout through the strategic placement of frequently paired items in close proximity to one another but also supports inventory management by ensuring that popular items are consistently accessible and stand out. Through the integration of the following three data components—TRANNO, TRANDATE, and ITEMNAME—into our market basket analysis, a complete understanding of customer purchasing behaviors is achieved. This analysis performs an essential part in informing decisions based on data, thereby improving the overall efficiency of purchasing experiences. With the ongoing development of our warehouse layout strategy in light of these insights.

3.2 Market Basket Analysis

Market basket analysis provides an approach to understanding customer behavior by analyzing concrete data, which has significant potential for enhancing operations management in retail stores. An MBA produces a collection of association rules that are defined based on itemsets. An itemset is a collection of items that are purchased together. Association rules are declarations that have the form of

$$x \Rightarrow y \tag{1}$$

Which mean Customers who purchased itemset x also acquired itemset y. In this context, x is commonly known as the antecedent, whereas y is known as the consequent. The support $S(x)$ of an itemset x is defined as

$$S(x) = P(x) \tag{2}$$

Rules with a low support of their antecedent occur very rarely. The confidence $C\ (x \Rightarrow y)$ of a rule $x \Rightarrow y$ is given by

$$C(x \Rightarrow y) = P(y|x) = \frac{P(x \cap y)}{P(x)} \tag{3}$$

Confidence may be used to determine complementary (high confidence) and supplementary (low confidence) products. Finally, the lift L $(x \Rightarrow y)$ of a rule x $(\Rightarrow y)$ is given by

$$L(x \Rightarrow y) = \frac{P(x \cap y)}{P(x)P(y)} \tag{4}$$

and can be defined as an indicator of the point at which the sets of items in a rule depart from independence. The probability concept is interpreted frequently in these definitions.

3.3 Layout Optimization

A store's warehouse layout is typically established by the store manager's own knowledge. They are divided into several categories and placed across the warehouse according on their use similarities. Although this criterion may be beneficial in reducing search time, it does not take into account the real purchase behavior of customers based on historical data. Unanticipated expenditures at retail establishments have been associated with travel distances within warehouses. With the intention of minimizing the overall travel distance of every transaction, we suggest that the warehouse layout be defined as the resolution to an optimization problem. Let d_{ij} represent the distance between a pair of products i and j. The variable is

$$x_{il} = \begin{cases} 1 \text{ if product i is located at position } l \\ 0 \qquad\qquad\qquad\qquad \text{else} \end{cases} \tag{5}$$

To define the problem as linear, the variable y_{ijlk} is formulated as x_{il} and x_{jk}: x_{il} represents a binary variable that indicates whether a specific product i is located at a specific position l.

$$y_{ijlk} = \begin{cases} 1 \text{ if product i,j is located at position l,k respectively} \\ 0 \qquad\qquad\qquad\qquad \text{else} \end{cases} \tag{6}$$

Layout Optimization based on confidence

$$\text{Minimize} \sum_{ijlk} y_{ijlk} d_{lk} c_{ij} \tag{7}$$

c_{ij} : Represent the confidence value of related to products i and j

Layout Optimization based on lift

$$\text{Minimize} \sum_{ijlk} y_{ijlk} d_{lk} l_{ij} \tag{8}$$

l_{ij} : Represent the lift value of related to products i and j

Layout Optimization based on support

$$\text{Minimize} \sum_{ijlk} y_{ijlk} d_{lk} s_{ij} \tag{9}$$

s_{ij} : Represent the support value of related to products i and j

Constraints: The following constraints are applied to the mentioned three objectives.

$$2_{yijlk} \leq x_{il} + x_{jk} \tag{10}$$

The constraint shown in equation (10) means that if both products i and l are located at positions j and k respectively, then the combined value of x_{il} and x_{jk} should be at least 2. It helps ensure that y_{ijlk} reflects the relationship between x_{il} and x_{jk}

$$\sum_{i} x_{ik} = 1, \forall k \tag{11}$$

The constraint in (11) states that for each position k, there must be exactly one product. It ensures that each position contains only one product.

$$\sum_{k} x_{ik} = 1, \forall I \tag{12}$$

Equation (12) implies that for each product i, it must be placed in one and only one position. It ensures that each product has a defined position.

$$d_{326} \geq 20 \tag{13}$$

The distance between the wood and the chemical supplies must be at least 20 units, as shown in equation (13). This could be crucial for safety reasons or logistical considerations where maintaining a specific distance between wood and chemical supplies helps prevent hazards like fire risk or contamination.

4 Experiment and Result

In the experimental result, we compare the total distance of the current warehouse layout from 30,510 sale transactions with the total distances of the rearranged layout from layout optimization based on confidence, lift and support.

The total distance calculation function provides a streamlined approach to managing and minimizing distances during a transaction, making it particularly beneficial in situations like retail stores, warehouses, and logistics operations.

A significant contribution is made by the function in the process of determining the overall distance traveled during a transaction. It takes into account a number of important distances, including the distance from the original entrance or exit point to the first item in the transaction, the distances between items on the transaction list, and the distance from the last item to the entrance or exit. Taking an all-encompassing strategy guarantees that all pertinent lengths are taken into consideration, hence compute the total distance traveled from start to finish.

In the real world, this function can be applied in a few different ways. Within this paper, the total distances are calculated from the entrance of the warehouse to each item in the transaction and back to the exit while the entrance and the exit are at the same point. An example of distance calculation is illustrated in Fig. 4 Within the setting of a warehouse, it simplifies the procedures of order fulfillment by enabling workers to travel between different items or shelves in an effective manner, resulting in minimizing the amount of time and effort that is required for each individual order.

In addition to its immediate applications, the function highlights the power of data and algorithms to optimize the procedures involved in logistics. The method of sorting goods according to their distance and iterating over them in sequence can be extended to a variety of difficulties, ranging from the management of supply chains to delivery routes, and it can assist businesses in saving time, resources, and money.

In conclusion, the calculate total distance function is an effective instrument for computing transactions that involve travel between a number of different places involving movement. In order to effectively reduce the overall distance traveled, a method that takes into consideration the distances to and from the "entrance/exit" as well as the distances between the items is provided. The relationship between data, algorithms, and operational efficiency is demonstrated by the fact that this results in significant time and cost reductions in retail, warehousing, and other logistics activities.

To illustrate this process, let's consider an example transaction titled 'OOQ66060004'. The transaction begins at the designated entrance/exit. From there, it progresses to each item ordered by the distance from the entrance. Thus, the '40030' is the first visit item, followed by item '40029', item '170879', and item '100060'. It finally reaches item '300184' before returning to its starting point at 'OOQ66060004'. The total distance covered throughout this transaction, including the return journey, amounts to 79.66 meters.

Initially, we established our current layout, which includes a total operational distance of 1,233,102.54 meters of 30510 sale transactions. This serves as the 'baseline' or initial position from which we analyse and evaluate subsequent strategies. An example distance of the transaction is shown in Table 1.

The first approach, developed using Market Basket Analysis (MBA) with a focus on the confidence value, resulted in a total travel distance of 946,353.18 meters. This indicates a considerable reduction from the original layout, demonstrating the value of grouping things based on their likelihood of being purchased together. The significant reduction in the trip distance suggests that this strategy can result in more effective order picking and lower labor expenses.

When compared to the original configuration, the lift-based layout had a total travel distance of 986,704.14 meters, which is a shorter distance than the

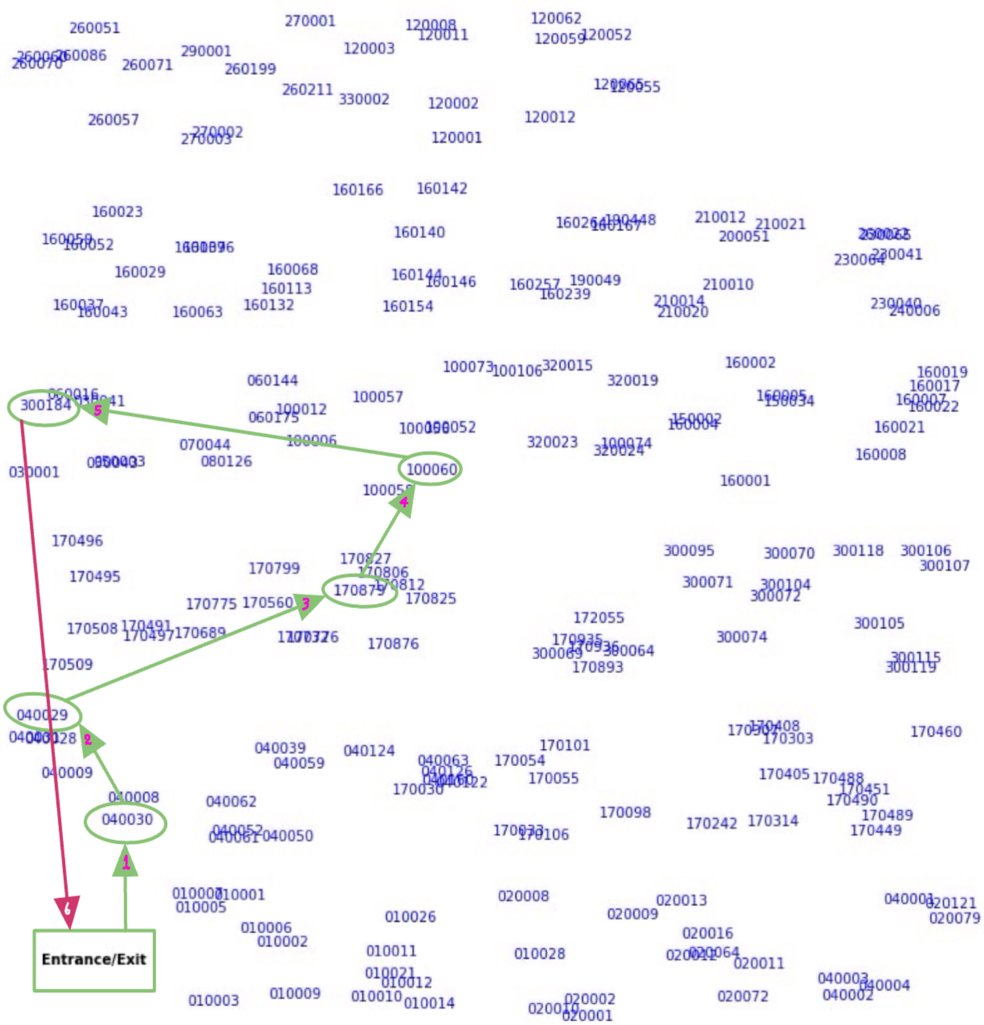

Fig. 3. The example of using the calculate total distance function

TRANNO	ITEMNAME	Total distance original layout
OCTC65020001	['40002', '40004']	24.03943922
OCTC65070001	['10001', '40001']	13.65685425
OOQ66060005	['40030', '40031', '170879']	24
OOQ66070006	['40029', '40030', '170879']	78.03028393
OOQ66090002	['20010', '20012']	17.88854382
ORCC65010002	['120052', '170775']	49.59833037
ORCC65010006	['10001', '20001']	18.60112616
ORCC65010019	['40028', '40029', '300104']	28.64911064
ORCC65010023	['10001', '20001']	18.60112616
ORCC65010024	['40029', '40030']	8
OOQ66060004	['40029', '40030', '100060', '170879', '300184']	79.66084734

Table 1. the example of transaction Items with Total Distances from Original Layout

confidence-based layout but a longer distance than the original layout. While lift is a measurement of the degree to which two things are associated with one another, the fact that the travel distance is slightly greater could indicate that this method is less effective at reducing the distances between items. In spite of this, the reduction in comparison to the initial layout indicates that the utilization of the lift value might still result in increased efficiency.

The approach using the support value results in the shortest overall trip distance of any of the optimal layouts, at 939,249.12 meters. Support represents the frequency of specific product combinations, and the shorter trip distance indicates that this statistic may be beneficial in driving warehouse change. The results indicate that choosing frequently occurring item combinations can result in a more effective warehouse structure.

TRANNO	ITEMNAME	total distance original	total distance lift	total distance confidence	total distance support
OCTC65020001	['40002', '40004']	8	4.03943922	25.68493303	26.37249697
OCTC65070001	['10001', '40001']	13.65685425	10.27073001	3.093513555	4.112495435
OOQ66060005	['40030', '40031', '170879']	24	48.65463237	56.61683453	41.76617836
OOQ66070006	['40029', '40030', '170879']	78.03028393	38.21015641	38.66948332	43.75310154
OOQ66090002	['20010', '20012']	17.88854382	12.63451109	10.29159892	4.395028789
ORCC65010002	['120052', '170775']	49.59833037	46.15120612	46.15120612	41.95352489
ORCC65010006	['10001', '20001']	18.60112616	11.21331969	3.654036743	3.654036743
ORCC65010019	['40028', '40029', '300104']	28.64911064	43.48096252	45.70169762	48.12327934
ORCC65010023	['10001', '20001']	18.60112616	11.21331969	3.654036743	3.654036743
ORCC65010024	['40029', '40030']	8	6.900752821	9.292454254	15.31679893
OOQ66060004	['40029', '40030', '100060', '170879', '300184']	79.66084734	54.35114266	55.39550162	59.75972414

Table 2. The example of tansaction Data with Distances and Measures

Fig 4 represents the total travel distance in meters for different warehouse layouts, providing a visual comparison between the original layout and three optimized layouts: Confidence-Based, Lift-Based, and Support-Based.

Table 2 depicts a table that contains information regarding the optimization of the layout of the warehouse. The table appears to include numerous columns and 30,510 rows, each of which represents a different transaction.

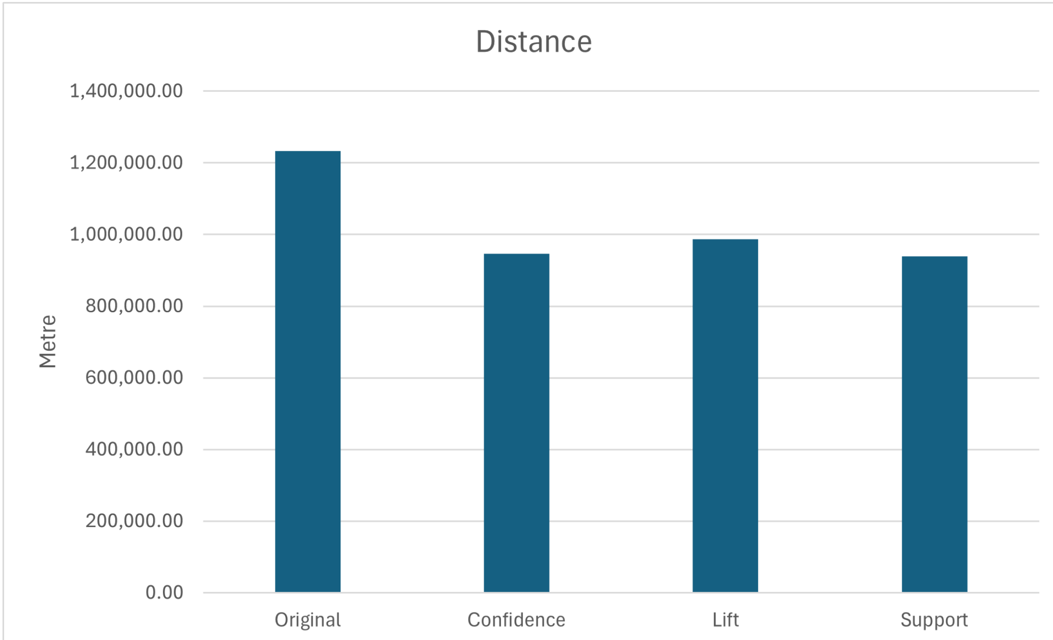

Fig. 4. Distance of optimization by using Item

In recent efforts to optimize our warehouse's operational efficiency, we have implemented a revised product placement strategy based on advanced market basket analysis techniques, specifically utilizing metrics such as confidence, lift, and support associated with each product. This analytical approach allowed us to determine which products are frequently bought together, thereby informing a strategic placement that enhances the likelihood of cross-selling and reduces the time taken for order fulfillment.

The results from this new layout have demonstrated a clear improvement over the previous configuration, with enhanced efficiency and increased sales potential. However, it has also introduced a significant challenge: the current product arrangement does not take into account the categorical division of products by departments. Products are placed primarily based on purchasing patterns without consideration for their departmental categorization, leading to a scattered layout.

This approach, while beneficial from a sales and picking efficiency perspective, poses difficulties in warehouse management. The scattered nature of product placement complicates the restocking process, makes inventory checks more labor-intensive, and could potentially increase the training time for new staff due to the non-intuitive placement of items.

Therefore, it is imperative that we further develop and refine our placement strategy by prioritizing product department categorization as the main focus. While the analytical placement based on purchase patterns has yielded positive results, the scattered layout has introduced complexities in warehouse management that cannot be overlooked. Using product department as the primary criterion for organizing the warehouse floor will facilitate more efficient operations, including restocking, inventory audits, and staff training.

Incorporating department-focused zones within the warehouse will enable us to maintain the benefits of market basket analysis—such as enhanced cross-selling opportunities and reduced order fulfillment times—while also making the overall layout more intuitive and manageable. This balanced approach will optimize both the operational efficiency and the administrative aspects of warehouse management, ensuring a more sustainable and productive operation in the long term.

5 Discussion

The findings of the experiment indicate that utilizing Market Basket Analysis (MBA) to optimize the layout of a warehouse can greatly cut down on the amount of time spent traveling for order pickup. In comparison to the initial plan, the optimized layouts resulted in significant improvements. These improvements were achieved by restructuring the layouts based on confidence, lift, and support. The strategy of optimizing by individual items, on the other hand, provides a number of practical challenges, especially with regard to the organization of the warehouse facilities and the management of stock. One of the most significant drawbacks of item-based optimization is that it has the potential to result in a layout that is fragmented and scattered. The layout that is produced as a result of the optimization may not have a clear categorization because the optimization focuses on grouping individual items based on purchasing habits. Because of this, inventory management might become more difficult, and it can also result in inefficiencies in stocking and retrieval, which could potentially cancel out the benefits of increased trip distance reduction.

6 Conclusion

This experiment illustrates the utility of market basket analysis as a valuable tool for optimizing warehouse layouts. The changed layouts resulting in reduced travel distances demonstrate that focusing on item relationships can effectively enhance warehouse efficiency. A significant part of this project was the development and implementation of a new tool that leveraged market basket analysis techniques, particularly the lift-based approach. This tool was designed to analyze item associations and generate a layout optimizing travel distances within the warehouse. While the resulting lift-based layout had a total travel distance of 986,704.14 meters, which was longer than the original layout, it showed a reduction compared to the confidence-based configuration, underscoring its potential. Further research could explore refining the tool by integrating different indicators or implementing alternative methods to enhance the optimization procedure.

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