Warehouse Layout Optimization: A Case Study based on the adaptation of the Multi-Layer Allocation Problem

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Abstract: Warehouses are key points of logistic processes. The design of a warehouse is a complex problem. It includes a series of interrelated decisions among warehouse processes, warehouse resources and warehouse organizations. This article deals with the implementation of the mathematical model for the Products Allocation Problem (PAP) in a multi-layer warehouse. The main goal of this work is the identification of the optimal warehouse configuration for a company operating in the sector of production and distribution of sports equipment and sportswear. The final aim of the layout optimization is the minimization of the handling costs and decentralization of the stored products, which on turn depends on the assignment of products to the storage slots. In order to solve the PAP model, a preliminary ABC analysis has been carried out to identify more significant class of products in terms of sales volume and handling movements. The consistency of the obtained solution has been successively evaluated considering the cost saving that could be obtained implementing the new layout configuration. Different scenarios have been analysed and evaluated. Numerical cost results show a good quality solution.

Keywords: Warehouse Layout, Product Allocation Problem Cost Analysis

1. Introduction

Effective management of warehouses is one of the main issues that deal with the competitiveness of companies.

Optimal allocation of products and successful inventory management are directly related with the warehouse management and they can be improved through the design of an efficient warehouse layout. The design of a warehouse’s layout represents one of the priority tasks of successful manufactures. An optimal warehouse layout contributes to decrease the overall production costs and to reduce the overall time required for the orders management and fulfilment. A better allocation of shift and products leads, in fact, to the reduction of times and costs generated by handling operations.

Obviously, an effective warehouse management is directly related with the warehouse layout. Several authors investigated the problem of inventory management as a consequence of the effective design of warehouse lay-out.

Traditional methodologies for layout design are based on the analysis and evaluation of different layout configurations by means of qualitative tools, based on the definition of a networks of locations and materials flows. Simulation based approach for warehouse and inventory management have been proposed by Cimino et al., 2008; Curcio et al., 2009; Mirabelli et al., 2009). Mathematical models and technological solution have been proposed by Vrysagotis and Kontis (2011),

In this research work, the optimal warehouse layout reconfiguration is obtained through the application and adaptation of the mathematical model proposed in Guerriero et al. (2013) for the definition of the Product Allocation Problem (PAP). The main idea is to use the mathematical model proposed by Guerriero et al. (2013) in order to evaluate different warehouse scenarios. A preliminary ABC analysis has been carried out to identify more significant class of products in terms of sales volume and handling costs.

This paper describes the results of a project developed in collaboration with a company devoted to the sale and distribution of sports equipment and sportswear for improving the warehouse layout.

The paper is structured as follows: Section 2 illustrates the relevant literature and introduces the Product Allocation Problem; Section 3 presents the main features of the warehouse under study and the warehouse optimization methodology based on the combination of the ABC Analysis for the identification of relevant classes of products and the adaptation of the Product Allocation Problem to a Multi-Layers Warehouses; in Section 4 results are presented and finally some conclusions are provided.
2. Related Works

Warehouse management involves location selection, sizing, layout design, administration system design, location control, delivery and data record (Thompkins et al., 2010).

The space reserved for material allocation and the time required for material handling are key drivers in the design and management of the storage’s areas. The strategy used to allocate products, in fact, influences almost all the warehouse performance and depends strongly on its layout. In such a context, storage location assignment problem consists of allocating products to the different slots in a warehouse with the main of minimizing the handling costs and maximizing the space utilization.

Several mathematical models for products allocation in a warehouse are present in literature, based on different principles and classification criteria of items defined on the base of the picking methodology adopted by the company, the storage systems, the handling systems, etc.

The majority of the models for warehouse optimization present in literature are devoted to the minimization of the total cost for picking operations. As a consequence, products are allocated with the final aim to decrease the picking distance. The basic principle is that the high-demand products have to be allocated in the slot closer to the input and output (I/O) doors for reducing the total time in handling.

Jarvis and McDowell (1991) state that the withdrawal time is proportional to the picking distance in case warehouses characterized by rectangular shapes. To this end, they recommend the adoption of a storage policy based on the allocation of products in stationary position with the scope of minimizing the expected picking time. They suggest placing the items with great demand in the aisle, thus reducing the travel time.

According to Petersen et al. (2004) storage assignment policies are classified into three broad categories: randomized, volume-base, and class-based.

The “randomized” or “shared slot” storage policy consists in devoting any free slot to a generic product that requires it: this technique guarantees the highest minimization of needed slots but its implementation requires the presence of a good information system capable to record the variable position of products within the warehouse (Petersen, 1999).

The simplest structured-storage schemes apply class-based and/or demand-based policies in the arrangement of the products.

In demand (or volume) –based storage the products are stored according to their demand (or their size) near the Pick-up / Drop-off point (P/D). Gibson and Sharp (1992) and Gray et al. (1992) stated that locating high volume items near to the P/D point increased the picking efficiency. Van der Berg and Gademann (2000) suggest the use of products classification strategies based on customer demand. They state that efficient strategies for products allocation can be obtained only after carrying-out a deep analysis of the incoming orders.

In class-based storage the products are classified, and items of each class are placed within the same area of the warehouse. Guenov and Raeside (1992) investigate the effect of the zone shape in a class-based storage and they suggest using the principle of the ABC classification to increase the final warehouse capacity. In Gu et al. (2010) the authors presented a detailed survey of the research on warehouse design, performance evaluation, practical case studies, and computational support tools.

Summarizing, the analysis of the above-mentioned studies highlights that the inventory management success is directly connected with the optimal use of space. An optimal method of storage must be finding to reduce at the same time both the lead-time, such as in the Just in Time policy, both the level of storage, trying to maintain at the same time a high level of the performance indices of the warehouse.

The main contribution of this work relies on using integer program to model the PAP and solve it to evaluate the warehouse layouts in a real case, and suggest for an improvement. A very limited number of contributions have addressed the problem Van den Berg and Gademann (2000). An important contribution is provided in Saneti al. (2011), in which authors deals with the problem of space assignment for the products in a warehouse considering various operational constraints mainly set to prevent decentralization of products in storage locations. A linear integer-programming model is proposed to solve the problem. An extension of the model presented in Saneti al. (2011) is provided in Guerriero et al. (2013), in which authors consider a multi-layer scenario and compatibility constraints in order to control the allocation of different classes of products in the same warehouse.

The mathematical model proposed for the PAP allows the allocation of the most required products into slots closest to the input/output (I/O) doors of the warehouse, while the other products are allocated in the remaining slots according to their compatibility with the previous ones. In the proposed work, the mathematical model defined in Guerriero et al. (2013) have been applied to a real warehouse layout configuration in order to obtain an optimal layout solution. The adopted storage assignment policy is class-based.

3. Materials and Methods

This paragraph introduces the company under study and describes the analysis carried out in order to identify the main features of the studied warehouse. The current operation was evaluated and analyzed. Then, ABC class-based storage was successfully implemented. Finally, the layout optimization was obtained using a linear programming technique to determine the new product allocation policy.
3.1 Background of the Case study: Description and Analysis of the company's warehouse

The company under study is located in South Italy and operates in the sector of distribution and sales of sports equipment and sportswear. The company adopts two different warehouses for the storage of the commercialized items, a principal warehouse and a secondary warehouse. The catalogue of the company includes more then ten lines of products and about one hundred items. In particular, the different lines of products include: (i) the team line devoted to the soccer team, (ii) the goalkeeper line, (iii) the basket line, (iv) the volley line, (v) the line for other sports, such as rugby, swim, athletics, (vi) the relax line, (vii) the training line, (viii) the winter line, which includes gilet, jackets and k-way, (ix) the line for free time including polo, trousers and kit for walking, (x) the bag line, including bags, sacs, trolley, (xi) the line of accessories, (xii) the line of socks, (xiii) the line of shoes (xiv) kit for football teams composed of a jacket, a training uniform, uniforms for football matches, a pair of socks, a suit walking, a duffel bag, and a scarf, (xv) the ball line.

Products are temporary stored in the distribution center in order to be successively delivered. As above mentioned, two different warehouses form the distribution center.

The principal warehouse is characterized by 6 corridors and 12 shelves lines (Figure 1). Four levels in height characterize every shelf.

![Figure 1 - Layout of the principal warehouse](image1)

A secondary warehouse is used for the storage of products for sporting clubs, products characterized by a large volume, such as vests, bathrobes, obstacles and other sporting items, and finally the products out-of-catalogue. The layout of the secondary warehouse is showed in Figure 2.

![Figure 2 - Layout of the second warehouse](image2)

Products are stored following the allocation criteria of fixed position, which leads to the occurrence of the phenomena of stock honeycomb. In addition, the storage positions are defined following a casual logic that leads to the presence of products characterized by low value of handling frequency in the better storage positions. Products are allocated, in fact, following subjective criteria, generally driven by the experience of the operators, while any policy is used for the allocation of products in the second warehouse, where products are often stacked on the ground rather than placed in the shelves. As a consequence of the adopted allocation strategy and of the lack of informative system for supporting the phase of products allocation, the numbers of cells in which items are stored are generally higher than the needed.

Referring to the picking operations, the company adopts the model of Basic Picking or Single Order Picking. When adopting the Basic Picking policy an order picker picks one order at a time following a route up and down each aisle until the entire order is picked. This policy permits to process orders with an accuracy index of approximately 90%, even if the lack of routing policies during the phase of order picking contributes to the increase of the picking time. The basic order picking method adopted by the company works well in operations characterized by a small number of total order and high number of picks per order. Nevertheless, it is not adapted for the management of orders in periods of massive flow, when the large number of orders and the congestion of many pickers in the same area slow down the processing. Consequently, while the adopted strategy guarantees a high index of accuracy, it results in a low efficiency in terms of velocity of picking.

In order to solve these problems and to reduce the overall time of picking, the majority of the products are allocated in the principal warehouse. Nonetheless, some of the products stored in the secondary warehouse, such as vests, are continuously handled and they contribute to the increase of the delivery time.

Other issues identified are strictly related to the company's sales structure and in particular to the seasonality that characterizes products: sales, in fact, are especially concentrated in the third and fourth quarters of the year, when the sports activities of the amateur association start.

To evaluate the capacity of exploitation of the available storage space, the surface utilization rate and the volume utilization rate have been calculated. The surface utilization rate is defined by the ratio of the surface effectively used for storing load units to the total surface of the warehouse, while the volume utilization rate is given by the ration of the volume occupied by the stored load unit and the total volume of the surface (Ghiani et
al., 2013). On the other hand, to evaluate the warehouse efficiency the selectivity index has been evaluated. The selectivity index is expressed by the ratio of the number of load units directly accessible in the picking phase to the potential receptivity.

The analysis of the performance indices of the two warehouses, shown in Table 1, shows a substantial underutilization of the structure mainly due to a lack of shelving in the middle.

The almost unit selectivity index reflects the current layout configuration based on the adoption of traditional single-depth shelves that permit to efficiently manage the high value of items stored in the warehouse. In addition, the handling system, based on the use of electric order picker with races of front support, guarantees the best use of the warehouse volume.

The as-is analysis carried-out on the structure of the principal warehouse has demonstrated the presence of inefficiencies and problems largely related to the strategy of products allocation. In addition, the layout analysis shows that the large quantity of boxes stored on the principal corridor, the lack of a reception area of goods, the lack of direct connections among lateral corridors are the main issues to be addressed. Table 2 presents the elements that impact on the performance of the distribution center, highlighting also the main effects produces on the management system.

In order to solve these issues, a series of analysis have been carried out with the main aim of improving the warehouse management and identify a better layout reconfiguration.

3.2 Warehouse optimization methodology

The main objective of the layout design is the definition of an “optimal” layout with respect to a set of objectives and constraints of different nature. The procedural approach that can be used for solving these problems requires the preliminary analysis of products, material flows and interdependencies. To this end, in the first part of the work, products have been analyzed and grouped into classes. Data analysis was useful to identify critical categories of products and to identify products involved in a greater number of movements, which affect in a significant way the warehouse management. The methodology used for the products classification is the ABC analysis (or Pareto chart). The products classification resulting from the ABC analysis has been successively used for the implementation of the PAP algorithm for products allocation and layout optimization. The implemented methodologies are describes in two separated sub-paragraphs.

<table>
<thead>
<tr>
<th>Table 2 - Main issues identified</th>
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<tbody>
<tr>
<td>Cause</td>
</tr>
<tr>
<td>Lack of reception area</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Lack of connection between the side corridors</td>
</tr>
<tr>
<td>Lack of shelving in the central area of the second warehouse</td>
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<tr>
<td></td>
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<tr>
<td>Products stored in the form of stacks</td>
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<td></td>
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<tr>
<td>Inadequate strategies for products allocation</td>
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<td></td>
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<tr>
<td>Presence of products stored in the second warehouse</td>
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<td>Seasonality of demand</td>
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</table>

3.2.1 The ABC Analysis

The ABC analysis classifies items into three main categories (A, B and C), depending on their estimated importance. In this work the traditional approach for products classification was conducted considering the sales volume generated by each class of products and subsequently the number of handlings undergone by each category of products.

The ABC analysis based on the sales volume has been carried out considering for the category A a value of the
sales volume major than 250 thousand euro, for the category B a sales volume contained in the range from 100 to 250 thousand euro and for the category C a value of the sales volume less than 100 thousand euro. Figure 3 shows the Pareto Chart the different lines of products belonging to the same category.

The “Relax line”, the “Training Line”, the “Winter line” and the line of “Accessories” result the most important categories (Figure 3). These classes of products provide more than 67% of sales and they represent approximately the 45% of active products in stock. A relative importance is assumed also by the lines “Free Time” and “Team line”.

Finally, a cross analysis was carried out combining the results of the two Pareto charts. The results of the combined results are shown in Table 3. These results highlight that about the 58% of sales volume less than 100 thousand euro and the 45% of active products in stock. A relative importance is assumed also by the lines “Free Time” and “Team line”.

The results of this analysis highlights that about the 58% of the sales volume less than 100 thousand euro and the 45% of active products in stock. A relative importance is assumed also by the lines “Free Time” and “Team line”.

3.2.2 Product Allocation Problem for Multi-Layer Warehouse: basic assumptions and parameters definition.

Usually, classical methodologies for solving PAP and its variants are two-steps approaches: firstly, it is required to group products according to their compatibility and then to assign the classes to the different slots in the warehouse. For the second step, it is necessary to know and to analyze all the structural characteristics of the warehouse. To this end, the specific layout of the warehouse was considered and some operational constraints were introduces to prevent the decentralization of products in the storage locations.

For the case under study, the layout reconfiguration and the problem of space assignment have been obtained solving the linear integer programming proposed by Sanei et al. (2011), revised considering the model proposed by Guerriero et al. (2013). The model has been extended considering a multi-layer scenario. The analyzed warehouse, in fact, is characterized by four levels of slots along the third dimension (height). Nevertheless, the compatibility constraints introduced in the model proposed by Guerriero et al. (2013) were not considered.

The model search for the best products allocation strategy in order to minimize the sum of the handling costs occurring in the multilevel warehouse and the costs of products decentralization. The primary objective is to allocate the classes in such a way that all the demand of a product type should be assigned to the same slot. When the demand exceeds the capacity of the slot products must necessarily occupy more than one location of storage and, according to the policy of reducing the decentralization, it is preferred to allocate in adjacent slots in the same block; in the same aisle; in opposite slots; in posterior slots and finally in generic slots.

The model is based on the assumption that the quantity to be stocked and the capacity required by each product type are known data. The final model guarantees the concentration of each product type in a specific stocking zone in order to simplify the inventory management and the equipment’s utilization.

In order solve the problem, the following assumptions must be verified:

Table 3 – Crossed results of the ABC analysis

<table>
<thead>
<tr>
<th>AREA A</th>
<th>AREA B</th>
<th>AREA C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relax Line,</td>
<td>Accessories,</td>
<td>Socks Line,</td>
</tr>
<tr>
<td>Accessories,</td>
<td>Team Line,</td>
<td>Free Time Line,</td>
</tr>
<tr>
<td>Training Line,</td>
<td>Free Line,</td>
<td>Winter Line,</td>
</tr>
<tr>
<td>Kit Line for</td>
<td>Bag Line,</td>
<td>Football Teams,</td>
</tr>
<tr>
<td>Football Teams,</td>
<td>Ball Line,</td>
<td>Shoes Line,</td>
</tr>
<tr>
<td>Winter Line</td>
<td></td>
<td>Line for Other</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sports</td>
</tr>
</tbody>
</table>

Figure 3 - Results of the ABC Analysis carried out on the sales volume

A second ABC analysis was carried out considering the totality of movements that invest every line of products. The results of this analysis highlight that about the 58% of movement are related to the categories “Relax Line”, “Training Line” and “Free Time”.

Finally, a cross analysis was carried out combining the results of the two Pareto charts. The results of the combined results are shown in Table 3.

Based on this strategy the storage points more favourable should be assigned with priority to the categories “Relax line” and “Training line” that are included in the area A, characterized by great relevance. Successively are assigned the categories belonging to the area BA, AB, BB, then products belonging to the categories BC, CA, and CB and finally products included in the crossed class CC.
• the warehouse layout should be characterized by (i) two doors, one for operations in the entrance to the warehouse and the other for outbound operations; (ii) two main corridors, (iii) \( w/2 \) transverse corridors (where \( w \) represents the number of storage positions shown in horizontal line that can be variable as long as they remain equal in number). In addition, the number of storage positions in vertical can be variable but must always be an even number.
• the policy adopted for allocating products is Class-based;
• the total capacity of the warehouse is sufficient to contain all the classes taken into account;
• the products are moved through two I/O doors, one in input and one in output;
• a slot has locations in height (multi-level);
• a slot can have adjacent positions in the same block, in the same corridor, opposite positions and posterior;
• in the same block and adjacent blocks of the same aisle are located only compatible classes;
• when a class must necessarily occupy more than one slot, the model must prefer the following order of priority: adjacent slots in the same block, adjacent slots in the same corridor, opposite slots, posterior slots. If you cannot satisfy none of the above conditions, products are allocated in a generic slot;
• all the slots for products’ allocation are characterized by the same capacity;
• all the loading units considered are characterized by the same size.

Some modifications have been applied on the initial warehouse configuration to ensure the compliance with the above-mentioned assumption.

The following features characterize the new layout configuration:
• 6 corridors and 12 shelving;
• 204 slots per level;
• 4 levels
• 2 I/O doors.

In particular, the I/O point signed with the number 1 is used for the handling of products, while the I/O point signed with the number 2 is used for the handling of products in output. The layout of the doors of I/O has been defined in order to create two symmetrical parts and, consequently, to set a symmetrical distance of the cells that are to the right and to the left of the doors.

A dataset was generated and used to solve the product allocation problem proposed by Guerrero et al. (2013) purified from the compatibility constraint. The model proposed by Guerrero et al. (2013), purified from the compatibility constraints, was implemented in Java (an Objected Oriented Programming Language), in Eclipse environment, and tested. During the implementation phase the following critical parameters were defined:
• number of class of products \( (n) = 13 \)
• number of vertical slots \( (m) = 17 \)
• number of horizontal slots \( (w) = 12 \)
• number of levels \( (h) = 4 \)
• number of I/O points \( (k) = 2 \)

The penalty vector has been set up in order to avoid decentralization of products.

In addition, tree different matrix have been generated: (1) the Distance Matrix \((D)\), where \(d_{ik}\) represents the distance (measured in meters) of the slot \((s,l)\) from the door \(k\), (2) the Handling matrix \((F)\), where \(f_{ik}\) is the number of daily handling operations (in load units) of the class \(i\) from the door \(k\) and (3) the Sales Matrix, which contain the demand of each class.

The cost for moving one load unit for a meter has been considered as a parametric cost equal to 1 * \(\varepsilon\) for movement along the flat surface and 1.5 * \(\varepsilon\) for movements in height.

### 4. Results and Discussions

The applications of the PAP algorithm lead to the optimal allocation of products in the various storage points. Figures 4,5,6, and 7 show the solution resulting for each level in comparison with the current layout. The block at the top depicts the initial configuration of the warehouse, and the bottom represents the new configuration obtained by applying the PAP model.

The improved solutions show as the “Relax Line” category, which is characterized by a high handling value, should be stored in the best storage positions, i.e. in the slots present in the central part of the warehouse. In addition, the optimized layout configuration shows a products allocation almost equal for each level.

A cost analysis has been carried out to evaluate the cost saving that could be obtained implementing the new layout configuration. The costs analysis highlights that the new layout configuration, obtained through the application of the PAP algorithm, leads to a saving of about 5,6% performances. With regards to the cost directly connected with the products handling, the optimal layout configuration allows the company to decrease the costs of about 2%. This percentage represents a good result when the complexity of the movements that take place within the warehouse of the company is considered.

The results of the costs analysis are showed in Table 4.

**Table 4 - Comparison between the optimal solution and the current solution**

<table>
<thead>
<tr>
<th></th>
<th>Total Costs</th>
<th>Handling costs</th>
<th>Decentralization costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Solution</strong></td>
<td>487724</td>
<td>165389</td>
<td>322335</td>
</tr>
<tr>
<td><strong>Optimal Solution</strong></td>
<td>460390</td>
<td>161950</td>
<td>298440</td>
</tr>
<tr>
<td><strong>Improvement in absolute terms</strong></td>
<td>27334</td>
<td>3439</td>
<td>23895</td>
</tr>
<tr>
<td><strong>Improvement in percentage terms</strong></td>
<td>5.60%</td>
<td>2.08%</td>
<td>7.41%</td>
</tr>
</tbody>
</table>
Figure 4 – Comparison between the initial layout and the optimal layout configuration for the first level

Figure 5 – Comparison between the initial layout and the optimal layout configuration for the second level
Figure 6 – Comparison between the initial layout and the optimal layout configuration for the third level

Figure 7 – Comparison between the initial layout and the optimal layout configuration for the fourth level
The consistency of the obtained solution was evaluated considering and analysing different scenarios. In particular, the consistency evaluation was carried out by analysing the changes in the optimal solution in case of changes in the number of the movements invested by every product. Three different cases have been analyzed; for each case, six different scenarios have been considered. Each scenario has been generated considering a variation of the total amount of handled products, in particular by decreasing this value of 20%, 10%, and 5% and increasing of the same percentage.

In the first case, the solution has been evaluated considering a change in the total amount of movements for all the products present in the company warehouses, with the constraint of maintaining constant the number of products in the warehouses. The solution has been analyzed comparing the six scenarios. The resulting data of all the scenarios show that the cost reduction percentage obtained with the implementation of the new layout configuration is always higher than 5%. In this case the percentage gain on the cost of changes is kept almost constant (with values between 2.15% and 2.03%).

The validity of the solution found by the algorithm PAP has been further evaluated by varying exclusively the movements of certain product categories and considering constant the number of stored products in stock for all product categories. The categories that undergo changes are those that, following ABC analysis, are characterized by a higher value of changes, that is, “Relax line”, “free time”, and “Training line.” The additional category of “Accessories” has been added at these categories. Even in this case, 6 possible scenarios have been analysed considering a variation of the movements between -20% and 20%. In this case the index of total performance returns a value greater than 5.50% and, unlike what happened in the previous case, it undergoes only small changes in varying the scenarios (from 5.67% to 5.54%). It is also important to emphasize that also the performance index relative to the costs of handling improves.

A third analysis has been carried out by varying the total amount of handling movements only concerning the categories relating to amateur clubs: in this case, in fact, have been taken into considerations “Training line”, “Team line”, “line Goalkeeper”, “Bag line”, “line Ball”, “Volley line” and “Basket line.” Also for this case were created six different scenarios with an oscillation of changes that vary between 20% and 20% compared to the current ones. The total performance index, in this case, is consistently greater than 5.40%, with an oscillation that goes from +5.79% to 5.44%. This result is quite positive and it demonstrates how the solution of allocation of products resulted PAP algorithm is quite solid and consistent.

The solution provided by the application of PAP algorithm can be considered quite positive: the comparisons between the layout configuration obtained through this solution and the current one (real layout configuration of the company), demonstrate that the new layout is characterized by a higher performance index in each case under study and for each scenario. Table 5 shows that the total performance index of the obtained solution is greater than 5.4%, which demonstrates the validity of the new solution: in the best case it does mark a 5.87%, while in the worst case it is characterized by a 5.44%.

5. Conclusions

In this work the multi-level allocation problem has been adapted to a real warehouse in order to identify an optimal layout re-configuration. Firstly a deep analysis of the company’s warehouse has been carried out, and then a series of performance parameters have been selected. The solution obtained through the application of the PAP model has been evaluated and validated. Data resulting from the results analysis demonstrate that the adoption of the new layout allows not only to allocate the products of the same category in the same zone of the warehouse but also to obtain a more orderly allocation of products in the warehouse itself. In addition, a well-organized and structured layout obtained applying the algorithm PAP accelerates the picking phase and decrease the products lead-time. In addition, the new layout, based on a strategy of storage of the products that is Class Based, allows avoiding the appearance of phenomena that is typical of the storage systems in a fixed location.

References


Table 5 – Evaluation of the performance indexed related to the obtained solution

<table>
<thead>
<tr>
<th></th>
<th>Total profit for the best case [%]</th>
<th>Total profit for the worst case [%]</th>
<th>Handling costs for the best case [%]</th>
<th>Handling cost for the worst case [%]</th>
<th>Decentr alization costs [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>5.87</td>
<td>5.37</td>
<td>2.15</td>
<td>2.03</td>
<td>7.41</td>
</tr>
<tr>
<td>Case 2</td>
<td>5.67</td>
<td>5.54</td>
<td>2.30</td>
<td>1.74</td>
<td>7.41</td>
</tr>
<tr>
<td>Case 3</td>
<td>5.79</td>
<td>5.44</td>
<td>2.34</td>
<td>1.86</td>
<td>7.41</td>
</tr>
<tr>
<td>Current situation</td>
<td>5.60</td>
<td>---</td>
<td>2.08</td>
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<td>7.41</td>
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