Storage Location Assignment Problem: implementation in a warehouse design optimization tool

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Abstract: This paper focuses on possible improvements of common practices of warehouse storage management taking cue from Operations Research SLAP (Storage Location Assignment Problem), thus aiming to reach an efficient and organized allocation of products to the warehouse slots. The implementation of a SLAP approach in a tool able to model multiple storage policies will be discussed, with the aim both to reduce the overall required warehouse space - to efficiently allocate produced goods - and to minimize the internal material handling times. The overcome of some of the limits of existing warehousing information management systems modules will be shown, sketching the design of a software tool able to return an organized slot-product allocation. The results of the validation of a prototype on an industrial case are presented, showing the efficiency increase of using the proposed approach with dedicated slot storage policy adoption.

Keywords: Warehouse Management, Storage Policies, Slot-Code Allocation.

1. Introduction

The warehouse management problem and, more specifically, the storage location assignment problem (SLAP) has represented a critical issue in Operations Management and Operations Research since 1976, when Hausman, Schwarz and Graves firstly introduced an accurate taxonomy of the possible storage location assignment policies of items within a warehouse: the problem concerns the assignment of stock to storage locations, and Hausman et al (1976) describe the main criteria to be adopted, which also Sharp (1989) and Frazelle (1990) agree to classify in dedicated storage, randomized storage and class-based storage.

Whilst warehouses are critical to a wide range of customer service activities, they are also significant from a cost perspective: figures indicate that the capital and operating costs of warehouses have been significant at least since 5-6 years ago: they represented about the 22% of logistics costs in 2005 in the US (Davis et al., 2005) and 25% in Europe (ELA/AT Kearney, 2004) while the current financial crisis has even worsen the situation. On top of this, expenditure on warehouse automation has increased steadily in Europe and this trend is reflected globally by figures that show that the relative sales have increased by an average of 5% per annum just for the 2003–2005 period (Modern Materials Handling, 2004, 2005, 2006).

With a critical impact on customer service levels and logistics costs, as well as considering the complexity of the related technical problems, it is thus imperative that warehouses are designed and managed to be cost effective (Frazelle, 2002); this is particularly important as warehousing costs are, to a large extent, determined at the design phase (Rouwenhorst et al., 2000).

Literature is full of important scientific contributes to the study of optimization criteria underlying warehouses design and management practices (Di Giulio et al. 1994; Meller and Gau, 1996; Meller, 1997; Tompkins, 1998, 2003). In the last decades, some authors have devoted several publications to the modeling of effective approaches to optimize spaces usage and material handling procedures in terms of inventory management: these authors mainly agreed that the two basic criteria for warehouses organization are the dedicated storage policy - in which each item has its own and fixed storage location - and the randomized strategy - in which the locations of the SKUs (stock keeping units) are randomly chosen (see Choe, 1991, Petersen and Gerald, 2004).

Though the overall attention paid by researchers in inventory theory, the contributes in terms of new criteria and tools development to manage storage systems, focusing on the cost optimization perspective, seem to be relatively limited so far (Renaud et al., 2007). As Rowley stated in 2000 and Pessotto remarked in 2009, there is still the evidence that anyone has yet succeeded in effectively combining the dedicated and the randomized storage policies apart from using sophisticated and expensive information management systems: indeed, they underline a significant difficulty by warehouses developed tools in being able to combine ease of use and tangible results guarantee, focusing on the reduction of implementation costs.

After many years, companies have understood that the mere adaptation of their business processes to those standards embedded in expensive inventory management modules of ERPs did not favor either their competitiveness increase or the cost decrease (Trunick, Escalle, 1999; Muscatello 2003; Malhotraa and Temponi, 2010).

From these findings, to avoid forcing companies (and specifically, those SMEs that represent the greatest part of European industrial context) to adopt inefficient warehouse management methods just based on their acquired experience, comes the idea of a new tool for the optimized management of industrial warehouses intended to be of value to every enterprise willing to increase its storage area's performances.

2. Storage Optimization Analysis

From an organizational point of view, performances of a storage area are fundamentally based on two variables: the space reserved for material allocation and the time required for their handling.

One solution to the problem of achieving a proper products allocation in a warehouse, is the one given by a "dedicated" (or "fixed-slot") policy type of storage (Lee, Elsayed, 2005): devoting a certain number of slots of the warehouse to each product guarantees the advantage of a notable simplicity in tracking products. However, permanently assigning only one product (code) to each slot would mean that this slot could not be reused when the product is not present, resulting in wasted space in case of goods subjected to a seasonal demand.

The required quantity of slots in a warehouse in order to adopt this storage policy is equal to the sum of maximum levels reached by each product storage during periods of reference. Defined with M_{pt} the number of slots used by the generic product p at time i, the total number of slots M_{DED} necessary to allocate all products is (Hausman et al, 1976):

$$M_{DED} = \sum_{p} max_t \{M_{pt}\} \quad [1]$$

It is therefore clear that this type of storage policy is the furthest away strategy in terms of slot minimization: for these reasons, the number of slots obtained following the dedicated policy is usually used as an upper bound (highest value) for them.

A solution to get around the problem mentioned above is a "randomized" (or "shared slot") storage policy (Petersen, 1999), i.e. assigning any free slot in the warehouse to a generic product that requires it.

A randomized strategy provides an absolute minimization of the number of slots needed to allocate all the products required: this number is the maximum value obtained by summing used slots in each period (Hausman et al, 1976):

$$M_{RAN} = max_t \left\{ \sum_{p} M_{pt} \right\} \quad [2]$$

The problem that lies in implementing this allocation procedure is the consequential difficulty in tracing products: the application of a randomized storage policy, necessarily requires the presence of an information system that records the variable allocation of products within a warehouse. Since the number of slots returned in output by this kind of procedure is the minimum number possible, it represents a lower bound (minimum value) of the number of needed slots.

The most critical issue of these storage optimization criteria relies in the fact that they generally only focus on the overall required warehouse space and on its internal organization: the time variable, which is fundamental from a cost point of view, is often not taken into account appropriately. Material handling times are strictly related to the number of warehouse employees, of material handling vehicles (i.e. reach trucks, forklifts, etc.) and, as a general concern, to the management cost of warehouses. Moreover, considering material flows within storage areas, handling times are completely dependent from the selected slot-code allocation: that's why it is so important to integrate an appropriate storage policy with an accurate material handling time-saving approach.

This paper presents the main criteria for the development of a warehouse design tool with an embedded specific function for calculating and reducing storage space and handling times. Specifically, the design of this tool represents one of the deliverables of a research project conceived by the Operations Management Research Group in the Department of Enterprise Engineering at "Tor Vergata" University of Rome, Italy. At present, the tool has been developed in a prototypic version.

3. Designing the tool

A warehouse design optimization tool should incorporate features of:

1. storage area layout design;
2. data analysis;
3. inventory management;
4. decision support.

A customizable warehouse map may help the user to perform *as-is* and *what-if* analysis on the alternative layouts:

- as-is analysis can be performed to evaluate existing warehouse's technical performance through specific Key Performances Indicators (KPIs);
- what-if analysis can be performed by a virtual relayout of the warehouse, assessing in real time the relative KPIs variation.

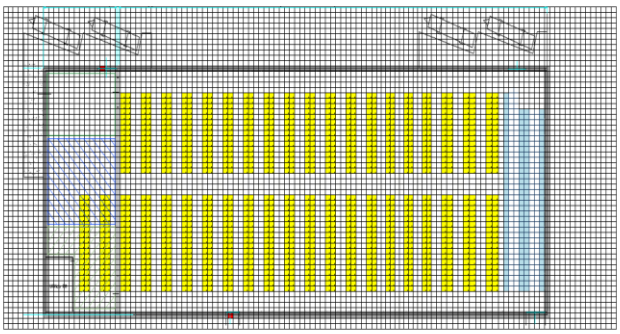

Figure 1. the example of a warehouse layout on the map

As shown in figure 1, users should be able to easily represent their current warehouse's layout locating existing shelves (and relative slots), aisles and input/output points upon the definition of the desired map's scale factor. This graphical representation can help the user in performing what-if analysis.

Typically, in order to obtain the warehouse inventory level for each product in a given time interval, hystorical data to be processed can be arranged in matrix form with two dimensions: the stored product versus the chosen time bucket unit (i.e. days). The cell located at the intersection between these two dimensions contains the information on how many slots were used by each product in all the days of the considered period.

The first step of the data-analysis procedure should consist in analyzing items movements occurred in the warehouse during the considered period; it should thus calculate the upper and lower bound on the number of required slots to allocate all products using [1] and [2].

Starting from these hystorical data, the calculation of the overall number of input and output movements per each product should be computed too, identifying "fast mover" products (high movement ratio - M.R.) and "slow mover" products (low movement ratio).

Basing on the created map, the number of ground slots, of total required shelves levels and of the overall available volume can thus be estimated considering:

- warehouse's height;
- conventional slots height;
- lifts height of trucks.

Pointed out warehouse input and output positions, considering the travel and lift speed of forklifts (or of the used material handling equipment), we can calculate:

- horizontal and vertical metric distances from each slot to the warehouse input/output point;
- average loading and picking time required for each available slot.

Changing the input/output positions, it is easy to automatically perform a recalculation and update of all the above distances and times.

A tool which aims to solve the SLAP may compute a specific "weight" for each slot according to the time needed to reach the specific slot, which can be related to the metric distance from the input/output points, to the enter/exit probability of products, and to a vertical time increment coefficient used to standardize the weights of ground and higher levels slots (e.g. computed from the ratio between travel and lift speed of the reach truck). In this way slots can be classified (directly on the map) as follows:

- "hot" slots (red): slots nearer to the warehouse input/output point and, thus, easily reachable (low weighted);
- "warm" slots (yellow): slots characterized by an average distances from the warehouse input/output point;
- "cold" slots (blue): slots farer from the warehouse input/output point and, thus, slowly reachable slots (high weighted);

The thresholds for this classification clearly need to be specified in advance from the analysts. However, the possibility of easily performing what-if analysis allows to proceed without worrying of a not appropriate determination of the thresholds in a very first run.

The tool may provide a visual representation of the warehouse layout, automatically colouring the slots map according to the different distances of each slot from the warehouse input-output point (see Figure 2). Clearly, modifying the warehouse layout (i.e. inserting, removing or moving shelves) would result in an immediate map update.

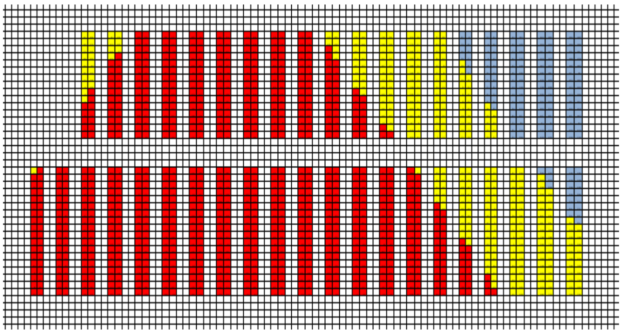

Figure 2. Hot/cold warehouse areas

A typical requirement for SLAP solution is ensuring that products with similar movement ratio are associated to similar-weighted slots, both for products with high M.R. and with low M.R.: here comes the idea of a pre-ordered list of products based on their decreasing M.R., thus forcing the tool to allocate products in an efficient way both from a time and distance perspective. Thus, matching the product list (sorted in decreasing input/output movements) with the slot list (sorted in increasing slots weights), the tool can generate an optimum slot-code assignment, where fast movers products (high M.R.) are assigned to the slots nearer to the warehouse input/output point, which ensures the minimization of material handling times.

Considering products specific volumes and weights, their movements in terms of handling frequency and distance of the slot in which are allocated, along with the key performance characteristics of the electric reach truck on the market (e.g. travel speed, lift speed, maximum lift heights, turning radius, etc.), the tool can suggest the most suitable model of forklifts to purchase, and how many of them would have been needed in order to support the handling movements recorded in the historical data.

The benefits originating from the usage of a warehouse design optimization tool solving SLAP are mainly:

- minimization of the total number of warehouse slots, i.e. of the required storage space;
    - reduction of cost for warehouse space purchasing/rent;
    - reduction of organizational complexity;
- minimization of the internal material handling times;
    - reduction of operative costs (costs of transportation means and employed personnel);
    - reduction of management costs.

The first objective is usually pursued by firms who are likely to bear high costs for purchase or rent of storage areas: for these players it is of extreme importance to minimize the space required for the allocation of materials, in order not to let the related costs play a relevant role on the company's economics. On the contrary, if a company is suffering from high expenditures in warehouse personnel or forklifts maintenance management, it should primarily focus on the second objective.

Obviously, the tool should offer the possibility of solving trade-offs among these objectives, thus pursuing a goal that considers as important both the minimization of the space required to allocate codes and the handling time minimization of products, according to the ratio among the purchase/rental cost of the storage area and the costs of handling materials within it.

4. Validating a tool prototype

A test was carried out on a real case warehouse transactions database, storing transactions referred to 3487 items on a period of 353 days (a whole working year for a selected company): due to the oversized and heavy weighted nature of products, single-stacking procedure were considered (thus forklifts were operating on "single command" mode, moving one product per tour); in the analysed warehouse, a unique warehouse input-output point and no "one-way" aisle were present.

The data analysis results show that, in the 80% of cases, a product was moved less than two times per day; an average number of 477 handlings per day was detected and, in the 83% of cases, less than 750 movements/day were registered as a whole.

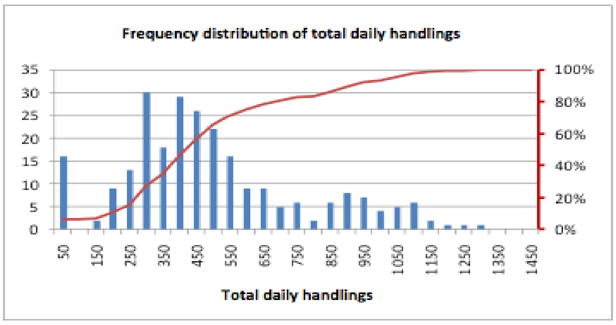

Figure 3. Daily handlings analysis

The Pareto analysis provided the following ABC classification:

- the 80% of material handlings were related to the 25,4% of products (hence, 887 products were classified as A-class codes);
- the 24,6% of products could be classified as B-class (858 codes);
- the residual 50% of products were classified as C-class (1748 codes).

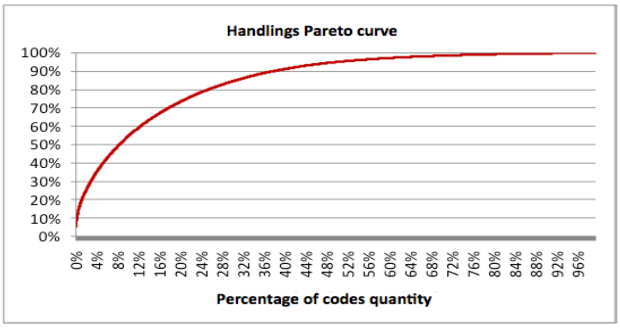

Figure 4. Pareto analysis of material handlings

Analysing the handling frequency distribution (per product) during the 353 considered days, it was noticed that:

- 472 codes, approximately the 13,5% of the total, were handled just once in the whole year;
- 781 codes, approximately the 22,4% of the total, were handled two or less times in the whole year;
- 1068 codes, approximately the 30,5% of the total, were handled three or less times in the whole year;
- 1788 codes, more than the 51% of the total, were handled at least ten times.

Given this pattern of data, showing that the vast majority of codes were almost permanently stored in the warehouse, it was decided to focus on reducing the handling times and the distances travelled by reach trucks rather that reducing the used storage area. On top of this, product were allocated with a dedicated policy; despite a pure randomized storage policy could have granted between 35% and 40% of used area saving, the absence of an effective warehouse information system did not allow to adopt any policy which differ from the fixed-slot.

Analysing the correlation between slots accessibility and handlings of product assigned to each slot in the as-is situation, an inaccurate slot-code assignment clearly arose.

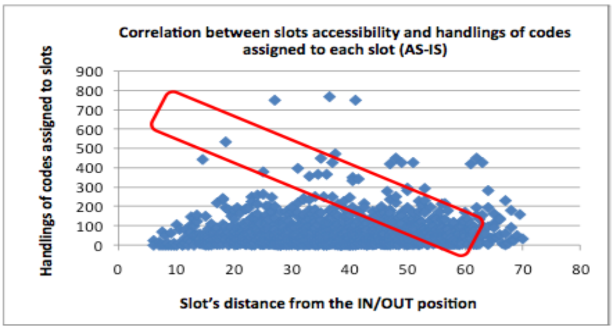

Figure 5. Correlation among slots accessibility and products M.R. (as-is situation)

As previously stated, high M.R. products should be placed in the most easily accessible slots, as well as farthest slots should host the slow-mover codes: in this way, the desired negative correlation between slot proximity from the warehouse input/output point and products M.R. should have been observable on the graph as a sort of descending line (approximately, in the red rectangle region).

In the as-is storage allocation, considering the products handling historical data in the analysed period of time, the average distance travelled to reach each slot resulted to be 38,9 meters and the overall distance travelled to handle all the products through the whole year resulted to be 3'389'621 meters.

A more efficient slot-code allocation was thus calculated, resulting in the following correlation graph.

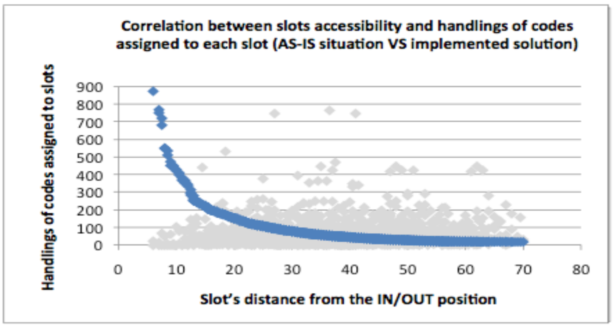

Figure 6. Slots accessibility - codes handlings correlation (as-is situation in grey – to-be results in blue)

As a result, the new travelling average value was 24,2 meters (instead of 38,9), thus granting a 37,8% reduction of material handling inefficiency; the overall travelled distances through the whole year fell from 3'389'621 to 2'107'673 meters. Alternatively, the optimization led to the possibility of managing the same material handling volumes using only the 62,2% of existing resources.

It is noticeable that this result was obtained without changing anything in the original warehouse layout; in this specific case, the tool prototype revealed its cost effective nature granting an efficiency increase in material handling - thus achieving considerable organizational advantages and cost savings – only through the solution of the Storage Location Assignment Problem.

5. Conclusions

In supply chains, warehouses are both essential components for linking the chain partners and fundamental factors that affect the productivity and operation costs of enterprises: representing a fundamental connection between the upstream (production) and downstream (distribution) entities, warehouses can therefore play a vital role in the success or failure of businesses. For this reason, this paper presented an analysis of storage areas optimization techniques, studying possible mechanisms to improve their internal processes efficiency by developing a tool for a cheaper allocation procedure and time-savings in handling procedures.

Since the organization of warehouses – finding an optimal layout and efficient material handling system procedures – is inevitably influenced by the correct allocation of products to slots, attention was focused on the concrete applicability of a tool which can practically solve the Storage Location Assignment Problem (SLAP).

Solving the SLAP in an efficient way can provide the reduction of warehousing costs related both to the used storage area and to the usage of material handling vehicles and warehousing personnel.

The reduction of needed slots results in smaller warehouse surface to buy or rent for products storage as well as in the reduction of the number of shelves, therefore generating a remarkable decrease in the influence of these cost entries on companies economics. On the other hand, the reduction of the distances travelled by reach trucks means considerable savings not only in terms of vehicles durability, but also in terms of time needed for material movements, number of needed vehicles and/or qualified personnel employing.

The validation of a tool prototype on a real case was presented, with the aim to minimize the material handling travel times finding the best solution to the storage location assignment problem in the given context and using a dedicated slot storage policy. The prototype resulted to be able to gain a 37,8% reduction of material handling inefficiency.

Future research should aim at refining the prototype's functionalities and, specifically, remove the limitation of considering single-command movement of the reach trucks and of considering two-way aisle all over the warehouse.

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