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Criteria for a warehouse tool with optimal storage/retrieval and product-allocation procedures

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Abstract: This paper presents the design criteria for a software tool able to support warehouse planning, minimizing both the overall required space and internal travel times. The tool allows what-if analysis on different slot-product allocations and stacking/picking scenarios, implementing either optimal or random products allocation with single or multiple command modes.

Keywords: Single/multiple command cycles; Slot-product allocation; Travel time; Warehouse Design.

Introduction

Warehousing is a key aspect of supply chain management and plays a fundamental role in the success of business: due to the critical impact on customer service levels and logistics costs, it is imperative that warehouses are designed and managed to be cost effective (Frazelle, 2002).

From a capital and operating cost perspective, warehouses management have increasingly become critical reaching the 23% of logistics costs already in 2011 in the US (Davis et al., 2011) and 39% in Europe (Groothedde, 2012), and the current financial crisis has even worsen the situation;

furthermore, figures show that material handling equipment investments grew an estimated 15.2% in 2011 and are forecasted to grow 8.0% in 2012 and 12.0% in 2013, according to the latest Material Handling Equipment Manufacturing Forecast (MHEM) released by Material Handling Industry of America (MHIA, 2012).

According to literature, the warehouse storage management (WSM) problem was firstly introduced in 1976 by Hausman, Schwarz and Graves proposing a detailed taxonomy of storage location assignment policies: at first the problem concerned the assignment of stock to storage locations following a dedicated, randomized or class-based storage policy (Sharp, 1989; Frazelle 1990) but in the following years it was extended considering also material handling (MH) distances and times travelled. Indeed, many authors have recently devoted publications to the modelling of efficient methodologies to optimize spaces usage and material handling procedures agreeing that the two basic criteria for warehouses organization are the fixed storage policy - in which each item has its own dedicated storage location - and the shared slot strategy - in which the locations of the SKUs (stock keeping units) are randomly chosen (see Choe, 1991, Petersen and Gerald, 2004). Among the main goals of an efficient warehouse design and optimisation arise the required space and average travel distance minimization together with the maximization of the accessibility to all product locations (De Koster, Le-Duc, & Roodbergen, 2007).

Since warehousing costs are, to a large extent, determined at the design phase (Rouwenhorst et al., 2000), numerous scientific contributes to the analysis of optimization criteria underlying warehouses design and management practices have been developed during the nineties (Di Giulio et al. 1994; Meller and Gau, 1996; Meller, 1997; Tompkins, 1998, 2003).

Despite the attention paid by researchers in inventory management, the inputs in terms of new criteria and tools development to manage warehouses in terms of space and times required, while concentrating on the cost optimization perspective, seem to be rather limited so far (Renaud et al., 2007): evidences show that none of the existing tools has yet succeeded in effectively combining features such as warehouse design, data analysis, optimal product allocation, travel distance and space minimization, decision support and ease of use focusing on reducing implementation costs (Rowley, 2000; Pessotto, 2009).

Nowadays, companies have understood how difficult it is to find a profitable combination of ease of use and tangible results guarantee in expensive inventory management modules of ERPs and that they do not often favor either their competitiveness growth or cost reduction (Trunick, Escalle, 1999; Muscatello 2003; Malhotraa and Temponi, 2010). From these evidences, to help companies preventing their adoption of inefficient warehouse management techniques - often based just on empirical experiences - and reducing their warehouse operational costs, arises the idea of a new tool to increase storage areas performances.

In this paper, the overtaking of some limits of existing warehouse information management systems will be thus discussed, showing the design process of a software which aims both at decreasing the overall needed warehouse space - through an efficient allocation of products - and at minimizing the internal MH times; to this last end, the embedded feature of average travel distance/time calculation considering single/-dual command cycles or other selectable order picking procedures will be also presented.

Space and time optimization analysis

From an organizational perspective, the two key variables of storage areas' performances are the space reserved for material allocation and the time required for their handling.

Regarding the item location problem, an efficient possible solution is the one given by a "dedicated" (or "fixed-slot") storage policy (Lee, Elsayed, 2005): assigning a precise number of slots to each product ensures the advantage of a considerable easiness in tracking them. However, devoting in a permanent way only one type of item to each slot - meaning that this could not be reused if the product is not present - would result in wasted space in case of seasonal demand goods. The dedicated policy is thus the less appropriate from the slot minimization perspective.

An alternative solution relies in the "randomized" (or “shared slot”) storage policy (Petersen, 1999) which 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 necessarily requires a good information system to record the variable position of products within the warehouse.

Speaking about the travel time minimization of MH vehicles, it obviously results to be related to the picking procedure chosen. Evidences show that order picking is the most labour-intensive and time-consuming warehouse activity (Tompkins, White, Bozer, & Tanchoco, 2002): indeed, up to 55% of the total warehouse operating cost is due to order picking operations (De Koster, Le-Duc, & Roodbergen, 2007).

Order picking can be reckoned as a general case of the “dual-command” procedure. In manual picking systems, a single-command cycle consists in travelling from an pickup/deposit (P/D) or input/output (I/O) place to a precise slot and back again to perform a storage or retrieval request (Maimborg, Krishnakumar, & Simons, 1988); as it is known, the dual-command cycle differs from the single one because it usually implies both a storage and retrieval request, so that order picking trucks first carry pallets from the I/O point to a location and then move to another location picking a pallet before coming back to the I/O point (Maimborg, Krishnakumar, & Simons, 1988). This last procedure obviously makes a more efficient use of time, minimizing unproductive travel times and distances; however, its effectiveness can drastically vary depending on the specific warehouse context.

Despite several authors have focused their researches on the general case of order picking cycle though, no closed-form evaluation procedure is yet available to estimate the optimal tour length for a general number of picks (Pohl, Meller, & Gue, 2009) and so far, simulations for its calculation have been performed only through routing heuristics assuming random storage policies (Roodbergen & Vis, 2006), (Le-Duc & De Koster, 2007), (Roodbergen, Sharp, & Vis, 2008).

What emerges from a literature analysis is that the majority of developed storage optimization criteria only focus on the overall required warehouse space and on its internal organization: the time variable, which is crucial from a cost point of view, is often not properly considered. MH times are strictly connected to the number of warehouse employees, vehicles (i.e. forklifts, etc.) thus to the management cost of warehouses. Furthermore, considering material flows within storage areas, trucks and forklifts travel distance travelled are strongly related to the slot-code allocation chosen: for these reasons, granting the integration of an appropriate storage policy with an accurate MH time-saving approach, this paper presents the main development steps of a warehouse design tool with an embedded specific function to compute and decrement storage space and internal travel times. The tool represents the deliverable 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, it has been developed in a prototypic version.

Designing the tool

According to the main operational needs of a warehouse planning software, the tool has been equipped with the following key features:

- Warehouse layout design feature;
- Inventory data analysis feature;
- Inventory management feature;
- Decision support feature.

The first function relies in a customizable warehouse map screen which effectively helps the user in representing his current warehouse layout positioning existing shelves, aisles, input and output points' coordinates upon the definition of the desired map scale factor: as-is analysis can be performed to evaluate the warehouse technical performance through specific Key Performances Indicators (KPIs). This feature also supports the user in carrying out *what-if* analysis on possible alternative layouts through a virtual re-layout of the existing warehouse, assessing in real time the relative KPI variation.

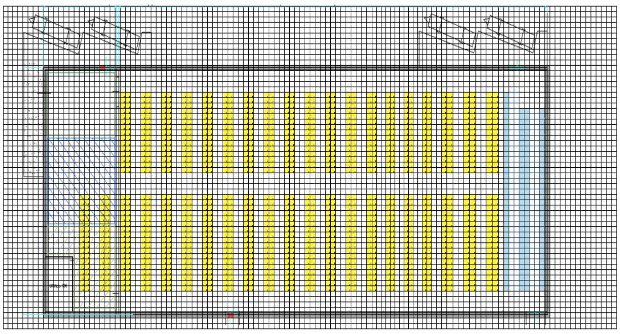

Figure 1. Snapshot showing an example of a warehouse layout on the map

(shelves are depicted in yellow and light blue)

Considering the chosen time bucket unit (i.e. days) and the products identification number, the first step of the data-analysis procedure consists in analyzing items movements occurred in the warehouse during the considered period; the tool then calculates the upper and lower bound of the required number of slots to allocate all products, respectively using a dedicated and a randomized storage policy, as well as the overall number of IN/OUT movements per each item identifying "fast mover" products (high movement ratio, MR) and "slow mover" products (low MR).

Basing on the created map, and considering the warehouse height, the slots height and the lifts height of trucks, the tool estimates:

- the number of ground slots (i.e. accessible without the need of a forklift);
- the number of total required shelves levels;
- the overall available volume, in number of slots

Once identified the input and output points coordinates, considering the travel and lift speed of trucks, the tool computes:

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

Input and output points coordinates (IN/OUT) can be changed at any time for what-if analysis, and the tool would automatically recalculate and update all the above mentioned results.

The inventory management feature starts computing a specific "weight" for each slot according to the time required to reach it, thus considering the metric distance from the IN/OUT position, the enter/exit probability of products, and a vertical time increment coefficient (based on the ratio between the different travel and lift speed of forklifts) used to standardize the weights of ground and higher levels' slots. According to the weights assigned and to specific thresholds specified by users, the tool classifies the slots in:

- "hot" slots (red colored): slots close to input/output position, thus easily reachable (low weighted);
- "warm" slots (yellow colored): slots characterized by an average distances from the warehouse IN/OUT point;
- "cold" slots (blue): slowly reachable slots (high weighted) due to considerable distance from the warehouse input/output position.

Basing on the outcome obtained the tool provides a visual representation of the warehouse layout, automatically coloring each slot of the warehouse map (see Figure 2): an eventual modification of the warehouse layout (i.e. by inserting, removing or shifting shelves position as well as changing the input or output points coordinates) results in an immediate map update.

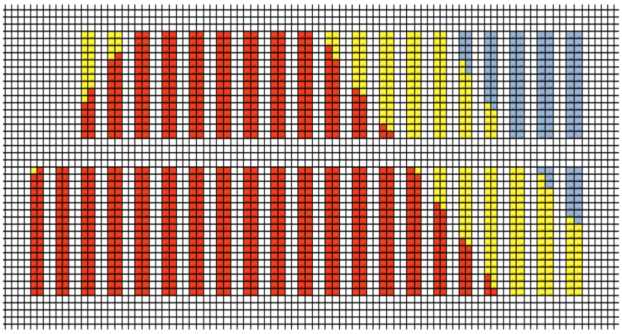

Figure 2. Snapshot showing an example of hot/cold areas distribution

The decision support (DS) feature of the tool mainly focuses on an optimal slot-product allocation. Typically, an efficient storage location assignment problem's solution ensures that products with close movement ratio are assigned to similar-weighted slots, both for products with high MR and with low MR: on the base of this assumption, the tool generates a pre-ordered list of products based on their decreasing MR and matches it with a slot list sorted by increasing slots weights. In this way, an optimum slot-code assignment, where fast movers are assigned to the slots closer to the warehouse IN/OUT point, is returned in output: this ensures an overall space minimization and guarantees a first minimization of material handling times.

A second function performed by the DS feature entails the advice of the most suitable model of forklifts to purchase and how many of them would be needed to perform all the handling movements recorded in the historical data. Considering products handling frequency, their weights and volumes, the distance of the slot in which they are located and the key performance characteristics of reach trucks on the market (travel speed, lift speed, maximum lift heights, turning radius, etc.) the tool suggests the best solution to carry on.

Regarding the travel time minimization of these vehicles, the tool embeds a specific picking procedure based on a dual-command cycle able to compute the most appropriate path to follow when performing storage/retrieving operations.

In single/dual-command cycles workers can pick/store on both sides of an aisle as well as change direction within it. In order to minimize the internal travel distance with dual-command cycles, many order-picker routing policies have been developed regarding retrieval requests: they can be classified as the “S-shape”, the “Return”, the “Mid-point”, the “Largest gap”, the “Combined” and “Optimal” policies (De Koster, Le-Duc and Roodbergen 2007).

The policy that ensures the greatest improvements - the Combined policy - requires to choose whether to entirely traverse an aisle with at least one pick, or enter and leave the aisle from the same side, using dynamic programming (Roodbergen & De Koster, 2001). Considering dual-command cycles instead of the general order picking, and under the assumption of one-block layouts (Figure 3), the tool calculates the minimum travel distance between two store/pick locations after each storage phase, thus allowing to decide whether to access the second location pick from the front or the back cross aisle.

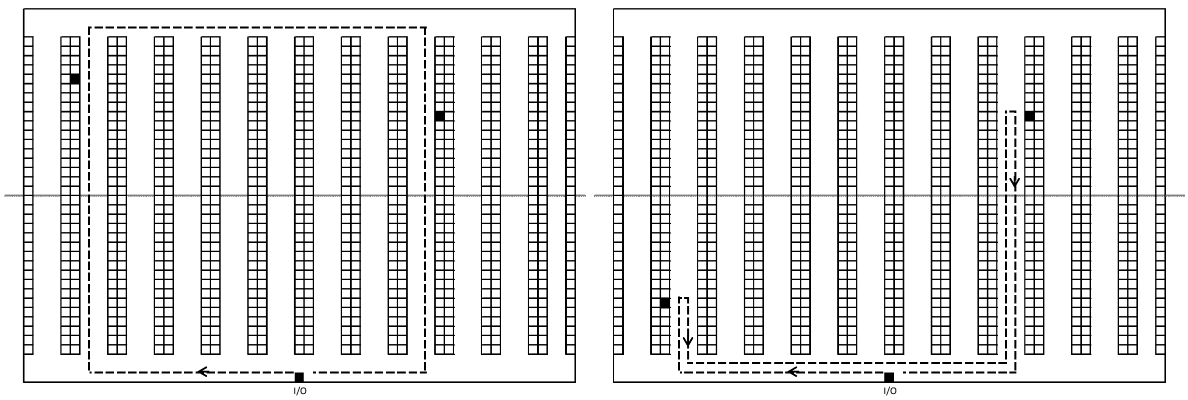

Figure 3. Picking policy examples

This picking methodology represents a second way to minimize the overall travel distance of trucks and forklifts, thus granting a considerable operative cost reduction of warehouse operations. Indeed, focusing on the cost perspective, the benefits originating from the adoption of the implemented tool are:

- the minimization of the total number of warehouse slots, i.e. of the required storage space: this fact results in a considerable reduction of purchasing/rental costs of the warehouse and of the organizational complexity variable;
- the minimization of internal material handling times: this aspect is related to a heavy reduction of operative costs (transportation vehicles and employed personnel) and of management costs.

The first goal is usually chased by companies subjected to high costs for the purchase or rent of storage areas: in these cases it is of primary importance to minimize the space required for the allocation of materials not to let these cost unduly strain on the enterprise economics. Likewise, if the main costs of a company are due to the warehouse personnel or vehicles maintenance, it should mainly focus on the second objective.

In order to meet as many users' needs as possible, the tool has been designed to offer the chance of multiple trade-offs solutions, thus pursuing goals that give great important both to the space and the time variable. To this end, the tool also grants the possibility to simulate the warehouse performance either with optimal or random products allocations: the 3D representation of the access frequency to slots for both configurations is shown in Figure 4 and 5.

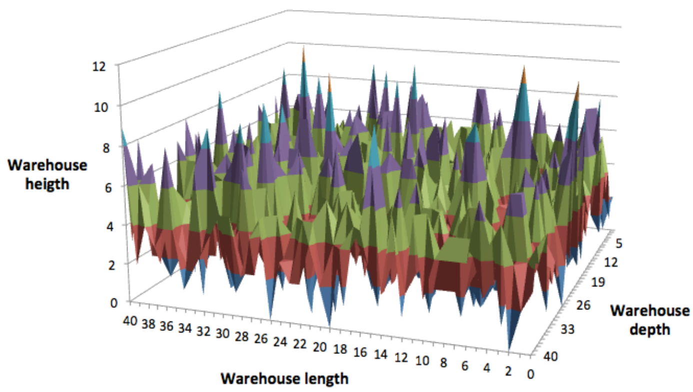

Figure 4. Example of access frequency to slots

adopting a random products distribution

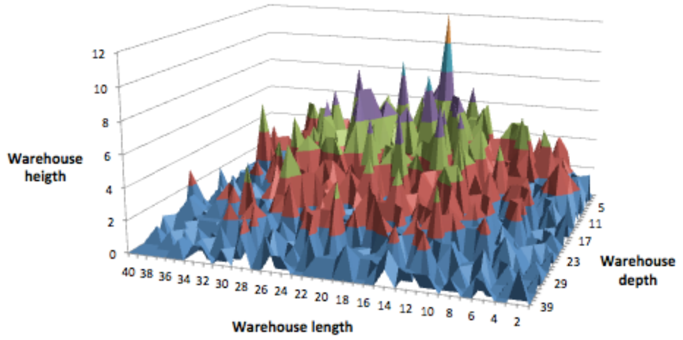

Figure 5. Example of access frequency to slots

adopting an optimal products distribution

The two examples, referred to a square warehouse with single IN/OUT point (at the center of the rear aisle, in each figure), allow to underline the considerable difference of accesses distribution when a slot-product allocation optimization is, or is not, performed: with an optimal slot-product allocation, fast mover items will be located in slots closer to the IN/OUT point, and their access frequency would be higher (green and purple peaks, in Figure 5); thus, the tool is able to determine the effect of optimal allocation in terms of time savings for stacking/picking activities, helping the user in the decision of investment in warehouse management systems able to support slot-product allocation management.

Conclusion

Warehouses represent an essential connection between upstream (production) and downstream (distribution) entities of modern supply chains, affecting the productivity and operation costs of enterprises and playing a vital role in the success or failure of businesses. With the aim to increase their efficiency without bearing huge investments, this paper presented an analysis of storage areas optimization techniques and the development of a tool able to improve both allocation and handling procedures.

Since an organized warehouse, characterized by an optimal layout and efficient material handling system, is inevitably dependent from a correct allocation of products as well as a correct picking procedure, attention was paid on making the tool the most applicable to those warehouse management needs related to both these aspects: the main aim was to provide the reduction of warehousing costs connected to the storage area, to the usage of material handling vehicles and to the warehousing personnel.

A reduction in the number of required slots results in a smaller warehouse surface to buy or rent for products storage as well as in the reduction of the number of shelves, therefore granting a considerable decrease of related costs; analogously, reduced distances travelled by reach trucks entail remarkable savings in terms of vehicles durability as well as time needed for material handlings, number of required vehicles to buy and/or of qualified personnel to employ.

Future researches should aim at refining the prototype's functionalities in terms of other possible picking procedures to implement and on testing it on different industrial warehouse configurations, thus removing the "one-block layout" assumption.

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