DIMENSIONING BLOCK STACKING SYSTEMS

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Abstract: *Palletized unit loads can be stored in several different ways. There are technologies with storage equipment and technologies without storage equipment. The oldest storage technology is block stacking system, which is still in use today. This technology only needs space, not storage equipment. This greatly reduces storage costs, but there are certain limitations in terms of selectivity, accessibility, and etc. This system should be optimized in order to make the best use of storage capacity/space. Dimensioning, which is the subject of this study, is one of the subjects of optimization. The goal is to demonstrate several approaches to dimensioning the block stacking system based on the characteristics of the problem to be solved. Methods for determining the optimal lane depth, and many other dimensions, will be presented in this paper. In addition, relevant papers on this topic will be presented and briefly discussed.*

Keywords: *Warehouse, Block staking systems, Dimension problem*

1. INTRODUCTION

Warehouse is a very important link in the supply chain, with specific tasks. One of the basic tasks / functions of the warehouse is storage, i.e., temporary retention of goods, with the intention to use them soon. This arise an additional question, which storage technology needs to be applied to realize this function. When it comes to the storage of palletized loads units, it is possible to apply technologies with and without the use of storage equipment (racks) (Vukićević, 1995).

A block stacking system is used to store unit load on top of each other on the warehouse floor. Different schemes are utilized in the constructing blocks to offer storage conditions and rational handling. At the end of the lane, the first pallet is placed on the floor, and the second one is placed on top of the first. If there is enough height, the third pallet can be placed on top of these two. If not, it needs to be set in the front of the first. This is how further filling actually in daily practice occurs. One lane usually contains only one SKU (stock keeping unit), and it can only be utilized to store another SKU after it has been completely empty. As a result, many lanes are only partially filled at some point through

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the storage process. *Honeycombing* is the recognized term for this effect. The number of pallets that can be stored in height is determined by the load's weight and stability, the handling equipment's characteristics, and the space's available height. In practice, four levels of agreement are the most usual. Because the pallets are kept in reverse order, the LIFO (*Last-In-First-Out*) storage method is applied (Rushton et al, 2014).

This storage system characterized low costs. Therefore, it is widely utilized in many manufacturing and non-manufacturing industries, as well as distribution centers, as the primary storage system. In the case when there are many pallets of one product in stock and several pallets are sent at the same time, the block stacking system is extremely efficient (Tompkins et al, 2010).

When storing big and difficult pallets, box, or containers, block stacking is also cost-effective and widely accepted. Bottled beverage firms, the food sector, the building materials industry, some distribution warehouses, and sea shipping ports all employ these systems.

Before deciding on block stacking system, it is necessary to evaluate the task, for which the following information is required: about the items, the characteristics of the goods flow (receipt-shipment); and the available space and its characteristics. The storage area is created in accordance with the task and the goals. The capacity, number of aisles and cross aisles, number of lanes, lane depth, stacking height, and other parameters are calculated during the dimensioning process.

The mentioned problems of block stacking system design set in different contexts and characteristics of the task have been the subject of research and are present in the professional and scientific literatures. The question arises as to their suitability for use in the practical problems encountered by designers and warehouse managers. From that aspect, it would be more convenient to set problems and solutions from the literature in the way that practice sets. Guided by this goal, this paper has the following structure: After the introduction, the formulation of the problem in section two is presented. In the third section, design problems were identified, and an overview of relevant papers was given. In the final section, a concluding comment was given and directions for possible expansion of this work.

2. PROBLEM STATEMENT

The goals of designing the storage area are to provide solutions that make optimum use of available storage space and enable the handling process to run properly. The goal's dominance is defined by the characteristics of the problem to be solved. The goals defined in this way are realized by choosing an appropriate system configuration (layout), which includes determining the block's parameters: lane depth, lane height, and block width. When using a block stacking system for pallet unit load, two basic concepts (layout) can be identified (Đurđević and Pavlov, 2021):

- Block stacking system (Figure 1-a),
- Block stacking system in uniformed storage fields (Figure 1-b).

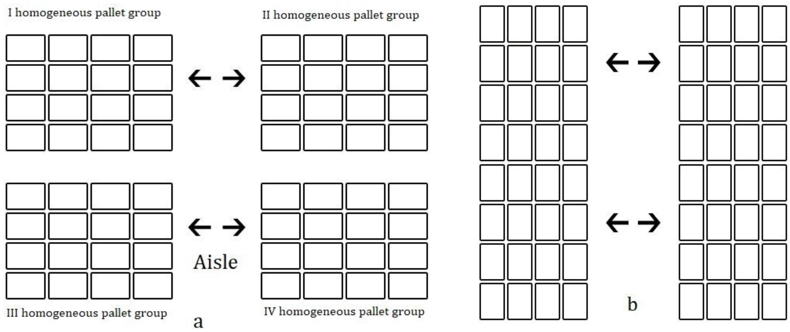

Figure 1 – Block stacking system (a) and block stacking system in uniformed storage fields (b) (Đurđević i Pavlov, 2021)

The surface on which one homogeneous group of pallets is placed in a modified block stacking system (b) represents one lane, or a unified field. Unlike a traditional block stacking system (a), which allows access to pallets in a single group regardless of the level of occupancy in adjacent areas. The pallets are positioned in the field on the wide side in respect to the aisle (to provide access to the handling equipment), which is the main feature of modified block stacking technology (b). When a high number of pallets appear in one homogeneous group, the traditional block system (a) is recommended to ensure the solution's economy without requiring significant additional manipulations. In comparison to the traditional block stacking system (a), the modified block system (b) worse uses space and is typically used when the range of goods is higher, the units of each good in stock are smaller, and the inventory turnover ratio is high (Vukićević, 1995).

In order to prevent the filling of unit loads or the relocation of pallets, in the case of a random allocation strategy, it is typical to temporarily assign one row to the product that is first stored in that row. Thus, that order is reserved for that product until it is completely emptied, and other (different) products are not allowed to be stored in that order. The application of this principle leads to an effect called honeycombing. There are two types of honeycombing, as it was presented in Figure 2: horizontal and vertical.

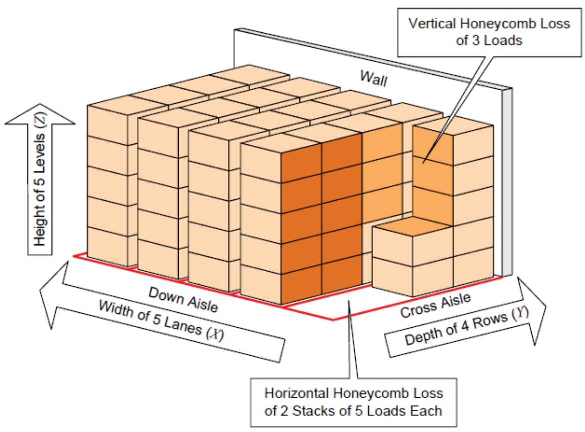

Figure 2 – Stacking pallets in block stacking system (Kay, 2015)

The use of block stacking technology in different task situations has long been a topic of discussion in the literature. The authors have been dealing with this problem for 50 years (one of the first is Kind, 1975). Relevant sources are: (i) Books (Vukićević (1995), Heragu (2008), Tompkins (2010), Bartholdi and Hackman (2014), Rushton (2014), Kay (2015)) and (ii) academic papers (Kind, Marsh, Goetschalckk, Young and Kim, Derhami et al., Venkitasubramony and Adil). In them, the problem of the block stacking system is described, set and solved by applying (explained in the previous part of the paper) different approaches and methods. The following section presents an overview and analysis of only a few (due to space constraints) relevant papers.

3. LITERATURE REVIEW

The analysis of papers or references in the literature will be conducted in a way that connects typical design problems with practical approaches/solutions, as indicated in the paper's goal. A description of typical problems is presented in the first section, followed by an overview and analysis of relevant papers from the literature based on identified problems. Defining the layout, identifying the optimal lane depth, and minimizing relocation of product are all common problems.

3.1 Problem/task description

One of the most important steps in designing a storage area that uses a block stacking system is determining the **layout** for the selected capacity. In this situation, the **optimal lane depth**, number of blocks, number of aisles and cross aisles, stacking height, and other parameters must be determined for the chosen (defined) capacity (Heragu, 2008). During exploitation, tasks for **relocating** specific goods appear to better utilize available space and improve the shipping process' efficiency.

A typical **layout** of block stacking system arrangement consists of numerous blocks (of different depth), each of which includes a few lanes for pallet storage. There are aisles and cross aisles between the blocks where the handling equipment operates. The problem is formulated as the selection of an appropriate block and aisles configuration.

The lane depth of order is the primary dimensioning topic in this paper. Different approaches to solving this problem might be used depending on the technological requirements. The number of pallets that can be placed in the same lane, one after the other, is referred to as lane depth. The number of pallet levels that can be stored on top of each other is determined by lane height, while block width for a group of pallet units is determined by lane depth (the greater the lane depth, the smaller the block width and inversely). The dimension problem can be resolved to choosing the optimal lane depth.

The use of space and the capacity to manage pallets are both impacted by determining the **optimal lane depth.** When individual lanes are very deep (over 10 pallets), the question of whether it is safe to leave one lane of products empty while the lanes next to it are nearly full arises. The entire system's stability may then be endangered. There are two approaches to determine the optimal lane depth: when the calculation is performed for the same goods (the one goods are in all lanes) and when there are a large number of different goods. The characteristics of the incoming and exiting goods flows also impact the lane depth.

The characteristics and features of the requirements that arise determine the dimension of a block stacking system. The emergent form and quantity of technological requirements (TR); the time and place of occurrence and completion of TR; the patience interval; the duration of TR; and the limiting factors influencing the realization of TR are the basic characteristics of TR. Stationarity and non-stationarity, stochasticity-deterministicity, continuity-discontinuity, and homogeneity-inhomogeneity are the features that describe them (Vukićević 1995). The most typical application of block stacking technology is when the relevant characteristic TR is emergent form; that is, when the quantity is such that this technology can be used, and the feature of that characteristic is homogeneity. Additionally, the presence of deterministic related to the requirements for goods handling would characterize a positive situation (by time and quantity). Of course, this is an ideal situation that rarely occurs in reality. There are many situations where the needs are dynamic and change over time.

As previously mentioned, during the operation of a block stacking system, at certain points in time, there are tasks / needs to move certain stocks to make better use of available space and improve the efficiency of the shipment process. This is present when storage and retrieval times of inventories are uncertain and storage space for inventories is limited. The task is to allocate inventories (units of cargo) to storage areas so that the total expected number of **relocations** is minimized (Yang & Kim (2006)).

3.2 Literature

This chapter is giving short literature review of some papers that deal with relevant research related to this topic. Table 1 summarized some of them.

Table 1 shows a review of the literature with previously identified problems.

Problems	References	Goal	Methods
(P1)- determining the optimal lane depth	Kind, D. A. (1975)	space utilization	analytical methods
	Marsh, W. H., & WH, M. (1979)	space utilization	analytical methods and simulations
	Goetschalckx, M., & Donald Ratldff, H. (1991)	space utilization	dynamic programming and heuristics
	Derhami, S., Smith, J. S., & Gue, K. R. (2017)	space utilization and accessibility	analytical methods
	Derhami, S., Smith, J. S., and Gue, K. R. (2019)	space utilization and accessibility	analytical methods and simulations
	Venkitasubramony, R., & Adil, G. K. (2019a)	space utilization	scenario based model
	Venkitasubramony, R., & Adil, G. K. (2019b)	space utilization and material handling costs	Analytical methods and computational experiments
(P2)– determining the layout of block stacking system	Derhami, S., Smith, J. S., & Gue, K. R. (2019)	space utilization and accessibility	analytical methods and simulations
	Derhami, S., Smith, J. S., & Gue, K. R. (2020)	space utilization and accessibility	simulations
(P3)- Relocation goods	Yang, J. H., & Kim, K. H. (2006)	Minimizing relocation	dynamic programming

Kind (1975) presented one of the earliest papers on determining the optimal lane depth, and because of its historical relevance, a more extensive description was offered. Letting

Q, w, and z denote the lot size in pallet loads, width of aisle (in pallet stacks), and stack height in pallet loads, respectively, his formula (1) determines the near optimal lane depth, d, as:

$$d = \sqrt{\frac{Q*w}{z}} - \frac{w}{2} \text{[number of pallets]} \quad (1)$$

He suggests a simple formula to determine a near - optimal lane depth, under these standard assumptions: (i) goods are allocated to storage spaces using the random storage operating policy, (ii) replenishment (in predetermined lot sizes) is instantaneous and done only when the inventory excluding safety stock has been completely depleted, (iii) lots are rotated on a first-in first-out basis, (iv) withdrawal of lots takes place at a constant rate, and (v) an empty lot is available for use immediately. The model is limited as a function of these assumptions, but it served as a foundation for other authors who enhanced the model by eliminating some assumptions.

Marsh (1979) dealt with the similar problem of lane depth determination. He evaluated space utilization for different variants of lane depth and storage policy using simulation.

Goetschalckx and Ratliff (1991) focused on the problems of determining the lane depth in two scenarios: (i) when the goods are homogeneous in one lane, and (ii) when the goods are inhomogeneous in one lane. The primary goal was to reduce the amount of storage space necessary. They used a dynamic programming approach to determine the optimal lane depth and heuristics to compare the results.

Derhami, S., Smith, J. S., & Gue, K. R. (2017) discussed the problem with block stacking technology in several papers (Derhami et al 2017, Derhami et al 2019, Derhami et al, 2020). They developed formulas for different characteristics of technological requirements in their paper (Derhami et al, 2017). They observed situations in which the delivery and dispatch intensities to and from the warehouse are known, and situations in which the delivery intensity is known but the dispatch is not. By determining the appropriate lane depth, they aimed to reduce the honeycombing effect. They also included a graphical method as an aid for addressing the problem (Figure 3).

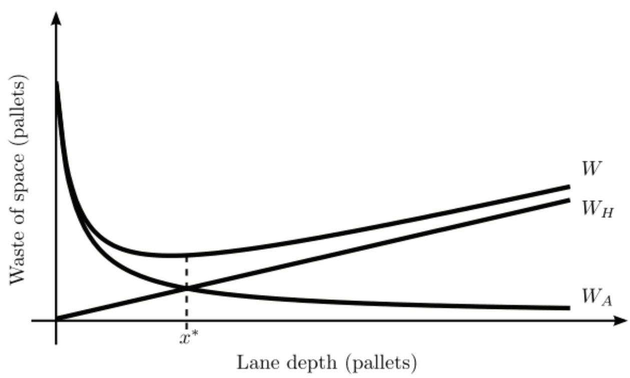

Figure 3 – Graphical method for determining lane depth

The diagram in Figure 3 can also be used to determine the optimal lane depth. The depth is determined using data from the honeycombing effect (W_H) and the area of aisles (W_A). The optimal lane depth was found at the intersection of these two curves. The honeycombing effect glans with lane depth, and the area of the occupied by aisles reduces, and inversely. The average loss of storage capacity is determined in cross section these two curves (Derhami et al, 2017). The optimal lane depth is reached when this loss (W) is the smallest. Authors of three cases that were observed:

1) Supply (P) and demand (λ) are both constant and deterministic (Formulas 2 and 3),

2) Supply (P) exceeds demand (λ), which is both constant and deterministic (Formulas 4 and 5),

3) The supply (P) is smaller than the demand (λ), which is stochastic and not constant (Formulas 6 and 7),

suggest the following formulas (2-7):

$$x^* \approx \sqrt{\frac{Q*a}{2*z}} \qquad (2)$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{c_i}\right)*Q_i}{2*\sum_{i=1}^{n} e_i*h_i}} \qquad (3)$$

$$x^* \approx \sqrt{\frac{a*(Q*(P-\lambda)-2*\lambda)}{2*z*P}} \qquad (4)$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{z_i*P_i}\right)*(Q_i*(P_i-\lambda_i)-2*\lambda_i)}{2*\sum_{i=1}^{n} e_i*h_i}} \qquad (5)$$

$$x^* \approx \sqrt{\frac{a*(Q-z)*(\lambda-P)}{2*z*\lambda}} \qquad (6)$$

$$x_c^* \approx \sqrt{\frac{a*\sum_{i=1}^{n}\left(\frac{e_i*h_i}{z_i*\lambda_i}\right)*(Q_i-2)*(\lambda_i-P_i)}{2*\sum_{i=1}^{n} e_i*h_i}} \qquad (7)$$

x^*- optimal lane depth for single SKU (in unit of pallet)

x^*_C- optimal common lane depth for multiple SKUs (in unit of pallet)

Q- production (arrival) batch quantity (in units of pallet)

a- aisle width (in units of pallet)

z- stackable height (in units of pallet)

e- clear height of the warehouse (in units of pallet)

h- height of a pallet of a SKU (in unit of distance i.e., inch, cm)

P- production rate (in units of pallet/time)

λ- depletion rate (in units of pallet/time)

Derhami, S., Smith, J. S., & Gue, K. R. (2020) focused their research on dimensioning and designing warehouse layout. The simulation method was used in the situation of dynamic solving systems. To run the program, authors first define all the possible scenarios (layouts). Because there are several scenarios depending on size of the warehouse, some limits must be established. The minimum and maximum number of aisles, as well as cross aisles, reflect these limits. The optimal lane depths (formula 9), the number of aisles, and the number of cross aisles is determined first, and then the deviations in relation to that number are defined. For all goods stored, it is assumed that the lane depth is constant (formula 8). The formulas are as follows:

$$\overline{x^*} = \frac{S^l - n_a^* * A}{2 * n_a^*} \quad (8)$$

$$n_a^* = \sqrt{\frac{S^l * N_S}{4 * S^W * A}} \quad (9)$$

It is necessary to introduce the following notation to make the used formulas more understandable:

$\overline{x^*}$ - optimal common bay depth (in units of pallets)

S^l – warehouse length (in units of pallets)

n_a^* - optimal number of aisles

A- aisle width (in units of pallets)

N_s – number of SKUs stored in warehouse

S^w – warehouse width (in units of pallets)

Venkitasubramony, R., & Adil, G. K. have addressed the determination of lane depth, number of aisles, and cross aisles in block warehouses stacking system in several papers Venkitasubramony, R., & Adil, G. K. (2019a), Venkitasubramony, R. and Adil, G. K. (2019b and Venkitasubramony, R. and Adil, G. K. (2021)). Venkitasubramony, R., and Adil, G. K. (2019a) used the scenario tree methods in their research. The basis for wood is the monthly average demand for products. The tree branches out from that node to the number of branches in the relevant months. Further branching to potential possibilities relating to the next month is performed from each branch (which represents a certain month). This branching continue till the final month arrives. Each branch combination represents a single scenario, with a probability of occurrence assigned to each branch. The final probability for each scenario is calculated using the individual's product, based on which the final ranking of the alternatives is performed, and the storage capacity is defined. The analytical method is used to obtain additional characteristic dimensions.

They're searching for a solution that will work in different ~~of~~ situations. The Robust Design Model is the model which they use. It intends to minimize overstocking's expected costs, risks, and costs. The lane depth, the number of lanes in the main warehouse, and the capacity necessary for renting are all considered factors in this model. The following notation must be introduced to better understand the goal function:

$x = [x_1, x_2]$- x_1 – lane depth (in pallets), a x_2 – number of lanes

y_m- additional warehouse capacity hired during a month m

g- the total expected space cost

λ- risk aversion parameter

ω- overflow penalty coefficient

OF- inventory surge

With limitations (11)– (12), the objective function (formula 10) is defined to minimize storage costs, capacity shortage costs, and capacity shortage risk (13).

$$F = g * (x, y_1) + \lambda * RISK(x, y_1) + \omega * OF(x, y_1) \rightarrow min \quad (10)$$

$$[x_{1(min)}, x_{2(min)}] \leq [x] \leq [x_{1(max)}, x_{2(max)}] \quad (11)$$

$$[y_{1(min)}] \leq [y_1] \leq [y_{1(max)}] \quad (12)$$

$$x_1, x_2 \in Z^+ \quad (13)$$

Restriction (11) relates to keeping the lane depth and number of lanes within a certain range, while restriction (12) refers to keeping the leased capacity within a certain range. The fact that both the lane depth and the number of lanes are given in integers is constraint (13) (in the number of pallets).

Yang and Kim (2006) explored at how to schedule goods in a block stacking system while reducing unit relocation during storage. They used several criteria and suggested that once a unit was transferred, no more relocations were required. When many diverse elements are stored in one lane, relocation occurs. When shipping one of them that is covered by other objects, the items must be relocated until the ones that are required are find. This problem is usual and difficult to research. As a result, he is entitled to greater research space.

4. CONCLUSION

For the warehouse to be profitable, the utilization of space in it must be at a satisfactory level. To achieve that, it is necessary to adequately designing the storage area. One of several technologies used in warehouse is the block stacking system. Although it is the oldest known technology, it is still in use due to its good characteristics. The advantage of this technology in relation to competitors (racks) is reflected in the fact that it is very simple, flexible, easily adapts to new requirements. With minimal costs (if space allows), the number of rows or the depth of block stacking can be increased relatively easily. The dimensioning method is of great importance for the efficiency of applied block stacking technology solutions.

The main goal of the paper was to connect the works from the literature with real practical problems that designers-engineers encounter when designing a block stacking storage. An overview of relevant works/papers was given for the identified group of design problems. Due to space limitations, some characteristic works/papers and models were presented in more detail, with the devoted on determining the optimal lane depth. The presented models can serve as a useful support to engineers in dimensioning the relevant parameters of the block stacking storage.

One of the extensions of this paper could be the application and testing of selected models from the literature on real problems from practice (e.g. case study). The characteristics of a specific task would guide the selection and application of appropriate approaches-models from the literature.

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