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WAREHOUSE DESIGN – DETERMINATION OF THE OPTIMAL STORAGE STRUCTURE

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Abstract: The paper shows a design conception for an existing warehouse. The conception can be applied to define an optimal storage structure based on a given warehouse floor area and available forecasts relating to types and volume of loading units (LU) to be stored. The study shows 6 possible alternatives for storage structure. Longitudinal and transversal twin racking arrangements with narrow and wide aisles were taken into consideration. Structure alternatives were compared based on storage capacity, specific storage capacity and utilization of floor area. The optimal storage structure was defined.
Keywords: warehouse, design conception, optimal storage, alternatives, racking arrangements

INTRODUCTION

Supply chain efficiencies depend upon the efficiency of logistics including warehousing activities. The efficiency of the warehouse depends on the layout, infrastructure and the operation of the warehouse. Warehouse design element aims to maximize the utility of space, equipment, and efficiency of operations.

Layout design [1] is completed taking into account the types and volumes of goods, required warehouse operations, and available warehouse infrastructure. The design aims to maximize space utilization, minimize material handling equipment movement and manpower movement.

Types of storage are determined by the nature of goods to be stored. Depending on the cargo whether raw materials, components, semi finished goods or finished goods, the types of storage can vary from bulk stock, block stock, racking, pallet racking, shelf racking, etc.

Most common storage type is the racking system. The racking design [1] takes into account the storage type, storage unit, volume, and weight coupled with the available floor space and roof height to design system that maximizes the storage capacity. Put away and picking process and transactional volumes are also taken into consideration.

METHOD, AIM AND CONSTRAINTS OF WAREHOUSE DESIGN

Our task was to form the optimal storage structure in an existing warehouse building. The product structure and the volume of goods to be stored were given. The aim of warehouse planning was the formation of possible storage structure alternatives for a given warehouse floor area and choose the optimal structure based on the following aspects:

- maximal storage capacity,
- maximal specific storage capacity,
- maximal utilization of floor area and space.

Constraints during the design were the followings: floor area, roof height, column arrangement, size and location of area used for order picking or loading in and loading out (Figure 1).

Areas b_{11}, b_{21} used for order picking, b_{31} is used for loading in and loading out activities. Areas b_{12}, b_{22}, b_{32}, b_{13}, b_{23} and b_{33} can be used for storage.

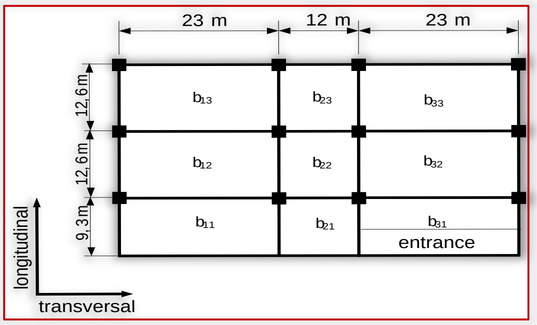

Figure 1. Layout of an existing warehouse building

FORMATION OF STORAGE STRUCTURES

At first we have to analyze the goods to be stored (type, volume, loading unit, turnover, etc.).

Storage structure, location of storage zones, applied storage techniques (racking, material handling tools and equipment), high of the building and the width of aisles are very important to take into consideration during the formation of storage alternatives.

The applicable storage structures can be the followings:

- racking storage:
  - adjustable pallet racking,
  - deep store drive-in pallet racking,
  - gravity pallet racking,
  - sliding pallet racking,
- without racking, storage on floor area in blocks.

It can be defined that the adjustable pallet racking is the adequate storage structure to be formed based on forecasts relating to the product types and volumes.

We examined two main types of this racking system in which the racking lines are in longitudinal and in transversal direction (Figure 1) [3]. It is worth to examine narrow- and wide aisle structures which requires different loading in-, loading out and order picking strategies and materials handling equipments.

The aim of the analysis is the elaboration of possible storage structures, determination of an optimal structure according to maximal storage capacity, maximal specific storage capacity, maximal utilization of floor area and space [4, 6].

Additional alternatives were examined according to the transversal and longitudinal location of loading units (LU) in the racking.

The following alternatives were examined based on the above mentioned aspects:

1. Longitudinal twin racking
Longitudinal racking system with narrow aisles (1.1.)
Loading units are in longitudinal direction on the racking (**1.1.1.**)
Loading units are in transversal direction on the racking (**1.1.2.**)
Longitudinal racking system with wide aisles (1.2.)
2. Transversal racking system
Transversal racking system with narrow aisles (2.1.)
Loading units are in longitudinal direction on the racking (**2.1.1.**)
Loading units are in transversal direction on the racking (**2.1.2.**)
Transversal racking system with wide aisles (2.2.)

Figure 2. Formation of storage alternatives

LONGITUDINAL TWIN RACKING SYSTEM

In the racking system the racking lines and aisles are in longitudinal direction, parallel to the longitudinal side of the building (Fig. 3-5). This structure provides a good utilization of floor area.

Both narrow and wide aisles were examined.

Longitudinal racking system with narrow aisles (1.1.):

Formation of the structure is depicted on Fig. 3-4.

- Loading units are in longitudinal direction on the racking (**1.1.1.** - Fig. 3.): In this case the width of twin racks is 1800 mm, width of narrow aisles is 1400 mm.

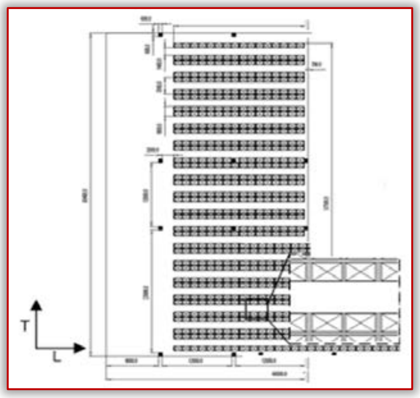

Figure 3. Narrow longitudinal aisle (LU in longitudinal)

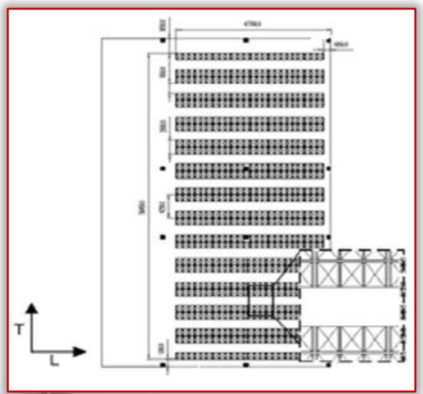

Figure 4. Narrow longitudinal aisle (LU in transversal)

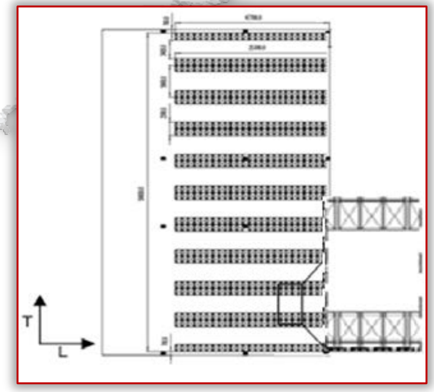

Figure 5. Wide longitudinal aisle (LU in transversal)

During the design we had to take into consideration the fix column arrangement of the building. We tried to define the racking lines that the columns will be in the racking line not in the aisles.

- Loading units are in transversal direction on the racking (**1.1.2.** - Fig. 4.): In this case the width of twin racks is 2500 mm, width of narrow aisles is 1850 mm.

Longitudinal racking system with wide aisles (1.2.):

We analyzed also the wide aisle structure (Fig. 5.). We suggest the application of conventional high lifting forklifts. The suggested width of the aisle is 3400 mm to provide the two-directional traffic of forklifts.

Transversal aisles were also formed to intensify the activity of forklifts, efficiency of loading in, loading out and order picking activities.

TRANSVERSAL TWIN RACKING SYSTEM

Racking system consists of racking lines in transversal direction, orthogonal to the longitudinal side of the building (Fig. 6-8.).

This structure results a larger number of racking lines and aisles, which provides an easier handling of a large number of product types and an easier traffic of forklifts.

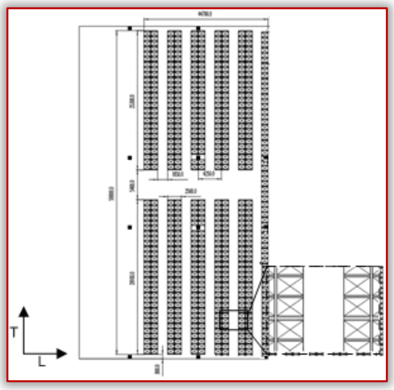

Figure 6. Narrow transversal aisle (LU in longitudinal)

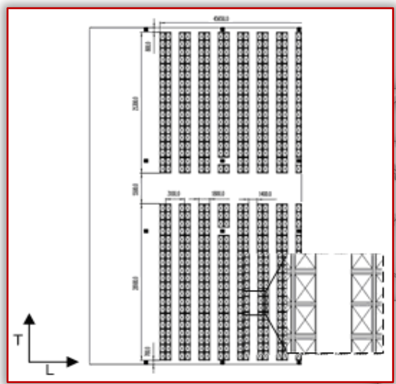

Figure 7. Narrow transversal aisle (LU in transversal)

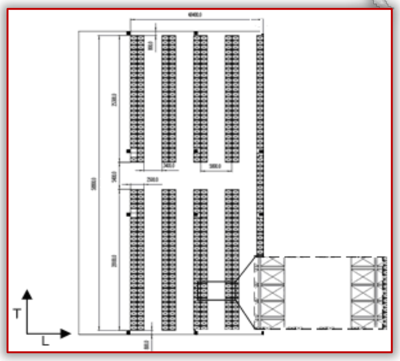

Figure 8. Wide transversal aisle (LU in longitudinal)

Transversal racking system with narrow aisles (2.1.):

Both transversal and longitudinal locations of loading units in the racking were examined (Fig. 6-7). We suggest the formation of a wide longitudinal aisle for supporting of activities completed in the transversal aisles.

- Loading units are in longitudinal direction on the racking (**2.1.1.** - Fig. 6.): In this case the width of twin racking is 2500 mm, width of narrow aisles is 1850 mm. Width of longitudinal aisle is 5400 mm.
- Loading units are in transversal direction on the racking (**2.1.2.** - Fig. 7.): Width of twin racking is 1800 mm, width of narrow aisles is 1400 mm. Width of longitudinal aisle is 5500 mm.

Transversal racking system with wide aisles (**2.2.** - Fig. 8.)**:**

We suggest the application of conventional high lifting forklifts. The width of aisles is 3400 mm to provide two-directional traffic of forklifts. The width of longitudinal service aisles is 5400 mm.

COMPARISON OF STRUCTURE ALTERNATIVES

Comparison of different structure alternatives was based on the following aspects: maximal storage capacity, maximal specific storage capacity, maximal utilization of floor area and space [5, 6].

Storage capacity of storage structures

Storage capacity of structures can be calculated by the following equation (dimension is Loading Unit):

$$n_i = r \cdot n_T \cdot n_L , \qquad (1)$$

where: r: number of layers of loading units (LU) in vertical direction on racking, n_T: number of LU stored in transversal direction on floor area, n_L: number of LU stored in longitudinal direction on floor area.

The number of layers of loading units in vertical direction on racking is 8 layers in all cases of structures (r=8).

The loss of storage capacity caused by fix location of building columns should be taken into consideration during the calculation of storage capacities.

The results (Table 1) of the calculations for the different storage structure are the followings:

Table 1. Storage capacity of different alternatives

Alternatives	Storage capacity (n_i) [pieces]
1.1.1.	4576
1.1.2.	5160
1.2.	3968
2.1.1.	5016
2.1.2.	4544
2.2.	4032

It can be summarized that a higher storage capacity can be provided by the application of longitudinal racking compared to transversal arrangement.

The optimal arrangement of narrow aisle structures is the longitudinal racking system in which the LUs are in transversal direction.

In case of wide aisle arrangement also the longitudinal racking system seems to be more advantageous.

It is not enough to compare only the storage capacities of narrow and wide aisle structures. If we want to compare these we have to take into consideration of construction cost, operation cost, service cost, service strategies and productivity of handling equipments of the alternatives simultaneously. This analysis requires further research work.

Specific storage capacity of storage structures

Longitudinal and transversal arrangement can be also compared based on the total number of LUs stored on the total storage floor area.

Specific storage capacity can be defined by the following equation:

$$\rho_i = \frac{n_i}{A_{ti}}, \tag{2}$$

where: ρ_i: specific storage capacity (ρ_i) [pieces/m^2], n_i: maximal number of LUs stored in case of the i^{th} alternative [pieces], A_{ti}: total storage area in case of the i^{th} alternative [m^2].

This total racking area is not includes the area of aisles. The result of calculations is summarized in Table 2.

Table 2. Specific storage capacity of different alternatives

Alternatives	Total storage area (A_{ti}) [m^2]	Specific storage capacity (ρ_i) [pieces/m^2]
1.1.1.	1392	3.29
1.1.2.	1392	3.7
1.2.	1392	2.85
2.1.1.	1328	3.78
2.1.2.	1330	3.42
2.2.	1350	2.99

Specific storage capacity of the two most advantageous narrow aisle structures is near the same and the specific storage capacity of the two wide aisle arrangements is also near the same. Specific storage capacity of narrow aisle structures is higher compared to wide aisle arrangements. The optimal structures are the longitudinal racking with narrow aisles (LUs in transversal direction) system and the transversal narrow aisle (LUs in longitudinal direction) arrangement. If we taking the storage capacity into consideration the longitudinal racking system with narrow aisle (LUs in transversal direction) is the ideal formation.

Utilization of floor area of different alternatives

Alternatives can be compared based on factor of utilization of floor area (φ_i) and utilization of internal space. Utilization of floor area [%] can be calculated:

$$\varphi_i = \frac{A_{ti}}{A_{ri}} \cdot 100\%, \tag{3}$$

where: φ_i: factor of floor area utilization of i^{th} alternative [%]; A_{ti}: total storage area in case of the i^{th} alternative [m^2]; A_{ri}: total racking area used for storage in case of the i^{th} alternative [m^2].

Result of calculations can be summarized in Table 3.

Table 3. Total storage area with racking area and utilization of floor area

Alternatives	Total storage area (A_{ti}) [m^2]	Racking area (A_{ri}) [m^2]	Utiliza-tion of floor area (φ_i) [%]
1.1.1.	1392	768	55,17%
1.1.2.	1392	770	55,32%
1.2.	1392	592	42,53%
2.1.1.	1328	734	55,27%
2.1.2.	1330	729	54,81%
2.2.	1350	601	44,52%

We can summarize that floor area utilization of narrow aisle arrangements are near the same and floor area utilization of wide aisle structures are also near the same. But if we taking the storage capacity into consideration the longitudinal racking system with narrow aisle (LUs in transversal direction) provides the optimal solution.

CONCLUSION

The paper shows the warehouse design conception of an existing warehouse, which conception is suitable to define an optimal storage structure for case of a given warehouse floor area.

We examined two main types of a twin racking system in which the racking lines are in longitudinal and in transversal direction. It is worth to examine narrow- and wide aisle structures which requires different loading in and loading out strategies and materials handling equipments. Additional alternatives were also examined according to the transversal and longitudinal location of loading units (LU) in the racking.

The aim of the analysis was the elaboration of possible storage structures, determination of an optimal structure according to maximal storage capacity, maximal specific storage capacity, maximal utilization of floor area and space.

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