Methodology for the Calculation of Functional Elements in Warehouses of Public Intermodal Logistics Centers

Metodologija izračuna funkcionalnih elemenata u skladištima javnih intermodalnih logističkih centara

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Summary

This article deals with the design of functional elements in the warehouses of public logistics centers. The methodology focuses on the determination of the minimum area required for operating a warehouse, the resulting dimensions and internal organization of the warehouse (especially individual sectors within warehouses) and the calculation of the operational requirements for the handling means to be used in a warehouse.

KEY WORDS

warehouse
logistics center
operational requirements
handling equipment
warehouse area

Sažetak

U ovom radu govori se o dizajnu funkcionalnih elemenata u skladištima javnih logističkih centara. Metodologija je fokusirana na određivanje minimalnog područja koje je potrebno za rad skladišta, dobijene dimenzije i internu organizaciju skladišta (posebice individualnih sektora u skladištima) i izračun operacijskih zahtjeva za korištenje opreme za rukovanje u skladištu.

KLJUČNE RIJEČI

skladište
logistički centar
operacijski zahtjevi
oprema za rukovanje
skladišno područje

INTRODUCTION

An essential part of every logistics center (freight center) is temporary storage areas for transported shipments. It is here that the shipments are stored, assembled (palletized) and/or packed and loaded onto combined freight cargo units (containers, swap bodies, etc.). Storage can be defined as an intelligently organized activity to ensure safe storage of goods while maintaining their original quantity, quality and other parameters. The shipments are stored in warehouses. A warehouse is an object or space intended for the short-term or long-term storage of materials and equipped with storage technologies and facilities [1], [2].

According to Lambert [3], storage is an important link between production and consumption and forms an integral part of every logistics chain. The role of warehouses in transportation is to compensate for material supply imbalances caused by transportation-based irregularities. Specifically, warehouses within logistics centers focus on maximizing profit by satisfying customers' shipping-related requirements. Warehouses may perform other functions as well e.g. collection of shipments into larger units for more efficient modes of transport, distribution of large shipments, packing of shipments, etc. [4].

THEORETICAL BASIS FOR THE DETERMINATION OF WAREHOUSE AREA

The best warehouse shape is a 2:3 rectangle allowing for the further expansion of the warehouse in the future. It is also advisable to select the warehouse section module in accordance with the construction modules i.e. 6 m or 12 m. By doing so, additional costs relating to the construction of custom built elements is avoided. The warehouses must include loading ramps with a minimum width of 3m. The ramps can be covered to protect them against the direct effects of weathering. The height of the upper edge of the ramp above the surface of a railway line should be 1.1 m whilst from a road surface it should be between 1 to 1.2 m depending on the type of road vehicles used [5], [6].

The construction and technical solutions of a warehouse are affected by the range of goods, type of follow-up transport, storage system and especially the storage technology, including the:

- principles of the flow of goods and layout (receipt, warehouse, shipping, packaging and relationship between the floor height and the height of external communications - ramps, etc.)

- type of handling units for individual types or groups of goods;
- horizontal transport system;
- method and scope of unloading;
- method of preparing goods for shipping and loading;
- method of handling and storing containers;
- calculation of space, premises, equipment and labor required.

Warehouse area is understood to mean the product of the area's size and the clear height of the warehouse. The clear height of the warehouse is given by the distance from the floor to the highest loft or roof structure.

The total area of a warehouse consists of the:

- effective area where shipments are stored;
- handling area for transport and handling alleys;
- complementary areas (e.g. area to store the warehouse scales and/or current inventory, warehouse staff rooms, sanitary facilities etc.);
- secondary areas for the storage of empty shipping containers, pallets, battery charging rooms, areas for parking trucks, etc.

The following indicators are crucial in determining the size of a warehouse and its ramps:

The average daily number of shipments Q_d, which is calculated from the total amount of goods in the reporting year and the number of working days in a year the warehouse is operational.

$$Q_d = \frac{Q_r}{N} \tag{1}$$

Whereby:

Q_r - total quantity of goods in tons in the reporting year;

N - number of working days in a year the warehouse is operational.

Quantity of positioned shipments in tonsQ_p calculated from the relation:

$$Q_p = Q_d.\varphi.t.\omega \tag{2}$$

Whereby:

φ - coefficient of inequality in transportation;

t - average storage time;

ω - expected growth rate.

The area for storing items, including transport and handling alleys, is calculated as follows:

$$F_c = Q_p.f_u.\beta.\gamma \tag{3}$$

Whereby:

f_u – storage area required per ton of positioned goods;

β – coefficient for additional handling and storage areas;

γ – stacking coefficient.

The total required storage area is then used to determine the individual parameters of a warehouse:

- warehouse compartment width - proposed for the pillar axe distance of 12 m, 18 m and 24 m. This corresponds to the clear widths of the compartment - about 11.6 m, 17.5 m and 23.4 m;
- warehouse length – with a warehouse width of 12 m and 18 m, it should be a multiple of 6 m. Minimum warehouse length must be 12 m. The maximum length should not exceed 204 m. If necessary, a warehouse length of 300 m is permitted.
- warehouse height - is influenced by the nature of the stored goods, the required warehouse capacity, technical parameters of the warehouse equipment, work technology and the possibility of vehicles to enter the warehouse area [1].

THEORETICAL BASIS FOR THE DETERMINATION OF THE OPERATIONAL REQUIREMENTS FOR HANDLING MEANS

The analysis and design of material handling technology requires knowledge of the characteristics and properties of the facilities and equipment for material handling and the properties of the handled materials.

The required number of trucks depends on their hourly output and the required hourly output. The hourly output of the trucks depends on the average amount of material (goods) in tons manipulated during one work cycle and on the duration of the work cycle. The required hourly output depends on the average quantity of goods (in tons) to be handled per hour in the warehouse. The total requirement for trucks is then expressed as the following ratio [6-8]:

$$z_c = \frac{Q_{vh}}{Q_h} \tag{4}$$

Whereby:

Q_{vh} - required hourly performance;

Q_h – hourly output of the trucks.

The hourly transport output of a transport carriage (and/or cyclically operating mechanization equipment) Q_h is derived from the basic equation:

$$Q_h = \frac{3600}{t_{cp}} \cdot M_d \tag{5}$$

The required hourly transport output (capacity) of the mechanical equipment can be determined for example on the basis of the required volume of handling operations per shift:

$$Q_{vh} = \frac{Q_{vs} \cdot k_{nh}}{T_{ps}} \tag{6}$$

Whereby:

Q_{vs} - volume of required handling operations per shift [t];

T_{ps} - productive time pool of a shift i.e. working hours of a shift reduced by the time required for breaks (including technological), maintenance and repair [h]

k_{nh} - coefficient of hourly inequalities of handling operations during the work shift.

SETTING THE PARAMETERS FOR A STANDARD PUBLIC WAREHOUSE LOGISTICS CENTER

The calculation of the average daily number of incoming shipments must be based on an analysis of traffic flows within the context of road and rail freight in the relevant catchment area of a logistics center (LC). Different groups of goods transported using both modes of transportation must be explored and the relevant commodities selected (i.e. groups of

Table 1 Estimated volumes of commodities passing through the modeled LC

Group of goods	Total volume of transports within the LC catchment area	Estimated percentage of transition to LC	Estimated potential for LC
fats and oils	1.000 t	15 %	112.5 t
glass products	3.000 t	25 %	562.5 t
textiles	6.000 t	25 %	1.125 t
food	185.000 t	18.7 %	34.612.5 t
metal products	360.000 t	30 %	107.100 t
machinery and equipment	57.000 t	25.7 %	14.662.5 t
undefined goods	66.000 t	50 %	24.750 t
construction materials and chemicals	451.000 t	30 %	135.300 t
total	1.129.000 t	-	318.225 t

Source: author

goods) that are suitable for storage in the LC. A model analysis of the estimated volumes of individual commodities which might pass through a LC is shown in Table 1 [7], [8].

The groups of goods identified include palletized goods, or goods suitable for palletizing, as well as non-palletized goods. Goods to enter the LC in bulk and suitable for palletizing can be loaded onto pallets and then stored. In total, the LC should receive around 173.213 tons of palletized goods and 145.013 tons of non-palletized goods per year. The calculations for the required storage areas were carried out separately for palletized and non-palletized goods.

Annually, the LC will receive an estimated total of 318.226 tons of goods, of which 173.213 tons will be on pallets and 145.013 tons will be stored in bulk.

The average daily amount of goods on pallets:

$$Q_d = \frac{Q_r}{N} = \frac{173213}{365} = 474,6t / day$$

The average daily amount of stored shipments is:

$$Q_p = Q_d.\varphi.t.\omega = 474,6*1,2*2*1,2 = 1367t / day$$

The coefficient of inequality φ was determined as 1.2 on the basis of a comparison between practice and foreign experience and according to the expected amount and type of goods, the average length of shipment storage in the LC of 2-3 days (counting two), and an expected annual increase in the volume of traffic after completion of the LC of approximately 20% (ω = 1.2).

Total operating area (effective + handling area) is then equal to:

$$F_c = Q_p.f_u.\beta.\gamma = 1367*2,56*3,02*0,5 = 5285m^2$$

The average daily amount of bulk goods (unsuitable for palletisation):

$$Q_d = \frac{Q_r}{N} = \frac{145013}{365} = 397,3t / day$$

The average daily amount of stored bulk consignments is:

$$Q_p = Q_d.\varphi.t.\omega = 397,3*1,2*2*1,2 = 1144,2t / day$$

Total operating area for bulk goods is expressed by the equation:

$$F_c = Q_p.f_u.\beta.\gamma = 1144,2*5*2,6*1 = 14875m^2$$

The total area required is then calculated as the sum of the area required for goods on pallets and the goods in bulk:

$$F_C^{skl} = F_C^{Pal} + F_C^{Vol} = 5285 + 14875 = 20160m^2$$

Following the principles and rules of warehouse design and taking into account the spatial possibilities, the total required warehouse area can be used to determine the outer dimensions of the entire warehouse building as 612 x 33 m. Since the maximum length of the storage section should not exceed 204 m for technological and operational reasons, the warehouse building should be divided into three individual storage areas (or separate storage sections), each with a length of 204 m. On this basis each section will have a total area of 6.732 m^2.

CALCULATION OF THE OPERATIONAL REQUIREMENTS FOR FORKLIFT TRUCKS IN THE LC

The warehouse will have AV 12 battery powered forklift trucks with a capacity of 1.2 tons. The required number of trucks depends on their hourly output and the required hourly output. With a truck turnaround time of about two minutes and with an estimated 1 ton of goods manipulated within a single turnaround (maximum truck load capacity is 1.2 tons and the maximum weight of the goods on a pallet is 1 ton), one truck handles approximately 30 tons per hour. The required hourly output of the trucks is expressed by the total volume of goods that will annually enter the logistics center i.e. 318.225 tons. With an estimated daily work shift of 12 hours, about 100 tons of goods have to be handled per hour. As a result, the total demand for trucks in the warehouse will be:

$$z_c = \frac{Q_{vh}}{Q_h} = \frac{100}{30} = 3,33 \text{ trucks}$$

This implies 1.11 trucks required for each separate storage section. When taking into account the need for reserve capacity and planned maintenance, repair of the trucks and inequalities in the run-up of the load into the logistics center, two forklift trucks should be considered in each warehouse section i.e. a total of six trucks.

CONCLUSION

The determination of the correct dimensions and parameters of a warehouse is vital. This is particularly important in terms of the required investment and operating costs so that the under sizing or oversizing of a warehouse is avoided. Both situations would result in either the investment being viewed as inefficient, or would lead to additional investment costs, or increase operating costs unnecessarily.

The methodology for the calculation of the functional elements of a warehouse consists of two parts. The first is the methodology for determining the dimensions of the warehouse in relation to the operating area of the warehouse. The second is the methodology for determining the operational requirements for handling devices used for loading at the warehouse [8], [9].

The output of this article is also a practical verification of the methodology on a typical public warehouse logistics center. The methodology was used to determine the minimum operational requirement for the warehouse, the overall dimensions of the warehouse and the operational requirements for forklift trucks in the warehouse.

The proposed methodology can be applied for any type of warehouse. The advantage of the methodology is also that the warehouse parameters are determined in accordance with the intended use of the warehouse which in turn supports the optimization of the investment and operating costs [9].

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