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INFLUENCE OF SELECTION OF MATERIAL HANDLING DEVICES ON SOLUTION FOR WAREHOUSE SYSTEM IN AUTOMOTIVE INDUSTRY

ABSTRACT: In the automotive industry, warehousing generally refers to the facilitation of storage, management, and distribution of automotive components. This paper considers the influence of the choice of the material handling devices on the solution of the warehouse system within the automotive industry. The types of convenient storage and retrieval equipment (forklifts) were considered. The calculation and selection of the standard parts of the rack structure were performed. According to the set design task and in accordance with the selected standard parts of the rack construction, three types of warehouses were designed, which are served by a standard forklift, reach truck and very narrow aisle truck. For all the three types of the warehouses, the layout of the pallet racks is shown, and the realized capacities are compared.

KEYWORDS: warehouse, material handling devices, storage and retrieval equipment

INTRODUCTION

Steel frame warehouse structures are the essential types of buildings that serve the commercial purpose of storing the goods in the automotive industry. Decision on the type of warehouse structure to construct depends on various reasons. Some of the aspects that should be taken into account include: the availability of space for construction, cost of construction, storage capacity and height and projected purpose of construction [1]. Mostly, handling of goods requires that the goods are stored on pallets which are placed on pallet racks as standard storage equipment.

Warehouses in automotive industry serve as strategic connections where various components and parts are received, organized, stored, and dispatched. These facilities are equipped with specialized infrastructure, advanced technologies, and skilled personnel that can handle the various requirements of the automotive industry. Their primary goal is to optimize inventory management, enhance operational efficiency, and ensure timely delivery of automotive goods.

Warehousing in the automotive industry encompasses a broad range of activities aimed at efficiently handling and organizing automotive inventory to support the smooth operation of the industry's supply chain. Efficient inventory management ensures that the right parts and components are available at the right time.

Efficient material movement is important in warehouses, terminals and manufacturing facilities. However, material handling is often overlooked or underestimated. Material handling involves the skill and knowledge of transferring, packaging and storing materials in various forms. Essentially, material handling involves the use of transportation systems, storage facilities and packaging methods to ensure the smooth physical flow of materials.

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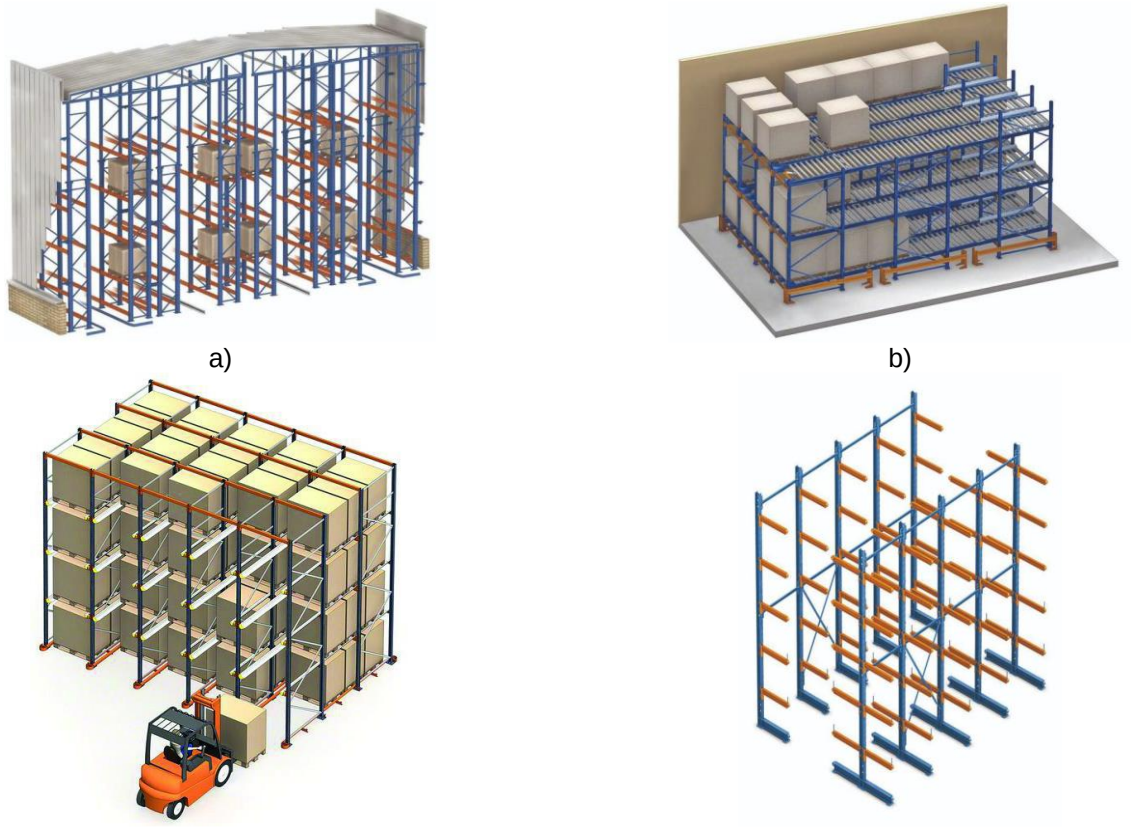
The material handling systems can be: manual, mechanized and automated. In general, the selection of appropriate equipment and devices for a specific system is based on the following recommendations:

- use the existing equipment whenever possible,
- apply the standardized and mechanized equipment (lower costs, stock reduction, more favourable maintenance),
- provide alternative solutions (provide other equipment in case of failure),
- take into account all requirements and limitations of application in the facility,
- predict and plan future needs and directions of development.

A proper storage and decision-making process for the selection of material handling equipment leads to: enhanced efficiency, improved flexibility, improved quality, optimized space utilization, reduced lead times and reduced costs. Beside the standard conventional pallet racking configuration, in the usage can be found configurations of pallet racks shown in Figure 1.



a) b) c) d)

Figure 1 Different types of pallet racks a) self-supporting racks, b) flow through box racks, c) drive-in or/and drive-through pallet racks, d) cantilever racks

The automotive industry operates on a finely tuned supply chain, where precision and timing are paramount. From sourcing the raw materials to delivering the finished vehicles, every step in the process must be synchronised seamlessly to ensure smooth operations and meet consumer demands. The supply chain process encompasses the flow of goods, materials, information, and resources from suppliers to manufacturers, distributors, retailers, and ultimately, the customers. In the context of warehousing in the automotive industry, the supply chain processes move automotive parts and components from suppliers to manufacturing facilities, distribution centres, dealerships and maintenance facilities.

DESIGNING LAYOUT OF PALLET RACKS

Conventional steel frame structures equipped with free standing rack configurations have been used to build warehouses, but with the advancement of technology, rack supported warehouses became very popular storage solution [2].

When designing the layout of pallet racks, it is necessary to comply with the following conditions:

- defined storage unit,
- defined way of handling the storage unit, i.e. appropriate storage and retrieval machines and
- defined storage space.

A typical selective pallet rack configuration is shown in Figure 2. The side frames and horizontal beams, usually made of thin-walled cold-formed profiles, form a spatial frame structure of the pallet racking system. The horizontal and vertical bracing system of frames provides the rack stability in the cross-aisle direction [3].

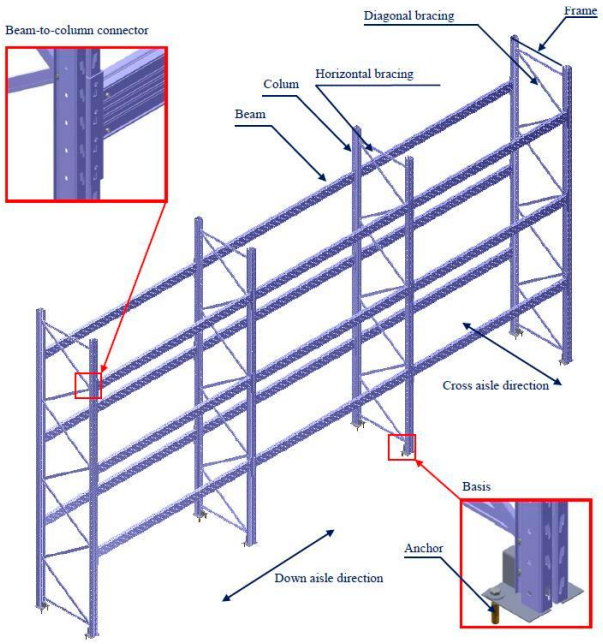


Figure 2 Typical configuration of a pallet rack structure

The dimensions of the planned storage area are: length of 32 m, width of 25 m and height of 9 m. The material is stored on standard EURO pallets with the basic dimensions of 800 mm x 1200 mm, while the height of the storage unit is 1100 mm. The maximum weight of the pallet is 1000 kg and the pallet is inserted transversely into the rack.

Calculation and selection of pallet rack construction's elements

The choice of the rack construction elements primarily depends on the available storage space and the storage unit.

Selection of storage unit beams

In order to safely use the rack structure, the minimum recommended clearances must be respected when selecting the supporting elements. Clearances exist to prevent collisions within the storage systems. Actually, they are required nominal distances between fixed and moving parts, taking into account all individual tolerances and deformations [4]. When defining the elements of the rack structure, the entry clearances that exist between the load handling device and the load make-up, the minimum aisle clearances between the unit load, and between the unit load and the rack structure were taken into account.

The length of the storage unit beams is defined by the number of storage units in the compartment. A larger number of units in the compartment results in a smaller number of vertical frames and beams. However, in the case of higher load capacities, a larger cross-section of the beams is required. In order to obtain a lighter construction, a smaller number of storage units on a pair of beams is desirable. Packing of the storage unit in the rack can be longitudinal or transverse. In this case, transverse packing is applied and two standard EURO pallets are placed on a pair of horizontal beams.

The length of a two-pallet beams is calculated according to the following expression:

$$L_g = 2 \cdot 1200 + 75 + 75 + 50 = 2600\ mm, \tag{1}$$

where the width of the pallet is 1200 mm, the clearance between the pallets and the vertical upright is 75 mm and the gap between the pallets is 50 mm.

The weight of the storage units and their number in the compartment define the geometry of the storage unit beams, i.e. the cross-section dimensions. Since the weight of one storage unit is 1000 kg, the load in one rack compartment with one storage unit is 1000 kg, i.e. with two storage units is 2000 kg. Based on this, the standard pairs of storage unit beams of the appropriate load capacity were selected from the manufacturer's catalogue according to [5].

The minimum required carrying capacity of the beams for two pallets, weighing 1000 kg each, can be determined as:

$$Q_g = 2 \cdot 1000 = 2000\ kg\ . \tag{2}$$

Based on the calculated required load capacity of 2000 kg and the length of the beams of 2600 mm, the profile of the standard INP10 girder was chosen, with a load capacity of 2395 kg.

Selection of upright frame

The width of the vertical frame is influenced by the way the storage unit is placed and by the transport and handling equipment used. As the placement method is transverse, the width of the upright frame corresponds to the width of the pallet itself, which is 800 mm.

Taking into account the height of the available space, the required clearances, the height of the beams and the perforation step of the upright frame columns, the floor step can be calculated according to the following expression:

$$h = 1100 + 100 + 100 = 1300\ mm\ , \tag{3}$$

where the clearances between the pallets and the beams are 100 mm and the height of the pallet beams is 100 mm.

The column perforation step is 75 mm, and the minimum number of column perforations corresponding to the calculated step height is calculated according to the expression:

$$p = \frac{1300}{75} = 17.33\ . \tag{4}$$

The first higher integer value of the number of perforations, 18, is adopted, so the actual floor step is then:

$$h = 18 \cdot 75 = 1350\ mm\ . \tag{5}$$

The number of floors can be determined as:

$$p = \frac{9000}{1350} = 6.92\ , \tag{6}$$

where the height of the storage space is 9000 mm, and the floor step is 1350 mm.

The number of floors is adopted as the first smaller integer value, which is 6 floors, with the first one being on the ground, as shown in Figure 3. The height of the column is calculated according to the expression:

$$H = 1350 \cdot (6 - 1) + 150 = 6900\ mm\ . \tag{7}$$

The carrying capacity of the frame can be determined as:

$$Q = 5 \cdot 2 \cdot 1000 = 10000\ kg\ , \tag{8}$$

where the number of beams levels is 5, the number of pallets is 2 and the weight of the pallet is 1000 kg.

Based on the load capacity of the frame and the standard floor step, a standard ”C” profile 90 mm x 50 mm x 22.5 mm x 3 mm is adopted for the column of the upright frame and the load capacity of this profile is 15264 kg.

Dimensioning of the transverse beams is done in relation to the weight of the pallet. The selected cross-section of the standard rectangular tube beams is 50 mm x 30 mm x 1.5 mm with carrying capacity of 1400 kg.

The plan of the facility in which storage units is to be stored must be clearly defined in order to optimally arrange the equipment that will be used in it. Data about the building, on which the correct layout of the racks as well as of other supporting equipment depend on are the following:

- effective length, width and height of the space where the racks with other equipment will be placed,
- location of services in the warehouse, position of the supporting columns and their verticality, lighting, windows, doors, emergency exits and other installations,

- type and location of fire fighting equipment.

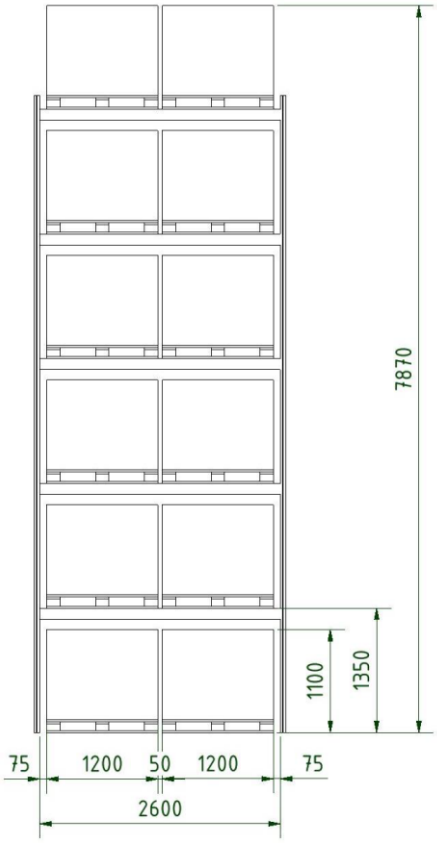


Figure 3 Floor layout in the rack section

The minimum effective width of the corridor, i.e. the required width of the passage between the storage units placed on the floor or on the opposite sides of the racks, is determined according to the recommendations given in [6], with detailed knowledge of:

- actual dimensions and turning radius of the forklift,
- actual dimensions of the pallet and the shape of the load on the pallet,
- positioning of the pallet on the forklift,
- working environment in the warehouse (fast or slow).

Selection of storage and retrieval equipment

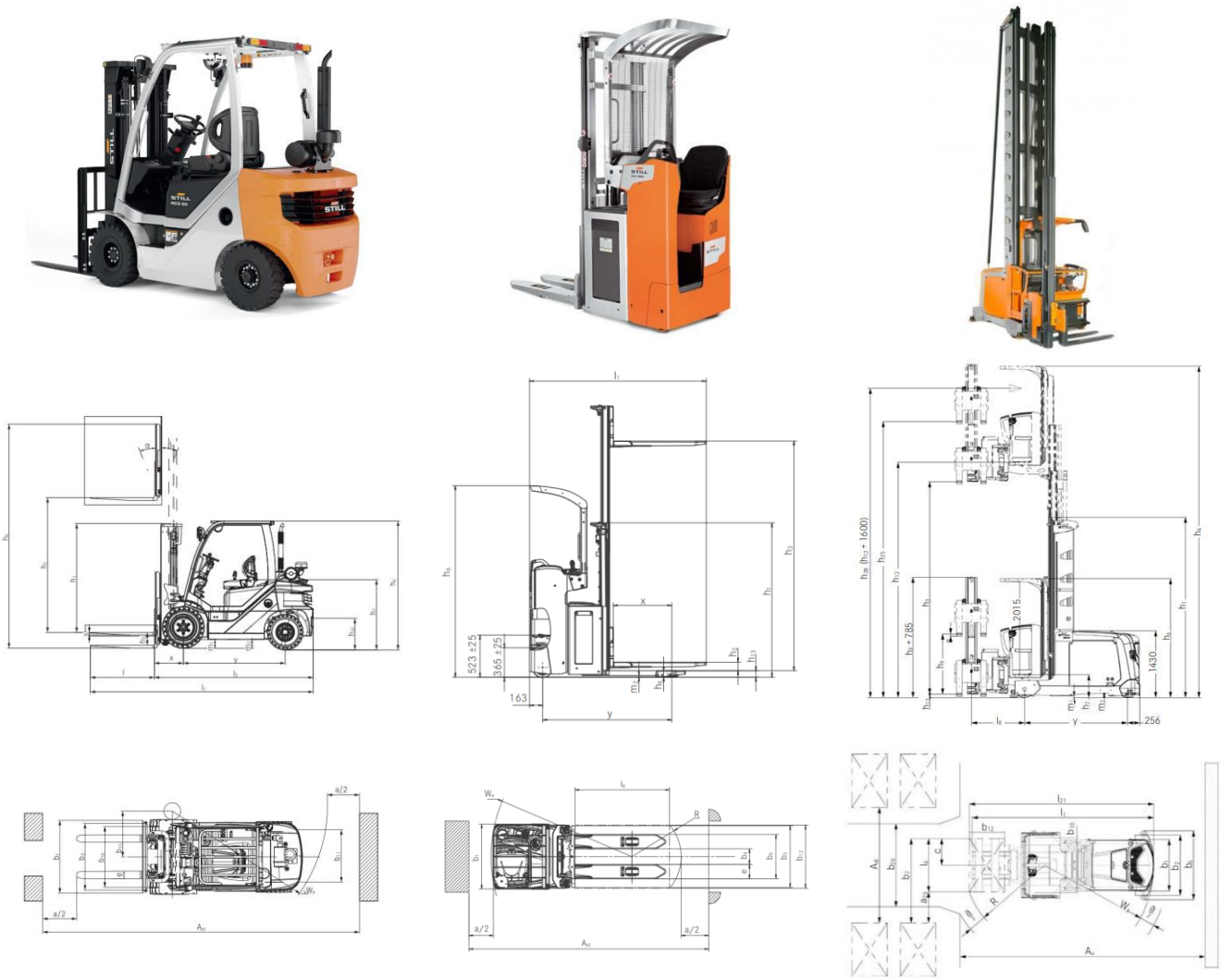
In addition to the load of the racking structure, the construction of the floor is also affected by the selected material handling equipment, also called storage and retrieval equipment. Data related to these machines, which significantly affect the solution of the storage system are: type and shape of the selected machine, structural data, control method, load distribution on the wheels, etc. [7].

In order to fulfil the investor's basic request to obtain as much capacity as possible in the available space, i.e. the largest possible amount of stored material, the selection of storage and retrieval machines also depends on the storage unit, the frequency of entry and exit of storage units into the rack storage, the orientation of the entry and exit zones, connections of rack storage with external transport.

Rack storages are most often served by forklifts, which represent the most developed form of storage and retrieval machines that, in addition to the ability to actively capture and store the storage units, also have the ability to stack the storage units by height. The following forklifts were selected for the analysis of the influence of the storage and retrieval machine on the storage space solution:

- standard forklift,
- reach truck,
- very narrow aisle truck.

Diesel and LPG standard forklift manufactured by STILL, shown in Figure 4 a) were selected [8].



a) b) c)

Figure 4 Selected storage and retrieval machines: a) standard forklift, b) reach truck c) very narrow aisle truck

The characteristics of the selected forklift, whose dimensions are shown in Figure 4 a), are:

- rated capacity/rated load: Q = 1500 kg,
- height of mast: h_1 = 2102 mm,
- free lift: h_2 = 1489 mm,
- lifting height: h_3 = 4350 mm,
- height of mast: h_4 = 5391 mm,
- aisle width for pallets 800 mm x 1200 mm lengthways: A_{st} = 3400 mm,
- lifting speed: v_1 = 0.7 m/s,
- driving speed: v_2 = 17 km/h.

Selected reach truck manufactured by STILL is shown in Figure 4 b). The characteristics of the selected forklift, whose dimensions are shown in Figure 4 b) are [8]:

- rated capacity/rated load: Q = 1600 kg,
- mast height with used free lift: h_1 = 2565 mm,
- free lift: h_2 = 2045 mm,
- lifting height: h_3 = 6216 mm,
- working aisle width for 800 mm x 1200 mm pallet lengthways: A_{st} = 2519 mm,
- driving speed: v = 10/12 km/h.

The very narrow aisle truck manufactured by STILL, which is shown in Figure 4 c), was selected. The characteristics of the selected forklift, whose dimensions are shown in Figure 4 c), are [8]:

- rated capacity/rated load: Q = 1250 kg,
- mast height with used free lift: h_1 = 5400 mm,
- free lift: h_2 = 4150 mm,
- lifting height: h_3 = 11550 mm,
- height, mast extended: h_4 = 14135 mm,

- working aisle width for 800 mm x 1200 mm pallet lengthways: A_{st} = 1875 mm,
- driving speed: v = 14 km/h.

ANALYSIS OF THE INFLUENCE OF THE CHOICE OF STORAGE AND RETRIEVAL MACHINES ON WAREHOUSE CAPACITY

The warehouse serviced by the forklift truck consists of the two single-row racks and the four double-row racks, as shown in Figure 5. The previous calculation showed that the warehouse of the adopted height and floor step can fit 6 floors, the first of which is on the ground. However, this is not possible in this type of the warehouse because the selected forklift truck does not have the ability to lift the load to the mentioned height. For this reason, this warehouse was designed with 4 floors or with three levels of beams.

As the pallets in this case are not stored on 6 but on 4 floors, it is necessary to recalculate the height of the column of the upright frame and select the profile again. According to equation (7), the minimum height of the column of the upright frame would be, in this case, 4200 mm and the profile 60 mm x 40 mm x 15 mm x 2 mm with load capacity of 6413 kg would be chosen for the column of the upright frame. When designing this warehouse, the width of the corridor between the racks should also be taken into account. In this case, it is 3400 mm because it is the minimum required space for forklift truck operation.

The capacity of the given warehouse is calculated as follows:

$$Q = 2 \cdot 100 \cdot 4 = 800 \ pallets \ , \tag{9}$$

where: the number of compartments on one level is 100, the number of pallets in one compartment is 2 and the number of floors is 4.

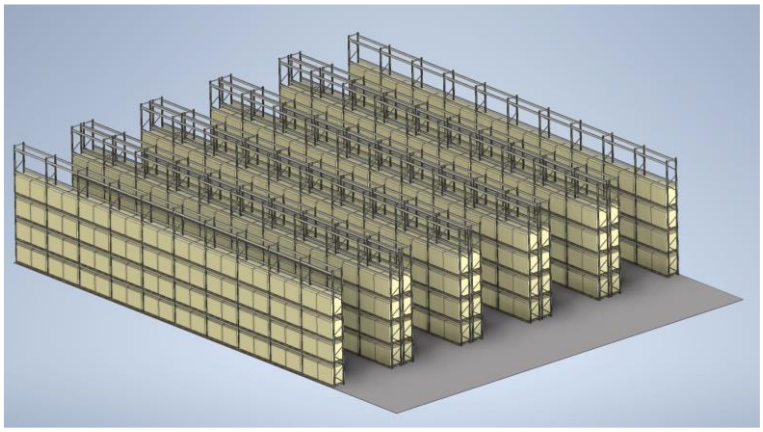


Figure 5 A warehouse serviced by standard forklift

Figure 6 shows the designed warehouse served by a reach truck.

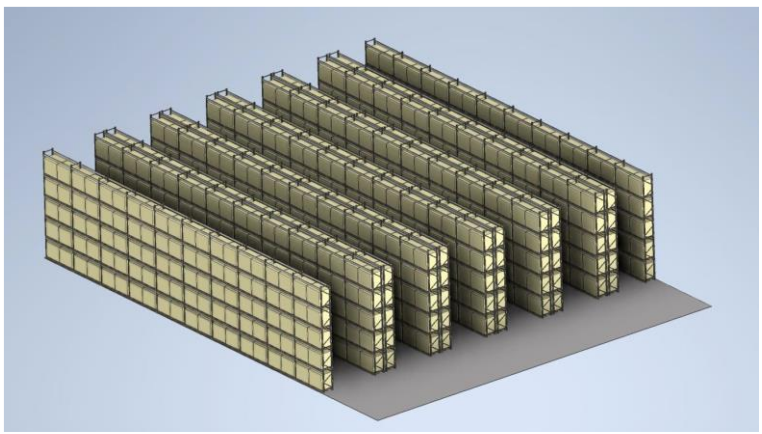


Figure 6 A warehouse serviced by a reach truck

The storage units or pallets in this warehouse are arranged on 7 racks, namely 2 single-row and 5 double-row racks. The total number of floors in this warehouse is 5, that is, the pallets are distributed on 4 levels of beams, because this is the only possible solution considering the lifting height of the selected rack forklift.

As the pallets in this case are not stored on 6 but on 5 floors, it is necessary to recalculate the height of the column of the upright frame and select the profile again. According to equation (7), the minimum height of the column of the vertical frame would be 5550 mm, and the profile 60 mm x 40 mm x 15 mm x 3 mm with load capacity of 9260 kg would be chosen for the column of the upright frame. For this type of forklift, a minimum corridor width of 2519 mm is necessary and this condition is fulfilled by the warehouse designed in this way.

The warehouse capacity is calculated as follows:

$$Q = 2 \cdot 120 \cdot 5 = 1200 \ pallets, \tag{10}$$

where the number of compartments on one level is 120, the number of pallets in one compartment is 2 and the number of floors is 5.

The last type of warehouse that has been designed is a warehouse that is served by a very narrow aisle truck. As shown in Figure 7, the warehouse consists of 2 single-row and 6 double-row racks.

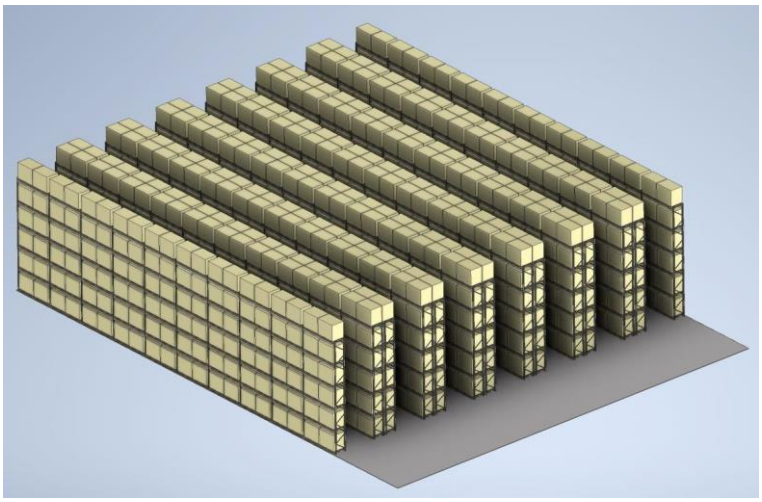


Figure 7 A warehouse serviced by a very narrow aisle truck

The selected very narrow aisle truck is the only one of these three types of selected forklifts that can meet the requirement regarding the lifting height obtained by the previous calculation. Hence, this warehouse is designed with a maximum of 6 floors of pallets, of which the first floor is on the ground. Also, another advantage of these forklifts is the smallest required width of the corridor for manipulation, so it is possible to place a larger number of racks in the warehouse of the selected dimensions, which directly affects the warehouse capacity.

The warehouse capacity is calculated as follows:

$$Q = 2 \cdot 140 \cdot 6 = 1680 \ pallets, \tag{11}$$

where the number of compartments on one level is 140, the number of pallets in one compartment is 2 and the number of floors is 6.

Table 1 shows the basic characteristics of the forklifts selected for analysis, which affect the design of the layout of the racks in the warehouse. It can be concluded that, in terms of lifting height and required width, the very narrow aisle truck is the most suitable for handling corridors, while in terms of carrying capacity, the most suitable is a standard forklift.

Table 1 Characteristics of the forklifts

Forklift type	Load capacity, kg	Lifting height, mm	Minimum stacking aisle width, mm
standard forklift	1500	4350	3400
reach truck	1400	6216	2519
very narrow aisle truck	1250	11550	1875

Figure 8 shows drawings of the conceptual solution of the arrangement of pallet racks.

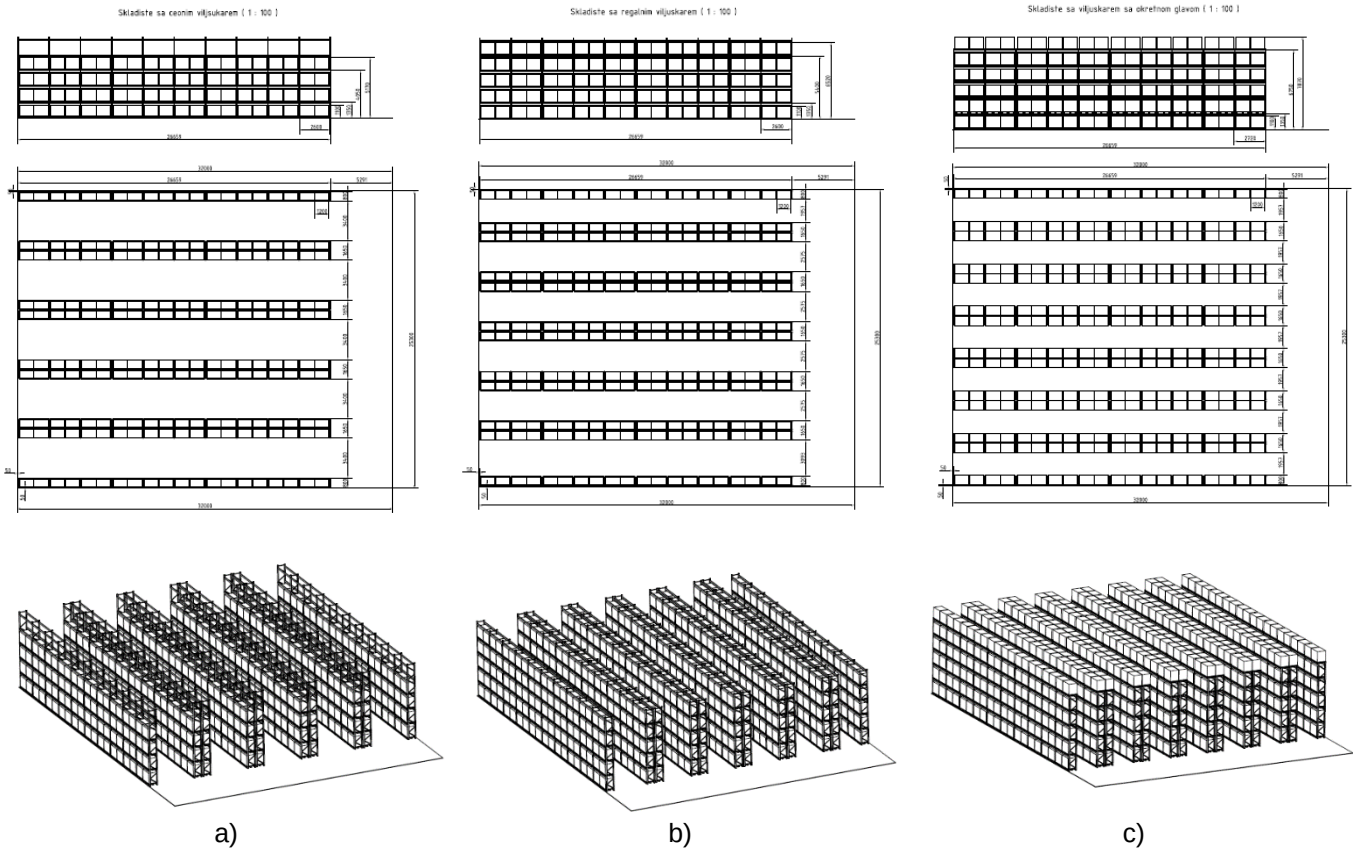


Figure 8 Drawings of the conceptual solution of the layout of pallet racks***:*** a) with standard forklift, b) with reach truck, c) with very narrow aisle truck

Table 2 shows the obtained data on the warehouses that were designed in this analysis.

Table 2 Characteristics of the designed warehouses

Material handling equipment	Number of floors	Number of compartments	Number of pallets in the compartment	Capacity (total number of pallets)
standard forklift	4	100	2	800
reach truck	5	120	2	1200
very narrow aisle truck	6	140	2	1680

From everything shown, it can be concluded that the very narrow aisle truck is a far better solution compared to the other two types of forklifts because the warehouse capacity served by this type of forklift is by far the largest.

CONCLUSIONS

Warehouse and storage technologies are developing at a high speed with the aim of easier, higher quality and more reliable storage of goods and products. By choosing the appropriate type of pallet racks and storage and retrieval machines, the optimal warehouse solution is chosen, while striving to achieve the highest level of efficiency with the lowest possible costs.

Forklifts are the most widespread storage and retrieval machines. Thanks to them, many production and transport processes are significantly facilitated and further improvement of the forklifts themselves and their adaptation to working conditions leads to even greater efficiency.

This paper shows the importance of choosing storage and retrieval machines and their impact on warehouse capacity. The significantly higher efficiency of the very narrow aisle truck, compared to the other two considered types of forklifts, was shown in terms of storage capacity. In case there is a need for a large warehouse capacity, a very narrow aisle truck is not the most cost-effective solution initially because the price of this forklift is slightly higher compared to the prices of the other two types, but, in the long run, this is definitely a more efficient solution.

When combining different layouts of pallet racks and selecting the different storage and retrieval machines in the observed area, the following basic principles should be observed [9-10]:

- racks should always be placed on the longer side of the intended storage space (this makes the corridors longer and fewer). In this way, transport routes are shortened, which increases the economic justification of the racks,
- placement of the racks in two different directions in the same area should be avoided, as this crosses transport routes and wastes a lot of space for manipulation,
- a single-row rack should be placed against the wall of the storage area,
- corridors should not be placed along the perimeter of the walls of the space.

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