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PROCEEDINGS

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Comparative analysis of applications of different storage systems

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Abstract *This paper examines the impact of choosing the different pallet racks and material handling devices on the storage system solution and transport capacity. Conceptual solutions were presented on the specific example of the proposed storage space and comparative analysis of the applications of different systems was performed with the goal of maximum utilization of storage space. Comparative analysis of the storage systems was performed according to the type of the racks and the storage and retrieval machines. The pallet racks used for comparison of the storage spaces are: classic pallet racks, double-deep pallet racks, mobile pallet racks, flow-through pallet racks, drive-in and drive-through pallet racks and push back pallet racks. The transport and handling equipment used to service the racks are standard forklift, reach truck and very narrow aisle truck. Warehouse capacity directly depends on the types of convenient storage and retrieval equipment. The entrance and exit are on the different sides on the same level of the intended storage space. For all the types of the warehouses, the layouts of the pallet racks are shown and the realized capacities are compared.*

Keywords *Storage and retrieval machines, warehouse, pallet rack*

1. INTRODUCTION

Modern production and distribution needs lead to intensive development of storage technology. Many existing storage systems very well fulfil the basic tasks of a warehouse - safe and efficient reception, storage and delivery of the largest possible quantity of goods, in the shortest possible time, within the smallest possible space and with as few workers as possible. However, each of the systems has its own advantages and disadvantages, so it is necessary to have a good knowledge about each of them in order to select the most suitable solution with the best characteristics.

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Structural design guidelines for all types of adjustable pallet racking systems (particularly for the self-sustaining warehouses, made of steel members that are subjected to seismic actions) can be found in special European standards and regulations [1]. The European Eurocode 3 standard offers clear definitions for steel structures connections and joints, which should be used in modern technical practice [2]. The comprehensive study of the racking structure and the analysis of each element can be achieved by using the determined structural properties and by following the procedures from the code [3] and standard [4].

Conventional steel frame structures with free standing rack configurations have been often used for building the warehouses. However, with the advancement of technology, the rack supported warehouses became very popular storage solution [5].

2. PALLET RACKS

Pallet racks make a system of mass storage of goods on pallets enabling the most efficient use of storage space and the smooth flow of transport and handling operations.
Pallet racking storage system consists of the three basic elements: racks, pallets, and forklifts or handling equipment. Each of them is selected based on materials being stored, the storage requirements, operating and positioning systems and the applied management [6].
Since racking structures represent a very simple and economical solution for storing goods in a warehouse, a large number of types of the warehouse racking systems were developed.
Spatial frame structure of the pallet racking system is made of the side frames and the horizontal beams, usually made of thin-walled cold-formed profiles, to make the pallet rack configuration. The rack stability in the cross-aisle direction is provided by the horizontal and vertical bracing system of frames. The beam-to-column connectors (as special parts) are welded to the beams or otherwise formed as an integral part of the beam. They have special devices like tabs, studs or hooks engaged in the perforations of the column. The stability of the rack in the direction of the corridor is ensured in this way, through the stiffness of the beam-to column connection.

2.1 Selective pallet racking systems

Selective pallet racking systems are the most common. They can accept a large number of different unit loads and allow direct access to the pallets. Their name implies that you can "select" a pallet without having to move other pallets out of the way, as shown in the Fig 1.

Fig. 1. Selective pallet racking systems

This is the simplest and the cheapest type of pallet racks and it can work with any type of forklifts, without the need for specialized material handling equipment. The elements of the rack structure are assembled, which allows easy change of the height of each level and adjustment according to the user requirements for optimal use of available space.
Very narrow aisle racking is a special case of selective racking with a minimum aisle width sufficient for straight-line passage of storage and retrieval machines. This type achieves very dense and space-efficient storage.
Double deep pallet racking is an upgrade the of standard selective racking, where each pallet shelf holds two rows of pallets instead of one. Storage capacity is increased, the number of access aisles has been reduced, but access to the pallets is slower, Fig 2.

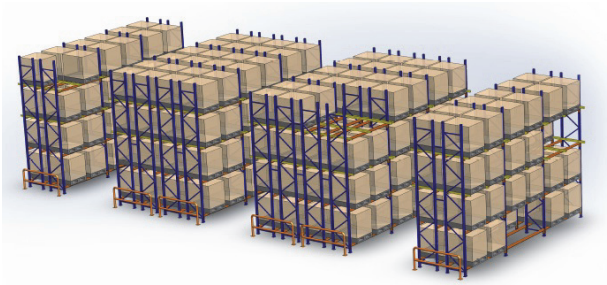


Fig. 2. Double deep pallet racking systems

The main disadvantage is the need for specialized forklifts or standard forklifts equipped with attachments for double-depth handling, which leads to the higher operating costs and the requirement for well-trained operators.

2.2 Mobile pallet racking systems

Mobile pallet racking systems are innovative storage solutions designed to maximize the storage capacity by eliminating the need for multiple static aisles, Fig 3.
The racking structure is assembled on a mobile base – a trolley, which moves on rails installed in the floor. The rails of the mobile racks are built into the floor, which allows for unhindered movement of forklifts. In this type of racking, there is only one aisle for pallet manipulation. By automatically opening the passage, the place intended for servicing is accessible. They are used in cases where the flow rate of stored goods is not primary.

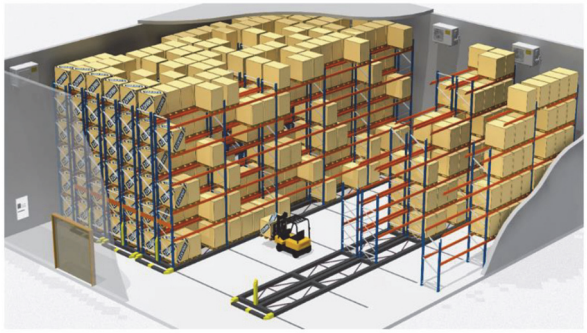


Fig. 3. Mobile pallet racking systems

2.3 Drive-in and drive-through racking systems

The basic principle of this storage system is to store the pallets, one after another, on the long rails supported by cantilever carriers on the rack columns. The goods are stored with regular front forklift that enters the rack tunnel. The system is efficient and achieves maximum utilization of storage space because there are no additional aisles and, therefore, no unused space, Fig 4.

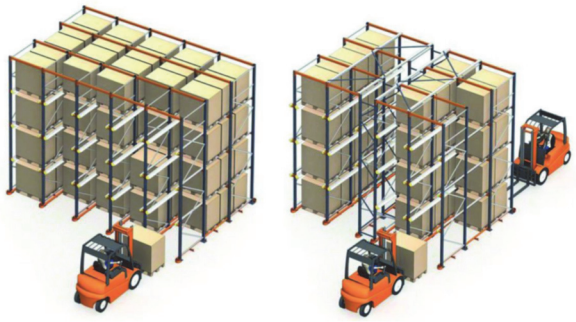


Fig. 4. Drive-in and drive-through racking systems

There are two possible ways to implement this racking system. The first is the Drive-In Rack, which is a rack system where access to the pallets is only possible from one side. It uses the FILO principle ("First In Last Out" – the pallet that is stored first is the last to leave the tunnel). The second type is the Drive-Through Rack system where the forklift can pass through the tunnel if there are no pallets in it, which corresponds to the FIFO system ("First In First Out" – the first pallet that enters the rack is the first to leave) [7].

2.4 Pallet flow racking system

Pallet flow racking system is a pallet storage method that uses gravity and wheels or rollers, to transfer and store the pallets in a storage module, Fig 5. The movement of the pallets can be achieved in two basic ways: by gravitational force and by a special (driving) force. The storage unit moves due to gravitational force on the rollers placed at a certain slope, which ranges from 3% to 5%. When the tunnel is not inclined or the slope is too small to propel the unit, pneumatic, electric or hydraulic roller drives can be used.

Fig. 5. Pallet flow racking system

Tracking of goods is simple, based on the FIFO principle, and the storage space is well utilized and filled.

3. DESIGNING LAYOUT OF PALLET RACKS

Conceptual solutions for pallet racking storage are obtained based on the following data:

Warehouse type:
- pallet racking warehouse.

Warehouse dimensions:
- length, L=50000 mm,
- width, B=47500 mm,
- width, H=13000 mm.

The storage unit is a EURO pallet with dimensions:
- length, a=1200 mm,
- width, b=800 mm,
- height, h=1200 mm,
- load capacity, m=1000 kg.

Transport and handling equipment:
- front forklifts,
- rack forklifts.

Method of loading the storage unit:

- transversely,
- longitudinally.

Selection of the rack elements:

- length of the storage unit beam, Lg=2600 mm.
- pallet cross beams:
  - cross section, 50 mm × 30 mm × 1,5 mm.
  - load capacity, Q=1400 kg.
- floor pitch, h=1500 mm.

The working aisle dimensions between each rack and the rack's height depend on the characteristics of the forklift trucks, lifting devices, dimensions of the external structure and specific needs [8 - 10].
Selective (classic) racks served by the front forklifts require larger passage between the racks and larger width of the manipulative passage, about 3500 mm.
The rack layout is divided into two blocks, due to the existence of an input-output zone. Single-row racks are installed in four rows, with a frame depths of 800 mm and a bay widths of 2600 mm with two pallets inserted crosswise in each bay.
Double-row racks are arranged in six rows with a rack spacing of 300 mm. Due to the entrance into the storage area, shorter racks are arranged on the one side. The width of the aisle for servicing the racks is 4375 mm.
Figure 6 shows the layout of classic racks served by the front forklift.
If the first floor is located on the ground, three rows of storage unit supports will be installed, which makes a total of four floors.
Rack features are:

- cross-loading – installation of cross beams,
- two pallets in a row,
- corridor width of 4375 mm,
- the first floor is located on the ground, a total of four floors,
- floor pitch of 1500 mm,
- storage capacity of 2480 pallets.

By using a racking forklift with a swivel head, the storage space capacity is increased. This type of forklift requires a smaller aisle width between the racks (around 1600 mm), while the maximum pallet lifting height is 10750 mm.

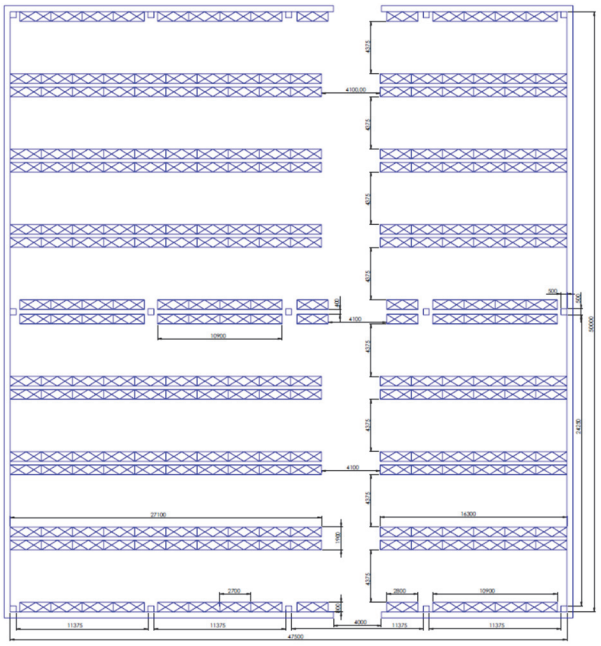


Fig. 6. Classic racks served by the front forklifts

Since the rack aisles are now significantly narrower than in the previous solution, it is possible to install a larger number of racks in the same space. Single-row racks are installed in four rows, as in the first solution, while the number of double-row racks has increased to 12 rows. Two pallets will be stored in a 2600 mm wide bin.
The racks are divided into two blocks, due to the position of the input-output zone. The width of the corridor between the racks is 1700 mm. For the adopted floor pitch of 1500 mm, with using the aforementioned forklift, a total of seven floors can be accommodated. The first floor will be located on the ground, while the other six floors will be placed on the supports of the storage unit.
Figure 7 shows the conceptual solution for the arrangement of classic racks served by a rack forklift with a swivel head.
Rack features are:

- cross-loading – installation of cross beams,
- two pallets in a row,
- corridor width of 1700 mm,
- the first floor is located on the ground, seven floors in total,
- floor pitch of 1500 mm,
- capacity of 6160 pallets.

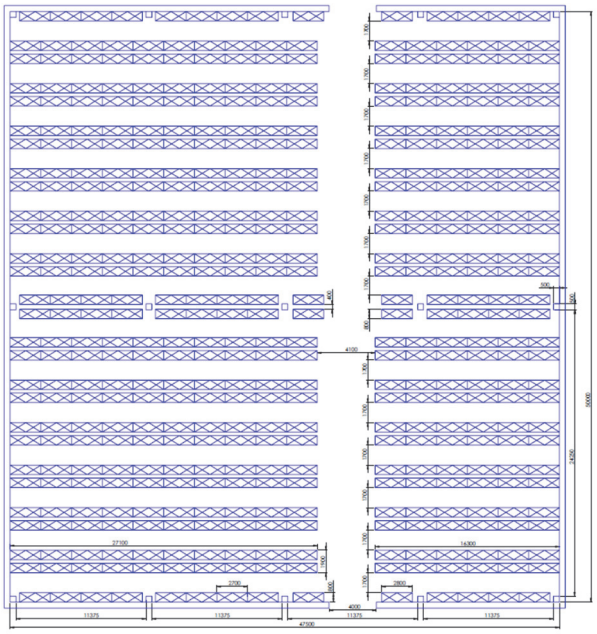


Fig. 7. Classic racks served by the rack forklifts with a swivel heads

By the use of forklifts with telescopic forks, the width of the aisles between the racks is further reduced, which allows for the installation of additional rows of racks in the warehouse.
This type of forklifts has a lifting height of 10230 mm and requires a minimum aisle width of 1200 mm. The racks are placed on the left side and the right side of the entrance of the warehouse. The single-row racks are placed in four rows on both sides, with a frame depth of 800 mm and a width of 2600 mm. The number of double-row racks is increased to 14 rows, with spacing between the racks of 300 mm and the aisle width of 1200 mm. For the adopted floor pitch of 1500 mm, by using the aforementioned forklift, a total of seven floors are achieved in the warehouse space.
Figure 8 shows the layout of classic racks served by a rack forklift with telescopic forks.
Rack features are:

- cross-loading – installation of cross beams,
- two pallets in a row,
- corridor width of 1200 mm,
- the first floor is located on the ground, seven floors in total,
- floor pitch of 1500 mm,
- capacity of 7112 pallets.

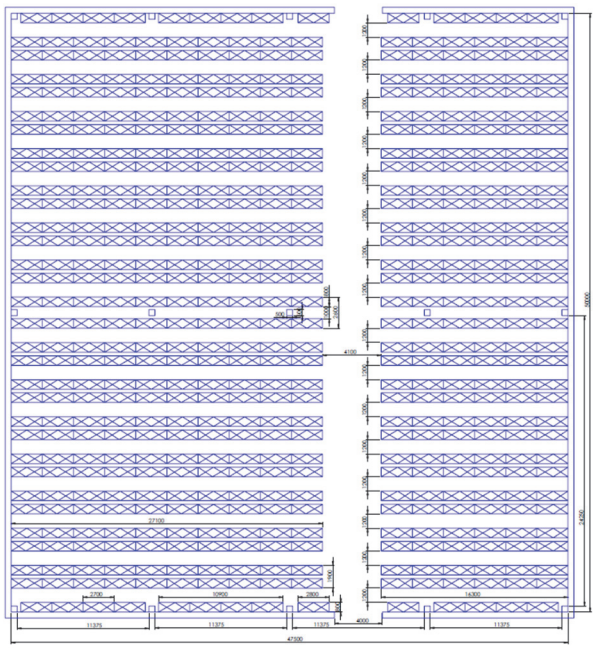


Fig. 8. Classic racks served by the forklift trucks with telescopic forks

Double-deep racks are designed to be serviced by the rack forklifts with telescopic forks that extend forward in order to reach the second in depth pallet into the rack.
By using this type of the forklift, the minimum required aisle width between the racks is 3190 mm, while the lifting height is 10500 mm. The racks are placed in two blocks, due to the entrance and exit from the storage space.
For the defined aisle width between the racks of 4150 mm, it is possible to accommodate 24 rows of double-deep racks on both sides. The depth of the racks is 800 mm, the width of the aisle is 2600 mm, with transverse pallet insertion.
Figure 9 shows the arrangement of the double-deep racks in the storage area.
Rack features are:

- cross-loading – installation of cross beams,
- two pallets in a row,
- corridor width of 4150 mm,
- the first floor is located on the ground, six floors in total,
- floor pitch of 1500 mm,
- capacity of 4608 pallets.

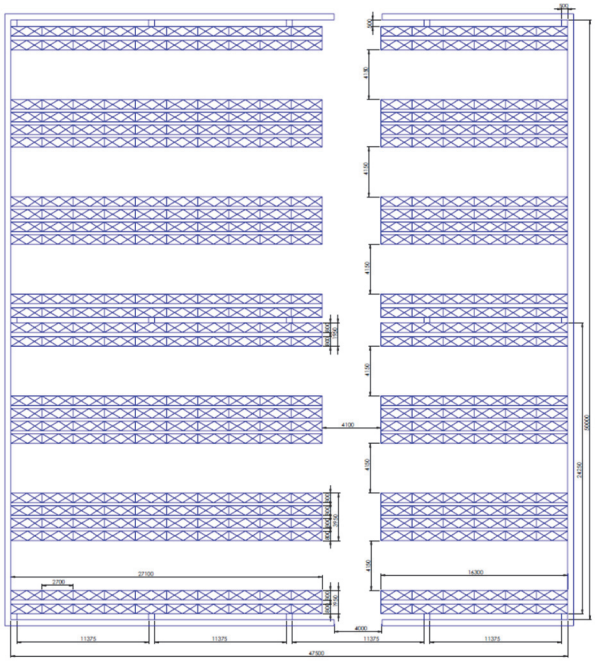


Fig. 9. Double-deep racks served by the forklifts with telescopic forks

Mobile racks are serviced, as a rule, by the front-end forklifts. These forklifts require large aisle and handling space width of 3500 mm and reach the maximum lifting height of 5890 mm. Mobile racks are placed in four blocks, due to the columns located in the middle of the storage space. One row of racks is placed against the walls of the warehouse, towards which the other racks will move. Two racks are moved at a time, in order to achieve the servicing of the two rows of racks from one aisle, 3650 mm wide. The depth of the mobile rack frame is 800 mm, and the width of the aisle is 2600 mm. In this type of racking structure, the first row of storage unit supports is placed 200 mm above the floor. The floor pitch is 1500 mm and the total number of floors is four.

Figure 10 shows the conceptual solution for mobile racks served by the front-end forklifts.

Rack features are:

- cross-loading – installation of cross beams,
- two pallets in a row,
- corridor width of 3650 mm,
- the first floor not on the ground, four floors in total,
- floor pitch of 1500 mm,
- capacity of 7350 pallets.

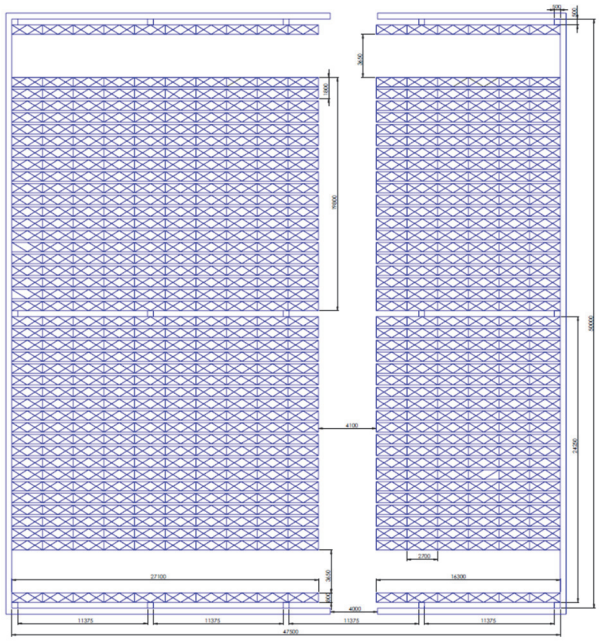


Fig. 10. Mobile racks served by the front-end forklift

The drive-through racks are serviced by the rack forklifts with the triplex mast. This type of forklifts has the lifting height of 11000 mm and requires the minimum aisle width of 2890 mm between the racks. The solution differs from the other types of racking design, because the pallet is stored on support rails that are laterally placed on the rack columns. The racks themselves are placed on both sides of the input-output zone. On the one side, 19 tunnels are placed in four blocks, while on the other side, 11 tunnels are placed, each 1450 mm wide. It is possible to store 11 pallets per depth. Seven floors with 7920 pallet places were adopted.

Figure 11 shows the layout of the drive-through racks.

Rack features are:

- cross-row storage,
- aisle width of 3600 mm,
- total of seven floors,
- floor pitch of 1500 mm,
- capacity of 7920 pallets.

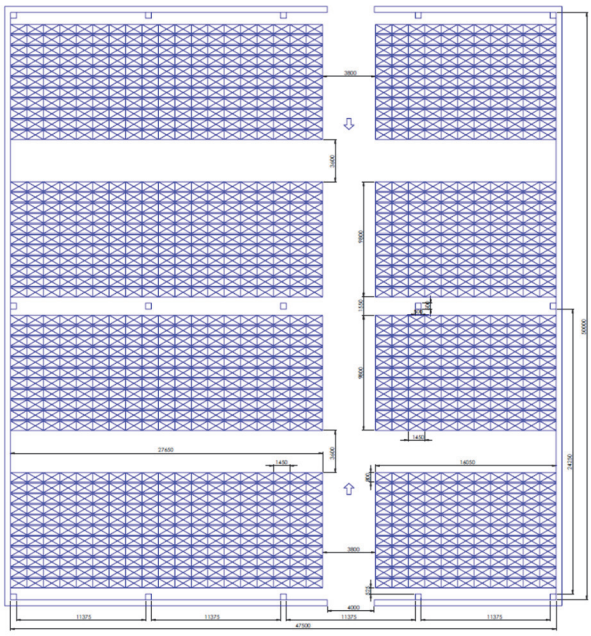


Fig. 11. Drive-through racks served by the rack forklift with triplex mast

The flow-through racks are serviced by the triplex mast forklifts. This type of racking has a roller track in its design, along which the pallets move during loading. Pallet movement is achieved by gravity force and the rack tunnel has a 3% slope.

The tunnels were installed in four blocks, because of the entrance and the exit of the storage space. On the one side, 13 tunnels were installed with two pallets in each tunnel, while on the other side, eight tunnels were installed with two pallets in each tunnel. In flow racks, pallet loading is longitudinal, so the width of the tunnel with two pallets is 2000 mm, and the length of the track is 16250 mm.

The FIFO system was applied, so the corridors were installed on the both sides of the racks, each being 4000 mm wide. The warehouse has six floors with 6552 pallet spaces.

The conceptual solution of the flow-through rack system is shown in Fig 12.

Rack features are:

- longitudinal stacking,
- two pallets in a tunnel,
- track length of 16250 mm,
- corridor width of 4000 mm,
- total of six floors,
- floor pitch of 1500 mm,
- capacity of 6552 pallets.

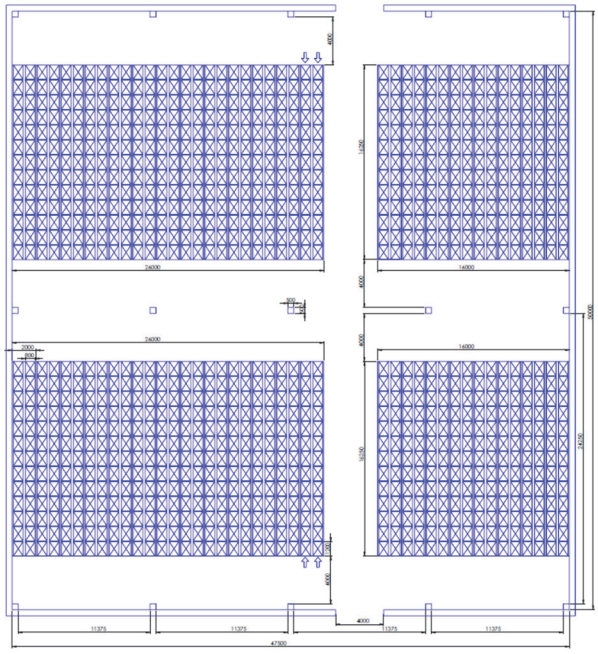


Fig. 12. Flow-through racks serviced by the rack forklift with the triplex mast

4. COMPARATIVE ANALYSIS OF PALLET STORAGE SYSTEMS

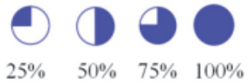
Comparative analysis shows how to achieve maximum storage space utilization by using the different types of racks and transport and handling equipment. Table 1 shows the comparative characteristics of the observed storage systems.

Table 1. Storage systems comparison table

	A			B	
	Selective pallet racks			B1	B2
	A1	A2	A3		
Cargo type	pallet	pallet	pallet	pallet	pallet
Space utilization	◑	◑	●	◑	◑
Vertical utilization of space	◑	◑	◑	◕	◕
Pallet availability	●	◑	●	◔	◔
Storage of various goods	●	◕	◕	◑	◑
FIFO/FILO principle	FIFO	FILO	FIFO	FILO	FIFO
Initial investment	◔	◔	●	◑	●

Legend:

- A - Direct pallet access racking solution
  - A1 - Selective pallet racks
  - A2 – Double-deep
  - A3 – Mobile
- B - Deep pallet racking solution
  - B1 - Drive-through racking
  - B2 – Flow racking
  - A3 – Mobile
- FIFO principle ("First in First Out")
- FILO principle ("First in Last Out")



In terms of the choice of transport and handling equipment, the best capacity is achieved by using the rack forklifts. By using these forklifts, the capacity of storage units is more than 50% higher than when working with a regular front-end forklift. From the economic point of view, the rack forklifts are more expensive than the front-end forklifts. Also, since the rack forklifts are used for servicing inside the storage space, the front-end forklift is still required to deliver pallets to the storage space and outside the rack aisle, which affects additional investment costs.

Depending on the type of the racking construction, maximum utilization of the storage space is achieved by using the drive-through racks served by the triplex mast forklifts, up to 7920 storage units. Drive-through racks do not require large initial investments in the construction itself.

The mobile racks require large initial investment, but, due to the space used, they are generally more financially viable. They are served by front-end forklifts and they can store as many as 7350 pallets.

The flow racks require large initial investment. By using the same forklift as for the drive-through racks, they can store 6552 storage units in the same storage space.

By using the classic racks, it is possible to achieve maximum utilization of the storage space, depending on the application of the transport and handling equipment. With serving with the front-end forklift truck, they achieve the capacity of 2480 pallets, while by using the rack forklifts with the swivel head and telescopic forks, the capacity increases to 6160 and 7112 pallets, respectively. The classic racks do not require large initial investments.

Attention should also be paid to the accessibility of the storage unit itself and one should strive to ensure that each unit with different type of goods is directly accessible, in order to reduce the time it takes to retrieve the pallet from the rack. With double-deep racks, it is not possible to access every pallet, so it is necessary to define a priority during storage. By using the drive-through and the flow racks, the same type of goods can be stored in one rack aisle. Selective and mobile racks provide access to every pallet, because it is inserted and retrieved from the same place.

The FIFO principle is the principle according to which the first pallet to be stored is the first to be removed from the rack. The main advantage is that the goods are taken in order, which is very important for perishable goods. The FILO principle is the principle where the first pallet to be stored is the last to be removed. The major disadvantage of this method of storage is that there is a possibility of the goods expiring.

5. CONCLUSION

The need to store as much goods as possible in as little storage space as possible is the result of vertical storage. Vertical storage allows for the availability of goods at all times. Depending on the type of goods being stored, the selection of the pallet racks and their elements, as well as transport and handling equipment, is made.

Based on the investor's requirements, a conceptual solution for the storage space is designed, which achieves a high level of efficiency with the lowest possible costs. During the design, it is necessary to adequately define the following conditions: storage space, storage unit and transport and handling equipment.

As part of the analysis of the storage systems, the comparison of conceptual solutions for storage space was carried out using different types of the racking structures served by the specific transport and handling equipment, according to the requirements of the already defined facility.

The following principles should be taken into account when comparing the features of the combinations of the different pallet rack layouts and selection of the different storage and retrieval machines in the observed area [11]:

- In order to make the storage corridors longer and less numerous, the racks should be placed along the longer side of the observed storage space. Thus, the transport

routes will be shortened, increasing the economic justification of the racks.
- Placement of the racks in the two different directions in the same area should be avoided, because the transport routes can cross and a lot of space is needed for manipulation.
- The single-row rack should be placed against the wall of the storage.
- Corridors should not be placed along the perimeter of the walls of the storage.

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