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INDUSTRIAL PLANTS

Chapter ten:

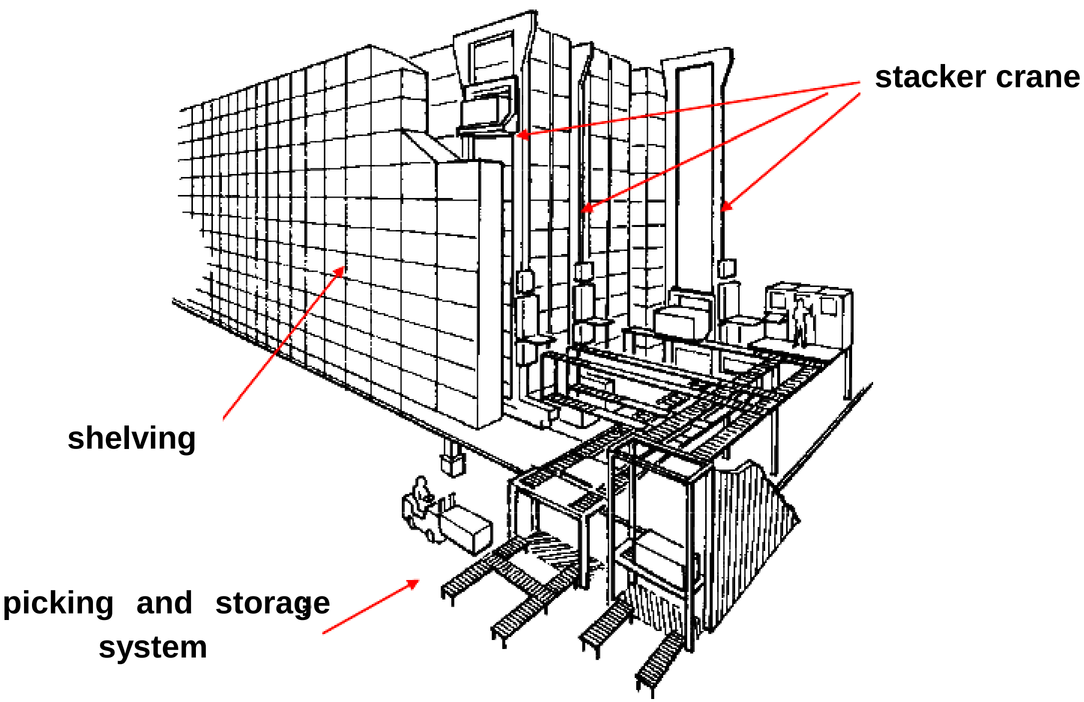
Industrial warehouses – second part

DOUBLE DEGREE MASTER IN
“PRODUCTION ENGINEERING AND MANAGEMENT”

SEAT OF PORDENONE
UNIVERSITY OF TRIESTE

Automated warehouses

The variety of solutions is large, but basically consist of shelving between which it moves an automatic stacker crane. It performs operations the picking and storage based on the demands of a computer system.

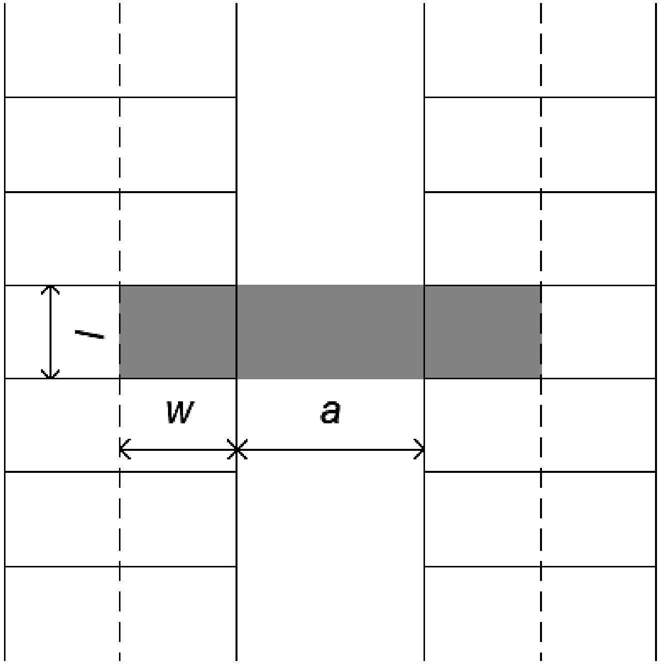


Automated warehouses

Utilization superficial

It defines **module unitary** the smallest element which, replicated, allows to obtain the entire storage area of the warehouse.
The surface of the module unitary is equal to:

$$(a + 2 \cdot w) \cdot l$$



Utilization superficial

For each type of warehouse seen, one can calculate the number of UdC that can be stored per module and hence the number of UdC for m^2 (pallets/m^2). Given the receptive request potentiality, you can then size the operational area of storage required for that type of warehouse.

Utilization superficial

Consider the possibilities of the various warehouses:

a) **warehouse to shelves double-sided with forklift retractile trucks**

Project data:

- size of UdC: 800 mm x 1200 mm x 1200 mm
- size of spot-pallets: 900 mm x 1250 mm x 1400 mm
- width of the corridor: 3,00 m
- maximum height of the outlet of the forks: 6500 mm

Dimensions of the module unitary in plan: 0,90x(1,25x2+3,00) = 4,95 m^2

Number of storage levels:

$$\mathrm{int}\left[\frac{6{,}50}{1{,}40}\right]+1=4+1=5$$

Total height of the shelving: 1,40 x 4 + 1,20 = 6,80 m

Number of pallets per module: 10

Utilization superficial UtS:

$$UtS=\frac{10\ \ pallets/\mathrm{mod}\,ule}{4{,}95\ \ m^2/\mathrm{mod}\,ule}=2{,}02\ \ pallets/\mathrm{mod}\,ule$$

Utilization superficial

Consider the possibilities of the various warehouses:

b) warehouse to shelves double-sided with turret trucks

Project data:

- size of UdC: 800 mm x 1200 mm x 1200 mm
- size of spot-pallets: 900 mm x 1250 mm x 1400 mm
- width of the corridor: 1,80 m
- maximum height of the outlet of the forks: 11700 mm

Dimensions of the module unitary in plan: 0,90x(1,25x2+1,80)=3,87 m^2

Number of storage levels:

$$\mathrm{int}\left[\frac{11{,}70}{1{,}40}\right]+1=8+1=9$$

Total height of the shelving: 1,40 x 8 + 1,20 = 12,40 m

Number of pallets per module: 18

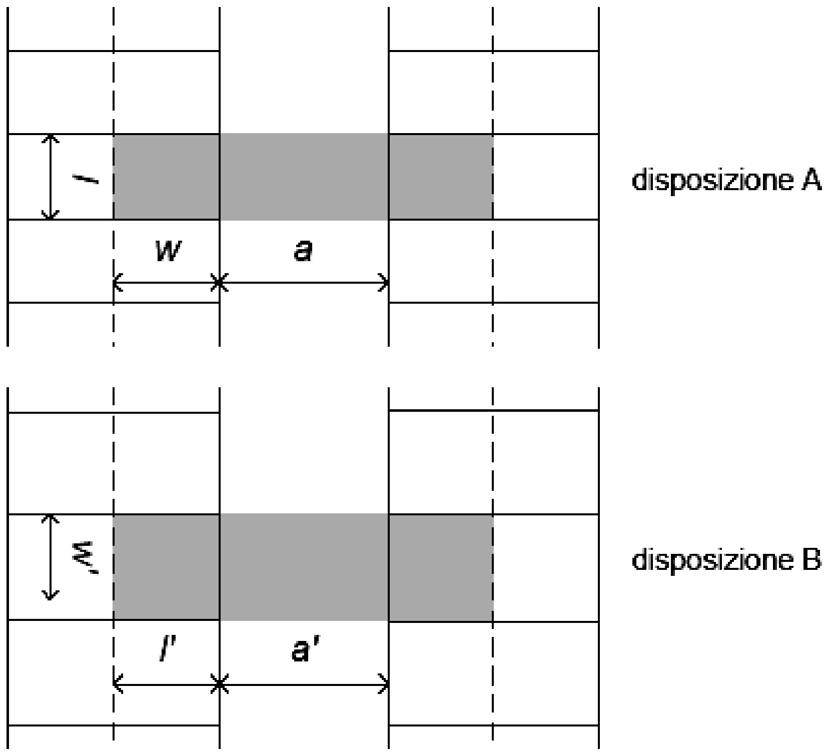
Utilization superficial UtS:

$$UtS=\frac{18\ \ pallets\ /\,\mathrm{mod}\,ule}{3{,}87\ \ m^2\ /\,\mathrm{mod}\,ule}=4{,}65\ \ pallets\ /\,\mathrm{mod}\,ule$$

Consider the possibilities of the various warehouses:

b) warehouse to shelves double-sided with turret trucks

Disposition of the units of loads: an evaluation if you have to do is arrange the model A (short side of the pallet in front) of the UdC or model B (long side of the pallet in front)



Utilization superficial

Consider the possibilities of the various warehouses:

c) warehouse served as turret trucks

Project data:

- plan dimensions of the UdC: 800 mm x 1200 mm
- width of the corridor: 1,70 m
- free of 100 mm per side orthogonal to the current and 50 mm per side parallel to the corridor

Dimensions of the module unitary in plan:

SMOD(A) = 0,90 x (1,30 x 2 + 1,70) = 3,87 m^2

SMOD(B) = 1,30 x (0,90 x 2 + 1,70) = 4,55 m^2

There is an increase of 14% passing from A to B.

Utilization superficial

Consider the possibilities of the various warehouses:

d) warehouse to shelves double-sided with forklift retractile truck

Project data:

- plan dimensions of the UdC: 800 mm x 1200 mm
- width of the corridor: 3,00 m (A) – 2,60 mm (B)
- free of 100 mm per side orthogonal to the current and 50 mm per side parallel to the corridor

Dimensions of the module unitary in plan:

SMOD(A) = 1,00 x (1,30 x 2 + 3,00) = 5,60 m^2

SMOD(B) = 1,40 x (0,90 x 2 + 2,60) = 6,16 m^2

There is an increase of 14% passing from A to B.

Performance indices

The **performance indices of a warehouse** are:

a) index of rotation (IR)

Is defined for any product i-th from ratio of the flow output and the average storage of the product i-th:

$$\underset{\forall\ product\ i}{IR_i} = \frac{(flow\ output)_i}{(average\ storage)_i}$$

represents the number of times that, in the time interval considered, stocks rotate at a warehouse.

Example:

if the interval is the solar year and the resulting index is 12, meaning that the warehouse, for the article in question, *is renewed* 12 times a year (in practice it is the presence of a average stock of a one month).

As lowest is IR, the greater the residence time in the warehouse and, consequently, the cost of its maintenance in stock.

Performance indices

The **performance indices of a warehouse** are:

a) index of rotation (IR)

Can be calculated on the number of pieces (*in quantity*) by item or homogeneous products.

Can be calculated *at value* for non-homogeneous products.

Example:

are unit of the product i-th sold during the year: 40,000 and an average stock of product i-th year: 5,000, we then have an index of rotation:

$$IR_i = \frac{40.000}{5.000} = 8$$

Performance indices

The **performance indices of a warehouse** are:

b) index of handling (IM)

With reference to a product i-th and to a period of time T, $(IM)_{i,T}$ is equal to the number of UdC of type i-th handled in the period T.

The index of handling corresponds to the number of withdrawals which can otherwise be of interest also UdC not complete (for picking operations).

Since the calculation shall take account of any filming of the same UdC within the warehouse, it may not coincide with the outlet flow of the products;

Performance indices

The **performance indices of a warehouse** are:

c) index of access (IA)

$$\underset{\forall\ product\ i}{IA_i} = \frac{(IM)_i}{(number\ of\ dedicated\ cells)_i} \quad \left(\frac{access}{time \cdot cells}\right)$$

Corresponds to the *average number of accesses to a single compartment* in a fixed period of time.

Is proportional to the probability that a generic access is reported to the compartment considered.

is numerically equal to IR only in the case where IRi a storage system provides only movements of UdC whole and that the dedicated cells are equal to the average stock of the product considered.

Performance indices

The figure shows, for the different types of warehouses, the index of access and the selectivity of the same.

Index of access \ Selectivity	Low	High
High	- live storage - stack - drive-in	- automated
Low	- movable shelves	- shelves served by forklift

Performance indices

When they have been defined the receptive potentiality and the potentiality for handling, remains defined, with the same operational management, an index of access IA ideal: it is able to saturate the two potentialities at the same time.

If:

- the allocation of UdC of uniform size is random;
- the potential for handling = 120 pallets/h;
- the potential receptive = 13.500 pallets;
- the warehouse operates on 2 shifts/day for 20 days/month;

we have:

$$IA_{ideal} = \frac{120 \cdot 16}{13.500} = 0{,}124 \ \frac{1}{days} = 2{,}84 \ \frac{1}{mounths} = 34{,}1 \ \frac{1}{years}$$

Performance indices

Fix the potentialities receptive and of handling, the system is able to guarantee 34 rotations/year.

If the stored products had a higher average rotation (for example, 36 rotations/year), the system may ensure the rotation of:

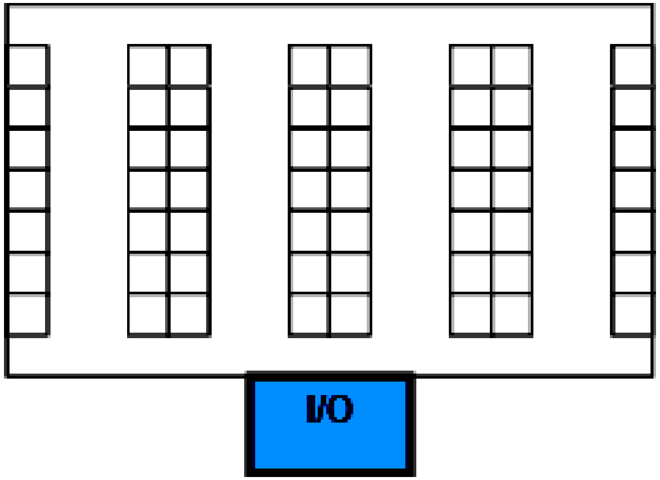
$$\frac{120 \cdot 16 \cdot 20 \cdot 12}{36} = 12.800 \ \ locations \ \ of \ \ pallet \, / \, year$$

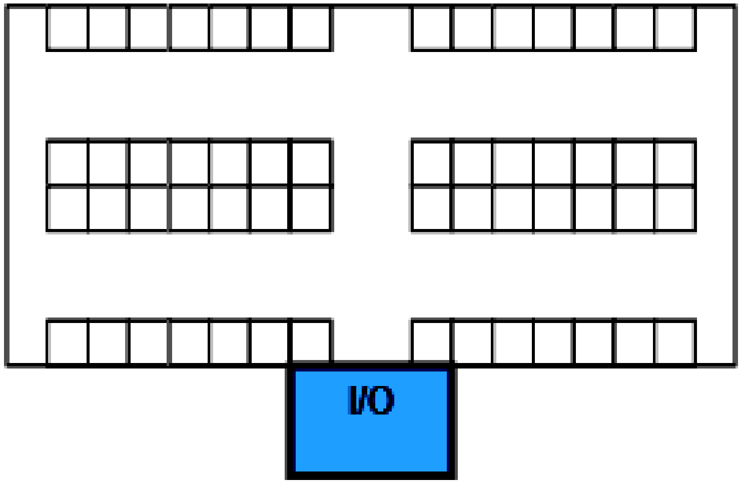
The products can saturate therefore the potentiality of handling of the system before of that receptive.

The optimum layout for traditional warehouses

We consider two types of layout:

- **longitudinally**, with the corridors that serving the shelves arranged perpendicularly to the front of the store;
- **transverse**, with the corridors arranged parallel to the area for loading/unloading of the warehouse.





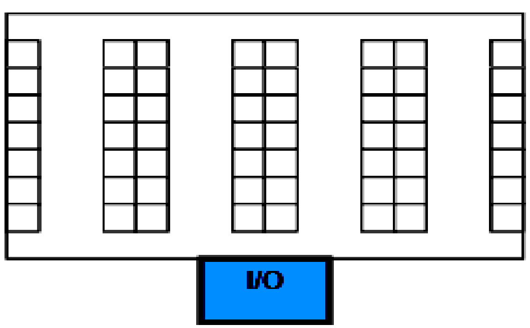
The optimum layout for traditional warehouses

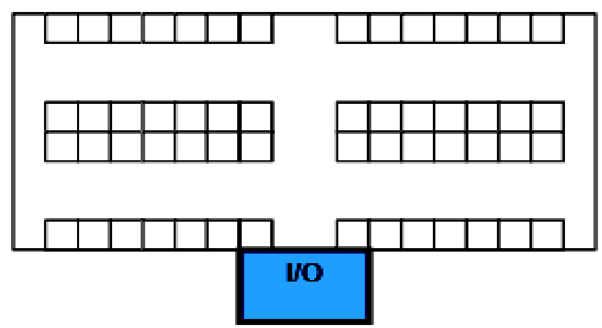
In the first case, the trolleys have a greater variety of routes, thereby preventing the forced passage through the central corridor and possible problems of traffic congestion when many trolleys operate simultaneously.

In the second case, at equal of UdC contained is better exploited most of the available area (assumed a rectangular shape) as it does not provide for connecting corridors along the longer side.

The two types of layout are basically equivalent: the choice is made by analyzing which of the two best fits the size constraints of the building.

If you do not consider any dimensional constraint, the optimal geometry is one that reduces the mileage of the trolleys waiting for the handling of UdC.





The optimum layout for traditional warehouses

We make the following assumptions:

- the warehouse is at rectangular plant, with opposite U and depth V, of surface $A = U \cdot V$;
- the point of input/output of the loading unit is positioned centrally on the front of the store;
- there is **equiprobability** access to rooms;
- the UdC is handled by **simple cycles** (for each entry or levy are entered all the necessary maneuvers, there are no **cycles combined** with injection and withdrawal).

Both r is the **distance expected** for each UdC corresponding to two simple cycles (sum of two round trips and two return trips).

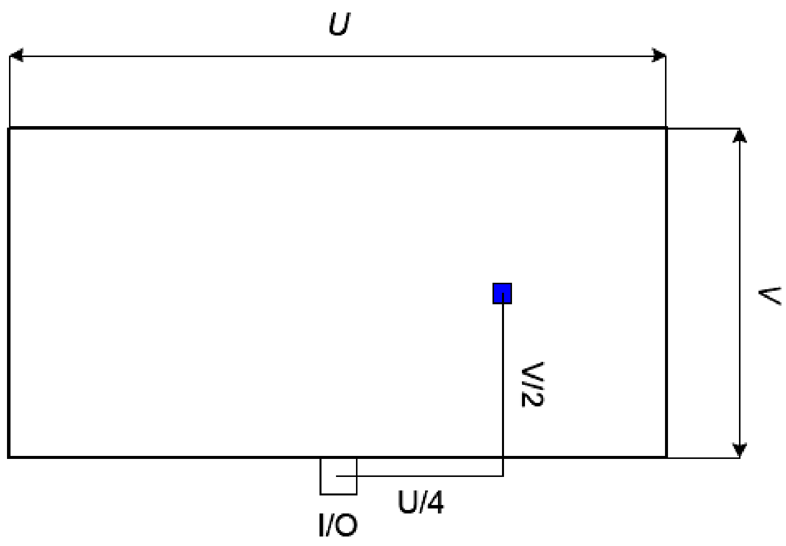
The **average total path** is the sum of the path along the front of the warehouse to enter the corridor and the desired location along the corridor to access the compartment (longitudinal layout).

The optimum layout for traditional warehouses

The hypothesis of equiprobability of access to the compartments (uniform distribution of probability of access) simplifies the calculation: the average value of the path, in both cases, is the **arithmetic mean between the maximum path and minimum path**.

The path segment from the trolley along the front of the warehouse with an average U/4, while the path segment perpendicular to the front of the warehouse is on average V/2. You get:

$$r = 4 \cdot \left(\frac{U}{4} + \frac{V}{2} \right) = U + 2 \cdot V$$



The optimum layout for traditional warehouses

and being A = U · V we have:

$$r = U + 2 \cdot \left(\frac{A}{U} \right)$$

The estimated distance is minimized (in the same area occupied) if:

$$\frac{dr}{dU} = 0 \qquad \rightarrow \qquad 1 - \frac{2 \cdot A}{U^2} = 0 \qquad \rightarrow \qquad U = \sqrt{2 \cdot A}$$

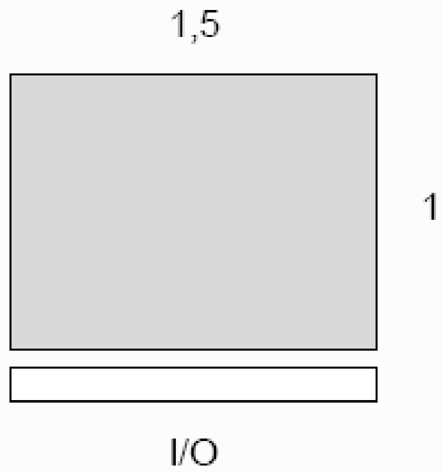
$$V = \frac{A}{U} = \sqrt{\frac{A}{2}} = \frac{U}{2}$$

The final result is then: U = 2V.

The result obtained is valid for both layout of longitudinal type both for layout of transversal type: comparing these two configurations, one notes that do not change the path of two components but only the sequence in which they traveled.

The optimum layout for traditional warehouses

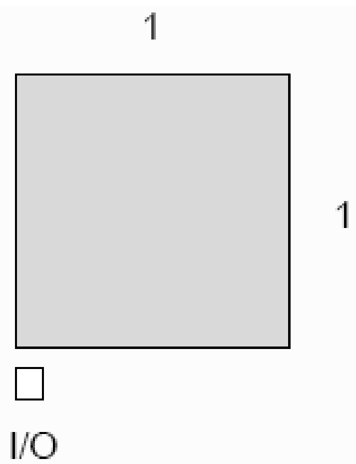
In the case of different positions of the point I/O we have:



Point I / O evenly distributed in front U

forward waiting: *U/3 + V/2*

optimal ratio: *U=1,5V*



Point I / O in vertex of the front U

Punto I/O nel vertice del fronte U

forward waiting: *U/2 + V/2*

optimal ratio: *U=V*

The optimum layout for traditional warehouses

It does now an example that involves the management of about 6,500 Euro-pallets.

There are three possible solutions that provide different types of stock in small batches lease 2.500 m^2.

Consider three options:

a) <u>option A: warehouse a traditional shelves</u>

- height useful the building: 7,5 m
- annual rental of lease: 50,00 €/m^2
- 3 euro-pallet for compartment with a maximum height of: 1,5 m
- trucks with retractable mast with a minimum width of the corridor: 2.6 m and maximum lifting height of the forks 5,5 m

b) <u>option B: intensive warehouse to high shelves</u>

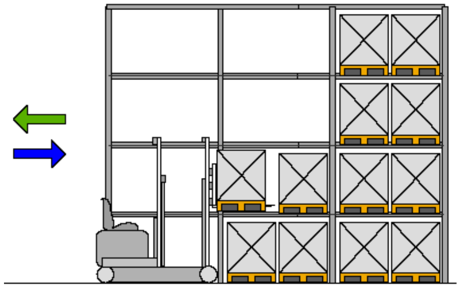
- height useful the building: 12,5 m
- annual rental of lease: 61,00 €/m^2
- 3 euro-pallet for compartment with a maximum height of: 1,5 m
- forklift trucks with a minimum width of the corridor 1.7 m and maximum lift of the forks 11 m

The optimum layout for traditional warehouses

Consider three options:

c) <u>option C: warehouse with shelves type "drive-in“</u>

- height useful the building: 5,5 m
- annual rental of lease: 45,00 €/m^2
- 5 columns of euro-pallet for compartment
- width of the corridor: 3,5 m
- maximum of 3 levels of pallets



For each lot shall be considered an area reserved for the operations of order entry and shipping.

It is supposed to set aside a constant percentage of 20%. You must calculate the area for each module taking into account a clearance of 100 mm for the solutions A and B between adjacent pallets, between pallet and the upright, and a footprint of 100 mm for the uprights.

The optimum layout for traditional warehouses

It calculates the number of levels for each module, for solutions A and B:

$$Nl = \text{int}\left(\frac{height \quad useful}{height \quad UdC + franks + thickness \quad current} \right)$$

It can be assumed a frank between pallets and current of 150 mm and a thickness of the current equal to 100 mm.

This would give the number of pallets per module:

$$\frac{number\ of \ pallets}{\text{mod}\,ule} = number\ of\ levels \cdot number\ of \ fronts \cdot \frac{number\ of \ pallets}{compartment}$$

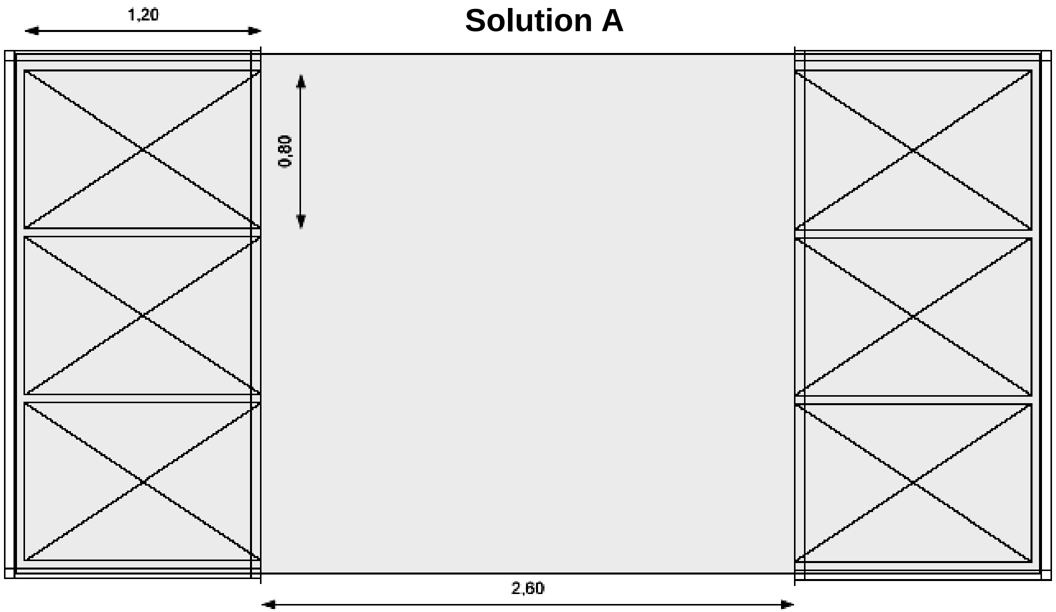
One can calculate the utilization superficial UtS:

$$UtS = \frac{\dfrac{number\ of \ pallets}{\text{mod}\,ule}}{surface \ \ for\ each \ \ \text{mod}\,ule}$$

It is advisable to verify that the means of transport internal used is able to reach the height of the last pallet.

The optimum layout for traditional warehouses

In the solution A, we have:



- length: 0,1 + 1,2 + 2,6 + 1,2 + 0,1 = 5,2 m
- width: 0,1 x 4 + 0,8 x 3 + 0,1 = 2,9 m
- storage area of the module unitary: 5,2 x 2,9 = 15,08 m^2
- number of levels for each module:

$$Nl = \text{int}\left(\frac{7{,}5}{1{,}5 + 0{,}15 + 0{,}1}\right) = 4 \ \ levels$$

The optimum layout for traditional warehouses

In the solution A, we have:

you have to check: as the first level on the floor, taking into account further three levels of pallets (equal to 1.75 x 3 m) and thickness of the last current (0.1 m) we have that total height by reach is 5.35 m < 5.5 m (maximum height of lifting of the forks).

One can calculate the utilization superficial UtS, starting from the number of pallets to form:

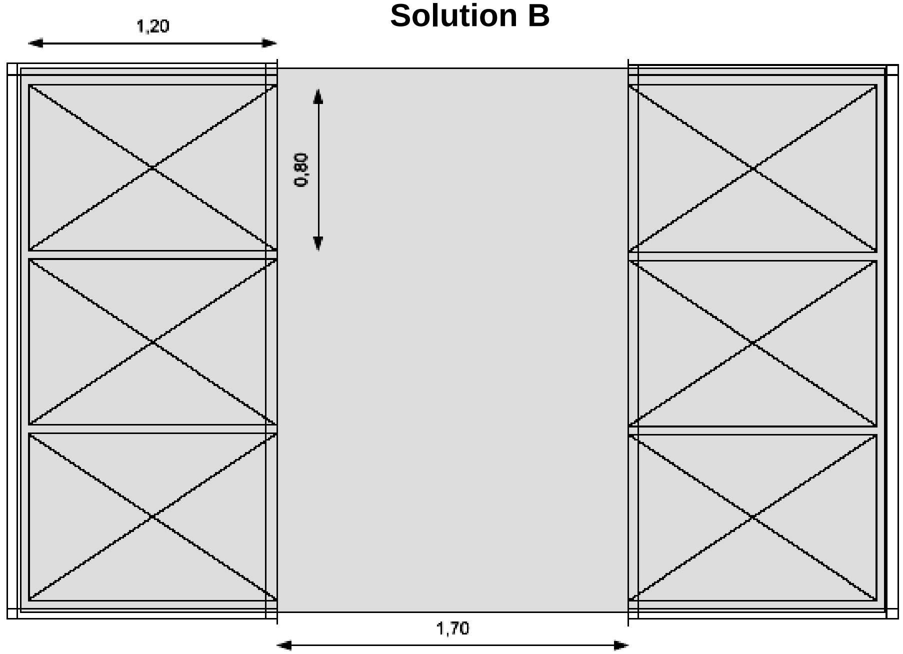
$$number\ of\ levels \cdot number\ of\ fronts \cdot \frac{number\ of\ pallets}{compartment} = 4 \cdot 2 \cdot 3 = 24\ \frac{number\ of\ pallets}{\mathrm{mod}\,ule}$$

$$UtS = \frac{\dfrac{number\ of\ pallets}{\mathrm{mod}\,ule}}{surface\ per\ each\ \mathrm{mod}\,ule} = \frac{24}{15{,}08} = 1{,}59\ \frac{pallets}{m^2}$$

The optimum layout for traditional warehouses

In the solution B, we have:

Solution B



- length: 0,1 + 1,2 + 1,7 + 1,2 + 0,1 = 4,3 m
- width: 0,1 x 4 + 0,8 x 3 + 0,1 = 2,9 m
- storage area of the module unitary: 4,3 x 2,9 = 12,47 m^2
- number of levels for each module:

$$Nl = \text{int}\left(\frac{12{,}5}{1{,}5 + 0{,}15 + 0{,}1}\right) = 7 \ \ levels$$

The optimum layout for traditional warehouses

In the solution B, we have:

you have to check: as the first level on the floor, taking into account further seven pallet levels (equal to 1.75 x 7 m) and thickness of ultimate power (0.1 m) we have that the total height to be reached is 12.35 m < 12.50 m (maximum height of lifting of the forks).

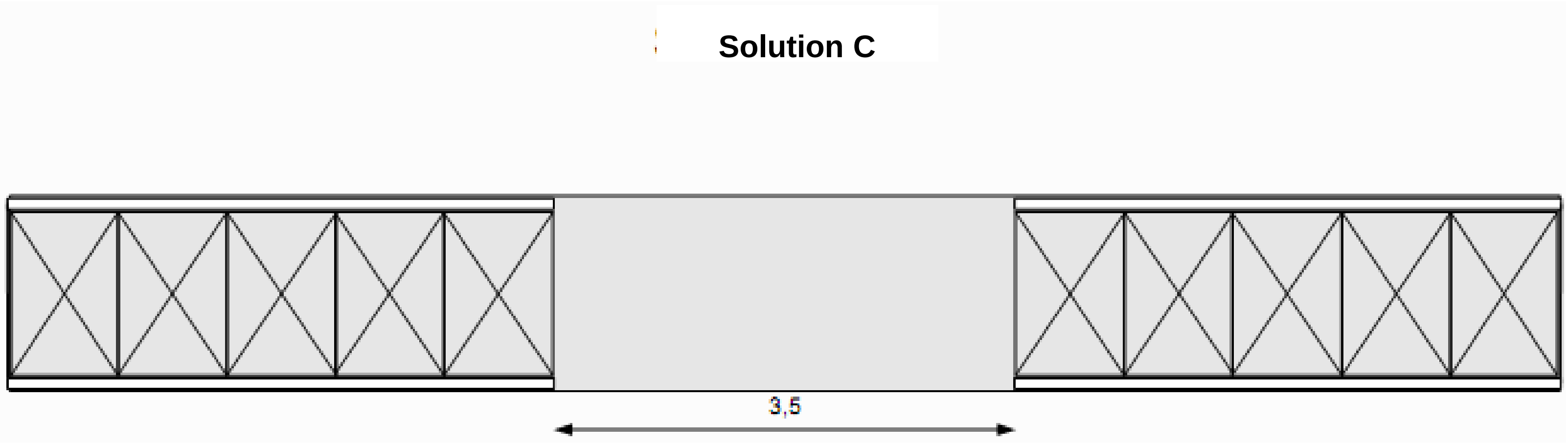
One can calculate the utilization superficial UtS, starting from the number of pallets to form:

$$number\ of\ levels \cdot number\ of\ fronts \cdot \frac{number\ of\ pallets}{compartment} = 7 \cdot 2 \cdot 3 = 42\ \ \frac{number\ of\ pallets}{module}$$

$$UtS = \frac{\dfrac{number\ of\ pallets}{module}}{surface\ per\ each\ module} = \frac{42}{12{,}47} = 3{,}37\ \ \frac{pallets}{m^2}$$

The optimum layout for traditional warehouses

In the solution C, we have:



- length: 0,1 + 0,8 x 5 + 3,5 + 0,8 x 5 + 0,1 = 11,7 m
- width: 0,1 x 2 + 1,2 = 1,4 m
- storage area of the module unitary: 11,7 x 1,4 = 16,38 m^2
- number of levels for each module:

$$Nl = \text{int}\left(\frac{5{,}5}{1{,}5 + 0{,}15 + 0{,}1}\right) = 3 \;\; levels$$

The optimum layout for traditional warehouses

In the solution C, we have:

you have to check: as the first level on the floor, taking into account further three levels of pallets (equal to 1.75 x 3 m) and thickness of the last current (0.1 m) we have that the total height to reach is 5.25 m < 5.50 m (maximum height of lifting of the forks).

One can calculate the utilization superficial UtS, starting from the number of pallets to form:

$$number\ of\ levels \cdot number\ of\ fronts \cdot \frac{number\ of\ pallets}{compartment} = 3 \cdot 2 \cdot 5 = 30\ \frac{number\ of\ pallets}{module}$$

$$UtS = \frac{\frac{number\ of\ pallets}{module}}{surface\ per\ each\ module} = \frac{30}{16,38} = 1,83\ \frac{pallets}{m^2}$$

The optimum layout for traditional warehouses

It is finally to compare the three solutions from a economic point of view.
The cost per pallet is calculated as the ratio of annual rent and the maximum number of pallets storable (area leased × UTS).
At example, in the case of solution A:

$$\cos t \;\; per \;\; pallet = \frac{250.000 \;\; €/\,year}{5.000 \;\; m^2 \cdot 1{,}59 \;\; pallet\,/\,m^2} = 31{,}44 \;\; \frac{€}{pallet \cdot year}$$

In conclusion, we report the results achieved by the processing costs for the pallet in the three solutions having the storage of 6,500 pallets:

Solution	UtS (pallet/m²)	Storage area (m²)	Total area +20% (m²)	Area rent (m²)	Unit cost (€/m² anno)	Renting (€/anno)	Pallet storable	Unit cost (€/pallet)
A	1,59	4.084	4.901	5.000	50,00	250.000,00	7.958	31,44
B	3,37	1.930	2.316	2.500	61,00	152.500,00	8.420	18,10
C	1,83	3.549	4.259	5.000	45,00	225.000,00	9.158	24,59

The preferred solution is the "B" according to this criterion, even if the handling system associated with that solution will determine the times of handling greater.