LAYOUT DESIGN OPTIONS FOR WAREHOUSE MANAGEMENT

Saderova J., Poplawski L., Balog M. Jr., Michalkova S., Cvoliga M.*

Abstract: The paper deals with design layout of rack system. Warehouse Management System allows you to significantly increase the efficiency of work in the warehouse when receiving goods or semi-finished products, their storage, inventory, monitoring of internal movements and states, when unloading and distribution to customers or for further processing in their production lines. In principle, the system consists of portable terminals, appropriate software, including an interface to an existing ERP or similar central corporate system, and a radio network to mediate data transmission in real-time. A managed warehouse is a modular and flexible system, so it can be successfully used for all sizes of warehouses, the number of storekeepers, items and assortment composition, i.e. wherever order in the warehouse is appreciated. A rack system layout is the arrangement of individual racks on the warehousing area. Rack layout design is a process influenced by several factors as rack field dimensions, the working aisle width, the traffic aisle width, etc. The paper presents concrete proposals of rack systems layout. The three layouts were designed, 2 with conventional aisles and 1 layout with a V-shaped aisle. Layout parameter was compared (number of rack fields, number of pallets in a rack system, rack system area, percentage of the warehousing area utilization). For each layout are designed way tracing of picking (routing of forklift) for the process of picking the boxes from 8 positions (locations). The routes were examined for the route length parameter, whereas the route starting points and final points were identical in all the cases. The suitable layout of rack system is recommended on the basis of selected parameters.

Key words: layout, design, options, warehouse management

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Introduction

In global logistics systems, warehousing plays a critical role. Warehouse, which is one of the supply chain elements, plays a vital role in the success or failure of the company (Baker and Canessa, 2009). Warehousing is one of the key factors in the supply chain management (Khouri et. al., 2018). Warehouse is the important link between producer and costumer (Gu et al., 2010). A warehouse is a location from

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where raw material, semi-product and finished products are received, transferred or put away, picked, sorted and accumulated, cross-docked and shipped in (Cakmak et al., 2012; Sofranko et al., 2015). Warehouse layout plan includes storage area plan, aisle plan, shelf types and sizes (Vrysagotis et. al., 2011). Generally, warehouse layout design models attempt to optimize different objectives such as the orientation of storage racks. In traditional warehouses, forklift drivers travel among aisles, to reach a storage location, resp. place of picking (Trebuła et. al., 2015). Aisle dimensions and arrangement are determined on the basis of several factors, e.g., a warehousing method, rack dimensions, dimensions of a used truck, rack arrangement, etc. (Vysrova et. al., 2019). Conventional warehouses comprise parallel as well as transversal aisles, arranged perpendicularly. Rack system arrangement and aisle types influence the speed of performed operations, transfer of storage units into racks, and transfer (routing) in order picking (Horta et. al., 2016). Several authors discuss in their technical articles the issues of two diagonal aisles in the “V” shape or they describe them as non-orthogonal aisles and non-traditional aisles - the Flying-V and Fishbone. Non-orthogonal aisles were first mentioned in years 1965-1972 (Öztürkog et. Al., 2014; Horta et. al., 2016). The issues related to the selection and arrangement of racks, arrangement of storage units, working technology type, orientation and parameters of working and traffic aisles, and routing in order picking influence the logistics performance (Rosova et. al., 2020; Straka et. al., 2016; Malindzakova et al., 2015), (Straka et al., 2018) and safety of the operation (Sofranko et al., 2012).

A rack system layout is the arrangement of individual racks on the warehousing area. Rack layout design is a process influenced by several factors and it must be planned in advance. The objective of this paper is a layout design for a warehousing area in a distribution warehouse according to the general layout creation algorithm (Saderova et. al., 2018).

Based on the analysis of warehouse design in the literature, it is clear that warehouse design involves a large number of interrelated decisions that integrate different methods and procedures. We know five areas that are addressed in the design of the warehouse: determining the overall structure, selecting the operational strategy, dimensioning the warehouse, the layout of the warehouse and the selection of storage technology (Saderova et. al., 2019). This paper deals with one of these areas, i.e. the choice of storage technique, in particular the storage system. Of course, the other four areas have links to the design of the storage system. The design of the storage system is realized, taking into account the principles of logistics: system approach, coordination, planning, algorithmic thinking and global optimization (Saderova et. al., 2018). The system approach is applied by looking at the processes and objects we control as a "system". With the system approach, warehousing can be characterized as a process and at the same time described as part of a logistics system - the warehousing subsystem. Coordination and planning are essential if we apply a systemic approach to the
process; local goals need to be aligned with the global goal of the whole system. The principle of algorithmic thinking uses the principle of creating program algorithms, where each branch must be consistently implemented, closed, nothing must be left to chance, unclosed. A layout is a spatial arrangement of machines or objects in a specific place. These can be production halls, workshops, warehouses. The material flow is taken into account when locating the individual devices. The layout should be ideal in the direction of this flow to avoid waste (Saderova et al., 2018). Another condition for creation is the ergonomics of the workplace. Various aspects are taken into account in order to avoid adverse effects and deterioration of production quality and to be able to work efficiently. Proper placement of equipment, materials and workers in the workplace is the basis for increasing productivity. If we want to streamline the workplace, the primary solution is to place machines, materials and processes so that we can optimize the flow of production. An important part of this optimization is to eliminate and simplify the movement of workers and products (Saderova et al., 2019).

**Literature review**

A planning process typically consists of individual steps displayed in Figure 1 in the following sequence: defining objectives, warehousing area analysis, input parameters determination, rack layout plan designing, calculation of characteristics, optimal layout plan selecting (Sofranko and Zeman, 2014; Saderova et al., 2019).

Defining objectives – in this case it is necessary to define specific objectives compliant with the warehousing strategy, e.g., the maximization of the quantity of warehousing positions, efficient utilization of the warehousing area, increasing the speed of placement and the speed of picking, etc. (Straka et al., 2016; Laciak and Sofranko, 2013).

Warehousing area analysis – the information should include the warehousing premises specifications (locations of doors, pillars, etc.) and the specification of the dimensions of the warehousing area where the racks are to be placed (Straka et al., 2017; Saderova et al., 2019).

Determination of input parameters for designing the plan – determination of the rack cell dimensions on the basis of the number of placed storage units, determination of the number of the rack field levels, calculation of the working aisle width and the traffic aisle width (Cech and Sofranko, 2018).

Rack layout plan designing – based on the input parameters, a rack and aisle layout plan is designed for a given warehousing area. For this particular warehousing area it is necessary to design several plans, differing in rack orientation and aisle arrangement (Straka et al., 2018).

Number of selected plan characteristics – for these plans it is necessary to calculate selected parameters and make a comparison thereof (Straka et al., 2016; Sofranko et al., 2020). Optimal plan (layout) selection – on the basis of selected criteria [10].
In addition to the above listed steps, it is also necessary to plan the execution thereof directly in the operation (Saderova et. al., 2019).

**Methodology, theory and calculation**

![Flowchart](image-url)

**Figure 1: Layout designing steps**

*source: author*
For the purpose of the rack system layout designing it is necessary to determine or calculate the following parameters (Saderova et. al., 2019):

1. Rack field dimensions, length “l” and width (depth) “w”, depending on the type and number of pallets placed in a rack field.

2. The working aisle width “wh”, the minimum width of the working aisle for a truck is calculated using the formula (1):

   $$ w_h = 2R + X + 2S $$

   Where:
   
   $R$ is the external turning radius (specified by the manufacturer) in mm,
   
   $X$ – a load’s (pallet’s) length exceeding the truck fork’s length in mm
   
   $S$ – safety clearance (B = ~200 mm).

3. The traffic aisle width “$w_t$“, a traffic aisle width for one-way traffic is calculated using the formula (2):

   $$ w_t = w + 2S $$

   Where:
   
   $w$ is the width of a truck or of a transferred load (depending on which of the dimensions is larger) in mm,
   
   $S$ – safety clearance (B = ~200 mm).

   The width of a two-way aisle is determined as the double the width of a one-way aisle. To compare individual alternatives, it is necessary to calculate the following parameters:

4. Rack system area “$A_R$” is calculated using the formula (3):

   $$ A_R = \sum_{i=1}^{k} \left[ m \cdot (A_{f} + n \cdot A_{a}) \right] $$

   Where:
   
   $A_f$ is the basic rack field area in m$^2$,
   
   $A_a$– additional rack field area in m$^2$,
   
   $n$ – number of additional rack fields,
   
   $m$ – number of racks

   $k$ – number of rack types (depending on the number of rack fields).

   $A_f$ and $A_a$ areas are calculated as the product of length “l” and width “w” of rack fields, dimensions of which depend on the type and the number of storage units (pallets) placed in a rack field, Figure 3.

5. Percentage of the warehousing area utilization, calculated as the quotient of the rack system area “$A_R$” to the warehousing area “$A_w$”.

   Layout design was carried out applying the above described procedure for the warehousing area in the distribution warehouse (Saderova et. al., 2019).
Result and discussion

1. Defining the objective – a primary objective is to design a layout of standard pallet racks in order to obtain the maximum number of warehousing positions on the given warehousing area. The secondary objective is to ensure efficient and cost-effective order picking, i.e. minimizing the routes when the goods are being picked up. The goods will be picked up upon a pick-list, manually, from the lowest position in the rack system (floor), by collecting the necessary number of boxes from the stored pallets. Having received a pick-list, a picker will move to the required location and collect the necessary number of boxes and then move to the following position, until the entire order is picked up (Straka et al., 2016; Rosova et al., 2013).

2. Warehousing area analysis – the warehousing area is a part of the distribution warehouse with the layout shown in Figure 2. The area for placing the rack system is sized 70x50 m, i.e. 3,500 m².

3. Determination of input parameters for the plan designing:
Storage unit – an EPAL pallet sized 1200x800x14.4 cm, the maximum weight of a storage unit is 800 kg.

Figure 2: Ground plan of the warehouse
A rack cell is designed for placing 3 storage units (pallets) and for 3 rack field levels (floor 2 levels). The rack field layout, including the dimensions, is shown in Figure 3, Table 1.

![Figure 3: Rack field scheme](image)

Table 1. Parameters of rack field

<table>
<thead>
<tr>
<th></th>
<th>d [mm]</th>
<th>w [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic rack field</td>
<td>2900</td>
<td>2800</td>
</tr>
<tr>
<td>additional rack field</td>
<td>1200</td>
<td>1200</td>
</tr>
</tbody>
</table>

A pallet will be placed into a rack using a forklift trolley, for which the manufacturer specifies the turning radius of 1,293 mm. The working aisle width was calculated, using the formulas (1) and (2), as 2,836 mm; the one-way traffic aisle width as 1,390 mm.

Order picking will be carried out using a picking forklift truck; its turning radius specified by the manufacturer is 1,395 mm; the aisle width specified by the manufacturer is 2,960 mm. The working aisle width was calculated, using the formulas (1) and (2), as 2,990 mm and the traffic aisle width as 1,010 mm.

When designing a layout, it is necessary to respect the minimum working aisle width of 2,990 mm and the minimum traffic aisle width of 1,190 mm, based on the calculations for both trucks.

4. Rack layout plan designing – for the selection of an optimal layout, three layouts were designed; 2 with conventional aisles and 1 layout with a V-shaped aisle.

Layout 1 (Fig.2) consists of racks of three different lengths. Rack parameters are listed in Table 2. The rack system layout is based on the longitudinal rack arrangement – 16 two-row racks and racks along the walls. The width of working aisles between the racks is 3 metres; the width of the longitudinal central aisle is...
4.4 meters; and the width of the central transversal two-lane traffic aisle is 2.8 meters.
This rack system layout option provides 416 rack fields with the total capacity of 3,744 pallet locations (the capacity on one storey is 1,248 pallets).
Layout 2 (Figure 4) consists of racks of three different lengths listed in Table 2. The rack system layout is based on transversal rack arrangement in a rack field – 24 two-row racks and racks along the walls, similar to Layout 1. Width of working aisles between the racks is 3 meters, whereas the central two-way traffic aisle, leading along the whole width of the rack field, is 2.4 meters. This rack system layout option provides 400 rack fields for the storage of 3,600 pallets (the capacity on one storey is 1,200 pallets).
Layout 3 (Figure 4) consists of racks of several different lengths listed in Table 2, with a dominant V-shaped aisle. The rack system layout provides in total 384 rack fields capable of storing 3,456 pallets (the capacity on one storey is 1,152 pallets).
This layout design is similar to Layout 1, with the difference being the orientation of a V-shaped traffic aisle, instead of the central transversal traffic aisle.

5. Optimal plan (layout) selection. The layout comparison based on parameters: number of rack fields, number of pallets in a rack system, rack system area AR [m$^2$] calculated using the formula (3) and the percentage of the warehousing area utilisation are shown in Table 2. Considering the data contained in Table 2, we can state that the primary objective is met by the Layout 1, providing the largest number of warehousing positions, i.e. 3,744, using 40.05% of the area.
However, which of the layouts meets the secondary objective?
Another step within the optimal layout type selection was the picking route modelling. The routes were examined for the route length parameter, whereas the route starting points and final points were identical in all the cases. The layouts and routes were designed in the AutoCAD software. Lengths of individual routes were read directly from the technical drawing created in the AutoCAD software.

Managerial implication

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Layout 1</th>
<th>Layout 2</th>
<th>Layout 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of rack fields [pc]</td>
<td>416</td>
<td>400</td>
<td>384</td>
</tr>
<tr>
<td>Number of pallets in a rack system [pc]</td>
<td>3744</td>
<td>3600</td>
<td>3456</td>
</tr>
<tr>
<td>$A_D$[m$^2$]</td>
<td>1401.96</td>
<td>1349.88</td>
<td>1290.36</td>
</tr>
<tr>
<td>$A_W$[m$^2$]</td>
<td>3500</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>Warehousing area utilisation [%]</td>
<td>40.05</td>
<td>38.56</td>
<td>36.86</td>
</tr>
</tbody>
</table>

A model example shows the process of picking the boxes from 8 positions (locations). Positions of the boxes were chosen so that they are as identical as
possible (minimum position variations) for all three layouts. Picking positions of boxes are presented as black fields, including the picking order. Picking routing is marked with a blue line and the routing direction is designated with an arrow, Fig. 4. A route length for Layout 1 is 280.2 m. For Layout 2 it is 252.2 m and for Layout 3 it is 276.8 m.
Conclusion

The article describes an example of 3 different designs of a rack system layout for a selected warehousing area. In addition to the calculation of warehousing locations, we also presented a model example of picking the boxes from racks. The routing and selection of an optimal route direction depend in practice mainly on the number of items to be picked up, their location in a rack system, the speed of a picking truck, and, last but not least, a driver’s skills. A different case is when the picking process is controlled by a control system which plans, controls and monitors the picking process, proposes a route for a truck so that it moves in a warehouse in a most efficient manner and in a sufficient speed.

Warehouse Management System allows you to significantly increase the efficiency of work in the warehouse when receiving goods or semi-finished products, their storage, inventory, monitoring of internal movements and states, when unloading and distribution to customers or for further processing in their production lines. In principle, the system consists of portable terminals, appropriate software, including an interface to an existing ERP or similar central corporate system, and a radio network to mediate data transmission in real-time. A managed warehouse is a modular and flexible system, so it can be successfully used for all sizes of warehouses, the number of storekeepers, items and assortment composition, i.e. wherever order in the warehouse is appreciated. The introduction of design a new layout design a new layout brings mainly the following benefits: higher productivity of warehouse operators, the possibility of a clear and up-to-date link between the performance indicators of storekeepers and the productivity of their work, significantly better use of storage space, optimization of storage positions and location of warehouse items, minimizing the error rate of the human factor and complaints, active use of accurate identification via barcodes or RFID, providing
up-to-date information on the state of the warehouse in real-time, multiple accelerations of inventories, online management reports at various levels of management, elimination of paper records, increase competitiveness and customer satisfaction.

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**OPCJE PROJEKTOWANIA UKŁADU W ZARZĄDZANIU MAGAZYNEM**

**Streszczenie:** W artykule omówiono projekt układu regałów. Warehouse Management System pozwala znacznie zwiększyć efektywność pracy w magazynie przy przyjmowaniu
towarów lub półproduktów, ich składowaniu, inwentaryzacji, monitorowaniu ruchów i stanów wewnętrznych, podczas rozładunku i dystrybucji do klientów lub do dalszego przetwarzania na ich liniach produkcyjnych. Zasadniczo system składa się z przenośnych terminali, odpowiedniego oprogramowania, w tym interfejsu do istniejącego ERP lub podobnego centralnego systemu korporacyjnego, oraz sieci radiowej pośredniczącej w transmisji danych w czasie rzeczywistym. Magazyn zarządzany jest systemem modulowym i elastycznym, dzięki czemu można go z powodzeniem stosować do każdej wielkości magazynów, ilości składów, towarów i składu asortymentowego, czyli wszędzie tam, gdzie ceni się porządek w magazynie. Układ regałów to rozmieszczenie poszczególnych regałów na powierzchni magazynowej. Projektowanie układu regałów jest procesem, na który ma wpływ kilka czynników, takich jak wymiary pól regałów, szerokość korytarza roboczego, szerokość korytarza komunikacyjnego itp. W artykule przedstawiono konkretne propozycje rozmieszczenia systemów regałowych. Zaprojektowano trzy układy, 2 z konwencjonalnymi przejściami i 1 z nawą w kształcie litery V. Porównano parametry układu (liczba pól regałowych, liczba palet w systemie regałowym, powierzchnia systemu regałowego, procent wykorzystania powierzchni magazynowej). Dla każdego układu zaprojektowano sposób śledzenia kompletacji (trasowania wózka widłowego) dla procesu kompletacji skrzynek z 8 pozycji (lokalizacji). Trasy zostały zbadane pod kątem parametru długości trasy, natomiast punkty początkowe i końcowe trasy były we wszystkich przypadkach identyczne. Na podstawie wybranych parametrów zalecane jest odpowiednie rozplanowanie systemu regałowego.

Słowa kluczowe: układ, projekt, opcje, gospodarka magazynowa

摘要：本文探讨了机架系统的布局设计。仓库管理系统使您在接收货物或半成品时，它们的存储、库存，内部移动和状态的监视，卸货和分发给客户或在他们的生产线中进行进一步处理时，可以显着提高仓库的工作效率。原则上，该系统由便携式终端、适当的软件（包括与现有ERP或类似中央公司的接口）以及无线网络组成，以实时地协调数据传输。受管仓库是一种模块化且灵活的系统，因此可以成功地用于各种规模的仓库，仓库管理员的数量，物品和分类组成，即仓库中需要订购的任何位置。机架系统布局是指仓库区域中各个机架的布置。机架布局设计是一个受机架领域尺寸，工作通道宽度，交通通道宽度等因素影响的过程。本文提出了机架系统布局的具体建议，设计了三种布局，其中两种具有常规过道，一种具有V形过道，比较了布局参数（机架字段的数量，机架系统中的托盘数，机架系统面积，仓储面积利用率的百分比）。对于每种布局，都设计了8个位置（位置）拾取箱子的追踪方法（叉车的路线），检查了路线的路线长度参数，而在所有情况下，路线起点和终点均相同。建议根据所选参数选择合适的机架系统布局。

关键词：布局，设计，选项，仓库管理