Automation of Warehouse Parameters Calculation and its Sketch Design

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Abstract. Warehouses in enterprises are a key element in ensuring the stability of production activities, particularly in terms of efficient supply chain and production process management. Proper selection and accurate calculation of warehouse parameters help reduce storage costs, which is an important and relevant task. Therefore, the aim of this study is to analyze warehouse system parameters and develop a computer program for their automated calculation. The practical significance of this task is justified by the widespread practice of warehouse use in various industries and the necessity for their rational operation. Warehouse Calculator is the new software, which create a sketch of a warehouse with pallet racks according to the specified input and output parameters. Its main task is to generate a database of calculation results and to build a sketch for the warehouse design documentation. The program algorithm calculates the warehouse area, its geometric dimensions (length, width, and height), considering user-input values and sizes, which are described in this paper. It also includes the calculation of columns. When starting a new calculation, standardized data is displayed by default in all fields. These values can be adjusted based on the individual problem and modified at any stage of its solving.

Keywords: Computation, Pallet Racks, Drawing, Software, Productivity, Innovation, Industrialization.

1 Introduction

The storage of materials or products is an essential component of the vast majority of production processes. Warehouses can be created at the beginning of the production cycle to ensure timely supply of materials to production in the required quantities. In addition, it can be predicted within the cycle for the temporary accumulation of intermediate products and at the end of the cycle for storing finished products. Temporary storage of goods outside the enterprise, such as in retail chains, also occurs [1].

At the warehouse, various operations are performed, including transportation, loading, unloading, sorting, picking, and intermediate transshipment [2].

Proper organizing of the warehouse contributes to maintaining the quality of consumables, raw materials, and finished products, organizing production and transportation operations, efficient use of enterprise space, reducing transportation vehicle downtime and transport costs [3].

The main factors in determining classification of individual sections of a warehouse are product specialization, the level of mechanization of operations, the need for sanitary, electrical, and other engineering structures, equipment, and communications. Depending on their purpose, all warehouse are divided into technological, auxiliary, and administrative-service areas [4].

2 Literature Review

A significant number of scientific studies are devoted to researching ways to improve the warehouse systems. Several of the most common study areas can be identified.

Part of the papers focuses on examining issues related to order picking and solving problems associated with the optimal placement of products in a warehouse. For example, the issue of managing the flow of products is discussed in [5], taking into account the number of storage spaces, the number of racks, resources for moving goods, and other performance indicators. In [6] authors propose the solution to the problem of coexisting new and old warehouses within a single distribution center. In [7] an optimal order-picking approach in automated warehouses is developed. In the study [8] the issue of production planning is analyzed, taking into account the physical constraints of warehouses. In [9], approaches to deal with the problem of warehouse reassignment are proposed.

There are also a number of works, dedicated to the routing of cargo flows. In [10], a solution to the task of minimizing the distance traveled by the crane when a set of items needs to be picked up from different locations is presented. There is also the investigation of the impact of cross aisles on picking productivity in scattered storage warehouses [11]. The goal of [12] is to minimize the duration of movement carried out by the stacker crane to perform necessary retrieval operations. In paper [13], a multi-robot path planning method as a pick-up path optimization strategy is considered. Scheduling and routing in warehouses are also described and analyzed in detail in [14, 15].

Some research studies address efficiency parameters. In [2], the method for evaluating performance indicators of warehouse system is proposed. The paper [4] focuses on the warehouse layout planning methods. In the paper [16] comparative metrics applicable to any storage system are developed. The work [17] describes methods of operational protection of material surfaces.

Much attention is paid to automation issues. There are various scientific developments that propose the use of software [17-20], robotic system [13, 21], and other intelligent machine resources [15, 22, 23] to improve the operation of warehouse systems.

The literature review shows that scientists are actively conducting research on a wide range of issues related to warehouse systems. However, there are no solutions that enable the automated calculation of the key parametric characteristics of a warehouse and present the results in the form of a warehouse sketch. Therefore, the objective of this study is to develop software capable of performing these tasks. To achieve this, we identified the general requirements for warehouse layout planning that formed the basis of Research Methodology presented in this paper:

- maximizing warehouse space utilization;
- ensuring that the width of aisles complies with the technical specifications;
- providing central aisles that allow free turning and bidirectional movement of floor lifting and transport equipment;
- organizing cargo flow to minimize conflicting transportation;
- positioning receiving areas on the side where the main flow of goods arrives, and picking areas on the side of the main shipment.

3 Research Methodology

The main parameter forming the foundation for all warehouse calculations is its area.

The Total Area (S_t) consists of the areas of technological zones and is calculated using the formula:

$$S_t = S_c + S_a + S_r + S_p + S_w, \tag{1}$$

where: S_c – cargo area, i.e., the area occupied directly by goods (racks, stacks, and other storage devices for goods); S_a – auxiliary area, i.e., the area occupied by driveways and aisles; S_r – receiving area; S_p – picking area; S_w – workstations area, i.e., the area in warehouse rooms allocated for equipment and workstations for warehouse workers [2, 4, 5, 16].

The Cargo Area (S_c) is determined as:

$$S_c = \frac{F_a \cdot F_v \cdot k_{u.l}}{254 \cdot C \cdot k_{w.c} \cdot H}, \tag{2}$$

where: F_a – forecast of annual turnover; F_v – forecast of inventory volume, days of turnover; $k_{u.l}$ – coefficient of uneven warehouse loading, determined as the ratio of the cargo turnover of the busiest month to the average monthly turnover of the warehouse, $k_{u.l}$ = 1,1…1,3; $k_{w.c}$ – coefficient of warehouse cargo volume utilization; C – estimated cost of 1m^3 of goods stored in the warehouse; H – height of cargo stacking for storage, m; 254 – number of working days in a year.

The coefficient of warehouse cargo volume utilization $k_{w.c.}$ characterizes the density and height of cargo stacking and is calculated using the following formula:

$$k_{w.c.} = \frac{V}{S_{p.r} \cdot H} \tag{3}$$

where: V – the volume of the goods in the package that can be stacked to its full height, m^3; $S_{p.r}$ – the area occupied by the projection of the external contours of the racks onto the horizontal plane, m^2.

Aisle and Drive Area (S_a) is determined after the selection of the mechanization option and depends on the type of lifting and transport machines used in the technological process. If the width of the working corridor of the machines operating between the racks is equal to the width of the rack equipment, then the area of aisles and drives will be equal to the cargo area or 90% of it.

Receiving Area (S_r) and Picking Area (S_p) are the areas of receiving and picking zones, which calculated based on approximate values of the calculated load per 1 m^2 of area in the receiving and picking zones:

$$S_r = \frac{F_a \cdot A_1 \cdot k_{u.l} \cdot t_r}{254 \cdot C \cdot q \cdot 100} \quad (4)$$

$$S_p = \frac{F_a \cdot A_2 \cdot k_{u.l} \cdot t_p}{254 \cdot C \cdot q \cdot 100} \quad (5)$$

where: A_1 – the share of goods passing through the warehouse receiving area, %; A_2 – the share of goods to be picked at the warehouse, %; t_r – the number of days during which the goods will remain in the receiving zone; t_p – the number of days during which the goods will remain in the picking zone; q – approximate values of the calculated load per square meter in the receiving and picking zones, t/m^2.

Workstations Area (S_w) depends on their location. It is arranged near the picking zone, allowing for maximum visibility of the warehouse space. If the quality of goods is to be inspected at the warehouse, the workstations for the relevant personnel are arranged near the receiving area, but away from the main cargo flows.

To determine the Total Area (S_t) using formulas (1)-(5), the following initial data must be provided [2, 5, 16].

Pallet dimensions: these are the key parameters used to calculate rack dimensions, and consequently, to design the warehouse space. It is recommended to select standardized values.

Number of pallet spaces: the minimum number of pallets that must fit within the allocated space.

Number of pallet spaces in the height and width of the rack: refers to the number of pallet positions within the rack (section).

Number of racks in a row: this value is arbitrary and determines the maximum number of racks that can fit in the space, as well as the maximum number of pallet positions.

Distance between rows (working aisle): any value can be chosen, but it is recommended to use standard dimensions suitable for different types of handling equipment.

Distance between double rows and the distance from the column to the rack: these measurements account for possible inaccuracies during construction or rack installation.

Pallet overhang from the rack and the distance between pallets on the rack: it is recommended to use the standard values.

Distance from the pallet with cargo to the crossbar: this value is arbitrary, but it is recommended to choose a size that, when combined with the pallet height, results in a value divisible by 50 to standardize rack sizes.

Multiple of the rack height: this value affects the spacing of diagonal bracing beams. The standardized value is 500 mm.

Profiles of beams, uprights, and crossbars: these values do not affect the rack dimensions but only alter the appearance of the rack in the graphical display and the sizes of its components in the calculation results.

Columns: column dimensions are arbitrary.

Clearances: the recommended minimum distance is 100 mm to account for wall irregularities and protruding structures.

By assigning numerical values to all the described characteristics, we can calculate the required and dimensional characteristics of the warehouse system.

However, the manual calculation process is time-consuming and may not be accurate enough. Therefore, we deemed it appropriate to develop a computer program to automate these calculations. As a result, we created the Warehouse Calculator software in C++. It can process the input data listed above (initial parameter values) and calculate over 20 warehouse system parameters. The program operates according to the algorithm presented in Figure 1.

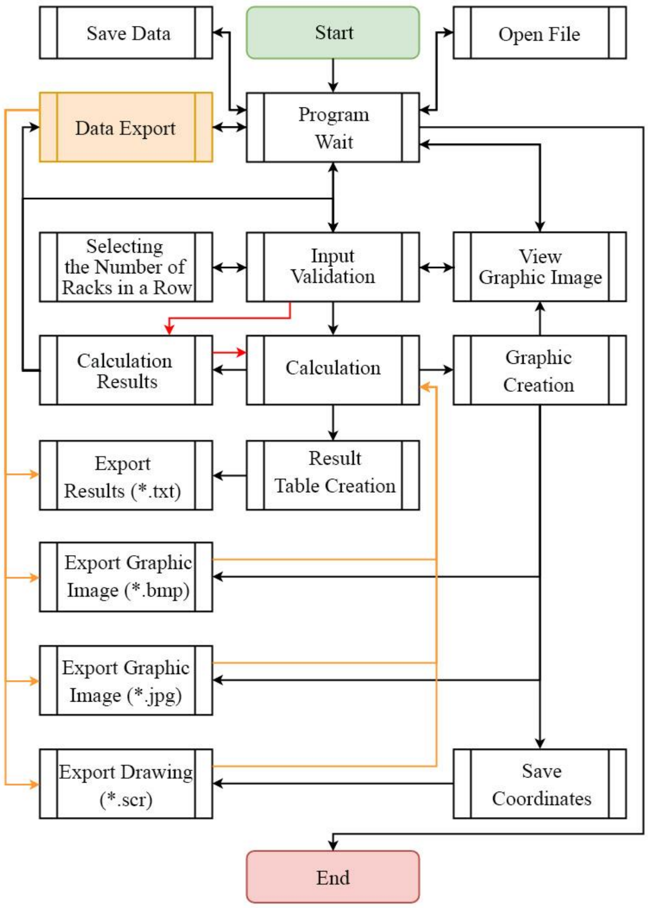


Fig. 1. Algorithm of the program operation

4 Results and Discussion

This section provides a detailed description of the Warehouse Calculator operation principle using the example of the task formulated below.

Given: number of pallet spaces – 845 units, pallet dimensions with cargo – 800×1200×1000 mm, EUR. Accept the recommended values for other parameters.

Find: the optimal Total Area (S_t) and dimensions of the warehouse; calculate the profiles of the rack components; create a graphical drawing.

The data input panel of the program is shown in Figure 2.

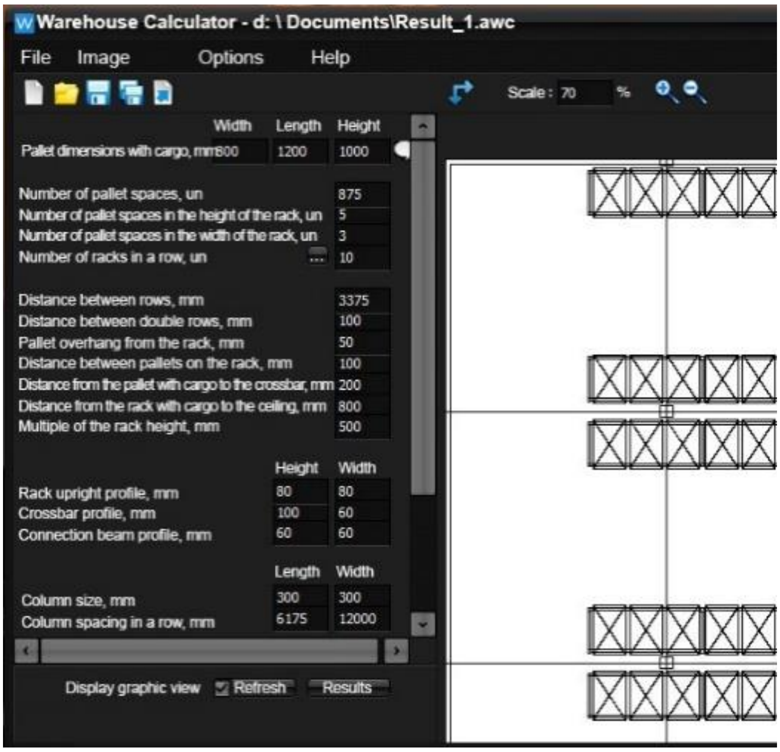


Fig. 2. Data input panel

In addition to the input fields for variable data, the data input panel features two buttons: ‘Update’, which runs the calculation function and refreshes the graphical output, and ‘Results’, which displays a panel with a table containing the calculation results (Fig. 3). If the data has been changed, the ‘Update’ command should be used first.

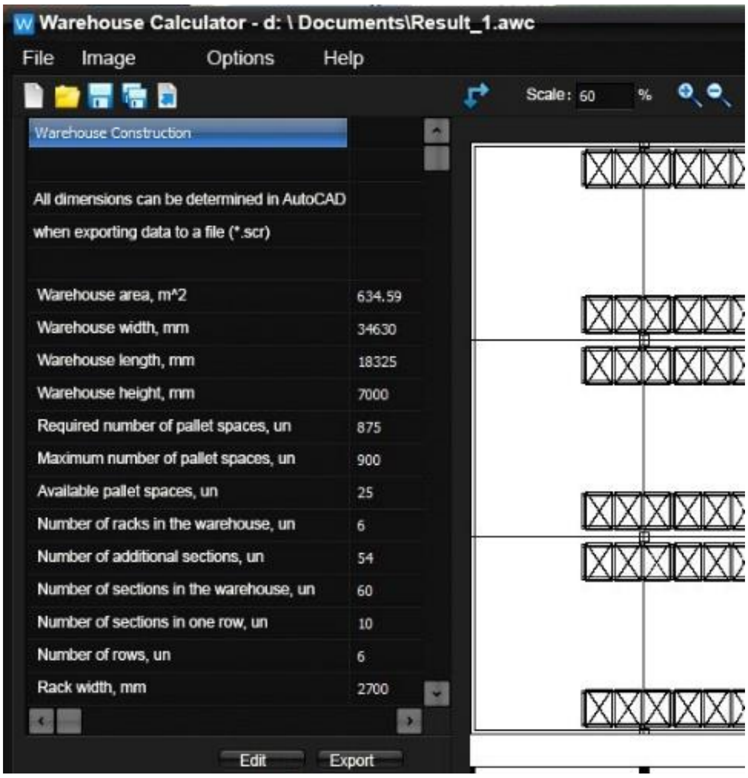


Fig. 3. Calculation results window

For most fields in the data input panel, a tooltip function has been added (Fig. 4). It provides explanations on where a specific dimension is used or what effect its value has.

To find the optimal number of racks in a row, it is recommended to use the selection function, which will analyze possible options and display the data in the form of a table. The best results, with the fewest free pallet positions, will be sorted and displayed in the top cells of the table (Fig. 5).

Changing pallet overhang from the rack and the distance between pallets on the rack may result in non-standard sizes, making rack selection more difficult.

Distance between double rows, distance from the column to the rack are not recommended to reduce.

To disable the 'Columns' parameter, it is necessary to set the value to '0'. The construction algorithm only allows changes to the column spacing across the width of the space. The spacing along the length is calculated based on the input dimensions and distances.

By entering the values of the described parameters into the data input cells, the following results are obtained (see Fig. 3).

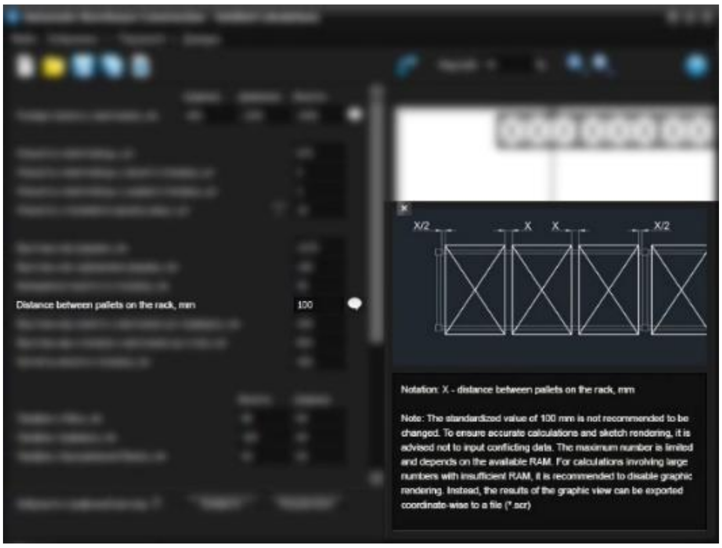


Fig. 4. Tooltip window

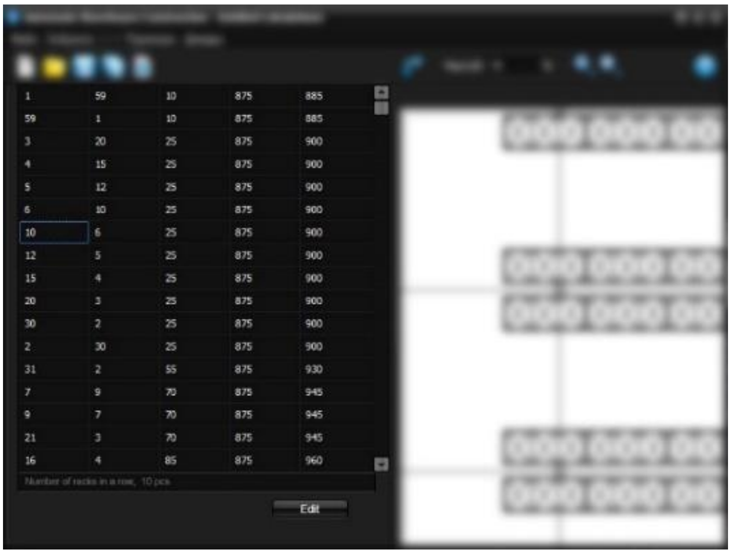


Fig. 5. Window for determining the optimal number of racks in a row

Generalized parameters: warehouse area – 634.59 m², warehouse width – 34,630 mm, warehouse length – 18,325 mm, warehouse height – 7,000 mm, required number of pallet spaces – 875 units, maximum number of pallet spaces – 900 units, available pallet spaces – 25 units, number of racks in the warehouse – 6 units, number of additional sections – 54 units, number of sections in the warehouse – 60 units, number of sections in one row – 10 units, number of rows – 6 units.

Rack dimensions: width – 2,700 mm, length – 1,100 mm, height – 5,500 mm, height with load – 6,200 mm. Pallet spaces per rack: in height – 5 units, in width – 3 units, total per rack – 15 units.

Rack components: rack upright dimensions – 80×80×5,500 mm, number of uprights – 132 units; crossbar dimensions – 100×60×2,700 mm, number of crossbars – 480 units; diagonal connecting beam dimensions – 60×60×1,065 mm, number of diagonal connecting beams – 726 units; straight connecting beam dimensions – 60×60×940 mm, number of straight connecting beams – 132 units.

The program is managed via the ‘Menu’ panel. File management for the calculation results is done using the tools shown in Fig. 6, a. All commands are assigned ‘hotkeys’ and ‘quick access’ icons for faster settings adjustment, such as ‘New’, ‘Open’, ‘Save’, ‘Save As’, ‘Export As’ and ‘Exit’.

‘Export As’ opens the export window shown in Fig. 6, b. The built-in subroutine allows saving output files in the following formats:

- (*.SCR) – a file with a set of commands for execution, saved sequentially. In this case, the commands are generated for AutoCAD, allowing the graphical output to be imported and edited there according to user-required settings. This file can be converted onto other formats. During conversion, the scale is automatically set to 100%, and AutoCAD’s default measurement units are used.
- (*.BMP) – a raster graphic file, where the image is stored as a two-dimensional pixel array.
- (*.JPG) – a raster format; compression is not applied by default, ensuring the highest image quality.
- (*.TXT) – a text format, used exclusively for outputting calculation results.

The graphic configuration of the sketch is managed using program tools such as (Fig. 6, c):

‘Scale’ includes two functions: zoom in and zoom out. The minimum scale is 1%, and the maximum is 100%.

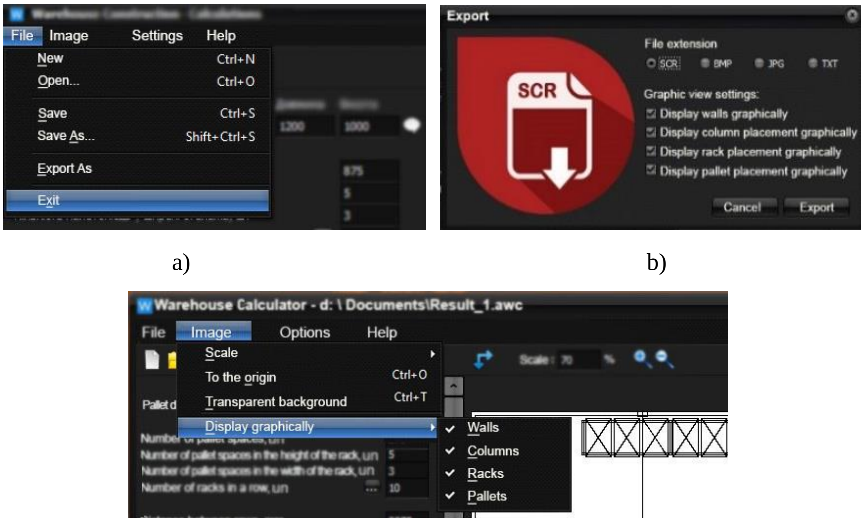
‘To the origin’ resets the image coordinates to the initial position.

‘Transparent background’ enables or disables the white background for the graphic, which does not affect calculations or file export.

‘Display graphically’ displays selected elements (walls, columns, racks, pallets) when generating the graphical output but does not affect the calculation results.

Warehouse Calculator can be used for warehouse design during the development of new production facilities, the reorganization of existing ones, the expansion of production programs in operating facilities, the creation of logistics centers for picking goods, warehouses for servicing retail networks, and other similar tasks.

According to the selected commands, the program produces a sketch of the designed warehouse (Fig. 7).



a) b)

c)

Fig. 6. Data output management: calculation results management (a), results export window (b), image settings

Fig. 7. The sketch of the warehouse

5 Conclusions

1. The review of recent publications reveals that researchers are actively studying various aspects of warehouse systems. Significant attention has been given to the problems of warehouse planning, cargo picking, flow routing, and the automation of warehouse

maintenance processes. However, there are no tools have been proposed that could automatically build the warehouse layout based on its structural and dimensional parameters.

2. We analyzed the parameters that are important for building a warehouse system, systematized them, and determined which ones can be used as fixed data and which need to be calculated.

3. In this paper, we present the Warehouse Calculator software for computing the structurally important warehouse parameters, alongside presenting the results as a warehouse layout. It calculates over 20 characteristics of the warehouse system based on the given input parameters. A useful feature of this program is that if the problem conditions change or the result require adjustment, user only need to modify the values of individual input parameters in the data input panel. Thus, the value of the software lies in automating manual calculations and drawing tasks, as well as in the ability to modify the input parameters at any stage of solving the problem.

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