The Procedure of Warehouses Designing as an Integral Part of The Warehouses Designing Method and The Designing Software

Kostrzewski M.

Abstract**—**The paper describes the new warehouses designing method, which includes e.g. the procedure for warehouses designing, the main subject matter of the paper, and the procedure for optimization of functional and spatial areas. There is also special care given about the critical review of the warehouses designing methods existing in the literature of the problem. Some information is given on implementation of the new designing method into the designing software *OL09*. In case of testing the *OL09* software's correctness, the verification of implemented warehouses designing procedure has been prepared and described. The verification was done in a way of a case study connected to designing a warehouse (an example consists of two solutions). While working on the software there were identified theoretical and practical aspects connected to the problem. There are also specified requirements for software development and further researches on the method itself.

Keywords**—**a warehouses designing method, a software, a warehouse designing procedure, an optimization procedure.

I. Introduction

In the literature review of the problem, a critical review of the warehouses designing methods was made. As a result of making the critical review of designing methods it was decided to develop the new warehouse designing method. The developed method was expanded to include additional evaluation indicators and optimization procedure.

In addition, it was decided to prepare the computer-supported designing tool based on the new designing method in the form of a software. This software provides strong support for designing methods.

An implementation of the method into software makes it possible to prepare a complete warehouse design. Realization of such software is difficult - the quantity of tasks which have to be made for this purpose. Usually computer-supported designing tools are limited only to some selected parts of warehouse or to a computer-supported simulation and visualization of a warehouse.

Additionally there was prepared the optimization procedure of the spatial and functional design. In practice, only optimal sizes of the building blocks and areas can be defined. Therefore it was decided that in there should be considered a problem of suboptimization of functional and spatial areas in warehouses. Suboptimization, among others, choose an appropriate types of storage and picking. The types are selected in such a way that the capital spending for a warehouse construction were as low as possible, taking into account the rational approach of space planning inside the building. In the paper the optimization of the warehouses geometry is taken into account due to the fact that many other design issues depend on the geometrical parameters.

Comprehensive discussion of the new method and its implementation into a software allowed to distinguish a quantity of theoretical and functional aspects of the problem. It is specifically described in the summary of the paper. In addition, there were given, with a precise manner, the possible directions of further researches.

Manuscript received March 20, 2012: Revised version received: March 20, 2012. This work was supported in part by funds under the statutory work of the Department of Transport Equipment Construction Bases (Faculty of Transport, Warsaw University of Technology) No. 504G/1160/3480.

K. M is with the Faculty of Transport, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland (phone: +48 22 234-54-60; fax: +48 22 425-65-43; e-mail: markos@it.pw.edu.pl).

II. Warehouses Designing Problem Identification in Literature

As far as warehouses designing methods are concerned there were identified 16 designing methods. There are methods of (designing steps within described methods are given in italicize text after comas):

1. Heskett, Glaskowsky, Ivie, 1973: *Determine warehouse requirements, Design material handling systems and facility design, Develop the facility layout*, [10],
2. Apple, 1977: *Procure data, Analyze data, Design processes, Plan material flow pat tern, Calculate equipment requirements, Plan individual work areas, Select material handling equipment, Determine storage requirements, Plan service and auxiliary activities, Determine space requirements, Allocate activity areas to total space, Construct the master layout*, [2],
3. Firth, Apple, Denham, Hall, Inglis, Saipe, 1988: *Identify the warehouse functions, Develop alternative methods, Combine functional alternatives into single system, Select the total system*, [6],
4. Hatton, 1990: *Determine the task (inc. Data collection), Analyze product quantity, Analyze product movement, Develop alternative concepts, Develop the management system (methods, procedures and systems)*, [9],

5. Mulcahy, 1994: *Collect data, Analyze data, Establish design year parameters, Consider alternative material handling equipment and concepts, Identify administrative function areas, Develop alternative layouts*, [13],

6. Oxley, 1994: *Define system requirements, Define and obtain data, Analyze data, Establish unit loads to be used, Determine operating procedures and methods, Consider equipment types & characteristics, Calculate equipment capacities and quantities, Define services & ancillary operations, Prepare possible layouts, Evaluate and assess, Identify the preferred design*, [14],

7. Fijalkowski, 1995: *Define a range of parameters changeability, Define a structure of outer inputs and outer outputs outside of a warehouse, Define a structure of internal inputs and outputs, Identify data connected with work organization, Identify parameters of evaluation, Make a sketch of a layout, Prepare description of the material-flow processes and information-flow processes, Make a plot of a flow of materials and information on a layout, Describe materials (or information) points of origin and materials (or information) destination points, Define quantity of units (materials and information) which flow on the routes between points of origin and destination points, Define a schedule of processes realized on these routes, Prepare cycles documentation, Define geometric and technical parameters of routes, Define operating parameters and elementary costs for equipment and human resources, Calculate transport cycle, Calculate a daily labor-intensive of material-flow processes realized by equipment, a daily reduced labor-intensive of material-flow processes realized by workers, a daily reduced labor-intensive of information-flow processes realized by equipment and a daily reduced labor-intensive of information-flow processes realized by workers, Calculate a reduced number of resources and workers, Draft organization of work, Calculate warehouse's capital spending and annual operational costs and logistics indicators, Calculate a reduced labor-intensive of resources, equipment and workers, a reduced number of resources and a reduced number of employees, Calculate a daily physical activity of employees, Make a complex variants evaluation*, [5],

8. Korzen, 1998: his method seems to be similar to Fijalkowski's's method,

9. Govindaraj, Blanco, Bodner, Goetschalckx, McGinnis, Sharp, 2000: *Assemble and analyze data, Determine functional requirements, Make high-level ('architecture') decisions, Undertake detailed system specification and optimization, Reiterate above steps*, [7],

10. Rouwenhorst, 2000: *Define concept, Acquire data, Produce functional specification, Produce technical specification, Select the means and equipment, Develop layout, Select planning and control policies*, [15],

11. Rowley, 2000: *Define system requirement and design constraints, Define and obtain relevant data, Analyse data, Establish unit loads to be used, Postulate operating procedures and systems, Consider equipment types and characteristics, Calculate equipment quantities, Define other facilities and services, Draft possible layouts, Select the preferred design, Evaluate and assess expected performance, Conduct computer simulations*, [16],

12. Rushton, Oxley, Croucher, 2000: *Define system requirements and design constraints, Define and obtain data, Analyze data, Establish unit loads to be used, Postulate basic operations and methods, Consider possible equipment types, Calculate equipment quantities, Calculate staffing levels, Prepare possible building and site layouts, Evaluate the design against requirements, Identify the preferred design*, [17],

13. Bodner, 2002: *Assemble data, Undertake data profiling, Determine high-level functionalities, Produce high-level specification ('architecture'), Undertake detailed system specification/optimization, Reiterate above steps*, [4],

14. Hassan, 2002*: Specify type and purpose of warehouse, Forecast and analyze expected demand, Establish operating policies, Determine inventory levels, Form classes (of products), Departmentalize (into areas) and establish general layout, Partition into storage areas, Design material handling, storage and sorting systems, Design aisles, Determine space requirements, Determine input/output points, Determine docks, Determine the storage arrangement, Form picking zones*, [8],

15. Waters, 2003: *Estimate future demand, Forecast movements through warehouse, Compare available handling equipment, Calculate the space needed for storage and movement, Identify which materials should be close to each other, Develop outline plans, Finalize plan*, [19],

16. Rushton, Croucher, Baker, 2006: *Define business requirements and design constraint, Define and obtain data, Formulate a planning base, Define the operational principles, Evaluate equipment types, Prepare internal and external layouts, Draw up high-level procedures and IS requirements, Evaluate design flexibility, Calculate equipment quantities, Calculate staffing levels, Calculate capital and operating costs, Evaluate the design against requirements, Finalize the preferred design*, [18].

The critical review of the literature proved that most of the proposed designing methods are schematic (e.g. methods No.: 3., 4., 9., 13.). Some of methods designing steps are not in logical order (e.g. methods No.: 1., 2., 6., 11., 12., 16.). There is also lack of uniformity and lack of interaction between designing steps as far as some methods are concerned. There are also some other defects of designing methods, for example: lack of a possibility of order-picking area designing (e.g. methods No.: 1., 14.). The order-picking process is a critical supply chain component for many companies to satisfy customer orders. Therefore it is really important to prepare proper possibilities of realizing this process in warehouse (warehouses) designing. Many papers are concerned with this problem and many of them are about preparing the simulation model connected to the problem e.g. [12], [20].

Another disadvantages of the mentioned methods are: a fact that methods do not treat the whole designing problem (e.g. methods No.: 1., 2., 6., 10., 15.) and at last a fact that some methods seem to be functional specification rather than designing methods (e.g. method No. 5.).

There are also advantages of these methods which were included into a new method presented in this paper, e.g. an idea of simulation while designing process.

Generally, there are many differences in designing methods. The main reason of that fact is that methods are results of different points of view of their authors on the designing process.

What is quite important, there are also some papers specifying a warehouse designing with taking into consideration a warehouse configuration, storage policies and other factors. These aspects are important not only to reduce the delivery time in a real warehouse, but also increase productivity while maintaining quality factors at competitively cost, [20]. But there are no sequence method proposed. These papers specify only some general solution to warehouses designing.

According to the authors of the report *Warehouse design: A structured approach* (2009) there still is lack of solid theoretical basis for warehouses designing methods, [3]. On the other hand, review of the literature reveals the existence of a numerous of written materials based on analysis of various aspects of warehouses designing. Among the numerous examples of there are:

- layouts and spatial plans, [24-29],
- tactics and systems used in order-picking processes, [30-33],
- selection of equipment, vehicles and equipment, including, among others: carousel shelving, palletizers, [34], [35],
- and at last but not the least problem of warehouse location, [23].

Following the critical review of the mentioned methods, the most comprehensive investigation was done by Fijalkowski's J. The method contains many groups of aspects. There are groups of aspects such as: technological, economic and organizational. There are not only aspects related to storage technology, examining the components of a project in terms of functional and spatial. Apart from them, it also shows the organizational issues, financial aspects, and insists on a comprehensive assessment stage for all the variants. In none of other methods (except for the method according to Korzen) has been proposed such a rich compilation of individual elements of the designing as in Fijalkowski's method. Due to the complexity of the Fijalkowski's warehouses designing method it was decided, after implementing some change in original method, to prepare a computer tool supporting the warehouses designing: *OL09* software. It should be noted that this method is labor and time-consuming. It requires long and careful calculations. A warehouse designer's work can be greatly accelerated by using an advanced software. The purpose of this software is not to exclude a designer of the designing process. Many decisions must be taken by them regardless of whether he uses a computer tool of supporting his work or not. The first important and rational aspect of using a computer tool is the ability of quickly designing a quantity of a design's variants. Another important factor for the support is preparing relatively fast calculations. The third aspect is to present results in an illustrative manner, facilitating communication between a designer of the warehouse and a principal.

III. Formalizing The Description of The Warehouses Designing Method

There was decided to prepare a computer tool supporting the warehouses designing: *OL09* software. *OL09* software was the last stage of the research. First there had to be prepared the warehouses designing method – method based on Fijalkowski's method enriched with a few new designing steps. To develop mentioned compilation of existing method and its enrichment, there had to be done the formalization of the description of the warehouses designing method. It has been done with a specific modeling language: *IDEF0*.

Integration Definition for Function Modeling is a modeling methodology for describing manufacturing functions, which offers a functional modeling language for the analysis, development, reengineering, and integration of information systems, business processes or software engineering analysis.

In order to build a functional model for computer-aided designing tool *OL09*, there were used *IDEF0* graphical notation rules. This was done for the reason that the *IDEF0* allows the preparation of graphic documentation describing a set of interrelated activities that occur in the warehouses designing steps. Documentation is an important contribution to the implementation of a *OL09* software. *IDEF0* is part of the *IDEF* – modeling languages in the field of software engineering, [1].

While the functional flow block diagram is used to show the functional flow of a product, *IDEF0* is used to show data flow (here: designing steps inputs and outputs), system (here: method) control, and the functional flow of lifecycle processes (here: designing steps after-effects). The graphical notations consist of graphic symbols and diagrams. The general view of function box used in *IDEF0* is shown on fig. 1.

Fragment of the functional model, as an example of formalizing idea, is shown in fig. 2.

IV. The Model of Warehouses Designing Method

A model of a computer-supported designing is a physical model due to focusing on an implementation of a software. An implementation represents software itself and software's architecture.

The outline scheme of the model of computer-supported warehouses designing in general form is shown in fig. 4. This is abbreviated form of the method's model which was done with *IDEF0* methodology – as it was mentioned, the functional model consists of 40 diagrams therefore it is not possible to show them all.

In the model of warehouses designing method, there are included:

- system functions modeling,
- the input data (assumptions),
- the procedure for warehouses designing,
- the procedure for optimization of functional and spatial areas,
- output data (for every *n* variants).

It must be particularly emphasized that the method consists of 2 procedures – mentioned before.

A complex variants evaluation is not an integral part of the model. Nevertheless it has been included in order to identify opportunities for designing method development.

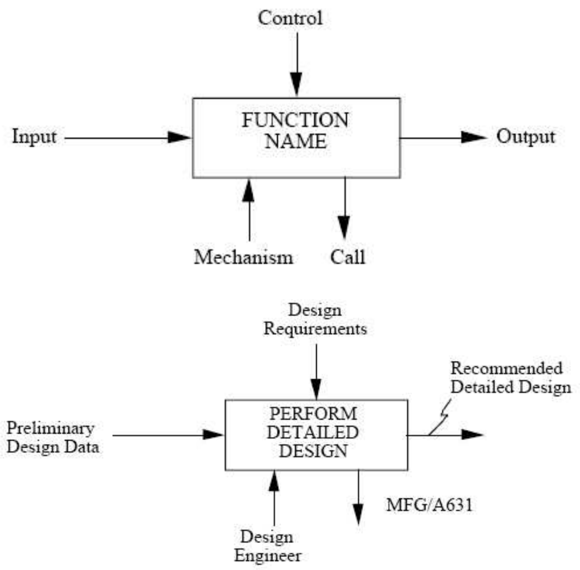

Fig. 1. Labels and names semantics used in *IDEF0*, general idea (a top part of figure) and example (a bottom part of figure) Source: [1]

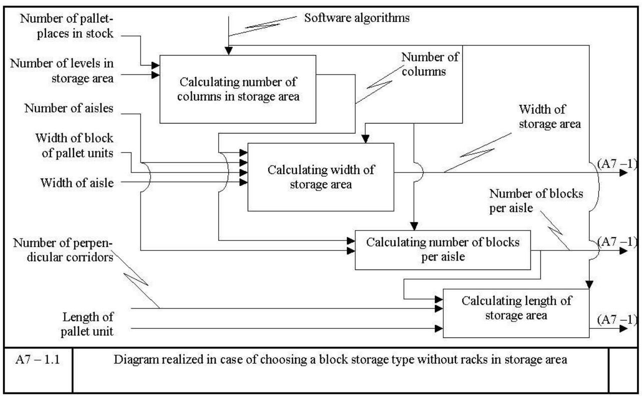

Fig. 2. The diagram for part of designing step No. 6.

V. The Procedure for Warehouses Designing

The procedure for warehouses designing consists of 3 phases: task defining, solution designing, solution evaluation.

Bolded designing steps (below) are those, in which changes were made in relation to the 'original' method (understood as Fijalkowski's method) or those which did not occur in the 'original' method. The reasons of changes are mentioned bellow.

The composition of the task defining phase includes the following steps:

- designing step No. 1: to choose designing parameters which can be variable in various variants and to define a range of parameters changeability,
- designing step No. 2: to define a structure of supplies (outer inputs) and shipments (outer outputs) outside of a warehouse,
- designing step No. 3: to define a structure of internal inputs and outputs,
- designing step No. 4: to identify data connected with work organization in warehouse,
- designing step No. 5: to identify parameters of evaluation.

The composition of the solution designing phase includes the following steps:

- designing step No. 6: to make a sketch of a spatial-functional layout,
- **designing step No. 6.a: to use spatial optimization tool** (designing steps No. 6.a and No. 6.b - not discussed in the paper),
- **designing step No. 6.b: to calculate a minimal capital spending coefficient and a warehouse space balancing coefficient,**
- designing step No. 7: to prepare description of the material-flow processes and information-flow processes in a warehouse,
- designing step No. 8: to make a plot of a flow of materials and information on a warehouse layout,
- designing step No. 9: to identify, to describe materials (or information) points of origin and materials (or information) destination points,
- designing step No. 10: to define quantity of units (materials and information) which flow on the routes between points mentioned in designing step No. 9 and to define a schedule of processes realized on these routes,
- **designing step No. 11: to define geometric and technical parameters of routes,**
- **designing step No. 12: to prepare material-flows or information-flows documentation and transport cycles documentation,**
- **designing step No. 13: to calculate the durations of each transport cycle (or other processes),**
- **designing step No. 14: to define operating parameters and elementary costs for resources of transport and elementary costs of human labor for workers,**
- designing step No. 15: to calculate a daily labor-intensive of material-flow processes realized by equipment, a daily reduced labor-intensive of material-flow processes realized by workers, a daily reduced labor-intensive of information-flow processes realized by equipment and a daily reduced labor-intensive of information-flow

processes realized by workers,

- designing step No. 16: to calculate a reduced number of resources and workers,
- designing step No. 17: to draft organization of work,
- designing step No. 18: to calculate warehouse's capital spending and annual operational costs and indicators.

The composition of the solution evaluation phase includes the following steps:

- designing step No. 19: to calculate a reduced labor-intensive of resources, equipment and workers, a reduced number of resources and a reduced number of employees,
- **designing step No. 20: to calculate indicators: a real-efficiency utilization coefficient and a cost-efficiency utilization coefficient,**
- **designing step No. 21: to calculate a daily physical activity of employees,**
- **designing step No. 22: to compare, to evaluate and to make a complex variants evaluation and to choose the best design variant.**

Designing steps No. 6.a and No. 6.b are optional steps for designing step No. 6. The authors of the paper [3] came to the conclusion that analytic designing is not enough. At the same time a warehouse – after making an analytic design of it – should be subjected as a simulation object. Therefore it was decided to prepare optimization tool which is based on simulation idea. Simulation here is a part of optimization in the research project. It helps to generate a lot of variants in a relatively fast way. The part of simulation in the software is narrowed to calculation and plotting a proper drawing. An optimization procedure was prepared of the spatial and functional design. In practice, there can only be defined the optimal sizes of the building blocks and areas only for one, predefined designing object. Too many parameters are involved for 'global' optimization be realized. Therefore it was decided to consider a problem of suboptimization of functional and spatial areas in warehouses.

The conclusion is that there was enrichment done to designing step No. 6 with the optional designing steps of optimization of functional and spatial areas. What is important is that this optional designing steps are connected to designing a warehouse such as a warehouse not a cross-docking facility because cross docking is a technique that eliminates storage and order-picking processes of a warehousing operational scheme (which is not researched here, but there can be found some information in [22]) still allowing it to serve its receiving and shipping functions.

Moreover there were proposed some changes in the arrangements of the designing procedure.

The first change concerns designing steps No. 11 and No. 12. Originally designing step No. 12 preceded designing step No. 11. The change was done because technical parameters of routes have to be defined first. Then a designer can define material-flows or information-flows documentation and transport cycles documentation. That is because they have to generate the idea which routes would be taken by which load moving.

The second change concerns designing steps No. 13 and No. 14. Originally designing step No. 14 preceded designing step No. 13. The change was done because calculations of the durations of each transport cycle is a part of transport cycles documentation, which is done in 12. The procedure for warehouses designing should be as heuristic as it is possible (with exception of feedbacks).

As designing step No. 20 calculations of new indicators are suggested: a real-efficiency utilization coefficient and a cost-efficiency utilization coefficient. The new indicators are predefined, [5].

The order of designing steps No. 21 and No. 22 is changed because of the fact that designing step No. 20 was inserted into the procedure.

VI. The Procedure for Optimization of Functional and Spatial Areas

Optimization is a method of determining the best (optimal) solution (search for extreme function) from the viewpoint of a specific criterion (index) of quality (e.g. cost, route, efficiency).

Formulating of optimization task (in this case: the mathematical model of the procedure for optimization of functional and spatial areas) is reduced to:

- adopting data (systematically choosing input values),
- determine the decision variables,
- identify constraints (an allowed set),
- task objective function (computing the value of the function).

More generally, optimization includes finding 'best available' values of some objective function given a defined domain, including a variety of different types of objective functions and different types of domains.

Procedure of suboptimization of functional and spatial areas is part of warehouses designing method. Schematic view of generalized form of the procedure for optimization of functional and spatial areas is shown in fig. 3. Since the main part of this paper is to describe designing procedure, the optimization procedure is here described very briefly. In the developed warehouses designing method, particular emphasis has been put on optimizing the spatial and functional layout. This problem is connected to the preparation of procedure for functional and spatial areas suboptimization, and its implementation in the form of *Suboptimisation of functional and spatial areas* module in *OL09* software. Suboptimization among others refers to choosing the appropriate types of storage in a storage area and an order-picking area. The types are selected in such a way that the capital spending for the construction of the warehouse were as low as possible (a minimal capital spending coefficient) taking into account the rational approach to planning a space inside the building (a warehouse space balancing coefficient).

VII. *OL09* Software

The prepared software helps to design a part of the logistics system. This part of logistics system is the warehouse. The software is based on the warehouses technological designing model (functional model). The model has been developed in the form of 40 diagrams. These diagrams are elements (unpublished in the paper beside one of diagrams, fig. 2.) of the scheme shown in fig. 4. The model is the result of reinterpretation, and further implementation, of 21 designing steps method developed by Fijalkowski's J., [5]. 21-steps method has been upgraded with adding designing step No. 6.a., No. 6.b. and No. 20.

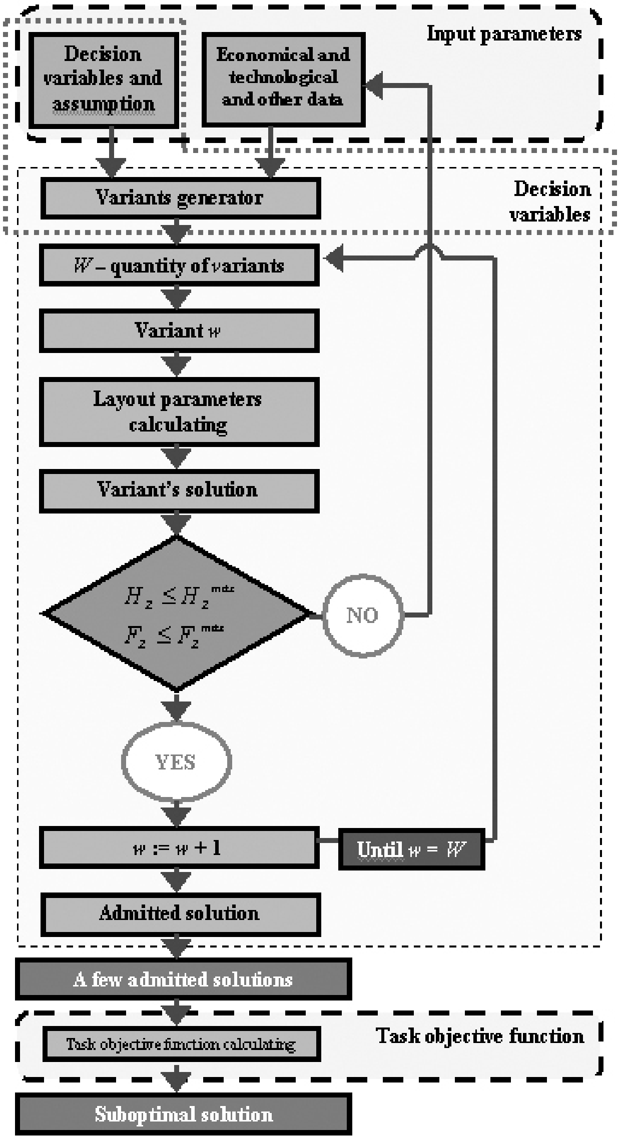

Fig. 3. A scheme of a procedure for optimization of functional and spatial areas

It should be noted that not all designing steps can be fully supported by the software. Involving a designer - very important within whole designing - is in these steps an essential requirement.

The procedure for warehouses designing is divided into three phases. Similar sections (phases) were used in the software. *OL09* software consists of three sections: *Task Defining, Solution Design, Solution Variant Evaluation*.

Taking into account mentioned sections, the software consists of the following modules:

- *Task Defining*,
- a group of modules - *Solution Design: Spatial-functional Layout Calculations, Sketch of a Spatial-functional Layout, Output Data for a Spatial-functional Layout, Origin and Destination Points, Material-flows Chart, Transport Cycles, parts I-III, Quantitative Parameters, Capital Spending and Costs, A Real- and A Cost-efficiency Utilization Coefficient.*,
- *Solution Variant Evaluation*,
- *Optimization of Functional and Spatial Areas*.

Task Defining module is based on the following steps of warehouses designing procedure: from No. 1 to No. 5 (fig. 4.).

Modules: *Spatial-functional Layout Calculations* and *Sketch of a Spatial-functional Layout* support realization of designing step No. 6 (fig. 4.). It should be noted that there are optional designing steps such as No. 6.a and 6.b which are a base for optimization of functional and spatial areas (the module *Optimization of Functional and Spatial Areas* is not discussed in the paper).

Designing step No. 7 has a descriptive character therefore it is not implemented in the software.

Material-flows Chart module is based on designing step No. 8 (fig. 4.).

Output Data for a Spatial-functional Layout module summarizes the preliminary designing phase. At the same time at this level, a preliminary verification of a variant is being realized. Some restrictions are checked. These restrictions are connected with maximal permissible warehouse area and its maximal permissible height.

Origin and Destination Points module is based on the following designing steps of warehouses designing procedure: No. 9 - No. 11 (fig. 4.).

Modules *Transport Cycles, part I-III* are based on the designing steps No. 12 and No. 13 (fig. 4.).

Quantitative Parameters module is based on the designing steps No. 15 and No. 16 (fig. 4.).

Capital Spending and Costs module is based on the following steps of warehouses designing procedure: No. 14, No. 17, No. 18 (fig. 4.).

A Real-efficiency Utilization Coefficient and A Cost-efficiency Utilization Coefficient module is based on designing step No. 20 (fig. 4.).

Solution Variant Evaluation module is based on the following steps of warehouses designing procedure: No. 19, No. 21 (fig. 4.).

Designing step No. 22 (fig. 4.) is not a subject of the software.

On fig. 5. there can be found an example view of *OL09* software (*Quantitative Parameters* module). *OL09* software was prepared in Polish version only. Therefore it has to be specified with a proper precision what can be found on the fig. 5. The specifications can be found in figure's descriptions.

VIII. *OL09* SOFTWARE EXAMPLE

The variant No. 2 of the solution is calculated with using of *OL09* software in contrary to variant No. 1 which is calculated analytically (Table 1.).

Table 1. Chosen output parameters calculated for the procedure without & with using *OL09* software

Name of parameter	Var. No. 1	Var. No. 2
1	*2*	*3*
Capital spending [PLN]	29 117 120.-	28 827 120.-
Annual operational costs [PLN/year]	7 006 960.-	6 707 762.-
An investment rate [PLN/nr. of pallet places]	3 385.71	3 351.99
A costs rate	0.67	0.68
A cost of one unit's material-flow rate [PLN/ pallet with goods units]	54.32	52.00
Quantity of equipment by type: W1/3/7/12	18/11/10/18	17/10/9/18
Quantity of workers by category: L1/2/3/4	36/22/20/36	34/20/18/36

Comparative results are different for the two types of solutions although the differences are not substantial. These differences are due to more accurate calculations in case of the *OL09* software using. Round numbers in the computer tool are limited only to the computational power of a computer. Therefore, it provides an accurate value of considered parameters. A kind of anxiety arise from different quantity of lift-tracks of the same type or quantity of employees of the same category.

In the solution in which *OL09* software assisted these are lower. Oversizing of parameters in warehouses designing is a danger, therefore, additional quantity of lift-tracks obtained in analytic solution could reach high value of the reserve value of work. Therefore, additional quantity of lift-tracks could be not in usage. It is well known that in such a situation it is better to buy another lift-track than 'suffer' the consequences of oversizing at the designing stage, especially of the financial aspect – prices of this type of equipment can be really high

IX. .CONCLUSION

The paper presents briefly the way of preparing implementation of warehouses designing procedure (as a part of method). Implementation was made in the form of computer software consisting of modules. It gives a strong possibilities for practical usage in designing. Implementing of the procedure (as a part of method) was the priority of research.

Some theoretical and practical aspects connected with the problem were identified.

The practical aspects are, among others:

- warehouses designing issue formalization and analysis – the usage of graphic notation (*IDEF0* allowed to prepare graphic description documentation of a set of interrelated activities occurring in facilities designing),

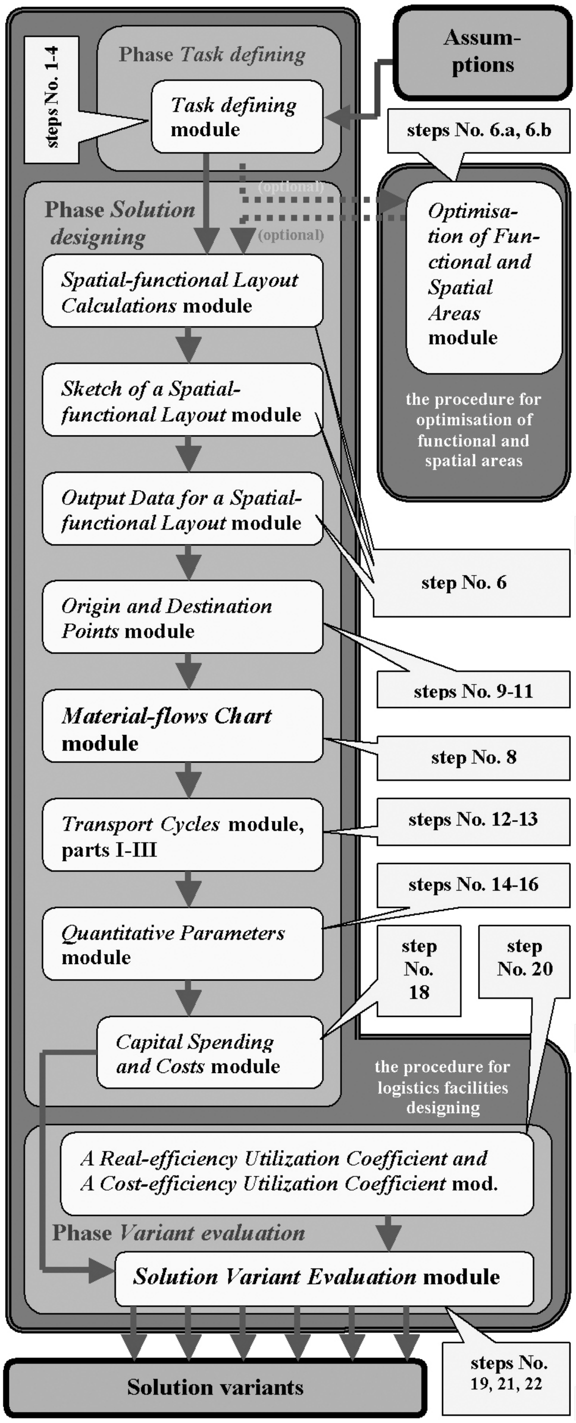

Fig. 4. The scheme of conducting *OL09* software with the relations between designing steps and modules of *OL09* software

- assessment of designing method based on existing methods with addition of some designing steps and enrichment with the procedure for optimization of functional and spatial areas (enrichment designing step No. 6, changing the order of steps No. 11 and 12, No. 13 and 14, adding new indicators, [5]),

- elaborating a proposition of mathematical formulas for calculations connected with warehouse geometry.

Among the practical aspects there are such as:

- graphical 2D module in software (an example sketch is shown on fig. 6.)
- optimization module,
- instruction for using the software,
- obtaining of variant solutions with using the software (freeing the designer from the painstaking work, repetitive tasks such as calculations, drawing sketches of warehouses layout.).

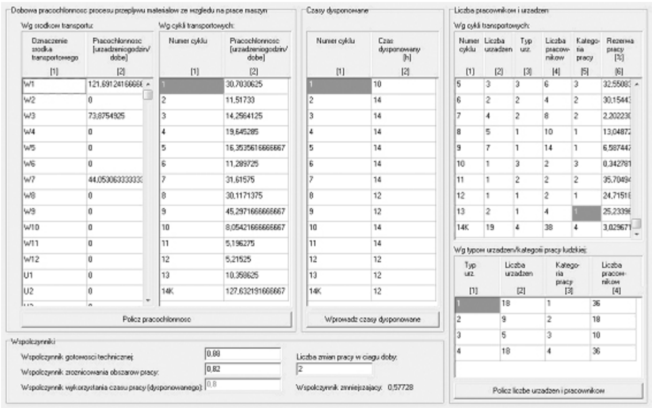

Fig. 15. Quantitative parameters module; the set of values concerns of indicators such as: a daily labor-intensive of warehouse processes, a daily labor-intensive of material-flow processes realized by equipment, a daily reduced labor-intensive of material-flow processes realized by workers, a number of equipment by type, a number of workers by category

The important fact is that *OL09* software takes into consideration most common known types of storage (both in a storage area and in an order-picking area) such as:

- a storage in stocks on a warehouse's floor,
- a storage in rows on a warehouse's floor,
- a storage in rows in a warehouse's rack with using front fork lift truck,
- a storage in rows in a warehouse's rack with using front-side fork lift truck,
- a storage in rows in a warehouse's rack with using a low and the average height rack stacker cranes,
- a storage in rows in a warehouse's rack with using a high rack stacker cranes between racks forming a support structure of the roof and walls of warehouse.

There still is a requirement for software development and further research. There are demands to: increase the flexibility of software by implementing other types of spatial systems and types of storage, extend the software by one module for different types of loading units, make preparation of a complex variants evaluation module for comparing different variants of the same warehouse design; this module would become a first step on a way of preparing database of designing indicators.

There should be also realized more precise research on stacker crane designing in technological way within *OL09* software. Development and further researches to this problem should be based on recent possibilities described in the literature such as [21].

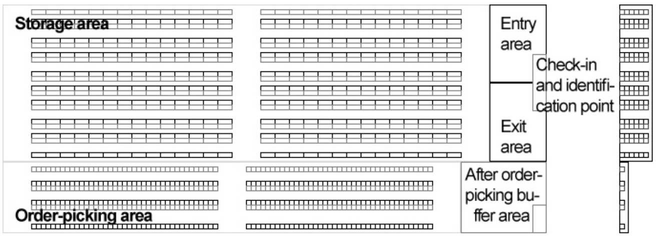

Fig. 6. An example sketch of warehouse layout in solution with using graphical 2D module in *OL09* software; top view on the left side of the figure and cross section view on the right side of the figure

What is important, *OL09* software enables to research other kind of problems, beside the important fact of obtaining of variant solutions in designing process. For example it enables to study the effects of impact of warehouse geometry expressed through its basic dimensions on logistics indicators. What is meant by warehouse dimensions are its width, length and height. The study connected to the problem was realized with using the software: *OL09* and presented in [12]. The software provides support for the technological part of the logistics system design: warehouse design. The idea of simulation was used for the research. Author assumed that the research will be conducted for the warehouse where the type of storage in storage area is rows rack storage (pallet selective rack elevation storage) with using turret truck, man-up turret truck or VNA truck (very narrow aisle truck). In turn, storage in order-picking area is rows storage on a warehouse floor (pallets pile up in a row) with using horizontal order picker. *OL09* software for such a combination of spatial organization may consider more than 56,000 alternatives. Due to the limitations imposed by the design assumptions (the area of land under the building - the surfaces of the rectangular area was adopted) and other limitations described in details in the paper [12] in the final analysis, 111 variants was taken into account. For these 111 alternatives has been done full technological projects. The limiting of alternatives was done with using *Optimization of Functional and Spatial areas* module.

This proves that *OL09* is universal software which means it can be used not only for warehouses designing.

REFERENCES

[1] Announcing the Standard for Integration Definition For Function Modeling (IDEF0), Draft Federal Information Processing Standards Publication 183, 1993

[2] Apple J.: Plant Layout and Material Handling, third ed. John Wiley, New York, 1977

[3] Ashayeri J., Gelders L.F., Warehouse design optimization zamieszczony, European Journal of Operational Research 21 (1985), pp. 285-294, Elsevier 1985

[4] Bodner, D., Govindaraj, T., Karathur, K.N., Zerangue, N.F., McGinnis, L.F.: A process model and support tools for warehouse design, 02 NSF Design, Service and Manufacturing Grantees and Research Conference, 2002

[5] Fijalkowski J., Warsaw University of Technology, private communication, 2011
[6] Firth D., Apple J., Denham R., Hall J., Inglis P., Saipe A.: Profitable Logistics Management. McGraw-Hill Ryerson, Toronto, 1988
[7] Govindaraj T., Blanco E., Bodner D., Goetschalckx L., McGinnis L., Sharp P.: Design of warehousing and distribution systems: An object model of facilities, functions and information, IEEE Intern. Conference on Systems, Man and Cybernetics, Nashville, Tennessee, USA, p. 1099–1104, 2000
[8] Hassan M.: A framework for the design of warehouse layout, Facilities 20 (13/14), p. 432–440, 2002
[9] Hatton G.: Designing a warehouse or distribution center, Gattorna, J.L. (Ed.), The Gower Handbook of Logistics and Distribution Management, fourth ed. Gower Publishing, Aldershot, p. 175–193, 1990
[10] Heskett J., Glaskowsky N., Ivie R.: Business Logistics, Physical Distribution and Materials Handling, second ed. Ronald Press, NY, 1973
[11] Kostrzewski M.: Warehouses designing method – a study of a procedure for warehouses designing and its OL09 software implementation, Archives of Transport, submitted for publication
[12] Kostrzewski M.: Warehouse Geometry Studies with Using Simulation Methods, Proceedings, Intertech 2010, Poznan
[13] Mulcahy D.: Warehouse Distribution and Operations Handbook McGraw-Hill, NY, 1994
[14] Oxley J.: Avoiding inferior design, Storage Handling and Distribution 38, p. 28–30, 1994
[15] Rouwenhorst B., Reuter B., Stockrahm V., van Houtum G. J., Mantel R. J., Zijm W. H. M.: Warehouse design and control: Framework and literature review, EJoOR No. 122, 2000
[16] Rowley J.: The principles of warehouse design, The Institute of Logistics & Transport, Corby, 2000
[17] Rushton A., Oxley J., Croucher P.: The Hand-book of Logistics and Distribution Manage-ment, second ed. Kogan Page, London, 2000
[18] Rushton A., Croucher P., Baker P.: The Hand-book of Logistics and Distribution Manage-ment, third ed. Kogan Page, London, 2006
[19] Waters D.: Logistics: An Introduction to Supply Chain Management, Palgrave Macmillan, NY, 2003
[20] Buil R., Piera M.A.: New warehouse design methodology at strategic and operational level, Dept. of Telecommunications and Systems Engineering, Autonomous University of Barcelona, Spain, 6th WSEAS International Conference on System Science and Simulation in Engineering, Venice, Italy, November 21-23, 2007, pp. 196-201
[21] Dorner J., Blaho M.: Design and control of an automatized stacker crane for warehouses Instutute of control and industrial informatics Faculty of Electrical Engineering and Information Technology Sloak University of Technology, Slovak Republic, WSEAS Recent Advances in Manufacturing Engineering
[22] Kapetanios G. Vrisagotisa V., Pappas D., Panta M., Siassiakos K.: Mathematical Tool For Warehousing Optimization Mechanical Department, Logistics Department, Technological Institute of Chalkida, Greece, Proceedings of the 9th WSEAS International Conference on Simulation, Modelling and Optimization
[23] Dohmen L.: An Optimization Technique for the Solution of an Enhanced Warehouse Location Problem, Research Institute for Rationalization and Operations Management at Aachen University of Technology , Pontdriesch, Germany, Proceedings of the 3rd WSEAS International Conference, Interlaken, Switzerland
[24] Ashayeri J., Goetschalckx M., Analysis and design of order picking systems, in: Ninth International Conference on Automation in Warehousing, 1988, pp. 125-135, 1988
[25] Bassan Y., Roll Y., Rosenblatt M.J.: Internal layout design of a warehouse, AIIETransactions 12 (4), 1980
[26] Berry J.R.: Elements of warehouse layout, International Journal of Production Research 7 (2), 1968
[27] Duve B., Mantel R., Logitrace: A decision support system for warehouse design, in: Progress in Material Handling Research, The Material Handling Industry of America, Charlotte, NC, 1996, pp. 111-124
[28] Grochowski L., Sosinski P.: Warehousing Space Modeling, The Archives of Transport No. 3 vol. 19, Warszawa 2007
[29] Stadtler H.: Optimal dimensions for automated storage/retrieval systems, in: Progress in Material Handling Research, The Material Handling Industry of America, Charlotte, NC, p. 551-571, 1996
[30] Armstrong R.D., Cook W.D., Saipe A.L: Optimal batching in a semi-automated order picking system, Journal of the Operational Research Society 30 (8), (1979), p. 711-720, 1979
[31] Brynzer H., Johansson M., Medbo L., A methodology for evaluation of order picking systems as a base for system design and managerial decisions, International Journal of Operations & Production Management 14 (3) (1994), pp. 126-139
[32] Yoon C.S., A structured procedure for order pick system analysis and design, Technical Report MHRC-TD-91-13, Georgia Institute of Technology, Atlanta, GA, 1992.
[33] Yoon C.S., Sharp G.P., Example application of the conitive design procedure for an order picking system: Case study, European Journal of Operational Research 87 (1995) 223-246
[34] Bartholdi J.J., Platzman III L.K.: Design of efficent binnumbering schemes for automated warehouse carousel storage systems, Technical Report MHRC-TR-85-09, Georgia Institute of Technology, Atlanta, GA, 1985
[35] Bunde L.M., Graves R.J.: The multi-line palletizer material flow problem, in: Progress in Material Handling Research: 1996, p. 179-191, The Material Handling Industry of America, Charlotte, NC, 1996

Kostrzewski M. - June 2011: resolution of Transport Faculty Council, conferring the title Doctor of Technical Sciences, Transport Faculty, Warsaw University of Technology, Warsaw, Poland supervisor: Prof. Ambroziak T., June 2005: graduate of Faculty of Transport, Warsaw University of Technology, Warsaw, Poland, supervisor: Dr. Eng. Fijalkowski J.

Scientific activities of his are connected to logistics systems designing, monitoring and analyzing of technical state of rail vehicles and track settlement. He works in MONIT Project - „Monitoring of Technical State of Construction and Evaluation of its Lifespan" which is a research Project within the Innovative Economy Operational Programme, Measure 1.1 Support for scientific research for establishment of a knowledge – based economy, Sub-measure 1.1.2 Strategic programmes of scientific research and development works. Project co-financed by the European Regional Development Fund under the Innovative Economy Operational Programme. He prepared 6 papers in 2011 (one of them in a monograph book), 4 papers in 2010, 2 papers in 2009, 1 paper in 2008, 3 papers in 2007, 3 publication in 2006.

Dr. Kostrzewski was awarded in 2006 with *1st Prize at Professor Zbigniew Korzen Contest for the best master thesis in logistics field* by International School of Logistics and Transport in Wroclaw and Polish Logistics Association (Dolny Slask Branch).