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OPTIMIZATION OF THE WAREHOUSE ELEMENTS OF THE ENTERPRISE'S LOGISTICS SYSTEM

ABSTRACT

Background: The article is devoted to the optimization of the warehouse process in an enterprise. The quality of the warehouse process and its effective implementation depends on the operation of the warehouse logistics system and warehouse infrastructure elements in the enterprise. Effective implementation of the warehouse process is possible provided that the logistic process is the best due to the specific evaluation indicators of this process. It is connected with the possibility of using appropriate procedures ensuring maximum efficiency of the warehouse logistics system, including the determination of the optimal set of its elements. Therefore, one of the most important problems, apart from many others, is the development of a procedure that allows optimal determination of the components of the warehouse logistics system. The methods of determining the elements of a warehouse logistic system, on the example of storage racks, using a multi-criteria optimization method, problems connected with it, and proposals for solving them are presented in this study.

Methods: Based on the developed mathematical model of multi-criteria optimization, an algorithm for obtaining the optimal storage system has been built, the main elements of which are the areas of operation: determining the optimal set of shelves; determination of the optimal picking technology; determining the optimal transport system; determination of the optimal technology for the automation of the warehouse process. The algorithm for obtaining elements of the optimal storage system includes the following stages: determining the set of acceptable solutions X; determining the criterion function for each area of activity F; determination of solutions for local optimization tasks according to the "ideal point" method for each area of activity; determination of the global solution of the elements of the optimal solution.

Results: The computational experiment consisted in using the developed algorithm to implement the warehouse logistics optimization procedure in the selection of storage racks. The scope of implementation includes: determining the set of acceptable solutions X, determining

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the value of the criterion function F(X) and determining the dominance relationship Φ; solution of the multicriteria optimization task; visualization of the solution.
Conclusions: The developed methodology presents, on the example of selection of storage racks, the way of optimization of the warehouse logistics process of the company. Analysis of the results of the numerical experiment of the methodology showed the usefulness of the developed algorithm to determine the elements of the optimal warehouse system of the company. The main advantage of the algorithm is its universality, which allows its use to select elements of other areas of the company's logistics process.

Keywords: warehouse logistic system, optimization of the logistics system, selection of storage racks.

INTRODUCTION

Effective implementation of the warehouse process in an enterprise is possible provided that the logistics process implemented is the best due to certain criteria. Hence, there is a need to develop a procedure that allows optimal designation of elements of a warehouse logistics system. Effective implementation of the warehouse process in the enterprise is possible provided that the logistics process is the best due to the specified criteria. Hence, there is a need to develop a procedure that allows optimal designation of elements of a warehouse logistics system. In the study, on the example of storage racks, methods of determining the elements of a warehouse logistics system are presented. A multi-criteria optimization method was used. Problems related to this and suggestions for their solution are presented in this study.

Formulating the optimization task, as presented in studies [Ameljańczyk 1986, Coyle and Bardi and Langley 2007, Tylicki and Latoś 2015] it is difficult to determine one scalar quality function F, because acceptable solutions X may have many different properties whose values testify to the quality of the solution. Hence the need to formulate a multicriteria optimization task with N quality indicators in the form of the F criterion function, which assigns to each acceptable solution $x \in X$ and there is a set of criteria $f_i \in F$ its numerical assessment in the form of the vector F(x). In the case of multi-criteria optimization, if there is a set of acceptable solutions $x_i \in X$ and there is a set of criteria $f_i \in F$ and a set by f_i dominance relation $\Phi_i \in \Phi$, the solution to the optimization task is implemented according to the following algorithm [Ameljańczyk 1986, Tylicki 2015]:

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1. Normalization of criterion space (space D*).
2. Determining the coordinates of an ideal point d **:
3. Calculation of the norm value norm │•│ with the parameter p=2 (norm │•│ is a measure of the distance of results d *∈D * from the ideal point d ** (r_i (D*)).
4. Determining the optimal result x^o (eg $x^o=x_2$ it means that the object x_2 is the best according to the criterion function F).

OPTIMIZATION OF THE WAREHOUSE LOGISTICS SYSTEM

The supply process is an important element of the logistics process of enterprises in the field of machines, spare parts and consumables. The supply process is implemented by a supply system created by a set of organizational cells along with the relationships between them. The main task of the company's logistics system is to collect, maintain and distribute inventory, hence one of the most important subsystems of the company's supply system is the warehouse logistics system MSL [Coyle and Bardi and Langley 2007, Jonak and Nieoczym 2004].

The procedures for determining the optimal storage system MSL^o use an algorithm whose main elements are, inter alia, the following areas of operation [Mindur 2017, Niziński and Żurek 2011]:

a) determining the optimal set of shelves;
b) determination of optimal picking technology;
c) determining the optimal transport system;
d) determining the optimal technology to automate the warehouse process.

The algorithm for obtaining the optimal MSL^o storage system, according to studies [Tylicki 2015, Tylicki and Latoś 2015], includes the following stages:

1. Determining the set of acceptable solutions x∈X.
2. Determination of the criterion function for each area of action F.
3. Determining the solutions of local optimization tasks according to the "ideal point" method for each area of operation.
4. Determination of the global solution elements of the optimal MSL^o solution.

The solution scheme for the optimization task of determining the optimal MSL^o storage system is proposed to be implemented according to the algorithm presented above, i.e.

1. Normalization of criterion space.
2. Determining the coordinates of an ideal point.

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3. Calculation of the norm value |•| with the parameter p=2.
4. Determining the optimal result xo in the optimization task.

As a result, optimal solutions are obtained with properly determined weight values wj depending on the distance $r_i(D^*)$. Appropriate solutions depending on the adopted option (local solution or global solution) take the form [Ameljańczyk 1986, Tylicki 2015]:

a) for one solution (local solution):
- optimal type of storage racks x_1^o,
- optimal x_2^o load picking technology,
- optimal transport system x_3^o,
- optimal x_4^o warehouse process automation technology;

b) for optimal solutions (global solution) with assigned functions of the X_w balance:
- optimal types of storage shelves $\{w_1x_{1,1}^o, w_2x_{1,2}^o, ..., w_kx_{1,k}^o\}$,
- optimal technologies for load picking $\{w_1x_{2,1}^o, w_2x_{2,2}^o, ..., w_nx_{1,n}^o\}$,
- optimal transport systems $\{w_1x_{3,1}^o, w_2x_{3,2}^o, ..., w_mx_{3,m}^o\}$,
- optimal technologies for warehouse process automation $\{w_1x_{4,1}^o, w_2x_{4,2}^o, ..., w_px_{3,p}^o\}$.

CHOICE OF WAREHOUSE RACKS

In the presented areas of the warehouse process, one of the problems is the selection of storage racks, hence it will be the subject of further analysis of the optimization of the company's logistics warehouse system. The algorithm diagram for the selection of storage racks includes stages, they are:

1. Determining the set of acceptable solutions X.
2. Determination of the criterion function F together with the dominance relation Φ.
3. Determining the optimal xo solution.

Up to 1.

Elements of set X are defined by appropriate features related to the functioning of the warehouse. For example, the set X may contain, among others, the following elements [Tylicki and Latoś 2015, Twaróg 2003]:

a) x_1 - shelf racks;
b) x_4 - gravity pallet flow racks;
c) x_5 - sliding shelves;
d) x_6 - vertical and horizontal circular shelves;

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e) x_7 - automatic lift racks Lean Lift;

f) x_8 - tunnel racks.

Up to 2.

Elements of set F should be related to the features of stocks and their storage technology. Below, for example, based on studies [Tylicki and Latoś 2015, Twaróg 2003], the criteria are presented:

1. In the enterprise logistics system assessment group:

a) warehouse utilization rate f_{11};

b) the average cost of storage location indicator f_{12};

c) storage cost index f_{13}.

2. In the enterprise warehouse management assessment group:

a) utilization rate of the storage capacity f_{21};

b) rate of storage capacity utilization f_{22};

c) storage cost index f_{23}.

3. In the group evaluating the effectiveness of the company's logistics activities:

a) storage capacity utilization rate f_{31};

b) the indicator of the intensity of the use of warehouse space f_{32};

c) rate of warehouse workers' work efficiency f_{33}.

4. In the group evaluating the efficiency of warehouse shelves in the aspect of the company's logistics operations [Tylicki and Latoś 2015, Twaróg 2003]:

a) f_{41} - the criterion of the shelf cost;

b) f_{42} - criterion of applicability of the FIFO rule;

c) f_{43} - criterion of susceptibility to automation of the warehouse process.

Up to 3.

The algorithm presented at this stage is related to the formulation and solution of the optimization task for storage racks $<X, F, \Phi>$. The solution of the optimization task is proposed, according to the procedure presented above, to be carried out according to the algorithm as in point 3, i.e.: normalization of the criterion space, determination of the coordinates of the ideal point, calculation of the norm value $|\bullet|$ with the parameter p = 2, determination of the optimal result xo in the task optimization (selection of the optimal shelf)..

Of course, as a result of implementing the above algorithm, optimal solutions can be obtained with specific weight values w_j depending on the distance $r_i(D^*)$. Then, optimal solutions for individual areas of activity, depending on the adopted option, take the form of:

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a) for one solution - the optimal type of xo shelving;

b) for optimal solutions with appropriately assigned X_w balance functions - optimal types of shelves $\{w_1x_1^o, w_2x_2^o, ..., w_px_p^o\}$.

EXAMPLE PROCEDURE FOR CHOOSING WAREHOUSE RACKS

The example presents the implementation of the warehouse logistics system optimization procedure and the results of its verification for the optimization task formulated above (selection of storage racks). The scope of implementation has been formulated on the basis of the algorithm developed above and includes:

a) determining the value of criterion function F(X) and determining the dominance relation Φ;

b) solution of the multi-criteria optimization task;

c) visualization of the solution.

Based on the above findings values of criteria $f_j \in F$ is possible by calculating their value on the basis of data obtained during the company's operations or by adopting them on the basis of expert knowledge. In developing the value of criteria for different types of storage racks $x_j \in X$ determining the value of the criteria $f_j \in F$ and dominance relations Φ, were adopted according to the second possibility [Tylicki and Latoś 2015, Twaróg 2003].

1. In the enterprise logistics system assessment group:

a) warehouse use index f_{11} with the dominance relation Φ_{11}=<MAX>: f_{11} = (number of used storage places) /(total number of used storage places);

b) indicator of the average cost of storage place f_{12} with the dominance relation Φ_{12}=<MAX>: f_{12}[PLN] = (warehouse costs [PLN, tonnes]) / (total number of used storage places);

c) storage cost index f_{13} with the dominance relation Φ_{13}=<MAX>: f_{13} = (storage costs [PLN])/(average inventory value).

2. In the enterprise warehouse management assessment group:

a) index of utilization of storage usable capacity f_{21} with the dominance relation Φ_{21}=<MAX>: f_{21} = (nominal storage capacity according to the storage space development plan [m^3]) / (total storage capacity [m^3]).

b) utilization rate of the storage capacity of f_{22} with the dominance relation Φ_{22}=<MAX>: f_{22}= (storage capacity of the storage capacity [m^3]) / (nominal storage capacity of the storage space according to the storage space plan [m^3]).

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c) storage cost index f_{23} with the dominance relation Φ_{23} =<MIN>: f_{23} = [PLN / t] = (total storage costs in the examined period [PLN]) / (value of inventory turnover according to expenditure in the examined period [t, PLN]).

3. In the group evaluating the effectiveness of the company's logistics activities:
a) indicator of the use of warehouse space f_{31} with the dominance relation Φ_{31} =<MAX>: f_{31}= (area occupied by inventory [m^2]) / (total usable area [m^2]).

b) the indicator of the intensity of the use of warehouse space f_{32} with the dominance relation Φ_{32}=<MAX>: f_{32} [PLN, tonnes / m^2]) = (inventory turnover in a given year [PLN, tonnes]) / (warehouse space [m^2]).

c) index of labor productivity of warehouse workers f_3 with the dominance relation Φ_{33}=<MAX>: f_{33} [PLN, tonnes] = (inventory turnover in a given year [PLN, tonnes]) / (number of warehouse employees).

4. In the group evaluating the efficiency of warehouse shelves in the aspect of the company's logistics operations [Tylicki and Latoś 2015]:

a) f41 - the criterion of the cost of the rack, the dominance relation Φ_{41}=<MIN>;

b) f42 - criterion of applicability of the FIFO principle, dominance relation Φ_{42}=<MAX>;

c) f43 - criterion of susceptibility to warehouse process automation, dominance relation Φ_{43} =<MAX>;

For example, [Tylicki and Latoś 2015, Twaróg 2003] can be taken:

1. For f_{11}: $f_{11}(x_1) = 0.7$; $f_{11}(x_4) = 0.8$; $f_{11}(x_5) = 0.7$; $f_{11}(x_6) = 0.8$; $f_{11}(x_7) = 0.8$; $f_{11}(x_8) = 0.8$.
2. For f_{12}: $f_{12}(x_1) = 0.7$; $f_{12}(x_4) = 0.8$; $f_{12}(x_5) = 0.8$; $f_{12}(x_6) = 0.6$; $f_{12}(x_7) = 0.5$; $f_{12}(x_8) = 0.6$.
3. For f_{13}: $f_{13}(x_1) = 0.7$; $f_{13}(x_4) = 0.8$; $f_{13}(x_5) = 0.8$; $f_{13}(x_6) = 0.6$; $f_{13}(x_7) = 0.5$; $f_{13}(x_8) = 0.6$.
4. For f_{21}: $f_{21}(x_1) = 0.7$; $f_{21}(x_4) = 0.8$; $f_{21}(x_5) = 0.7$; $f_{21}(x_6) = 0.8$; $f_{21}(x_7) = 0.8$; $f_{21}(x_8) = 0.8$.
5. For f_{22}: $f_{22}(x_1) = 0.7$; $f_{22}(x_4) = 0.8$; $f_{22}(x_5) = 0.7$; $f_{22}(x_6) = 0.7$; $f_{22}(x_7) = 0.8$; $f_{22}(x_8) = 0.8$.
6. For f_{23}: $f_{23}(x1) = 0.8$; $f_{23}(x_4) = 0.7$; $f_{23}(x_5) = 0.7$; $f_{23}(x_6) = 0.7$; $f_{23}(x_7) = 0.5$; $f_{23}(x_8) = 0.6$.
7. For f_{31}: $f_{31}(x_1) = 0.7$; $f_{31}(x_4) = 0.8$; $f_{31}(x_5) = 0.7$; $f_{31}(x_6) = 0.8$; $f_{31}(x_7) = 0.8$; $f_{31}(x_8) = 0.8$.
8. For f_{32}: $f_{32}(x_1) = 0.7$; $f_{32}(x_4) = 0.8$; $f_{32}(x_5) = 0.8$; $f_{32}(x_6) = 0.7$; $f_{32}(x_7) = 0.5$; $f_{32}(x_8) = 0.6$.
9. For f_{33}: $f_{33}(x_1) = 0.6$; $f_{33}(x_4) = 0.7$; $f_{33}(x_5) = 0.8$; $f_{33}(x_6) = 0.7$; $f_{33}(x_7) = 0.8$; $f_{33}(x_8) = 0.8$.
10. For f_{41}: $f_{41}(x_1) = 0.4$; $f_{41}(x_4) = 0.6$; $f_{41}(x_5) = 0.7$; $f_{41}(x_6) = 0.7$; $f_{41}(x_7) = 0.8$; $f_{41}(x_8) = 0.8$.
11. For f_{42}: $f_{42}(x1) = 1$; $f_{42}(x_4) = 0$; $f_{42}(x_5) = 1$; $f_{42}(x_6) = 0$; $f_{42}(x_7) = 1$; $f_{42}(x_8) = 1$.
12. For f_{43}: $f_{43}(x_1) = 0.1$; $f_{43}(x_4) = 0.3$; $f_{43}(x_5) = 0.4$; $f_{43}(x_6) = 0.8$; $f_{43}(x_7) = 0.8$; $f_{43}(x_8) = 0.8$.

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Dominance relation Φ = {Φ_{11}<MAX>, Φ_{12}=<MAX>, Φ_{13}=<MAX>, Φ_{21}=<MAX>, Φ_{22}=<MAX>, Φ_{23}=<MAX>, Φ_{31}=<MIN>, Φ_{32}=<MAX>, Φ_{33}=<MIN>, Φ_{41}=<MAX>, Φ_{42}=<MIN>, Φ_{43}=<MAX>}.

In order to solve the multicriteria optimization task, a computer program "Multi-criteria optimization task 2017" was developed [Computer program 2017, Tylicki 2015], which enables:

a) presentation of the set X_j and selection of elements $x_j \in X_j$;

b) presentation of the set F_j and selection, by the computer program operator, elements of $f_j \in F_j$ and dominance relations $\Phi_j \in \Phi$;

c) data entry according to two options: option 1 - manual data input ($f_j \in F_j$ values), option 2 - calculation of $fj \in Fj$ values based on data obtained during experimental or simulation tests.),

d) visualization of the solution of the optimization task (calculations and reporting - tables 1, 2, 3, 4).

Table 1. Values of criteria fj
Tabela1. Wartości kryteriów $f_j \in F_j$ i relacji dominowania Φ

F / X	x_1	x_4	x_5	x_6	x_7	x_8	Φ
f_{11}	0,7	0,8	0,7	0,8	0,8	0,8	MAX
f_{12}	0,7	0,8	0,8	0,6	0,5	0,6	MAX
f_{13}	0,7	0,8	0,8	0,6	0,5	0,6	MAX
f_{21}	0,7	0,8	0,7	0,8	0,8	0,8	MAX
f_{22}	0,7	0,8	0,7	0,7	0,8	0,8	MAX
f_{23}	0,8	0,7	0,7	0,7	0,5	0,6	MIN
f_{31}	0,7	0,8	0,7	0,8	0,8	0,8	MAX
f_{32}	0,7	0,8	0,8	0,7	0,5	0,6	MIN
f_{33}	0,6	0,7	0,8	0,7	0,8	0,8	MAX
f_{41}	0,4	0,6	0,7	0,7	0,8	0,8	MIN
f_{42}	1	0	1	0	1	1	MAX
f_{43}	0,1	0,3	0,4	0,8	0,8	0,8	MAX

Źródło: opracowanie własne.
Source: own work.

Table 2. Visualization of the solution for criteria f_{11} - f_{23}
Tabela 2. Wizualizacja rozwiązania dla kryteriów f_{11} - f_{23}

F / X	x_1	x_4	x_5	x_6	x_7	x_8

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f_{11}	0,7	0,8	0,7	0,8	0,8	0,8
Max (f_{11})	0,8					
f_{11}*	0,875	1	0,875	1	1	1
f_{12}	0,7	0,8	0,8	0,6	0,5	0,6
Max (f_{12})	0,8					
f_{12}*	0,875	1	1	0,75	0,625	0,75
f_{13}	0,7	0,8	0,8	0,6	0,5	0,6
Max (f_{13})	0,8					
f_{13}*	0,875	1	1	0,75	0,625	0,75
f_{21}	0,7	0,8	0,7	0,8	0,8	0,8
Max (f_{21})	0,8					
f_{21}*	0,87	1	0,875	1	1	1
f_{22}	0,7	0,8	0,7	0,7	0,8	0,8
Max (f_{22})	0,8					
f_{22}*	0,875	1	0,875	0,875	1	1
f_{23}	0,8	0,7	0,7	0,7	0,5	0,6
Max (f_{23})	0,8					
f_{23}*	1	0,875	0,875	0,875	0,625	0,75

Źródło: opracowanie własne.
Source: own work.

Table 3. Solution visualization for criteria f_{31} - f_{43}
Tabela 3. Wizualizacja rozwiązania dla kryteriów f_{31} - f_{43}

F / X	**x_1**	**x_4**	**x_5**	**x_6**	**x_7**	**x_8**
f_{31}	0,7	0,8	0,7	0,8	0,8	0,8
Max (f_{31})	0,8					
f_{31}*	0,875	1	0,875	1	1	1
f_{32}	0,7	0,8	0,8	0,7	0,5	0,6
Max (f_{32})	0,8					
f_{32}*	0,875	1	1	0,875	0,625	0,75
f_{33}	0,6	0,7	0,8	0,7	0,8	0,8
Max (f_{33})	0,8					
f_{33}*	0,75	0,875	1	0,875	1	1
f_{41}	0,4	0,6	0,7	0,7	0,8	0,8

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Max (f_{41})	0,8					
f_{41}*	0,5	0,75	0,875	0,875	1	1
f_{42}	1	0	1	0	1	1
Max (f_{42})	1					
f_{42}*	1	0	1	0	1	1
f_{43}	0,1	0,3	0,4	0,8	0,8	0,8
Max (f_{43})	0,8					
f_{43}*	0,125	0,375	0,5	1	1	1

Źródło: opracowanie własne.
Source: own work.

Table 4. Distance values r_i and weight values w_i for $f_j \in F_j$
Tabela 4. Wartości odległości r_i i wartości wagi w_i dla $f_j \in F_j$

x_i	r_i	w_i
x_1	1,090	0,122
x_2	1,000	0,124
x_3	1,269	0,119
x_4	1,218	0,120
x_5	**0,586**	**0,132**
x_6	1,097	0,122
x_7	0,750	0,129
x_8	**0,500**	**0,133**

Źródło: opracowanie własne.
Source: own work.

The solution to the optimization task for $fj \in Fj$ (Table 4) is to choose sliding shelves (x_5: r_5=0.586, w_5 = 0.132) or tunnel shelves (x_8: r_8 = 0.5, w_8 = 0.133).

Table 5. Distance values r_i and weight values w_i for criteria f_{31}, f_{41}
Tabela 5. Wartości odległości r_i i wartości wagi w_i dla kryteriów f_{31}, f_{41}

x_i	r_i	w_i
x_1	3,204	0,125
x_4	3,167	0,125
x_5	3,165	0,125
x_6	3,165	0,125

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x_7	**3,162**	**0,125**
x_8	**3,162**	**0,125**

Źródło: opracowanie własne.
Source: own work.

The solution to the optimization task for criteria f_{31}, f_{41} (Table 5) is the choice of automatic lift racks Lean Lift (x_7: $r_7 = 3.162$; $w_7 = 0.125$) or tunnel racks (x_8: $r_8 = 3.162$; $w_8 = 0.125$).

SUMMARY

The methodology presented above presents, on the example of the selection of the type of storage racks, a way to optimize the company's logistics process. Analysis of the results of the methodical numerical experiment showed the usefulness of the developed algorithm to determine the elements of the enterprise's optimal storage system. The main advantage of the algorithm is its universality, which allows it to be used to select elements of other areas of the company's logistics process.

The analysis of the presented methodology (Table 3.4.5), however, also showed some shortcomings, these are primarily:

a) it is not possible to take into account the program operator's preferences regarding the construction of "own" criteria for a set of acceptable solutions $x \in X$;

b) it is not possible to reduce the number of criteria by classifying some of them as constraints and determining on their basis a set of acceptable solutions $x \in X$.

The search for new solutions in this area and the removal of the above deficiencies in the methodology for optimizing the company's logistics process in terms of its practical application is the subject of the author's further work.

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