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SELECTION OF OPTIMAL WAREHOUSE CAPACITY ENLARGMENT POSSIBILITY USING THE CHURCHMAN-ACKOFF WEIGHTING METHOD

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Abstract:
In real-life situations, the number of the produced product variations at companies is constantly increasing in order to satisfy unique costumer needs. This trend leads to an increase in the inventory level and the lack of the storage capacity as well. In this paper I will introduce the possible problem–solution main alternatives that were revealed in connection with a real industrial research project and a decision-making method that enables the selection of the best problem–solution alternative. The decision-making method was created using normalization and the Churchman-Ackoff weighting method.

Key words:
Lack of warehousing capacity, decision-making method, logistics.

INTRODUCTION

Nowadays the increasing number of product types has a significant effect on enlarging the warehouse capacity need of production companies. This occurs because it is necessary to store more and more product types in different warehouses in order to satisfy unique customer needs based on stockpiling rules [1]. An important objective of companies is the reduction in the ordering lead time by improvement of logistics processes [2]. Generally the improvement of the logistics processes has been realised by the tool and rules system of the lean philosophy [3]. In most cases this enables the reduction in the inventory levels and warehouse capacities for manufacturing companies [3]. In real-time situtations there are many cases when an increase in the inventory level is necessary (e. g.: relevant expansion of consumer market [4], manufacturing of new products [5], etc.); consequently, the enlargement of the storage capacity is essential. A review of the literature reveals that most papers deal with the selection of the appropriate warehouse position on the basis of several decision criteria [6-8] and do not analyse the possibility of optimal warehouse capacity enlargement. This paper proposes an approach to managing the problem of insufficient storage capacity.

We can distinguish several cases when the warehouse capacities are not sufficient for companies because of the increase in the inventory levels. The main question is how we can solve the lack of warehouse capacity.

Alternative solutions to the lack of warehouse capacity:

- Main alternative I: Expansion in storage capacity of the central warehouse (by transformation of the current storage system, respectively warehouse expansion).
- Main alternative II: Rental of distribution warehouse(s).
- Main alternative III: Requisition of a distribution warehouse with larger storage capacity (this warehouse will satisfy the storage needs for the central warehouse and some nearby distribution warehouses).

The aim of this paper is to introduce a decision-making method that enables the selection of the best solution alternative in case of lack of warehouse capacity. This method is able to select the most appropriate alternative for companies which have only one central warehouse or one central warehouse and several distribution centers. The paper will introduce the main alternatives and the logistics indicators which are necessary to apply the decision-making method. The paper will not examine other alternatives besides the main alternatives (e. g.: formation of the storage system, applied material handling equipment and the applied unit load forming device, etc.). We have to only examine those main alternatives selected by the company (naturally the method allows us to create and examine multiple alternatives within the main alternatives as well).

1 SOLUTION ALTERNATIVES FOR LACK OF THE STORAGE CAPACITY

Three kinds of main alternatives can be identified in order to eliminate the lack of the warehouse capacity. We can use the main alternatives regarding different distribution logistics systems as well. These are the following:

- one central warehouse is in the distribution system,
- one central warehouse and more than one distribution centers are in the distribution system.

The assumptions regarding the examined logistics system are the following:

- formation of the distribution logistics centers is optimal in the aspect of the warehouse capacity, consequently their capacities may not be increased by installation of a new warehousing system and/or application of a new warehousing arrangement and/or selection of better supply position.
- assignment of the customers to the distribution centers is carried out based on predefined regions,
- there are disaggregated unit loads in the storage places because of the commissioning activities ,
- only one product type is placed in each storage position.

I. Expansion in storage capacity of the central warehouse

In this case the lack of storage capacity will be solved by expansion in the capacity of the central warehouse.

- The customer will be served through the increased central warehouse regarding Version 1a
- The customer will be basically served through the distribution centers regarding Version 1b, but it can also occur from:
    - the central warehouse, or

- another distribution center,

in the case of product shortage (not the preferred option).

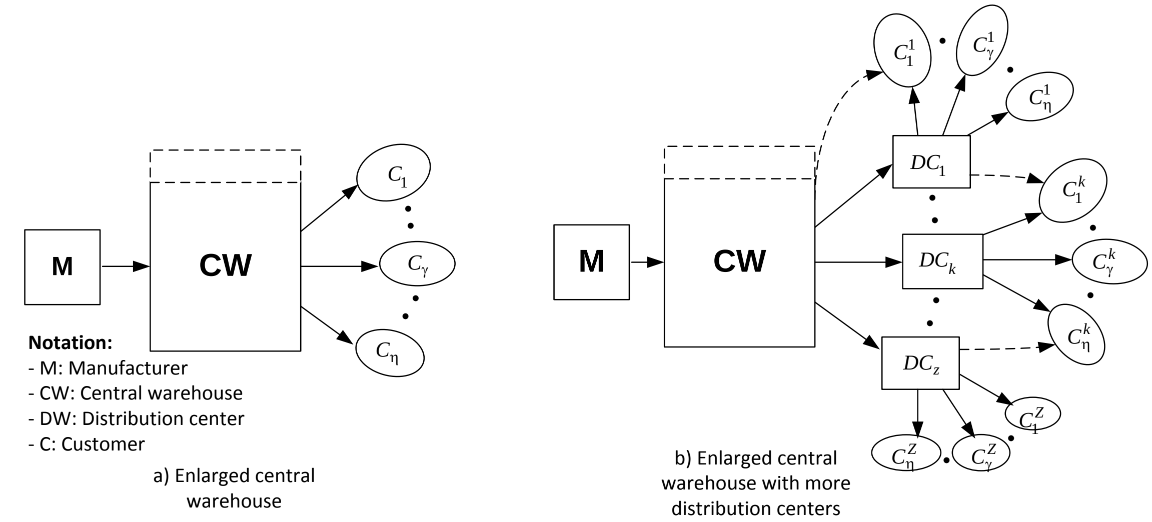

Fig. 1 *Expansion in storage capacity of the central warehouse*

II. Rental of a new distribution warehouse

In this version the lack of capacity is solved by a new distribution warehouse.

- In Version 1a the consumer catering takes place from a central warehouse and a distribution warehouse, but also possible are (in case of lack of product):
  - the catering for consumers of the central warehouse is possible from a distribution warehouse as well (not significant),
  - the catering for consumers of a distribution warehouse is possible from the central warehouse as well (not significant).
- In version 1b the catering for a consumer of a distribution warehouse occurs by only one distribution warehouse but other possibilities exist (in the case of lack of product):
  - from the central warehouse;
  - from another distribution warehouse;

  catering (not significant).

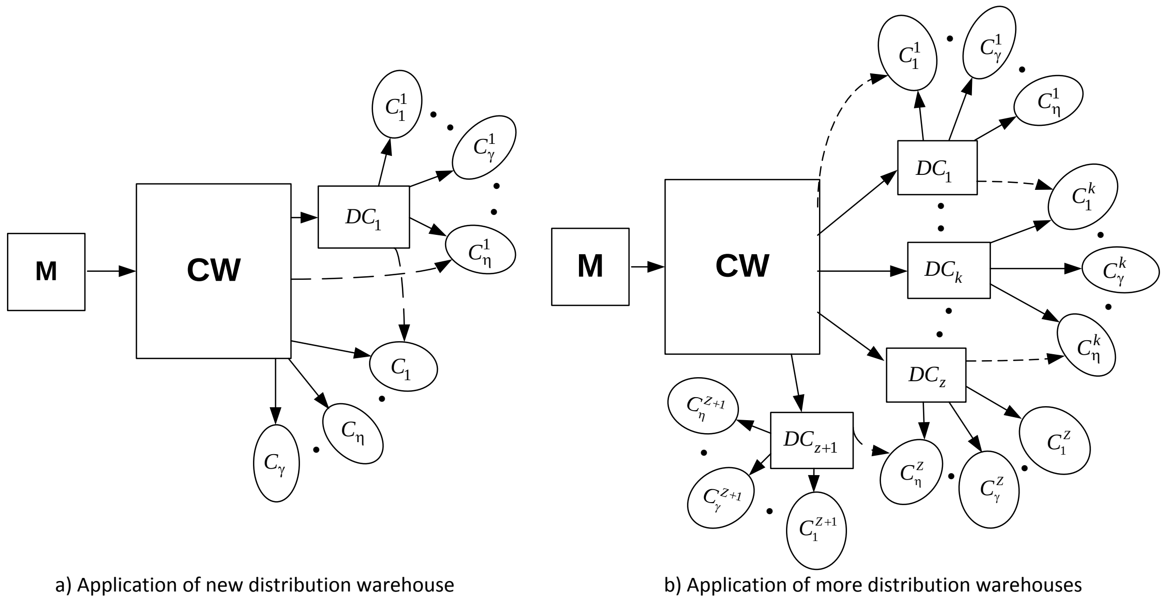

Fig. 2 *Rental of a new distribution warehouse*

III. Requisition of a bigger storage capacity distribution warehouse [9]

In this case the central warehouse will be closed down in favour of a new bigger capacity distribution warehouse instead of the central warehouse. In extreme cases it can occur that nearby distribution warehouses will be also shut down and their inventory will be relocated in the new bigger distribution warehouse. The method of consumer catering is similar to that of Alternative I; the difference is only that the central warehouse is replaced by a bigger distribution warehouse. The former central warehouse can be exploited for other aims.

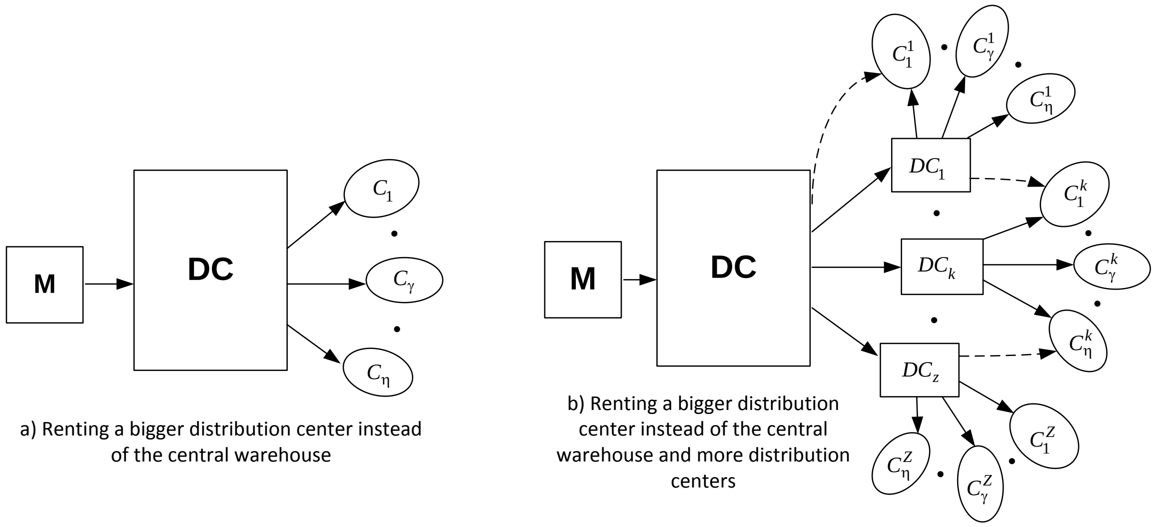

***Fig. 3** Renting a bigger distribution center instead of the central warehouse*

2 DETERMINATION OF VOLUME OF STORAGE CAPACITY ENLARGEMENT IN CASE OF MAIN ALTERNATIVES

The margin of storage capacity of the existing warehouse system and the forecasts relating to future stock levels should be known for the determination of volume of capacity enlargement.

In case of main alternatives I and II: The volume of capacity enlargement can be defined based on the following equation:

$$C_v^{enl} = \underset{i}{Max}\left\{\sum_{j=1}^{n}\left\lceil q_{ij} / C_j \right\rceil\right\} + Q_{enl} - C_{cw}, \qquad [LU] \qquad (1)$$

where: Q_{enl} *- forecast capacity enlargement [LU],*
C_{cw} *- actual storage capacity of the central warehouse [LU],*
i - days of the analyzed term [day],
j - number of stored products [piece],
q_{ij} *- quantity of product j stored on day i [piece],*
C_j *- quantity of products j placed on a loading unit [piece/LU],*
v - identification of Main Version I or II.

In case of Main Alternative III: Enlargement of the central warehouse can be avoided by the application of this alternative, which is very advantageous because of the decrease in the investment cost, and the created empty area can be used for other tasks. The required capacity can be defined by Equation 2. In extreme cases it can occur that nearby distribution warehouse(s) also will be eliminated.

$$C_v^{enl} = \underset{i}{Max}\left\{ \sum_{c\in\Theta_v} \sum_{j=1}^{n} \left\lceil q_{ij} / C_j \right\rceil \right\} + Q_{enl} \,, \tag{2}$$

where: c - storage spaces to be merged,

Θ_v - set of warehouses to be merged regarding the main alternative v,

i - days of the analyzed term [day],

j - number of stored products [piece],

v - main alternative III.

3 LOGISTICS INDICATORS FOR EVALUATION OF WAREHOUSE ENLARGEMENT ALTERNATIVES

In this section, indicators are introduced that influence the total costs of the distribution system, e.g. storage and transportation costs, either directly or indirectly. In addition, the efficiency and the service level (subjective factors) were also an important part of the evaluation that represents the efficient operation of the system.

Material flow work: Supplying customers can be completed differently in the examined main alternatives. If we would like to compare the transportation performance of the alternatives then it is necessary to evaluate the material flow work (Eq. (3)). We can suppose that the material flow work is proportional to the cost of transportation [9].

$$W_v = Spur Q_v L_v^T \,, \qquad \left[t \cdot km\right] \tag{3}$$

where: Q_v - the matrix which describes the quantity of products to be transported between the objects of the distribution logistics system in case of main variation v [LU],

L^t_v - length of material flow routes of the products to be transported between the objects of the distribution logistics system in case of main variation v [km].

Specific storage cost (cost per loading unit): The other very important logistics indicator that creates a comparison possibility between the main alternatives is the specific storage cost, which can be defined based on Equation (4).

$$f_v = (K_v + B_v - P_v) / q_{vki} \,, \qquad \left[EUR / LU\right] \tag{4}$$

where: K_v- operation cost of warehouses in case of main alternative v [EUR],

B_v - annual amortization of the investment in case of main variation v [EUR],

P_v - annual surplus returns from the utilization of the free area created [EUR],

q_{vki} - the product volume transported in the examined time period [LU].

Efficiency of order picking, loading in and loading out activities: Efficiency parameters are important indicators of warehousing processes, because higher efficiency can result in better ability to deliver or in lower stock levels [9]. Efficiency of order picking activity can be defined by the following equation:

$$Q_v^K = \psi_v^K \frac{60}{\overline{T_v^K}} d_v^K , \qquad [LU / Hour] \quad (5)$$

where: ψ_v^K *- factor for loss of time caused by disturbance of parallel order picking processes in case of main alternative v,*

$\overline{T_v^K}$ *- average cycle time of order picking process in case of main alternative v,*

d_v^K *- number of parallel order picking processes in case of main alternative v,*

K - related to order picking activity.

The load in- and load out efficiency can be interpreted similarly.

Standard of service [9]: Standard of service is a subjective indicator, it is a general impression about the examined alternative (e.g. development level of the applied information system, condition of equipment, etc.). It is scored from 1 to 10 points.

4 DESCRIPTION OF DECISION-MAKING METHOD

The aim of the decision-making method is to select the best main alternative, the one in which the values of the determined logistics indicators are the most advantageous. We can distinguish two kinds of logistics indicators when considering the aim of the selection. In case of the first the aim is minimizing (e. g. specific storage cost; material flow work; efficiency of order picking, loading in and loading out) and for the other it is maximizing (e.g. standard of service). By application of a multi-objective decision-making method we can take components to be maximized or minimized into consideration at the same time. The objective function components have to be normalized and transformed to use the method. Afterwards we have to create the weighted sum of the normalized components and select the best alternative.

Normalization of objective function components to be minimized:
- we determine the average value of logistics indicators to be minimized,
- differences between the minimum value and the average value as well as the maximum value and average value will be divided to 5-5 intervals
- we have to score the indicator values of examined alternatives from 1 to 10 using an earlier defined scale; if the value of an examined indicator is lower the value of the objective function will be more advantageous.

Normalization of objective function components to be maximized:
- we determine the average of logistics indicators to be maximized,
- differences between the minimum value and the average value as well as the maximum value and average value will be divided to 5-5 intervals,
- we have to score the indicator values of examined alternatives from 1 to 10 points by the help of earlier defined scale,
- transformation of objective functions to be maximized should be completed for easier handling (the given points should be subtracted from 11, so the objective function components to be maximized will be transformed to objective function components to be minimized).

- *Weighting of the normalized objective function components (Churchman-Ackoff method)* [10]:
  - Step 1: We have to give the ranking of the normalized logistics indicators based on their importance (c_1 is the most important, then c_2 , …, c_p).
  - Step 2: We need to determine the weight of the c_1 normalized indicator as $w_1=1$, afterwards it is necessary to also give the weight of the other normalized indicator in comparison to c_1 (w_2, …, w_p).
  - Step 3: We have to compare every normalized indicator with the sets of the possible normalized indicators in order to increase the accuracy of the determination, e. g. comparison of c_1 with {c_2, …., c_p}, {c_2,….,c_{p-1}},…, {c_2…c_3} (If c_1 will be more important and the described inequality does not agree with this then we have to modify the weight of w_1).
  - Step 4: Comparison of c_2 with the set of {c_3, c_4,…,c_p} according to Step 2.
  - Step 5: Resumption of the comparison to the last possibility (c_{p-2} and {c_{p-1}, c_p}).
  - Step 6: Normalization of weight: division of the weight of normalized indicators with $\sum_{l=1}^{p} w_l$, thus the sum of the final weights will be 1.

Objective function used to obtain the optimal alternative: The objective function (Equation 6) was created as the weighted sum of the normalized objective function components (the weights were determined based on the Churchman-Ackoff method).

$$\underset{v}{Min}\{ \sum_{l=1}^{p} w_l * Y_{vl} \} \rightarrow v \ , \ 0 \leq w_l \leq 1, \ \sum_{l=1}^{p} w_l = 1, \tag{6}$$

where: v - analyzed alternatives,
l - analyzed objective function component,
w_l – *weight of a given objective function component,*
Y_{vl} - value of the objective function component l in case of main alternative v.

5 SUMMARY

In this paper a logistics problem was examined, namely the lack of storage capacity. I revealed the main system alternatives for managing this problem. Afterwards the concept of a decision- making method for selection of the best alternative was discussed. The decision-making method was created based on the most important logistics indicators and the Churchman-Ackoff weighting method. Naturally the revealed method can be extended to other research areas as well (e. g. selection of appropriate material handling equipment, selection of adequate warehousing system variation, etc.).

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