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CONVERSION POSSIBILITIES OF STORAGE ZONES OF DISTRIBUTION WAREHOUSES IN CASE OF CHANGING STRUCTURES AND VOLUME OF ORDER PICKED PRODUCTS

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Abstract. The paper examines a warehouse system which is including some storage buildings and divided into storage zones based on product groups in case of changing structure and volume of order picked products. The products of a commission are collected from different zones of different storage buildings. Warehouses are through-stores: loading in is completed on one side and only the order picking is completed on the other side. The inner structure of warehouses and types of products provide the possibility of relocation and conversion of different zones in case of changing structure and volume of commissions to reduce order picking work and cost, and improve productivity. This study presents a mathematical description of an order picking system taking the structure of commissions, location of zones, conversion possibilities of different product-zones and deterministic and stochastic changing order picking demands into consideration. The paper presents an optimisation process to determine location of different storage zones.

Keywords: storing, conversion of resources, optimisation of order picking system

1. Introduction

Today in the world of globalization not only the production but the sourcing and distribution is getting globalised. Distribution warehouses and logistic service centres with significant storage capacity are coming alive in large number. The profitability of operation of these big warehouses are greatly influenced by their capacity and the enhanced delivery lead time of the orders. One feature of the globalisation is the dynamic change in volume and structure of the transit commodities. The competitiveness of distribution warehouses are predominantly influenced by their flexibility to the dynamically alternating requirements. The authors tried to elaborate a general mathematical model and method for a common appeared storage problem.

The purpose of this study is to point at the efficiency of storage activity to maintain the most advantageous cost level i.e. the profitability in case of changing structure and volume of order picked commodities.

With other words to achieve the following targets:

to assure the required volume of products be stored,

to maximise the order picking capability,

to minimise the order picking lead time and labour demand.

We have not found any theoretical basis, mathematical models and methods for theoretical problems of resource conversion of order picking distribution stores during our literature mining. But lot of authors focused on the importance of the utilization of different dynamically changing logistics resources, changing in time and in space (*A. Chikan*, 1994; *R. Coaper*, *R. Kaplem*, 1991; *W. Domschke, A. Scholl*, 1993; *B. Gubenko*, 1996; *R. Jünemann*, 1989; *B. Kulcsár*, 1998; *H.-Chr. Pfohl*, 1996; *P. Schönsleben*, 1998; *P. Michelberger.*, *L. Szeidl*, *P. Várlaki*, 2001; *D. Simchi-Levi, X. Chen, J. Bramel*, 1997).

In the above mentioned literature there are not available mathematical models and methods which can be applied in case of order picking stores. Virtual enterprise and virtual logistics company can provide a new and good opportunity for conversion and utilization of logistics resources (*Camarinha-Matos, L. M.*, 2004). The solution of the problem requires the knowledge of flexibility improving methods and procedures for flexible and integrated production systems and integrated logistics systems (CIL) (*J. Cselényi, T. Bányai*, 2002; *J. Cselényi, B. Illés*, 2004).

The research activity was based on the above mentioned literature and according to the demand of Hungarian enterprises (mostly mechatronical companies) and service companies. Research topics for determination and conversation of optimal logistics resources were defined for PhD students of the "József Hatvany" Doctoral

School for Information Science, Engineering and Technology at the University of Miskolc. Results of this research activity were published in papers of *R. Bálint, J. Cselényi*, 2002; *J. Cselényi, K. Dunai, Á. Gubán, R. Bálint,* 2003.

2. The Limitations of the Examined Objective

At the distribution warehousing systems the optimal tackling methodology of the variability of structure and volume is greatly depends on how the order picking system can be modelled.

The study taken into account the possibilities provided by the virtual enterprises detailed in paper of *Camarinha-Matos, L. M.*. Warehouses joined into a virtual logistics network provide the conversion possibilities of resources, because the utilization of different warehouses and storage zones is known in given time intervals. Study of *J. Cselényi, B. Illés* discuss the integration of CIM-CIL which is not only relating to technological processes, activities completed at one work place, but relating to storage activities of cooperating enterprises and companies using common convertible resources.

In the study we wish to analyze those models of storage systems which are highly productive and the best known in practice.

The features of the examined model of distribution warehouse order picking system are:

- the warehousing system contains several buildings, some of them a system of isolated pavilions, others are block lay-out,
- each building has several input and output loading docks,
- the storage process in each building is implemented in zones separated by longitudinal passages which may be block or lined installations,
- order picking process is implemented in the passages,
- loading units of the same size are deposited in each in each storage zone, loading unit is homogenous, but in a given zone different type of commodities can be stored / each type of commodities, which can be stored in loading unit forming equipment that is typical in the given zone /,
- whereas the storage implemented in several buildings and within a building in several zones it may well occur that a given type of loading unit forming equipment can be found in more than one zones, consequently the same sort of commodity may be found in several zones,
- the warehouses can be head or transit stores, the order picking process may be performed manual or powered,
- the model assists in preparing strategic decisions by the mathematical analysis of historic data of the previous T_0 period and taking into account the long term

predicted data resulting the conversion of the existing logistic resources and order picking strategies,
the model is suitable, in case of a given storage capacity and lay-out respectively to realise a common order picking task with regards the variation in structure and volume of commodities to be order picked and to define the optimal conversion possibilities, comprising:

- the selection of order picking passages,
- the re-storage of commodities:
  - » into another storage zone within the same building,
  - » from one building into another building's certain storage zone,
- tackling of variation in capacity requirement / increase-decrease / of a certain commodity,
- the structure and volume of order picked goods in the outgoing shipments.

The next step is the mathematical description of the data model, which is necessary to solve the above outlined problem.

3. Mathematical Description of the Data Model

The analysis is limited to

$$n = n_1 + n_2 + n_3 \tag{1}$$

storage zones in 3 buildings. This limitation does not mean any theoretical restriction, merely is given in the interest of a less extensive and easier mathematical description.

Given the storage capacity of the individual storage zones in LU / loading units /:

$$\overline{r_0} = \left[r_{0j} \right]_{(j=1\cdots n)\ \text{storage zones}} \tag{2}$$

The matrix, which expresses the possibility the placement of individual commodities in the storage zones:

$$F = \left[f_{ij} \right]_{(i=1\cdots p)\ \text{type of commodities}}, \tag{3}$$

where f_{ij}=1or 0.

If f_{ij}=0, then the *i-th* commodity can not be placed in the *j-th* storage zone, because there a different kind of loading unit forming equipment is applied.

If f_{ij}=1, then the *i-th* commodity can be placed into the *j-th* storage zone.

In the forthcoming period / let say in 1 year / the following order picked varieties must be composed:

$$K = \left[k_{\delta i}\right]_{\substack{(\delta=1\cdots w)\\(i=1\cdots p)}}, \tag{4}$$

where $k_{\delta i}$ is the number of *i-th* commodity in the kind of order picked varieties.

The number of annual requirement from the different kind of order picked varieties is:

$$z = \left[z_\delta\right]_{(\delta=1\cdots w)}, \tag{5}$$

where $z_\delta = \left[\frac{pcs}{year}\right]$.

The number of annual requirement for the order picked varieties from the *i-th* commodity is:

$$a_i = \sum_{\delta=1}^{w} z_\delta k_{\delta i} \quad (i=1\cdots p) \tag{6}$$

In the previous period the requirements for order picked varieties were $K^*, \overline{z}^*, \overline{a}^*$ respectively. The commodities in the store were deposited in the light of the above and expressed by the matrix R:

$$R^* = \begin{matrix} 1 \\ i \\ p \end{matrix} \left[\begin{array}{c|c|c} & j & \\ I. & II. & III. \\ & r_{ij}^* & \end{array} \right] \tag{7}$$

where:

$j = 1\cdots n_1$ Zones in store No. I.

$j = (n_1+1)\cdots(n_1+n_2)$ Zones in store No. II.

$j = (n_1+n_2+1)\cdots(n_1+n_2+n_3)$ Zones in store No. III.

r_{ij}^* is the number of the loading units containing the *i-th* commodity in the *j-th* storage zone.

In the previous period it was valid, that:

$$\sum_{i=1}^{p} r_{ij}^{*} \le r_{0j}. \tag{8}$$

The available free storage capacity in the individual storage zones is:

$$\Delta r_{0j}^{*} = r_{0j} - \sum_{i=1}^{p} r_{ij}^{*} \tag{9}$$

The number of commodities in the homogenous loading units is:

$$E = \left[e_{i\mu} \right]_{\substack{i=\cdots p \\ \mu=\cdots \omega}} \tag{10}$$

where $e_{i\mu}$ is the number of the *i-th* commodity in the *μ-th* loading unit forming equipment.

The feature of the *E* matrix is, that every row should contain only elements, those differ from 0.

In those *j* zones in the *i-th* row of the *F* matrix, where $f_{ij}=1$ everywhere identical loading unit forming equipment can be found, in addition in the *i-th* row of the *E* matrix $e_{i\mu}>0$.

The annual number of the *i-th* commodity in the storage zones at the current placement is:

$$\overline{h^{*}} = [h_i^{*}] \; (i = 1 \ldots p), \tag{11}$$

where:

$$h_i^{*} = c_i^{*} \sum_{j=1}^{n} e_{ij} r_{ij}^{*}, \tag{12}$$

and c_i^{*} is the circulating velocity of the *i-th* commodity in the previous period.

An important element of the data model is the matrix *B*, that describes the composition from order picked commodities in the outgoing particular freights:

$$B = [b_{k\delta}], \tag{13}$$

where

k=1 ...*u*: freight type,

δ=1…w: type of commission variety,

$b_{k\delta}$: the number of δ type commission variety in the *k-th* freight type.

The number of annual outgoing freight types is:

$$y = [y_k], \tag{14}$$

where k= 1…u ,

y_k : the annual outgoing number of the *k-th* freight: $y_k = \left[\frac{freight}{year}\right]$.

Different kind of analysis can be done based on the available data model.

4. A Couple of Analysis Based on the Data Model

It can be analyzed, if the required quantity of commodities to be order picked in the forthcoming period can be stored in the available transit warehouses or the missing capacity need to be replaced with regards the followings:

- temporary capacity must be established,
- capacity need to be hired,
- if the anticipated increase in store capacity requirement may be predicted for a long term period the feasibility of building new stores or extending the existing buildings should be analyzed.

The available storage capacity for the *μ-th* loading unit forming equipment is sufficient, if:

$$\frac{\sum_{j \in \Theta_\mu} r_{oj}}{\sum_{j \in V_\mu} \frac{a_i}{e_{i\mu}} \frac{1}{c_i^*}} \geq 1, \tag{15}$$

where

$\mu = 1 \ldots \omega$,

Θ_μ is the set of the those *j-th* storage zones, where the *μ-th* type loading unit forming equipment can be stored,

V_μ : the set of those *i-th* commodities which can be stored in the *μ-th* type of loading unit forming equipment.

It is easy to see, if the (15) condition does not exist, the (15) condition can easily be restored by the circulation velocity of the c_i^* commodities.

If the (15) condition is satisfied, that makes out the available free capacity of the μ-*th* type loading unit forming equipment measured in “loading unit” number:

$$r_{o\mu} = \sum_{j\in\Theta_\mu} r_{oj} - \sum_{i\in V_\mu} \frac{a_i}{e_{i\mu}} \frac{1}{c_i^*}. \tag{16}$$

Based on the available data model it is also can be analyzed, that how many annual order picked varieties can be completed in the individual storage zones.

The output of the order picking process can be increased, the delivery lead time and labour demand and costs can be reduced by increasing the number of order picked varieties in one particular passage. The requirement of it is the availability of commodities in the given volume.

Within a given period the sub-proportion of the annual order picked varieties can also be analyzed with regards the *i-th* commodity from the *δ-th* commission varieties to be placed into the *j-th* zone:

$$\varphi_{\delta i}^{j} = \frac{z_\delta k_{\delta i}}{r_{ij} e_{i\mu} c_i^*}, \tag{17}$$

where r_{ij} and c_i are corresponding to data of the forthcoming period. Last, but not least we will refer to the principles and methodology of the modification of r_{ij} to r_{ij}^*

In the *j-th* storage zone the Φ^j order picking varieties sub proportion matrix can be generated:

$$\Phi^j = [\varphi_{\delta i}^j], \tag{18}$$

where δ=1...*w*, commission variety,

i=1...*p*, type of commodity.

Analyzing the Φ^j matrix, if:

$\varphi_{\delta i}^j \le 1$, then in the *j-th* zone the *i-th* commodity for the *δ-th* commission variety is fully available / 100 % /,

$\varphi^j_{\delta i} > 1$, then in the *j-th* storage zone only a fragment of the *i-th* commodity for the *δ-th* commission variety is available, i.e. the *δ-th* commission variety may be completed only in fragment,

$\varphi^j_{\delta i} = \infty$ may occur, if $r_{ij}=0$ i.e. in the *j-th* zone the *i-th* commodity is not available.

The Φ^j matrix may contribute to the solution of conversion task to be described in the next chapter providing important data or information.

5. Conversion Strategies Applying the Data Model

If the K^* matrix, the $\overline{z}^*$ and $\overline{a}^*$ vectors relating to the previous period alter to K matrix and $\overline{z}$ and $\overline{a}$ vectors for the next period then the conversion of the existing logistic resources and order picking strategies become necessary. The conversion may include:

the alteration of the R^* matrix, comprising,

- the alteration of the commodities and storage capacity in the individual storage zones, that may be created by,
  - » relocation of the given volume storage capacity of a commodity existing in the previous period,
  - » in the consequence of increase of the volume of a given commodity,
  - » in the consequence of decrease of the volume of a given commodity,
- the relocation of the particular storage zones into an other building,
- the selection of the optimal passage for order picking process,
- the definition of the optimal loading entries / channels /.

Further on – in consequence of the available limited volume we provide only strategic principles to select the optimal order picking passages.

The selection of the optimal order picking passages /storage zones/ may be defined in some consequtive steps.

Step 1.

Analyzing those rows of Φ^j matrix, at all elements where $k_{\delta i} > 1$, the following is true:

$$1 \geq \varphi^j_{\delta i} \geq 0\,, \tag{19}$$

$(i=1 \ldots p)$, $i \neq \rho$, if $k_{\delta i} = 0$, then neglected the requirements of the identical commodities in other commission varieties the δ*-th* commission variety can be completed from the *j-th* zone, but further investigation is required.

If the (19) relation is valid only in one row of Φ^j matrix, i.e. valid only for one type loading unit, then must be analyzed, that

- if

$$r_{ij} < r_{ij}^{*}, \tag{20}$$

(i=1…p),

then in the previous period provided available place in the *j-th* zone for the *i-th* commodity is adequate.

- if

$$r_{ij} > r_{ij}^{*}, \tag{21}$$

(i=1…p), but

$$r_{ij}^{*} + \Delta r_{oj} \geq r_{ij}, \tag{22}$$

then the required storage capacity surplus at r_{ij} can be stored into the free places of the *j-th* zone.

In these cases all the required conditions are given in the *j-th* zone to complete all number of the δ-type commission variety.

If exists even one type of commodity, in which case no one condition of the above is satisfied, then the δ-type commission variety can only partly be completed.

Step 2.

If (19) relation is valid in more rows of Φ^j (N_{j2} defines the set of those commission varieties, where (19) exists) then should be satisfied:

$$\varphi_{\delta 2}^{j} = \frac{\sum\limits_{\delta \in N_{j2}} z_{\delta} k_{\delta i}}{r_{ij} e_{i\mu} c_{i}} \leq 1, \tag{23}$$

(i=1…p),

in addition either (20) or (21) and (22) should be exist.

If for the whole set of N_{j2} the (23) and the relating conditions are not satisfied then the set should be reduced to N^{*}_{j2} so, that at the required conditions let

$$\sum_{\delta \in N^{*}_{j2}} z_{\delta} \to Max. \tag{24}$$

be true.

If for the whole set of N_{j2} the (23) and the relating conditions are not satisfied, then we analyze how big is the defiance in the whole set of commission variety:

$$\Delta\varphi^{j}_{i2} = 1 - \varphi^{j}_{i2} \tag{25}$$

The (25) also refers to, if the reduction of N_{j2} set is advisable by principles governed other than (23) what kind of latitude is available.

Steps 3. ,4., 5.

In the referred paras we have analyzed that completing the 75%, 50% and 25% of the annual order picked varieties requirement (ε=0.75, 0.50, 0.25) in which cases satisfied the

$$\varphi^{j}_{ik} = \frac{\sum_{\delta \in N_{j\varepsilon}} \varepsilon z_{\delta} k_{\delta i}}{r_{ij} e_{i\mu} c_{i}} \leq 1 \tag{26}$$

and related conditions.

Step 6.

Types of δ commission varieties in the *j-th* storage zone should be analyzed which can not be completed at all in lack of one or more kind of commodities.

$M^{j}_{\delta i}$ represents that subset in the δ commission variety-set, which one can not be completed in lack of *i-th* commodity.

$M^{j}_{\delta i}$ subset includes those *i-th* kind of commodities, which satisfies the following conditions:

$$k_{\delta i} > 0 \text{ and } r_{ij} = 0. \tag{27}$$

It can be calculated, that in the *j-th* passage which maximum proportion of the *δ-th* commission variety can be completed:

$$\eta_{\rho}^{j} = \frac{\sum_{i \in M_{\delta i}^{j}} z_{\delta} k_{\delta i}}{z_{\delta} k_{\delta i}}. \tag{28}$$

Step 7.

In this step we summarize the results of the previous 6 steps. It is necessary to do so, to point at how to tackle exactly the optimum order picking process of a commission variety set which is required for the application of an opportunity set.

The summary includes the breakdown per zones relating to the individual commission varieties:

which kind of commission varieties can be completed without limits,

which kind of commission varieties can be completed with limits:

- which kind of commission varieties – members of those subsets – which can be completed in maximum number,
- how big is the required storage capacity to be freed by relocating the not involved commodities to complete the whole set,

identifies those commission varieties, of which the 75%, 50% and 25% of the annual requirement may be completed,

identifies those commission types, of which no one commission variety can be completed in the given storage zone and in what percentage of the commission variety can be completed.

Step 8.

This step describes the optimization of the individual order picking varieties i.e. in which zone or zones should be completed the commission varieties so, that we fix up the next two relations, described in chapter 1.:

minimising the P labour requirement, let

$$P \rightarrow min.$$

so, that the required order picking performance requirement let be balanced,

the performance requirement of order picking let minimum be, what we wish to be limited to:

- the movement of commodities between the zones,
- converted transportation from the individual zones,
- vehicle loading only by the order picking process governed by the freights.

The algorithm of optimization will be provided in the next scheduled study on this topic.

6. Conclusion

The study presents the rearrangement of order picking strategies and logistic resources which frequently may occur in distribution warehouses in the consequence of alteration structure and volume of order picked varieties. With other words how to rearrange the task-complex in the interest to find the optimal solution.

We have summarized the required data for the optimal decision making, the methodology of data collecting, elaborated the mathematical connexion that is required to provide an adequate data model. We have expounded those investigations and examinations which help to create an algorithm of optimisation with regards the functions, conditions and parameters to be optimised.

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