THE ALGORITHM FOR DESIGNATING THE NUMBER OF TRANSSHIPMENT VEHICLES IN THE CROSS-DOCKING SYSTEM

IZDEBSKI Mariusz[1], JACYNA-GOŁDA Ilona[2], PYZA Dariusz[1], AMBROZIAK Tomasz[1]

[1]*Warsaw University of Transport, Faculty of Transport, Warsaw, mizdeb@wt.pw.edu.pl*
[2] *Warsaw University of Transport, Faculty of Industrial Engineering, Warsaw, i.jacyna-golda@wip.pw.edu.pl*

Abstract

This paper presents the algorithm for designating the number of the transshipment vehicles in the cross-docking system. The problem of minimizing the number of vehicles was presented in a mathematical way. For the examined problem the decision variables, limits and the function of criterion were determined. The crucial importance in this problem is to designate the minimum driving routes of transshipment vehicles in the transshipment facility. For this purpose, the optimization algorithm was developed. The scientific work carried out in the frame of PBS 3 project "*System for modeling and 3D visualization of storage facilities*" (*SIMMAG3D*) financed by the NCBR.

Keywords: Cross-docking system, genetic algorithm, optimization

1. INTRODUCTION

Cross-docking is a process of the consolidation of the cargo which are transported in the same direction from different places of the origin [4], [8], [3], [11]. Rationalization of cross-docking is to minimize the labor intensity of the process and the interference in the cargo through the omission of storage of the material between the phase of loading and unloading or storage in a short time [6], [1], [2], [9], [5].Processes of this type are carried out in cross-docking terminals which are objects of an appropriate spatial shape and the organization of work. The **Figure 1** shows an example of multi-touch cross-docking facility.

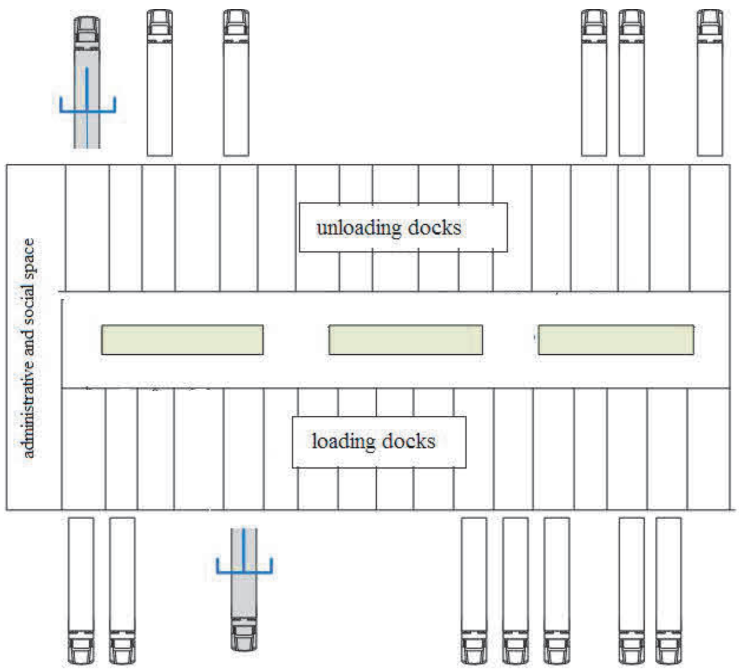

Figure 1 Multi-touch cross-docking facility. Source: own study.

The cargo collected in the area of service and imported from other terminals are accepted and unloaded into the buffer areas on the input of the system (unloading docks). Then they are transported to the respective areas in the output buffer in accordance with the direction of transport (loading docks). The aim of the paper is to present the way of designating the number of the transshipment equipment (e.g. internal transport vehicles) realizing transport of pallet loading units on relations: unloading dock (entrance dock) - loading dock (output dock) in the cross-docking system.

2. DESIGNATING THE NUMBER OF THE TRANSSHIPMENT EQUIPMENT IN THE CROSS-DOCKING SYSTEM

The presented model of the problem of determining the number of the transshipment equipment in the cross-docking system refers to a multi-touch object. Unloading vehicles in the entrance docks and loading in output docks takes place in different time windows. The cargo are temporarily stored in the input buffer. The reloading process takes place after unloading all vehicles in a given time window. In order to determine parameters of model indications are defined as follows in **Table 1**.

Table 1 Parameters of the model

Parameters	Explanations
t_{d}	working time of the object
φ_{tz}	the coefficient of the use of working time
φ_{gt}	the coefficient of technical readiness
φ_{zo}	the coefficient of work area variation
$\lambda(i,j,r)$	the decision variable which determines the number of transportation cycles between *i* - th unloading dock and *j* - th loading dock for *r* - th type of the product
$\mathbf{T}=[t(i,j,r)]$	the matrix of time of transportation cycles between *i* - th unloading dock and *j* - th loading dock for *r* - th type of the product
$\boldsymbol{DI}=\{1,\ldots,i,\ldots,\overline{\mathrm{DI}}\}$	the set of the numbers of unloading docks at the entrance of system
$\boldsymbol{DO}=\{1,\ldots,j,\ldots,\overline{\mathrm{DO}}\}$	the set of the numbers of loading docks at the output of system
$\boldsymbol{DIR}=\{1,\ldots,r,\ldots\overline{\mathrm{DIR}}\}$	the set of numbers of types of products which are unloaded and loaded in the docks
$\mathbf{VIR}=[vir(i,r)]$	the matrix of value of *r* - th type of the product in *i* - th unloading dock
$\mathbf{VIR}1=[vir1(j,r)]$	the matrix of value of *r* - th type of the product in *j* - th loading dock

The number of the transshipment equipment may be calculated by the use of the formula [7]:

$$n=\frac{\sum_{k=1}^{\mathrm{K}}\lambda_k\cdot t_k}{t_d\cdot\varphi_{tz}\cdot\varphi_{gt}\cdot\varphi_{zo}} \tag{1}$$

where: λ_k - the size of the cargo volume transported in k-th transportation cycle, t_k - execution time of k-th transportation cycle, φ_{tz}, φ_{gt}, φ_{zo}, t_{d} - see **Table 1**.

Taking into account the specific nature of cross-docking terminals in which at the input we have the homogeneous cargo, the pattern (1) can be modified to the form:

$$n(\lambda) = \frac{\sum_{i \in DI} \sum_{j \in DO} \sum_{r \in DIR} \lambda(i,j,r) \cdot t(i,j,r)}{t_d \cdot \varphi_{tz} \cdot \varphi_{gt} \cdot \varphi_{zo}} \longrightarrow min \tag{2}$$

In order to determine the transshipment equipment, limits were defined:

- All products of the given type from each unloading dock must be exported:

$$\forall r \in \boldsymbol{DIR}, i \in \boldsymbol{DI} \quad \sum_{j \in \boldsymbol{DO}} \lambda(i,j,r) = vir(i,r) \tag{3}$$

- The demand for the product in each loading dock must be met:

$$\forall r \in \boldsymbol{DIR}, j \in \boldsymbol{DO} \sum_{i \in \boldsymbol{DI}} \lambda(i,j,r) = vir1(j,r) \tag{4}$$

According to the pattern (2) assuming that the value of the denominator is constant, the number of the transshipment equipment depends on the numerator of the pattern, that is the total time of all transportation cycles performed in the reloading process. For the known times between docks $t(i,j,r)$, the total time depends on the number of cycles performed between the unloading docks and loading docks, these cycles are determined by the decision variable $\lambda(i,j,r)$. It is difficult to determine the amount of cycles between these docks for which the total time would be a minimum size. It should take into account the fact that the stream of the cargo from any unloading dock may enter to the each loading dock. This situation determines the different times of transportation cycles. Determining the optimal size of the number of cycles in given relations will minimize the total time of transshipment operations between the input and output buffer. The process of determining the number of the transshipment equipment on relations: vehicles - the unloading dock and the loading dock - the vehicles has been omitted. In this case, the transshipment cycle time is constant and is not regarded as a problem of decision-making.

Additional assumptions:

- The minimum number of transshipment equipment is determined for a given time window in which a reloading process is realized.
- The cargo are delivered and reloaded in pallet loading units.
- The mean of transport used in the transportation cycle carries exactly one unit of cargo from unloading dock to the loading dock. Transportation cycles are carried out using one type of the mean of transport.
- The size of the product in each loading dock is known.
- The demand for the product in each loading dock is known.
- The transportation cycle consists of the following steps: transport the unit load from the input buffer to the output buffer and the return to the starting point.
- Geometric centers of unloading and loading dock determine the length of the driving route with or without the cargo.
- In order to simplify the model the assumption was taken that driving time with the cargo is equal to the driving time without the cargo.

3. THE GENETIC ALGORITHM FOR DESIGNATING THE NUMBER OF TRANSSHIPMENT EQUIPMENT IN THE CROSS-DOCKING SYSTEM

In order to determine the minimum number of the transshipment equipment a genetic algorithm was developed. The main task of the algorithm is to determine the minimum number of cycles in individual relations (i, j). To form a genetic algorithm it is advisable to define the chromosome structure, the adaptation function, cross-linking process and mutation. Subsequent steps of formulating an algorithm are as follows:

- Step 1: determination of the structure of input data. The structure of input data was presented as matrices **M (*r*)**, which present the number of transportation cycles between the unloading and loading docks for *r*-th type of the product. Lines describe the numbers of unloading docks and columns describe the numbers of loading docks. An example of a matrix of seven unloading and loading docks was shown in **Figure 2**.

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	5	5
3	0	0	0	3	3	5	5
4	0	0	3	0	2	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Figure 2 The structure of input data of a genetic algorithm for *r*-th type of the product.
Source: own study.

- Step 2: definition of the adaptation function. To search for the minimum value of the function of adaptation Fp_n for n-th structure, this function acquires the following form:

$$\mathrm{Fp}_n = \mathrm{C} - \boldsymbol{T_n} \tag{5}$$

where: C - value higher than the value of total transportation time, $\boldsymbol{T}_n$ - the total transportation time in the n-th structure of the matrix **M (*r*)**, $m_{i,j,r}$ - the cell of the matrix:

$$\forall r \in \boldsymbol{DIR} \quad \boldsymbol{T}_n = \sum_{i \in \boldsymbol{DI}} \sum_{j \in \boldsymbol{DO}} m_{i,j,r} \cdot t(i,j,r) \tag{6}$$

- Step 3: determination of the cross-linking operator. The cross-linking operator is adequate to the adopted matrix structure. To implement the cross-linking process for each type r, two matrices are developed: **DIV(*r*)** which comprises rounded up average values from both parents, and matrix **REM(*r*)** containing information whether the rounding up was indeed necessary. Assuming that the value of matrices **M1(*r*)** and **M2(*r*)** (parents) in all cells assume determination $m^1{}_{i,j,r}$, $m^2{}_{i,j,r}$ values of elements of matrices DIV(*r*) and REM(*r*) are calculated from the following dependencies:

$$dim_{i,j,r} = \left\lfloor (m^1{}_{i,j,r} + m^2{}_{i,j,r}) / 2 \right\rfloor \tag{7}$$

$$rem_{i,j,r} = (m^1{}_{i,j,r} + m^2{}_{i,j,r}) / mod\, 2 \tag{8}$$

The full description of the cross-linking process was presented in [10], and presented in a graphical way to **Figure 3**. The applied cross-linking operator guarantees the correctness of individuals following a completed cross-linking process, without the necessity of using repair algorithms.

Structure 1

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	5	5
3	0	0	0	3	3	5	5
4	0	0	3	0	2	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

DIV

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	6	4
3	0	0	0	2	3	4	6
4	0	0	3	0	1	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

New structure 1

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	6	4
3	0	0	0	3	3	4	6
4	0	0	3	0	2	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Structure 2

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	7	3
3	0	0	0	2	4	3	7
4	0	0	3	1	1	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

REM

	1	2	3	4	5	6	7
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	1	1	0	0
4	0	0	0	1	1	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

New structure 2

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	6	4
3	0	0	0	2	1	4	6
4	0	0	3	1	1	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Figure 3 Cross-linking of the matrix structure. Source: own study.

- Step 4: determination of mutation operator. The operation rule of mutation operator consists in sampling of two figures p and q from the range: $2 \le p \le k$ and $2 \le q \le n$, which determine the number of lines and columns of a sub-matrix with dimensions $p \times q$ (p - number of lines in the main matrix (processed by the algorithm), q - number of columns in this matrix). The generated matrix is modified in such a way that the total value in columns and lines before and after the modification process is not changed. The detailed mutation process has been outlined in [10], and in a graphical way it was presented on **Figure 4**.

Matrix

	1	2	3	4	5	6	7
1	0	0	7	5	10	10	5
2	0	0	5	3	15	6	4
3	0	0	0	3	3	4	6
4	0	0	3	0	2	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Sub-matrix

3	4	5
7	5	10
5	3	15
7	5	10

Modyfication

3	4	5
6	6	10
6	2	15
7	5	10

Mutation

	1	2	3	4	5	6	7
1	0	0	6	6	10	10	5
2	0	0	6	2	15	6	4
3	0	0	7	5	10	4	6
4	0	0	3	0	2	2	5
5	0	0	1	1	0	8	20
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Figure 4 Cross-linking of the matrix structure. Source: own study.

Steps 2-4 of the algorithm are reiterated a given number of times, until the stop condition has been achieved. A condition for stop in the developed algorithm is the fixed iterations number. In the selection process the roulette method was adopted, while the process of cross-linking and mutation occurs with a defined likelihood set at the beginning of functioning of an algorithm. The final effect of the algorithm is the matrix that specifies the minimum number of cycles between the unloading and loading docks for r-th product and generates the minimum time of transportation cycles (minimum driving routes) for this product. The number of transportation cycles shall be determined separately for each type of the product. After entering the data into the formula (2), we obtain the minimum number of the equipment which realize the transshipment of the cargo from the input to output docks.

4. CONCLUSION

Determination of the number of the reloading equipment in the cross docking system is a problem optimization. A decisive role in determining this number plays a total transportation cycle time between the unloading and loading docks. This time depends on the number of cycles between docks that are designated by the proposed genetic algorithm. A further direction of research related to the presented genetic algorithm is its implementation in the form of a computer application. To allow an in-depth analysis of functioning of the algorithm research should be performed using various selection methods.

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