ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.3228

OPTIMIZING THE NUMBER OF DOCKS AT TRANSHIPMENT TERMINALS USING GENETIC ALGORITHM

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Abstract

This article presents the issue of designating the number of docks at the transhipment terminals using genetic algorithm. Transhipment terminals refer to cross-docking terminals. The main factor that influences on the number of these docks is the stream of cargo flowing into the given terminal. In order to determine this flow of cargo the mathematical model of the distribution of this flow was developed. This model takes into account constraints like those that e.g. processing capacity at the transhipment terminal cannot be exceeded or demand of recipients must be met. The criterion function in this model determines the minimum cost of the flow of cargo between all objects in the transport network. To designate the optimal stream of cargo flowing into the transport network the genetic algorithm was developed. In this article, the stages of construction of this algorithm were presented. The structure processed by the algorithm, the process of crossover and mutation were described. In the article in order to solve the problem of designating the number of docks at the transhipment terminals the genetic algorithm was developed.

Keywords: *transhipment terminals, genetic algorithm, optimization, cross docking*

1. Introduction

The decisive factor in the design of transhipment terminals in addition to the allocation of vehicles to docks [1-3, 12] is the problem of optimizing the number of loading docks. This article considers the transhipment terminals based on the cross-docking system, Fig. 1. The cargo in cross-docking system is unloaded into the buffer areas on the input of the system (unloading docks). Then it is transported to the respective areas in the output buffer in accordance with the direction of transport (loading docks). The load is brought by vehicles.

In the article in order to solve the problem of designating the number of docks at the transhipment terminals the genetic algorithm was developed. Genetic algorithms belong to a group of heuristic algorithms, which do not guarantee the optimal solution, but only close to the optimal solution so-called sub-optimal. Despite this inconvenience, genetic algorithms are a practical tool for optimization and are used in a variety of complex decision problems e.g. vehicles routing problems [11], single-criteria warehouses location problem [5, 7]. The complexity of the problem of designating the number of docks at the transhipment terminals limits the use of accurate methods to find optimal solutions and allows accepting sub-optimal solutions. The application of the genetic algorithm in designating the number of docks at the transhipment terminals was dictated by the fact that the authors do not find the application of this algorithm in the examined issue.

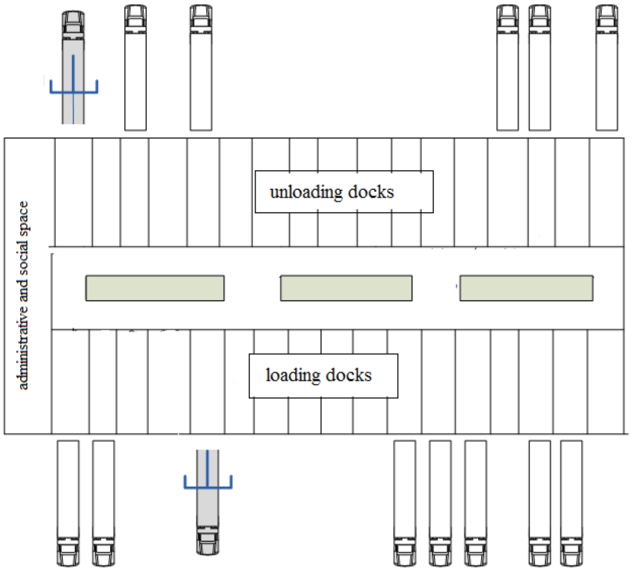

Fig. 1. The transhipment terminals

2. Mathematical model of the problem

Transhipment terminals, which are located in the transport network consisting of such facilities as suppliers, terminals and final recipients, are considered. Transport between transhipment terminals is possible. A transport task can be defined as the transport of an ordered load from the sender to the recipient directly or via the transhipment terminals.

The number of docks (unloading and loading docks) at the transhipment terminals is determined by the formula [6]:

$$n = \left\lceil \frac{\lambda \cdot t}{Z \cdot t_d \cdot \varphi} \right\rceil, \tag{1}$$

where:

λ – the stream of cargo flowing into the terminals,

t – service time of vehicles,

Z – payload of the vehicle,

t_d – working time of the terminal,

φ – degree of use of working time.

The decisive factor in determining the number of reloading docks is to indicate the stream of cargo entering the particular transhipment terminal. This stream depends on many factors, such as the unit cost of transporting the load to a given terminal, reloading costs, distances of a terminal from other network objects.

The distribution of the cargo stream in the network is modelled for the following input data:

- $\mathbf{V} = \{v : v = 1,2,...,v',... \mathrm{V}\}$ – the set of point elements of the transport network i.e. suppliers, transhipment terminals, recipients,
- $\boldsymbol{D} = \{v : \alpha(v) = 1 \text{ for } v \in \boldsymbol{V}\}$ – the set of suppliers,
- $\boldsymbol{TZ} = \{v : \alpha(v) = 2 \text{ for } v \in \boldsymbol{V}\}$ – the set of transhipment terminals,
- $\boldsymbol{O} = \{v : \alpha(v) = 4 \text{ for } v \in \boldsymbol{V}\}$ – the set of recipients,
- $\boldsymbol{H} = \{h : h = 1,...,\mathrm{H}\}$ – the set cargo numbers provided by suppliers,

- $\mathbf{D1} = [d1(v,v^{'}) : d1(v,v^{'}) \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{TZ}]$ – the matrix of the distance between suppliers and transhipment terminals,
- $\mathbf{D}2 = [d2(v,v^{'}) : d2(v,v^{'}) \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{O}]$ – the matrix of the distance between suppliers and recipients,
- $\mathbf{D}3 = [d3(v,v^{'}) : d3(v,v^{'}) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{TZ}]$ – the matrix of the distance between transhipment terminals,
- $\mathbf{D}4 = [d4(v,v^{'}) : d4(v,v_{,}^{'}) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{O}]$– the matrix of the distance between transhipment terminals and recipients,
- $\mathbf{Q}1 = [q1(v,h) : q1(v,h) \in \mathbf{R}^{+}\{0\}, v \in \mathbf{D}, h \in \mathbf{H}]$ – the production capacity of suppliers,
- $\mathbf{Q}2 = [q2(v,h) : q2(v,h) \in \mathbf{R}^{+}\{0\}, v \in \boldsymbol{O}, h \in \mathbf{H}]$– demand of the recipients,
- $\mathbf{Q}3 = [q3(v,h) : q3(v,h,r) \in \mathbf{R}^{+}\{0\}, v \in \boldsymbol{TZ}, h \in \mathbf{H}]$ – maximum processing capacity at the transhipment terminal for h-th cargo,
- $\mathbf{C1} = [c1(v,v',h) : c1(v,v',h) \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{TZ}, h \in \boldsymbol{H}]$ – the unit cost of carriage for h-th cargo on the connection: suppliers – transhipment terminals,
- $\mathbf{C2} = [c2(v,v',h) : c2(v,v') \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{O}, h \in \boldsymbol{H}]$ – the unit cost of carriage for h-th cargo on the connection: suppliers – recipients,
- $\mathbf{C3} = [c3(v,v^{'},h) : c3(v,v^{'},h) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{TZ}, h \in \boldsymbol{H}]$ – the unit cost of carriage for h-th cargo on the connection: transhipment terminals – transhipment terminals,
- $\mathbf{C}4 = [c4(v,v^{'},h) : c4(v,v^{'},h) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{O}, h \in \boldsymbol{H}]$ – the unit cost of carriage for h-th cargo on the connection: transhipment terminals – recipients,
- $\mathbf{CZD} = [czd(v,h) : czd(v,h) \in \mathbf{R}^{+}\{0\}, v \in \mathbf{D}, h \in \mathbf{H}]$ – the unit cost of loading h-th cargo for each supplier,
- $\mathbf{CWZ} = [cwz(v,h) : cwz(v,h) \in \mathbf{R}^{+}\{0\}, v \in \boldsymbol{TZ}, h \in \mathbf{H},]$ – the unit cost of reloading h-th cargo for each transhipment terminal.

The decision variables take the form:

- $\mathbf{X}1 = \left[\boldsymbol{x}1(v,v',h) : \boldsymbol{x}1(v,v',h) \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{TZ}, h \in \boldsymbol{H}\right]$ – the amount of cargo transported between the supplier and the transhipment terminal,
- $\mathbf{X}2 = \left[\boldsymbol{x}2(v,v',h) : \boldsymbol{x}2(v,v',h) \in \mathbf{R}^{+}, v \in \boldsymbol{D}, v^{'} \in \boldsymbol{O}, h \in \boldsymbol{H}\right]$ – the amount of cargo transported between suppliers and recipients,
- $\mathbf{X}3 = \left[\boldsymbol{x}3(v,v',h) : \boldsymbol{x}3(v,v',h) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{TZ}, h \in \boldsymbol{H}\right]$ – the amount of cargo transported between the transhipment terminals,
- $\mathbf{X}4 = \left[\boldsymbol{x}4(v,v',h) : \boldsymbol{x}4(v,v',h) \in \mathbf{R}^{+}, v \in \boldsymbol{TZ}, v^{'} \in \boldsymbol{O}, h \in \boldsymbol{H}\right]$ – the amount of cargo transported between transhipment terminals and recipients.

The constraints of the distribution take the form:

- the production capacity of suppliers cannot be exceeded – Providers deliver the cargo directly to the recipient or indirectly to the terminals:

$$\forall v \in \boldsymbol{D}, \forall h \in \boldsymbol{H} \sum_{v' \in \boldsymbol{TZ}} x1(v,v',h) + \sum_{v' \in \boldsymbol{O}} x2(v,v',h) \leq q1(v,h), \tag{2}$$

- demand of recipients must be met:

$$\forall v' \in \boldsymbol{O}, \forall h \in \boldsymbol{H} \sum_{v \in \boldsymbol{TZ}} x4(v,v',h) + \sum_{v \in \boldsymbol{D}} x2(v,v',h) = q2(v',h), \tag{3}$$

- processing capacity at the transhipment terminal cannot be exceeded:

$$\forall v' \in \boldsymbol{TZ}, \forall h \in \boldsymbol{H} \sum_{v \in \boldsymbol{D}} x1(v,v',h) + \sum_{v \in \boldsymbol{TZ}} x3(v,v',h) \leq q3(v',h), \tag{4}$$

– the size of the load flowing into the terminal is equal to the amount of cargo coming from it:

$$\forall v' \in \boldsymbol{TZ}, \forall h \in \boldsymbol{H} \sum_{v \in \boldsymbol{D}} x1(v,v',h) + \sum_{v \in \boldsymbol{TZ}} x3(v,v',h) = \sum_{v \in \boldsymbol{TZ}} x3(v',v,h) + \sum_{v \in \boldsymbol{O}} x4(v',v,h). \quad (5)$$

The stream of cargo is distributed according to the criterion function. The criterion function takes the following form:

$$\begin{aligned}
&\mathbf{F}1(\mathbf{X}1,\mathbf{X}2,\mathbf{X}3,\mathbf{X}4) = \\
&\sum_{v \in \boldsymbol{D}} \sum_{v' \in \boldsymbol{TZ}} \sum_{h \in \boldsymbol{H}} x1(v,v',h) \cdot [czd(v,h) + cwz(v',h) + c1(v,v',h) \cdot d1(v,v',h)] + \\
&\sum_{v \in \boldsymbol{TZ}} \sum_{v' \in \boldsymbol{TZ}} \sum_{h \in \boldsymbol{H}} x3(v,v',h) \cdot [cwz(v',h) + c3(v,v',h) \cdot d3(v,v',h)] + \\
&\sum_{v \in \boldsymbol{TZ}} \sum_{v' \in \mathbf{O}} \sum_{h \in \boldsymbol{H}} x4(v,v',h) \cdot [c4(v,v',h) \cdot d4(v,v',h)] + \sum_{v \in \boldsymbol{D}} \sum_{v' \in \mathbf{O}} \sum_{h \in \boldsymbol{H}} x2(v,v',h) \cdot [c2(v,v',h) \cdot d2(v,v',h)]. \quad (6) \\
&\longrightarrow \min
\end{aligned}$$

3. Genetic algorithm for the problem

The purpose of the genetic algorithm is to determine the amount of cargo, which flows between the individual transport network objects for which the criterion function will reach a minimum value. The stages of the genetic algorithm take the following form: determining the structure processed by the algorithm, determining the adaptation function, which evaluates the structure according to minimum transportation and reloading costs, the selection, the crossover and the mutation.

The crossover process and mutation 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 crossover and mutation occurs with a defined likelihood set at the beginning of functioning of the algorithm. In order to prevent early convergence of the algorithm linear scaling needs to be applied [4].

3.1. Structure of the genetic algorithm

The structure of input data was presented as matrix **M(*h*)**, which presents the flow of *h*-th cargo between particular elements of the transport network. Lines and columns of this matrix define facilities of the transport network structure. In order to determine the flow of cargo, lines were defined as the starting points from which cargo flows out to the other facilities. Matrix cells are located in the following sequence: suppliers, terminals and recipients. The graphical representation of the matrix structure **M(*h*)** with sample volumes was shown on Fig. 2 (**D**-suppliers, **TZ**-terminals, **O**-recipients). On the basis of volumes in the matrix of **M(*h*)**, the criterion function presented in the chapter 2 can be calculated e.g. the decision variable, which determines the cargo flow between D1 and TZ1 takes the value 20.

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	10	15
D2	0	0	15	20	0	0	5	5
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

Fig. 2. The structure of the genetic algorithm

The key issue is to determine the correct structure processed by the algorithm that would meet limitations of the mathematical model. The steps of the procedure, which designates the initial structure, can be presented as follows:

- Step 1: Setting the values of all cells of the matrix on 0. This value determines the connections for which it is not possible to transport the raw material, e.g. between suppliers,
- Step 2: Setting the cells of matrix: D1, TZ1 – D2, TZ4 in a random way (relations: suppliers – terminals). The values in cells must meet the limits: the production capacity of suppliers (2) and processing capacity at the transhipment terminal (4) cannot be exceeded. Out of these limits, one can choose the minimum value. The values of cells are set in a random way from the range [0, the minimum value] e.g. the supplier D1 offers 100 units of cargo, processing capacity for the terminal TZ1 is 60, so the range takes the size [0, 60]. It should be remembered that for another terminals e.g. TZ2 the supplier D1 offers 80 units of cargo,
- Step 3: Setting the cells of matrix: TZ1, TZ1 – TZ4, TZ4 (relations between the terminals). The diagonal of the matrix is always set to 0. Charge flow is in one direction, so the values are put in the cells above the diagonal. The values of cells are set in a random way from the range [0, the minimum value]. The minimum value is selected among the two values: the value of cargo flowing into a terminal and processing capacity of another terminals e.g. the terminal TZ1 has 35 units of cargo, processing capacity of the terminal TZ2 is 100, the range takes the size [0, 35],
- Step 4: Setting the cells of matrix: TZ1, O1 – TZ4 – O2 (relations: terminals – recipients). The values of these cells cannot be determined in a random way because demand of recipients (3) may not be fulfilled. It should be remembered that all loads must exit the loading terminals to meet the limitation on flow behaviour in the terminals (5). The minimum value between the two values i.e. demand of recipients and the volume of cargo in a given terminal is put into the cells. In order to fulfil the limit (5) the volume of cargo flowing into all terminals cannot be bigger than demand of recipients,
- Step 5: Setting the cells of matrix: D1, O1 – D2, O2 (relations: suppliers – recipients). The values of these cells cannot be determined in a random way because demand of recipients (3) may not be fulfilled. It should be remembered that the values of each cells could not exceeded the production capacity of suppliers and demand of recipients.

3.2. The adaptation function

On the basis of the adaptation function, the genetic algorithms designate the final solution. The genetic algorithms look for the maximal solution. In order to take into account the mentioned aspect the adaptation function $\mathbf{Fp}_n$ for n-th structure takes the following form:

$$\mathrm{Fp}_n = \mathrm{C} - \mathbf{KPS}_n\,, \tag{7}$$

where:
C – the value much higher than the value of the costs of the cargo flow in the network,
$\mathbf{KPS}_n$ – the cost of the cargo flow in n-this structure, formula (6) for h-th cargo.

The tendency of genetic algorithms is to maximize the function of adaptation. Maximization of the function Fp_n consequently is the process of minimization of the function $\mathbf{KPS}_n$, what is the assumed optimization aim.

3.3. The crossover process

To implement the crossover process, two matrices are developed: **DIV**(h) which comprise rounded up average values from both parents, and matrix **REM**(h) containing information whether the rounding up was indeed necessary. Assuming that the value of matrices **M1**(h) and **M2**(h)

(parents) in all cells assume determination $m^1{}_{v,v'}$, $m^2{}_{v,v'}$, values of elements of matrices **DIV**(h) and **REM**(h) are calculated from the following dependencies:

$$dim_{v,v'} = \lfloor (m^1{}_{v,v'} + m^2{}_{v,v'})/2 \rfloor, \tag{8}$$

$$rem_{v,v'} = (m^1{}_{v,v'} + m^2{}_{v,v'})/\,mod 2\,, \tag{9}$$

The full description of the crossover operator process was presented in [10] and presented in a graphical way to Fig. 3-5. The values with the matrix **REM** are added to the matrix **DIV**. As a result of this operation two new structures are developed. The applied crossover operator guarantees the correctness of individuals following a completed crossover, without the necessity of using repair algorithms.

M1(h)

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	10	15
D2	0	0	15	20	0	0	5	5
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

M2(h)

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	7	18
D2	0	0	15	20	0	0	8	2
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

Fig. 3. Structures in the crossover process

DIV(h)

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	8	16
D2	0	0	15	20	0	0	6	3
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

REM(h)

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	0	0	0	0	1	1
D2	0	0	0	0	0	0	1	1
TZ1	0	0	0	0	0	0	0	0
TZ2	0	0	0	0	0	0	0	0
TZ3	0	0	0	0	0	0	0	0
TZ4	0	0	0	0	0	0	0	0

Fig. 4. The matrices DIV and REM

New structure 1

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	9	16
D2	0	0	15	20	0	0	6	4
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

New structure 2

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	8	17
D2	0	0	15	20	0	0	7	3
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

Fig. 5. New matrices after crossover process

3. 4. The mutation process

The operation rule of mutation operator consists of 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 $p \times q$ (k – number of lines in the main matrix (processed by the algorithm), n – 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 Fig. 6.

Before mutation

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	10	15
D2	0	0	15	20	0	0	5	5
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

After mutation

	D1	D2	TZ1	TZ2	TZ3	TZ4	O1	O2
D1	0	0	20	10	0	0	7	18
D2	0	0	15	20	0	0	8	2
TZ1	0	0	0	15	10	10	0	0
TZ2	0	0	0	0	20	25	0	0
TZ3	0	0	0	0	0	10	10	0
TZ4	0	0	0	0	0	0	10	35

Fig. 6. Mutation process

4. Conclusion

The problem of designating the number of docks at the transhipment terminals is the optimization issue. In order to solve this problem the genetic algorithm was developed. It should be remembered that the optimal results generated by the algorithm depend on many parameters e.g.: mutation, crossover, the number of iterations or the size of the population. It should be emphasized that the generated solution by the genetic algorithm is sub – optimal. In spite of this, the speed of the algorithm is its advantage. In the next step, this algorithm will be implemented. The generated solutions will be compared with random results in order to check its effectiveness.

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