SELECTION OF THE PROPER LAYOUT OF MANUFACTURING LINES

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Abstract. A model is proposed which helps select the type of layout - circular or linear, for deploying technology machines. Based on the coefficient of volumetric efficiency, the proposed model is solved using the software package MATLAB and could assist in selecting logistic and technological machines to obtain the minimum total cost.

Keywords: logistic modelling, design, placement of objects, layout, technological chain

1. Introduction

It is known [1] that parts move one at a time or in a batch and that one technological chain may have the same or different number of technological machines for each operation.

It is also well-recognized [3] that there are two different routing schemes in manufacturing - linear and circular.

A number of studies [2, 8, 9, 10] consider the design of technological chains.

This paper deals with technological chain of the same number of machines (one) for each operation, in the case of circular and linear organization.

The objective is to select the proper layout of production lines for a particular production - circular or linear, in which the coefficient of volumetric efficiency is the greatest.

2. The form of the objective function

The following data is given:

$P_i(a_i, b_i)$ - existing objects (technological machines), $i = 1, 2, \ldots, m$; $m \geq 2$, located in the same production unit (section, department, etc.), which forms the m number of parallel lines or circles (contours); there is a single machine deployed at the beginning of each line (contour); these objects are pre-defined technological machines that are available depending on the specific production requirements;

- plant-size (section-size), in which the problem is solved;
- p - new objects (technological machines);
- $Q_{ij}(x_{ij}, y_{ij})$, $j = 2, 3, \ldots, n$; $n > 2$, are located in m parallel lines or contours $i = 1, 2, \ldots, m$; $m \geq 2$; n of those have transport and technological inter-connection and form a single line ($p = m{\cdot}n - m$);
- the m-number of these lines are situated in parallel for the linear arrangement, and in m-contours (loops) for the circular arrangement;
- $W_{i,(j-1,j)} = \|Wi, (j-1, j)\|$ ($i = 1, 2, \ldots, m$ and $j = 2, 3, \ldots, n$), depending on the type of process chain, it is the relative cost of part transportation between j–1 and j-th machine for material-handling machines (MHM) with cyclic operation OR the relative cost of part transportation between j–1 and j-th machine for MHM with continuous operation.

The problem is considered under the following conditions:

1. Existing and new objects allow to be assumed as points;
2. Placing of existing objects is determinate;
3. The space solution is two-dimensional and discrete;
4. The Minkowski's metric is used as a measure of distance
$$D_i = d\left(Q_{i,j-1}; Q_{i,j}\right) = \left|x_{i,j} - x_{i,j-1}\right| + \left|y_{i,j} - y_{i,j-1}\right|;$$
5. The optimum solution is the one which leads to minimization of the total cost;
6. The logistics equipment capacity is not exceeded.

The objective function is of the form:

$$\varphi = \sum_{i=1}^{m}\left(\sum_{j=1}^{n-1} W_{i,(j-1,j)} \cdot d\left(Q_{i,j-1}; Q_{i,j}\right)\right) + \sum_{i=1}^{m}\sum_{j=1}^{n} S_{ij} \cdot h_{ij} \cdot Z = \sum_{i=1}^{m}\left(\sum_{j=1}^{n-1} W_{i,(j-1,j)} \cdot \left[\left|x_{i,j} - x_{i,j-1}\right| + \left|y_{i,j} - y_{i,j-1}\right|\right]\right) + \sum_{i=1}^{m}\sum_{j=1}^{n} S_{ij} \cdot h_{ij} \cdot Z \quad (1)$$

where

S_{ij} - occupied floor area by the j-th machine dimensions in the i-th row (loop);

h_{ij} - height of the j-th machine;

Z - price per cubic meter of the room space.

The model is solved under the following restrictions:

$$X_{\max} \le K_1;\ Y_{\max} \le K_2;\ H_{\max} \le K_3;$$
$$X_{\min} \ge K_4;\ Y_{\min} \ge K_5;\ H_{\min} \ge K_6; \quad (2)$$
$$X_{i,j}^{\min} \ge P_{i,j};\ Y_{i,j}^{\min} \ge q_{i,j},$$

where:

the constants K_h (h = 1, 2, 3, 4, 5, 6); $P_{i,j}$; $q_{i,j}$ (i = 1, 2, ……, m; j = 2, 3, …, n) are selected for the specific requirements of the production system;

$X_{\max}$, $Y_{\max}$, $H_{\max}$, $X_{\min}$, $Y_{\min}$, $H_{\min}$ determine the size of the plant (section) for which the problem is solved;

$X_{i,j}^{\min}$, $Y_{i,j}^{\min}$ - the minimum distance that can exist between j-1 and j-th technological machine, defined by ergonomic and production needs;

$\sum_{j=1}^{n} S_j \cdot h_j \cdot Z$ < room volume.

The two deployment schemes have the following differences.

Deployment of machines in a circular cargo route layout

This layout requires consistent implementation of MHM links between various objects in a length limited space (Figure 1). Each course can be served by one or several heterogeneous MHMs. In general, one MHM does not serve all addresses, i.e. the transfer of the cargo between two machines, connected in sequential technology, can be carried out by different types and number of MHMs.

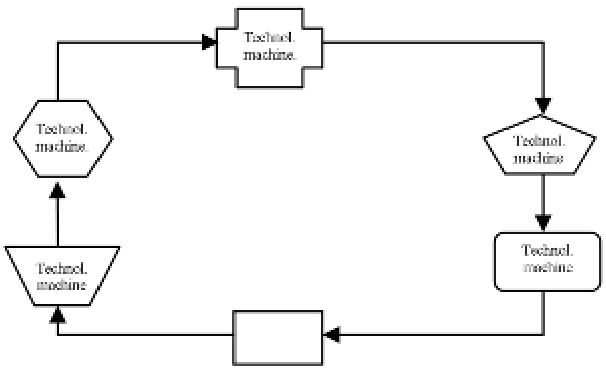

Figure 1. Circular production scheme

Based on the abovementioned, it could be said that the circular scheme is a linear scheme built on limited space length.

In this scheme, there could be r (r = 1, 2, …, R) number of MHMs, between two objects, where the MHMs perform cargo transfer between j-1 and j-th tech machine.

$$W_{i,(j-1,j)} = \begin{Vmatrix} W_{1(1,2)} & W_{1(2,3)} & \cdots & W_{1(n-1,n)} \\ W_{2(1,2)} & W_{2(2,3)} & \cdots & W_{2(n-1,n)} \\ \cdots & \cdots & \cdots & \cdots \\ W_{m(1,2)} & W_{m(2,3)} & \cdots & W_{m(n-1,n)} \end{Vmatrix} \quad (3)$$

j = 2, 3, …, n; n > 2

where every matrix element is

$$W_{i(j-1,j)} = W_{i(j-1,j)}^{1} + \cdots + W_{i(j-1,j)}^{R} \quad (4)$$

Analysis of existing production systems shows that R is usually relatively small number. It should be noted that different lines give the design advantage that they can be treated as separate sections.

Linear motion of the parts

The most common type of linear motion is as follows (Figure 2):

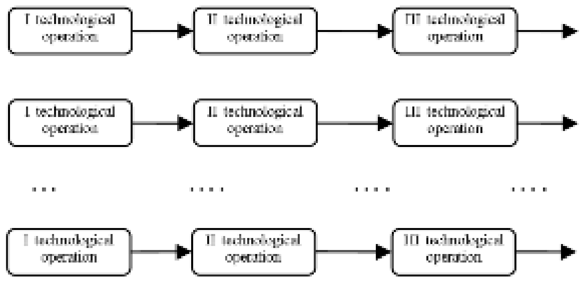

Figure 2. Linear production scheme

The objective function (1) and the matrix of relative transportation costs (3) here are similar. In this arrangement, two objects can have r = 1 number of MHMs and machines performing cargo transfer between j-1 and j-th technological machine.

For simplicity, it is adopted that $Q_{i,1} = P_j$, i = 1, 2, …, m; j = 2, 3, …, n.

It is required to find out such an arrangement of the objects Q_{ij}; i = 1, 2, …, m; $m \ge 2$; j = 2, 3, …, n; $n > 2$, which minimizes the total cost for a given period of time (years, day, etc.) for the movement of cargo in parallel technological lines.

By finding the minimum of the functional of the two schemes, there could be determined the number and type of logistics technology and equipment and their respective characteristics. To solve the problem (to select the proper layout of the production lines) the coefficient of volumetric efficiency [4] is used:

$$e_V = \frac{e.V'}{V} = \frac{(Q_{HT}.W - E)}{(K + f.K)}.\frac{V'}{V} \quad (5)$$

After transformations, the following is obtained:

$$e_V = \sum_{m=1}^{M} \frac{Q_{HT.}W - (E_1 + E_2)}{[(K_1 + fK_1) + (K_2 + fK_2)]} \cdot \frac{(V_1^{'} + V_2^{'})}{V_m} \quad (6)$$

where:

Q_{HT} is a natural expression of the production;
W - price of the product;
E_1 - operational technological cost;
E_2 - operational transport cost, function of t and the type of MHM;
$V_1^{'}$ - volume of technological and logistical equipment;
$V_2^{'}$ - volume of the storage;
V_m - that part of the volume of the production site, occupied by a line (loop);
V - volume of the production site;
f - per cent interest;
m - number of distinct sections with circular pattern (parallel lines, linear motion);
$q^{'}_{i,j}$ - volume of goods (parts, waste, etc.) stored in $M^{'}_{i,j}$;
$q^{''}_{i}$ - volume of goods stored in $M_i^{''}$;
K_1 - capital investments in technological machines;
K_2 - capital investments in MHMs and facilities;

$$V_2^{'} = \sum_{i=1}^{m}\sum_{j=1}^{n} K_{i,j} \cdot q^{'}_{i,j} + \sum_{i=1}^{m} K_i \cdot q_i^{''} \quad (7)$$

$$K_{i,j} \cdot q^{'}_{i,j} = M^{'}_{i,j}; \qquad K_i \cdot q_i^{'} = M_i^{''}$$

where:

$\sum_{j=1}^{n} M^{'}_{i,j}$ are storage areas for working machines in a row (loop), considered as volumes;

$\sum_{i=1}^{m} M_i^{''}$ - buffer storage locations within the workshop, considered as volumes for each line (loop);

$K_{i,j}$ - coefficient showing the relationship of the volume of goods to the volume actually required for their storage.

Then

$$M_i = \sum_{j=1}^{n} M^{'}_{i,j} + M_i^{''}, \quad (8)$$

the total number of storage sites will be

$$N = \sum_{i=1}^{m} M_i = V_2^{'}. \quad (9)$$

It is required to find $e_V = \arg.\max f(e)$ for circular and linear scheme and select the volume efficiency coefficient with greater value under the following conditions:

- $V_1^{'} > 0$;
- $V_2^{'} \geq 0$;
- $V' < V$;
- availability of capital.

The above model is solved with the help of the software package MATLAB [8].

The task is extremely complex [6, 7].

The most appropriate approach to explore the presented links is the matrix formulation [5, 7].

3. An example

An example problem is solved based on equation (1). The scheme in Figure 3 presents the assumed symbols of the links and locations of objects, and is used as a specific case in further considerations.

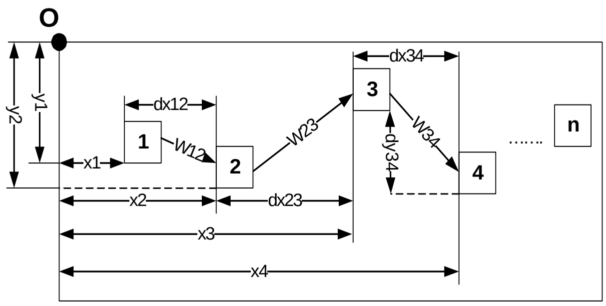

Figure 3. Scheme of objects arrangement

For clarity of interpretation, the case when $m = 1$ and $n = 6$ is analysed.

The location is relative to the coordinate origin O.

The following is assumed:

- there is only feed forward connection between objects;
- independent parameters are the coordinates of objects (resp. the distances between them);
- S_{ij} - the occupied floor area of the j-th machine dimensions in the i-th row, is subject to the discrete uniform distribution;
- $dx_{i,j} = |x_{i,j} - x_{i,j-1}|$ - the x-distances between adjacent sites, are subject to the discrete uniform distribution;
- $W_{i,(j-1,j)}$ - the changes in transport costs between the objects, are subject to the normal distribution with mean 8 and standard deviation 2.

An M-file program in MATLAB is developed to solve the problem.

Some of the results are presented in the figures below.

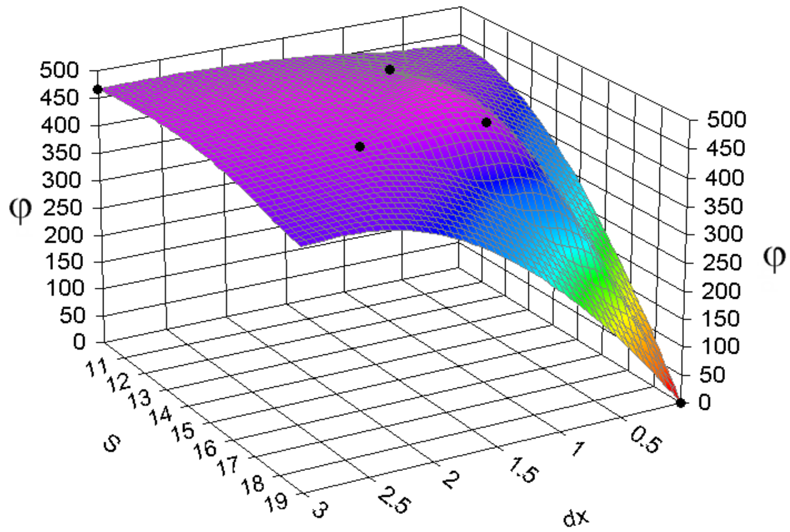

Figure 4. Variation of φ with respect to the occupied floor area *S* and distances *dx*

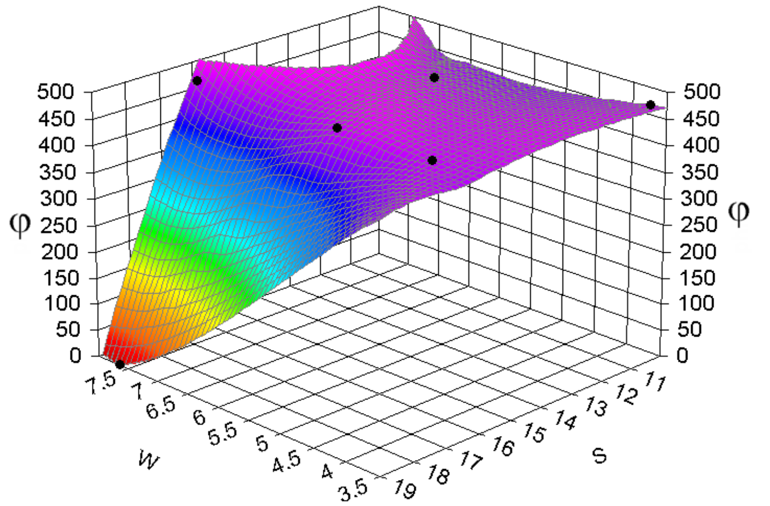

Figure 5. Variation of φ with respect to the occupied floor area *S* and transport costs *W*

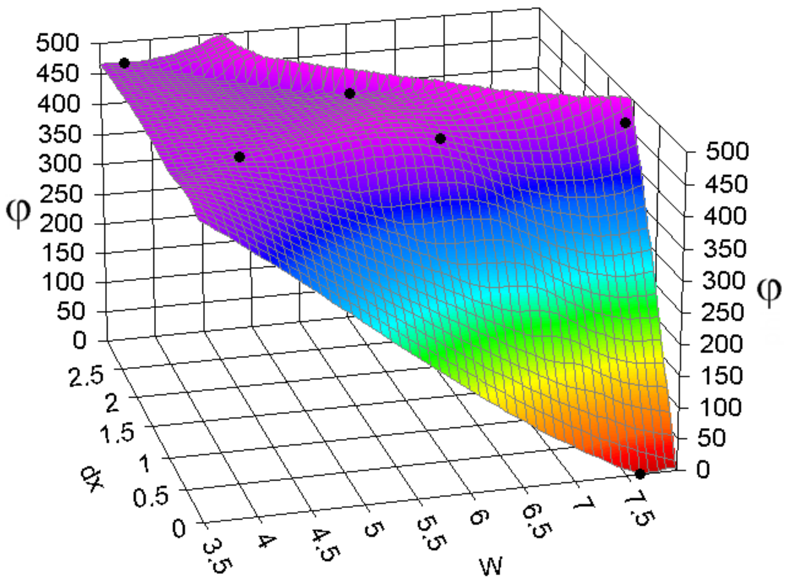

Figure 6. Variation of φ with respect to the transport costs *W* and distances *dx*

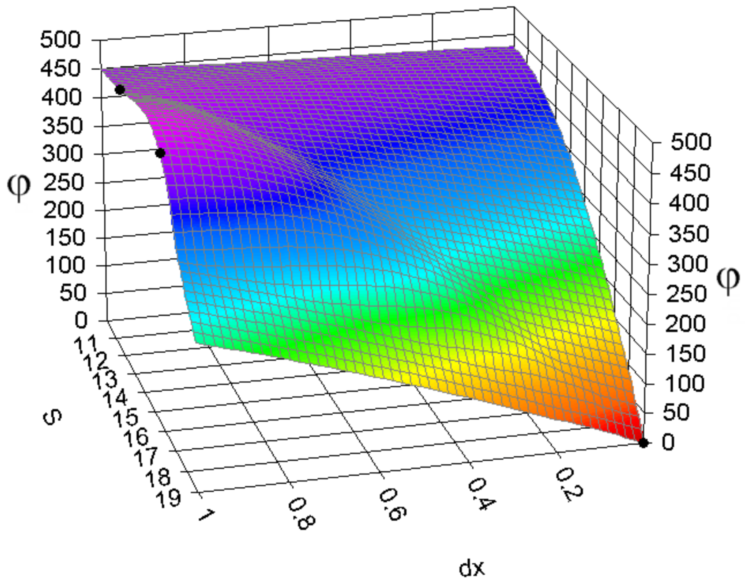

Figure 7. Section graph of Figure 2 for the variation of φ with respect to the occupied floor area *S* and relatively constant distances *dx*

It is possible to make graphical sections, e.g. for the assumption of relatively constant distances between objects $dx \in [0, 1]$.

It is obvious that the presented model provides ample opportunities for stochastic research and analysis, and for performing subsequent optimization. When performing optimization it is needed to clarify the laws governing the occupied floor area, the distances between two neighbouring objects, as well as changes in transport costs. Optimization parameters must be strictly defined, in order to facilitate the selection of the most appropriate optimization approach.

After optimization of φ there is an array of data obtained. It is used to set the size and costs needed to determine the coefficient of volumetric efficiency of the two schemes which optimal difference is obtained using [11].

4. Conclusions

1. A model is proposed for selecting the type of scheme for arranging technological machines - circular or linear, in order to minimize the total costs.

2. The proposed model is realized by using the coefficient of volumetric efficiency and is solved using the software package MATLAB.

3. The proposed model assists in selecting logistic and technological machines to obtain the minimum total costs.

References

1. Georgiev, K. (1970) *Organization of machine production.* Technika, Sofia, Bulgaria, p. 87-95 (in Bulgarian)
2. Givkov, D. (1989) *Modeling and optimization of manufacturing processes*. VMEI, Sofia, Bulgaria, p. 61-77 (in Bulgarian)
3. Kazakov, N. (2000) *Logistiks.* Softrade, ISBN 954-9725-27-8, Sofia, Bulgaria, p. 147-149 (in Bulgarian)
4. Kazakov, N., Georgieva, N. (1988) *Coefficient of volumetric efficiency in the design of industrial enterprises*. Mashinostroene, ISSN 0025-455X, № 1, p. 5-7
5. Browning, T. (2001) *Applying the design structure matrix to system decomposition and integration problems*. IEEE, Transactions Engineering Management, no. 48, p. 292-306
6. Carroll, R.J., Ruppert, D. (1988) *Transformations and Weighting in Regression.* Chapman & Hall, ISBN 0-412-01421-1, London, England
7. Deb, K. (2001) *Multi-Objective Optimization using Evolutionary Algorithms*, John Wiley & Sons Ltd, ISBN 978-0-471-81339-6, Chichester, England
8. Daniel, C., Wood, F. (1980) *Fitting Equations to Data*. John Wiley & Sons, ISBN 0-471-19460-3, New York, USA
9. Saaksvuori, A., Immonen, A. (2008) *Product Lifecycle Management*. Springer, ISBN 978-3-540-78173-8
10. Crawford, C, Di Benedetto, C. (2006) *New Products Management*. McGraw-Hill /Irwin, ISBN 0-071-33265-0
11. Tudjarov, B., Penchev, V., Hristov, V. (2011) *XML Modeling of Genetic Algorithms*. BJED, ISSN 1313-7530, № 8, p. 31-34

Received in April 2013