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An Application of Taxonomy in Determining the Technological Lines in a Manufacturing Process

When the number of units forming the equipment of an enterprise is large, taxonomy offers an efficient means of achieving the distribution of this equipment along technological lines in such a manner that the number of passings of the parts from one technological line to another should be minimum.

An important path in increasing the efficiency of investments is to design the objective for the size strictly required in view of normal carrying out of the technological processes. With this in view, the classifiying of equipment in technological lines — when this is necessary — is of particular importance. Correct distribution of the equipment materializes into important savings of production space since it contributes to shortening the path of internal transports. A classification of equipments along technological lines may also take place in the case of enterprises in operation when the technological process is essentially changed or when applying the studies related to the scientific organization of production and of labour, in case the existing location of the equipment is unsatisfactory and an obvious economic efficiency is obtained by their new arrangement.

In case a small number of equipment units is dealt with, the solution for classifying them can be found intuitively. If the number of equipment units is sufficiently large, classifying based on traditional methods proves to be inefficient. In such cases, in view of achieving such a distribution of the equipment units in the technological lines that the number of passings of the parts from one technological line to another, be minimum, an efficient instrument is taxonomy, the science dealing with the solving of problems of

classification. It allows to classify a set of elements (in the present case the set of equipment units) in relation to a series of criteria (properties).

Rational location of the equipment units by means of the methods offered by taxonomy involves several stages, viz.:

— determining optimum loading of equipment units as a function of the chosen technology;

— classifying equipment units in technological lines;

— determining the best-suited location of the equipment units within each technological line so that the transport distances be minimum.

In agreement with the action for a scientific organization of production and labour at I.O.R. (Romanian Optical Enterprise) one of the methods of taxonomy was applied in the photo-objectives department, namely "cluster analysis"[1] — [4] in view of distributing the units in the technological lines. This study was carried out after, the optimum loading of the equipment was solved. In the computations made the cost of transport from one operation to the next was not taken into account since the parts and transport distances are approximately equal.

We have considered $\mathcal{U} = (U_1, ..., U_{25})$ as the set of equipment units and $\mathcal{P} = (P_1 ..., P_{18})$ as a set of properties.

If an equipment unit U_i has the property P_j it means that it may be used for processing item j. A matrix can be associated to the sets $\mathcal{U}$ and $\mathcal{P}$ (Table I).

$$E = ((e_{ij})), \quad i = 1...18, \quad j = 1 \ ... \ 25$$

defined as follows:

$$e_{ij} = \begin{cases} 1, \text{ if part } j \text{ is processed on unit } U_i; \\ 0, \text{ if part } j \text{ is not processed on unit } U_i. \end{cases}$$

In view of obtaining as uniform a loading as possible on all equipment units, a matrix of part processing was first solved.

Matrix E evidences the line vectors [1]

$$e_i = (e_{i1}, ..., e_{i18}),$$

$$i = 1, 2, ..., 25,$$

belonging to a vectorial space above the body $L_2 = \{0.1\}$. The operations in this space are defined as follows:

$$e_i + e_j = (e_{i1} + e_{j1}, ..., e_{i18} + e_{j18})$$

$$\lambda e_i = (\lambda e_{i1}, ..., \lambda e_{i18}), \quad \lambda \in L_2$$

and "+" is defined as follows:

+	0	1
0	0	1
1	1	0

Table I

*Matrix of equipment units set in relation to their properties**

Code mark \ Code equipment	1	1	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1					1	1											
2	1												1					
3							1									1		1
4	1	1										1						
5						1				1								
6	1								1	1		1						
7		1								1			1					
8	1									1		1	1					1
9		1	1	1		1	1											
10									1		1			1				
11	1														1			
12		1					1											
13	1	1					1		1									
14	1	1			1							1			1			
15						1						1				1		
16							1	1										
17	1		1														1	
18	1								1									
19	1					1	1		1									
20		1				1					1							
21		1							1		1		1					
22						1												
23													1					
24											1							
25													1		1			

In boxes not containing figures the value is considered zero.

Considering the distances (d) between the elements (e_i, e_j):

$$d(e_i,\ e_j) = p(e_i + e_j)$$

where p is the weight of the $e_i + e_j$ vector, matrix D of order 25 is formed. (Table II). Since this matrix is symmetrical, it is sufficient to write only the elements placed above the main diagonal.

Table II

Matrix of distancés D

0	3	4	4	3	5	6	6	4	6	3	3	3	6	4	3	4	3	1	4	7	2	4	4	5
	0	5	3	4	4	3	3	7	5	2	4	4	5	5	4	3	2	4	5	4	3	1	3	2
		0	6	5	7	6	6	6	6	5	3	5	8	4	3	6	5	5	6	7	4	4	4	5
			0	5	3	4	4	6	6	3	3	3	2	4	5	4	3	5	4	5	4	4	4	5
				0	4	3	5	5	5	4	4	6	7	3	4	5	4	4	3	6	1	3	3	4
					0	5	3	9	5	4	6	4	5	5	6	5	2	4	7	6	5	5	5	6
						0	4	6	6	5	3	5	6	6	5	6	5	7	4	3	4	2	4	3
							0	10	8	5	7	7	6	6	7	6	5	7	8	7	6	4	6	5
								0	8	7	3	5	8	6	5	6	7	5	4	7	4	6	6	7
									0	5	5	5	8	6	5	6	3	5	4	3	4	4	2	5
										0	4	4	3	5	4	3	2	4	5	6	3	3	3	2
											0	2	5	5	2	5	4	4	3	4	3	3	3	4
												0	5	7	4	5	2	2	5	4	5	5	5	6
													0	6	7	6	5	7	6	7	6	6	6	5
														0	5	6	5	5	4	7	2	4	4	5
															0	5	4	4	5	6	3	3	3	4
																0	3	5	6	7	4	4	4	5
																	0	2	5	4	3	3	3	4
																		0	5	6	3	5	5	6
																			0	3	2	4	2	5
																				0	5	3	3	4
																					0	2	2	3
																						0	2	1
																							0	3
																								0

An undirected graph G formed by means of 26 levels (from 0 to 25) is associated to matrix D. The units $U_1, \ldots, U_{25}$ appear on level 0; all the pairs (e_i, e_j) for wich $d(e_i,\ e_j) = 1$ appear on level 1, a.s.f. From units U_i and U_j branches are traced to the pair (e_i, e_j). Practically, graph G cannot be drawn on account of the large number of vertices and edges. Thus, we associate to graph G the representation G' where the edges are no longer taken into consideration but only the vertices, and instead of (e_i, e_j), one will simply write (i, j). (Fig.1).

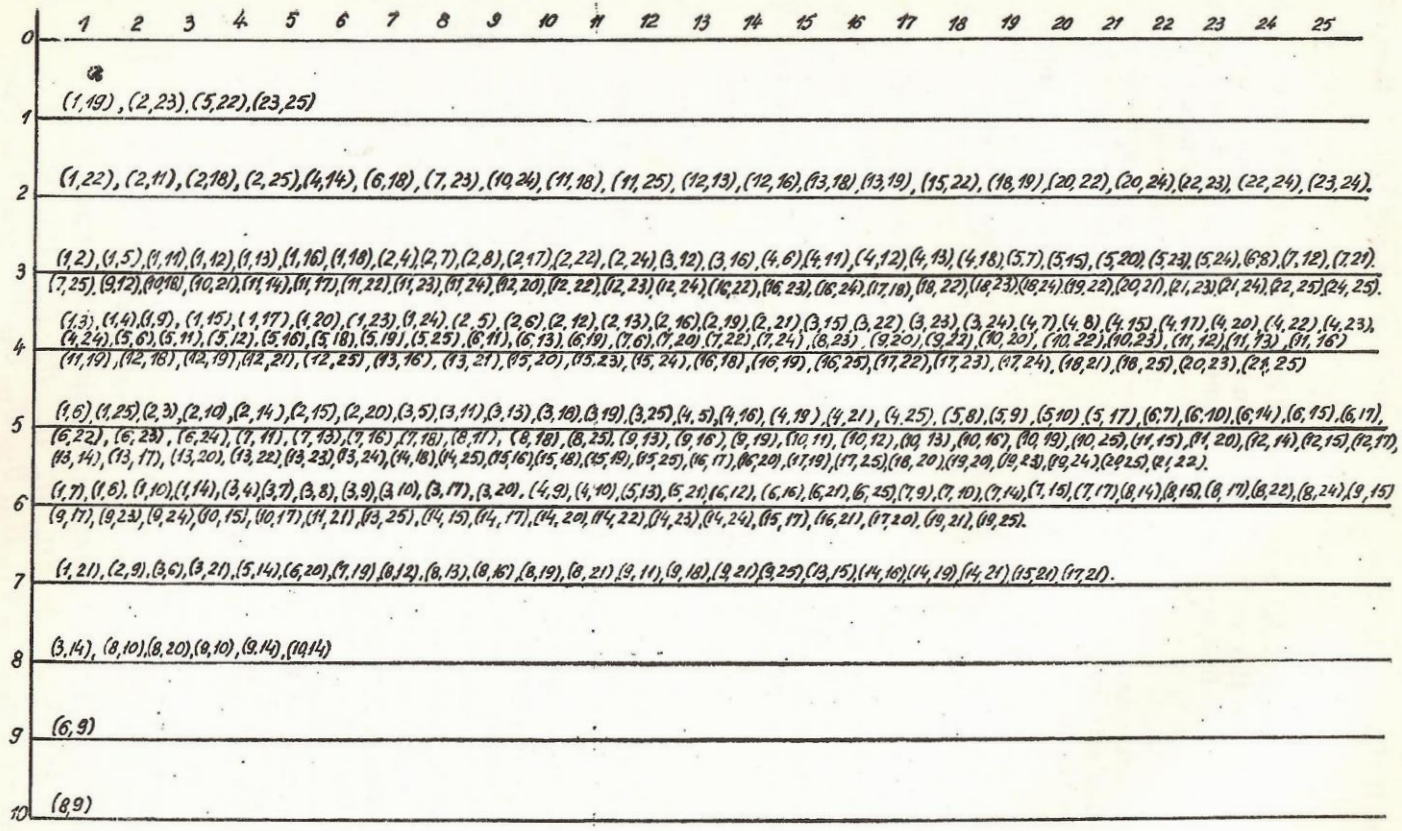
The representation G', associated to graph G, contains the same quantity of information as graph G, respectively the matrix D.

We turn graph G' into a tree, i.e. into a graph having the following properties:

1. from every node of the graph (including the initial vertices) only a single branch starts towards the lower levels;

2. it has only one final vertex, situated on level n or on one higher than this.

The construction of the tree amounts to find all the subsets of elements ($i_1, \ldots, i_k$) so that:


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
0
1
(1,19), (2,23), (5,22), (23,25)
2
(1,22), (2,11), (2,18), (2,25), (4,14), (6,18), (7,23), (10,24), (11,18), (11,25), (12,13), (12,16), (13,18), (13,19), (15,22), (18,19), (20,22), (20,24), (22,23), (22,24), (23,24).
3
(1,2), (1,5), (1,11), (1,12), (1,13), (1,16), (1,18), (2,4), (2,7), (2,8), (2,17), (2,22), (2,24), (3,12), (3,16), (4,6), (4,11), (4,12), (4,13), (4,18), (5,7), (5,15), (5,20), (5,23), (5,24), (6,8), (7,12), (7,21), (7,25), (9,12), (10,18), (10,21), (11,14), (11,17), (11,22), (11,23), (11,24), (12,20), (12,22), (12,23), (12,24), (16,22), (16,23), (16,24), (17,18), (18,22), (18,23), (18,24), (19,22), (20,21), (21,23), (21,24), (22,25), (24,25).
4
(1,3), (1,4), (1,9), (1,15), (1,17), (1,20), (1,23), (1,24), (2,5), (2,6), (2,12), (2,13), (2,16), (2,19), (2,21), (3,15), (3,22), (3,23), (3,24), (4,7), (4,8), (4,15), (4,17), (4,20), (4,22), (4,23), (4,24), (5,6), (5,11), (5,12), (5,16), (5,18), (5,19), (5,25), (6,11), (6,13), (6,19), (7,6), (7,20), (7,22), (7,24), (8,23), (9,20), (9,22), (10,20), (10,22), (10,23), (11,12), (11,13), (11,16), (11,19), (12,18), (12,19), (12,21), (12,25), (13,16), (13,21), (15,20), (15,23), (15,24), (16,18), (16,19), (16,25), (17,22), (17,23), (17,24), (18,21), (18,25), (20,23), (21,25)
5
(1,6), (1,25), (2,3), (2,10), (2,14), (2,15), (2,20), (3,5), (3,11), (3,13), (3,18), (3,19), (3,25), (4,5), (4,16), (4,19), (4,21), (4,25), (5,8), (5,9), (5,10), (5,17), (6,7), (6,10), (6,14), (6,15), (6,17), (6,22), (6,23), (6,24), (7,11), (7,13), (7,16), (7,18), (8,11), (8,18), (8,25), (9,13), (9,16), (9,19), (10,11), (10,12), (10,13), (10,16), (10,19), (10,25), (11,15), (11,20), (12,14), (12,15), (12,17), (13,14), (13,17), (13,20), (13,22), (13,23), (13,24), (14,18), (14,25), (15,16), (15,18), (15,19), (15,25), (16,17), (16,20), (17,19), (17,25), (18,20), (19,20), (19,23), (19,24), (20,25), (21,22).
6
(1,7), (1,8), (1,10), (1,14), (3,4), (3,7), (3,8), (3,9), (3,10), (3,17), (3,20), (4,9), (4,10), (5,13), (5,21), (6,12), (6,16), (6,21), (6,25), (7,9), (7,10), (7,14), (7,15), (7,17), (8,14), (8,15), (8,17), (8,22), (8,24), (9,15), (9,17), (9,23), (9,24), (10,15), (10,17), (11,21), (13,25), (14,15), (14,17), (14,20), (14,22), (14,23), (14,24), (15,17), (16,21), (17,20), (19,21), (19,25).
7
(1,21), (2,9), (3,6), (3,21), (5,14), (6,20), (7,19), (8,12), (8,13), (8,16), (8,19), (8,21), (9,11), (9,18), (9,21), (9,25), (13,15), (14,16), (14,19), (14,21), (15,21), (17,21).
8
(3,14), (8,10), (8,20), (9,10), (9,14), (10,14)
9
(6,9)
10
(8,9)

a. If $(i_1, i_2, ..., i_k)$ is on a certain level, let us say level s, then all the $\frac{k(k-1)}{2}$ pairs (i_1, i_2), (i_1, i_3), ..., (i_{k-1}, i_k), are on the levels $1,2, ..., s$.

b. The set $(i_1,...,i_k)$ is not included in any of the sets formed up to it.

To achieve this we shall proceed in the following manner: we write on the first level the first set of indices obtained. In the case under consideration no such set can form on level 1. For the second level we shall take all the pairs situated on levels 1 and 2 and we shall endeavour to make absorptions; we pass the sets found on to level 2 if they have indices completely different from other sets on the same level and fulfil the conditions ***a*** and ***b***. In our situation the pairs (2, 11), (2, 18), (11, 18) have been absorbed by the triplet (2, 11, 18) which we have placed on level 2 (Fig.2). Other sets that are recorded on level 2 are (22, 23, 24) and (13, 19). Proceeding further, the tree in fig. 2 is obtained. The technological lines are shown by the two branches of the tree, which start from the vertex situated on level 10; no pair intervenes on the other levels (11—26).

The analysis of the tree in Fig. 2 leads to a few interesting remarks. This tree shows that the equipment units U_2, U_{11}, U_{18} are at a distance not exceeding 2, the units U_{12}, U_{16}, U_{22}, U_{23}, U_{24} are at a distance not exceeding 3. In a certain sense U_2, U_{11}, U_{18} are closer as a function than U_7, U_{10}, U_{13}.

The similarity between two vectors e_i and e_j is defined as follows:

$$s(e_i, e_j) = n - d(e_i, e_j)$$

There results from the formula that the larger the distance between vectors is, the larger the difference between vectors, hence the smaller is the similarity. For example, equipment unit U_7 is closer to the group of equipment units (2, 11, 17, 18) than equipment unit U_{10}.

For the technology adopted, this division into classes leads to a minimum number of passings from one class to another. The division into classes thus obtained results in the number of passings from one class to another to amount to 23, which means that a part is subject to at least one processing in the same class before passing on to the other class.

The most unfavourable division into two classes would lead to a number of 71 passings. By changing equipment units U_5 and U_9 from different classes, 27 passings are obtained. In view of a comparison we present hereafter the classification obtained by means of the cluster analysis method and the solution adopted by the plant. The number of passings in the solution used by the plant is 25, i.e. approximately 9 per cent larger than the one found by means of the cluster analysis method.

Cluster analysis solution

1st line: U_2, U_4, U_5, U_6, U_7, U_8, U_{11}, U_{14}, U_{15}, U_{17}, U_{18}, U_{21}, U_{25}
2nd line: U_1, U_3, U_9, U_{10}, U_{12}, U_{13}, U_{16}, U_{19}, U_{20}, U_{22}, U_{23}, U_{24}

Solution of the I.O.R. Production Organizing Department.

1st line: U_1, U_2, U_4, U_5, U_6, U_7, U_8, U_9, U_{10}, U_{11}, U_{17}, U_{18}, U_{20}
2nd line: U_3, U_{12}, U_{13}, U_{14}, U_{15}, U_{16}, U_{19}, U_{21}, U_{22}, U_{23}, U_{24}. U_{25}.

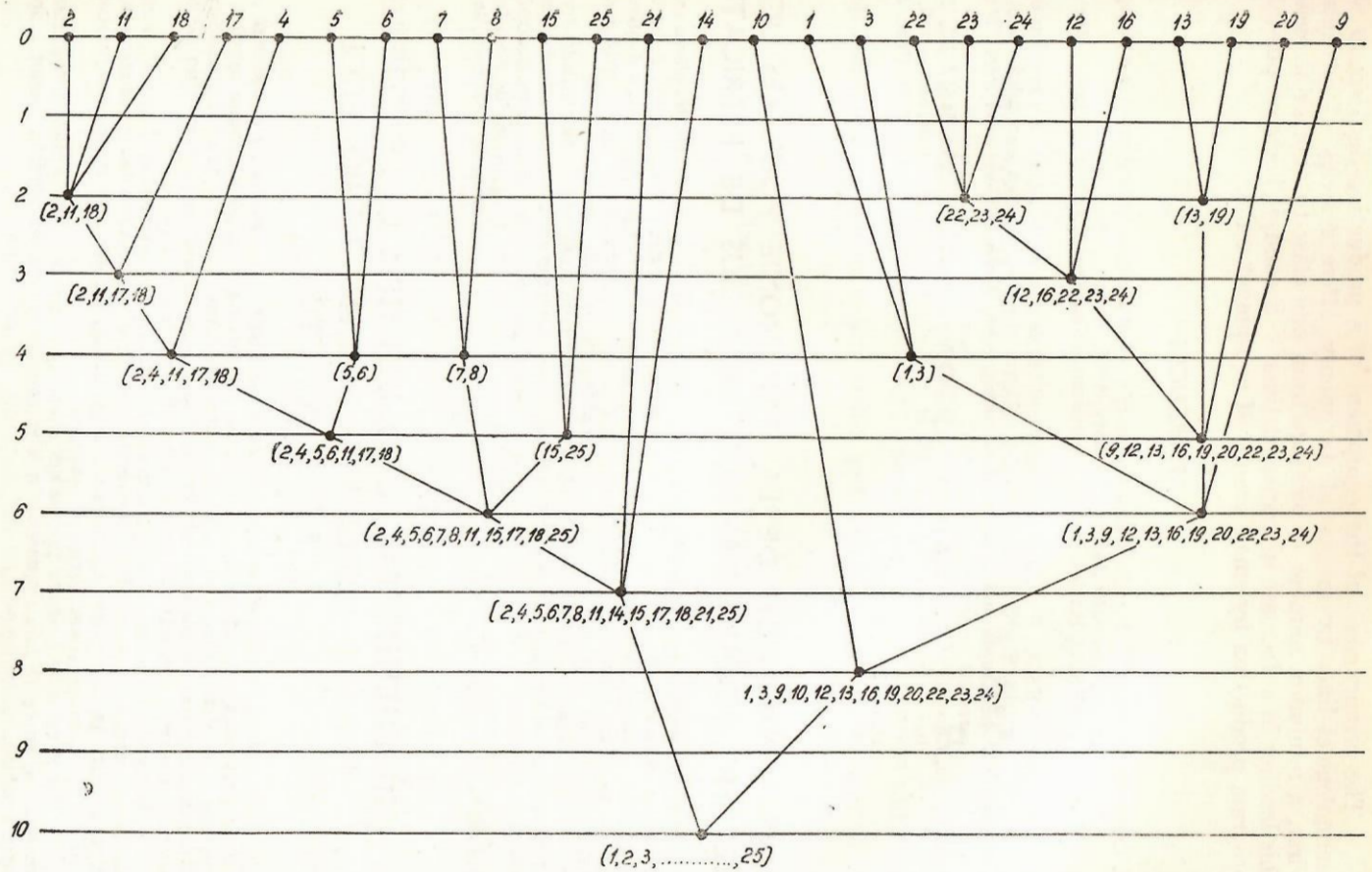


Fig. 2. Tree of equipment unit classification

The arrangement of the equipment of a production department along technological lines by means of taxonomy offers a series of advantages. First, a minimum number of passings from one class to another is ensured, this leading to a decrease in transport time. Second, it becomes possible to program production by small groups of equipment units.

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UNE APPLICATION DE LA TAXONOMIE POUR LES LIGNES TECHNOLOGIQUES DANS UN PROCESSUS DE FABRICATION

L'emplacement fortuit de l'équipement mène à des croisements répétés des pièces en cours d'usinage entre les différents lieux de travail, à une agglomération de circulation des pièces le long des corridors étroits, à des stagnations, à un surcroît du transport, ainsi qu'à d'autres désavantages. C'est pourquoi il est nécessaire de grouper l'équipement par lignes technologiques, c'est-à-dire, pour nous exprimer en termes mathématiques, par classes.

Dans le cas d'une entreprise possédant un assez grand nombre d'équipements divers, la classification fondée sur le „bon sens" et le talent organisateur s'avère insufisante. La nécessité s'impose de trouver un algorithme qui prête à être programmé sur des ordinateurs électroniques.

Les auteurs de l'étude présentent les bases théoriques de l'algorithme de classification, qui est ensuite appliqué à l'établissement des lignes technologiques dans un processus de fabrication.

ПРИМЕНЕНИЕ ТАКСОНОМИИ ПРИ ОПРЕДЕЛЕНИИ ТЕХНОЛОГИЧЕСКИХ ЛИНИЙ В ПРОЦЕССЕ ПРОИЗВОДСТВА

Случайное расположение оборудования приводит к пересечению направлений движения обрабатываемых частей на разных участках работы, к загромождению путей в узких коридорах, к остановкам, к удлинению расстояний перевозок и к другим недостаткам. Поэтому необходимо, чтобы все множество оборудования было бы разделено по технологическим линиям, т.е. в математических терминах, по классам.

В случае, когда число оборудования на предприятии достаточно большое, классификация по методу основанному на интуиции и таланте оказывается неудовлетворительной. Нужно найти такой алгоритм, который мог бы быть обработан путем его программирования на электронной вычислительной машине.

В данном исследовании авторы представляют теоретические основы алгоритма классификации, который затем применен для установления технологических линий в процессе производства.