Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066-8570 Volume **11**, Number **2**/**2019**

MATRIX LAYOUT OF WORKSTATIONS IN A MANUFACTURING SYSTEM FOR STRUCTURAL SIMPLIFICATION AND FOOTPRINT REDUCTION

Alexandra-Silvia POLENA[1]

Rezumat. *Lucrarea prezintă necesitatea înlocuirii unor mașini din linia de fabricație cu centre de prelucrare multifuncționale (centre CNC) analizându-se dacă două sau trei mașini de prelucrare se pot înlocui cu una singură capabilă să facă toate operațiile, reducând suprafața ocupată, timpul auxiliar și determinând o creștere a productivității.*

Abstract. *The paper presents the necessity of replacing machines from the production line with multifunctional machining centres (CNC centres) by analysing whether two or three machining machines can be replaced by a single one able to do all the operations, reducing the occupied area, the auxiliary time resulting in an increase in productivity*.

Keywords: resources, operations, system layout, footprint reduction.

1. Introduction

One of the main classifications of economic goods makes a distinct separation into two categories: consumer goods and production goods [2].

Consumer goods are products or services that directly meet economic needs (television, house, books, etc.), and production goods meet human needs, but indirectly through use in a production process [2].

Generally, the goal of a production process is to provide goods and services that people can use or consume to meet their own needs [2].

In the long run, goods are used as a means to achieve the goal of a process. For example: milling machine, turning device, personal computer, etc. and these goods are an intermediate step in the effort to cover human needs and are tools used to obtain consumer goods [2].

Once the type and quantity of consumer goods yet to be manufactured is determined, the type and quantity of production goods and facilities needed in the process will be calculated. The limit to which utility can be considered by logical processes is limited only by technical knowledge and the ability to reason [2].

Although the utility of consumer goods is initially subjectively determined, the utility of production assets as a means of achieving an objective is often determined on objective grounds [2].

[1]Ph.D. Stud. Eng., affiliation: Faculty IMST, PolitehnicaUniversity, Bucharest, Romania (e-mail: polenasilvia@yahoo.com).

The use of scientific and engineering knowledge for the benefit of people is achieved through the design and manufacturing activities of the goods we use: machinery, structures, products and services [1].

A technological process variant can be analysed from a purely technical point of view, referring to the succession of different operations, their composition and the calculation of certain specific parameters. At the same time, it can be analysed in terms of its economic aspect, cost and efficiency. Consequently, in order to have a chance to be selected, a proposal to solve an engineering problem must be technically possible and economically acceptable [1].

The activities associated with the engineering design process can be repeated until the final project is obtained. Thus, in a first phase, an entire cycle of the process can be traced to select a preliminary (conceptual) variant. Then, in another phase, the activities are repeated to develop, on the basis of the preliminary variant / variants, a detailed project / variant. The seven stages of economic analysis will also be repeated as necessary to assist decision-making in each phase [1].

Table 1. Comparison between Industrial Economic Analysis and Design Activities [1]

Economic Analysis in Engineering	*Engineering Design*
Steps:	Activities:
1. Recognizing, defining and evaluating the problem.	1. Recognition of a problem/need. 2. Wording and assessment of the problem/need.
2. Developing feasible alternatives.	3. Synthesis of all possible technical solutions (variants).
3. Determine the values associated with each alternative. 4. Selecting comparison criteria. 5. Analysis and comparison of alternatives.	4. Analysis, optimization and evaluation.
6. Select the optimal alternative.	5. Specify the preferred option.
7. Implementation, monitoring and evaluation of results.	6. Implementation

The resource designates a necessary means to carry out an activity (example: a person, a team, an external collaborator, a machine, a stock of raw materials or semi-finished products, etc.). Every resource is symbolically represented by a calendar. In this case, the notion of calendar takes a particular meaning: the time-based description of the number of units of work that the resource can devote to project activities. This timing can be done in hours, days, weeks, months, etc. [7].

Assigning a resource to a specific activity in the project consists in making part of the resource calendar available for carrying out that activity. The same resource can be assigned to several activities, the same project or different projects. At the same time, more resources can be allotted to the same activities [7].

The task is the part of the redundant resource calendar for carrying out a project activity. The tasks are measured in units of work.

For example, for human resources, tasks can be measured in: hours - person, weeks - person, etc. Resource intensity refers to the percentage of the timetable of that resource allocated to an activity. Assigning a resource for a certain activity can be interpreted differently depending on the intensity of participation in the activity. There are no limitations on production resources. In the case of the first variant, it is assumed that the manufacture of the three landmarks is done independently on their own resources. This means that the number of resources is equal to the total operations of the three landmarks. It is assumed that these resources have no time constraints and that their operation is carried out in perfect conditions. The economic consignment is determined, the production cycle duration, the batch repeat period, the cost per unit of product.

Product authorization programs are developed and verified if they meet the requirements of the Production Program Director (PPD) [7]. The production batch is the quantity of identical parts that are released in production, simultaneously or successively, which consumes only one preparation / completion time. The optimum production batch is the batch resulting from the calculations, but not always what results from the calculations can be applied in practice. Therefore, the optimum lot is approximated to a value that is dividing the annual output as close as possible to that of the calculation and which is an economic manufacturing batch.

In the production process, the objects of work are subjected to successive transformations, according to the technological process adopted.

These transformations are repeated identically for each batch, forming a production cycle, with a basic indicator of its duration.

Duration is the time measured from the entry of the work objects in the first stage of production to the final production, and serves to [7]:

- correctly establish the different gaps between the stages of transformation of the work objects into the basic production units;
- fixe real delivery times for products;
- elaborate the need for circulating capital employed in production and its speed of rotation;
- assess the degree of organization of production and use of resources.

The batch repeat period (Tr) is the interval separating the release into production of two successive lots containing work items of the same kind. By extension, in the case of the manufacture of several lots of different parts, on the same production resources, the repeat period Tr is the duration separating the production launch of two successive equivalent batches Nj.

In the context of production planning and management, the term "resource" means a means of pursuing and conducting an activity.

Any resource is symbolically represented as a calendar. The term of "calendar" acquires here a conventional task. Tasks are measured in units of work (hours - person, days - person, week - person, etc.).

The same resource can be allocated to several activities of the same project or to several activities of different projects. At the same time, more resources can be allocated to one or more activities.

Assigning a resource for a certain activity gets different interpretations depending on the intensity of participation in the activity. The term "intensity" means the percentage of the calendar allocated to an activity.

2. Obtaining and comparing two variants of the technological process from which the optimal variant will result

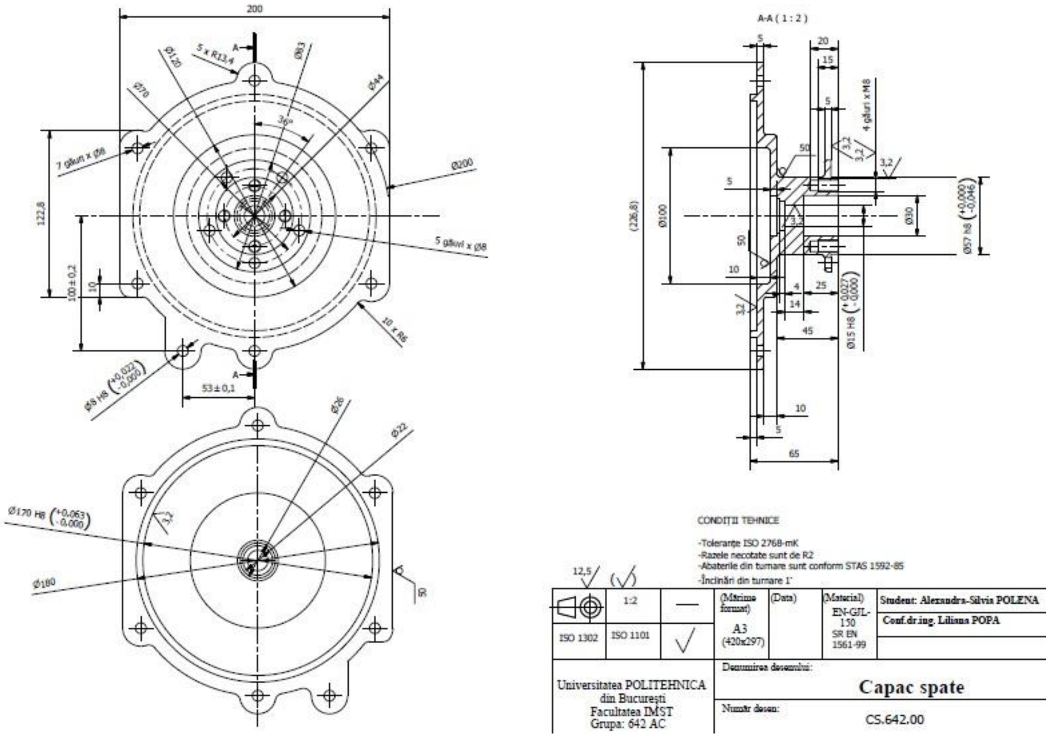


Fig. 1. *Tesla* Pump Back Cover.

To present the paper, the "Tesla Pump" product, which is a multi-part assembly, has been chosen as a manufacturing process model (Fig. 1).
In order to choose the scheduling and leadership of production, it is necessary to analyse three aspects of this ensemble.

Thus, it was chosen: the pump back cover marked P_2, the shaft marked with P_7 and bearing support P_{15}.

After completing the stages of the production project presented in the literature, some details will be briefly presented which led to the final results presented in this paper. For the Tesla Pump (P2) rear benchmark, two technological process variants (PT1 - the first technological process variant, PT2 - the 2nd technological process variant) were analysed where PT1 lathe was used to perform the required machining operations and a CNC centre, and at PT2 a lathe and two drilling machines were chosen.

For each technological process variant, PT1, PT2, the complementary operations were established and are presented in Table 2:

Table 2. Complementary operations processes variants PT1, PT2

PT1	*PT2*
00. Casting	00. Casting
10. Turning I	10. Turning I
15. Interim Inspection	15. Interim Inspection
20. Turning II	20. Turning II
25. Interim Inspection	25. Interim Inspection
30. Centring-Drilling-Boring	30. Turning III
35. Interim Inspection	35. Interim Inspection
40.Centring-Drilling-Threading	40. Turning IV
45. Interim Inspection	45. Interim Inspection
48. Washing	50. Drilling-Boring
50. Final inspection	55. Interim Inspection
60. Conservation-storage	60. Drilling-Threading
	65. Interim Inspection
	68. Washing
	70. Final inspection
	80. Conservation-storage

At the operating level, time norms were calculated, in [min / pc] based on the literature according to Table 3.

Following the economic analysis of the two technological process variants, PT1 and PT2 to determine the manufacturing cost, we calculated for each of the two variants.
The cost of the consumed material, the labour cost, the cost of the social security, the cost of the unemployment benefit, the cost of directing, the cost of depreciation and capital repair of the machinery, the direct manufacturing cost, the cost of depreciation and maintenance of the special equipment and the manufacturing cost associated with the production volume X and the technological process.

Table 3. Time norms:

PT1		*PT2*	
Task	*Time Norm, T_n, min/piece*	*Task*	*Time Norm, T_n, min/piece*
10.Turning I	19.02	10.Turning I	13.58
15.Interim Inspection	1.2	15. Interim Inspection	1.2
20. Turning II	9.74	20. Turning II	6.80
25. Interim Inspection	1.2	25.Interim Inspection	1.2
30.Centring-Drilling-Boring	6.83	30. Turning III	10.12
35. Interim Inspection	1.2	35.Interim Inspection	1.2
40.Centring-Drilling-Threading	6.12	40. Turning IV	7.91
45. Interim Inspection	1.2	45. Interim Inspection	1.2
48.Washing	0.5	50. Drilling-Boring	6.15
50. Final inspection	8	55. Interim Inspection	1.2
60. Conservation-storage	2	60. Drilling-Threading	5.50
-	-	65. Interim Inspection	1.2
-	-	68. Washing	0.5
-	-	70. Final inspection	2
-	-	80. Conservation-storage	2

Thus, for example, for the production schedule of 2000 pcs / year, the manufacturing costs associated with the PT1, PT2 technological process variants are: for PT1 is C_1 = 48133,5 *RON* and for PT2 is C_2 = 52021,8 *RON* from the resulting that the optimal option is *PT1*'s technological process.

3. Obtaining a reduction in the number of jobs due to the determination of the optimal technological process

On the basis of the analysis of the production project, the technological sheets of the three parts of the assembly were determined: P2 - Tesla Pump Cover; P7 - Shaft; P15 - Bearing support.

Table 4. Technological datasheets of the landmarksP_2

Technological datasheets of the landmarksP_2					
No.	*Task*	*Symbol*	*Resource*	T_u	$T_{pî}$
1	Tuning I	S11	OKUMA LB3000 EX	19.1	60
2	Interim Inspection	I12	Bank inspection	2.7	15
3	Tuning II	S13	OKUMA LB3000 EX	9.8	70
4	Interim Inspection	I14	Bank inspection	2.7	15
5	Centring-Drilling-Boring	C15	CP500 CNC	6.9	80
6	Interim Inspection	I16	Bank inspection	2.7	15
7	Centring-Drilling-Threading	C17	CP500 CNC	6.2	80
8	Interim Inspection	I18	Bank inspection	2.7	15
9	Washing	P19	Washing installation	1.2	5
10	Final Inspection	I1.10	Bank inspection	2.8	10
11	Conservation-storage	D1.11	Deposit bank	2.2	5

Table 5. Technological datasheets of the landmarksP_7

Technological datasheets of the landmarksP_7					
No.	*Task*	*Symbol*	*Resource*	T_u	$T_{pî}$
1	Milling	C21	CP500 CNC	13.7	50
2	Deburring	V22	Bank locksmith	6.5	20
3	Interim Inspection	I23	Bank inspection	2.4	15
4	Broaching	B24	BO100	1.5	20
5	Washing	P25	Washing installation	2.2	5
6	Final inspection	I26	Bank inspection	1.4	10
7	Conservation - Storage	D27	Deposit bank	1.8	5

Table 6. Technological datasheets of the landmarksP_{15}

Technological datasheets of the landmarksP_{15}					
No.	*Task*	*Symbol*	*Resource*	T_u	$T_{pî}$
1	Debiting	E31	FA – 300	1.6	10
2	Mortising	M32	M 320	8.8	30
3	Interim Inspection	I33	Bank inspection	2.7	15
4	Drilling	G34	G40	10.5	50
5	Boring	G35	G40	6.5	40
6	Washing	P36	Washing installation	1.2	5
7	Final inspection	I37	Bank inspection	2.8	10
8	Conservation - Storage	D38	Deposit bank	2.2	5

After performing important stages according to the literature, such as: product disaggregation structure (lower order structures called subsystems: assemblies, subassemblies); calculating gross needs; calculation of net requirement; it is necessary to determine the type of production, to determine the form of production organization and to determine the duration of the production cycle.

Once established, the operational management of the production of the 3 landmarks will be achieved for the situation where: the number of machines of a given brand is limited, being equal to the number required for carrying out the activities of the project; some machines assigned to the project are periodically unavailable at certain time intervals during each production cycle, thus: *the activities performed on the M320 can begin not before t0 + 16 hours and may end not after t0 + 56 hours each production cycle of the project* (*Tr = 192* hours) due to the unavailability of the machine in the other periods; due to the limited nature of the resources used, the durations of the manufacturing operations will be increased to include the intervals between the operations as well as other interruptions of operations for various reasons (machine feathers, non-compliant parts, etc.). Prior to the production of the parts, the production tasks are analysed and the necessary resources are established. For each operation, corresponding resources are assigned, with a certain intensity, depending on the availability and capacity of that period. The intensity is 100%, because each machine can only work at one time at a time. The duration of the activities is as follows:

$$\mathbf{T}_{\mathbf{k}}^{*} = \lceil \mathbf{T_k} \rceil \quad [\mathrm{h}] \qquad (1)$$

Table 7 establishes the resources for the P_2 benchmark.

Table 7. Resources P_2

P_2 benchmark							
No.	*Name of Task*	*Task Code*	*Resource Name*	*Resource Code*	*Intensity*	*T_k*	*T_k^**
1	Turning I	S11	OKUMA LB 3000 EX	R1	100%	58.29	59
2	Interim Inspection	I12	Bank inspection	R2		8.34	9
3	Turning II	S13	OKUMA LB 3000 EX	R1		30.54	31
4	Interim Inspection	I14	Bank inspection	R2		8.34	9
5	Centring-Drilling-Boring	C15	CP 500 CNC	R3		22.02	23
6	Interim Inspection	I16	Bank inspection	R2		8.34	9
7	Centring-Drilling-Threading	C17	CP 500 CNC	R3		19.92	20
8	Interim Inspection	I18	Bank inspection	R2		8.34	9
9	Washing	P19	Washing installation	R4		3.66	4
10	Final inspection	I1.10	Bank inspection	R2		8.55	9
11	Conservation-storage	D1.11	Deposit bank	R5		6.66	7

Table 8 sets the resources for the P_7 benchmark.

Table 8. Resources P_7

P7 benchmark							
No.	*Name of Task*	*Task code*	*Resource Name*	*Resource code*	*Intensity*	T_k	T_k^*
1	Milling	C21	CP 500 CNC	R3	100%	80.27	81
2	Deburring	V22	Bank locksmith	R6		37.99	38
3	Interim Inspection	I23	Bank inspection	R2		14.15	15
4	Broaching	B24	BO 100	R7		8.99	9
5	Washing	P25	Washing installation	R4		12.81	13
6	Final inspection	I26	Final inspection	R2		8.23	9
7	Conservation - Storage	D27	Deposit bank	R5		10.49	11

Table 9 sets the resources for the P_{15} benchmark.

Table 9. Resources P_{15}

P15 benchmark							
No.	*Name of Task*	*Task code*	*Resource Name*	*Resourc e code*	*Intensity*	T_k	T_k^*
1	Debiting	E31	FA-300	R8	100%	4.31	5
2	Mortising	M32	M 320	R9		23.37	24
3	Interim Inspection	I33	Bank inspection	R2		7.25	8
4	Drilling	G34	G40	R10		28.13	29
5	Boring	G35	G40	R10		17.55	18
6	Washing	P36	Washing installation	R4		3.19	4
7	Final inspection	I37	Bank inspection	R2		7.43	8
8	Conservation-Storage	D38	Deposit bank	R5		5.79	6

The number of resources required is calculated using the relationship:

$$m_u = \lceil m'_u \rceil \; ; \quad (2)$$

$$m'_u = \frac{\sum_{k(u)} T_k^* \cdot n_l \cdot m_k}{F_n - n_l \cdot T_{iu}} \quad (3)$$

$$T_{iu} = S_{CMDu} + T_r - F_{CMTu} [\text{ore}] \quad (4)$$

Table 10. Number of resources needed

Resource	*Resource name*	ΣT_k	n_l	F_n	m_k	T_{iu}	m'_u	m_u
R1	OKUMA LB 3000 EX	90	10	1960	1	0	0.45	1
R2	Bank inspection	85				0	0.43	1
R3	CP 500 CNC	124				0	0.63	1
R4	Washing bank	21				0	0.10	1
R5	Deposit bank	24				0	0.12	1

R6	Bank locksmith	38				0	0.19	1
R7	BO 100	9				0	0.04	1
R8	FA-300	5				0	0.02	1
R9	M 320	24				152	0.54	1
R10	G40	47				0	0.23	1

The number of resources required is shown in Table 10. The value of the resource load (Table 11) is calculated using the relation:

$$\mathbf{k_{îT}} = \frac{\sum \mathbf{m'_u}}{\sum \mathbf{m_u}} \quad (5)$$

Table 11. Degree of resource loading

$\Sigma m'_u$	Σm_u	$k_{îT}$
2.75	10	0.27

Based on a critical resource diagram, the organizational structure of the production workshop is achieved and is presented in Figure 2:

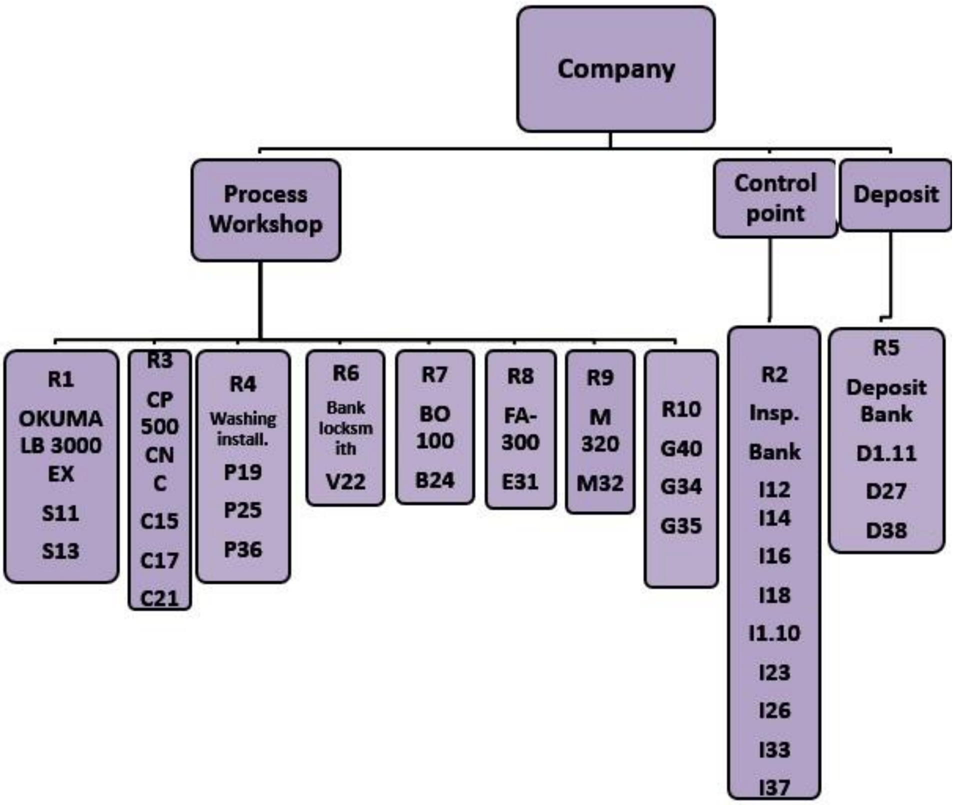


Fig. 2. The organizational structure of the production workshop.

the location of the resources used in their manufacture is optimized by applying the link method.

The number of batches is obtained with the relations:

After the organizational structure of the production workshop was established, the resource load plans were established by designing the duration of the activities on the resource calendars, taking into account the project management stages according to time and using the "Lisaj method" according to the specialised literature to eliminate the over-loading of the resources on machines. Since the technological flows of the three manufactured parts are different,

$$\boldsymbol{n_{lt}} = \begin{cases} \dfrac{N_g}{N_e}, & \textbf{for successive organization;} \\ \\ \dfrac{N_g}{N_{te}}, & \textbf{for mixed organization} \end{cases} \qquad (6)$$

Table 12 shows the transport consignments for each landmark.

Table 12. Consignments landmarks

Benchmark	N_g	N_{te}	N_e	*No. of batches* (n_{lt})
P2	1800	-	180	10
P7	3480	174	-	20
P15	1560	–	156	10

In order to place the resources for the optimal scenario, a centralising table of the resource grouping (Table 13) will be drawn up.

Table 13. Centralising table of the resource grouping

Bench mark	Tasks											No. of batches
P2	R1	R2	R1	R2	R3	R2	R3	R2	R4	R2	R5	10
P7	R3	R6	R2	R7	R4	R2	R5	-	-	-	-	20
P15	R8	R9	R2	R10	R10	R4	R2	R5	-	-	-	10

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R10		10		10						**2** 20
R9		10						10	**1** 10	**VIII**
R8								**1** 10	**X**	
R7		20		20			**2** 40	**IX**		
R6		20	20			**2** 40	**V**			
R5		40			**1** 40	**IV**				
R4		30		**3** 60	**VI**					
R3		40	**2** 60	**II**						
R2	30	**8** 200	**III**							
R1	**1** 30	**I**								
	VII									

Fig. 3. Resource Placement Matrix.

The resource placement matrix completed with the total flow indices with the total flow number and the corresponding number of links is shown in Figure 3.

The criteria for determining load priority are ranked as follows:

- Max (the number of links that corresponds to the group of resources being placed);
- Min (flow density).

The position of each resource that is placed in the rankings is specified next to the placement matrix.

After the placement matrix is done, the graph of the theoretical location is taken into account, taking into account the existing links and the data obtained in the placement matrix.

The representation must take into account the conditions: there should be intersections between links; the distance between the links is minimal.

The optimal resource location for product P is shown in Figure 4.

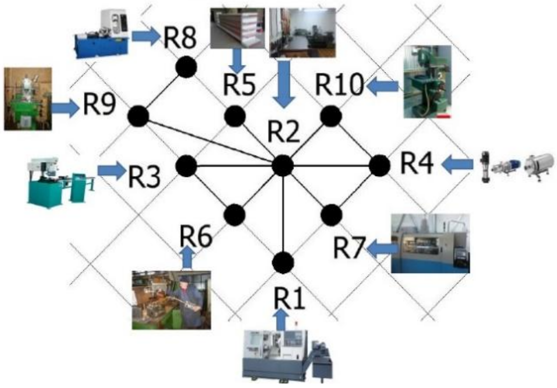
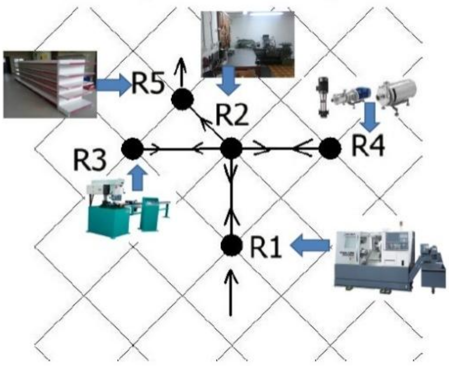


Fig. 4. Optimal location of product resources P.



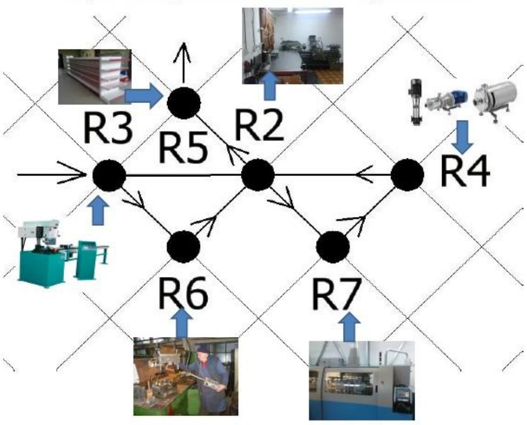


Fig. 5 **Fig. 6**

Optimal location of P_2 reference resources Optimal location of P_7 reference resources

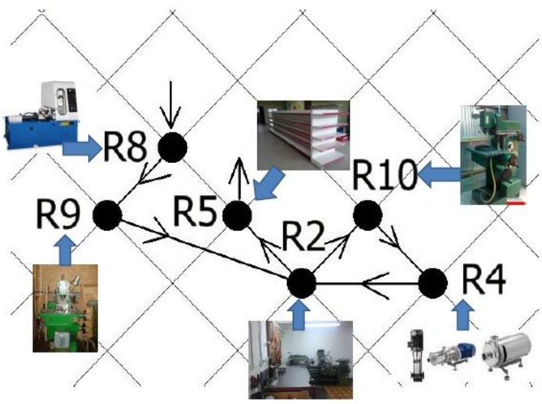


Fig. 7. Optimal location of P_{15} reference resources.

Optimal locations for the P_2, P_7, P_{15} markers are represented in Figures 5, 6, 7.

Conclusions

Since manufacturing issues can occur in any company, it has been chosen to present whether 2 or 3 machines can be replaced with one that is capable of doing all the operations, reducing both areas occupied, the auxiliary time and the financial losses, while increasing productivity.

"Matrix layout of workstations in a manufacturing system for structural simplification and reduced occupancy" is a small part of a chapter complex that lies at the base of the manufacturing lines.

Notations / Abbreviations

No	*Notations*	*Significations*
1	F_n	nominal background time
2	m_k	the number of machines adopted
3	m_u	the number of resources required
4	N_e	the economic manufacturing batch
5	N_g	net demand
6	n_l	number of batches
7	N_{te}	the economic transport batch
8	S	level on stocks
9	T_k	duration of the operation per lot
10	T_{nk}	time norm for k operation
11	$T_{pî}$	the time of preparation-closure of the job
12	TP_{kg}	degree of homogeneity
13	T_r	repeat period of batches
14	T_u	unit processing time

REFERENCES

[1] C. Doicin, *Analiză economică în inginerie* (Ed. Bren, Bucharest, Romania, 2009).

[2] C. Doicin, *Analiza proiectelor de investiții în inginerie* (Ed. Bren, Bucharest, Romania, 2009).

[3] M. Gheorghe, *Ingineria și Managementul Proceselor de Producție 1- Notițe curs, 2012-2013* (Bucharest, Romania).

[4] *Ghid Proiect de Produse, Procese și Sisteme 2, 2013-2014* (Bucharest, Romania).

[5] C. Neagu, E. Nițu, L. Melnic, M. Catană, *Ingineria şi Managementul Producției: Bazele Teoretice* (Ed. D.P.R.A., Bucharest, 2006).

[6] C. Neagu, E. Nițu, M. Catană, M. Roșu, *Ingineria şi Managementul Producției: Aplicații*, (Ed. Bren, Bucharest, 2007).

[7] A.S. Polena, *Studiu tehnico-economic privind concepția, programarea şi conducerea unui proiect de proces şi sistem de producție privind Capac spate – Ax – Suport rulment. Auditul – instrument al managementului calității*, license project (IMST, Politehnica Univ., Bucharest, 2014).