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MODELING AND SIMULATION OF A MANUFACTURING WORKSHOP IN ORDER TO INSERT MULTIFUNCTIONAL WORKSTATIONS

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Abstract: *The paper presents the possibilities to improve the product manufacturing line processes by optimizing the manufacturing workshop surface, working time and costs, as well as the importance of simulating the manufacturing workshop in a 3D software, as a preliminary step before purchasing the equipment needed to obtain the product in efficient manufacturing conditions. Main contribution of this article is the detailed presentation of the influence of the number of parts in the batch on optimal variant of the manufacturing system.*

Key words: *CNC machining, flow simulation, manufacturing cost, Delmia Quest.*

1. INTRODUCTION

A proposal, in industrial economic analysis studies, refers to a unique project to be considered as an investment opportunity. Finally, the proposal must contain a full description of the objectives and economic elements in terms of benefits and costs [3].

The alternative is a result of the combination of several proposals, most often a particular combination of proposals. Thus, any proposal can be considered as an investment alternative, and on the other hand, an alternative is and can be formed both by a single proposal and by a group of proposals [3].

If the acceptance of a proposal from one set does not affect the acceptance of another proposal from that set, the proposal will be considered independent [3].

In addition, if the proposals are different and there are no obvious reasons for their dependence on each other, they will be considered as independent proposals. One such example is the proposals for the acquisition of a certain numerically controlled machine tool and non-destructive testing equipment, which will be considered as independent proposals [3].

In some cases, the proposals in a set will depend on each other so that the acceptance of one will influence the acceptance of the others. Such a case occurs when the decision has been made to meet a certain need and there are several proposals, each leading to a satisfaction of the analyzed need [3].

Another type of dependency occurs when, once certain main activities have been carried out, several auxiliaries must also be carried out. The set of main and auxiliary activities forms a set of grouped proposals. A grouped relationship is a one-way dependency between proposals. Thus, the acceptance of a grouped proposal depends on the acceptance of some essential proposals, but the acceptance of the initial proposals is independent of the acceptance of the grouped proposal [3].

When there are budget constraints available for investments and the initial cost of the investments exceeds the allocated amount, financial constraints are introduced which will generate financial dependencies between the various proposals. These are complex and will appear regardless of the type of proposals [3].

Except in some situations, each organization has a limited number of people at a time, but each situation involves limitations of resources, time and space.

Building an alternative is a creative process and involves two components: a means (a method) and a completion (a goal) [3].

Alternatives that are unlikely to be feasible are often proposed for analysis. It is considered, however, that it is better to consider many unprofitable alternatives than to lose sight of a profitable one. The analysis should not be performed for any situation of use of resources, but for the most efficient way to use them [3].

Alternatives that are not considered cannot be chosen regardless of their effectiveness. The main criterion for "judging" an alternative will be the expected result, compared to other alternatives that can be followed [3].

Economic systems, small-scale or large-scale, have their own quantitative laws that in a normal, market economy cannot be ignored and would be irrational and counterproductive to be ignored.

Historically, these simpler or more complicated laws were noticed early on and were first the subject of experimental observation in order to accumulate empirical rules to produce efficiently, to spend reasonably, and to make a good profit from one or another of the activities of producing goods for the market or services.

The costs involved must also be taken into account when analyzing alternatives. The costs will obviously be deducted from the potential revenues from the activities selected to be carried out. This limits the expenses that can be justified for economic analysis studies in engineering [3].

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The measure of the net success of a business can be thought of as the difference between the revenues obtained and the costs associated with those revenues, including the costs of analysis [3].

2. CURRENT STAGE

Innovation is a new technical achievement at the level of a unit (workshop, company, enterprise, etc.).

The workshop is a part of an industrial enterprise in which operations necessary for the processing of products are carried out and which has all the specialized and automated means necessary for those operations.

The workshop means: compliant products, universal means of production, versatile staff, reduced work and organization by technology.

Modeling is a tool of scientific representation that aims to build similar systems that present as accurately as possible the real system proving a great practical experience of the one who builds the model.

A model is an abstract representation of reality. Many ideas can be tested on the model. It is preferable to make mistakes by computer simulation, where costs are almost non-existent. Simulation is defined as the process of designing and realizing a model, an experiment in order to understand the behavior of the system and evaluate a large number of possible strategies for its operation.

Simulation of systems with discrete events is suitable for studying flows during a manufacturing operation, for determining the capacity of the system, observing the distribution of parts and workstations.

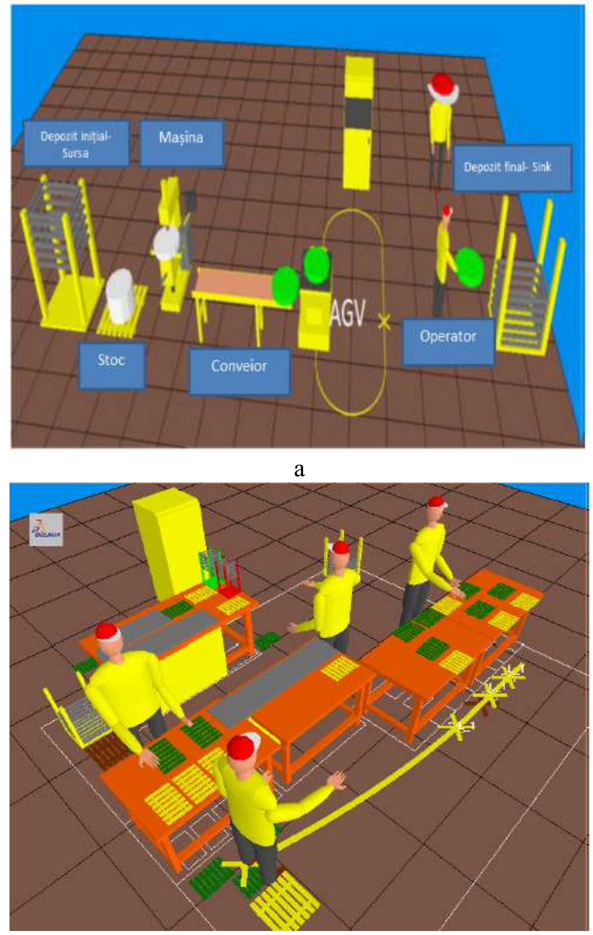
In the feasibility analysis of a workshop, the simulation serves to justify and quantify the necessary investments. In this case, the simulation is a tool to highlight the expected costs and performance. It is determined: the number of machines and their type; nature and size of warehouses (storage, shops, supply systems, storage areas, etc.); the nature and dimensions of the handling system of parts, tools, semi-finished products, etc .; the volume of labor required.

The simulation allows the evaluation and comparison of different workshop management strategies, in order to adopt the most efficient solution. In this sense, various solutions can be evaluated and compared regarding: production planning; priority rules given to products or technological variants; resource distribution strategies (machines, production lines, operators, etc.) and product launch campaigns on the market.

Delmia Quest software is a simulation tool used to model, experiment and analyze the location plan and manufacturing flow, thus being a very helpful tool in evaluating the changes that will be made in the manufacturing cell before undergoing the improvements. manufacturing, in a word to make real capital investment.

In this case, the simulation is a diagnostic tool because the simulation on an existing model of the workshop allows the detection of its *weak* points: the existence of bottlenecks, interruptions of the flow of parts provided by the transport system, insufficient number of pallets, etc.

The best solution will thus be highlighted, retained and for this, the investment recovery time is calculated.



a

b

Fig. 1. Delmia Quest production model simulation: *a* – one simulation model; *b* – another simulation model.

3. STEPS FOR PERFORMING A SIMULATION OF A PRODUCTION WORKSHOP

Production projects involve many stages of making a final product, including: setting performance requirements, establishing production volume, establishing manufacturing technologies, planning and conducting operations, ensuring the operation of the system, determining the necessary number of machines and location establishing management and control methods, as well as inventory management and all that such projects involve.

All these stages are presented in the specialized literature, and for the example by simulating in the Delmia Quest software a workshop, the final results on the technological process variants were extracted, without being presented in detail.

Thus, for the realization of a Tesla Pump Back Cover, two technological process variants were developed for a production of 2000 pieces/year.

The first variant, denoted PT1, is the optimal variant compared to the second variant of technological process, denoted PT2, because the number of operations required for processing is smaller, the production cycle time is shorter, and the manufacturing costs the same.

The main difference was the choice of processing machines, which led to a reduction in production time,

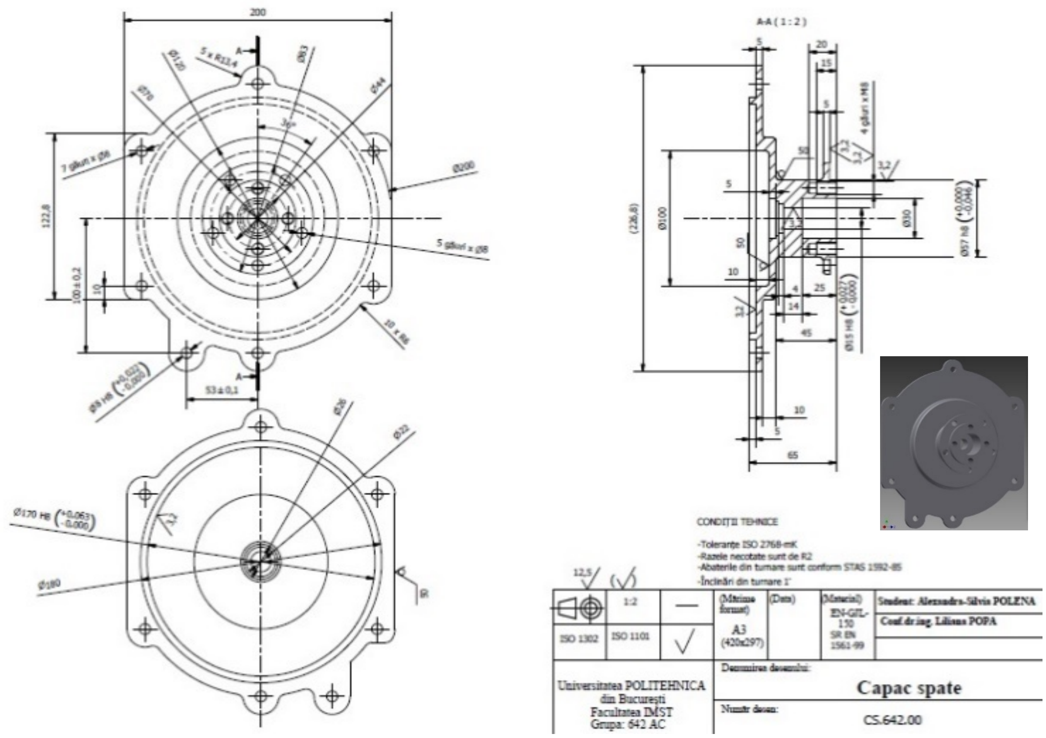


Fig. 2. Tesla Pump back cover.

the number of workers and the efficiency of the workspace.

The Tesla Pump back cover part (Fig. 2) can be made by the following operations necessary for processing: casting, turning, drilling, reaming, threading, washing, control and storage.

Depending on the annual production volume, the type and number of operations can be chosen lathes, CNC centers, drilling and reaming machines, drilling and threading machines, inspection bench, washing and storage facilities.

Thus, in the first variant of technological process PT2, the operations necessary for processing are: casting, turning I, intermediate inspection, turning II, intermediate inspection, spot drilling-drilling-reaming, intermediate inspection, spot drilling-drilling-threading, intermediate inspection, washing, final inspection and preservation-storage. These operations are done on the following machine tools and equipment: CNC lathe, inspection bench, CNC turning center, washing installation and storage bench.

In the second variant of the technological process PT2, the operations necessary for processing are: casting, turning I, intermediate inspection, turning II, intermediate inspection, turning III, intermediate inspection, turning IV, intermediate inspection, drilling-reaming, intermediate inspection, drilling-threading, intermediate inspection, washing, final inspection and preservation-storage. The following equipment is used for these operations: CNC lathe, inspection bench, G16 drilling machine, G18 drilling machine, washing system and storage bench.

Starting from the number of necessary operations, the characteristics of equipment, devices, cutting tools, verifiers, adjustment procedures, excess material and intermediate dimensions, but also cutting parameters were selected or calculated for each time according to the literature. These time norms include: basic times, auxiliary times, operative times, work service times, rest times and physiological needs, unit times, preparation times - completion of the job, etc.

At the operation level, the time norm, T_n [min/pieces] has the expression [7]:

$$T_n = T_u + \frac{T_{pi}}{n_0} \Leftrightarrow T_n = T_b + T_a + T_{dt} + T_{do} + T_{on} + \frac{T_{pi}}{n_0} \quad (1)$$

$$T_b = \sum T_{bk}\ , T_{bk} = \left(\frac{l_1 + l_{\max} + l_2}{w} i\right)_k,\ \ w = ns, \quad (2)$$

$$T_a = T_{a1} + \sum (T_{a2} + T_{a3} + T_{a4})_k\ ,\ T_{op} = T_b + T_a \quad (3)$$

where T_u − unit processing time [min/piece]; T_{pi} = time of preparation – closure of the job [min]; n_0 – number of parts of the batch [pieces]; T_b = base time [min/piece]; T_a – auxiliary time [min/piece]; k – processing phase serial number; T_{a1} – clamping and detaching time [min/piece]; T_{a2}, T_{a3}, T_{a4} – auxiliary command, adjustment, and control times [min/piece]; T_{op} = operating time [min/piece]; T_{dt} – technical service time [min/piece]; T_{do} – organizational service time [min/piece]; T_{on} – rest time and physiological needs [min/piece]; $l_{\max}$ = maximum working surface length [mm]; l_1 and l_2 – inbound and outbound safety runs [mm]; i – number of passes; n – speed [rpm]; s = feed [mm/rot]; w = feed rate [mm/min] [7].

Table 1

PT1 and PT2 comparison – 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. Inspection	1.2	15. Inspection	1.2
20. Turning II	9.74	20. Turning II	6.80
25. Inspection	1.2	25. Inspection	1.2
30. Centering-Drilling-Boring	6.83	30. Turning III	10.12
35. Inspection	1.2	35. Inspection	1.2
40. Centering-Drilling-Threading	6.12	40. Turning IV	7.91
45. Inspection	1.2	45. Inspection	1.2
48. Washing	0.5	50. Drilling-Boring	6.15
50. Final inspection	8	55. Inspection	1.2
60.Conservation-storage	2	60. Drilling-Threading	5.50
-	-	65. Inspection	1.2
-	-	68. Washing	0.5
-	-	70. Final inspection	2
-	-	80. Conservation-storage	2

Table 1 presents the results of these time calculations, comparing the two variants of the technological process.

Based on these time rules and taking into account the annual production schedule of the Tesla Pump back cover, all production costs for PT1 and PT2 were calculated (cost of material consumed, cost of labor, cost of social security, cost of unemployment benefits, overhead cost, cost of depreciation and overhaul of machinery, direct manufacturing cost, cost of depreciation and maintenance of special equipment, etc.), which resulted in the PT1 variant being the optimal one, both in terms of associated manufacturing costs and manufacturing times.

Manufacturing costs were obtained by calculating, for each operation, all costs involved in the manufacture of the product (cost of material, labor, cost of directing, etc.).

The general expression of the manufacturing cost is [6, 7]:

$$C = AX + B \quad (4)$$

where: C – manufacturing cost [RON]; X – production volume [no. of pieces]; A – direct unit manufacturing cost (dependent on the product / part) [RON/piece]; B – indirect manufacturing cost (independent of product / part) [RON].

The graph of the manufacturing cost is presented in Fig. 3.

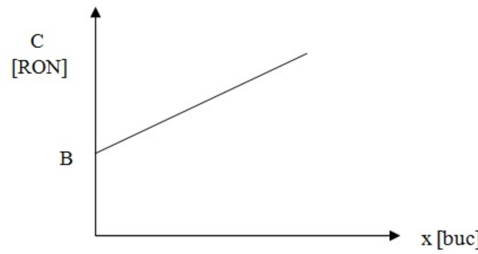


Fig. 3. Manufacturing cost chart.

The direct unit manufacturing cost (depending on the product/part), A [RON/piece] is:

$$A = C_\alpha + C_\beta + C_\eta + C_\theta, \quad (5)$$

where: C_α – cost of the consumed material [RON/piece]; C_β – cost of gross salary [RON/piece]; C_η − cost of directing (for energy, working substances, cleaning, etc.) [RON/piece] and C_θ − cost of depreciation and capital repairs of equipment [RON/piece].

The cost of the consumed material $C_\alpha C\alpha$ [RON/piece] is calculated with the relation [7]:

$$C_\alpha = m_r c_r + m_d c_d, \quad (6)$$

where: m_r− mass of the landmark [kg/piece]; m_d − mass of waste [kg / piece]; c_r − unit cost of the reference material [RON/kg]; c_d − unit cost of the waste material [RON/kg] (recommended $c_d = 0.5\ c_{dr}$.

The cost of gross salary C_β [RON/piece], with the condition that all activities in the operation are performed by the same operator, is [7]:

$$C_\beta = \sum Tn_i S_i/60 + 25\% + 10\% + 10\%, \quad (7)$$

where: T_n − time norm [min/piece]; S − operator's salary [RON/hour] (recommended S_i = 4−8 RON/hour; i − serial number of the operation, i = 1, 2, ...

The cost of directing C_η [RON/piece] is [4]:

$$C_\eta = K_\eta\, C_\beta/100, \quad (8)$$

where: K_η − percentage [%] (recommended K_η = 35 – 85).

The cost of depreciation and capital repairs of equipment C_θ [RON/piece] is [4]:

$$C_\theta = \sum V_{u_i}\left(1/Z_{u_i} + K_{u_i}/100\right) Tn_i/60H_{u_i}, \quad (9)$$

where V_u − purchase value of the machine [RON]; Z_u − number of years of amortization [years]; K_u − percentage share of capital repairs [%]; H_u − number of operating hours per year [hours/year] (recommended Z_u = 5–10; K_u = 15–35; $H_u = z\ h\ s$).

For K given by:

$$K = \left(1 + K_\eta/100\right), \quad (10)$$

it results [6, 18]:

$$A = C_\alpha + KC_\beta + C_\theta. \quad (11)$$

Indirect manufacturing cost B [RON] represents the cost of depreciation and maintenance of special / specialized equipment (tools, devices, etc.) [4, 7]:

$$B = \sum V_{e_i}\left(1/Z_{e_i} + K_{e_i}/100\right), \tag{12}$$

where V_e − purchase value of the equipment [RON]; Z_e − number of years of depreciation [years]; K_e − percentage of maintenance [%] and is recommended according to Table 2.

For the technological variant v, v = 1 or 2, of technological process/technological operation (as the case may be), the expression of the manufacturing cost associated with some technological variants is [4, 7]:

$$C_v = A_v X + B_v \tag{13}$$

For the two technological variants 1 and 2, the same manufacturing cost is achieved, $C_1 = C_2$, for a production volume X_{cr} [piece] [7],

$$X_{cr} = (B_2 - B_1)/(A_1 - A_2). \tag{14}$$

The summary of the costs related to the technological processes PT1 and PT2 is presented in Table 3.

For the two technological variants PT1 and PT2, the same manufacturing cost is achieved $C_1 = C_2$ for a production volume X_{cr} [pieces]:

$$X_{cr} = \frac{(B_2 - B_1)}{(A_1 - A_2)} = \frac{(1021.8 - 1813.5)}{(20.39 - 22.06)} = 475 \text{ pieces} \tag{15}$$

Table 2

Recommended values of Z_e and K_e

Equipment	Z_e	K_e
The tool	1−2	10−20
Fitment	1−3	15−30
Verifier	1−2	10−15

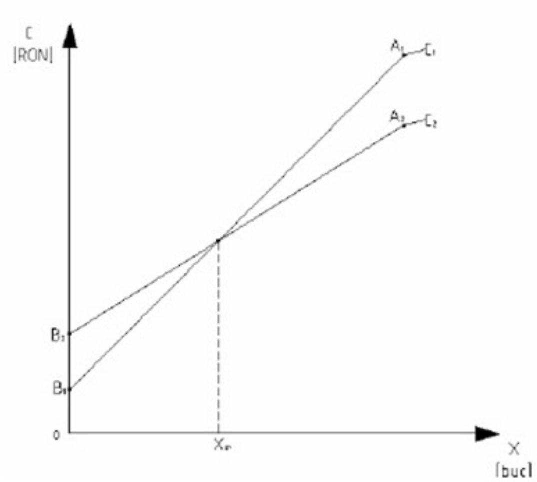


Fig. 4. The manufacturing cost graph associated with some technological variants.

Tabel 3

Manufacturing costs associated with the technological process variants (PT1 and PT2) of part P2 − Tesla Pump back cover

For the production program, *P* = 2 000 pieces/year		
	PT1 [RON/piece]	**PT2 [RON/piece]**
Cost of the consumed material	8.29	8.29
Cost of gross salary	6.11	7.22
Cost of directing (for energy,working substances,cleaning, etc.)	0.022	0.027
Cost of depreciation and capital repairs of equipment	3.55	3.67
Direct manufacturing cost	23.16	25.5
Cost of depreciation and maintenance of special equipment	1813.5	1021.8
Manufacturing cost associated with production volume	42 593.5 RON	45 141.8 RON

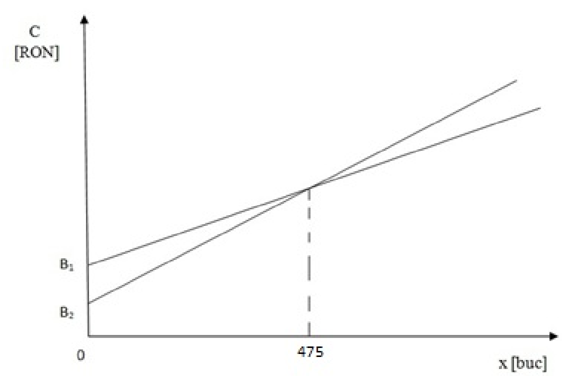


Fig. 5. Graph of manufacturing cost associated with technological variants PT1 and PT2.

4. ORGANIZING A PRODUCTION WORKSHOP IN A SIMULATION PROGRAM

Following the previous steps, it turned out that the technological process variant of the Tesla Pump back cover is PT1, which includes the related operations performed on the CNC lathe, CNC center, inspection bench, washing installation and storage bench.

In order to visualize what the production line will look like for this part, the production line simulation program called Delmia Quest was used, this being done after the realization of the optimal location scheme with the help of the links method, presented in the literature.

Thus, the optimal layout of the rear cover part Tesla Pump − denoted P2 − is presented in Fig. 6, and the simulation made from this scheme is shown in Fig. 7 − for the optimal variant of technological process PT1, and Fig. 8 shows the variant of technological process PT2, in order to compare these two variants.

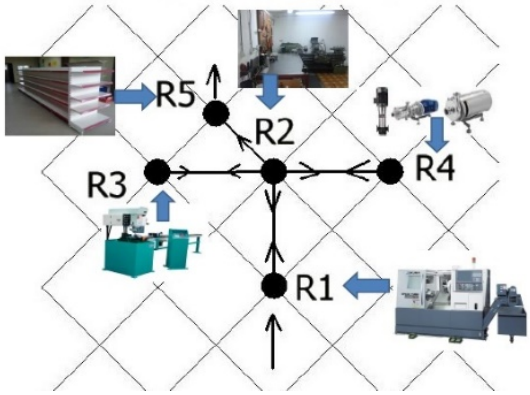


Fig. 6. Scheme of optimal location of P_2 benchmark resources: Tesla Pump back cover.

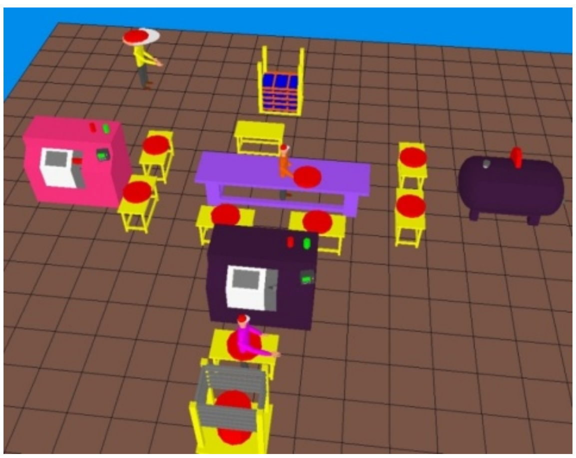


Fig. 7. Location of P_2 benchmark resources – PT1 variant made in Delmia Quest.

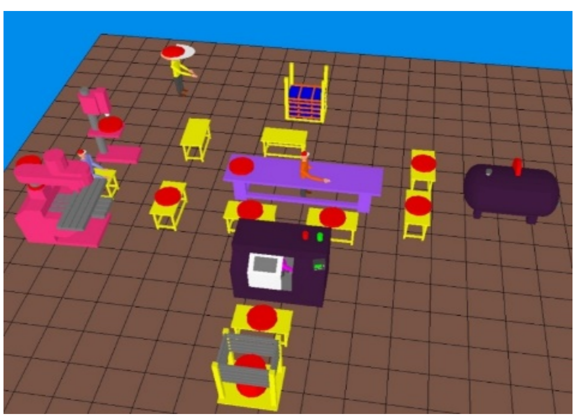
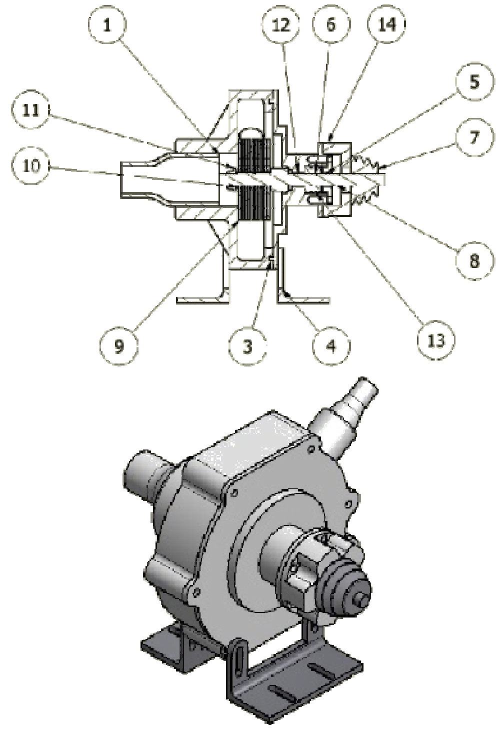


Fig. 8. Location of P2 benchmark resources – PT2 variant made in Delmia Quest.

To achieve an image as close to reality as possible, it is not enough to consider a single repetition of a product set, but to follow the same steps for at least two landmarks (except the one passed through all stages previously) until it is located in the manufacturing workshop.

The back cover (denoted P_2), which has reached the location stage, is part of the *Tesla Pump* assembly, denoted *P*, Fig. 9.



Legend:
1 – Big cap
2 – Small cap
3 – Shell
4 – Corner
5 – Compressors
6 – Tire
7 – The belt piece
8 – Shaft
9 – Disc rotor
10 – Spacer
11 – Screw nut
12 – Inner bushing
13 – Back cover
14 – Bearing support

Fig. 9. Drawing and parts of the product *Tesla pump*.

From all the 14 parts, 2 parts belonging to the assembly were chosen, namely: shaft marked P_7 and bearing support marked P_{15}, for which, together with P_2 (back cover), the technological sheets and the example of the resources were drawn up to each landmark.

These data sheets for each of the three components are presented in Table 4, and the resources of the components are presented in Table 5.

After going through the specific steps of obtaining the optimal location for each part (, the optimal location of the production workshop for the 3 parts of this *Tesla Pump* as a whole will look like in Fig. 10.

These steps refer to: the product disaggregation structure (lower order structures called subsystems: assemblies, subassemblies); the calculation of the gross need; net demand calculation; elaboration of the production plan, it is necessary to determine the type of production, to establish the form of production organization and to determine the duration of the production cycle.

Tabel 4

Technology data sheets: P_2 - Tesla Pump back cover; P_7 - Shaft; P_{15} - Bearing support

Technology data sheet for product P_2					
No	**Name of Task**	**Task Code**	**Resource Name**	T_u	T_{pi}
1	Turning I	S11	OKUMA LB3000 EX	19.1	60
2	Inspection	I12	Bank inspection	2.7	15
3	Turning II	S13	OKUMA LB3000 EX	9.8	70
4	Inspection	I14	Bank inspection	2.7	15
5	Centering-Drilling-Boring	C15	CP500 CNC	6.9	80
6	Inspection	I16	Bank inspection	2.7	15
7	Centering-Drilling-Threading	C17	CP500 CNC	6.2	80
8	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
Technology data sheet for product P_7					
No	**Name of Task**	**Task Code**	**Resource Name**	T_u	T_{pi}
1	Milling	C21	CP500 CNC	13.7	50
2	Deburring	V22	Bank locksmith	6.5	20
3	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
Technology data sheet for product P_{15}					
No	**Name of Task**	**Task Code**	**Resource Name**	T_u	T_{pi}
1	Debiting	E31	FA - 300	1.6	10
2	Mortising	M32	M 320	8.8	30
3	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

Tabel 5

Landmark resources: P_2 − Tesla Pump back cover; P_7 − Shaft; P_{15} − Bearing support

Landmark P_2							
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	Inspection	I12	Bank inspection	R2		8.34	9
3	Turning II	S13	OKUMA LB 3000 EX	R1		30.54	31
4	Inspection	I14	Bank inspection	R2		8.34	9
5	Centering-Drilling-Boring	C15	CP 500 CNC	R3		22.02	23
6	Inspection	I16	Bank inspection	R2		8,34	9
7	Centering-Drilling-Threading	C17	CP 500 CNC	R3		19.92	20
8	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
Landmark P_7							
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	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	Bank inspection	R2		8.23	9
7	Conservation-storage	D27	Deposit bank	R5		10.49	11
Landmark P_{15}							
No	**Name of Task**	**Task Code**	**Resource Name**	**Resource 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	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

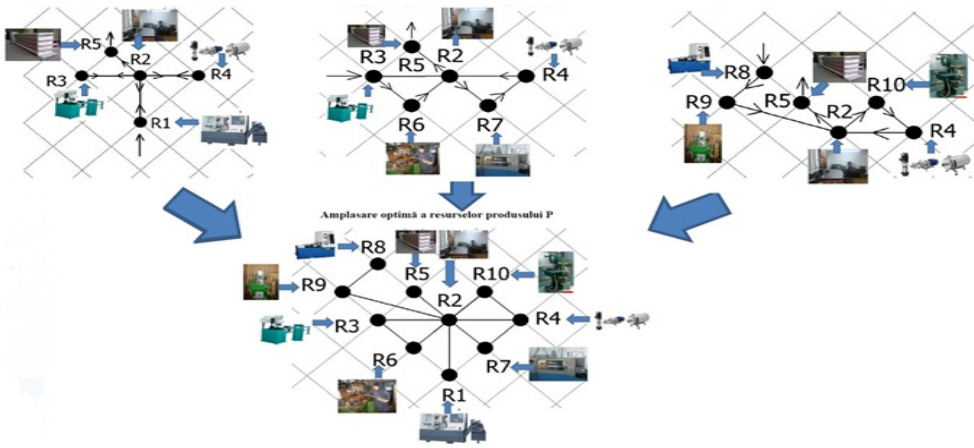


Fig. 10. Schemes of the optimal location of the production workshop.

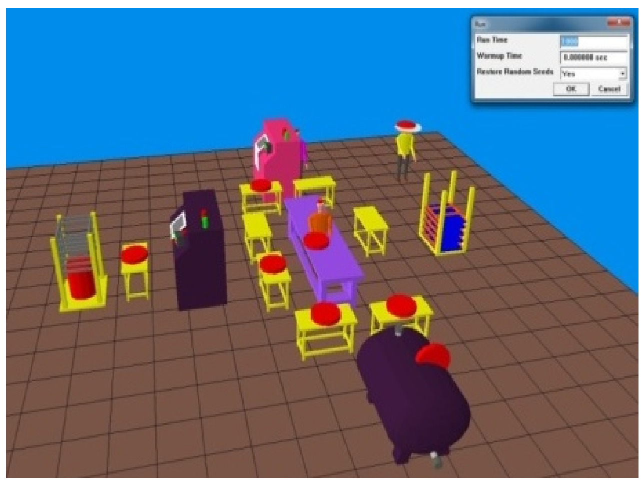


Fig. 11. P_2 location made in Delmia Quest.

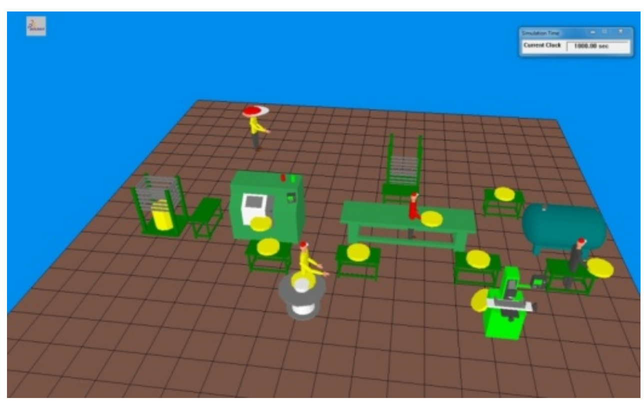


Fig. 12. P_7 location made in Delmia Quest.

Once established, the operational management of the production of the 3 landmarks will be performed for the situation in which: the number of machines of a certain brand is limited, being equal to the number necessary for the realization of the project activities; some machines allocated to the project are periodically unavailable at certain intervals during each production cycle.

Through the software Delmia Quest one can make several graphics with which one can identify several irregularities regarding the machines and the entire manufacturing process.

An example of a 2D charts obtained in Delmia Quest (for machines presents in Fig. 12) shows how many parts were processed, and different states of machines: busy, idle, locked (blocked) etc.

In Fig. 15, the graphs show (expressed as a percentage) how many parts the machine is working on (busy-green) or, if the machine is idle, the parts waits.

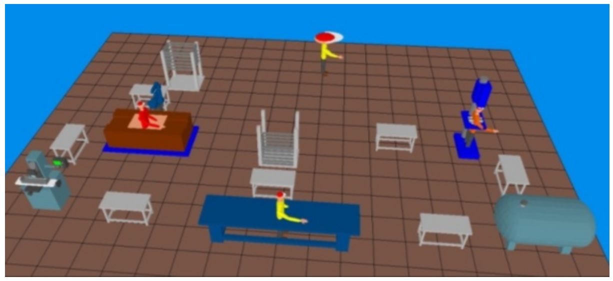


Fig. 13. Optimal location of P_{15} benchmark resources made in Delmia Quest.

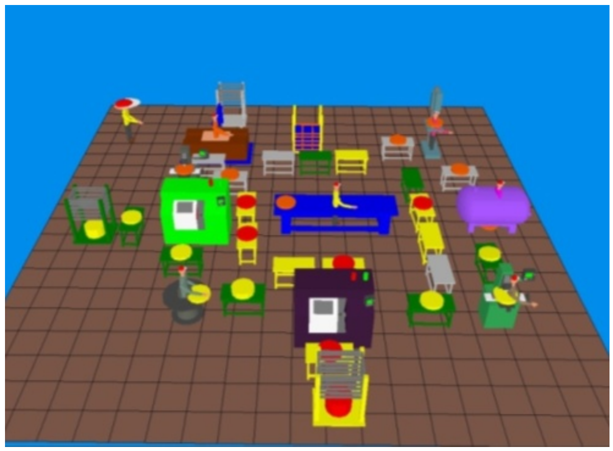


Fig. 14. Optimal location of P product resources made in Delmia Quest.

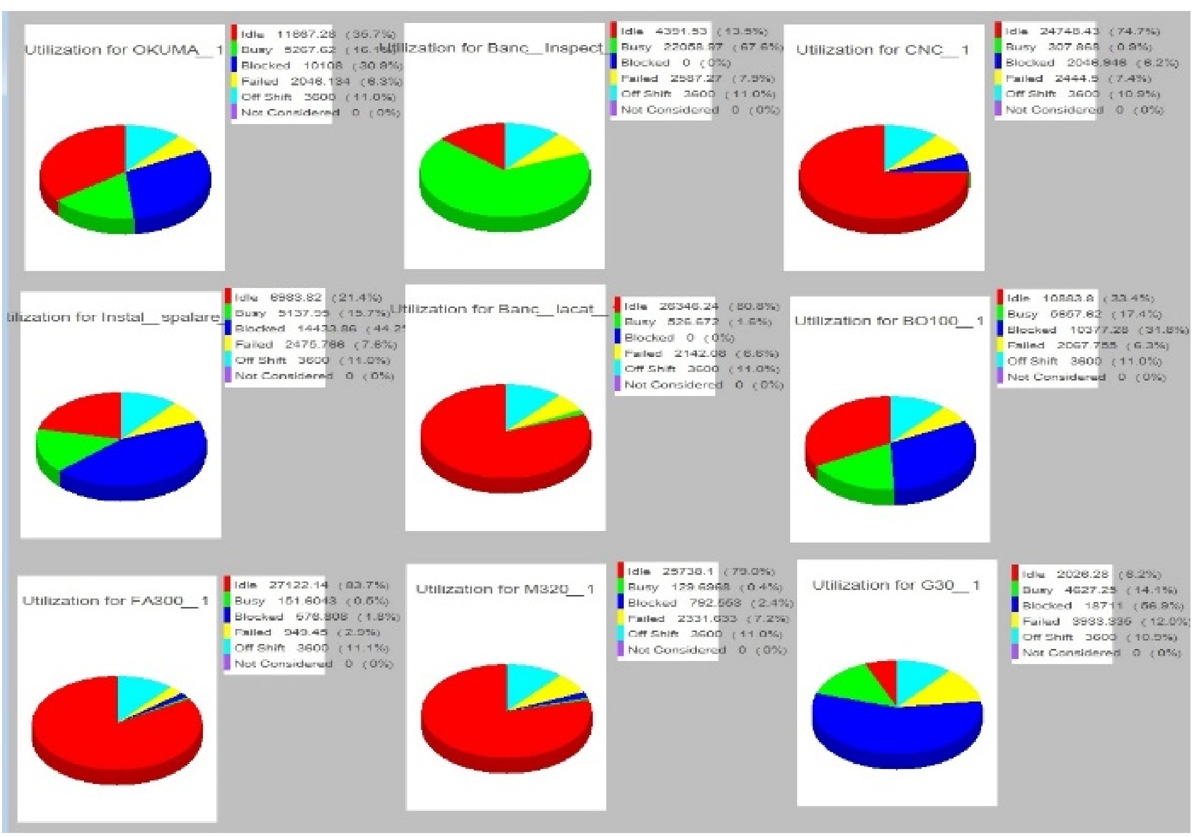


Fig. 15. Graphical representation in percentage of the number of machined parts on each machine.

Other graphs made in Delmia Quest may show: the number of parts machined by the machine, the maximum number of parts that can be machined by a machine, or the number of hours each employee works on the machine.

5. CONCLUSIONS

Workshop modeling and simulation of a specific production in order to insert other multifunctional workstations is a complex research that highlight the continuous effort of the specialists to maximize processing capacity of the manufacturing workshops.

During the simulation of any production line in a software, all the parts, which together lead to a product, go through complex stages of analysis, calculations, planning, resource establishment, etc., to finally take into account and space available for those resources and economic criteria.

Once the simulation of a manufacturing line is performed, the software offers the possibility to easily make changes to the theoretical models and helps to make the best decisions related to the manufacturing and development process of a product through a graphical visualization.

This article presented how the determination of the number of parts in the batch decides the optimal technological variant. Thus, for a batch with a number of parts smaller than 475 pieces, the PT2 technological process variant is recommended, and for a batch with a number of parts larger than 475 pieces, the PT1 technological process variant is recommended.

If the issue of the production of the whole assembly of which a certain part is part (in the example presented, the pump cover) is raised, the programming and management of the production in conditions of limited resources and imposed data are considered. This includes: establishing production resources and corresponding schedules; elaboration of critical resources diagrams; the organizational structure of the production workshop; elaboration of the logical network of the production project; project management based on time (calculation of "earliest" and "latest" data, calculation of margins and determination of the critical path); project management according to resources; resource management by ordering resources; selecting the optimal scenario; elaboration of the plan, table and graph of cumulated task; correlating work schedules with the optimal location of all resources; and, finally, the calculation of the production cost taking into account those listed.

The second part of the paper demonstrated using Delmia Quest software what such a production line would look like for a batch of 2000 pcs / year for a type of part, but also what the workshop would look like in the case of the production of two more parts.

At the same time, by observing the simulation, measures can be taken such as: relocating parts can be reallocated if a machine fails or if an employee working on a machine could not mount a part on another machine while the original machine is processing a part.

Based on the graphs resulting from the simulation, changes can be made to: factory reorganization plan, technological process flows, employee schedule, resource locations, machines, intermediate depots, final depots, introduction of constraints or times when equipment needs to be repaired.

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