COMPARATIVE STUDY OF MANUFACTURING COST ON CONVENTIONAL MACHINE TOOLS AND NC EQUIPMENTS

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Acest articol prezintă o procedură pentru a determina cea mai recomandată tehnologie şi maşină-unealtă ce urmează a fi achiziţionată, din punct de vedere a celui mai eficient cost, care să conducă la eficienţă economică maximă a investiţiei. Sunt considerate două alternative comparative: una de prelucrare pe maşini-unelte clasice şi cealaltă de prelucrare pe echipamente cu comandă numerică. Toate elementele care, în general, influenţează costul prelucrărilor au fost incluse în calcule. Procedura a fost aplicată în cazul unei situaţii reale – prelucrarea unui piston la societatea comercială „Timpuri Noi".

This article presents a procedure for determining the best recommended technologie and machine tool to be purchased, that would be considered the most efficient from the point of view of costs as yield the maximum economic efficiency on the investment. Two comparative alternatives have been provided: one working on classical machine tools and the other working on numerical control equipment. When preparing the calculations, all the elements were considered that generally affect the manufacturing cost. The procedure has been applied in the case of a real situation – the manufacturing of a piston at the "Timpuri Noi" enterprise.

Key words: cost, conventional machines, NC equipment, piston.

1. Introduction

In the framework of the Machine Building Industry, a central interest has been assigned to the Car Industry production segment, which has been registering annual sales rates that would amount to tens of millions of different types of finite products, and hundreds of millions of spare parts [1].

Therefore, the companies that are involved in similar jobs and have the necessary technical – organizational, labour and professional structure that is required for the best manufacturing of the items in the car industry should have to prepare first a feasibility study [14, 18]. This means to prepare an assessment of what would be the most suitable machine tools to purchase that are capable to
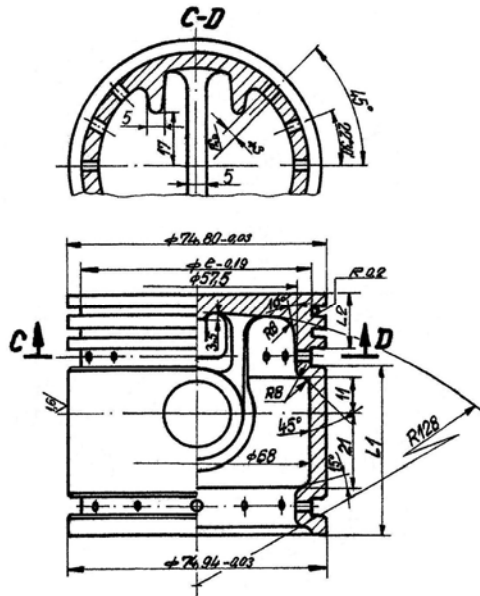
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provide for the utilization of modern technologies and thus enable the producer to penetrate the market segment of most cost efficient car parts production.

This article presents the contribution of the authors to provide a relevant support for the trading companies in their attempt to better substantiate their projects relating to the purchase of machine tools for car industry parts machining.

Such project substantiation would help team become faster and more efficient in attracting the necessary funding sources (from both the share holders and the financial institutions, such as: banks, organizations providing investment funds etc.).

2. Technologies used in manufacturing of pistons on conventional machine tools and NC equipments

For the purpose study, regarding the manufacturing of car components on conventional machine tools and numerical control equipment, the authors of this article have focused on the item "Piston stage I", with the execution drawing shown in figure 1 [19].

Fig. 1. The piston stage I [19]

The machining technology for the production of the "Piston stage I" on the conventional machining technology has been detailed in Table 1 [19].

The machining technology for the production of the "Piston stage I" on the numerical control equipment MAZAK has been detailed in Table 2 [3].

Table 1

The conventional Machining Technology

No. of operation	Working point	Operation	Category	Tp_i [min]	T_u [min]
05	Inspection table	Reception	4	6	0.32
10	Lathe SN 400	Rough turning	3	10	1.61
15	Lathe SN 400	Pre-drilling	3	10	1.61
20	Lathe SP 250	Exterior rough turning	4	25	9.15
25	Workbench	Testing	4	5	2.15
30	Drilling machine GR 40	Boss drilling	3	8	0.97
35	Drilling machine GR 40	Radial drilling C1	3	8	1.61
40	Drilling machine GR 40	Radial drilling C2	3	8	1.61
45	Workbench	Adjustment	2	6	0.75
50	Bath	Washing, blowing	1	7	1.61
55	Lathe SN 400	Finish turning	3	10	1.07
60	Lathe SP 250	Interior finish turning	4	20	1.61
65	Reaming machine	Rough boring	4	20	1.61
70	Lathe SN 400	Groove cutting	3	12	1.61
75	Reaming machine	Finish cutting	5	20	1.61
80	Drilling machine GR 40	Settlement	3	5	1.07
85	Workbench	Adjustment	2	6	0.86
90	Bath	Washing, blowing	1	7	0.16
95	Inspection table	Inspection	5	6	0.67
100	Workbench	Packing	1	4	0.32
105	Warehouse	Storage	1	10	0.21

Table 2

The MAZAK Machining Technology

No. of operation	Working point	Operation	Category	Tp_i [min]	T_u [min]
05	Inspection table	Reception	4	6	0.32
10	Lathe SP 250	Rough turning	4	25	9.15
15	MAZAK machining center	Complete machining	5	240	2.36
20	Bath	Washing, blowing	1	7	0.16
25	Inspection table	Final inspection	5	6	0.40
30	Workbench	Packing	1	4	0.32
35	Warehouse	Storage	1	10	0.21

3. Cost calculation of manufacturing "Piston stage I" on conventional machine tools

Based on the technical works relevant in this domain [1, 8, 10, 11, 15], the authors of the paper selected the most adequate and complex calculation formula of the manufacturing cost:

$$C_1 = A_1 + \frac{B_1 + D_1}{n} \quad [\text{€/piece}] \tag{1}$$

where: A_1 – the expenses independent of the lot (variable expenses), [€/piece]; B_1 – the lot dependent expenses (constant expenses) for preparing and completion of manufacturing, as well as administrative preparation of the lot launching, [€/piece]; D_1 – the lot dependent expenses (permanent expenses), for the pay off on the equipment and checking tools and devices during the preparation – completion period [€/piece]; n – the industrial lot launched into manufacturing, [pieces/lot].

The first category of expenses are calculated with the formula:

$$A_1 = c_{m1} + c_{s1} + c_{a1} + c_{i1} \quad [\text{€/piece}] \tag{2}$$

where: c_{m1} – the cost of the material of the part [€/piece]; c_{s1} – the direct expenses with basic wages payment, [€/piece]; c_{a1} – the expenses on the pay off period of the equipment and checking tools and devices during the unitary stages of machining, [€/piece]; c_{i1} – the indirect expenses on the manufacturing section, [€/piece].

These categories of expenses are determined with the formulae:

$$c_{m1} = m_s \cdot c_s - m_d \cdot c_d \quad [\text{€/piece}] \tag{3}$$

$$c_{s1} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot s_{m_i} \quad [\text{€/piece}] \tag{4}$$

$$c_{a1} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot a_i \quad [\text{€/piece}] \tag{5}$$

$$c_{i1} = c_{s1} \cdot \frac{R_f}{100} \quad [\text{€/piece}] \tag{6}$$

where:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} + \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} + \frac{C_D + C_V}{N_{adv} \cdot z_e \cdot k_s \cdot h} \quad [\text{€/piece}] \tag{7}$$

m_s – the mass of semi-product, [kg/piece]; c_s – the cost of one kilogram of semi-product, [€/kg]; m_d – mass of waste material (resulting chips), [kg/piece]; c_d – the cost of one kilogram of waste, [€/kg]; T_{u_i} – the unitary time for the operation i, [min.]; s_{m_i} – the salary of the worker in charge of performing the operation i [€/hour]; C_{MU} – the acquisition cost of the machine-tool, [€]; z_e – the number of working days in one year, [days/year]; k – the number of shifts per day; h – the number of hours per shift; C_{sc} – the acquisition cost of the cutting tool per operation, [€]; T – the cutting tool durability in the sharpening interval [hours]; r – the number of sharpening operations, until the cutting tool becomes unless; s_m

– the wages of the tool sharpening worker, [€/month]; t_r – the tool sharpening time, corresponding to the operation of the technological flow, [min]; C_D – the cost of special fastening device, not delivered with the machine tool, [€]; C_v – the acquisition cost of the checking device for a particular operation, [€]; N_{adv} – the number of the legal pay off years for the checking tools and devices; R_f – the overhead expenses of the machining section.

To calculate these expenses, we provide all the necessary information for the studied item „piston stage I", as it is manufactured at the "Timpuri Noi" enterprise: $m_s = 0.42$ [kg]; $c_s = 16.26$ [€/kg]; $m_d = 0.11$[kg]; $c_d = 0.23$ [€/kg] [2].

One obtains:

$$c_{m1} = m_s \cdot c_s - m_d \cdot c_d = 0.42 \cdot 16.26 - 0.11 \cdot 0.23 = 6.804 \text{ [€/piece]}$$

Considering the data in table 1, the cost calculations can be provided for wages, as $c_{s1} = 0.954$ [€/piece].

To calculate the pay off expenses for the equipment, the checking tools and devices, we provide below the separate calculation of pay off values, as follows:

• lathes [5, 16]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{15000}{10 \cdot 252 \cdot 3 \cdot 8} = 0.248 \text{ [€/piece]}$$

• drilling machines [6, 17]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{10000}{12 \cdot 252 \cdot 3 \cdot 8} = 0.138 \text{ [€/piece]}$$

• boring machines [5, 15]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{10000}{10 \cdot 252 \cdot 3 \cdot 8} = 0.165 \text{ [€/piece]}$$

• cutting tools (STAS 6377/80):

$$a_{sc1} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{5.43 + 1.9 \cdot 15 \cdot 10 / 60}{2.5 \cdot 15} = 0.271 \text{ [€/hour]}$$

• special groove cutter 4.5:

$$a_{sc2} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.26 + 1.9 \cdot 15 \cdot 6 / 60}{2 \cdot 15} = 0.238 \text{ [€/hour]}$$

• special groove cutter 2.5:

$$a_{sc3} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.00 + 1.9 \cdot 15 \cdot 6 / 60}{2 \cdot 15} = 0.228 \text{ [€/hour]}$$

• special finishing exterior cutter:

$$a_{sc4} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{5.14 + 1.9 \cdot 15 \cdot 8 / 60}{2.5 \cdot 15} = 0.238 \text{ [€/hour]}$$

• drill $\varnothing$ 15.5:

$$a_{sc\,5} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.29 + 1.9 \cdot 40 \cdot 15 / 60}{3 \cdot 40} = 0.194 \ \text{€/hour}$$

• drill $\varnothing$ 3:

$$a_{sc\,6} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{0.857 + 1.9 \cdot 40 \cdot 7 / 60}{3 \cdot 40} = 0.081 \ [\text{€/hour}]$$

• drill $\varnothing$ 8:

$$a_{sc\,7} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{101.43 + 1.9 \cdot 10 \cdot 12 / 60}{1.5 \cdot 10} = 7.01 \ [\text{€/hour}]$$

In the case of special devices and checking tools, the pay off expressed in €/hour, only means 5% of the cutting tools average pay off (which are fast consumables). In this situation, considering the data provided in table 1 and the above relations, the pay off expenses can be calculated:

$$c_{a1} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot a_i = 0.578 \ [\text{€/piece}]$$

The indirect expenses of the manufacturing unit are calculated with the ratio below [4, 12]:

$$c_{i1} = c_{s1} \cdot \frac{R_f}{100} = 0.954 \cdot \frac{80}{100} = 0.763 \ [\text{€/piece}]$$

Thus, the expenses independent of the lot result:

$$A_1 = 6.804 + 0.954 + 0.578 + 0.763 = 9.10 \ [\text{€/piece}]$$

The lot dependent expenses for the preparation and completion of manufacturing, as well as the management of preparing the lot launching are calculated with the ratio below:

$$B_1 = \left(1 + \frac{Rg}{100}\right) \cdot \sum_{i=1}^{k} \frac{T_{p_i}}{60} \cdot s_{r_i} \ [\text{€/lot}] \tag{8}$$

where: Rg – general overhead of the organisation (Rg = 120%); T_{p_i} – the preparation – completion period for each operation i of the technological flow [min]; s_{r_i} – wages of the adjustment operator for operation i, [€/hour]; k – number of operations.

Under these conditions, considering the data in table 1, the following statement is true $B_1 = 14.296$ [€/lot].

The lot dependent expenses for the pay off of the equipment, checking tools and devices, during the preparation – completion period are calculated with the equation [7, 13]:

$$D_1 = \sum_{i=1}^{k} \frac{T_{p_i}}{60} \cdot a_i \quad [\text{€/lot}] \tag{9}$$

where a_i is the pay off ratio and it was calculated before; it can be concluded that $D_1 = 5.825$ [€/lot].

Applying the ratio (1), the manufacturing cost can be derived of the piston stage I in the manufacturing alternative on conventional machine tools:

$$C_1 = A_1 + \frac{B_1 + D_1}{n} = 9.10 + \frac{14.296 + 5.825}{n} = 9.10 + \frac{20.12}{n} \quad [\text{€/piece}] \tag{10}$$

For the calculation of the most cost efficient lot, the relation below is used [3, 9, 16]:

$$n_0 = \sqrt{\frac{2 N_j \cdot (B_1 + D_1)}{(c_{m1} + A_1) \cdot \tau \cdot \varepsilon_n}} \quad [\text{pieces/lot}] \tag{11}$$

where B_1, D_1, c_{m1} and A_1 were calculated before; N_j – the manufacturing volume of one year (N_j = 1,000,000 pieces); ε_n – constant value that depends on the economic efficiency required (loss expressed in EURO at one euro-gold fixed net current assets ε_n=0.1...0.25); τ – constant value depending on the form of organisation and the manufacturing rate, as follows [17]:

$$\tau = \frac{\alpha}{r_j} = \frac{9.15}{0.377} = 24.27 \tag{12}$$

Considering the similar organization form for the volume and production type [3]:

$$r_j = \frac{F_n}{N_j} = \frac{z_e \cdot k_s \cdot h \cdot 60}{N_j} = \frac{262 \cdot 3 \cdot 8 \cdot 60}{1,000,000} = 0.377 \quad [\text{min/piece}] \tag{13}$$

In this situation, if all the results are replaced in formula (11), it is defined the manufacturing lot adjusted, n = 800 [pieces/lot] and therefore the manufacturing cost calculated with the relation (10) is C_1 = 9.13 [€/piece].

4. Calculation of the manufacturing cost for "Piston stage I" on Mazak Machining center with NC

The calculation formula structure is maintained as in the case of conventional machine tools, only changing the index, to make the difference:

$$C_2 = A_2 + \frac{B_2 + D_2}{n} \quad [\text{€/piece}] \tag{14}$$

The parameters significance is similar to formula (1), but with different values.

Also, the formula structure for the calculation of the expenses independent of the lot is the same as in the case of the conventional machine tools, but with different values, except for the cost of material: $c_{m2} = c_{m1} = 6.804$ [€/piece].

$$A_2 = c_{m2} + c_{s2} + c_{a2} + c_{i2} \quad \text{[€/piece]} \tag{15}$$

Considering the calculation in the case of machining on the NC equipment MAZAK, the semi-products are used after rough cutting on conventional equipment with $T_u = 9.15$ [min]; $T_{pi} = 25$ [min].

In this case, also considering the rest of data presented in table 2:

$$c_{s2} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot s_{m_i} = 0.407 \quad \text{[€/piece]}$$

To calculate the expenses with the pay off for equipment, checking tools and devices, separate calculations are provided below for the pay off ratio.

The MAZAK machining center:

$$a_{cp} = \frac{C_{MU}}{N_{an} \cdot z_e \cdot k_s \cdot h} = \frac{190,860}{10 \cdot 252 \cdot 3 \cdot 8} = 3.156 \quad \text{[€/hour]}$$

Removable plate cutter:

$$a_{sc1} = \frac{C_{MU} + C_{pl}}{T \cdot n_c} = \frac{8.571 + 8.00}{2.5 \cdot 3} = 2.209 \quad \text{[€/hour]}$$

The piston segment groove cutter:

$$a_{sc2} = \frac{C_{sc} + s_{m_i} \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.57 + 1.9 \cdot 15 \cdot 6 / 60}{2 \cdot 15} = 0.247 \quad \text{[€/hour]}$$

The hole machining $\phi 3$ for the conventional alternative $c_{sc3} = 0.081$ [€/hour]. The hole machining $\phi 15.5$ for the conventional alternative $c_{sc4} = 0.194$ [€/hour]. The boring bars for the conventional alternative $c_{sc5} = 7.01$ [€/hour].

In this case, also considering the data presented in table 2 with the pay off for equipment, checking tools and devices:

$$c_{a2} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot a_i = 0.277 \quad \text{[€/piece]}$$

The indirect expenses are: : $\quad c_{i2} = c_{s2} \cdot \frac{R_f}{100} = 0.407 \cdot \frac{80}{100} = 0.326$ [€/piece]

and also : $\quad A_2 = 6.804 + 0.407 + 0.277 + 0.326 = 7.814$ [€/piece]

Lot dependent expenses for preparation and completion of manufacturing, as well as the administrative preparation of the lot launching is calculated similarly with the conventional alternative, but with the values that are indicated in table 2, resulting $B_2 = 21.122$ [€/lot].

Also the lot dependent expenses on the pay off for the equipment, checking tools and devices are calculated similarly with the conventional alternative, but using the values in table 2, resulting $D_2 = 21.291$ [€/lot].

For the optimum cost efficiency calculation, the similar procedure is applicable as in the case of conventional equipment, with the ratio under (11), but using the ante calculated values, to obtain the adjusted lot, $n = 2,000$ [pieces/lot].

In this case the manufacturing cost of the piston stage I, on the NC MAZAK equipment, is:

$$C_2 = A_2 + \frac{B_2 + D_2}{n} = 7.814 + \frac{21.122 + 21.291}{2,000} = 7.83 \ \ [\text{€/piece}] \quad (16)$$

If new investment funds are foreseen for both alternatives, that is for alternative 1 using conventional machine tools, and alternative 2 using MAZAK equipment, for the annual production of 1,000,000 [pieces/year] (as it is the case with the „Timpuri Noi" enterprise), significant savings result for alternative 2 using MAZAK equipment:

$$E = N_j \cdot (C_1 - C_2) = 10^6 (9.13 - 7.83) = 1,300,000 \ \ [\text{€/year}] \quad (17)$$

The mention should be made that the calculated economies only refer to the manufacturing of the " Piston stage I".

5. Conclusions

This paper provides the answer to the question: "What technologies and machine tools must be purchased to obtain the maximum economic efficiency of the invested funds?" With this end in view, the authors have defined a detailed economic calculation of manufacturing costs for a piston from a motor set assembly in two comparative alternatives: the variant 1 on conventional machine tools and the variant 2 on Japanese numerical control equipment of the type MAZAK machining equipment.

The former communist states have become attractive not only for the car producers in Western Europe. Japanese as well as South Korean producers are eager to "produce them at the very location where they can be sold", thus avoiding import taxes and expenses with car transportation between continents.

South Korea is a well known country for its low production cost and therefore it looks rather surprisingly to see that car production in Eastern Europe is more accessible than their exportation from the country of origin. The car spare parts are more expensive, but the number of local suppliers is also increasing. Romania ranks the sixth place among the greatest car producers in Central and Eastern Europe.

The calculations included in this article are based on all the elements affecting the manufacturing cost: material, labour, pay off on the equipment,

checking tools and devices that are still in the legal pay off period, indirect expenses, fix and variable expenses, expenses for the preparation and completion of manufacturing, administrative preparation of lot launching into manufacturing.

In the end, the savings obtained in a concrete machining process of a piston at "Timpuri Noi" enterprise in Bucharest were calculated.

This is what makes this article important for both the scientific and practical aspects on a concrete existing case.

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