DETERMINATION OF THE ECONOMIC EFFICIENCY OF INVESTMENTS TO THE USE OF CNC MACHINING CENTERS

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Acest articol tratează problema determinării eficienţei economice a investiţiilor la utilizarea centrelor de prelucrare cu comandă numerică în activitatea de fabricaţie. În acest scop sunt analizate două variante comparative: una de prelucrare pe maşini-unelte convenţionale şi cealaltă de prelucrare pe echipamente cu comandă numerică. Studiul de caz analizat se referă la prelucrarea unui tip de piston la societatea comercială „Timpuri Noi"din Bucureşti. Pentru determinarea costurilor au fost folosite cele mai complexe formule de calcul luând în considerare toate elementele ce influenţează în general costul de prelucrare. Articolul prezintă importanţă pentru studiile tehnice teoretice şi pentru activitatea de fabricaţie.

This article treats the problem of determination of the economic efficiency of investments to the use of CNC machining centers in manufacturing activity. For this purpose two comparative variants have been analyzed: one working on conventional machine tools and the other working on CNC equipments. The analyzed case study refers to the manufacturing of a type of piston at the "Timpuri Noi" enterprise in Bucharest. The most complex formulae for costs have been used taking into account all the elements which in generally affect the manufacturing cost. The article presents importance for theoretical technical studies and for manufacturing activity.

Key words: cost, conventional machines, CNC machining centers, piston.

1. Introduction

The car industry production registers 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, labor and professional structure that is required for the best manufacturing of the items in the car industry, should have to

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prepare first a feasibility study [2, 3]. This means to prepare first an assessment of what would be the most suitable machine tools to purchase that are capable to provide for the utilization of modern technologies and thus enable the producer to penetrate the market segment of most cost efficient car parts production [4].

This article presents the contribution of the authors provinding 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 shareholder system, and the financial institutions, such as: banks, organizations providing investment funds etc.).

2. Technologies used in manufacturing of pistons on conventional machine tools and CNC machining centers

For the study regarding the manufacturing of car components on conventional machine tools and CNC machining centers, the authors have focused on the item piston stage II, with the execution drawing shown in figure 1 [19].

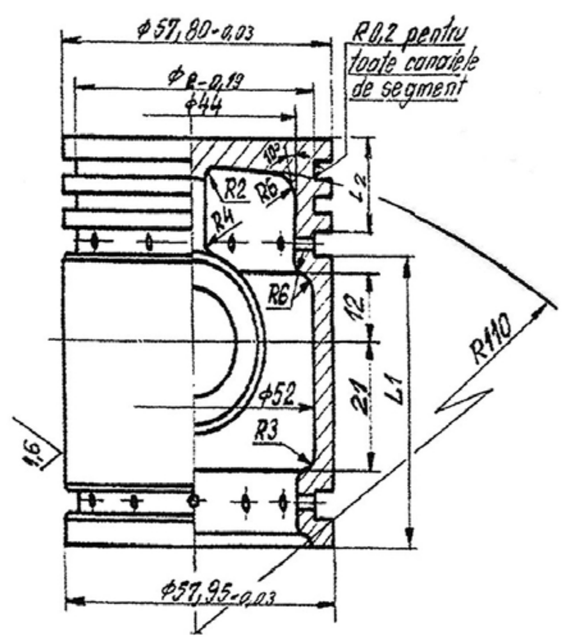

Fig.1. The piston stage II [19]

The machining technology for the production of the piston stage II on the conventional machining technology is detailed in the table 1 [19].

The machining technology for the production of the piston stage II on the numerical control equipment MAZAK is detailed in the table 2.

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	0.30
10	Lathe SN 400	Rough turning	3	10	1.40
15	Lathe SN 400	Pre-drilling	3	10	1.29
20	Lathe SP 250	Exterior rough turning	4	25	5.92
25	Workbench	Testing	4	5	1.61
30	Drilling machine GR 40	Boss drilling	3	8	0.86
35	Drilling machine GR 40	Radial drilling C1	3	8	1.62
40	Drilling machine GR 40	Radial drilling C2	3	8	1.62
45	Workbench	Adjustment	2	6	0.64
50	Bath	Washing, blowing	1	7	0.16
55	Lathe SN 400	Finish turning	3	10	0.85
60	Lathe SP 250	Interior finish turning	4	24	2.15
65	Reaming machine	Rough boring	4	20	1.07
70	Lathe SN 400	Groove cutting	3	12	1.07
75	Reaming machine	Finish cutting	5	20	1.07
80	Drilling machine GR 40	Settlement	3	5	0.86
85	Workbench	Adjustment	2	6	0.64
90	Bath	Washing, blowing	1	7	0.16
95	Inspection table	Inspection	5	6	0.67
100	Workbench	Packing	1	4	0.16
105	Warehouse	Storage	1	10	0.16

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	0.30
10	Lathe SP 250	Rough turning	4	25	5.92
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	0.67
30	Workbench	Packing	1	4	0.16
35	Warehouse	Storage	1	10	0.16

3. Cost calculation of manufacturing of the item piston stage II on conventional machine tools

Based on the technical works relevant in this domain [1, 5, 6, 7, 8], the authors of this 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 shall be 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 part material, [€/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 shall be determined with the formulas:

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

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

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

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

where:

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

m_s – the mass of semiproduct, [kg/piece];
c_s – the cost of one kilogram of semiproduct, [€/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 obsolete;
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 II, as it is manufactured at the ”Timpuri Noi” enterprise: $m_s = 0.244$ [kg]; $c_s = 16.26$ [€/kg]; $m_d = 0.063$[kg]; $c_d = 0.23$ [€/kg] [9].

One obtains:

$$c_{m1} = m_s \cdot c_s - m_d \cdot c_d = 0.244 \cdot 16.26 - 0.063 \cdot 0.23 = 3.953 \text{ [€/piece]} \tag{8}$$

Considering the data in table 1 and the formula (4) the cost calculation can be provided for wages, as $c_{s1} = 0.751$ [€/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 [10, 11]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{15{,}000}{10 \cdot 252 \cdot 3 \cdot 8} = 0.248 \text{ [€/hour]} \tag{9}$$

- drilling machines [12, 13]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{10{,}000}{12 \cdot 252 \cdot 3 \cdot 8} = 0.138 \quad [\text{€/hour}] \tag{10}$$

- boring machines [8, 10]:

$$a_i = \frac{C_{MU}}{N_{an_i} \cdot z_e \cdot k_s \cdot h} = \frac{10{,}000}{10 \cdot 252 \cdot 3 \cdot 8} = 0.165 \quad [\text{€/hour}] \tag{11}$$

- cutting tools (STAS 6377/80):

$$a_{sc1} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{5.43 + 1.9 \cdot 15 \cdot 10 / 60}{2.5 \cdot 15} = 0.271 \quad [\text{€/hour}] \tag{12}$$

- groove cutter 2:

$$a_{sc2} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.11 + 1.9 \cdot 15 \cdot 10 / 60}{2 \cdot 15} = 0.232 \quad [\text{€/hour}] \tag{13}$$

- groove cutter 3.5:

$$a_{sc3} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.15 + 1.9 \cdot 15 \cdot 10 / 60}{2 \cdot 15} = 0.233 \quad [\text{€/hour}] \tag{14}$$

- groove cutter 4:

$$a_{sc4} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.25 + 1.9 \cdot 15 \cdot 10 / 60}{2 \cdot 15} = 0.236 \quad [\text{€/hour}] \tag{15}$$

- groove cutter 2.5:

$$a_{sc5} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.00 + 1.9 \cdot 15 \cdot 10 / 60}{2 \cdot 15} = 0.228 \quad [\text{€/hour}] \tag{16}$$

- special finishing exterior cutter:

$$a_{sc6} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{5.14 + 1.9 \cdot 15 \cdot 10 / 60}{2 \cdot 15} = 0.238 \quad [\text{€/hour}] \tag{17}$$

- drill ∅ 15.5:

$$a_{sc7} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.29 + 1.9 \cdot 40 \cdot 15 / 60}{2 \cdot 15} = 0.194 \quad [\text{€/hour}] \tag{18}$$

- boring bar ∅ 17.4:

$$a_{sc8} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{101.43 + 1.9 \cdot 10 \cdot 12 / 60}{1.5 \cdot 1} = 7.010 \quad [\text{€/hour}] \tag{19}$$

- boring bar ∅ 18:

$$a_{sc9} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{101.43 + 1.9 \cdot 10 \cdot 12 / 60}{1.5 \cdot 10} = 7.010 \quad [\text{€/hour}] \tag{20}$$

• drill ∅ 2.5:

$$a_{sc10} = \frac{C_{sc} + s_m \cdot r \cdot t_r / 60}{T \cdot r} = \frac{0.725 + 1.9 \cdot 40 \cdot 7 / 60}{3 \cdot 40} = 0.079 \text{ [€/hour]} \qquad (21)$$

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 formula (5), the pay off expenses is:

$$c_{a1} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot a_i = 0.278 \text{ [€/piece]} \qquad (22)$$

The indirect expenses of the manufacturing unit are [14, 15]:

$$c_{i1} = c_{s1} \cdot \frac{R_f}{100} = 0.751 \cdot \frac{80}{100} = 0.601 \text{ [€/piece]} \qquad (23)$$

Thus, the expenses independent of the lot result:

$$A_1 = 3.953 + 0.751 + 0.278 + 0.601 = 5.583 \text{ [€/piece]}$$

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

$$B_1 = \left(1 + \frac{Rg}{100}\right) \cdot \sum_{i=1}^{k} \frac{T_{p_i}}{60} \cdot s_{r_i} \text{ [€/lot]} \qquad (24)$$

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 $B_1 = 14.52$ [€/lot].

The lot dependent expenses for the pay off the equipment, checking tools and devices, during the preparation – completion period are calculated with the rationship [16, 17]:

$$D_1 = \sum_{i=1}^{k} \frac{T_{p_i}}{60} \cdot a_i \text{ [€/lot]} \qquad (25)$$

where a_i is the pay off ratio and it is calculated before; it can be concluded that $D_1 = 2.55$ [€/lot].

Applying the equation (1), the manufacturing cost of the piston stage II in the manufacturing alternative on conventional machine tools is:

$$C_1 = A_1 + \frac{B_1 + D_1}{n} = 5.583 + \frac{14.52 + 2.55}{n} = 5.583 + \frac{17.07}{n} \quad [\text{€/piece}] \qquad (26)$$

For the calculation of the most cost efficient lot, the relation is [11, 18]:

$$n_0 = \sqrt{\frac{2N_j \cdot (B_1 + D_1)}{(c_{m1} + A_1) \cdot \tau \cdot \varepsilon_n}} \quad [\text{pieces/lot}] \qquad (27)$$

where:
B_1, D_1, c_{m1} and A_1 were calculated before;
N_j – the manufacturing volume of one year (N_j = 500,000 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 – a constant value depending on the form of organization α and the manufacturing rate r_j, as follows [13]:

$$\tau = \frac{\alpha}{r_j} \qquad (28)$$

The resulted production type for the item piston stage II is mass production, with tendency to big series. The form of organisation "in parallel"; is recommend thus $\alpha = \max_i \left(T_{u_i}\right) = 5.92$ min.

Considering the similar organization form for the volume and production type:

$$r_j = \frac{F_n}{N_j} = \frac{z_e \cdot k_s \cdot h \cdot 60}{N_j} = \frac{262 \cdot 3 \cdot 8 \cdot 60}{500{,}000} = 0.754 \quad [\text{min/piece}] \qquad (29)$$

Then the constant value $\tau = 7.851$.

In this situation, if all the results are replaced in formula (27), the manufacturing lot adjusted n_0 = 1,000 [pieces/lot]. Therefore the manufacturing cost calculated with the relation (26) is C_1 = 5.60 [€/piece].

4. Calculation of the manufacturing cost for the item piston stage II on MAZAK Machining center with CNC

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

$$C_2 = A_2 + \frac{B_2 + D_2}{n} \quad [\text{€/piece}] \tag{30}$$

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: $c_{m2} = c_{m1} = 3.953$ [€/piece].

$$A_2 = c_{m2} + c_{s2} + c_{a2} + c_{i2} \quad [\text{€/piece}] \tag{31}$$

Considering the calculation in the case of machining on the CNC equipment MAZAK, the semi-products are used after rough cutting on conventional equipment with $T_u = 5.92$ [min]; $T_{pi} = 25$ [min].

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

$$c_{s2} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot s_{m_i} = 0.265 \quad [\text{€/piece}] \tag{32}$$

To calculate the expenses with the pay off for equipment, checking tools and devices, the calculations of the pay off ratio, are as folows:

- MAZAK machining center:

$$a_{cp} = \frac{C_{MU}}{N_{an} \cdot z_e \cdot k_s \cdot h} = \frac{190{,}860}{10 \cdot 252 \cdot 3 \cdot 8} = 3.156 \quad [\text{€/hour}] \tag{33}$$

- removable plate cutter:

$$a_{sc1} = \frac{C_{MU} + C_{pl}}{T \cdot n_c} = \frac{8.571 + 8.00}{2.5 \cdot 3} = 2.209 \quad [\text{€/hour}] \tag{34}$$

- piston segment groove cutter:

$$a_{sc2} = \frac{C_{sc} + s_{m_i} \cdot r \cdot t_r / 60}{T \cdot r} = \frac{4.57 + 1.9 \cdot 15 \cdot 6/60}{2 \cdot 15} = 0.247 \quad [\text{€/hour}] \tag{35}$$

- drill ∅ 2.5: $c_{sc3} = 0.079$ [€/hour]
- drill ∅ 15.5: $c_{sc4} = 0.194$ [€/hour]
- boring bars: $c_{sc5} = c_{sc6} = 7.01$ [€/hour]

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

$$c_{a2} = \sum_{i=1}^{k} \frac{T_{u_i}}{60} \cdot a_i = 0.242 \quad [\text{€/piece}] \tag{36}$$

The indirect expenses are provided in the ratio:

$$c_{i2} = c_{s2} \cdot \frac{R_f}{100} = 0.265 \cdot \frac{80}{100} = 0.212 \text{ [€/piece]} \tag{37}$$

and also:

$$A_2 = 3.953 + 0.265 + 0.242 + 0.212 = 4.672 \text{ [€/piece]}$$

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 $B_2 = 19.078$ [€/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 $D_2 = 18.99$ [€/lot].

For the calculation of the optimum cost efficiency, the similar procedure is applicable as in the case of conventional equipment, with the ratio under (27), but using the ante calculated values, to obtain the adjusted lot, $n_0 = 2{,}000$ [pieces/lot].

In this case the manufacturing cost of the piston stage II, on the CNC MAZAK equipment, is:

$$C_2 = A_2 + \frac{B_2 + D_2}{n} = 4.672 + \frac{19.078 + 18.99}{2{,}000} = 4.69 \text{ [€/piece]} \tag{38}$$

If the new investment funds are foreseen for both alternatives, that is for first alternative using conventional machine tools, and second alternative using MAZAK equipment, for the annual production of 500,000 [pieces/year] (as it is the case with the ”Timpuri Noi” enterprise), significant savings result for second alternative using MAZAK equipment:

$$E = N_j \cdot (C_1 - C_2) = 500{,}000 \cdot (5.60 - 4.69) = 455{,}000 \text{ [€/year]} \tag{39}$$

The calculated economies refer to the manufacturing of the piston stage II.

5. Determination of the indicators of the economic efficiency of investments

Taking into account the current market price $P = 7.89$ [€/piece] of the item piston stage II (at the exchange rate of 12/05/2011) and the fact that the annual investment will be on total expenditure and on interest bank credit, the following indicators of the economic efficiency of investments can be calculated:

- the annual gross profit, P_b (reinvested tax free);
- the investment rate of return, R_i;
- the investment recovery period, T_r.

a) The first variant, working on conventional machine tools:

$$P_{b1} = N_j \cdot (P - C_1) = 500{,}000 \cdot (7.89 - 5.60) = 1{,}145{,}000 \text{ [€/year]} \quad (40)$$

$$R_{i1} = \frac{P_{b1}}{I_1} \cdot 100\% = \frac{P_{b1}}{1.12 \cdot N_j \cdot C_1} \cdot 100\% = 36.5\% \quad (41)$$

$$T_{r1} = \frac{I_1}{P_{b1}} = \frac{1.12 \cdot N_j \cdot C_1}{P_{b1}} = 2.74 \text{ years} \quad (42)$$

b) The second variant, working on MAZAK machining center with CNC:

$$P_{b2} = N_j \cdot (P - C_2) = 500{,}000 \cdot (7.89 - 4.69) = 1{,}600{,}000 \text{ [€/year]} \quad (43)$$

$$R_{i2} = \frac{P_{b2}}{I_2} \cdot 100\% = \frac{P_{b2}}{1.12 \cdot N_j \cdot C_2} \cdot 100\% = 60.9\% \quad (44)$$

$$T_{r2} = \frac{I_2}{P_{b2}} = \frac{1.12 \cdot N_j \cdot C_2}{P_{b2}} = 1.64 \text{ years} \quad (45)$$

The gross profit of the second variant is bigger with 455,000 [€] than the gross profit of the first variant. The investment rate of return is almost two times higher for the second variant compared to the first variant. The period of the investment recovery is very small for the second variant.

6. 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 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 one on conventional machine tools and the second variant on CNC equipment of the type MAZAK machining center.

The calculations included in this article are based on all the elements affecting the manufacturing cost: material, labor, 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. Finally, the main indicators of economic efficiency of investments for the two analyzed variants were determined.

The calculated values were obtained in a concrete machining instance of a piston at ”Timpuri Noi” enterprise in Bucharest.

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

REFERENCES

[1] *Atkinson A.*, Management Accounting, 3rd ed., Ed. Prentice Hall, Upper Saddle River, New Jersey, 2001.

[2] *Oswald P.*, Cost Estimating, 3rd ed., Ed. Prentice Hall, New York, 1992.

[3] *White J. et al.*, Principles of Engineering Economic Analysis, 4th ed., Ed. John Wiley & Sons, New York, 1998.

[4] *Breazu A.*, Stadiul actual al fabricării componentelor auto în România, Raport ştiinţific nr.1 al tezei de doctorat (Actual stage of the car components manufacturing in Romania, Scientific report no. 1 of the Doctoral Thesis), University Politehnica of Bucharest, 2007. (in Romanian)

[5] *Fabrycky W., Thuesen G., Verma D.*, Economic Decision Analysis, Ed. Prentice Hall, Upper Saddle River, New Jersey, 2007.

[6] *Oswald P.*, Cost Estimating, 3rd ed., Ed. Prentice Hall, New York, 1992.

[7] *Riggs J.*, *Bedworth D., Randhawa S.*, Engineering Economics, 4th ed., Ed. McGraw Hill, 1996.

[8] *Vlase A. et al.*, Tehnologia Construcţiilor de Maşini (Machine Manufacturing Technology), Technical Publishing House, Bucharest, 1996. (in Romanian)

[9] *Breazu A. A.*, Studiul comparativ al aspectelor economice legate de costurile de fabricaţie a componentelor auto pe maşini-unelte clasice şi cu comandă numerică, Raport ştiinţific nr.2 al tezei de doctorat (Comparative study of the economic aspects concerning the manufacturing costs of the car components working on classical machine tools and on numerical control equipments, Scientific report no.2 of the Doctoral Thesis), University Politehnica of Bucharest, 2008. (in Romanian)

[10] *Doicin C., Baicu C., Tudor-Soare C.*, Aplicaţii ale analizei economice în inginerie (Economic analysis applications in engineering), Ed. Bren, Bucharest, 2002.

[11] *Vlase A. et al.*, Tehnologii de prelucrare pe strunguri (Lathes processing technologies), Technical Publishing House, Bucharest, 1989. (in Romanian)

[12] *Doicin C.*, Analiză economică în inginerie (Economic analysis in engineering), Ed. Bren, Bucharest, 2009. (in Romanian)

[13] *Vlase et al.*, Tehnologii de prelucrare pe maşini de găurit (Drilling machines processing technologies), Technical Publishing House, Bucharest, 1994.

[14] *Diaconu I., Moldoveanu L, Ivan M.*, Costuri, preţuri şi tarife în economia modernă (Costs, prices and tariffs in modern economy), Ed. Tradiţie, Bucharest, 1997.

[15] *Stancu I.*, Finanţe (Finances), Ed. Economică, Bucharest, 2002.

[16] *Drury C.*, Standard Costing, Academic Press Limited, London, 1992.

[17] *Sullivan W.*, *Bontadelli J., Wicks E.,* Engineering Economy, 11th ed., Prentice Hall, Upper Saddle River, New Jersey, 2000.

[18] *Horngren C., Foster G., Datar S.*, Cost Accounting. A Managerial Emphasis, Ed. Prentice Hall, Upper Saddle River, New Jersey, 2003.

[19] * * *, "Timpuri Noi" Enterprise documentation, Bucharest.