ANALYSIS OF OPTIMAL PRODUCTION PROGRAM IN METALWORING INDUSTRY

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Abstract. *This paper investigates the effects of the manner of calculating the product cost price on forming the impact criteria in production program optimization in metalworking companies by means of genetic algorithms. An algorithm was defined for multi-objective production program optimization using genetic algorithms, with the application of nonlinear function of minimal costs and linear function for maximizing the machinery capacity level. The aim of the paper is to investigate the basic hypothesis that the manner of calculating the product cost price in metalworking companies within the framework of the goal to minimize the business operating costs has significant influence on the results obtained by applying genetic algorithms in production program optimization. The results of investigation indicate significant differences in an optimal production program gained by calculating the product cost price via traditional and activity-based costing approach to defining the nonlinear cost function, depending on the volume of production.*

1. INTRODUCTION

The analysis of the production program of enterprises is an important and complex segment of managing the enterprise, considering the fact that it influences all elements, such as planning of the material, human resources, machinery resources, research and development, marketing etc. Permanent analysis of optimal production program enables the enterprise to correct all its business activities according to its needs and goals that are mainly related to internal resources realization. Namely, market competitiveness depends largely on rational utilization of internal resources. This paper is an extension of knowledge acquired to date about production program optimization in metalworking companies, and requires integration of knowledge about economy, production processes and optimization by means of genetic algorithms.

In investigations carried out to date the production program optimization was based on multi-criteria approach using linear functions [**1, 2**]. Using nonlinear functions in multi-objective optimization enables the application of genetic algorithms and is a step forward in the analysis of the product optimal quantities to maximize production resources utilization [**3, 4, 5**]. On the other hand, economic calculation of the product cost price is a complex procedure, so that the analysis of optimal production program most commonly employed direct costs to determine the cost price and to define the cost function. However, cost functions based only on product variable costs cannot provide real optimal product quantities but are more suitable for ranking products that should be given priority in manufacturing. Introducing overhead costs in the function of cost price is a complex calculation procedure most often difficult to understand by the user in a concrete enterprise, considering that it is not easy to classify individual expenses. It is thought that in metalworking companies, roughly assessing, direct costs account for about 60% of total unit costs, while the share of overhead costs is 40% [**6**].

2. OVERVIEW OF PREVIOUS RESEARCH

Total business operating costs consist of the sum of fixed and variable costs. Fixed costs are independent of the volume of production and include the expenses of annuity, depreciation, employees' pays etc. Variable costs depend on the volume of production, and involve costs of material procurement, packing, overtime pay for employees etc. Consequently, total business operating costs are determined by fixed costs, variable costs and volume of production [**7**].

In theory or practice there is no methodology to precisely determine unit cost of a certain product, but this is reduced to assessment based on reallocation of expenses most commonly performed as follows:

1. Total fixed costs are determined as the sum of all costs created for manufacturing the product.
2. Calculation of total variable costs created for manufacturing the product.
3. Total fixed costs are determined as the sum of total fixed costs and total variable costs.

4. Product unit costs are determined when dividing the obtained total business operating costs by the volume of production.

Such manner of determining the product unit cost has become quite common in today's business operations. The problem arises when the enterprise has more than one product in its production program. Fixed and variable production costs are most often calculated per month, or more precisely, annually, quarterly and monthly. However, to determine the product unit cost, the calculation of costs at a monthly level is the most accurate determination for the acquired detailing level. Namely, in the analysis of production costs, fixed costs include monthly accounts (energy sources, pays, taxes and dues), so that the time period mentioned has become established as the most adequate for approximate determination of the product unit cost [**8,9**]. However, the situation is quite different in variable costs. Variable costs of production depend primarily on the type of production, i. e. whether it is mass, serial or individual. Therefore, each case requires analysis.

Variable costs, as above mentioned, depend on the volume of production, but if a product range includes several products (as is the case very often), variable costs should be grouped according to various products [**10**].

$$T_c = F_c + V_c \qquad (1)$$

T_c – total costs

F_c – fixed costs

V_c – variable costs

Let n products be manufactured in the enterprise (i=1,2,…,n), unit cost for each product would be:

$$W_{ci} = \frac{F_{ci}}{Q_i} + \frac{V_{ci}}{Q_i} \qquad (2)$$

where:

W_c - unit cost price of the i-th product

Q_i - volume of production of the i-th product

V_{ci} - – variable costs for the i-th product

The product selling price is most commonly determined according to marketing researches of a concrete enterprise and is based on the supply-and-demand ratio, product quality and the like. Profit, being a difference between the selling price and total costs, is often used in the analysis of business operations as a basic function for optimization of business operations [**7,9**]. In profit equation the selling price is data accurately determined, while total costs are often based on the assessment, i.e. approximate variable costs per product unit. Profit is mainly calculated using the formula:

$$P = S_p - T_c = S_p - (F_c + V_c) \qquad (3)$$

where:

P - profit

S_p - selling price

The function of profit should contain more detailed information because in real conditions the production program consists of several products. Hence, profit for the i-th product should be calculated using the formula:

$$P_i = S_{pi} - (F_{ci} + V_{ci}) \quad i = 1,2,...n. \qquad (4)$$

P_i – profit for the i-th product

S_{pi} - selling price for the i-th product and total profit of the enterprise would be:

$$P = \sum_{i=1}^{n} S_{pi} - \sum_{i=1}^{n}(F_{ci} + V_{ci}) = \sum_{i=1}^{n} S_{pi} - F_c - \sum_{i=1}^{n} V_{ci} \qquad (5)$$

$$F(P)_{\max} = \sum_{i=1}^{n} S_{pi} - \sum_{i=1}^{n}(F_{ci} + V_{ci}) = \sum_{i=1}^{n} S_{pi} - F_c - \sum_{i=1}^{n} V_{ci} \qquad (6)$$

One of the goals in this investigation is to set up a function for profit maximization to represent as realistic picture of business operations as possible, i.e. to set up the functions of fixed and variable costs as realistic as possible but not to represent approximations.

So, let's start from the basic equation for unit costs per unit of the observed product:

$$W_{ci} = \frac{F_{ci}}{Q_i} + \frac{V_{ci}}{Q_i} \qquad (7)$$

In the traditional approach, unit variable costs are separated for each product (e.g. raw material costs, material costs, variable costs etc.) and there are fixed overhead costs for the entire enterprise. In this approach the allocation of fixed overhead costs is performed proportionally against material costs or labor costs or machine time per product. Hundal [**6**] reports that such approach can lead to higher costs being allocated to low-volume products than to those produced in mass quantities.

$$C_{MANF} = (A\%) \cdot C_{MATL} + (B\%) \cdot C_{LABD} \qquad (8)$$

where:

C_{LABD} - direct labor costs

C_{MATL} - total materials costs

C_{MANF} - manufacturing costs

where: coefficients A and B vary within the range of 100-150% and 200-500% respectively.

Hundal [**6**] also reports that traditional costing method derives from the time of mass production when products were simple and few. Today, a larger portion of costs is related to direct labor costs, while fixed costs make up only 10 – 20% of total costs.

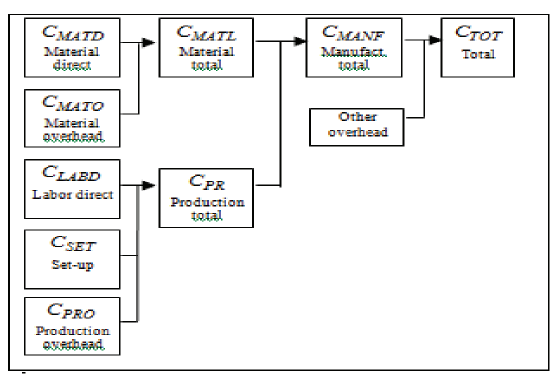

Fig. 1. Detailed breakdown of production costs [6]

In the activity-based system the allocation of costs is performed according to the activities connected to the production of a certain product.

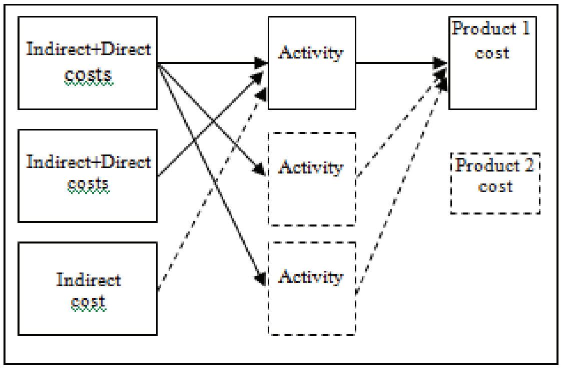

Fig. 2. Activity based costing approach in determination of product costs

So, profit maximization refers to the finding of the extrema for the function specified and with realistic constraints existing in a concrete enterprise:

$$\max \mathrm{P} = Z_1(X) = \sum_{i=1}^{n} Q_i (W_{pi} - W_{vi}) - T_c \qquad (9)$$

P - profit
Q_i – quantity of the i-th product
Wpi – unit selling cost of the i-th product
Wvi – unit variable costs of the i-th product
F_c – constant costs

In real conditions the functions of dependence of production volume and total revenue and total costs are nonlinear. Maximum profit in the graph below represents maximum difference between the total profit curve and total costs, Fig. 3.

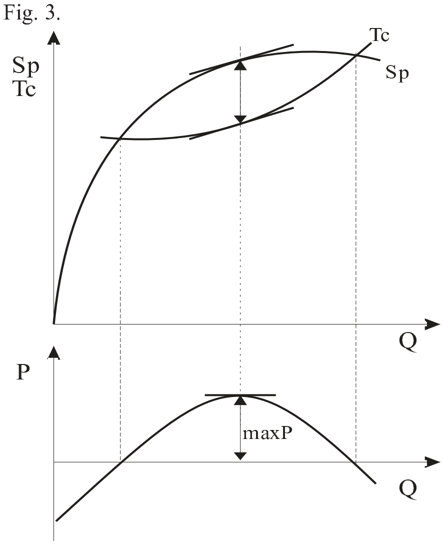

Fig. 3. Graphic representation of profit maximization [**7**]

In the enterprise's real business operating conditions the functions of total revenue and total costs are nonlinear. The function of total revenue consists of the sum of variable costs and fixed costs, i.e. the sum of linear function of fixed costs and nonlinear function of variable costs.

Mathematically, it is possible to determine the nonlinear function of variable costs by applying the Lagrange interpolation polynomial based on the values of variable costs from the previous period [**11, 12**] using:

$$P(Q) = \sum_{j=1}^{n} P_j(Q) \qquad (10)$$

where:

$$P_j(Q) = y_j \prod_{\substack{k=1 \\ k \neq j}}^{n} \frac{Q - Q_k}{Q_j - Q_k} \qquad (11)$$

Maximization of the capacity utilization level can be determined via the function:

$$Z_2(X) = \sum_{i}^{m} \sum_{j=1}^{n} \frac{1}{a_{io}} a_{ij} Q_j, \ (i = 1,2,...,m) \qquad (12)$$

where:
Q_j – quantity of the j-th product included in the production program
a_{ij} – time needed to produce unit of the j-th product on the i-th machine
a_{io} – the i-th machine capacity expressed in time units
n – miscellaneous products that can be produced (j = 1, 2, …n)
m – miscellaneous tools for work (i = 1, 2, …,m).

3. METHODOLOGY

To perform multi-objective production program optimization, an algorithm, a set of sequential steps, was developed, representing the methodology of investigation. In the literature available investigations related to multi-objective optimization, when we have nonlinear functions, lead to the application of genetic algorithms as an appropriate tool for solving the problem set up [**4, 13, 14, 15**].

Figure 4 shows steps in generating a model for multi-criteria production program optimization. The first step requires problem definition. In accordance with problem definition, there follows generation of criteria whose maximum and minimum values we want to realize. In production program optimization the criteria can involve profit maximization, minimization of production costs, maximization of machine capacity utilization and the like [**16**]. After the criteria are defined, it is possible to set up objective functions in a linear or nonlinear form, depending on how they represent a real model.

Defining of constraints within the framework of a set up model refers to real production constraints that can derive from production potentials, i.e. machinery capacity, human resources, material resources but also from the demands for the observed product on the market.

In this investigation two cases have been generated and their results are compared. The first case refers to the calculation of cost price using the traditional approach, while the second case represents an activity-based costing approach in calculating the cost price. Calculation of cost price for both cases has been employed to generate two functions that describe the dependence of the product cost price on the volume of production, while the second objective function is linear dependence of machinery capacity utilization level depending on the volume of production, and is identical in both cases.

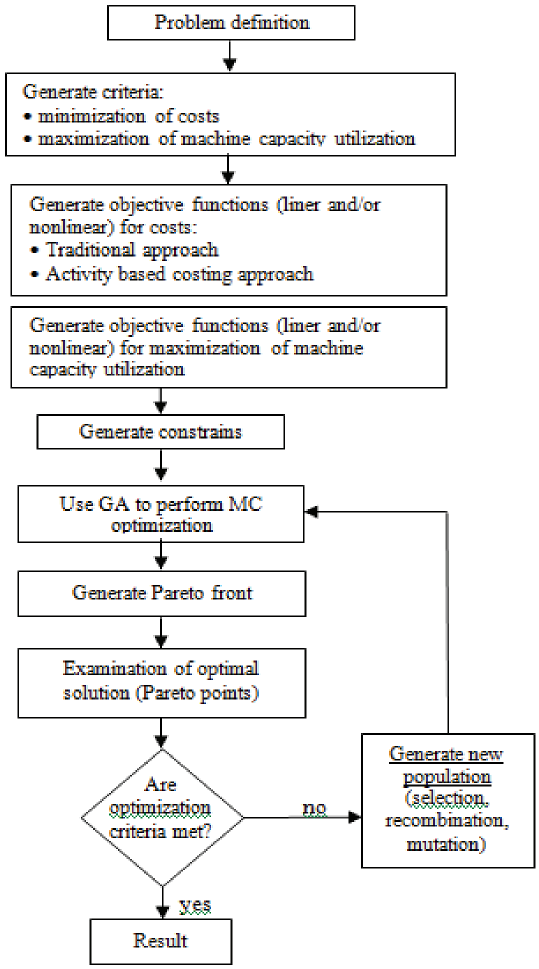

Fig. 4. Flow diagram: Steps in developing model for multiciteria production program optimization

Case 1: Objective functions. The first objective function is generated via traditional approach

$$Z_1'(X)\min = \sum_{i=1}^{n} W_i \cdot Q_i$$

$$Z_2(X)_{\max} = \sum_{i}^{m} \sum_{j=1}^{n} \frac{1}{a_{io}} a_{ij} Q_j, \; (i = 1,2,...,m)$$

Case 2: Objective functions. The first objective function is generated via activity-based costing (ABC) approach

$$Z_1''(X)\min = \sum_{i=1}^{n} W_i \cdot Q_i$$

$$Z_2(X)_{\max} = \sum_{i}^{m} \sum_{j=1}^{n} \frac{1}{a_{io}} a_{ij} Q_j, \; (i = 1,2,...,m)$$

Constraints:

1. Market demand constraint can be expressed by:

$$0 \le Q_j \le y_j, \qquad (j = 1,2,...,n)$$

2. Maximum available capacity utilization level

$$\sum_{j=1}^{n} a_{ij} x_j \le a_{io}, \quad (i = 1,2,..., m)$$

where:

y_j – quantity of the j-th product that can be sold on the market.

After the objective functions are formed and constraints are defined using GA, the Pareto front is generated and optimal solutions are examined. Using a real example, the application of the developed model for production program optimization is presented below.

4. NUMERICAL EXAMPLE

Investigation to follow refers to the application of described methodology using a concrete example of the enterprise. The selected enterprise is engaged in manufacturing welded pipes, of various profiles, so that the differences in product unit cost price are not high. The basic hypothesis was to investigate whether any difference occurs in production program optimization using genetic algorithms when calculating unit cost price by applying different approaches, i.e. traditional or ABC approach. Therefore, applying the designed methodology in the enterprise where there are no significant differences in the manufacturing process of a certain type of product, the results are expected to differ. However, differences are more pronounced in the enterprise that has a more diverse production program. We have monitored the production process in a factory engaged in the production of welded and seamless pipes. Production is carried out on two lines of similar capacity, and welded pipes of rectangular, circular and square profiles are manufactured.

Figure 5 shows data recorded in one month, and delays and interruptions of work during weekend or holiday are included.

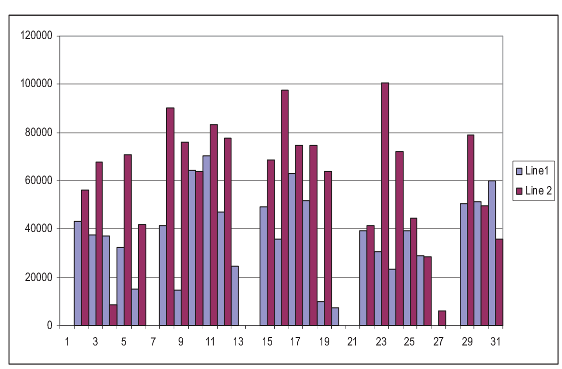

Fig. 5. A one-month daily production on two lines

Figure 6 shows data recorded during 211 work days (without holidays, delays, time anticipated for overhauling etc.). Larger oscillations in the volume of production are noticeable in line 2.

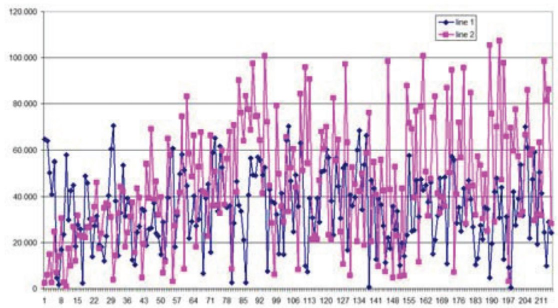

Fig. 6. Production on two lines

For the observed time period, the analysis included direct and overhead costs, market demands, machinery capacities, human resources and constraints that may occur due to shortage of material, tools, etc.

Table 1. Planned and realized product quantities from the production program in the observed time period

Variable	Product	Planned quantity (t)	Realized quantity (t)	%
X1	Hot-rolling rolls	12,500	11,855	94.84
X2	Hot-rolled sheets 7–15 mm	1,750	1,720	98.29
X3	Hot-rolled sheets 16–100mm	1,000	970	97.00
X4	Hot-rolled sheets Č 0563	625	378	60.48
X5	Cold-rolling rolls	2,500	2,430	97.20
X6	Galvanized rolls	1,125	808	71.82
X7	Galvanized strips	75	77	102.60
X8	Welded pipes – square	3,750	2,377	63.39
X9	Welded pipes – rectangular	2,500	1,500	60.00
X10	Welded pipes – circular	3,000	1,600	53.33
X11	Seamless pipes	625	514	82.24
X12	Galvanized pipes	190	189	99.47
X13	INP/UNP carriers	1,125	1,100	97.78
X14	Euro carriers	185	133	71.89
X15	L profiles	875	845	96.57
X16	ZP profiles	175	113	64.57
X17	Solid steels (rolled and drawn light)	325	297	91.38
X18	Firiket	150	140	93.33
X19	Flab	350	310	88.57
X20	Ribbed reinforcement	100	59	59.00
X21	Electrodes	12,5	10,5	84.00
X22	Al rolls	75	41	54.67
X23	Al pipes	12,5	10,5	84.00
X24	Al profiles	37,5	30	80.00

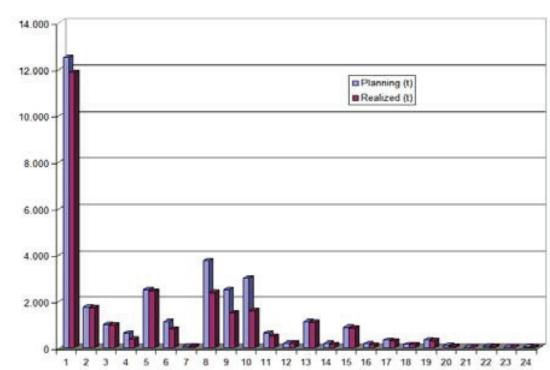

Fig.7. Planned and realized production for the observed three-month period

It is easy to find out using the ABC analysis that the production of X1, X5, X8, X2, X10 and X9 products accounts for 80% of the total production. In the analysis below products X1 and X5 are observed as well as variables X1 and X2 respectively.

Capacity utilization:

$$Z(x_1, x_2)_{\max} = 43.09x_1 + 8.83x_2$$

The demand is larger than capacity resources; the capacity of two production lines is a constraint (max. capacity is 250 t per shift and per line).

Product unit prices:

Product X1 traditional :

$$Z_1(x_1)_{\min} = 536.11x_1^2 - 689.59x_1 + 5346.1$$

activity-based approach:

$$Z_1(x_1)_{\min} = 553.17x_1^2 - 624.3x_1 + 5458.4$$

Product X2 traditional:

$$Z_1(x_2)_{\min} = -2255x_2^2 + 8751.4x_2 - 396$$

activity base approach:

$$Z_1(x_2)_{\min} = -2368.4x_2^2 + 9246.6x_2 - 455.83$$

So, the objective functions are:

1. **Case 1**

$$Z_1'(x_1, x_2)_{\min} = 536.11x_1^2 - 689.91x_1 - 2255x_2^2 + 8751.4x_2 + 4950.1$$

$$Z_2'(x_1, x_2)_{\max} = 43.09x_1 + 8.83x_2$$

2. **Case 2**

$$Z_1''(x_1, x_2)_{\min} = 553.17x_1^2 - 624.3x_1 - 2368.4x_2^2 + 9246.6x_2 + 5503$$

$$Z_2''(x_1, x_2)_{\max} = 43.09x_1 + 8.83x_2$$

5. RESULTS

Using a Matlab software package, options for multi-objective optimization via genetic algorithms for the defined objective and constraint functions, produces the results as presented in Figures 8, 9, 10 and 11.

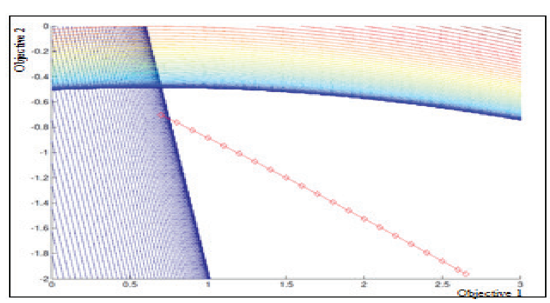

Fig. 8. Contours of objective functions for case 1

Figures 8 and 10 display contours of the objective functions, nonlinear function of product cost, depending on the volume of production and linear function of machinery capacity utilization, for the observed two cases.

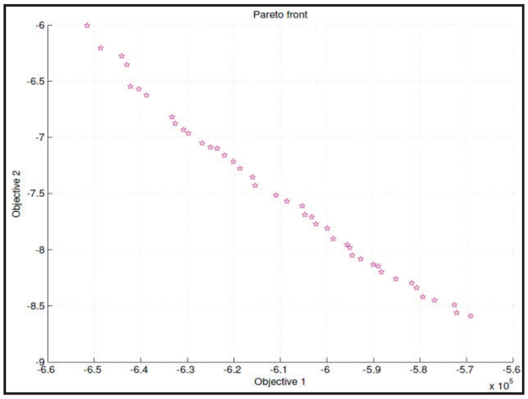

Fig. 9. Pareto front for case 1

Figures 9, 11 show a set of points representing optimal solution for the observed functions for the two observed cases each.

Optimal solution is readable from diagrams and Figures 9, 11 respectively, where the point of minimum is sought, i.e. the point closest to the coordinate-system origin and represents the minimum for the two opposing criteria (maximum is sought for one criterion and is multiplied by -1 to obtain the reverse case and then minimum is sought, which is necessary to generate the Pareto front).

In Tables 2 and 3 only singled out points are given, representing the middle part of a set of points (the analysis involves over 50 points), i.e. a set of points closest to the coordinate-system origin. Point No 6 represents optimal solution for case 1, while point No 37 is optimal solution for case 2.

Table 2. Points singled out from Pareto front for case 1

Node no.	X1 (t)	X2 (t)	Z1	Z2
27	11.9	19.7	-6.3	6.9
30	12.0	19.7	-6.3	6.9
9	12.1	19.7	-6.3	7.0
29	12.3	19.7	-6.3	7.0
35	12.4	19.7	-6.2	7.1
31	12.4	19.7	-6.2	7.1
7	12.6	19.7	-6.2	7.2
3	12.7	19.7	-6.2	7.2
4	12.8	19.7	-6.2	7.3
28	13.0	19.7	-6.2	7.4
42	13.2	19.7	-6.2	7.4
22	13.4	19.7	-6.1	7.5
6	13.5	19.7	-6.1	7.6
12	13.6	19.7	-6.1	7.6
19	13.8	19.7	-6.0	7.7
34	13.9	19.7	-6.0	7.7
10	14.0	19.7	-6.0	7.8
11	14.1	19.7	-6.0	7.8
38	14.3	19.7	-6.0	7.9
33	14.4	19.7	-6.0	8.0
39	14.5	19.7	-6.0	8.0
20	14.6	19.7	-5.9	8.0
21	14.7	19.7	-5.9	8.1
32	14.8	19.7	-5.9	8.1
23	14.9	19.7	-5.9	8.1
16	15.0	19.7	-5.9	8.2
27	11.9	19.7	-6.3	6.9
30	12.0	19.7	-6.3	6.9
9	12.1	19.7	-6.3	7.0

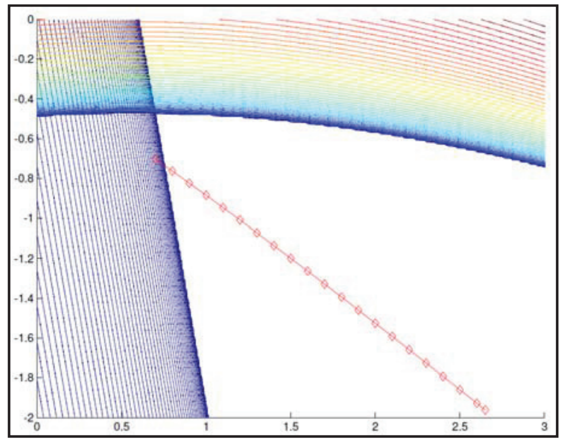

Fig. 10. Contours of objective functions for case 1

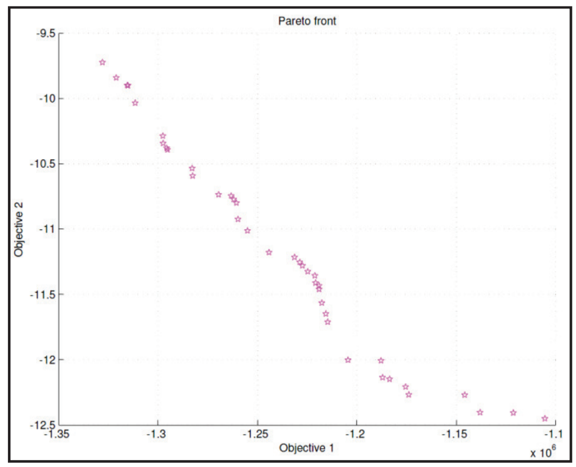

Fig. 11. Pareto front for case 2

Table 3. Points singled out from Pareto front for case 2

Node no.	X1	X2	Z1	Z2
3	22.37	26.82	-11.95	1.14
28	22.33	26.95	-11.94	1.14
36	21.66	26.91	-12.18	1.12
12	21.52	26.89	-11.88	1.16
6	21.33	26.87	-13.06	0.97
35	21.10	26.83	-12.59	1.05
15	21.04	26.82	-11.92	1.14
10	20.99	26.83	-12.72	1.04
9	20.86	26.80	-10.76	1.25
37	**20.79**	**26.82**	**-10.92**	**1.24**
39	20.68	26.82	-12.38	1.07
8	20.62	26.82	-12.29	1.10
2	20.53	26.83	-11.45	1.23
11	20.43	26.92	-12.35	1.09
20	20.04	26.94	-11.08	1.24
22	19.83	26.94	-12.58	1.06
5	19.55	26.90	-12.74	1.03
38	19.49	26.90	-11.47	1.22
19	19.42	26.90	-12.99	0.98
29	19.39	26.95	-11.76	1.20
24	19.05	27.00	-12.45	1.07
14	18.92	26.98	-12.71	1.04
30	18.58	27.02	-12.93	0.99
16	18.55	27.02	-12.74	1.03
32	18.46	27.02	-12.93	0.99
25	18.34	27.00	-11.17	1.23

The results for production program optimization indicate that there are significant differences in the obtained optimal quantities of the observed products when the product cost price is calculated via traditional or ABC approach. In calculating the cost price via the two mentioned approaches the nonlinear functions of cost price were used, depending on the volume of production. Although those calculations of the cost price via two approaches indicated at first sight very similar dependences of production volume on cost price, it turned out later that there are significant differences in optimal production volume of the observed products, i.e. in case 1 (traditional approach) optimal quantities are x1 = 13.5 t, x2 = 19.7 t, and in case 2 (ABC approach) optimal quantities are x1 = 20.1 t, x2 = 26.82 t.

6. CONCLUSION

This investigation presents the analysis of production program with respect to impact criteria: cost price and machinery capacity utilization level. Cost price depending on the volume of production is represented by nonlinear function for the case when the calculation of product cost price is performed by the ABC approach. Optimal product quantity with respect to the two set up criteria is determined by forming the Pareto front in the optimization model using genetic algorithms. The results indicate significant differences in the optimal production program, which depends on the type of approach applied in determining the product cost price. Determination of optimal production program is more adequate when the ABC approach is used, because it describes a real model more approximately.

7. REFERENCES

[1] N. Fafandjel, A. Zamarin, M. Hadjina: *Shipyard production cost structure optimization model related to product type,* International Journal of Production Reasearch, 2010, Vol. 48, No. 5, pp. 1479-1491, ISSN 0020-7543.

[2] C. McNair: *Defining and Shaping the Future of Cost Management*, Journal of Cost Management, Vol. 14, No. 5, 2000, pp. 28-32, ISSN 1092-8057.

[3] J. Sanchis, et al.: *A new perspective on multi-objective optimization by enhanced normalized normal constraint method,* Structural and Multidisciplinary Optimization, 2008, Vol. 36, No. 5, pp. 537–546, ISSN 1615-1488.

[4] S. Utyuzhnikov, P. Fantini, M. Guenov: *A method for generating a well- distributed Pareto set in nonlinear multi-objective optimization,* Journal of Computational and Applied Mathematics, 2009, Vol. 223, No. 2, pp. 820–841, ISSN 0377-0427.

[5] L. Chi-Ming, G.Mitsuo: *An Effective Decision-Based Genetic Algorithm Approach to Multi-objective Portfolio Optimization Problem*, Applied Mathematical Sciences, 2007, Vol. 1, No. 5, pp. 201 – 210, ISSN 0066-5452.

[6] M.S. Hundal: *Product Costing: A Comparasion of Convetional and Activity-based Costing Methods,* Journal of Engineering Design, 1997, Vol. 8, No. 1, ISSN: 0954-4828.

[7] J. Zimmerman: *Accounting for Decision Making and Control*, 7th ed., McGraw-Hill, ISBN-13 978-0-07-813672-6, New York, 2011.

[8] D.E. Akyol. G. Tunecl, G.M. Bayhan: *A comparative analysis od activity-based costing and traditional costing,* World Academy of Science, Enigneering and Technology, Vol. 3. 2005, pp 44-47, ISSN 2010376X.

[9] R. Kaplan, R. Cooper: *Cost & Effect: Using Integrated Cost Systems to Drive Profitability and Performance,* Harvard Business School Press, ISBN 0-87584-788-9, Boston, 1998.

[10] P. Kukumanu: *Multiproduct cost-volume-profit model with product limits*, Production plannig & control, 1998, Vol. 8, No. 1, pp. 87-95, ISSN: 0953-7287.

[11] E. Waring: *Problems Concerning Interpolations.* Philos. Trans. Roy. Soc. London Ser. A, Vol. 69, 1779. pp. 59- 67, ISSN 0031-8116.

[12] H. Jeffreys, B. Jeffreys: *Methods of Mathematical Physics*, 3rd ed. Cambridge University Press, ISBN-10: 0521664020, England: 2000.

[13] P.S. Georgilakis: *Genetic algorithm model for profit maximization of generating companies in deregulated electricity markets,* Applied Artificial Intelligence, Vol. 26, No.6, pp. 538-552, ISSN 0883-9514.

[14] C. Hwang, M. Abu Sayed, *Multiple Objective Decision Making – Methods and Applications,* Springer Verlag, 1979, ISBN 10 0387091114

[15] N. Palli, S. Azarm, P. McCluskey, P. Sandarajan, *An Interactive -Inequality Constraint Method for Multiple Objectives Decision Making*, Transactions of the ASME, Journal of Mechanical Design, 1998, Vol. 120, No.4, pp. 678–686, ISSN 1050-0472.

[16] M. Gen, R. Cheng: *Genetic Algorithms and Engineering Optimization*, John Wiley, New York, 2000, ISBN 0-471-12741-8.