Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 16
ISSUE 1-2
May-June
2006

The optimisation of a technological process forms a competitive position of the factory

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Received 15.11.2005; accepted in revised form 15.04.2006

Industrial management and organisation

ABSTRACT

Purpose: The paper presents an attempt of improving a productivity of the sleeve's technological process by optimization times of machining operations.
Design/methodology/approach: The optimization of times of turning operations was done by using the analytic and graphic method, which belongs to the linear programming.
Findings: The optimization of times of turning operations by using the methods of linear programming caused shortening the total manufacturing time of a sleeve by 2%. The changes of times permitted on enlargement the volume of produced lots, what guarantees the growth of production about 5%. The calculated volume of optimum productive lot allows enlargement of the level of total productivity of studied process from 95 to 99%.
Research limitations/implications: The methods of optimization such as linear programming depend on degree of complexity of physical and technical relations of the analysed machining processes.
Practical implications: The work is an example of an analysis of chosen technological process in aspect of its productivity. It could be helpful to improve a level of total productivity of technological processes by using simple methods of linear programming.
Originality/value: The paper presents some results of optimization of machining operations of the sleeve's technological process, which caused enlargement of the volume of produced fabrications and growth of the level of total productivity.
Keywords: Industrial management; Productivity; Performance management; Optimisation; Linear programming

1. Introduction

The position of factory on market depends on many factors. Level of advancement is one of the factors, which permits on realization of requirements determined through market. In the face of it gaining over modern technology for company is priority of its activity and operative management [8].

The strategy of development of technology should be the main part of company's strategy. When a new technology is initiating in the company it may appear a risk connected with using a new technology and time its initiation. The risk of initiation a new technology may be limited across accumulating, processing and using in decission making process information about market, technique, technology and competences of employees [4].

2. Technology and factory

New technologies can be gained by investing in the research and development from the own country or they can be imported from abroad also. It is possible to mention three basic sources of a technological innovation [8]:

- own scientific investigations - this is the most important source of innovation, because it means creating technological knowledge;
- the strange technical thought - the form of licence, the know - how, import of modern machines and devices, acceptance the foreign investments and different forms of transfer of strange technologies;
- inventive activity - states a supplement of mentioned two kinds of sources and depends on improving products and productive processes realized on industrial scale.

In case of Polish enterprises, gainning of new technologies from a first source is complicated with regard on costs.

Therefore, the development of enterprises depends on import of technology created abroad. However, a technology which is an object of transfer from different countries is always obsolete in relation of technology used in these countries at present. As a result, there is a low level of a competitiveness on markets of products, which were produced by using that technologies [3,4].

The transfer of technology is quite complicated operation and requires workings on definite levels, which they are following [4]:

- level of recognition - checking, which elements of advanced technology can be transfered directly and which require additional adapting;
- level of adaptation - the adaptation of technology's elements, which are transfered by conditions of the importer's country;
- level of restructuring social and economic activity - the creation of conditions of surroundings, which will be friendly to assimilating the modern technologies.

The requirements of Polish enterprises in range of technology are large. The majority of companies and factories in Poland possess technologies, which were applied on the world about 20 to 15 years ago. The present technologies are developing in instant time, it causes that technological distance between developing and developed countries is rising [8].

In practice the realization of technological processes is in exact relationship from elements of systems of quality management. Steering of technological processes can not be realized without givin consideration of all settings in company processes [13].

The quality of technological processes should be guaranteed by following tasks [15]:

- monitoring the control's methods of materials, quality and factors, which determine the proper course of process;
- choice the optimum operations of all possible;
- complete processes with suitable working instructions;
- creation of descriptions, illustrations, models quality;
- planning the verification of quality of product, process, auxiliary materials, environment in aim of minimalizing the mistakes;
- assuring the ability of processes' quality;
- applying for verification qualities by the statistical control process;
- detailed descriptions of methods of working staff;
- verification the final qualities of products.

The initiation of the modern technologies is very expensive process, however in long period of time, technology is one of main factors, which influences on quality of product. When the technology is more modern, the quality of products is better, if we assume that the external and internal activities of enterprise will be constant (fig.1) [8].

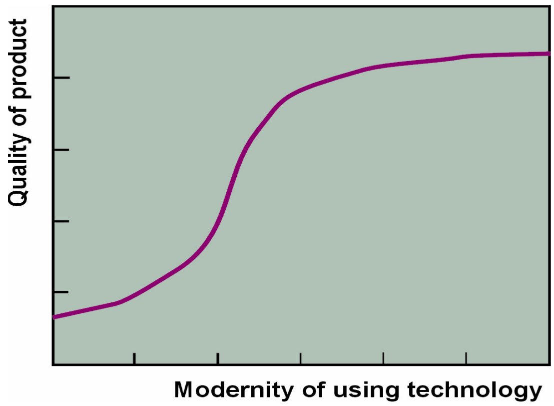

Fig. 1. The level of quality of products versus modernity of using technology [8].

The better quality of products causes not only the growth of competitiveness, but what is more, it influences on the productivity of process, as a result that the modern technologies influence on shortening the duration of the production cycle and increasing the number of products [3,15].

Each companies, which want to reach the competitive position on the market, should compile the strategy of technology. The basic actions of preparation of technology's strategy are following [9,8]:

- recognition of all using tehnologies in company,
- identification of technologies, which are applied in different companies or being with object of scientific investigations,
- qualification of probable destiny of key technologies,
- qualification of the most significant technologies for company,
- estimation technological ability of a factory,
- accomplishment of choice of a strategy technology, which will integrate the important technologies to improve competitiveness of enterprise.

3. A value of the manufacturing technology

Manufacturing processes belong to the basic strategic activities in a factory. Analysing the activities of company is very important. It helps in the selection of suitable techniques of production, which should guarantee established productivity and quality of realized processes [9].

The applied technology of production is the basis of creating added value. The maximization of added value for each process states the essential element of formation the competitive position of enterprise on market. Moreover, it permits on enlargement the efficiency of production [9].

The introduction of competitive products on market depends on many influencings such as an engineering designing, a pattern designing, a preparation of production as well as production. However, the decisive determinant about competitiveness of new products is the quality of applied technology. It is connected with introduction of product on market (fig.2) [2].

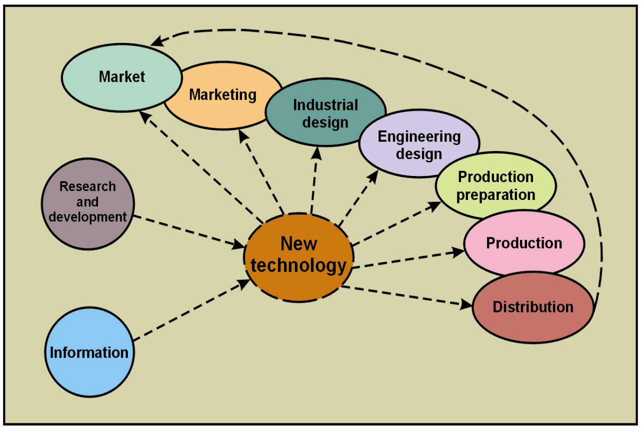

Fig. 2. The influence of technology to introduce a new product on a market [2].

Manufacturing the products, which realize the qualitative requirements on high level as well as minimization of total costs is possible, only when every operation in manufacturing process is executed in correct way. It is important to introduction an integral control of quality to each operation of process [15].

4. Methodology of optimization

Optimization problems are possible to meet in different fields of life. The idea of optimization could be understand as choosing the best solution of many available with regard on received criterions and conditions. The theory of optimization deals with investigation of methods of optimization [5,7].

The theory of optimization founds the widest use. It is the most useful in field of making decisions. The process of making optimum decisions consists in searching of admissible solutions, for which definite parameters achieve maximum values [5].

The process of making decisions contains the following stages [11]:

- formulation of problem,
- determination of limitations,
- formulation the model of problem,
- choice method of solution,
- realization of proper decission procedure,
- analysis of results and verification of model.

The process of making decisions should be the most profitable on each stage of manufacturing and technological process. The skill of making the optimum decisions states the unusually value, particularly in situation, when the significant economic, technical or social results are required [7].

The optimization of most tasks is realized by using the model of considered problem. Because all occurences and quantities are related and depended on random disturbances, their model states always simplification of a reality.

The general division of decission models with regard on basic criterions are presented in Table 1.

Table 1.
The classification of decission models used in the optimization theory [11]

No.	Assessment criteria of models	Kind of model	
1.	Form of an objective function	Linear	Nonlinear
2.	Kind of variables	Continuous	Discrete
3.	Description	Deterministic	Random
4.	Amount of states of model	Static	Dynamic

Presented models of optimization theory were prepared by many scientists as well as mathematicians, engineers, economists, statisticians. The theory of optimization as the independent science can be treated as branch of applied mathematics. This science appeals to different sections of mathematics with regard on unifications applied notions and using general rights and statements [5].

There are many varied problems, which could be formulated as optimization models. The methods of optimization such as [5]:

- linear programming,
- nonlinear programming,
- dynamic programming,
- theory of games,
- forwarding questions,
- genetic algorithms,

are using in distribution of supplies, planning, steering, aprroximation and estimation.

Optimization as scientific discipline is based on methods and techniques of operations research. It seems to be one of the most developing direction of science, which is using the possibility of information technology. Procedures and methods of optimization are often using in designing the manufacturing processes (fig.3), but they could be applied in different fields of life, not only engineering tasks [5].

The development of optimization methods is a result of created engineering object. Designing the engineering objects causes applying the optimum methods of their manufacturing, so theory of optimization should be used to improve the existent technological processes in many factories [7].

The wide range of tasks in process of designing engineering objects requires a regarding of quality assessments. Theory of optimization is also using in field of economics and management. Therefore, methods of optimization are applied to increase a quality of products and assure a high degree of their competitiveness on market [12].

5. Optimization of the sleeve's technological process

5.1. Information of the analysed process

The work presented the analysis of sleeve's technological process in aspect of its productivity. The required data for realization a study of chosen process seems to be the technological parameters of produced sleeve, kind of material, the volume of total production and lot of production.

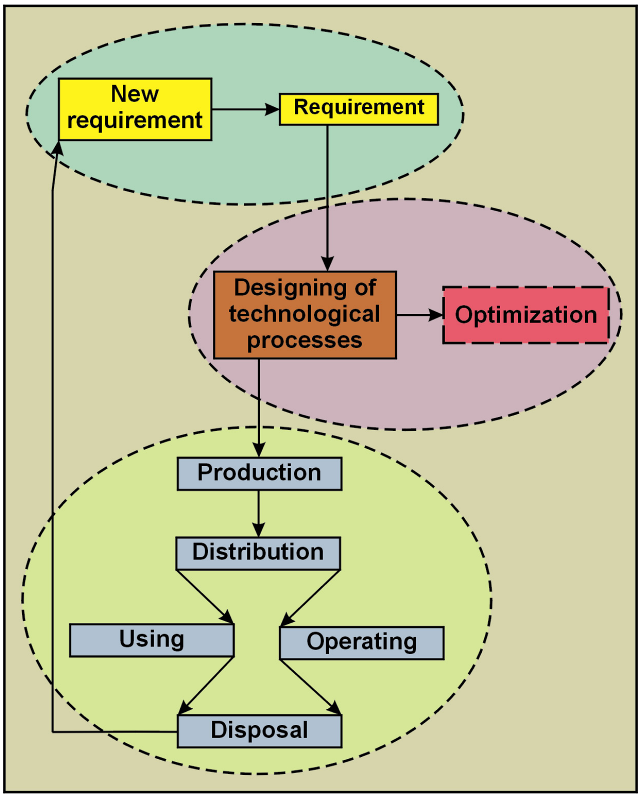

Fig. 3. The part of optimization in the designing technological process [7].

The analysed technological process assumes the middle-lot production of a sleeve about volume of 2000 units realized annually in five lots of 400 units. Manufacturing of sleeve requires a carbon steel to thermal improving (C35), which is hugged by norm PN - EN 10083-2 + A1:1999. That sort of steel is melted as a killed steel and it is calssified as a quality steel. It is used to manufacturing of machines' elements in thermal improved state [1,2].

The analysis of studied technological process of a sleeve in support of operation sheet (Table 2) allows to mention the operation of roughing, profiling, finishing, heat treatment and quality inspection [1].

5.2. Opimization of turning operations

The optimization of machinig parameters could be realized by analytic and graphic methods, which belongs to methods of the linear programming. This type of optimization depends on degree of complexity of physical and technical relations of the analysed process [6,11].

The optimization of machinig in studied technological process of sleeve consists of a calculation of optimum values of the feed *(p)* and the speed of turning *(v)* [6].

The values of optimized parameters of machining should assure the required surface roughness (R_a), and what is more [11,14]:

- power of processing *(N)* should not exceed the value of 2000 [W],
- strenght of turning tool and element (P_z) should not exceed the value of 1100 [N],
- temperature in machining zone (t_s) should not exceed the value of 400 °C.

The basic determinant of turning is a roughness (R_a), a strength (P_z) and a temperature of machining (t_s), which could be introduced by the empirical dependences (1-3) [11]:

$$R_a = 46{,}3 \cdot p^{1{,}5} \cdot v^{-0{,}2}\ [\mu m] \quad (1)$$
$$P_z = 3260 \cdot p^{0{,}75} \cdot v^{-0{,}15}\ [N] \quad (2)$$
$$t_s = 67{,}76 \cdot p^{0{,}325} \cdot v^{0{,}4}\ [^\circ C] \quad (3)$$

The empirical dependences contain the value of feed *(p)* expressed in [mm], and the speed of machining *(v)* expressed in [m/min]. The dependences are not assigned on physical relationships, but they are results of approximation of research's effects. The mathematical model of optimization of turning parameters consists of the objective function (4) and restrictive conditions (5) [11]:

$$p \cdot v \rightarrow max \quad (4)$$

$$\begin{cases} 46{,}3 \cdot p^{1{,}5} \cdot v^{-0{,}2} \le 20 \\ 3260 \cdot p^{0{,}75} \cdot v^{-0{,}15} \le 1100 \\ 67{,}76 \cdot p^{0{,}325} \cdot v^{0{,}4} \le 400 \\ N \le 2000 \end{cases} \quad (5)$$

The mentioned model is an example of nonlinear optimization. The objective function states the maximization of product of the feed and speed of machining *(pv)*, which assures the shortest time of turning [10].

The limitation of machining power *(N)* could be presented as following dependence (6) [11]:

$$N = P_z \cdot v = (3260 \cdot p^{0{,}75} \cdot v^{-0{,}15}) \cdot (v / 60) = = 54{,}333 \cdot p^{0{,}75} \cdot v^{0{,}85} \quad (6)$$

The nonlinear model should be transformed to linear figure by finding the logarithm of objective function (7) and restrictive conditions (8):

$$ln(pv) \rightarrow max \quad (7)$$

$$\begin{cases} \ln(46{,}3 \cdot p^{1{,}5} \cdot v^{-0{,}2}) \le \ln 20 \\ \ln(3260 \cdot p^{0{,}75} \cdot v^{-0{,}15}) \le \ln 1100 \\ \ln(67{,}76 \cdot p^{0{,}325} \cdot v^{0{,}4}) \le \ln 400 \\ \ln(54{,}333 \cdot p^{0{,}75} \cdot v^{0{,}85}) \le \ln 2000 \end{cases} \quad (8)$$

After transformations, the analysed problem has a form of:

$$lnp + lnv \rightarrow max \qquad (9)$$

$$\begin{cases} \ln46{,}3 + 1{,}5 \cdot \ln p - 0{,}2 \cdot \ln v \leq \ln20 \\ \ln3260 + 0{,}75 \cdot \ln p - 0{,}15 \cdot \ln v \leq \ln1100 \\ \ln67{,}76 + 0{,}325 \cdot \ln p + 0{,}4 \cdot \ln v \leq \ln400 \\ \ln54{,}333 + 0{,}75 \cdot \ln p + 0{,}85 \cdot \ln v \leq \ln2000 \end{cases} \qquad (10)$$

The logarithms *lnp* and *lnv* could be marked in following way: *lnp* = *x* and *lnv* = *y*, use of these substitutions permits on following model's formula (11,12):

$$x + y \rightarrow max \qquad (11)$$

$$\begin{cases} 1{,}5 \cdot x - 0{,}2 \cdot y \leq \ln20 - \ln46{,}3 \\ 0{,}75 \cdot x - 0{,}15 \cdot y \leq \ln1100 - \ln3260 \\ 0{,}325 \cdot x + 0{,}4 \cdot y \leq \ln400 - \ln67{,}76 \\ 0{,}75 \cdot x + 0{,}85 \cdot y \leq \ln2000 - \ln54{,}333 \end{cases} \qquad (12)$$

To solve a mentioned task by linear method it is important to assumed the nonnegative of variables. The assumptions of $x = lnp \geq 0$, $y = lnv \geq 0$ where $p \geq 1$, $v \geq 1$ are true, when speed of machining *(v)* will be higher than 1 m/min. But the assumtion of $p \geq 1$ *mm* in case of the feed, could limit the set of optimum solutions. Therefore, it is safer to express the value of feed in micrometers. Changing of a value of feed on micrometers requires the following transformations (13) [11]:

$$p' = 1000\,p \;\leftrightarrow\; p = p' / 1000 \;\leftrightarrow\; \ln p = x = \ln p' - \ln1000 \;\leftrightarrow\; x = x' - \ln1000 \qquad (13)$$

After substitution the $x = x' - ln1000$ to objective function and restrictive conditions the model of problem is following:

$$x' - ln1000 + y \rightarrow max \qquad (14)$$

$$\begin{cases} 1{,}5 \cdot x' - 0{,}2 \cdot y \leq \ln20 - \ln46{,}3 + 1{,}5 \cdot \ln1000 \\ 0{,}75 \cdot x' - 0{,}15 \cdot y \leq \ln1100 - \ln3260 + 0{,}75 \cdot \ln1000 \\ 0{,}325 \cdot x' + 0{,}4 \cdot y \leq \ln400 - \ln67{,}76 + 0{,}325 \cdot \ln1000 \\ 0{,}75 \cdot x' + 0{,}85 \cdot y \leq \ln2000 - \ln54{,}333 + 0{,}75 \cdot \ln1000 \end{cases} \qquad (15)$$

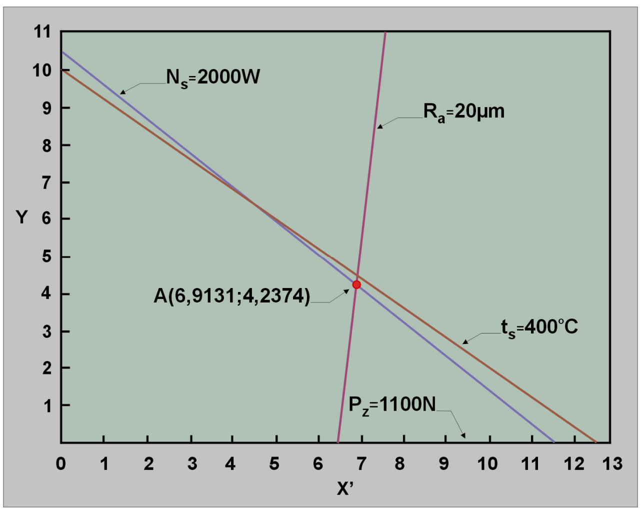

Fig. 4. The geometric solution of optimization of turning operation.

There is a necessity to introduce artificial variables $(s_1 \ldots s_4)$ to above model in aim of ballance of nonnegative conditions and importing its to standard form (16,17):

$$x' + y - ln1000 \rightarrow max \qquad (16)$$

$$\begin{cases} 1{,}5 \cdot x' - 0{,}2 \cdot y + s_1 \leq 9{,}5222 \\ 0{,}75 \cdot x' - 0{,}15 \cdot y + s_2 \leq 8{,}1329 \\ 0{,}325 \cdot x' + 0{,}4 \cdot y + s_3 \leq 4{,}0205 \\ 0{,}75 \cdot x' + 0{,}85 \cdot y + s_4 \leq 8{,}7866 \\ x', y, s_1, s_2, s_3, s_4 \geq 0 \end{cases} \qquad (17)$$

The analysed task in standard form is possible to solve by geometric method (fig.4).

The highest value of objective function assures parameters which natural logarithms define the coordinates of point A: x' = 6,9131; y = 4,2374. Optimum value of parameters *p* and *v* is: $p = exp(x') = e^{6,9131} = 1005\ \mu m = 1\ mm$ and $v = exp(y) = e^{4,2374} = 69{,}2\ m/min$.

5.3. Results of optimization

The optimum value of feed *(p)* allows to calculate the new value of main time of turning. The main time of turning (t_g) could be determine by following formula (18) [10]:

$$t_g = (L / n \cdot p) \qquad (18)$$

The new values of main time of turning operations for chosen cuts are lower than given times in analysed process (Table 3). That situation allows to decrease the total time of realization the volume of production and increase the productive potential of process. Moreover, shortening the main times of turning influences on level of productivity of studied technological process.

The methods of linear programming, which is used to optimization the parameters of turning operations enables changing some times of realization the technological process of sleeve (Table 4). The optimizing the times of turning allows to determine the optimum volume of lot (n_o) with using the following model (19,20):

$$n_o \rightarrow max \qquad (19)$$

$$\begin{cases} n_o \geq 0 \\ b\left[\left(n_o \cdot \sum t_{jo}\right) + \sum t_{pz}\right] \leq T_d \end{cases} \qquad (20)$$

where:
n_o – optimum volume of fabrications in lot [units]
b – set quantity of lots (b = 5)
$\sum t_{jo}$ – sum of optimum times per unit [min]
$\sum t_{pz}$ – sum of setuptime for lot [min]
T_d – annual available standards hours for one - shift mode of working [min] (T_d = 27365 min)

The dependences (19,20) and optimized times of turning operations (Table 4) allow to calculate the optimum volume of a lot:

$$n_o \rightarrow max \qquad (21)$$

Table 2.
Operation sheet of the sleeve's technological process [1].

Fabrication		Name of element	Code, figure, position		Number of order	
A32		Sleeve	A 32.120.31		21300.105/95	
Sort of material: C35		Shape and size of material	Unit/product: 1	kg/unit: 0,26	Units/order: 400	
Index of material		Rolled bar	Norm of material: kg/unit 1,22		Material kg/order 488	
No.	Department / Position	Description of operations			T_{pz} / t_j	$T = T_{pz} + n \cdot t_j$
05	Heat treatment / Chamber oven	Thermal improving to hardness 36HRC			30 / 0,2	230
10	Roughing / Turret lathe	Surface turning			73 / 6,4	2633
15	Profiling / Manufacturing lathe	Face turning			24 / 1,21	508
20	Profiling / Horizontal milling machine	Slot milling			34 / 1,84	770
25	Profiling / Fitting	Removing burrs			/ 0,95	380
30	Finishing / External grinder	Surface grinding			20 / 2,33	952
35	Quality inspection / Production control	Final inspection				
40	Quality inspection / Maintenance	Maintenance				
Work out		Check	Confirm	Delivery	Sheet	1/1

Table 3.
Calculation of a main time of turning on the ground of optimal rate of feed.

Operation	Description of operations	Cut	Description of cut	Length of surface L [mm]	Speed of rotation n [rot/min]	Calculated rate of feed p [mm/rot]	Optimized main time of machining $t_g = (L / n \cdot p)$ [min]	Reduction of main time
10	Surface turning	4	Surface turning	50	610	1	0,08	62%
		6	Face turning	10	710	1	0,01	86%
15	Face turning	1	Face turning	15	810	1	0,02	78%
		2	Phase turning	2	660	1	0,003	90%

Table 4.
New times of operation of the sleeve's technological process.

No.	Description of operations	t_g	t_p	t_w	t_u	t_{pz}	t_j	T
05	Thermal improving to hardness 36HRC	-	-	0,18	0,02	30	0,2	230
10	Surface turning	2,66	2,97	5,63	0,58	73	6,21	2557
15	Face turning	0,023	0,98	1,003	0,11	24	1,113	469
20	Slot milling	0,69	0,98	1,67	0,17	34	1,84	770
25	Removing burrs	-	0,86	0,86	0,09	-	0,95	380
30	Surface grinding	0,5	1,62	2,12	0,21	20	2,33	952

$$\begin{cases} n_o \geq 0 \\ 5[(n_o \cdot 12{,}64) + 181] \leq 27365 \end{cases} \quad (22)$$

$$\begin{cases} n_o \geq 0 \\ 63{,}2 n_o \leq 27365 - 905 \end{cases} \quad (23)$$

$$n_o = 419 \text{ [units]} \quad (24)$$

The calculated volume of a lot n_o = 419 units guarantees the growth of volume of a lot in analysed process about 5%.

5.4. Measurement of productivity

Determination of total productivity of studied technological process is possible by calculating the total manufacturing costs of sleeve and establishing the size of value added (profit).

Researches and analyses of market of typical machines' parts and their manufacturing costs were very important to working out a list of basic economic parameters for calculation of the productivity (Table.5).

Table 5.
Information to calculating an index of total productivity (n = 400 units).

No.	Parameter	Mark	Value [zł]
1.	Price (1 unit)	c_i	100
2.	Manufacturing cost (1 unit)	k_c	51,25
3.	Profit (1 unit)	$w_i = c_i - k_c$	48,75
4.	Total profit	$W_D = n \cdot w_i$	19500
5.	Total manufacturing cost	$K_P = n \cdot k_c$	20500

The total productivity *(P_C)* of analysed manufacturing process could be calculate by the following formula (25) [9]:

$$P_C = \frac{W_D}{K_P} 100\,\% \tag{25}$$

Using the formula (25) and data from Table 5 allows to determine the total productivity of analysed process:

$$P_C = \frac{19500}{20500} 100\,\% = 95\,\% \tag{26}$$

The value of coefficient of total productivity informs about high relation of value added to manufacturing costs. The optimization methods from the range of the linear programming, which was used to minimization of time of turning operations allow to increase the volume of production and the level of optimum productivity of analysed process.

The enlargement of volume of produced lot from 400 to 419 units guarantees the growth of productivity and an unchanged level of total manufacturing costs for given productive lot.

$$P_{Co} = \frac{n_o \cdot w_i}{K_P} 100\,\% \tag{27}$$

The formula (27) allows to calculating the optimum total productivity *(P_{Co})* (28):

$$P_{Co} = \frac{419 \cdot 48{,}75}{20500} 100\,\% = 99\,\% \tag{28}$$

The determined level of optimum productivity is a very good result, which confirms that almost of total supplies was used to manufacturing the set volume of a sleeve's lots.

6. Conclusions

The analysis of chosen technological process of a sleeve in support of measurement the productivity and the basic optimization methods permitted on formulating several conclusions:

- the optimization of times of turning operations by using the methods of linear programming caused fall of total manufacturing time from 5473 till 5355 minutes, what states 2% shortening the total manufacturing time of a sleeve;
- the changes of times permitted on enlargement the volume of produced lots from 400 to 419 units, what guarantees the growth of production about 5%;
- the calculated volume of optimum productive lot allows the enlargement of the level of total productivity of the studied process from 95 to 99%.

The comparison of results of productivity's coefficients of analysed process before and after using the optimization methods confirms, that the properly designed structure of technological process decides about its rentability and competitiveness.

There is no need to use a new technology, when we want to produce a larger volume of details. The best solution is reorganization the structure of existing technological process and optimal using the total manufacturing supplies.

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