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MATERIALS REQUIREMENT PLANNING WITH THE USE OF ACTIVITY BASED COSTING

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Abstract:
One of the rationalization areas is the material supply process. New tasks of material supply are: integration of supply with the operation of the entire system, especially at the product design stage, effective use of material resources, reduction of the level of supply costs from the point of view of production costs. In the conditions of unit and small batch production the materials requirement needs to be carefully planned and optimized due to the use of many different kinds, types and sizes of materials and dynamic changes of demand over time. In this situation there are needed tools enabling the measurement of production costs for particular tasks on the basis of currently realized processes. One of these tools is activity based costing which is a groundwork for decision making process in the material supply area. Basing on activity based costing, a model of materials requirements planning was developed, which considers minimizing the number of different kinds and sizes of materials by using alternative materials and, consequently, lowering production costs.

Key words: *activity based costing, planning of material requirements*

INTRODUCTION

The machine industry is characterized by differentiated assortment of the used materials. Analyzing materials requirement considering reasonable materials management in enterprises using a wide range of different kinds of materials deserves a lot of effort and time. In the Traditionally, attention in procurement was mainly focused on the best possible relation of material price to its quality. In the contemporary approach, planning and determining materials supply should be proceeded by different company departments: research and development, production, purchasing and management accounting [1].

In the conditions of unit and small lot production, determining the types of required materials and their quality is frequently difficult, as constructors and technologists strive to use technically perfect materials, regardless of costs. On the other hand, supply team's task should focus on reducing excessive quality and assortment requirements and aiming at qualitatively rational and more cost-effective materials, which is not always fully implemented by them [2].

Cost savings may result from significant reductions in the assortment of the ordered materials, taking into consideration the type of material, its form, condition and quantity, as well as from applying alternative materials. The excessive variety and complexity of material assortment induce significant costs related to ordering, transporting, delivering, freezing financial means and maintaining the inordinate quantity of different materials, because of, among others, selling materials in standard dimensions [3]. On the other hand, using alternative materials should be preceded with an analysis related to the influence of the change on manufacturing costs and time, as well as the structure of production processes [4]. Such a situation requires reducing the assortment of the ordered materials in a given time period, for which the total production costs would the lowest [5, 6].

The aim of the research is to develop a method, which, after initial cost estimation of a designed product and accepting its order, would allow for further optimization of product construction and the production process, according to a cost criterion, considering the assumed plan of materials requirement. Solving the problem involves:

– applying proper tools for measuring and settling costs of the newly-designed products,
– determining activity cost for an exemplary production system,
– using a preliminary plan of materials requirement resulting from the accepted production orders for a given period of time, considering the available stock,
– using databases determining the possibility of replacing the assumed semi-materials with some alternatives,
– analyzing the influence of materials change on the manufacturing costs and time, as well as production process structures,

– determining total time of production orders realization, taking into account alternative materials.

Applying activity-based costing, and considering cost drivers within this method, allows to significantly reduce costs on the stage of production processes planning [7, 8]. Conducting a simulation of the influence of alternative decisions on the stage of planning the production processes related to starting material selection makes it possible to estimate the level of prime costs before the decisions are taken and resources for their realization are acquired [9].

THE INFLUENCE OF REPLACING MATERIALS ON THE TIME AND COST OF MANUFACTURING PROCESSES

When using an alternative material, it should be considered to what extent the conversion will affect the cost of manufacturing, and in particular the material standard, which determines the cost of direct materials, and employee's working time standard and machine working time affecting the costs of direct labor and the costs of machining activities.

The cost of direct materials per unit is the product of the quantity of materials consumed per product according to the gross standard, and the price of the material, decreased by the product of the quantity of usable waste and their price [8]. The cost of the direct materials of product *p* is determined by the formula:

$$Kmb^p = \sum_{m=1}^{M} NM_m \cdot c_m \quad (1)$$

where:

NM_m - norm for material *m*;

c_m - unit price of material *m*.

The value of the cost of direct materials after the conversion is influenced by a new material norm determining the demand for material *w*, which results from the demand for the replaced material *y*, presented by the formula, and unit price of the alternative material.

$$NM_{wy} = \frac{W_w}{W_y} \cdot NM_y \quad (2)$$

where:

NM_{wy} - demand for material *w* resulting from the demand for the replaced material *y*;

W_w - external dimension material *w* (diameter);

W_y - external dimension material *y* (diameter);

NM_y - material requirement of the replaced material *y*.

The elements of working time standard *t* and the cost of direct labor *Krb* are determined by the following formulas [10]:

$$NTp_w = t_{pz} + t_{jp_w} \cdot n \quad (3)$$

$$Krb_w = NTp_w \cdot St_p \quad (4)$$

where:

Krb_w - the cost of direct labor after conversion;

NTp_w - imputed working time standard of an employee, related to the new material;

t_{pz} - set-up time;

n - the number of item units to be produced;

t_{jpw} - employee’s unit time after conversion;

St_p - pay rate.

Unit time standard related to performing an operation by an employee after exchanging the material is presented in the following formula. This is the final formula for unit time of an operation, when the material belonging to the machinability group *η* is replaced by the material from the machining group λ:

$$t_{jp_w} = t_{jp} \cdot \frac{(\frac{1}{q^{\lambda-\eta}} + k_{pom})}{1 + k_{pom}} \quad (5)$$

where:

t_{jp} - unit time of the employee provided for by the standard for the operation related to product unit before conversion;

k_{pom} - auxiliary time coefficient (the calculations assumed 8%);

q = 1.26.

The costs of manufacturing activities performed on a cost position are determined by the formulas:

$$Kact_w = NTm_w \cdot Kmh \quad (6)$$

$$NTm_w = t_{pz} + t_{jm_w} \cdot m \quad (7)$$

where:

$Kact_w$ - position cost after conversion;

NTm_w - imputed machine working time standard related to the new material;

t_{jmw} - unit time related to machine work after conversion;

Kmh - cost of a machine hour.

Unit time standard related to performing an operation by a machine after replacing material is presented in the following formula:

$$t_{jm_w} = t_{jm} \cdot \frac{(\frac{1}{q^{\lambda-\eta}} + k_{pom})}{1 + k_{pom}} \quad (8)$$

where:

t_{jm} - unit time standard related to performing an operation by a machine before material exchange.

The above formulas indicate that replacing the starting material will directly affect the cost of direct materials and indirectly – by changing the operation times – influence the costs of labor and costs of activities related to individual positions at which operations of the manufacturing process are carried out [11].

COST ANALYSIS OF THE MATERIAL SUPPLY PROCESS

When selecting alternative materials, it is not only important to buy the material at a favorable price, but also the lowest possible costs of the entire purchasing process. The purchase price is only one of the elements that are included in the manufacturing costs. The goal in managing the material supply process should be to minimize the costs of the whole process, not just its components, taking into account the costs of the manufacturing process [12].

In the scope of the material supply process, the following activities have been distinguished – Figure 1:

– Ordering materials;
– Transporting materials;
– Accepting delivery;
– Storing.

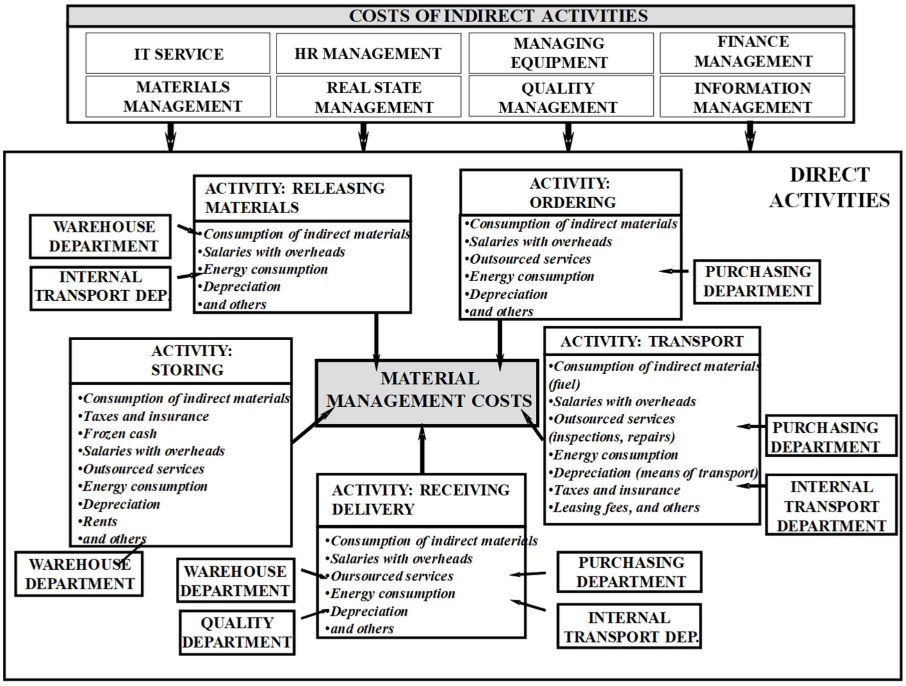

Fig. 1 Structure of materials management costs

In such a situation, frequent ordering, just when they are needed, lowers the costs of storing and maintaining materials, although not entirely. Due to keeping safety stock for such differentiated assortment, also the costs of ordering each delivery, transportation and reception of the deliveries are increased [13]. The solution to the above problems in this type of enterprises may be the introduction of alternative materials, which are in demand in large quantities, instead of materials that are rare and scarce. The staff responsible for material demand in enterprises ordering a variety of materials, sometimes not very different, in very small quantities, in rather short intervals, do not think about the possibility of reducing the range of ordered materials, buying it in larger quantities. This would allow for purchasing materials from fewer suppliers, obtaining quantity discounts in connection with the increased purchase from one supplier, reducing the purchase costs associated with issuing approvals, cutting material or buying in typical dimensions, and would reduce transport costs (fewer suppliers, joining together material needs) and the costs of accepting deliveries. Minimization of the number of types and forms of the ordered materials would contribute to lowering storing costs due to reduces warehouse area, which consists of the storage area occupied by the stored material and the area for communication purposes for internal passages and aisles in the warehouse [14, 15].

Using alternative materials will bring about:

– Increased costs of direct material, influenced by higher material norm. The cost can at the same time be reduced as a result of obtaining lower unit price for the material due to e.g. quantitative discounts, lack of additional costs of certificates and costs of cutting, or purchasing standard materials instead of specialized and unpopular ones;
– Increased costs of direct labor and costs of machining;
– Reduced total costs of ordering, transporting and receiving materials, which are influenced by decreased assortment of the ordered materials, smaller number of suppliers, bringing together material demand.
– Reduced storing costs and costs related to freezing financial means, resulting from fewer storage items and from maintaining lower safety stock.

The cost analysis shows that, as a result of using alternative materials, some production cost components increase, and some of them decrease. Those responsible for planning materials requirement should carry out an analysis regarding total production costs, not only the area of individual cost components [16, 17].

THE PROPOSED METHOD OF MATERIAL NEEDS DETERMINATION

Application of activity-based costing allows to determine the costs of activities in the material supply process and, on their basis, to take proper decisions related to planning material requirements and controlling reserves in order to bear possibly lowest expenses.

The information related to manufacturing orders in a given time period, and, in particular, to the material supply for the manufactured elements, possible material substitutes, stock availability and data from activity-based costing system concerning the cost of applying alternative materials can be used to generate all variants of materials demand, taking into account alternative materials too – Figure 2.

The criteria for optimization during material items selection include:

– costs of manufacturing production orders, that is total cost related to all the processed orders, on the basis of which a plan for materials requirement was prepared;
– total time of production orders realization.

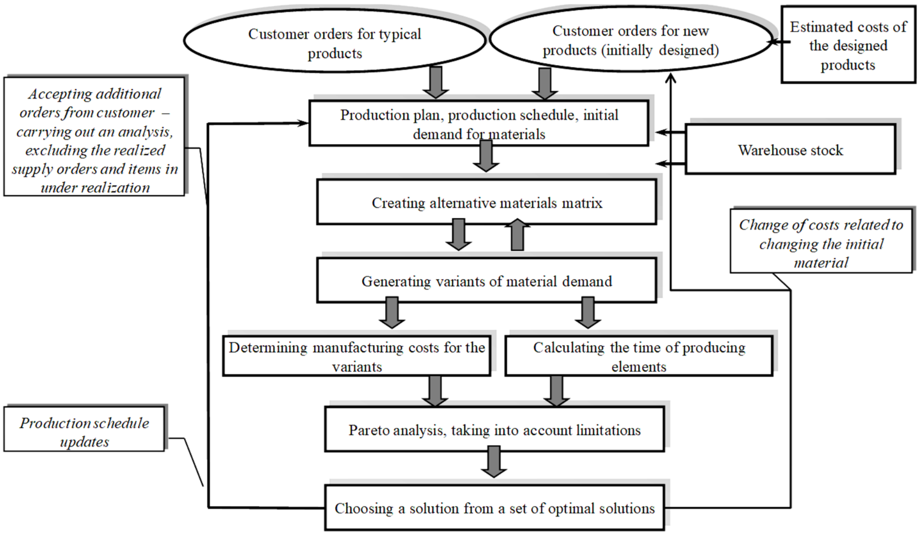

Fig. 2 A model of determining materials requirement

The optimization aims at finding minimal total cost of manufacturing elements for particular material items within a given variant of materials requirement.

The optimization is limited by:

– time of elements manufacture;
– total cost of realizing orders with a value not higher than total initial cost of materials requirement;
– materials availability and quality parameters.

AN EXAMPLE OF COST REDUCTION

A material demand analysis was conducted for an exemplary enterprise with unit and small series production related to steel bars, which constitute one of the basic semi-materials for the manufactured products.

The following costs were calculated for the chosen variant of alternative materials application. Table 1 presents calculations of the differences in the cost of direct materials, including:

– material norms for the semi-material before conversion (*NMy*), and after it (*NMw*);
– prices of semi-materials *Cy* and *Cw*;
– calculated costs of direct materials *KMBy* and *KMBw*;
– differences in the cost of direct materials, denoted as *Delta KMB*.

Table 1

Differences in the cost of direct materials

ANALIZA KMB : Kwerenda wybierająca

Kl	SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FIN.	NMy kg	Cy, PLN/kg	KMBy	NMw kg	Cw PLN/kg	KMBw	Delta KMB
1	Round rolled bar 1H18N9T D=140mm	Round rolled bar 1H18N9T D=140mm	14.52kg	9.90	143.75PLN	14.52	9.90	143.75PLN	0.00PLN
1	Round rolled bar 3H13 D=110mm	Round rolled bar 1H18N9T D=140mm	4.48kg	7.80	34.91PLN	5.70	9.90	56.40PLN	21.48PLN
1	Round rolled bar 55 D=55mm	Round rolled bar 55 D=55mm	0.56kg	0.51	0.28PLN	0.56	0.51	0.28PLN	0.00PLN
1	Round rolled bar 55 D=50mm	Round rolled bar 55 D=55mm	0.31kg	0.55	0.17PLN	0.34	0.51	0.17PLN	0.00PLN
1	Round rolled bar 55 D=35mm	Round rolled bar 55 D=55mm	0.17kg	1.21	0.20PLN	0.26	0.51	0.13PLN	-0.07PLN
1	Round rolled bar 18HGT D=30mm	Round rolled bar 55 D=55mm	0.88kg	2.15	1.89PLN	0.88	2.15	1.89PLN	0.00PLN

Rekord: 1 z 6

In Table 2, for one of the analyzed semi-materials constituting a part of the element from column ID_ELEMENT, differences in the processing costs were calculated, including:

– technological operations (of cutting SCPOO and lathing STTWZ)
– machine time norms and norms of employee's working time before the change – *NTMy* i *NTPy*
– machine time norms and norms of employee's working time after the change – *NTMw* and *NTPw*
– cost of a machine hour *Kmh*
– pay rates *Stp*
– costs of activities for the specified operations *KACTy, KACTw*;
– costs of direct labor *KRBy, KRBw*;
– the difference of the costs mentioned above, denoted as *Delta KP*.

Table 2

Differences in costs of direct labor and machining costs

ANALIZA KP OPER : Kwerenda wybierająca

ID_ELEMENT	KOD_OPER	LP	kv.	NTmy [h]	NTmw [h]	Kmh PLN/min	KACTy	KACTw	NTpy	NTpw	Stp PLN/h	KRBy	KRBw	Delta KP
0875110001800004	SCP00	10	1.26	0.54	0.75	0.3863	12.52PLN	17.27PLN	0.42	0.55	9.00	3.79PLN	4.99PLN	5.96PLN
0875110001800004	STTW2	20	1.26	1.26	1.52	0.3643	27.54PLN	33.23PLN	0.91	1.08	9.00	8.19PLN	9.71PLN	7.20PLN

Rekord: 1 z 2

Table 3 lists additional costs of turning resulting from exchanging the material for material with larger diameter.

Table 3

Costs related to additional operations

ANALIZA K DOT TOCZ : Kwerenda wybierająca

SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FINISHED	D KRB	D KP	D Kactiv MAN
Round rolled bar 1H18N9T D=140mm	Round rolled bar 1H18N9T D=140mm	0.00PLN	0.00PLN	0.00PLN
Round rolled bar 3H13 D=110mm	Round rolled bar 1H18N9T D=140mm	13.26PLN	58.71PLN	45.45PLN
Round rolled bar 55 D=55mm	Round rolled bar 55 D=55mm	0.00PLN	0.00PLN	0.00PLN
Round rolled bar 55 D=50mm	Round rolled bar 55 D=55mm	4.68PLN	19.11PLN	14.43PLN
Round rolled bar 55 D=35mm	Round rolled bar 55 D=55mm	4.68PLN	19.11PLN	14.43PLN
Round rolled bar 18HGT D=30mm	Round rolled bar 18HGT D=30mm	0.00PLN	0.00PLN	0.00PLN

Rekord: 2 z 6

Table 4 features the differences in figures related to direct labor costs, costs of activities related to operations (denoted as *Delta KP*), and costs of additional operations resulting from replacing particular materials (denoted as *D KP TURN*).

Table 4

Differences in costs related to manufacturing activities

ANALIZA KP : Kwerenda wybierająca

SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FINISHED	Delta KP	D KP TURN
Round rolled bar 1H18N9T D=140mm	Round rolled bar 1H18N9T D=140mm	0.00PLN	0.00PLN
Round rolled bar 3H13 D=110mm	Round rolled bar 1H18N9T D=140mm	13.16PLN	58.71PLN
Round rolled bar 55 D=55mm	Round rolled bar 55 D=55mm	0.00PLN	0.00PLN
Round rolled bar 55 D=50mm	Round rolled bar 55 D=55mm	0.35PLN	19.11PLN
Round rolled bar 55 D=35mm	Round rolled bar 55 D=55mm	1,49PLN	19.11PLN
Round rolled bar 18HGT D=30mm	Round rolled bar 18HGT D=30mm	0.00PLN	0.00PLN

Rekord: 2 z 6

In the next table (Table 5) the calculations concerning the cost of material management, i.e. the costs of ordering, transporting, receiving and storing of steel per item, and total costs of these activities have been compiled, denoted as *KActivGM*. This table presents the above differences of the analyzed costs for given semi-products, and total costs difference denoted as *Delta GM*. In this case, it is the difference of *GM* costs and i the sum of *KMB* and *KP* costs. Figure 3 is a summary of the above tables, which features an initial plan of materials requirements for a chosen period, and one of possible solutions with a calculated difference in total manufacturing costs.

The developed algorithm reducing demand for materials was used for a weekly production schedule. Figure 3 presents the initial demand for steel bars for the analyzed period of time, resulting from constructional solutions, and final, reduced materials requirements for this period (assortment was reduced by 4 items) together with the difference in total manufacturing costs, amounting to 2203.89 PLN.

Table 5

Activity costs connected to materials management and the differences in total production costs

ANALIZA KOSZT GM : Kwerenda wybierająca

SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FINISHED	Delta Kmb	Delta KP	K GM	Delta GM
Round rolled bar 1H18N9T D=140mm	Round rolled bar 1H18N9T D=140mm	0.00PLN	0.00PLN	0.00PLN	0.00PLN
Round rolled bar 3H3 D=110mm	Round rolled bar 1H18N9T D=140mm	21.48PLN	71.87PLN	231.89PLN	-138.54PLN

ACTIVITY	K Activ GM TOTAL	KEY	base	WSP Activ	K Activ GM
Storing steel	7 790.12PLN	No.of storage items prev.year	218.00	218.0000	35.73PLN
Receiving steel	9 312.53PLN	No.of items on the document	153.50	153.5000	60.67PLN
Internal transport of steel	18 120.25PLN	No.of items on the document	153.50	153.5000	118.05PLN
Ordering steel	2 677.78PLN	No.of items on the document	153.50	153.5000	17.44PLN

SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FINISHED	Delta Kmb	Delta KP	K GM	Delta GM
Round rolled bar 55 D=55mm	Round rolled bar 55 D=55mm	0.00PLN	0.00PLN	0.00PLN	0.00PLN
Round rolled bar 55 D=50mm	Round rolled bar 55 D=55mm	0.00PLN	19.46PLN	89.23PLN	-69.77PLN

ACTIVITY	K Activ GM TOTAL	KEY	base	WSP Activ	K Activ GM
Storing steel	7 790.12PLN	No.of storage items prev.year	218.00	218.0000	35.73PLN
Receiving steel	9 312.53PLN	No.of items on the document	153.50	562.8333	16.55PLN
Internal transport of steel	18 120.25PLN	No.of items on the document	153.50	562.8333	32.19PLN
Ordering steel	2 677.78PLN	No.of items on the document	153.50	562.8333	4.76PLN

SEMI-FINISHED DEMAND	ALTERNATIVE SEMI-FINISHED	Delta Kmb	Delta KP	K GM	Delta GM
Round rolled bar 55 D=35mm	Round rolled bar 55 D=55mm	-0.07PLN	20.60PLN	203.87PLN	-183.34PLN
Round rolled bar 18HGT D=30mm	Round rolled bar 18HGT D=30mm	0.00PLN	0.00PLN	0.00PLN	0.00PLN

Rekord: 1 z 4

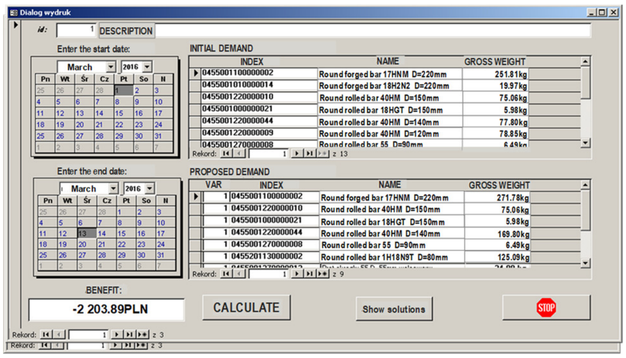

Fig. 3 The selected solution with a calculation of the difference in costs

After adding the semi-finished products from the initial material requirement plans for a period of two months, a demand for 32 different steel bars was obtained in the analyzed periods. After reducing the above assortment according to the developed algorithm, the demand for different types of steel rods involves 19 items. The level of product range reduction in the considered period of time amounted to 41%.

SUMMARY

The above examples prove the possibility of adapting material resources to the dynamically changing production plan, contributing to the reduction of the ordered assortment quantity.

The general advantages resulting from reducing the assortment of the ordered materials include:

– possibility of purchasing more material, which can lower the unit price;
– fewer suppliers;
– lower costs of materials management;
– reduced warehouse area;
– reduced risk related to maintaining safety stock and freezing financial means in excessive reserves;
– possibility of purchasing materials in standard sizes, which lower additional costs, e.g. of steel cutting, and costs of certificates issued for a batch of a given material.

The optimization should take place in a dynamic way, according to the situation occurring in the production. Application of the model is possible in most enterprises in the context of small and medium-sized companies, functioning in conditions of unit and small lot production. The condition is to have CAPP class IT tools and MRP class systems and to implement the activity-based costing. These tools are important for considering processes in a holistic approach, not fragmentarily, only within the procurement process itself, which does not bring the desired results [18, 19, 20].

REFERENCES

[1] I. Kuric. “New methods and trends in product development and planning”, in *Proc. of the 1st International Conference on Quality and Innovation in Engineering and Management*, 2011, pp. 453-456.

[2] J. Matuszek and A. Moczała. “The modelling and simulation method in computer aided co-operation”. *Control and Cybernetics*, vol. 39, 2010, pp. 117-131.

[3] D. Plinta and M. Krajcovic. “Production system designing with the use of digital factory and augmented reality technologies”, in *Proc. of the International Conference on Automation Advances in Intelligent Systems and Computing*, vol. 350, 2015, pp. 187-196.

[4] P. Bubeník, F. Horák. “Knowledge-based systems to support production planning”. *Technical gazette*, vol. 21/3, 2014, pp. 505-509.

[5] K. Dohn, A. Gumiński and A. Pawluś. “Supply processes in a machine-building enterprise concerning metallurgical products – case study”, in *Proc. of the 24th International Conference on Metallurgy and Materials*, 2015, pp. 1902-1907.

[6] A. Burduk, K. Musial, J. Kochańska, D. Górnicka, A. Stetsenko. „Tabu Search and genetic algorithm for production process scheduling problem”. *LOGFORUM*, vol.15 (2), 2019, pp. 181-189.

[7] A. Saniuk, S. Saniuk and K. Witkowski. “Using activity based costing in the metalworking processes”, in *Proc. of the 19th International Metallurgical and Materials Conference*, 2011, pp. 1328-1333.

[8] R.S. Kaplan and S.R. Anderson. “Time-driven activity-based costing”. *Harvard Business School Press*, 2004.

[9] B. Skołud. “Market oriented approach to the production management on the operational level”, in *Proc. of the ModTech International Conference, Advanced Materials Research*, 2013, pp. 663-668.

[10] M. Baron-Puda. “Methodology of determining optimal quantity and quality of human resources in unit and small batch production environment”. *Zarządzanie Przedsiębiorstwem*, vol. 3, 2013, pp. 2-14.

[11] G. Ćwikła. “Real-time monitoring station for production systems”. *Advanced Materials Research*, vol.837, 2014, pp. 334-339.

[12] A. Gola and A. Świć. “Computer-Aided Machine Tool Selection for Focused Flexibility Manufacturing Systems Using Economical Criteria”. *Actual Problems of Economics*, vol. 124, no. 10, 2011, pp. 383-389.

[13] P.R. Jr. Murphy and D.F. Wood. “Contemporary Logistics”. *Pearson*, 2011.

[14] G.M. Melega, S.A. de Araujo, R. Jans. “Classification and literature review of integrated lot-sizing and cutting stock problems”. *European Journal of Operational Research*, vol. 271 (1), 2018, pp. 1-19.

[15] D. Więcek and D. Więcek. “Production Costs of Machine Elements Estimated in the Design Phase”, *Book Series: Advances in Intelligent Systems and Computing*, Vol. 637, 2018, pp. 380-391.

[16] P. Grznár, M. Gregor, Š. Mozol, M. Krajčovič, L. Dulina, M. Gašo, M. Major. “A System to Determine the Optimal Work-in-Progress Inventory Stored in Interoperation Manufacturing Buffers”. *Sustainability*, vol. 11(14), 3949, 2019.

[17] M. Krajčovič, V. Hančinský, L. Dulina, P. Grznár, M. Gašo, J. Vaculík. “Parameter setting for a genetic algorithm layout planner as a toll of sustainable manufacturing”. *Sustainability*, vol. 11(7), 2019, pp. 1-26.

[18] D. Więcek. “Implementation of artificial intelligence in estimating prime costs of producing machine elements”. *Advances in Manufacturing Science and Technology*, vol. 37, no. 1, 2013, pp. 43-53.

[19] T. Gregor, M. Krajčovič and D. Więcek. “Smart connected Logistics”. *Procedia Engineering*, vol. 192, pp. 265-270, 2017.

[20] L. Gala, J. Basl. “ERP innovation based on requirements of social responsibility measurement and evaluation”. *Schriftenreihe Informatik*, vol. 41, 2013, pp. 149-156.

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