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COMPUTER AIDED FMS MACHINE TOOLS SUBSYSTEM SELECTION USING THE EVOLUTIONARY SYSTEM OF MULTICRITERIA ANALYSIS

Abstract

One of the key problems in the area of flexible manufacturing systems (FMS) design is a problem of proper design of manufacturing subsystem and especially the machine tools selection. Although the problem seems to be simple, in fact it is difficult to solve because of large variety and number of parameters and also brief foredesign which are highly influential for the decision. This study shows possibility of implementation the Evolutionary System of Multicriteria Analysis <ESAW> for defining the importance of solutions in the process of casing-class FMS machine tools selection.

1. INTRODUCTION

One of the key problems in the area of Flexible Manufacturing Systems (FMSs) design is a problem of manufacturing subsystem design and especially machine tools selection for designed FMS. It is the first and very important step which determines the system effectiveness to large extent. The proper selection of machine tools subsystem could both significantly minimize investments for construction, as well as lead to minimization of costs of system operation or make the most of machines. Moreover the purchased machinery stock directly determines the efficiency, automation and flexibility level of the whole FMS and the result of this step is a foundation for designing the residual subsystems of flexible manufacturing system [21].

Although the problem seems to be simple, selection of proper machine tools for designed system is not an easy one. The basic resource of the problem is a great variety and number of parameters and also complexity of design conditions which are need to be taken into account during the selection process. Therefore appears the necessity of using the formalized optimization methods which assist to find the best solution in the process of FMS machine-tools subsystem design.

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When taking into account that machine tools selection process is realized using more than one criterion of evaluation of solutions – the useful are methods of multicriteria analysis [9,17,24].

Various researchers have studied to determine the suitable equipment for the different manufacturing facilities using mathematical models, heuristic algorithms and MCDM methods. Some of them have been focused on machine tool selection directly. Several studies regarding the machine tool selection problem can be given as follows. Lin an Yang [12] presented a machine selection model from a range of machines for the manufacture of particular part types using the AHP method. Tabucanon et al. [20] developed a decision support framework for selecting the most appropriated machines in flexible manufacturing systems (FMS). Atamani and Lashkari [2] developed a model for machine tool selection and operation allocation in FMS. Wang et al. [22] presented fuzzy multiple attribute decision making model to select the appropriate machines for FMS. Fuzzy technique for order preference by similarity to ideal solution (TOPSIS) presented Onut at al. [16]. Arslan et al. [1] presented a muliti-criteria weighted average (MCVA) method for machine tool selection. Yourdakul [23] proposed a model linking machine alternatives to manufacturing strategy for machine tool selection. In that study, evaluation of machine tool alternatives was modelled considering strategic implications of the machine tool selection decisions by using the AHP method. Ayag and Ozdemir [3] used the fuzzy AHP technique to weight the machine tool alternatives under eight main and nineteen subcriteria and then carried out benefit/cost ratio analysis by using both the fuzzy AHP score and procurement cost of each alternative. By using the same criteria again, Ayag [4] proposed a hybrid approach, which integrates the AHP with simulation techniques, to determine the best machine tool satisfying the needs and expectations of a manufacturing organization among set of possible alternatives in the market. Mishra et al. [13] suggested a fuzzy goal-programming model having multiple conflicting objectives and constraints pertaining to the machine tool selection and operation allocation problem, and used a random search optimization methodology. Chan and Swarknar [6] presented a fuzzy goal programming approach to model the machine tool selection and operation allocation problem of FMS. An ant colony optimization based approach was also applied to optimized the model. Cimren at al. [7] proposed a decision support system for machine tool selection using the analytic hierarchy process. Dagdeviren [8] presented an integrated approach which employs analytic hierarchy process (AHP) and preference ranking organization method for enrichment evaluations (PROMETHEE) together for the equipment selection problem. Selection of a machine tool for FMS using ELECTRE III presented Balaij at al. [5]. Rao and Parnichkun [18] presented a methodology based on a combinatorial mathematics-basede decision method for evaluation alternative flexible manufacturing systems.

Although there were a number of publications evaluating the machine tools alternatives in the literature, many of them have been prepared using the MCDM methods considering human judgments, tangible, intangible and multiple criteria. In this paper the possibility of implementation the Evolutionary System of Multicriteria Analysis for the defining the importance of solutions in the process of casing-class FMS machine tools selection was shown. In particular, the issue of the process of machine tools selection, the essence of Evolutionary System of Multicriteria Analysis and solutions of the process of defining the importance of solutions for selected decision problem were presented.

2. THE ALGORITHM OF THE PROCESS OF CASING-CLASS FMS MACHINE TOOLS SELECTION

The process of selection of machine tools subsystem for designed casing-class FMS is implemented using the assumptions of the methodology presented in works [9,19]. The selection is realized according the four-stages algorithm presented in fig. 1.

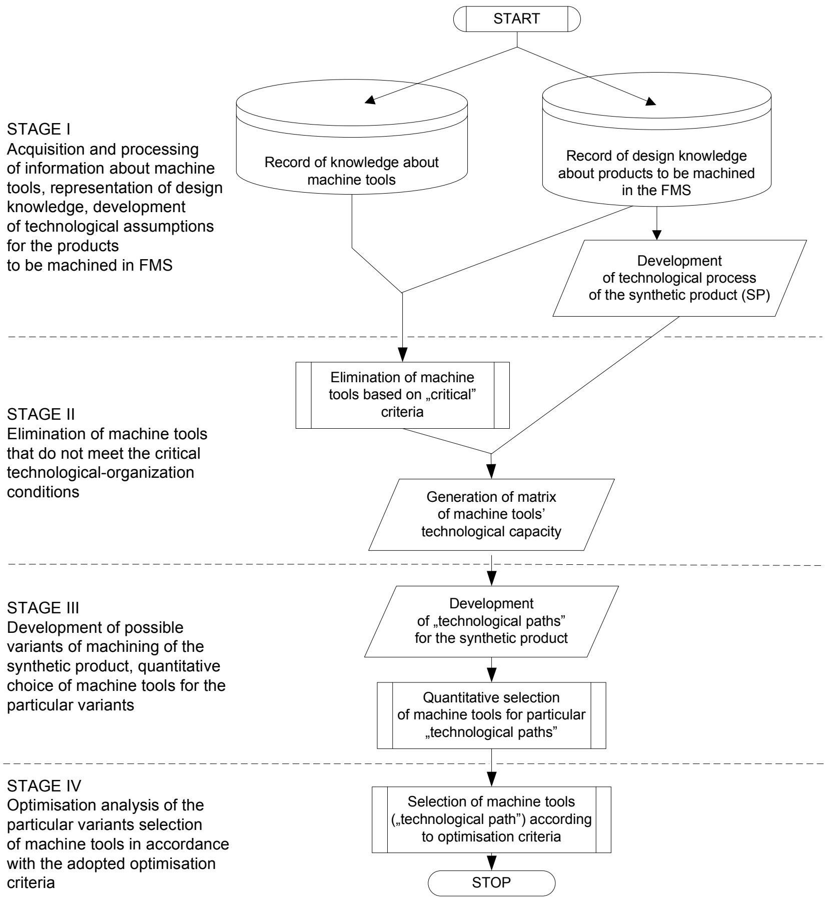

Fig.1. Main algorithm of the methodology of machine tools selection in casing-class FMS [9,19]

The first step in the process of selection is the preparation of a record of knowledge about all machines tools from among which the choice is to be made $O = \{o_1, o_2, \ldots o_n\} = \{o_i\}$, products to be machined in the FMS being designed $W = \{w_1, w_2, \ldots, w_t\} = \{w_\alpha\}$ and development and saving of technological process of the synthetic product (SP).

In the second stage elimination from the O database of those machine tools that are incapable of producing the parts that are to be machined in the system, based on certain limit criteria ("critical" criteria) is realized. In accordance with the adopted assumptions, we should eliminate from the database those machine tools that:

1. Do not meet the limit conditions resulting from the technical parameters of products to be machined in FMS.
2. Do not meet the limitations imposed by the user and/or designer of the flexible manufacturing system.
3. Do not have the design-technological capabilities to perform the machining operations provided for realization within the process of manufacturing.

Those machine tools that „remain" in the database after the stage of elimination constitute of set of machine tools that are taken into consideration at further stages of selection ($X = \{x_1, x_2, \ldots x_m\} = \{x_k\}$).

Machine tools which meet the critical conditions are saved in the set of technological machines $X = \{x_1, x_2, \ldots x_m\} = \{x_k\}$. On the base of X set and the developed technological process of synthetic product the A_{kj} [0-1] matrix of machine tools capabilities is generated. The matrix defines which of the machine tools has the ability to realize specified cut from the technological process of WS.

In the stage three the generation of technological paths and the quantitative selection of machine tools for particular technological paths is realized. Technological paths determines possible ways of going the synthetic product through the system, i.e. following machine tools which realizes following cuts in the technological process of WS. Technological paths and the results of quantitative selection of machine tools which is realized using the method of balancing the burden level of particular machine tools with the manufacturing tasks forms solutions to be analyzed in fourth stage of methodology.

The last step in the process of selection is a choice the best solution using the accepted criteria of evaluation. The optimization criteria (target functions) in presented model are as follows:

1) Minimisation of total costs of machine tools acquisition and operation (per annum) calculated using formula (1):

$$F_1(M_\mu) = \sum_{k=1}^{m} \{L_k[(C_k * a_{ok}) + k_{sk}]\} \rightarrow \min \tag{1}$$

where: L_k – number of *k* machine tools, C_k – total purchasing price of *k* machine tool, a_{ok} – annual depreciation rate of *k* machine tool, k_{sk} – average annual cost of service for *k* machine tool.

2) Minimization of time of machining (throughput time) of synthetic product (exclusive of inter-cut transport and storage operations time) – calculated using formula (2):

$$F_1(M_\mu) = \{[\max(t_{wnk};t_{wpk}) + t_{1k}] + \sum_{j=2}^{z} \{\lambda * \max(t_{wnk};t_{wpk}) + [(1-\lambda) * t_{wnk}] + t_{jk}\}\} \rightarrow \min \tag{2}$$

where:

value λ assumes the following values:

$$\lambda = \begin{cases} 0 & \text{, when cut } \delta_j \text{ is realized on the same machine tool as cut } \delta_{j-1} \\ 1 & \text{, when cut } \delta_j \text{ is realized on another machine tool than cut } \delta_{j-1} \end{cases}$$

t_{wnk} – tool change time „from chip to chip" on *k* machine tool, t_{wpk} – technological palette change time on *k* machine tool, t_{1k} – unit time of realization of first operations in technological process of synthetic product on *k* machine tool, t_{jk} – unit time of realization of *j* cut on *k* machine tool.

3. STRUCTURE AND CHARACTERISTICS OF THE EVOLUNTARY SYSTEM OF MULTICRITERIA ANALYSIS

To solve the task of optimization defined in section 2 (stage 4) the Evolutionary System for Multicriteria Analysis <ESAW> was used. The system takes advantage of many different cooperating with each other methods and enables to generate one solution or small set of solutions, optimal in Pareto sense which are not much sensitive for changing the preferences for criteria given by experts [14].

The Evolutionary System of Multicriteria Analysis was built taking into account the internal features included both into analyzed values of solutions and parameter given in percentage. Values of evaluation of solutions decide of position of ideal vector, which is a basic reference point in the Compromise Solution Determination Method. The indistinctive interval given in percentage enables filtration of solutions using the Undifferentation Interval Method. The final effect of filtration depends both on the defined value of indistinctive interval and mutual position of analyzed valuation of solutions in the criteria space [15].

The Evolutionary System of Multicriteria Analysis includes following methods: the Boundary Value Method (BVM), the Ideal Point Definition Method (IPDM), the Undifferentation Interval Method (UIM) and the Compromise Solution Determination Method (CSDM) (fig. 2).

- ***Boundary Value Method (BVM)***

  BVM eliminates undominated solutions, which values of rate are located on the extreme border of set of undominated solutions along orthogonal directions of components of criteria vector – i.e. values of solutions which determine the corner points and these one which are located in its neighborhood [14]. The values of solutions which determine the corner points usually defines the ideal value (ideal vector), so its elimination causes necessity of determining new ideal vector. BVM is over a wide range similar to formulated in an area of one-criterion and multicriteria optimization task of satisfaction [15]. In a task of multicriteria optimization occurs the vector target function $F(x) = [F_1(x), F_2(x), \ldots, F_j(x)]^T$, it is needed to specify j satisfactory values f_{sj}. (where $j \in J = \{1, 2, \ldots, J\}$ is a number of target function). The task of satisfaction assumes the shape as follows:

$$F(x_s) = \underset{x \in X}{sat}\ F(x) \qquad , \tag{3}$$

$$\underset{x \in X}{sat}\ F(x) = \begin{cases} F_j \le f_{Sj} & in \quad task \quad \min \quad F_j(x),\ j \in J = \overline{1, J} \\ F_j \ge f_{Sj} & in \quad task \quad \min \quad F_j(x),\ j \in J = \overline{1, J} \end{cases}$$

  where: F_j – j component of the target function, x – vector of decision variables, f_{sj} – j satisfactory value of crierion, xs – vector of decision variables for which the target function F(x) take the favourable value in comparison with previously selected satisfactory value.

- ***Ideal Point Definition Method (IPDM)***

  In the IPDM method the situation is reversed. It was proposed to treat the referential point which is the positive standard as a new ideal point. Accepted ideal point chooses from the set of valuations of undominated solutions the subset of valuations of solutions which satisfy the conditions that any of component values will not be adequately lesser (or larger) than the value of component of ideal point (depending if the task is the minimization or maximization one).

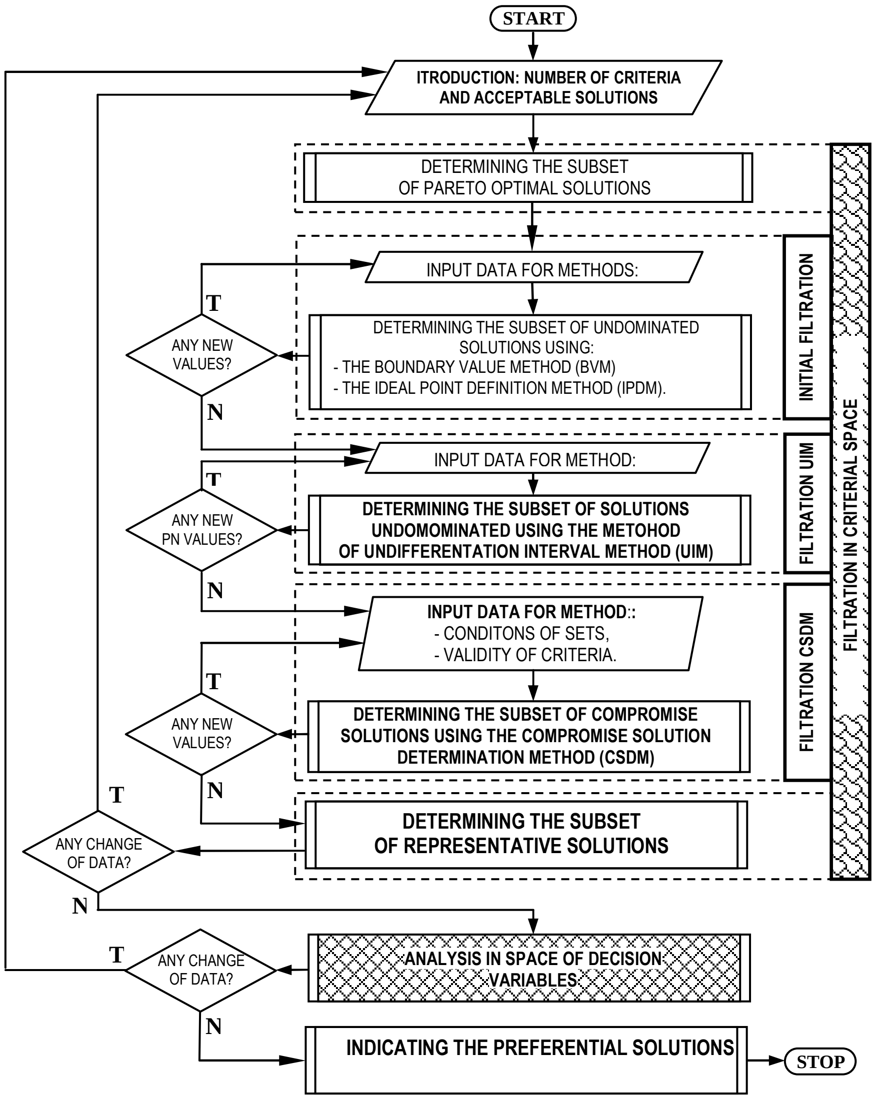

Fig. 2. Block diagram of the Evolutionary System of Multicriteria Analysis [14]

There is, of course, possibility of simultaneous using this two mentioned above methods of selection: BVM and IPDM. The selection of set of undominated solutions with accepted positive standard as a new ideal point $F^{o,}$ and satisfactory values f_s was presented in fig 3. Using the inverse criteria in the multicriteria analysis causes that the elimination of solutions, which have very small values one component, leads simultaneously to rejecting this solutions with have big or very big values of different components.

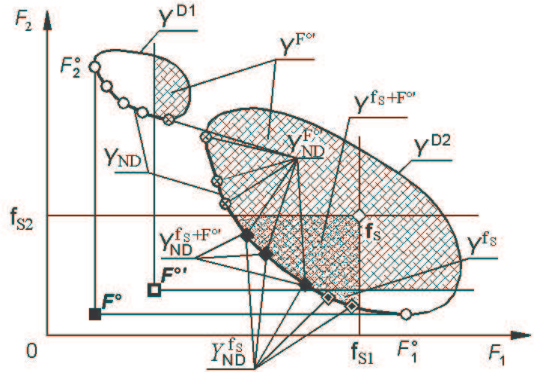

Fig. 3. Selection of the set of undominated solutions (○) using simultaneously BVM and IPDM methods, ■ – ideal point (PI), □ - new PI, ⊗- valuation of the solutions which meet the new ideal point, ✸- satisfying valuation (OS), ◈- valuation of solutions which meet the OS, ✖- valuation of solution which meet the OS and new ideal point [15].

- ***Undifferentation Interval Method (UIM)***

  The selection using the UIM method was realized according to valuations of undominated solutions. Elimination of elements of subset uses on the idea of optimality in the sense of undifferentation interval which is based on the idea of modified mutation. The multicriteria analysis of undominated solutions is realized in the criteria space and pursue to find if the value of mutated solution ("made worse") by the accepted interval of undifferentation UI still remains as an undominated solution and will be added to actually created set of undominated solutions. In case of minimization of criteria, the element $x^{\wedge} \in \Omega$ will be undominated in the sense of undifferentation interval if and only if in the Ω set there is not an element x^{+}, that for each $\lambda \in N$,

$$\begin{aligned} &\textit{when} \quad F_1(x^{\wedge}) \geq 0: \quad F_l(x^{\wedge}) < F_1(x^{+}) \quad \textit{proceed} \quad (1+\frac{PN_l}{100})F_l(x^{\wedge}) > F_l(x^{+}) \\ &\textit{when} \quad F_1(x^{\wedge}) < 0: \quad F_l(x^{\wedge}) < F_1(x^{+}) \quad \textit{proceed} \quad (1-\frac{PN_l}{100})F_l(x^{\wedge}) > F_l(x^{+}) \end{aligned} \tag{4}$$

where: Ω – non-empty set of solutions optimal in Pareto sense.

The situation where the element $x^{\wedge}$ is eliminated, because after the mutation of valuation of this element about the value of selected interval of undifferentation PN_1, so it gets into the domination cone with the top in $F(x^{+})$ point was presented in fig . 4a. The case when both of solutions $x^{\wedge}$ and x^{+} are undominated elements in the sense of undifferentation interval method are presented in fig. 4b.

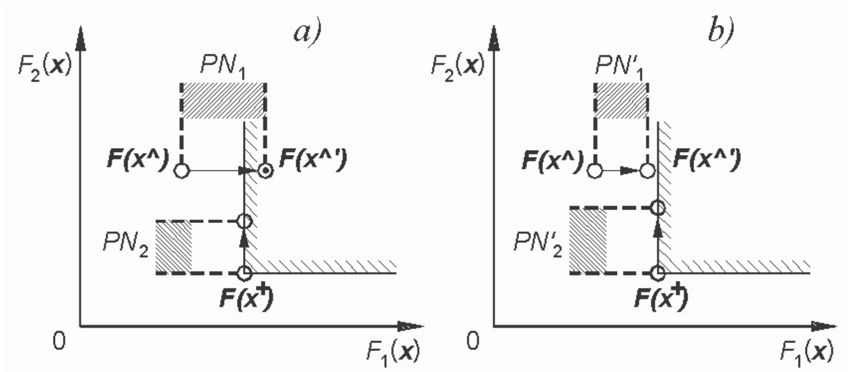

Fig. 4. Graphic visualization of (4) condition in case of two-criteria minimization [14]

- ***Compromise Solution Determination Method (CSDM)***

  This method tends to finding "the best solution" or subset of "the best solutions" using the analysis of domination relations in the set of vector values of indexes. In tasks of selection the decider has at his disposal complete set of acceptable solutions and theirs valuations and is not able to make new solutions. Therefore the operation of intersection applies to components of valuations of generated compromise solutions and components of the ideal point. Received in this way new ideal points, called following-up ideal points, fulfill the function of reference points during the next multicriteria analysis. The operation of intersection allows to get many reference points which are the base for generating successive compromise solutions. To visualize the way of operating the CSDM method, the situation, where the analyzed set of undominated solutions is an unseparately one and is composed of two subsets Y^{D1} and Y^{D2} was presented in fig 5. The subset of valuations of compromise solutions reflects the shape of analyzed set of valuations even in case if it consists of two subsets.

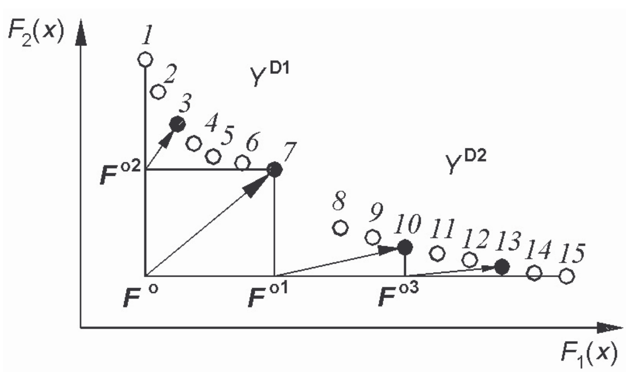

Fig. 5. An example lay-out of valuations of compromise solutions [15].

4. PROCESS OF DEFINING THE IMPORTANCE OF SOLUTION IN THE PROBLEM OF FMS MACHINE TOOLS SELECTION

Using the methodology presented in section 2, the process of machine tools selection for the task formulated in paper [10] was realized. As result of execution stages I-III the solution in form of 36 different technological paths $M=\{M_1, M_2, \ldots, M_{36}\}$ with corresponding values of target functions $F_1(M_\mu)$, $F_2(M_\mu)$ were received. The values of target functions connected with the solutions are presented in tab. 1.

Tab. 1. Values of target functions in realized experiment of selection

Symbol (number) of solution	Value of target function		Symbol (number) of solution	Value of target function	
	$F_1(M_\mu)$ [sek.]	$F_2(M_\mu)$ [zł]		$F_1(M_\mu)$ [sek.]	$F_2(M_\mu)$ [zł]
M_1	33 482	3 553 054,74	M_{19}	33 029	4 306 080,63
M_2	33 675	3 765 964,99	M_{20}	33 222	3 901 027,01
M_3	33 597	3 548 251,65	M_{21}	33 144	3 548 251,65
M_4	33 445	3 905 830,10	M_{22}	32 992	4 658 855,99
M_5	33 712	3 413 189,64	M_{23}	33 259	3 548 251,65
M_6	33 560	3 901 027,01	M_{24}	33 107	3 901 027,01
M_7	33 565	3 535 561,80	M_{25}	33 112	4 288 587,69
M_8	33 758	3 395 696,70	M_{26}	33 305	3 530 758,72
M_9	33 680	3 530 758,72	M_{27}	33 227	3 530 758,72
M_{10}	33 528	3 535 561,80	M_{28}	33 075	4 288 587,69
M_{11}	33 795	3 395 696,70	M_{29}	33 342	3 530 758,72
M_{12}	33 643	3 530 758,72	M_{30}	33 190	3 530 758,72
M_{13}	33 638	3 468 319,36	M_{31}	33 185	4 221 345,26
M_{14}	33 831	3 681 229,62	M_{32}	33 378	3 816 291,64
M_{15}	33 753	3 463 516,28	M_{33}	33 300	3 463 516,28
M_{16}	33 601	3 821 094,72	M_{34}	33 148	4 574 120,62
M_{17}	33 868	3 328 454,26	M_{35}	33 415	3 463 516,28
M_{18}	33 716	3 816 291,64	M_{36}	33 263	3 816 291,64

The lay-out of received solutions according to calculated target functions was presented in fig. 6.

A multicriteria analysis was realized using the Evolutionary System of Multicriteria Analysis according to algorithm presented in section 3 (fig. 2). In the first step the optimal in Pareto sense solutions were determined. This set contains 10 elements as follows: M_5, M_8, M_{17}, M_{19}, M_{21}, M_{22}, M_{24}, M_{28}, M_{30}, M_{33}.

In second step the selection using the Undifferentation Interval Method (UIM) was realized. There were accepted values of interval of undifferentation as follows: PN = 0% according to the criterion $F_1(M_\mu)$ and PN = 1,0% according to the criterion $F_2(M_\mu)$. Non-zero value of interval of undifferentation according to the criterion $F_2(M_\mu)$ was accepted as a result of possible inaccuracy of calculated target functions what follows from rounding and differences in rates when calculating the prices of purchasing the machine tools. As a result of realized analysis using the UIM method the received subset was limited to 7 elements. This are: M_5, M_{17}, M_{19}, M_{21}, M_{22}, M_{24}, M_{33}.

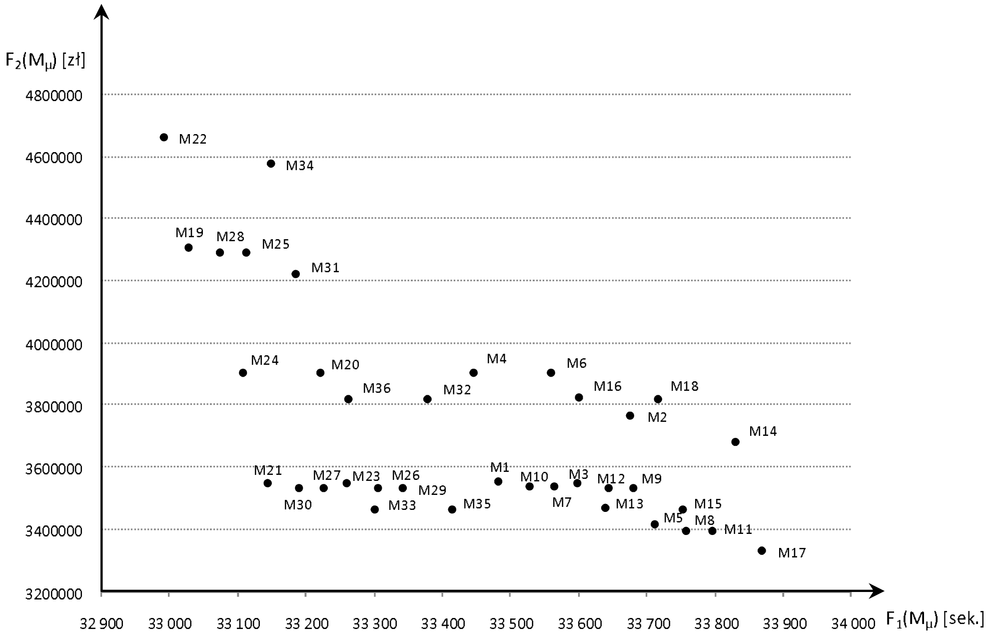

Fig. 5. Lay-out of solutions according to calculated target function

In third step, the filtration using the Compromise Solution Determination Method was realized. The metrics both min-max and min-max with weight with different preferences of analyzed criteria were used. The results of analyses were presented in Tab. 2. It is worth to pay attention that to find the degree of sensitiveness each of solution, the weights from 0,2 to 0,8 for each of criteria have been taken.

Tab. 2. Results of filtration using the CSDM method

No.	Preferention weights $\sum\omega_l = 1$	First compromise solution	Subset of compromise solutions
1.	$\omega_l = \omega_2 = 0,5$	M_5	$\mathbf{M_5}^*$, $\mathbf{M_{33}}$, M_{21},
2.	$\omega_l = 0,6$; $\omega_2 = 0,4$	M_5	$\mathbf{M_5}$, $\mathbf{M_{33}}$, M_{21},
3.	$\omega_l = 0,7$; $\omega_2 = 0,3$	M_{33}	$\mathbf{M_{33}}$, $\mathbf{M_5}$, M_{21}
4.	$\omega_l = 0,8$; $\omega_2 = 0,2$	M_{33}	$\mathbf{M_{33}}$, $\mathbf{M_5}$, M_{24}
5.	$\omega_l = 0,4$; $\omega_2 = 0,6$	M_{17}	M_{17}, $\mathbf{M_5}$, $\mathbf{M_{33}}$
6.	$\omega_l = 0,3$; $\omega_2 = 0,7$	M_{17}	M_{17}, $\mathbf{M_5}$, $\mathbf{M_{33}}$
7.	$\omega_l = 0,2$; $\omega_2 = 0,8$	M_{17}	M_{17}, $\mathbf{M_5}$, $\mathbf{M_{33}}$

* - preffered solution – present in each of compromise solutions' subset

In fourth step the subset of representative solutions was searched. Analysis of the results presented in tab. 2 showed that solutions M_5 and M_{33} exists in each of determined subset of solutions, solutions M_{17} and M_{21} appeared three times and the M_{24} solution appeared one time. Ipso facto the realized analysis in the space of decision variables showed that received solutions M_5 and M_{33} are characterized by the minimal sensitivity of changing the weights of particular criteria and taking into account major assumptions of Evolutionary System of Multicriteria Analysis – they are preferred solutions (with the same degree of importance). The final decision of about solution should be done by the designer taking into account particular analysis and criteria of individual preferences according to received values of target functions.

5. CONCLUSIONS

Decision support systems should help the designer to find the optimal solution among many possibilities for the defined decision task. It is especially highly important, when the quality of analyzed variants of solutions is described with many criteria and the decision problem is burdened with the high risk of non-objective criteria when taking the decision.

One of the more important problem in the area of modern manufacturing systems design is a question of proper machine tools (technological machines) selection. When take into account that in the process of machine tools selection the relation between objective and subjective criteria is 20 to 80 [11] and the choice should be done considering some or several frequently inverse criteria, the need of searching methods which maximize the objectivity of taken decision.

In this paper the possibility of implementation the Evolutionary System of Multicriteria Analysis <ESAW> for the defining the importance of solutions in the process of casing-class FMS machine tools selection was shown. Results of realized analysis shows that the <ESAW> system allows to find among the number of analyzed solutions few (or sometimes only one) proffered solutions from the selected criteria of evaluation point of view. Thanks to fact that the selection process is based onto internal features of solutions' set – the preferred solutions are characterized with the "immunity" for subjective criteria of decider's evaluation.

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