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COMPUTER AIDED FMS MACHINE TOOLS SUBSYSTEM SELECTION – CONCEPTION OF METHODOLOGY

Abstract

The aim of the article is to present a new methodology of computer aided FMS machine tools selection. Flexible manufacturing systems (FMSs) are systems which allows manufacturing parts in small lot sizes keeping high level of productivity and low costs of production. Despite the fact applied research on designing FMS systems have been continued for several years there are no methodical solution that can help design engineers to select machine tools for FMS in a optimal way. This article shows the main algorithm and stages of the methodology which is based on computer database systems, algorithms of elimination and method of multicriteria optimisation.

1. INTRODUCTION

One of the principles of the rationalization of production process which nowadays is more and more important is principle of flexibility. It places emphasis on necessity of fast and easy adaptation of production process to new conditions which change depending on specific situation and most often are connected with implementation of putting new processes in motion. The result of such understood, modern approach to organization of production process is implementing in an industrial practice flexible manufacturing systems (FMSs) which compound automation and computerization features and are characterized by huge possibilities of adaptation.

Flexible manufacturing systems (FMSs) are modern form of organization of production which combines two inverse features of production systems:
1) High efficiency; the same as in a production line (in a system of rhythmic production),
2) Variety of manufactured product range – the same as in technological seat (in a system of non-rhythmic production).

Thus, FMSs allow for filling a gap between high specialized production cells with inflexible automation of production and production cells with inflexible automation of production and production cells characterized by universal production – thanks to flexible automation.

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Flexible manufacturing systems (FMSs) design is still in the area of scientists' interest and nowadays it is one of the basic directions of fundamental research works in the science field of engineering and production management [7]. Up to now problems of FMS machine tools selection can be found in works of H.J. Warnecke [7], C.M. Harmonovsky [4], S. Lis, K. Santarek and S. Strzelczak [5], D. Borenstein, J.L. Becker and E.R. Santos [1], R. Dorf and A. Kusiak [2], A.O. Harczenko [3] and L. Zawadzka [7]. Unfortunately, the solutions presented in those publications are still very general and methodology of flexible manufacturing systems design is still in the stage of working out. [7].

Flexible manufacturing system design is a complex and multistage process. The main role makes problem of manufacturing subsystem design, especially selection of machine tools for designed FMS. It is the first and very important stage 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. The purchased machinery stock directly determines the efficiency, automation and flexibility level of the whole FMS.

The research problem of selection of flexible machine tools subsystem FMS are equal to finding the solution (i.e. defining the type and the amount of machine tools for FMS) that would be optimal for designed system. The authors of this article undertook a study aimed at developing a methodological solution which would permit optimal selection of machine tools for designed FMS and the main points of this methodology based on computer software are presented in this paper.

2. THE STRUCTURE OF A FLEXIBLE MANUFACTURING SYSTEM – A PLACE OF THE MACHINE TOOL SUBSYSTEM IN THE FMS STRUCTURE

Flexible Manufacturing Systems (FMSs) are automated, integrated systems of equipment and information flow, arranged for the economic production of small batches of complex components. These systems in which the control of operations is performed by a central computer.

One of the most important tasks while designing FMS in the choice of components and their appropriate functional configuration. The computer system of control and supervision plays a main role. From the point of view of similarity of realized functions, one can distinguish the following FMS subsystems [5]:

- *manufacturing subsystem* – includes workstations: processing, preparatory and controlling,
- *transport subsystem* – technical devices and means necessary for transfer of work objects as well as pallets, tools etc.,
- *storing subsystem* – technical devices and means for storing semi-finished products, stocks of work in progress, pallets, tools etc.,
- *manipulation subsystem* – technical devices and means enabling transferring of work objects, pallets and tools among the subsystems: production transport, storing,
- *workshop help subsystem* – a set of tools: machining, measuring and controlling as well as pallets and chucks used in the production system,
- *power and waste removing subsystems* – technical devices and means providing the system with auxiliary materials, energy as well as removing industrial waste,

- *control subsystem* – technical devices and means assuring efficient joint operating of all functional subsystems as well as technical control of subsystems' elements and the system,
- *control and diagnostic subsystem* – technical devices and means for measurement and assuring the quality of manufactured products and reliability of the production means.

Connections between particular subsystems relate to the flow of material, energy and information flux. The aforementioned connections are illustrated on the Fig. 1.
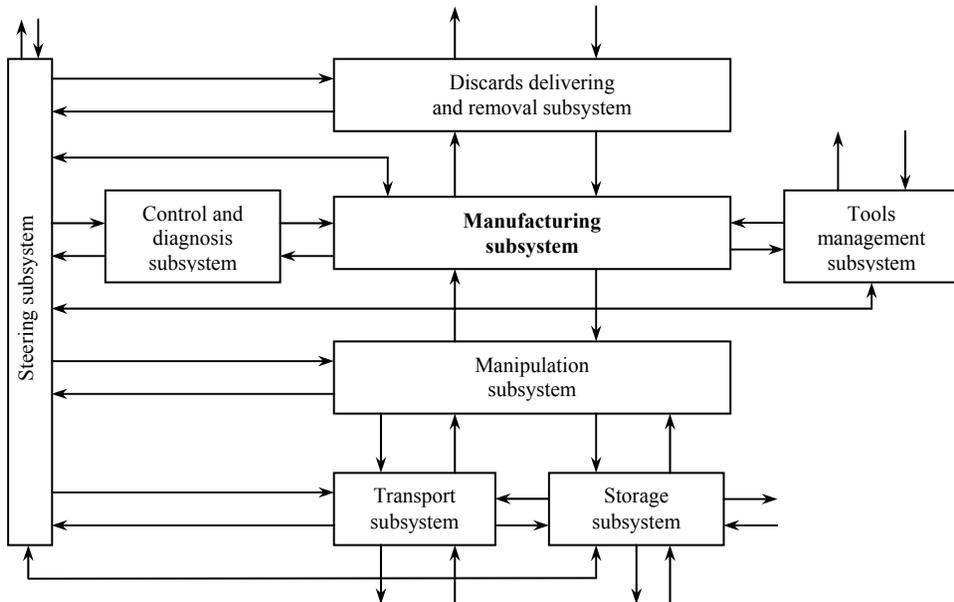

Fig.1. Functional FMS subsytems [5]

The manufacturing subsystem constitutes the most important FMS functional subsystem. It fulfils the basic tasks of the system, determining such important technical-economical parameters of FMS as: productivity, the quality of production, flexibility, the degree of automation, capital outlay, production costs etc. Generally, it includes technological devices, machines, machine tools and work stations applying specific production methods: shaping processing, joining, plating etc., as well as supporting functions: removing chips, cleaning, changing of the object attachment etc. The manufacturing subsystem in particular consists of the following sites:
- processing (machine tools subsystem),
- preparatory (cooling down, stabilization of temperature, changing of the object attachments to the pallets etc.),
- auxiliary (cleaning, labeling, maintenance, removing chips),
- control-measuring.

Processing sites (machine tools subsystem) constitute the core of the manufacturing subsystem. This subsystem, depending on the kind of devices applied in the system, is closely connected with preparatory, auxiliary and control-measuring sites, when the flow of both material and energy flux is taken into account (Fig. 2).
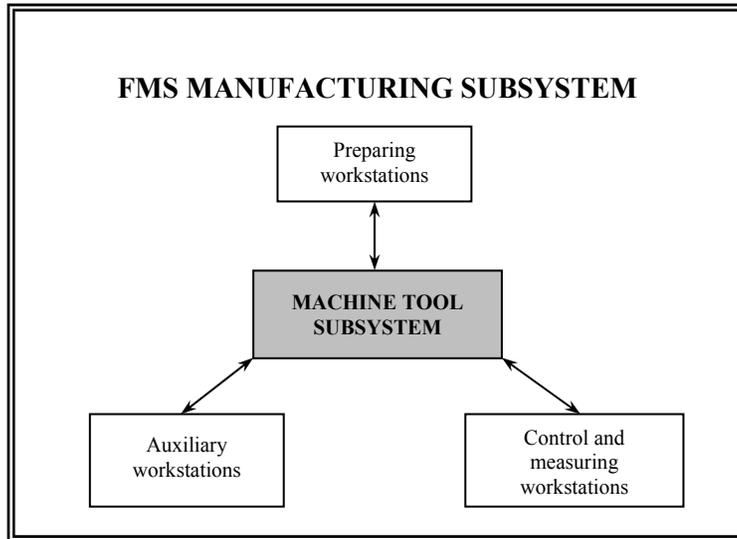
FMS MANUFACTURING SUBSYSTEM

Preparing
workstations

**MACHINE TOOL
SUBSYSTEM**

Auxiliary
workstations

Control and
measuring
workstations

Fig.2. A place of machine tool subsystem in the FMS structure

3. MAIN STAGES OF THE METHODOLOGY

Designing the FMS manufacturing system is a complex process since it requires the appropriate solutions on the designing levels of the particular FMS subsystems as well as the appropriate correlation of the particular subsystems enabling the optimization of the flow in the sphere of both material and information flux. The solution could be various, depending on individual limitations – however, the algorithm of machine tools selection must be based on the following assumptions, independently from conditions and nature of the company:

1) Machine tools that are the part of the FMS production subsystem should ensure the feasibility of all operations on all products to be made in FMS, maintaining assumed precision,

2) System of individual machine tools control that helps to create coordinated, central control FMS,

3) Minimization of total machine and means of transportation purchase cost and production and transportation cost while using them.

The developed methodology of the selection of FMS machine tools subsystem constitutes a sequent of operations leading to an optimal solution, among machine tools available on the market, for the conditions of the designed FMS that is specification of machine tool type, by means of which processing will be performed. The proposed approach is based on the 4-stage course of the process of machine tools selection by means of elimination (Fig. 3):

➢ STAGE no. 1: Gathering and processing data about machine tools, representation of constructional knowledge, developing technological assumptions about objects intended to processing in FMS;

- ➢ STAGE no. 2: Elimination of machine tools which don't perform „critical" technological and organizational requirements;
- ➢ STAGE no. 3: Developing possible variants („technological paths") of processing for representative objects, quantitative selection of machine tools for each variant;
- ➢ STAGE no. 4: Optimization analysis for each of the variant, selection of machine tools in relation to accepted optimization criteria.
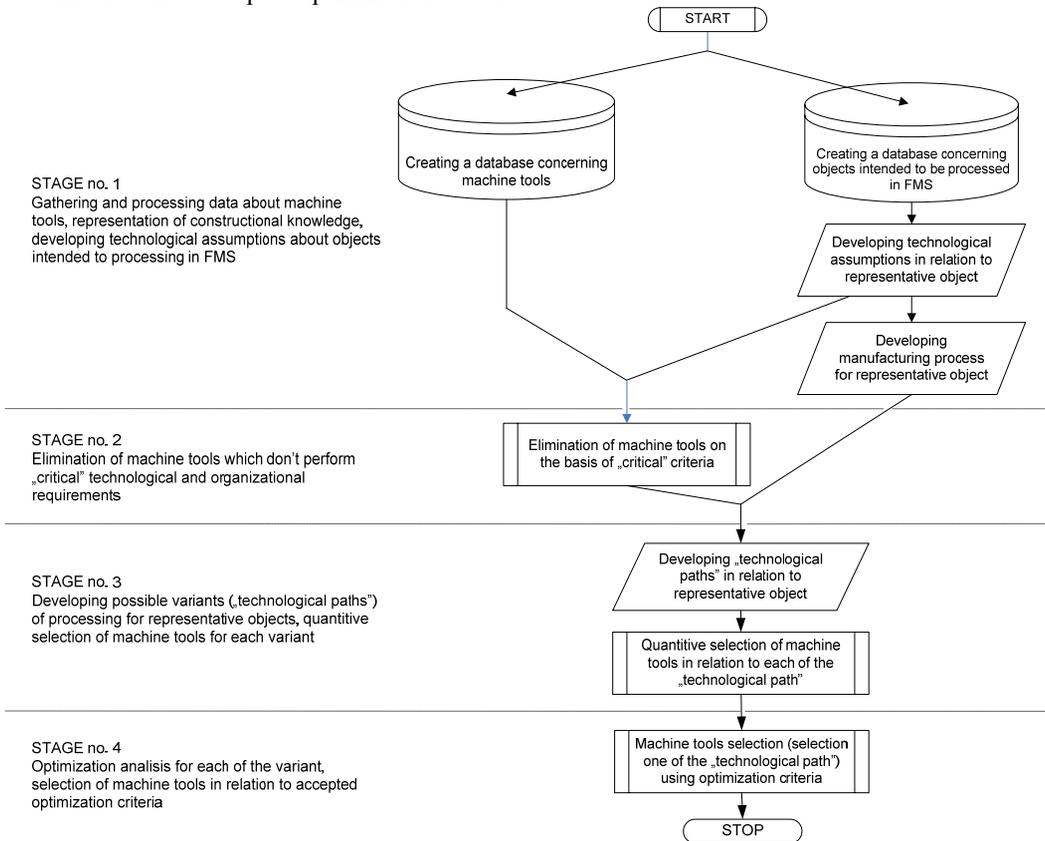

Fig.3. General alghoritm of methodology of FMS machine tools subsystem selection

3.1. Creating a database concerning machine tools

The main target of the developed methodology is optimal machine tools selection for designed FMS from the group of machine tools which are available on the market or/and in the company. For this purpose it is necessary to develop database concerning machine tools intended for processing parts of a certain class that can be applied in the designed system. There are a lot of machine tools available on the market, with different functional characteristics and diversified technical parameters. Since the contemporary designed flexible manufacturing systems are based virtually exclusively on numerically controlled machines, the designed database will include data one machine tools with the CNC control. Furthermore, it should include, among other things, the following information:

- a name and a type of machine tool and a name of a manufacturer,
- a name of control system: SINUMERIK, FANUC, RAZMER, SCHARMANN, NUMS, BOSH, and others,
- a list of control systems compatible with a parent system as well as the cost of adjusting a parent system to the aforementioned systems,
- replacement of tools: automatic, manual (in the case of manual tool operating of a machine tool it is essential to include the information on the possibility of automation of tools replacement and the costs of such an operation),
- replacement of processed objects: automatic, manual (in the case of a manual operating it is essential to include the information on the possibility of automation of tools replacement and the costs of such an operation),
- technological possibilities: the sorts of processed machining groups,
- a type and measurements of a table: measurements of a table in the X axis, measurements of a table the Y axis,
- translocations of a table: translocations according to the X axis, Y axis, Z axis as well as the rotation on the A axis, B axis, C axis,
- the amount of axes numerically controlled and the position of the spindle axis in relation to the table surface,
- the accuracy class of a machine tool,
- the accuracy of machining and the accuracy of a table positioning,
- the capacity of storehouse for tools,
- working moves and the rotation speed of a spindle,
- maximum permissible table load.

Created machine tools database contains a set of machine tools $O=\{o_1,o_2,...,o_n\}$) which will be taking into account into selection process..Fig 4 presents main window of user interface of database concerning machine tools (in Polish).
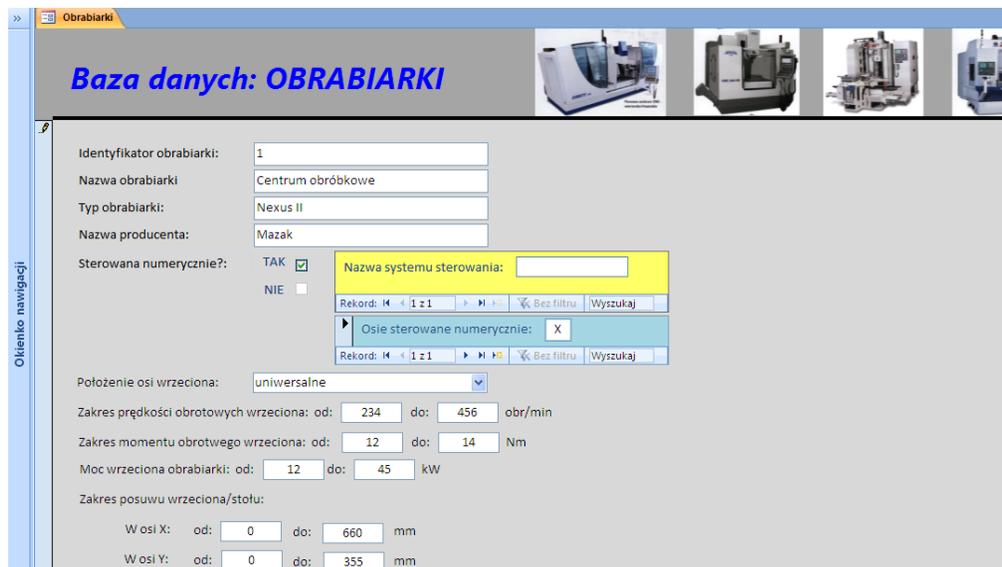

Fig.4. Main computer window of machine tools database interface

3.2. Creating a database concerning objects intended to be processed in FMS

Despite information about machine tools information on objects processed in the designed FMS constitutes an input in the process of machine tools subsystem selection. It is known that flexible manufacturing systems are designed for manufacturing parts of certain classes with similar technological features and diversified construction features (eg. parts of the body class, rotatory-symmetrical parts etc.). Furthermore, they are created for the groups of parts homogeneous to some extent, eg. with a similar mass, a certain extent of dimension measurements or intended range of accuracy classes. What is important is that designing FMS for processing is not profitable for all groups of parts.

Creating database concerning objects intended for processing in FMS itself should be preceded by technical-economical analysis and selection of objects processed in the designed system. On can come across in the literature certain methodical solutions allowing for selecting groups of parts intended for a selected group of parts to design and create a database.

For this purpose it was developed three stages database which is characterized by three level structure:

➢ LEVEL 1 – where user can input such data as: general information on the object, an identification number, a classification symbol, measurements of an object (length – L, breadth – B, height – H), weight of an object, amounts of processed objects in one year time,

➢ LEVEL 2 – where user defines all machining sides of objects (for this purpose the method of identification machining sides was developed too);

➢ LEVEL 3 – where user input residual data on machined objects (generally it is accepted two types of machined objects: holes and surfaces (Fig. 5).
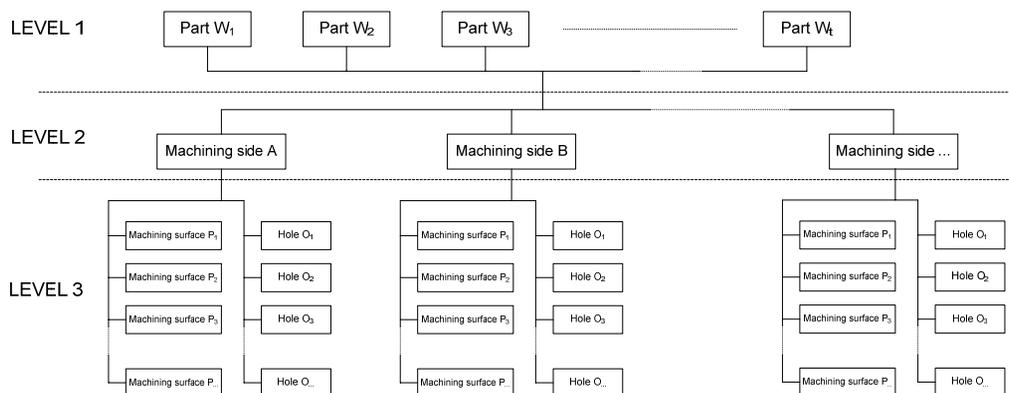
Fig.5. Structure of database concerning objects to be processed in FMS

3.3. Developing technological assumptions in relation to representative object

The structure of data base concerning objects to be processed in FMS enables gathering data which gives possibility of developing in a simply way technical assumptions for representative object. By the concept of representative object (WR) we mean object which

is characterized by all construction-technological-organizational parameters which are characteristic for all parts (P={$p_1,p_2,...p_r$} set) intended for processing in FMS. In other words representative object is characterized by all machining sides and objects intended for processing which occurs in each of the {$p_1,p_2,...p_r$} objects and other technological parameters of particular objects according to accepted mathematical rules.

It is need to add that representative object is a virtual on and in the most events it isn't possible to develop real model of representative object.

3.4. Developing manufacturing process for representative object

The next step of presented methodology is to develop (on the basis of technological assumptions) technological process for representative object. Technological process developed for selection machine tools is simplified model of classical technological process developed in a traditional way. It consists of list of sets, which must be realized to completed machining of representative model. Technological process is developed by process engineer – expert in an area of defined group of parts. Task for the process engineer is limited to:
- define type of cut which is necessary to realize specified object,
- attribute type of cut to specific object,
- determine the sequence of realization following cuts in a technological process.

3.5. Machine tools elimination in the basis of 'critical' criteria

The core of the second stage in the process of machine tools selection of a designed FMS constitutes the elimination of machine tools from a database that are unable to produce parts being the objects of production in the system on the basis of certain criteria. In order to carry out such an elimination, on should collect information on objects and machines from databases as well as filtering process performance based on criteria presented in Tab. 1.

Tab. 1. Critical criteria for machine tools elimination process

Parameter of machine tool		Criteria of selection/parameter of machine tool
Computer Numerical Control	=	YES
Pallet system	=	YES
Tool storage	=	YES
Automatic tool changer	=	YES
Table loading capacity ($MS_{max}(o_i)$)	$\geq$	Max. weight of product ($\max\{m_{w\alpha}\}$)
Pallet size ({$P_L(o_i)$; $P_B(o_i)$})	$\geq$	Length, breadth + dimension necessary for fix the biggest object ({$\max(L_{w\alpha}+Z_{Lw\alpha})$; $\max(B_{w\alpha}+Z_{Bw\alpha})$})
Volume of workspace ({$L_r(o_i)$}, {$B_r(o_i)$}, {$H_r(o_i)$})	=	measurements of the biggest object ({$L_{w\alpha}$}, {$B_{w\alpha}$}, {$H_{w\alpha}$})
Types of realized technological operations	$\geq$	Types of realized operations necessary for machining the representative object
Position of a spindle axe	=	Which allows machining on the specified machining side
Type of the table		
Name of manufacturer, Name of control system, Spindle driver motor, Spindle torque range, Axes numerically controlled, Type of spindle taper, Measurements, weight	=	According to specified by user requirements

Fig. 6. presents first fragment of algorithm which allows for elimination according to criteria specified in Tab. 1.
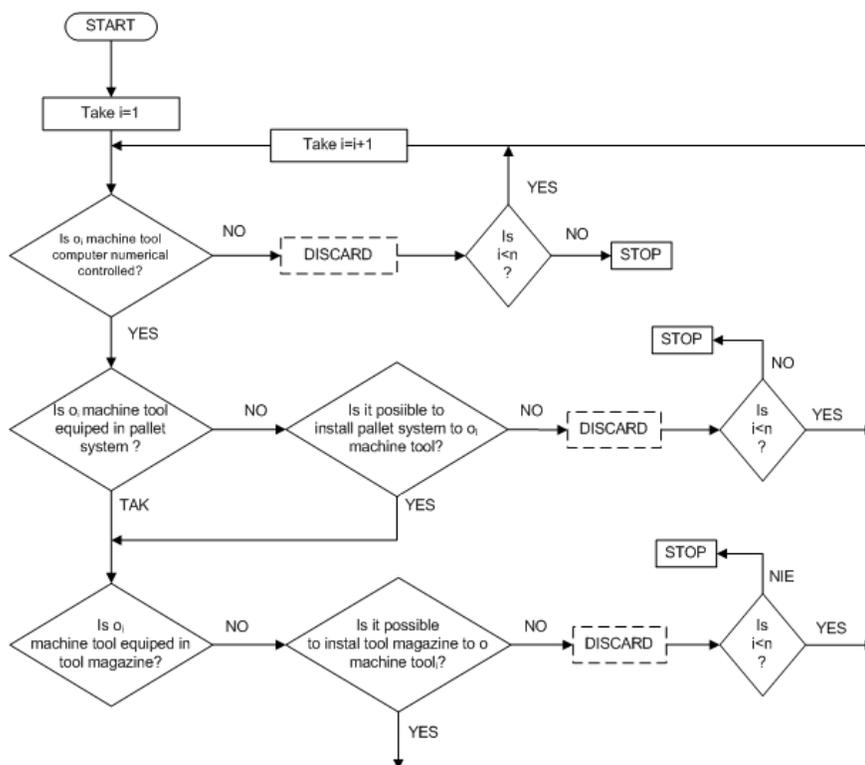

Fig.6. The algorithm of elimination of the machine tools on the basis of 'critical criteria' (fragment)

3.6. Developing „technological paths" in relation to representative object

After the second stage in database (set X) stayed only these machine tools which allows for mainlining at least one cut in the technological process of representative object. The aim of next step is to develop possible "technological paths" for realization machining process WR. For this purpose the proper going through algorithm was developed where input data makes 0-1 matrix which determines possibility of realization specified δ_j cut on specified machine tool x_i. The algorithm was develop using the principle of concentrating next cuts on the machine tool. The general visualization of this process was presented in Fig. 7.
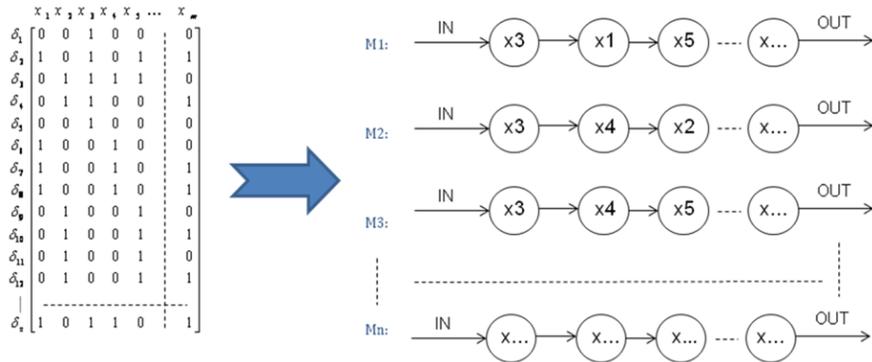
Where: x_1, x_2, ..., x_m – machine tools from the X set, $\delta_1...\delta_z$ – following cuts during manufacturing process, , [1] – „one" in the matrix means possibility of machining specified cut on the specified machine tool, [0] – "zero" means such possibility doesn't exist

Fig.7. Developing „technological paths" in relation to representative object

3.7. Quantitative selection of machine tools in relation to each of the „technological path"

When have data concerning predicted hours of work of designed system in one year time and information about time per cut for each cut and each machine tool – it is possible to balance loading of each machine tool in system and find necessary number of machine tools using formula (1):

$$\sum_{j=1}^{z} N_{w\alpha}\left(t_{jkj} + \max(t_{wnk}; t_{wpk})\right) \leq F_{xk} \tag{1}$$

Where: k – machine type index; j – cut index; $N_{w\alpha}$ – number of parts w_α manufactured in one year time; t_{jkj} – time per cut j on the k machine tool (in hours); t_{wnk} – tool change time (chip to chip), t_{wpk} – pallet change time, F_{xk} - k machine tool work time of in one year time.

The result of this process is information about necessary number of each type of machine tool for each variant of technological path (Fig. 8).
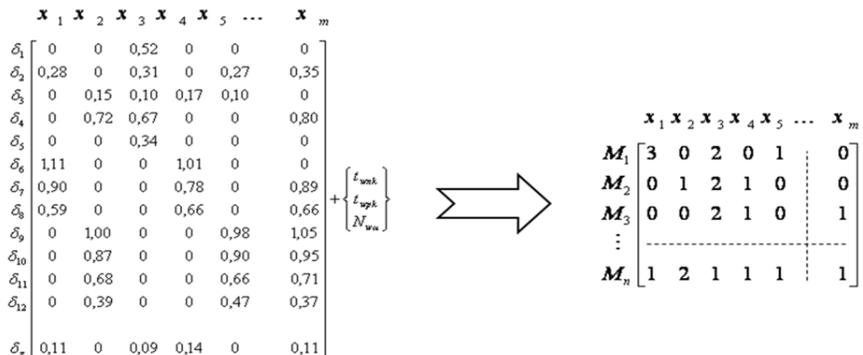

Fig.8. Quantitative selection of machine tools in relation to each of the „technological path"

3.8. Machine tools selection (selection one of the „technological path") using optimization criteria

The core of the fourth stage of methodology is optimal machine tools selection (choice 'technological path') using defined target functions. For solution these problem it was used Evolutionary System of Multicriteria Analysis <ESMA> developed in Lublin University of Technology. This system allows to find optimal solution in a Pareto sense for multi-criteria function. Target functions for optimization process are as follows:

1. Minimization of the total cost of machine tools purchasing and utilization (in period of one year) [COST]

$$\sum_{k=1}^{m} a_k * \left(c_k + e_k \right) \rightarrow \min \tag{2}$$

where: k – a type of machine tool index, a_i – a number of purchased i machine tools, c_k – value of one-year depreciation of k machine tool (depreciation calculated using proportional method), e_k – one-year cost of utilization k machine tool

2. Minimization of the representative object machining time (throughput time) [TIME]

$$\sum_{k=1}^{m} \sum_{j=1}^{z} \left(t_{jkj} + \max \left(t_{wnk}; t_{wpk} \right) \right) \rightarrow \min \tag{3}$$

where: k – a type of machine tool index, j – a type of cut index, t_{jkj} – cycle time of cut j realized on k machine tool, t_{wnk} – tool change time „chip to chip" on the k machine tool, t_{wpk} – pallet change time on the k machine tool

Calculation the value of target function for each variant (technological paths) allows to develop solutions map (Fig. 9) and to find optimal solution in a Pareto sense for specified target functions (Fig. 10).
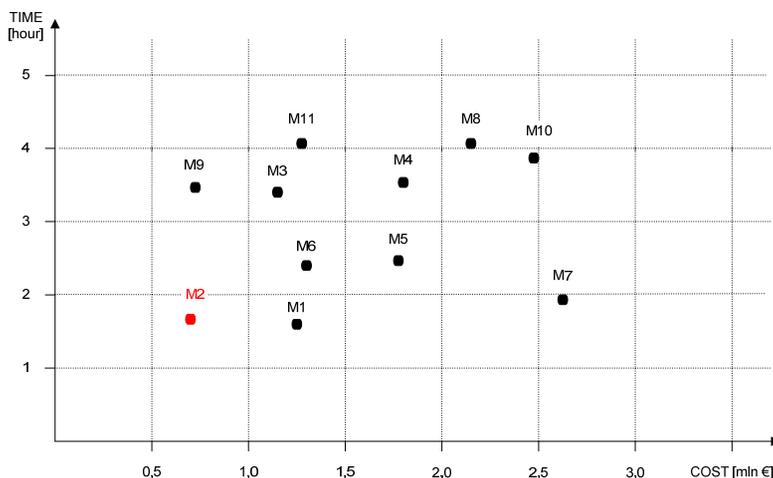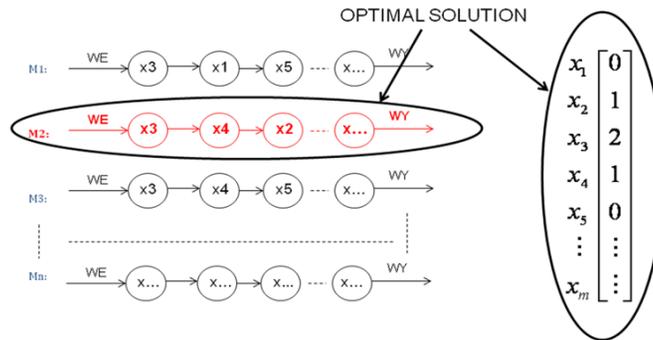

Fig.9. Map of solutions

Fig.10. Graphical representation of optimal solution

3. SUMMARY

Flexible manufacturing systems are important step toward fully automated and computer-integrated production. As a technology that integrates different stand-alone machines and control equipment, its designing and implementation is not easy task. FMSs are-state-of-the art production systems designed to emulate flexibility of job shops while retaining the efficiency of dedicated production lines. Such systems should be designed to increase productivity while satisfying demand with decreasing throughput time.

The decision to invest in a flexible manufacturing system is a difficult on for management to take. They cost a lot of money, often several million Euros they are not easy to get right, and justification has to be based on radix improvements in performance.

The method presented here is a tool which allows optimal machine tools selection for designed flexible manufacturing system. Computer program based on this methodology provides a real supportive tool for FMS designer and permits fast finding of optimal solution understood as a set of machine tools appropriate for machining of a defined set of parts.

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