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INTELLIGENT DECISION SUPPORT SYSTEM FOR FMS MACHINE TOOL SUBSYSTEM DESIGN

Abstract

The aim of the article is to develop a new methodology of analysis and evaluation of Flexible Manufacturing System (FMS) machine tool subsystem design configurations. It examines the use an integrated, systemic, global and user oriented approach for the complex problem of selecting among several configuration alternatives the most suitable for a specific case. The methodology is implemented using the Decision Support System framework, offering an objective tool to help managers and engineers during the design stage of the developent cycle of an flexible manufacturing systems.

1. INTRODUCTION

Increasing global competition has made many business leaders and policy makers turn their attention to such critical issues as productivity and quality. Businesses seek new approaches to production processes and manufacturing techniques and explore new boundaries of technology. One of the frequently prescribed remedies for the problem of decreased productivity and declining quality is the automation of factories. More specifically, technologies such as Computer Integrated Manufacturing Systems (CIMS), robotics, and Flexible Manufacturing Systems (FMSs) are the focal points of much research and exploration. Such views, as shown in the following “official” statement, are representative of the new attitude towards advanced technologies: “FMS can help our economic recovery... Flexible manufacturing systems can bring tremendous economic advantages to batch manufacturers. Beyond the attraction of increased efficincy, companies must automate if they are to compete in foreign and domestic markets with companies in Japan, Germany and other foreign countries, which are automating their manufacturing operations vigorously [3]”.

FMSs have been introduced in several European countries, North America, and South Asia. However, the results do not live up to the expectations. Several unsuccessful implementations are reported in the literature. One of the main reasons for the failure of FMS systems is the

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difficulty of designing such systems properly due to the large commitment of manpower and skill for the specification and integration of several complex manufacturing elements into a system. In addition, high capital costs and acquisition risks are well-accepted features of FMS that exert considerable pressure design team.

Meredith and Hill [7] highlight this problem when they affirm that one of the major causes for a large number of failures of advanced manufacturing systems is the lack of total understanding of the technology involved before its implementation. These complex systems demand an extensive pre-design, whereby not only should the technology be analyzed, but also its effects on the organization as a whole.

FMS machine tool subsystem design is a first and very important step in the process of flexible manufacturing system design 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.

FMS machine tool subsystem design is a problem concerned with the selection of: (i) subsystem configurations from a wide variety available, and (ii) control strategy alternatives in the light of several criteria (costs, production, flexibility), many of which are difficult to quantify.

This work presents a novel methodology of analysis and evaluation to select a suitable FMS machine tool subsystem for a particular situation which is implemented using the Decision Support System (DSS) framework.

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 are essentially composed of workstations and material transfer systems in which the control of operations is performed by a central computer.

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

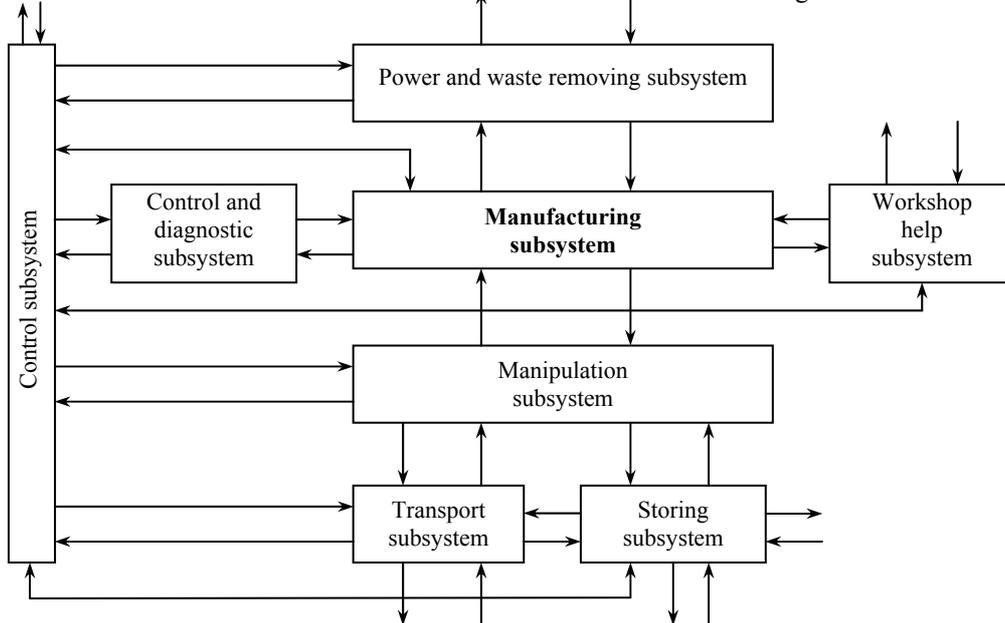


Fig. 1. Functional FMS subsystems [5]

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 (clearing, 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).

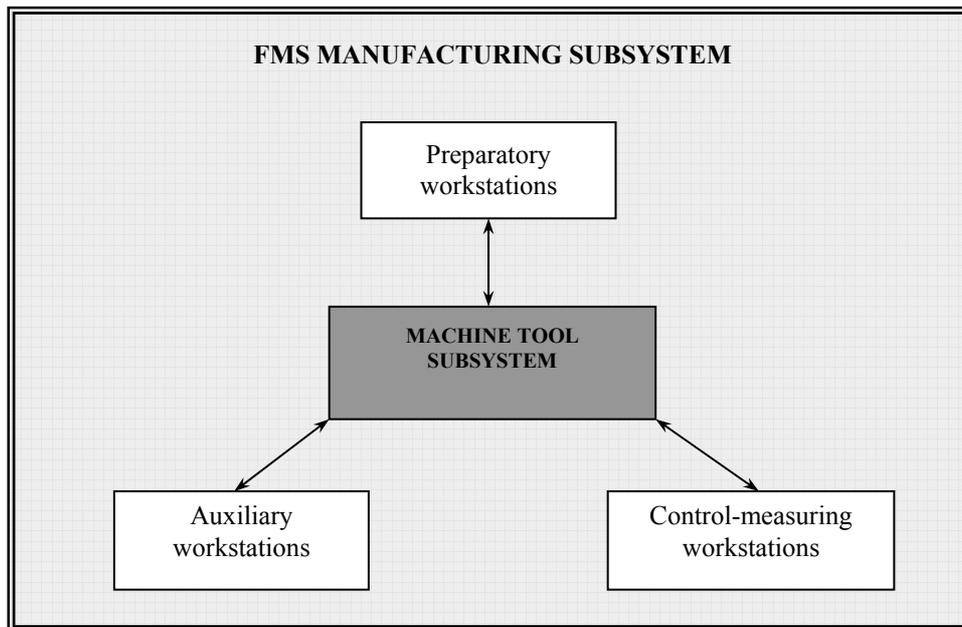


Fig. 2. A place of the machine tool subsystem in the FMS structure

3. GUIDELINES CONCERNING THE CONCEPTION OF MACHINE TOOLS' SUBSYSTEM SELECTION

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 issues of the production subsystem designing, and in particular the selection of machine tools of the designed FMS fulfil a special role. It is the first stage of the system designing, which determines its effectiveness in large measure. The proper selection of the machine tools' subsystem may reduce capital outlay on construction to a large extent as well as lead to minimization of operating costs of the system or maximization of the degree of the machines' use. The purchased machinery directly influences productivity, automation and the degree of the flexibility of the whole FMS.

3.1. Criteria of the selection of the production system machine tools

- *Machine tools included in the FMS production system should assure the possibility of performing all operations on all products to be manufactured in FMS keeping to intended accuracy*

Input data of the machine tools' subsystem selection constitute the information on the objects to be produced in the designed FMS. It is known that not all objects can be processed on any machine tool. The processing of the set of objects marked for the processing in the (P^*)

system is possible, when the *technological possibilities of the machine tools' subsystem match the technological needs of the P^* set of objects*. The degree of such a correspondence is determined by means of K_{opESP} coefficient [11]:

$$K_{opESP} = \frac{|f_{of<S} \cap f_p^*|}{f_p^*} \quad (1)$$

where:

f_{opFMS} – a set of technological functions, performer by the machine tools' subsystem,
 f_p^* – a set of technological functions necessary for complete processing of (P^*) objects

Machine tools' subsystem should be selected in such a way that $f_p^* \subseteq f_{opFMS}$, that is the technological possibilities of the machine tools' subsystem and technological needs of the set of objects correspond fully ($K_{op} = 1$).

- ***A control circuit of particular machine tools enabling coordinated, central FMS control***

Joint operating of machine tools with the major FMS control system is possible via a CNC control circuit. Thus the control system of the machine tool included in the subsystem constitutes an important criterion in the machine tools selection. Creating the machinery based on the same kind of control or mutually compatible systems allows for avoiding problems and reduction of the considerable costs connected with adjusting the machine tool's control system to the central control system.

- ***Minimization of the total costs of machinery purchase and production costs connected with the use of machines***

Capital outlay on the FMS construction is considerable. Thus the issue of minimization of costs connected both with creating and maintenance of the designed system plays a crucial role. Selection of appropriate machine tools' subsystem significantly influences these costs. Thus the task of designer is to find such a solution that these costs are minimal:

$$K_{coESP} \rightarrow \min \quad (2)$$

where:

K_{coESP} – total costs of the purchase and maintenance of machine tools of the designed FMS production system

3.2. Algorithm of the selection of machine tools of the flexible manufacturing system

Algorithm 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 types, by means of which processing will be performed. The proposed approach is based on the 3-stage course of the process of machine tools selection by means of elimination (Fig. 3) [2].

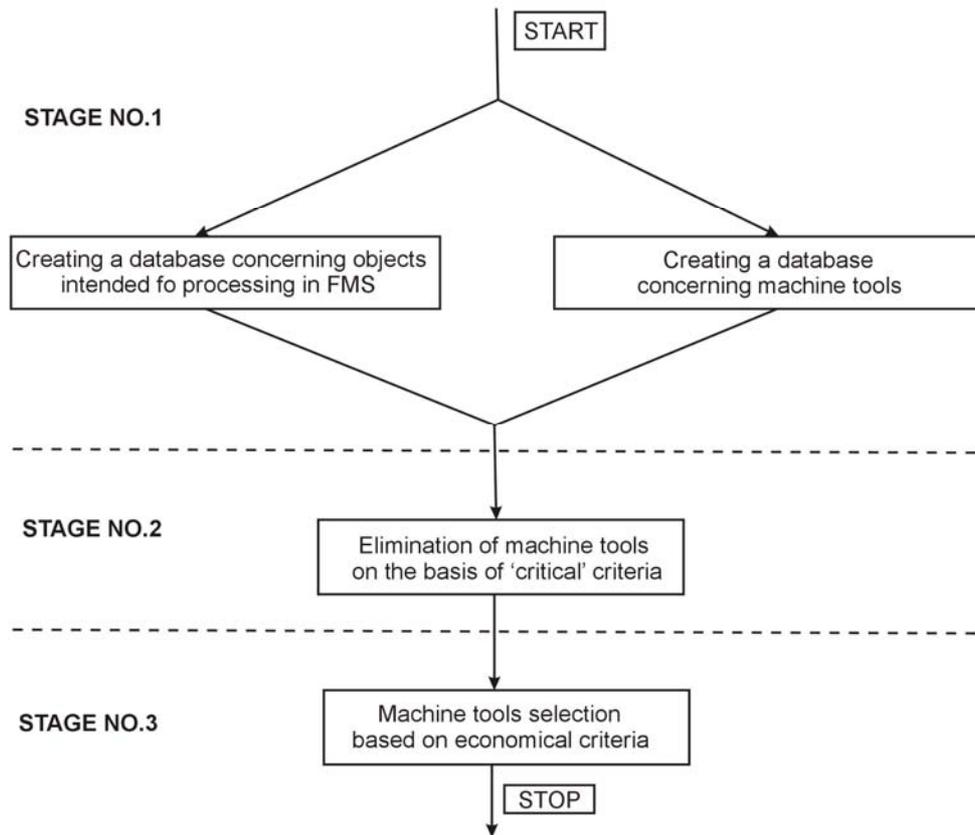


Fig. 3. Diagram of the selection FMS machine tools subsystem

The first step in the process of machine tools selection is creating a database concerning objects intended for production in the designed FMS as well as machine tools for processing of parts of certain classes available on the market.

3.4 Information structure of database concerning objects intended for processing in FMS

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

An exemplary database concerning objects of the body class should include the following information:

- general information on the object: a name of the object, an identification number, a classification symbol etc.,
- a type of shape: a cube, a cover, a door, a sheet, a beam, a cantilever, a rack, a machine body etc.,
- a sort of shape: eg. a cuboidal cube, a cube with additional milled elements etc.,
- a variety of shape: eg. without holes, with holes having parallel axes etc.,
- measurements of an object (length – L, breadth – B, height – H) and its weight,
- a symbol of the material: eg. Zl 100, Zl 150, Zl 200, Zl X, Zs 37017, L 400, L 450, St 3S, St 4S, 35, Ak 52 etc.,
- a sort and a class of the pig iron accuracy,
- amount of processed object sides,
- particular operations in a technological process,
- accuracy of surface construction, surface roughness, deviations from a parallel position, deviations from a perpendicular position,
- the unit cost of material.

3.5 Information structure of a database concerning machine tools

Apart from a database on objects processed in FMS, the second database to be created in the stage no.1 is a 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 on machine tools with the CNC control. Furthermore, it should include, among other things, the following information:

- a name and a type of a machine tool and a name of a manufacturer,
- a control system: SINUMERIK, FANUC, RAZMER, SCHARMANN, NUMS, BOSCH, 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 a 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 a storehouse for tools,
- working moves and the rotation speed of a spindle,
- maximum permissible table load.

3.6 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 critical criteria. In order to carry out such an elimination, one should collect information on objects and machines from databases as well as filtering process performance based, for instance, on the following criteria:

- measurements of the machine tool table in the X and Y axes \geq measurements L and B of the processed object,
- the possibility of performing the i operation on the j machine tool,
- the accuracy class of the machine tool \geq the accuracy class of the processed object,
- weight of the processed object \leq maximum machine tool load ,
- the control system of a machine tool enabling the FMS central control,
- the accuracy of the processed object and tool positioning that assures obtaining the intended product accuracy

Certainly, in such a list of information concerning the particular criteria, all possible combinations of the object-machine tool systems must be verified. The result of the selection and elimination constitutes a group of machine tools with the ability to process objects, for which the system is designed.

3.7 Machine tools selection based on economical criteria

The performed elimination of machines in the second phase allowed for selecting the machine tools able to manufacture the intended products. A group of machine tools, which can potentially create the subsystem of FMS manufacturing, has been selected as a result of this stage. However, the production of a given part on a given machine tool is not always economically justified since it is connected with the purchase costs of particular machine tools as well as the unit costs of the processing of the parts on the selected machines. The task of machine tools selection based on the economical criteria to the designed manufacturing system has been formulated as a problem of the integer programming by means of the function (3) minimization for particular groups of machine tools [9]:

$$\sum_{i \in I} c_i u_i + \sum_{i \in I} \sum_{j \in J} g_{ij} x_{ij} \rightarrow \min \quad (3)$$

with limitations:

$$\sum_{i \in I} x_{ij} \geq a_j \quad j \in J \quad (4)$$

$$\sum_{j \in J} p_{ij} x_{ij} \leq T_i u_i \quad i \in I \quad (5)$$

$$\sum_{i \in I} c_i u_i \leq B \quad (6)$$

where:

i – a type of machine index, $i \in I$,

j – a type of operation index, $j \in J$,

a_j – a number of j operations which has to be performed,

b_k – a number of k parts which has to be produced,

B – a total budget for the purchase of the FMS equipment,

c_i – the cost of the i machine purchase,

g_{ij} – the cost of performing the j operation on the i machine,

p_{ij} – the time of performing the j operation on the i machine,

T_i – the i machine disposable time,

u_i – a decision variable – a number of purchased i machines,

x_{ij} – a decision variable – a number of j operations intended for the i machine.

The target function (3) represents the total costs of the machine tools purchase as well as the production costs while applying them. The limitation (4) assures the performance of all operations and transport of all parts of each type. Limitation (5) protects against the exceeding the disposable times of the machines, whereas (6) protects against exceeding the disposable budget.

Determining the target function for particular groups of machines will allow for the selection of the most optimal set of machine tools that create the body of the manufacturing subsystem.

4. METODOLOGY OF ANALYSIS AND EVALUATION

The methodology to be described is based on Sawney's [10] methodology for evaluating strategic investments in manufacturing companies. The main objective of the methodology in this paper is to select a suitable FMS machine tool subsystem design for a particular situation. Fundamentally, the methodology has at its main goal the support and development of the design team's confidence in the selection of the "best" FMS design. Since the methodology deals with a wide spectrum of factors, including strategic, operational, and financial, the correct use of the methodology will call for a multidepartmental group within a firm with representations from at least the following departments: Product Engineering, Process Engineering, Quality, Marketing, Accountancy, Top Management, etc.

The methodology is focused on two main activities: (i) the analysis of several FMS machine tools subsystem design configurations and logical control (offering technical, financial, and strategic measurements), and (ii) their posterior evaluation in order to determine which is the most suitable for a particular situation. It is assumed, therefore, that several activities have already taken place and that the designer has (i) an initial configuration of the machine tools subsystem (that includes the set of parts to be produced, a detailed processing plan for each part in the set, a set of machines and information about MHS equipment), and (ii) an initial description of the control policies for this initial configuration.

The methodology can be described as follows (figure 4 presents a graphical description of the methodology):

Step 1. Definition of a manufacturing strategy.

This step consist of translating the firm's corporate strategy into a manufacturing strategy. A manufacturing strategy can be defined as the "pattern of discussion over time which enables a business unit to achieve a specific set of manufacturing capabilities" [8].

This manufacturing strategy can be quantified by a set of manufacturing strategy componenets (MSCs) reprezented by operational, financial, and strategic manufacturing-based performance measurements, such as capacity, productivity, flexibilty and costs.

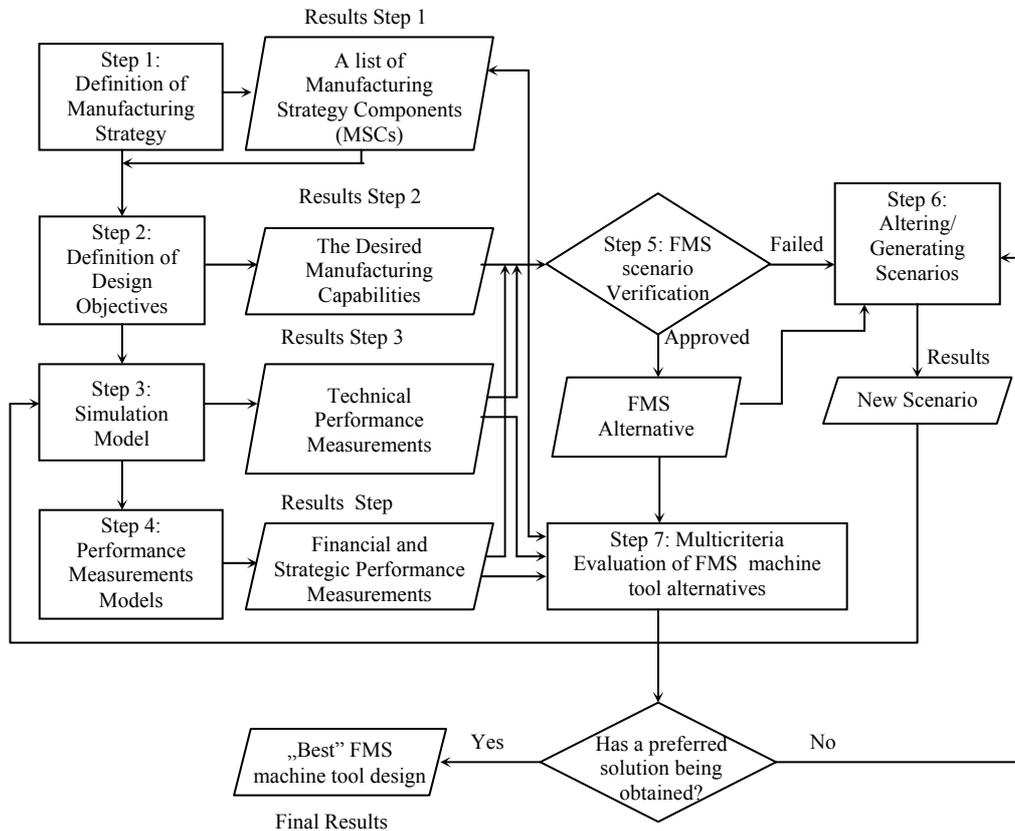


Fig. 4. Metodology description [10]

Step 2. Definition of design objectives.

This step assigns some MSC target levels. In assigning target levels, the design team is defining design objectives toward manufacturing excellence. These target levels are used by the methodology to evaluate FMS scenarios. These targets can be considered as the threshold for certain MSCs that, if not reached, will lead to discardment of an FMS scenario from further analysis. The target levels can be defined using market requirements or actual current

performance of the system. An example is the definition of a maximum utilization rate of 85% for all hardware components within the FMS machine tools subsystem scenario.

Step 3. *Simulating model.*

The main goal of this step is to analyse FMS machine tools subsystem scenarios concerning technical performance measurements, such as lead time, machine tools utilization and bottleneck identification. The choice of the simulation technique is based on the claim made by several researches involved with FMS design and planning process (see Harmonovsky [4]) that simulation is the most powerful technique for analysis of FMS. Besides the results presented above, the simulation model performs a sensitivity analysis of critical input parameters such as the size of the lots of certain products.

Step 4. *Strategic and financial performance.*

The function of this step is to quantify financial and strategic performance measurements of FMS scenarios such as costs flexibility, and quality. In order to achieve this goal, the step utilizes a set of estimation models. The models are developed with the goal of capturing the contribution of each performance measurement for the analysed scenario.

Step 5. *Verification of FMS design scenarios.*

The main goal of this step is to evaluate FMS machine tools subsystem scenarios in order to define whether the scenario has performance measurements in accordance with the design objectives, as defined in step 2. If all the design objectives are met, the scenario will be pronounced an FMS machine tool subsystem alternative and will be further evaluated by the MCDM model in step 7. Otherwise, the FMS scenario will be analysed in step 6 in order to discover what is wrong with it and ascertain improvement possibilities in an attempt to generate a new scenario with better performance.

Step 6. *Generating scenarios.*

If a scenario fails the verification process in step 5, this step is activated with the objective of changing the current scenario to generate new improved ones. The idea is to find possible opportunities of improvement in the scenario in order to generate an alternative through an *analysis-diagnosis-recommendation process*. Basically, this step will analyze the scenario to (i) identify cause(s) for bad performance in one or more design objectives, (ii) diagnose the problem(s) with the scenario, and then (iii) recommend possible changes in the current design. To execute this task, existing knowledge about FMS machine tool subsystem design is used. Briefly, this knowledge can be described as a set of facts, heuristics, and assumptions applied by experienced FMS designers.

The result of this step will be possible changes in the actual scenario (such as include a machine in cell C_i , etc.) Unfortunately, due to the empirical approach of this solution process and the high interdependencies between the design objectives, it is not possible to guarantee that these recommendations will generate a better scenario. And, consequently, this new scenario must be analyzed and evaluated in a similar way to the old scenario, creating a loop to step 3. If successive scenarios are generated and all fail the test specified in step 5, there are two possible causes which will demand a total re-analysis of the problem: the levels of the technical constraints are not in accordance with the FMS machine tool subsystem features, and the knowledge present is inappropriate for the particular situation and requires a revision.

Step 7. *Multiple criteria decision analysis.*

Based on the set of MSCs defined in step 2 and the results of steps 3 and 4, this step develops a multicriteria decision model to evaluate FMS machine tool subsystem alternatives generated during the methodology execution. The aims of this step are as follows: (i) to support the design team in exploring the strengths and weaknesses of each alternative, (ii) to assist priorities between conflicting MSCs, (iii) to study the sensitivity of the behaviour of

alternatives to changes in underlying decision situations, and finally, (iv) to identify a preferred course of action.

This step can be divided into the two following substeps:

Model structuring. This step is focused on alternatives and criteria. Since alternatives are generated interactively by the design team and methodology, the emphasis of this step is our framework is on the process of translating the MSCs into evaluation and analysis criteria consistent with the strategic behaviour of a firm. This step requires the design team to provide the following types of subjective assessments [10]: the importance of each MSC to the manufacturing strategy, and the relative relevancy of the performance measures for evaluating each MSC.

Evaluation and choice. This step involves the identification of a preferred FMS alternative from the discrete number of alternatives as defined interactively by the design team and methodology.

5. THE INTELLIGENT DECISION SUPPORT SYSTEM

In this section, the Integrated Decision Support System (IDSS) developed in order to to implement the methodology of analysis and evaluation of FMS machine tool subsystem is described. The DSS is called IDSSF_{LEX} and it was developed by D. Borenstein [1].

IDSSF_{LEX} is a prototype “Intelligent” Decision Support System for the evaluation and analysis of manufacturing systems configurations. The IDSSF_{LEX} described here combines several methods of operational research, systems analysis, and artificial intelligence (AI) into one integrated software system which provides a friendly environment for the several activities involved in the design of such a complex system.

The system is made “intelligent” by the construction of a descriptive model of an FMS. This model is an object-oriented one with specifications in a declarative, as well as in a procedural mode. Through the process specifications of the defined objects, it is possible to investigate the dynamics of the decision-making process and resulting behaviour. It was also expanded the the scope of this descriptive by integrating knowledge-based techniques in order to include decision rules for recommending actions given a set of conditions. Object-oriented programming (OOP) is an intelligent way of representing the world and dynamic changes in the world, whereas a knowledge-based paradigm is a way of making intelligent decisions about how to react to unexpected changes. In essence, OOP and knowledge-based systems are incorporated by way of implementing the concepts and elements involved in FMS machine tools subsystem design, offering a very flexible and coupled man-machine system.

The main justification for its development is the complex decisions involved during the design stage of an FMS implementation, which is a fundamental step for the successful implementation of this technology [6].

Additionally, although there are FMS vendors that will simply sell a whole FMS, these suppliers are unable to offer a system that “fits” entirely to each particular application. In addition to this main purpose, the system has the following generic objectives (common to any “intelligent” decision support system):

1. To assist in the design of alternative courses of action, and the elucidation of their outcomes.
2. To assess the criteria used in order to select the best option for the particular conditions of a project.

3. To assist in a systematic multicriteria evaluation and comparison of the alternatives generated and studied.
4. To supply factual information, based on existing data, statistics and scientific evidence.

5.1 Software system description

IDSS_{FLEX} involves the three common basic components in DSS: User-System Interface, Data Subsystem and Model Subsystem [1]. The Model Subsystem is composed of six models, namely: simulation model, decision analysis model, flexibility estimation model, quality estimation model, manufacturing cost estimation model, and a knowledge-base representation model.

The computational implementation of the system is divided into six different modules. The objective of the decision is to divide the system into six modules is to allow each module to be used in an individual way. Each module is a complete system by itself. This strategy has also facilitated the development of the system both in programming and in verification. Figure 5 presents the architecture of IDSS_{FLEX}. The arrows represent the information flow and the names in parentheses indicate the module label as a stand-alone computer software.

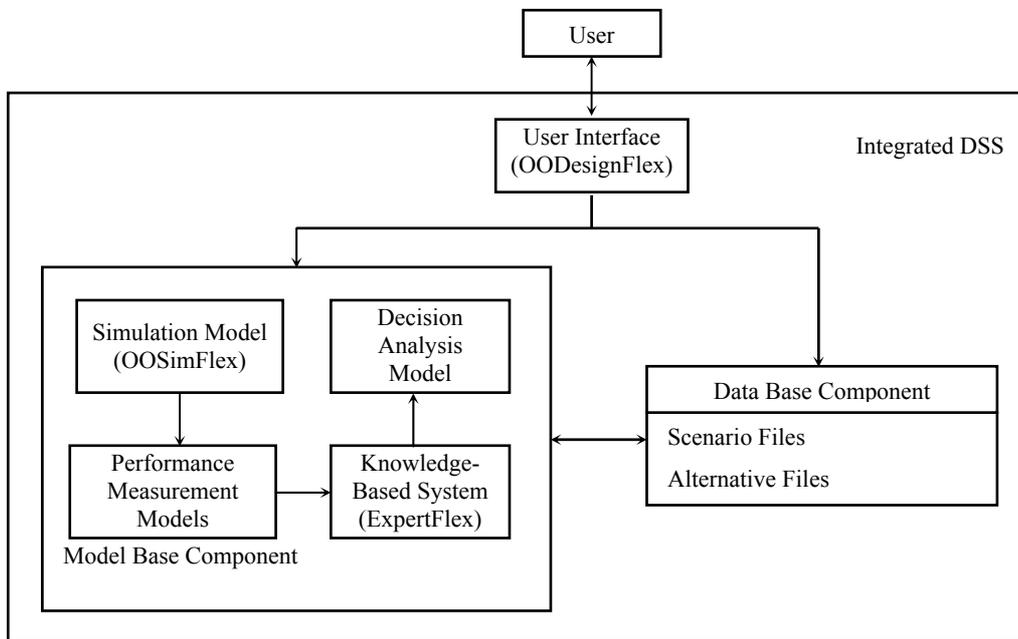


Fig. 5. IDSS_{FLEX} architecture

Simulation module (OOS_{IM}F_{LEX}). The simulation model has as its main function to analyze FMS machine tool subsystems scenarios, offering technical performance data such as utilization of the resources, part lead-time, etc. The simulation analyzes integration of complex

subsystem. In order to get the best response and total control of the software, it was necessary to develop our own simulation model, instead of using a commercial package. The simulation module is an Object-Oriented Simulation Model implemented in C++.

Strategic and financial performance measurement models. The module has as its main objective to measure strategic and financial characteristics, namely manufacturing costs, flexibility, and quality. This module is a combination of different analytical models for the quantification of these factors embedded in the simulation module. At this stage of development, IDSS_{FLEX} uses the following measures, modified as appropriate [6]: (i) Kochikar and Narendram's framework to measure manufacturing flexibility, (ii) Son's, and Stam and Kuula's process-oriented parametric manufacturing estimation costs, and (iii) Son and Hsu's estimation model that follows a quantitative approach to measure quality, which considers both manufacturing process and statistical quality control.

Multi-criteria decision making module (SCORE_{FLEX}). This module is a computer-based aid to multiple criteria decision based upon a single weighted multi-attribute function. The software incorporates a hierarchical structure of criteria and provides extensive facilities of analysis including visual interactive sensitivity analysis.

Knowledge-based system module (EXPERT_{FLEX}). The main objective of this module is to verify whether a certain FMS machine tool subsystem scenario met financial and technical design objectives defined by the design team. If a problem is found, this module starts an analysis of the problem that finishes with a diagnosis of the bad performance of the scenario, with respect to one or more design specifications. Following the diagnosis, the system provides possible improvements in the scenario in order to meet the design specifications. The *analysis-diagnosis-recommendation cycle* is carried out based on previous knowledge acquired during past advanced manufacturing technology design.

User-interface module (OOD_{DESIGN}_{FLEX}). This module is a visual interactive computer aid design tool for the modelling of FMS machine tool subsystem. It has the following functions: (i) to control the flow of information between the machine tools within the software system, (ii) to run the different models within IDSS_{FLEX}, (iii) to build, interactively, different FMS models to the specification of the physical FMS machine tool subsystem layout, specification of data, definition of the parts to be processed, and operational requirements of each part, (iv) to describe the results, and (v) to define the manufacturing goals. In order to achieve a satisfactory level of interaction, present the output in a meaningful way and to provide a smooth and error-prone communication to the user, this module uses three techniques, namely menu-driven, graphic-based, and object oriented representation. Basically, the user interface provides a meaningful framework within which information can flow in both the directions of user and computer in such a way that the user can concentrate and take responsibility upon the decision context.

Database module. This module contains all the information necessary for the execution of the several modules the IDSS as well as the results computed by them. The IDSS uses a large volume of information, some given by the user, some computed by the several IDSS's model modules. It is stored in files, and each module has its own mechanism in order to cope with input/output files. The information is divided into two files:

- Scenarios files. Stores information related to FMS scenarios. There is one file for each FMS machine tool subsystem scenario existing in the system. The scenario files are divided into two categories: (i) *Scenario File 1* contains the information related to FMS machine tool subsystem configurations (using information shown in section 3.4) and parts information (as it was shown in section 3.3). This file stores all the information defined interactively by the user and the user-interface module which constitutes the

required input data for the several models presented in model-base subsystem; (ii) *Scenario File 2* contains not only the information existing in the previous file, but also the results computed by the simulation model and the performance measurement models. It stores a complete description of a certain scenario.

- Alternative file. Stores information related to FMS machine tool subsystem alternatives. There is only one file per FMS machine tool subsystem project. This file is exclusively manipulated by $S_{CORE_{LEX}}$, and basically contains the following data: (i) the set of criteria (structured in a hierarchy) for the analysis of the different alternatives, and (ii) the scores of each alternative for each end level of criteria established in the criteria hierarchy.

In addition to the modules described above, the current implementation of IDSS- F_{LEX} uses EXCEL to carry out statistical analysis of the simulation model results. EXCEL's high quality graphical facilities are also used to present the results obtained from the simulator.

6. SUMMARY

Flexible manufacturing systems are important step towards fully automated and computer-integrated production. As a technology that integrates different stand-alone machines and control equipment, its designing and implementation is not an 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 one for management to take. They cost a lot of money, often several milion pounds they are not easy to get right, and justification has to be based on radix improvements in performance [12].

Many of the working systems were built as prototypes of something for the future, without expectation of quick results or a substantial return. Most were in response to the entushiam of one or two people rather than immediate business pressures. A fair number were inflexible, unreliable and did not really solve a major business problem.

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 issues of the production subsystem designing, and in particular the selection of machine tools of the designed FMS fulfil a special role. It is the first stage of the system designing, which determines its effectiveness in large measure. The proper selection of the machine tools' subsystem may reduce capital outlay on construction to a large extent as well as lead to minimization of operating costs of the system or maximization of the degree of the machines' use. The purchased machinery directly influences productivity, automation and the degree of the flexibility of the whole FMS.

In the paper, an Intelligent Decision Support System, called IDSSF- F_{LEX} , for FMS machine tool subsystem design is introduced. IDSSF- F_{LEX} is a prototypical computational system which selects from among several configuration and control strategy alternatives of design the most appropriate one of specific case. In order to accomplish such an objective, the system presents simultaneously the following features: ability to quantify subjective factors, ability to account for individual preferences, and ability to cope with multiple criteria decision making.

Therefore, the methodology and presented computational system can play an important role during the detailed design phase of an FMS implementation.

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