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‘Choosing a Manufacturing Systems’ Model Type

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Abstract

Purpose: This paper considers a novel solution to one of the key problems in modern mechanical engineering – the modeling of modern manufacturing systems in the field of mechanical engineering.

Design/methodology/approach: This article considers the choice of the model type of manufacturing systems. It is shown that from systemology’s perspective, all existing models are divided into imitating (replicating) and optimizing models, while the problem of designing manufacturing systems belongs to the class of semi-structured problems. Therefore, at the macro-designing stage it is expedient to use optimizing models, rather than the imitating ones.

Findings and originality/value: This paper gives a broad definition of the technological process as a set of actions for constructing a product, designing the technological process for a sequence of shaping products and manufacturing. It defines production flexibility and the adaptation of the manufacturing system to changes in conditions.

Originality/value: These solutions can be used in such fields of science and technology as automation in manufacturing, computer aided design (CAD) and modeling (CAM), computer aided engineering analysis, flexible manufacturing systems, flexible automation and production engineering.

Keywords: Manufacturing system; Designing; Macro-design; Optimizing models

Introduction

The theoretical and practical relevance of this paper consists in creating a new system of structural optimization of technological processes for planning and technical re-equipment of mechanical engineering facilities under the conditions of their scientific and technical development and restructuring, which implies the implementation of high-end technologies and differs from the known systems, firstly, in the object of process engineering and, secondly, in methodological, mathematical and computer support, based on latest scientific achievements.

The conducted researches laid the foundation for the establishment of methods, recommendation and structure of the formation and use of automated manufacturing systems and the formal methods of operating management, planning and performance monitoring.

The wide use of system models is a key feature of the systems analysis [1,2]. It is associated with the following circumstances. According to the standard classification [3], all problems are subdivided into three classes:

- Well-structured, or quantitatively formulated problems;
- Unstructured, or qualitatively expressed problems;
- Semi-structured, or mixed problems that include both qualitative and quantitative elements;
- As of today, only the first two problems have been studied [4-6].

The systems analysis appeared as a means for solving semi-structured problems, as a methodology for substantiating a decision under conditions of considerable uncertainty. It combines the general scheme of the systems approach with the analytical decision-making process [6,7].

Models of Manufacturing Systems

From systemology’s perspective [4], all existing models are divided into imitating (replicating) and optimizing models. The first approach consists in approximating the model to the system by approximating the coordinates of the model to the “phase” coordinates of system. The expediency of applying imitating models is “in direct proportion” to the problem’s level of structuring. The creation of flexible technological manufacturing systems is based on the application of machining centers (MC), program-controlled multi-operation machines (PCMOM), flexible manufacturing cells (FMC), equipped with means of automation of work piece and/or instrument loading, transportation and warehousing of work pieces and components; automation of changing the instruments and equipment, perfect control systems and the organization of flexible automated manufacturing (FAM). The adverse conjuncture in the machine-building market is a result of an economic downturn that is experienced by most developed countries. Suffice to mention the tens of thousands of job cuts among the leading corporations in Russia. As a result, the existing market requirements increase and new ones appear, for example:

- Fast updating of products and reduction of the life cycle of products and expenses associated with their maintenance,
- Expansion of the product range with a view to satisfying consumer requirements,
- Improvement of quality and competitiveness of products by the quality/price criterion,

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- Increase in the pressure of the social factor (deficit and expensiveness of skilled labor) and the environmental protection factor (waste recycling, etc.).

According to estimations, during the next 30-60 years, the automation of manufacturing will continue. This process is the basic means of satisfying the abovementioned requirements.

In terms of the modeling of manufacturing systems (MS), the level of a model's adequacy reduces, while the abstraction level rises both with the growth of the level of conditions' uncertainty and with the designing stage of MS. The more adequate a respective model is to a complex system, the higher its estimated qualities and lower its explanatory qualities are.

Since, on the one hand, the problem of designing MS qualifies as a semi-structured problem (due to a considerable level of conditions' uncertainty), while, on the other hand, a minimal level of structuring is typical of the first stage of MS creation - macro designing, at this stage it is expedient to use optimizing models, rather than the imitating ones.

Optimizing models are aimed at narrowing the field of the numerical experiment by preventively excluding obviously inefficient solutions. Based on cruder (simpler) optimizing models, one can obtain only so-called "upper" estimates of the system's efficiency. However, no other solution exists in the situation that is typical of the macro-designing stage of MS creation [8,9].

There are three methods of estimating the efficiency of complex engineering systems (ES):

- The classic method that involves determining the economic efficiency of ES in monetary or natural form and according to its payback period;
- The estimating method that involves attempting to estimate the tendencies of ES development;
- The scientific method that involves a complex, system, qualitative and quantitative analysis of the tendencies of ES development [10-12].

In order to determine the main function of MS, it is also necessary to formulate the purpose of MS - the objectives and tasks it has to complete.

Essentially, MS is manufacturing, particularly, the manufacturing of goods that perform certain functions required by the consumer (generally, a machine that implements any technological process in the broad sense of the term "technology"). Proceeding from the current requirements, society continuously generates and submits orders to the manufacturing industry, thus, acting both as a "consumer" and as a "client" [13,14].

An order that is submitted to a manufacturing facility is a non-material model (at various levels of its description) of a product, i.e. information that contains semantic, quantitative, and temporary aspects. Thus, the main function of manufacturing is to transform information on a product into a physical product.

The terms "manufacturing", "manufacturing process", "manufacturing system" have meanings of various broadness, i.e. they can be applied (and are applied) both globally and locally [15]. For the purpose of clarity, it is suggested to consider the metasystem level in the first case and the individual system level in the second case. Unlike a metasystem that manufactures a product for another metasystem, an individual system can manufacture a product for another (or other) individual system within one metasystem [16].

All actions that constitute the manufacturing process are subdivided into shaping (main), auxiliary and supporting ones. The shaping actions that transform the image of a product into a real product constitute the technological process.

At the early stage of technological development, the simplicity of orders allowed transforming them into a product by a single performer. However, as technology developed, the content of these tasks became so complicated that their solution required dividing the technological process into phases that were performed subsequently by many individual systems.

Modeling Results

The authors of this paper analyzed the existing systems and methods of modeling complex manufacturing systems and suggested new methods for analyzing such systems with a view to increasing production efficiency.

In general, the chain of individual systems is divided into three subsystems: the designer, the technologist, and the manufacturer.

The designer subsystem transforms the purpose of a product into its image (model) that is usually described by symbols of connections between sizes and connections between materials. The technologist subsystem transforms these connections into the manufacturer's symbols - the program for shaping and assembling. Finally, the manufacturer subsystem implements the technologist's program by physically affecting the work piece. It is worth noting that the above mentioned definition of the technological process does not contradict the known definition that includes only the last phase of transforming the information on the order - the change of the work piece's quality, but rather is a more general term. Moreover, the former definition emphasizes the fairness the latter one, since the qualitative change of the object is necessary for it to display information.

The second most important term of MS is "flexible". Both historically and epistemologically, the concept of "flexibility of manufacturing" or "flexible manufacturing" emphasizes the difference between the latter and "rigid manufacturing", i.e. a manufacturing that is incapable of executing other consumer's orders. In Figure 1, the incoming order can be expressed as function X (t) (a train of qualitative and quantitative characteristics of the order):

$$X = \{x_1, x_2, x_3, \ldots, x_n\}$$

The output function Y(t), which represents the execution of the order, is constantly compared to the input function X(t) during the operation of MS, therefore, a mismatch error ε(t) occurs if any qualitative or quantitative characteristics (for example, the number of copies) of the order are changed.

Conclusion

In order to assure the adequacy of the reflection of environment by the system, the latter should have means of eliminating mismatches, i.e. learning (increase in the number of connections) and adapting capabilities. As the system's level of training increases, its adaptive capabilities decrease and vanish at the maximum level of imposed connections that correspond to a system with a rigid and determined behavior.

Hence, the flexibility of manufacturing should be interpreted as the

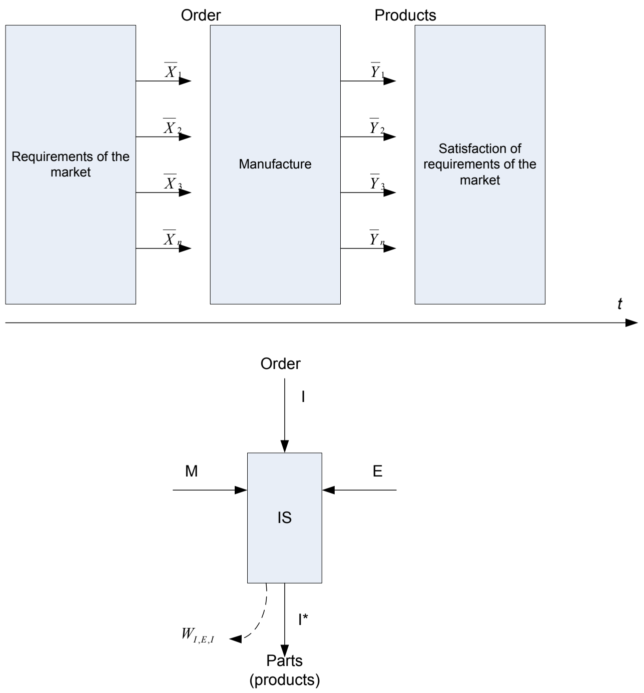

Figure 1: MS purpose: I-information; E-energy; M-materials; W-waste.

ability to adapt a manufacturing system to the changes of incoming orders. It is obvious that the concept of "flexible manufacturing" should be associated with a specific manufacturing system and a specific interval in the time of its existence. For example, the manufacturing flexibility at the metasystem level over a long period can differ considerably from the flexibility of its constituent subsystems and individual systems.

The provided definition of flexibility should not blend the concepts of "system adaptation" and "system change" or the variability (lability) property the system. The system is viewed as set of elements (universe) with certain connections between them (structure). Any substantial change of the universe or structure leads to the emergence of a different system.

The authors consider the suggested conclusions useful for application in the CAD/CAM subsystems that are being developed upon the request of large mechanical engineering enterprises, as well as the enterprises of the automotive and aviation industry.

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