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Modelling of the Collective Decision Making Process for Compact Manufacture Organisation

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Abstract: This paper addresses the organisation and management of compact (i.e. unsuperfluous resources) systems. The definition of compact manufacturing system (CMS) as well as the basic principles and general algorithms of its design are given. It is shown that the difficult task of designing of a system is effectively solved by a "collective intelligence" system using concurrent engineering. The author offers to use the tensor analogy for collective intelligence system development. Thus, production (its mathematical model) is a semantic invariant of a manufacturing sector of its life cycle. The production information description is mapped into the systems of co-ordinates appropriate to the semantic (professional) spaces of the concurrent engineering process participants such as: marketologists, economists, designers, technologists, system designers, operators, sellers etc. Hence, the invariant of a set of the consumers' requirements will be iteratively transformed into consistent constructive, technological and technical (industrial) invariants of production. The offered tensor model of design interaction underlies a tensor database for collective intelligent system computer support. In this paper the practical experience of applying a collective intelligence system to the design of compact industrial systems to manufacture machine building and light industry products is discussed. In particular the compact industrial system on the laser-machining base is examined.

Keywords: collective decision; decision support system; tensor modelling; compact manufacturing system

1. INTRODUCTION

A quick response to change in a market situation and achievement of competitive advantages requires a strategy of maximum increase of a production variety within existing limitations on resources of the manufacturing framework. The known structural, morphological and space-temporary redundancy of traditional flexible manufacturing systems causes not only a quick response in change of the orders stream but also (to a greater degree) a high cost of manufacturing systems creation and operation. Attempts to lower essential expenses of the equipment of manufacturing system have resulted in the "Compact Production" concept.

As shown by Svirsky [1999], the compact manufacturing system (CMS) is a human-machine production complex, which combines a curtailing in space and time with a minimum level of structural and resource redundancy, and supported by highly intelligent means of computer designing and control.

2. CMS ORGANISATIONAL DESIGN METHODOLOGY

2.1 Aspects of manufacture compactness

The creation of such unsurplus manufacture is based on maintenance of various aspects of its **compactness**. The basic parameter of the enterprise operation is the **financial** compactness, which means low cost of highly effective manufacturing process. In this case it is necessary to use CMS at the enterprise, which should exhibit the following appropriate parameters:

- **functional** compactness means effective performance of the most difficult and labour-consuming operations through the automated equipment, and other necessary actions are carried out manually (to reduce the pay-back volume);
- **temporary** compactness provides high efficiency and mobility of the design and technological operations that, in turn, provides essential reduction of a production cycle from the

order reception till its execution (reduction of the pay-back period);

- **spatial** compactness is achieved at the expense of small dimensions of the basic process equipment and results in reduction of the required areas for production zone (reduction of expenses by buildings and structures or rent);

- **information** compactness results in reduction of expenses on design and technological preparation of manufacture by an application of “paperless” technology on the basis of standard program and technical maintenance (reduction of turnaround means with a rather low level of capital expenses).

2.2 CMS organisation principles

To accommodate all these aspects of compact manufacturing organisation, general methodology is based on seven main principles: I) conformity of structure of CMS to its purpose; II) localisation of functional invariants (essentials); III) recursive decomposition of CMS hierarchical structure; IV) functional sufficiency of the CMS components; V) optimal parity of expenses on a functional invariant and variable adapter; VI) evolutionary local change of CMS structure at the expense of the equaliser adaptive reorganisation; VII) reflection of the stages of system development in its structural components.

The principle (I) in the concentrated form expresses that, firstly, the purpose (Z) is the main sister creation factor; secondly, the object in view can be achieved to some extent by the creation and/or use of a set of the CMS structures {St}; thirdly, the selected CMS structure objective is achieved by means of the execution of hierarchically organised functions (F):

$$Z \Rightarrow \{F\} \Rightarrow \{St\} \quad (1)$$

The principle (II) builds on principle (I) to separate common essential (invariant) units of the multipurpose CMS purposes objectives, functions and structures sets:

$$\text{Inv } \{Z\} \Rightarrow \text{Inv } \{F\} \Rightarrow \text{Inv } \{St\} \quad (2)$$

The principle (III) provides the presence of invariant and adaptive modules at each level of hierarchy structure of system:

$$\text{St (CMS)} = \bigcup_{i=1}^N \text{Inv}_i \cup \text{adp}_N \quad (3)$$

The principle (IV) regulates a degree of parametric implementation of any hierarchy level functions (L_f) above a necessary minimum value for CMS purpose achievement ($L_{E \text{ opt}}$), since any exceedance of this value causes an unjustified increase in expenses at CMS creation and maintenance:

$$L_f = [L_f] \Rightarrow L_E = L_{E \text{ opt}} \quad (4)$$

The principle (V) determines the best variant of an allocation of resources at the implementation of the constant and variable parts of the CMS according to their functional importance:

$$\frac{L_3(\text{Inv})}{L_3(\text{adp})} = \frac{R F_{\text{inv}}}{R F_{\text{adp}}} \quad (5)$$

The principle (VI) of the evolutionary approach to the decision of tasks of development and modernisation CMS allows permanent structural adaptation CMS to respond to varied external conditions:

$$\text{St (CMS)}_0 \Rightarrow \text{St (CMS)}_1 \Rightarrow \dots \Rightarrow \text{St (CMS)}_T \quad (6)$$

The principle (VII) together with principle (VI) determines CMS structure in each given moment of its functioning time:

$$f: [\text{St (CMS)}_0 \Rightarrow \dots \Rightarrow \text{St (CMS)}_T] \rightarrow \text{St (CMS)}_T \quad (7)$$

2.3 CMS design algorithmic technique

It was shown by Svirsky [2000] that the process of creation of CMS as a complex technical system consists of three main stages: CMS macro-design; CMS structural and parametric synthesis; CMS adaptive structural adjustment.

The macro-design stage includes a marketing and CMS macro-technical shape creation. The task of marketing research is the definition of the nomenclature of production of CMS normal (profitable) operation during a design period. The search of potentially profitable production is carried out by finding “areas of activity” in the space of economic activity and forecasting of dynamics of their change. As a result of the primary analysis of the market (on the basis of the different information sources), some set of the goods whose production probability will be highly profitable during the design period comes to light. The capacity of target segments of the market is predicted simultaneously.

The selected sorts of production are analysed with the purpose of definition of a degree of their

technological generality. To do this, the standard technological processes of their manufacture are compared. The importance of a technological generality is expedient for estimation, with the help of the relative given expenses on operation:

$$K = C_{M_i} t_i / \sum (C_{M_i} t_i), \quad (8)$$

C_{M_i} - given minute expenses for operation, t_i - absolute duration of operation.

The secondary analysis of the market will be carried out with the purpose of creation of the best set of connected (by technological invariants) sorts of production. The CMS profile is thus formed. At the last stage of the macro designing the CMS general specification is formed.

The structural synthesis is carried out on the basis of the principles of CMS creation and the results of the design stage. The structure of CMS equipment complex has brightly expressed its modular character. During the choice of CMS equipment the task of parametric synthesis is solved. The numerical values of parameters nominals are determined by a functional-cost analysis of the whole system.

After CMS input in operation, a continuous process of perfecting design to meet the varying conditions of the external (market) environment requires adaptive structural adjustment of the industrial system. The procedures of the third design stage in general repeat the first two stages: however their results carry more local character, being limited by changes of structure and parameters of the adapter, not mentioning the unit of a technological invariant. During CMS operation the information on a parity functional and cost parameters of invariant and adaptive units is stored. This allows more precise selection of the best parity of expenses at the implementation of CMS functional units with the help of the principle (VII).

3 TENSOR ANALOGY OF DESIGN DECISION-MAKERS INTERACTION

Production undergoes natural transformation and appears consistently as the object of necessity - object of designing - object of production - object of exchange - object of consumption (maintenance) during its living cycle. It is the main factor of a "production - consumption" cycle. The development and operation of the industrial system represents as an important stage of this cycle. The success of a design solution of the manufacturing system directly depends on complete registration of

the factors influential in efficiency lost during all periods of its operation. And it, in turn, makes necessary simultaneous and agreed operation of many experts. The collective method of designing is rather effective in this situation. It allows an industrial firm to react flexibly to a varying conjuncture of the market and to receive competitive advantages. With collective designing the experts of different branches of knowledge and practical activity will derive the uniform command for shared, agreed operation. The interaction of the adjacent subjects in collective designing has conflict character. And the conflict here appears in an extended sense - as a way of interaction of complex systems. The conflict interactions inside a design coalition have the character of a symbiosis. The problems of understanding, mutual understanding and argument have an exceptional value in these conditions. The process of dialogue with the colleagues has sign character and requires of the subjects of designing to use this or that sign system. The sign systems used by the different subjects have professional specificity and differ, in particular, in the amount and sort of the non-verbal component. The language and non-language sign systems, which are applied with implementation of the design process, are incorporated among themselves by semantic links. Such sign systems connected among themselves will derive a semiotic field. The collection of semiotic fields within the space of which the design activity of the subjects is carried out will derive a local universal semiotic set (Fig. 1).

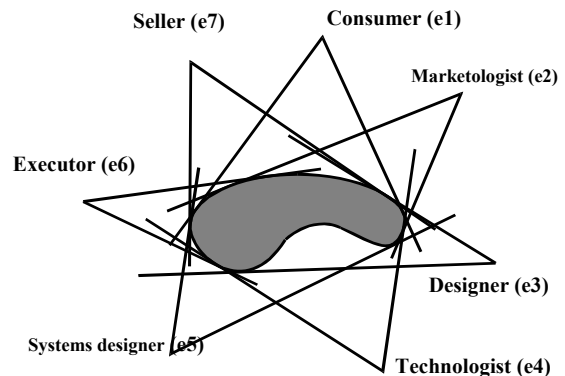


Figure 1. Subject/object model of production cycle

The solution of conflicts between the mutually cooperating subjects represents a semantic invariant of appropriate semiotic fields of a universal set. Thus the semantic invariant of production finds its reflection in semantic spaces of the subjects as professional senses at each stage of a production cycle. It is possible to tell, by geometrical analogy,

that the professional sense of a semantic invariant of production represents some area in the appropriate n-dimension co-ordinate semantic space of each of the subjects.

The transition from one semantic space to another can be formally described with the help of a tensor:

$$e_{i+1} = t_{i+1}^i e_i \quad (9)$$

The acceptance of agreed solutions usually increases general operating time beyond the project owing to realisation of various procedures on co-ordination of shared intellectual efforts and integration of individual solutions. In this situation the problem of design process productivity rise without loss of quality of designing is solved — at the expense of wide use of modern information technologies and computer systems. Through dialogue with the computer in real-time scale, participants of workplace design conferences have real-time access to anyone with the required information and program resources of the firm, and also have the possibility of dialogue with colleagues both inside and outside the firm. For intensification of processes of thinking and information interchange it is useful to use associative units (basic psychological images). Such a possibility is provided by multimedia technology realised in a tensor database.

4 TENSOR DATABASE MODEL

It was shown by Armensky [1989] that the extended tensor algebra is relatively complete. However along with structural transformations of the attitudes (as well as relations) carried out traditionally by relational algebra, the ability of tensor algebra to work with the quantitative characteristics makes this formalism more powerful and appropriate for use in modelling automated designing information systems.

On each design stage there can be difficulties in information system construction. Therefore it is necessary to prepare additional intermediate systems of co-ordinates and special spaces. Generally the object of information system research is the network, which can be described as follows: on accounting set C , on which the binary relation R is ordered. $R \in C \times C$, $x \in C$, $y \in C$ and (x,y) - the order pair. The transformation $F(R) = \sum_{r \in R} F(r)$ is determining. Then a network is a system, in which to tops and edges some sizes are put in conformity, i.e. the functions

$f_1: C \rightarrow x$; $f_2: C \rightarrow y$ are given. The set of all displays differs from initial sets. However any sets with the necessary properties and structures are under construction with use of formed functional space.

Use of the tensor approach for the description of CMS designing process enables us to construct tensors T_i for the multilevel (hierarchical) description of projected object which, at transition from i -level of designing to j -level in view of known dependencies, are transformed with the help of some transformation:

$$M_i^j : T_j = M_i^j \cdot T^j \quad (10)$$

The most abstract structure in the tensor description is the generalised space V as the set of three objects:

$$V = \{L; A; Out\}, \quad (11)$$

where L - тензорный language of dialogue; A - rule, which is a set system of invariant objects; Out - system of a conclusion.

For example, at the description of transition from a product design to its manufacture technology V -the tensor model should consist of two objects $\{I; T_1\}$; I - the set of systems of co-ordinates, on to which projected object by development of technological process is broken down; T_1 - set of tensors, in which, two kinds of the tensors are allocated in turn. $T_1^{(1)}$ - tensors directly describing separate stages of technological process, their property and connection among themselves; $T_1^{(2)}$ - zero-tensors represented by zero-matrixes $M^{(2)} = 0$ in all allowable systems of co-ordinates. On each cycle of technological process development some levels of the description are created: U_0 - level of the description of routing process (consisting of separate operations), U_1 - operational process (consisting of transitions), U_2 - level of the description of a detail, U_3 - description of groups of surfaces (functional modules) etc. Thus there are tasks of creation of intermediate systems of co-ordinates and special spaces. Hence the construction of the tensors of descriptions $T_{\alpha\beta\gamma\delta\dots}$ and tensors of transitions $T_{a_1 a_2 \dots a_n}^{b_1 b_2 \dots b_n \dots}$ is reduced to the description of transitions (rules of display) univalent tensors X_{a_i} to X^{b_j} (i.e. X_{a_i}

$= C_{a_i}^{b_j} X^{b_j}$) specifying invariant object of designing from the various points of view, i.e. in various systems of co-ordinates (see Fig. 1).

A tensor approach to modelling and organisation of information maintenance of intelligence enables a direct transition from one space to another and a "roundabout" way through components of a tensor database of a lower level, i.e. with minimal degree of detailed elaboration (Fig.2).

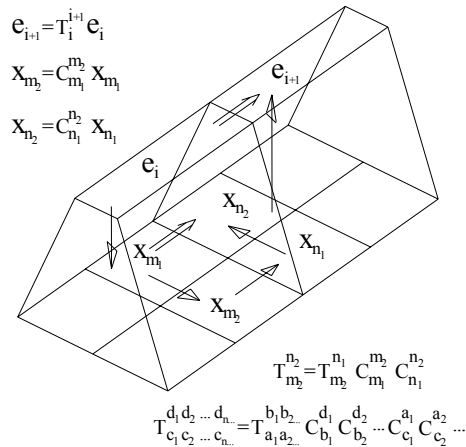


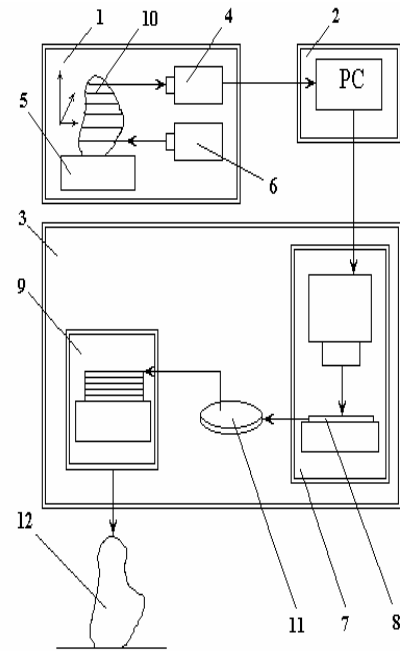
Figure 2. The general circuit of tensor transformations of information spaces

5. CASE STUDY

An application of the offered tensor approach to organisation of "marketologist-designer" on the basis of a "quality functions development" method; "designer-technologist"; "technologist-economist"; and other interfaces in a collective intelligence system was shown by Svirsky et al [2001]. The same system of collective intelligence with the tensor database was used for compact Rapid Production system creation in the CAD Centre at Vitebsk State Technological University.

The lean CMS for small-lot Rapid Production consists of automated equipment of the CAD, Rapid Prototyping, Rapid Tooling and Manufacturing. Reverse Engineering subsystem (Fig. 3) supplies Circulation subsystem (for example sheet-stamping press) with the necessary cheap adapters (dies). The structural adaptation of such an industrial system to the change of a market conjuncture is carried out by programmed adjustment of the Rapid Tooling subsystem on a CNC controlled laser set-up base (Fig. 4) as an adaptive component of an in-line technological

complex of the whole compact Rapid Production system.



1 - an information input module; 2 - an information processing module; 3 - an industrial module; 4 - a video camera; 5 - a co-ordinate table; 6 - a projector; 7 - a laser cutting installation; 8 - a cutting material; 9 - an assembly unit; 10 - an initial (analogue) object; 11 - a cut-out layer; 12 - a ready object (die).

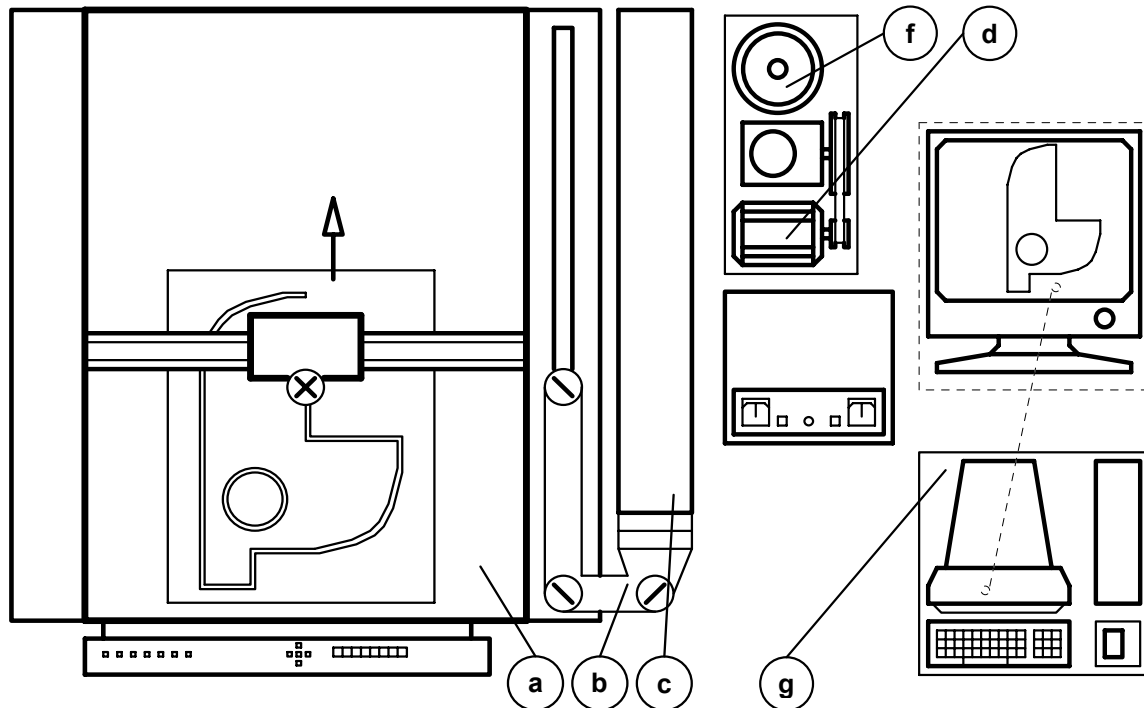
Figure 3. A compact reverse engineering subsystem configuration

The structure of the laser machining subsystem consists of:

- CO₂-laser (power consumption 800 W);
- the optical channel;
- control system (personal computer) for direct conversion of the graphics information about a detail (standard file of graphics exchange *.dxf) in co-ordinate desktop control signals;
- co-ordinate desktop.

The made compact laser machining subsystem has the following technological parameters:

- Processed materials: plastics, wood, textiles, natural and artificial leather;
- Overall dimensions of products: up to 1700 x 1200 mm;
- Width of a source material: up to 20 mm;
- Technological accuracy: about 0.05 mm;
- Technological speed: up to 24 m/minutes;
- Overall dimensions of installation: 3000 x 2000 mm.



a) - a co-ordinate table, b) - an optical system, c) - CO₂-laser, d) - a cooling system, f) - an air-flow system, g) - a control system; the system of ventilation and clearing is not shown.

Figure 4. CO₂-laser cutting subsystem

During concurrent design of CMS on laser machining base, a new method of polymer materials laser cutting was offered by Kuchinsky S.P et al [1999]. It consists in non-metal laser machining process carrying out under water lay (i.e. in steam-gas channel condition). It makes possible both to exclude environment pollution by harmful products of burning and to improve considerably a processing quality.

6. CONCLUSION

Thus the fruitfulness of the tensor approach to the modelling and construction of information system for CMS concurrent design in conditions of collective intelligence is shown. The author's further researches will be directed to the use of agent-systems for CMS designing process complete automation.

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