DESIGN MODELLING AND SIMULATION METHODS FOR COMPACT INTELLECTUAL PRODUCTION ORGANIZATION

Svirsky Dmitry

CAD Centre at Vitebsk State Technological University, 72 Moskovsky ave., 210035 Vitebsk, Belarus, e-mail: *d_svir@mail.ru*

Abstract. The rapid manufacturing of the small serials of the competitive products represents the effective applying of the technological systems of a Compact Intellectual Production. The general technique of compact manufacturing systems designing envisions at the macro structuring stage the localization of commodity constructive invariant, which one together with set of constructive adapters structurally and parametric describes all variety of the production. Then at the optimisation synthesis stage this specification is transformed in the algorithmic specification of invariant and adaptive components of a manufacturing process, which are realized by invariants and adapters of the process equipment accordingly.

1. Introduction

The most probable scenario of a global commercial production progressing in the conditions rapid manufacturing of the small serials of the competitive products represents the effective applying of the technological systems of a Compact Intellectual Production. The firms, which are designing and producing the competitive goods, are ready in any necessary moment to aggregate the intellectual, financial and technological possibilities for reaching a successful commercial result of joint cooperation in a composition of a virtual corporation, introducing the own purposes in the field of production of the new goods and services within the framework of intellectual production. The 'CALS'-means are used in the intellectual production systems for contracting the engineering and production processes realization in both a time and an area by use of Concurrent Engineering and Rapid Production. The difference of the systems of compact intellectual manufacturing from the intellectual production systems in general consists in minimum their function and resource redundancy – i.e. 'compactness'.

The general technique of compact manufacturing systems designing envisions at the macro structuring stage the localization of commodity constructive invariant, which one together with set of constructive adapters structurally and parametric describes all variety of the production. Then at the optimization synthesis stage this specification is transformed in the algorithmic specification of invariant and adaptive components of a manufacturing process, which are realized by invariants and adapters of the process equipment accordingly.

A pattern recognition method is applied on macro designing stage for the allocation of a constructive invariant in each of several sets of potentially competitive production, which are selected in the portfolio. The evolutionary programming is used for the transformation of the constructive invariant of the most favourable set of the goods in a technological invariant and in turn in an invariant of the process equipment on compact intellectual production structural syntheses stage. The optimisation syntheses of the process equipment adaptive component is carried out during all period of compact intellectual production maintenance. The original criterion is used for this purpose. The compact intellectual production modelling result is shown in the report.

2. Praxyological criterion of compactness of production systems

If a manufacturing system is modelled as a 'black box' (Figure 1), then an analysis of the parameter W of transformation of input coordinate X of 'dipole' in its output coordinate Y becomes the most convenient mean for the system efficiency and competitiveness estimation.

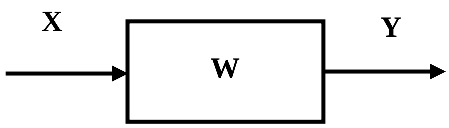

Figure 1. The manufacturing system as a 'black box'.

The variable **X** is interpreted as the flowing raw, power, and labor resources, indispensable for production operation in a given condition. The variable **Y** represents the volume of finish products emitted during a determined period. Then the transfer function **W = Y / X** identifies a ratio of the output (in cost expression) to the current expenditures - i.e. particular index of the production operation efficiency.

If **Y** is esteemed as ‘result of production’ and **X** as a part of ‘expenditures for operatings realization’ (or (technologies) for its manufacturing, then **W = Y / X** in praxyological sense characterizes ‘profitability of the result’ [1]. The differential of the same variables D = Y - X represents ‘usefulness of the result’ and institutes praxyologically the quality of the production system operation for transformation of the resources in final product. This transformation is possible in a decisive extent due to availability and exploitation of an engineering (infra)structure of the production system – the capital fond. Therefore the all-up index with necessity should include the capital productivity. Thus the praxyological criterion of production system efficiency finally is:

$$Kp = (P - Cr)/Cc, \tag{1}$$

where *P*- the product output during a determined period, *Cr* – the expenditures on the flowing resources, and Cc - the expenditures on an engineering (infra)structure creation and maintenance.

Figure 2 shows the communal nature of variation of the efficiency criterion during a manufacturing system life cycle.

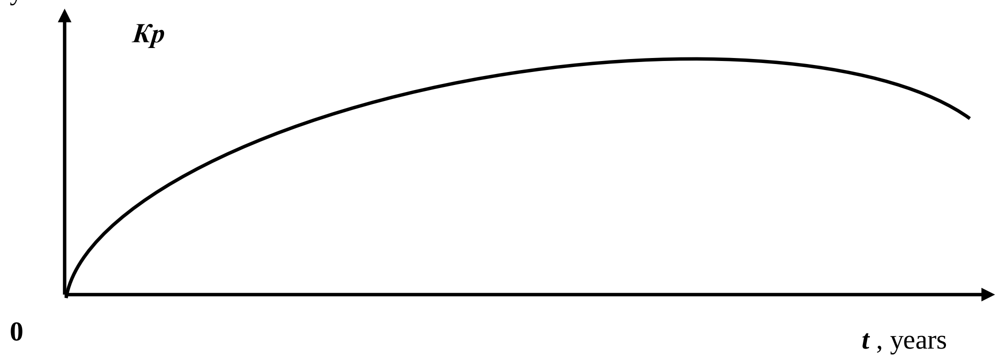

Figure 2. Dynamics of the efficiency index variation

The rate of competitiveness increases from at the stage of development of new commodity and all-up preparing of its production '0' up to some magnitude, on which one its value is stabile during the long-lived period characterized by normal conditions of the manufacturing system operation. In due course the intensity of destructive processes in the capital fond increases that results in magnification of expenditures for keeping it up in a given state, therefore the efficiency index is slashed at same ‘usefulness of result’ in the numerator of expression (1).

There is a concept of ‘an ideal system’ in theory of the engineering systems. It is "a system, which one is not present, but its function is executed". The expenditures for exploitation of a similar manufacturing system would convert a denominator of expression (1) in '0', and the rate of competitiveness would reach as much as large value. The fullest heightening of extent ‘idealness’ can be substantially reached in a compact manufacturing system. If the essence of an ideal system can be formulated so: "from anything - to demanded useful effect", the compact system is a retreat from ideal on a boundary between "anything superfluous" and "from superfluous - to maximal profit" [2].

Even in conditions of oscillating of a market conjuncture and applicable intrasystem variations the functional compactness of a manufacturing system is ensured by the separation of invariant and adaptive components in its engineering structure. Detailing the schema (see Figure 1) of compact system up to 'a gray box' (Figure 3) is necessary to mark the exterior perturbations, affecting at a system - variation of the orders stream f. These variations are perceived by an adaptive component of the system and are countervailed there: f - f = 0, so that the main (invariant) part of manufacturing structure operates rhythmically in a normal given condition.

The organizational design of the compact production is carried out on the basis of following principles:

- Strict conformity of CPS structure to the purpose of its creation;
- Recursive decomposition of CPS structure;
- Localization of functional invariants;
- Functional sufficiency of CPS components;

- Optimal proportion of expenditures for both a functional invariant and a labile compensator at each level of CPS hierarchy structure;
- The evolutionary approach to problem solving of CPS progressing;
- Embodying of CPS progressing stages in its structure.

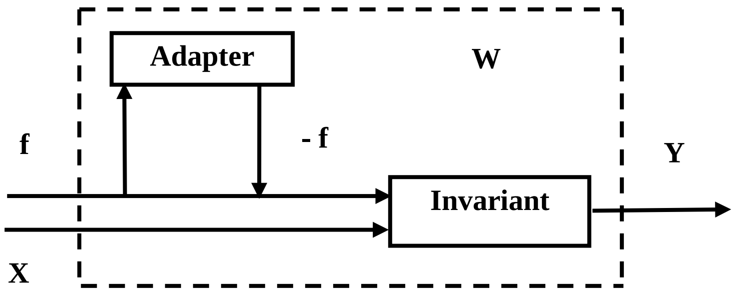

Figure 3. CPS as a 'gray box'

3. Methods of CPS design modelling

The CPS organisational design is carried out in three stages: 1) CPS macro designing; 2) CPS structural syntheses; and 3) CMS structural adjustment (maintenance). The different modelling methods are used on each CPS design stage.

The macro-designing stage includes a marketing and CPS macro-technical shape creation. The task of marketing research is the definition of the nomenclature of production of CPS normal (profitable) operation during designed 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 which production probability will be highly profitable during designed 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 by comparing the standard technological processes of their manufacture. The secondary analysis of the market further will be carried out with the purpose of creation of the best set connected (by technological invariants) sorts of production. The CPS profile thus is formed. Pattern recognition methods may be used for the decision of the tasks of (a) the potentially favourable production set definition on CPS structure formation stage; (b) the analysis of a degree of similarity of structure of typical technological processes of manufacturing of different kinds of production on CPS technical shape formation. As is known, the general problem of objects recognition in optimization statement may be formulated thus: in conditions of the initial description of initial set of objects in language of the certain dictionary of attributes it is necessary within the limits of available resources for the measuring system creation to determine the optimum alphabet of classes and optimum working dictionary of attributes, which at the best decisive rule provide the most effective utilization of the decisions accepted by results of recognition. If both attribute space and alphabet of classes are known, the problem of recognition can be treated as a problem of definition of the best somewhat decisive rules. In this case general problem of recognition is reduced to a choice of criteria and their meanings for making the decision about a belonging of that or other object to the certain class. The example of determining similarity of article configurations for constructive invariant localization is shown in Figure 4.

On the last step of the macro-designing the CPS general specification is formed. QFD-method of ‘quality function deployment’ is used for this task solving [3]. It consists in filling the special matrixes of so-called ‘Houses of Quality’ for correct step-by-step transformation of the consumer requirements to the commodity into the technical parameters of the designed CPS technological modules. ‘House of Quality’ pattern is shown in Figure 5. There are ***N*** ranged consumer requirements in the field (1). ***M*** technical parameters are in the field (2). There are indexes of correlation between the consumer requirements and the technical parameters in the field (3). The indexes of correlation between the technical parameters are in the field (4). The indexes of importance of each technical parameter in accordance with the consumer requirements are in the field (5). The results of benchmarking are in the last field (6). Thus the description of the constructive invariant of the commodity transforms into specification of the technological (and then technical) invariants of CPS.

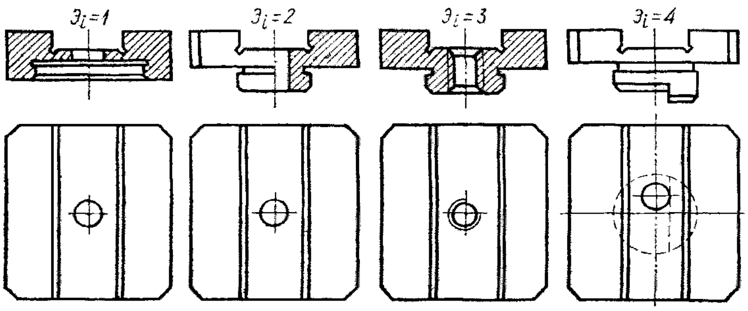

Figure 4. Constructive invariant in the machine parts configurations

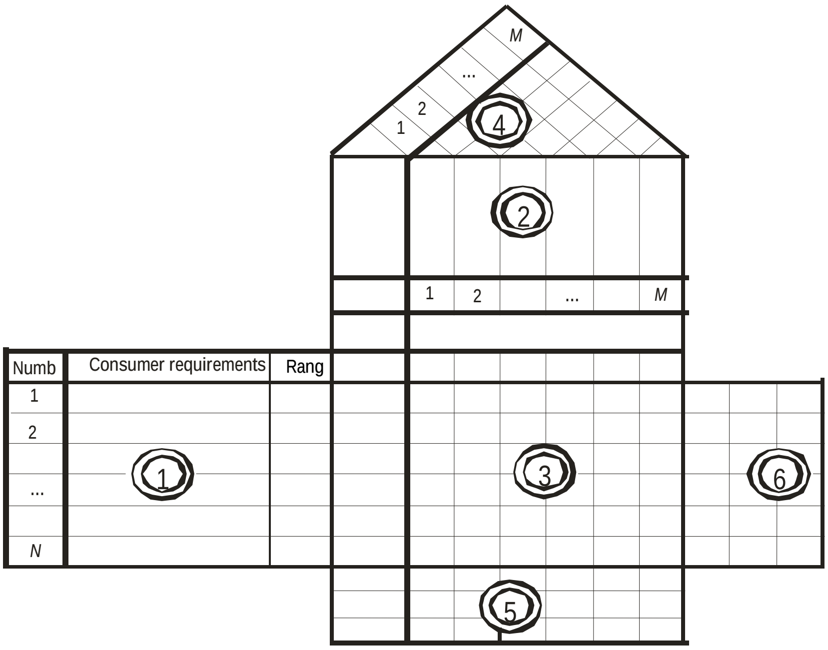

Figure 5. 'House of Quality' pattern

Next design stage – the optimization synthesis of CPS structure is carried out by using of the methods of a combinatorial optimization [4] with the help of criterion (1). The CPS specificity as a new type of the technological systems requires using a new approach to its structure synthesis – the 'group' technology. This conception is based on supporting of an effective existence of systems engineering object – a family of the devices – a set of technological modules, integrated by commonality of the properties and a uniform element base. The main stages of CPS group designing are following: (a) determination of the designed family composition; (b) development of the modules family element base; (c) CPS technological modules synthesis from the element base.

During alternatives generation there are simple situations, when the components of one class are ganged to one or few components of other classes in element base, and more composite cases, when components of each class are ganged to components of all other classes. Therefore the method of hetero-level synthesizing of CPS alternatives is applied. The CPS suboptimization, i.e. balance of its components quality arguments is carried out by using of ABC-analysis. Evolutionary algorithm is used for the generation of CPS design versions is carried out on set of structural components of element base, which covers the generalized parametric space and representing some of its areas confined (from above and from below) by determined values of each engineering (quality) argument.

After CPS initial (base) configuration creation and beginning of its operation the last and the longest stage of system maintenance comes. The CPS design process continuous in form of its perfecting so as the varying conditions of the external (market) environment make necessary 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 [5]. During CPS operation the information on a parity functional and cost parameters of invariant and adaptive units is stored. It allows to select more precisely the best parity of expenses at the implementation of CPS functional units.

4. CPS for rapid small-lot production on small-to-media enterprises

In Figure 6 the general structure of CPS for small-lot production in small and media enterprises conditions is shown. The configuration of CPS on laser machining consists of Rapid Tooling and Circulation subsystems. In turn Rapid Tooling subsystem consists of Reverse Engineering and Rapid Prototyping functional modules. Circulation subsystem as CPS functional invariant realizes the high productive shell-cover technological principle and Rapid Tooling subsystem as CPS adaptive component realizes the flexible technological principle of level-by-level synthesis.

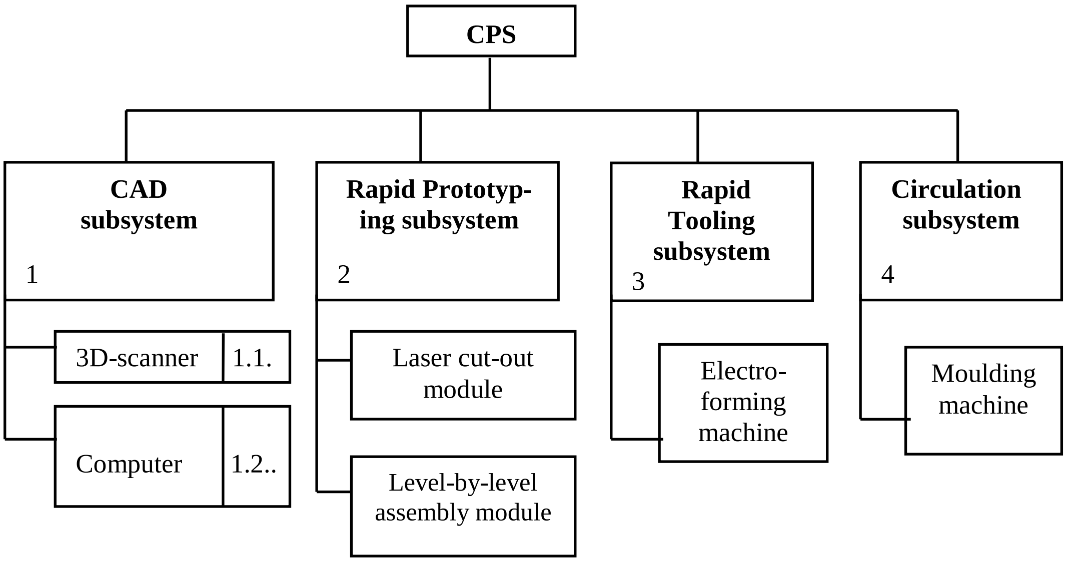

Figure 6. Principal structure of CPS on the laser machining base

5. Conclusion

Different modelling methods are used on each stage of CPS designing process. Pattern recognition methods are applied for determination of the constructive invariant of production set during CPS macro designing. Transformation of constructive invariant into technological invariant is realized by the method of the quality function deployment there too. Combinatorial methods (in particular an evolutionary algorithm) are used during the stage of CPS structure optimization synthesis on praxyological criterion. The structure combinatorial optimization on CPS maintenance stage is confined within adapter technological module. While synthesis of the CPS base structure is carried out with using the group technique for designing the invariant as well as the adapter technical modules.

References

[1]. T. Kotarbinski, *Traktat o dobrej robocie*. Warsaw, 1965, 895 p.

[2]. D. Svirsky, *The compact production system as the object of CAD*. Minsk, 2000, 48p.

[3]. D. Svirsky, "QFD-method integration in tensor concept of collective intellect support system for compact production organization". *Proc. ISQFD'02 Int. Symposium.* Munich. 2002 (www. qfd-id.de/en/events/ isqfd02/abstracts/b4.html)

[4]. D. Svirsky, "Application of combinatorial optimisation methods for the compact manufacturing systems concurrent design". *Proc. XV Conference of the European Chapter on Combinatorial Optimisation*. Lugano, 2002, p. 52.

[5]. D. Svirsky, "Compact integrated system design modelling and its design process simulation". *Proc. 8th IFAC Symposium 'Computer aided control systems design'*. Salford, 2000.