Methodology of The Manufacturing Companies Viability Evolutionary Management[1]

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Abstract

The paper discusses promising approaches to enhancing the efficiency of vertically integrated business entities through deliberate and systematic enhancement of the complexity of components and the internal structure of information control systems, ensuring the required viability level of these entities. This direction is based on the methodology of complexity control, developed by the authors, and forms the foundation of a methodological approach that describes the systematic and evolutionary replacement of operators and technologists as decision-makers with functionally equivalent software and hardware control systems used in existing and future production facilities.

Keywords

control object, «black box», integrated control system, human factor, viability, complexity control

1. Introduction

A manufacturing company is a complex economic activity object (EAO), consisting of a set of interrelated control objects (CO) and control subjects (CS), united in physical, territorial or functional-logical domains [1-3]. The vitality and viability of CO and EAO as a whole is ensured by material-energy and organizational-information components based on vertical and horizontal flows of resources, including material, information, energy and financial, with multiple feedbacks [4]. Coordination of the work of these components is carried out by the organizational and management apparatus that processes internal and external information flows to form control actions. To support the persons who make, justify and implement decisions (DM, PJD, PID), multilevel integrated information and management systems (IIMS) are developed, partially or fully automating their activities.

In accordance with the principle of necessary diversity, the complexity of an IIMS should correspond to the complexity of EAO, which requires the construction of multidimensional quantitative-qualitative models, including digital twins (DTs) [4]. However, the synthesis of adequate DTs, taking into account all functionality and external influences, is often impossible due to limitations of tools, methodological approaches and resources. Additional complexity is introduced by the presence of legacy operational-technological and information technology (OT/IT) systems that provide local automation [2,3].

The current level of technology does not allow to fully formalize the management processes, which necessitates the involvement of cognitive abilities of the DM [5-6], [7]. Their participation is most significant under conditions of uncertainty, multicriteria, incomplete data and insufficient formalization of the subject area. However, erroneous decisions of operators can lead to a decrease in efficiency or accidents, which actualizes the task of minimizing the human factor.

It is proposed to consider its viability (VAb) — the ability to maintain key production and business indicators (marginality, resource intensity, turnover of funds, etc.) at a given life cycle (LC) interval —

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as an integral characteristic of EAO stability (three-component human-machine structure of DM ↔ IIMS ↔ EAO) [4], [14], [13], [15], [17]. At present, there is no generally accepted formalization of VA, which makes it urgent to develop a methodology for the distribution of control functions between DM and OT/IT systems in the evolutionary development of the EAO ↔ IIMS complex.

2. Hierarchy and components of IIMS for complex EAO

It is noted in [5, 6, 8, 10, 11] that the information circulating in the EAO structure and processed by IIMS means can be considered as one of the main types of their resources, allowing in some situations to compensate for the lack of other types of resources. The generally accepted methods of improving the quality of control of EAO and its individual CO as components imply providing them with the necessary sources of quantitative data on the current physical state (Controlled Variable (CV)), acting disturbances (Disturbance Variable (DV)) and required control actions (Manipulated Variable (MV) [1-3,9-11]. At the same time, on the basis of quantitative assessment of vectors CV, DV, MV, using the appropriate mathematical tools, multifactor DT-models of individual CO, technological lines and production domains can be formed and integrated, forming generalized DT [7]. The analysis shows that the more detailed the DTs created for individual CO, as well as for EAO and the corresponding IIMS, the more accurately DTs describe and predict their functioning, and the more efficient and stable the control algorithms work, the less costly and more safe, qualitative and productive will be the functioning of EAO as a whole.

Fig. 1 shows how within the production domain, initially described by the conceptual model as a «Black-Box» (BB) with a set of CO as «nested» functional technological units, quantitative and/or qualitative CV, DV, MV are consistently identified. It is also shown how DT are sequentially (on the basis of incoming information and knowledge of experts and DM) detailed and complicated, which allows the initially opaque BB to «brighten» (formally describe) in terms of understanding the work of its internal mechanisms [4,7,10,11].

For the BB components «brightened» by means of the existing formal methods the necessary models and algorithms are created, on the basis of which OT/IT subsystems are formed as components of IIMS [1], which, in its turn, provides individual CO or entire technological lines (domains) with continuous accident-free operation in automatic (automated) mode with the required performance quality indicators. As a result, there is an evolutionary replacement of human factor in individual IIMS circuits, and the very principle underlying this approach can be formulated as «manage better than the best DM».

In order to develop a methodological basis for correct decomposition of complex CO and technological lines (domains) when building DT and creating IIMS components for processing information flows during the evolutionary replacement of DM, let us consider the existing ways of building the EAO management space in the form of hierarchically related functional subsystems.

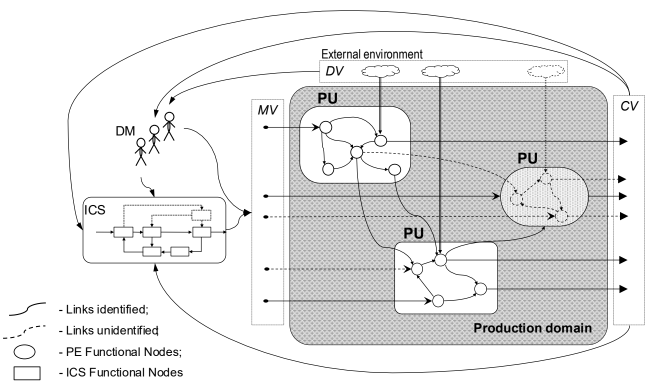

Figure 1: EAO as a «black box», consistently «brightened» by means of complex predictive modeling tools

As an example, Fig. 2 presents a generalized (typical) structure of multilevel IIMS recommended by international standards [2-3], showing the location and rough estimation[2] of the degree of DM involvement in management tasks for a large EAO.

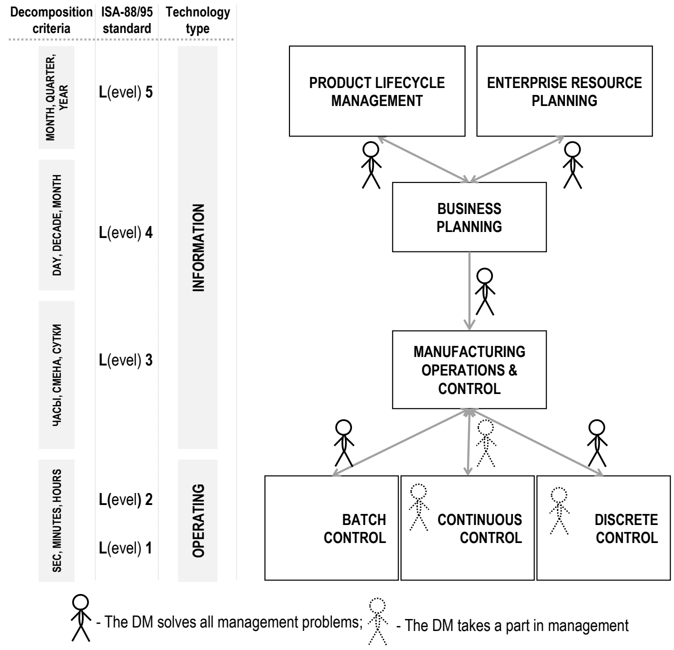

Figure 2: Hierarchical structure of IIMS of a large EAO and proposed criteria for its decomposition by time horizon and management levels

It should be noted that historically the maintenance of EAO in a viable state has been dealt with by a team of DMs of various specializations by processing and analyzing incoming data and information, as well as solving management tasks at all L1...L5 - levels on the basis of acquired knowledge and skills. For example, for L1...L2 - it is maintenance of physical indicators for CO (temperatures, flow rates, pressures, concentrations, etc.) in the established ranges; for L3...L4 - ensuring uniform production utilization by planning the use of its resources and selecting the required indicators of its management, etc.

Summarizing the above, we note that when choosing the place of OT/IT-components to replace DM in the space of control tasks of complex EAO, it is advisable to follow at least two principles: firstly, the quality of information flows processing should be improved due to the creation and use of adequate DT and control models on their basis; secondly, DM should be maximally relieved of the functions of routine processing of the most saturated information flows and regulation by a set of secondary auxiliary subsystems and technological indicators.

3. Methodological approaches to increasing «transparency» of information flow management processes in EAO and IIMS

The development of approaches to increase the "transparency" ("brightening") of the structure of information flow management processes in EAO, which will allow for the formal consideration (describe) external and internal perturbations, will expand the methodological basis for building the IIMS architecture.

Fig. 3 summarizes graphically the information spaces of the three main components of the EAO:

1) «Production domain», consisting of a group of CO1…COn;

[2] The proposed assessment of the degree of DM participation is not exhaustive, but only indicative of the current state of the art for best manufacturing practices

2) «External Environment» as a host of factors, poorly predictable but significant to the effective operation of EAO and its VAb as a whole;

3) «DM» as a set of expert analysts (operators), in specific subject areas, capable of maintaining EAO in VAb state by purposefully compensating (situationally parrying) sets of both external and internal perturbations [5, 6, 10].

In addition, there is a "correction mechanism" by means of which the real production and technological data formed (generated) by CO are compared with the data obtained using Predictive Modeling (PM) tools based on the created DT. Based on the fact of comparison of real and synthesized data, adjustments of characteristics of intermediate DT components are developed for each CO for the purpose of their parametric and structural adaptation and subsequent use in the proactive control of EAO [10].

One of the traditional ways of quantitative assessment of interrelationships of material, energy and information resources and flows within a weakly formalized EAO, aimed at increasing the "transparency" (degree of formal description) of the processes under study, are approaches and methods based on Simulation-stochastic modeling (SSM).

For example, with the help of SSM methods for real technological parameters CV, MV, as indicators of CO and technological lines operation, it is possible in practice to construct response functions in the form of one or a set of analytical polynomials [7, 9]. With the use of these polynomials, it is possible to quantitatively evaluate the relationship between material and information resources and flows for various perturbing influence scenarios with respect to the EAO structure. When applying agent-based logical-dynamic models (LDM), these polynomial dependencies can be replaced by already approximated areas of attainability (A-of-A), the analysis of which allows to identify and predict more complex regularities associated with production activities [7, 10]. At the subsequent steps of EAO and IIMS research, for example, during DT synthesis, the obtained polynomials and A-of-A can be used in the construction and adaptation of DT in the process of functioning of the specified objects and systems.

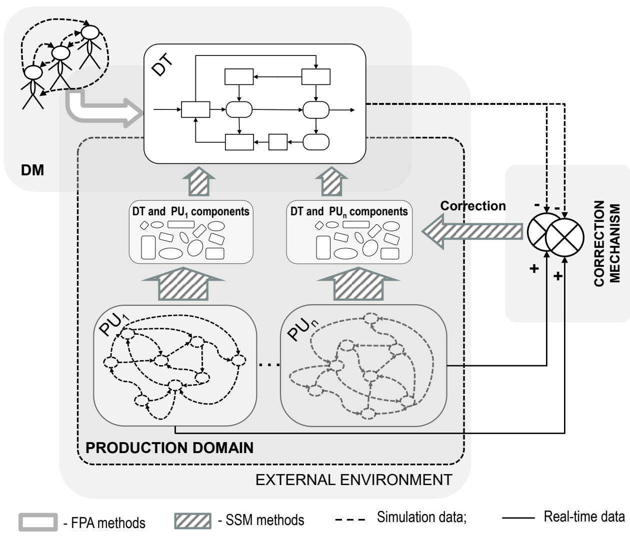

Figure 4: Formation of DT part of EAO by combining SSM and FPM

The analysis shows that one of the most effective approaches to the extraction of expert knowledge and its subsequent representation in a formalized form is the Fuzzy possibility approach (FPA) and the corresponding Fuzzy possibility models (FPM) [9]. Using FPA, it is possible to transform qualitative knowledge of experts (operators-technologists) about internal and external causal relationships in EAO and/or external influences on them into quantitative estimates (e.g., by standard defuzzification means). In this case, the declarative and procedural knowledge of the expert about EAO and IIMS processed by FPA methods, for example, information about DM skills and abilities related to monitoring and control of their components, are also formalized by analytical polynomial(s) reflecting the estimation of real CV, DV when choosing the best MV values. In general, the response functions constructed by the FPA method allow us to obtain quantitative estimates of information flows and processes occurring both in the internal EAO and IIMS circuits (estimation of MV → CV influence) and outside them (estimation of DV → CV influence).

Below (see Table 1), the calculation models used and the proposed generalized interpretations of the results obtained with their help by SSM and FPM[5] are presented for analysis in a summarized form. The analysis shows that the proposed combined application of SSM and FPM[3] techniques in the processing and analysis of real technological data allows to formally describe and link the structures of physical (material) and information flows $CO_1 \ldots CO_n$ EAO, to reveal and practically use the declarative and procedural knowledge of DM about the ways and methods of maintaining the required level of VAb EAO [9,10].

Table 1
Analysis of combined application of SSM and FPM techniques

Methodology		Description
Characteristic	Type	
Type of calculation model for output variables	SSM	Calculated value of the output variable with significant coefficients of the approximating polynomial: $y^{(k)} = b_0 + \sum_{i=1}^{n} b_i^{(k)} \overset{\circ}{x}_i + \sum_{j<u<n}^{n} b_{ju}^{(k)} \overset{\circ}{x}_j \overset{\circ}{x}_u +$ $+ b^{(k)}_{12\ldots n} \overset{\circ}{x}_1 \overset{\circ}{x}_2 \ldots \overset{\circ}{x}_n$ is formed according to the calculation matrix $\overset{\circ}{\boldsymbol{X}} = \lVert \overset{\circ}{\boldsymbol{X}}_{ir} \rVert_{N\times m}, r = \overline{1,m}$, where $m = n + p$; p – the number of nonlinear coefficients; Significance of the coefficients is determined by Student's t-test: $t = \frac{b_m}{s_{b_m}}$, where s_{b_m} - coefficient determination error
	FPM	Estimated value of fuzzy output variable with significant coefficients of approximating polynomial: $\tilde{y}^{(k)} = \tilde{b}_0 + \sum_{j=1}^{n} \tilde{b}_i^{(k)} \overset{\circ}{\tilde{x}}_i + \sum_{j<u<n}^{n} b_{ju}^{(k)} \overset{\circ}{\tilde{x}}_j \overset{\circ}{\tilde{x}}_u +$ $+ \tilde{b}^{(k)}_{12\ldots n} \overset{\circ}{\tilde{x}}_1 \overset{\circ}{\tilde{x}}_2 \ldots \overset{\circ}{\tilde{x}}_n$ is formed according to the calculation matrix $\overset{\circ}{\tilde{\mathbf{X}}} = \lVert \overset{\circ}{\tilde{\mathbf{x}}}_{ij} \rVert_{N\times m}$. The model is built based on the formed fuzzy model significance and validity criteria, and a set of polynomial expansion terms approximating the DM implicit knowledge of the EAO component control.
Interpretation of calculation results	SSM	$\mathbf{y} = \mathbf{f}(\mathbf{x}, \mathbf{b}_0, \mathbf{b}_1, \ldots, \mathbf{b}_n, \mathbf{b}_{12}, \ldots)$ – coefficients reflecting the specifics of mathematical formalization of the EAO component under study, where $\mathbf{x} = (x_1, x_2, \ldots, x_r), r = \overline{1,m}$ – real variables specifying the factor space of CO operation as a component of EAO. The approach is to use real process data procedurally.
	FPM	$\tilde{\mathbf{y}} = \tilde{\mathbf{f}}(\tilde{\mathbf{x}}, \tilde{\mathbf{b}}_0, \tilde{\mathbf{b}}_1, \ldots, \tilde{\mathbf{b}}_n, \tilde{\mathbf{b}}_{12}, \ldots)$ – coefficients reflecting a quantitative assessment of the DM's knowledge, experience and intuition in relation to the job, where $\tilde{\mathbf{x}} = (\tilde{x}_1, \tilde{x}_2, \ldots, \tilde{x}_r), r = \overline{1,m}$ – fuzzy variables specifying the factor space of EAO operation based on DM declarative knowledge. The approach is to use the declarative knowledge of the expert.

As a result, the combination of these techniques results in a structurally and quantitatively maximized "clarified" DT component. It should be noted that the DT synthesized in this way will cover all three participants of economic activity, which is practically unattainable when applying SSM and FPM methods separately.

In general, considering the processes of complex predictive modeling (including SSM and FPM) as controlled processes, it is possible to approach the solution of all major problems of evolutionary redistribution of functions in the studied automated (human-machine) EAO control systems at the constructive level. For this purpose, the works [7, 10] proposed specific ways to realize the concept of complexity management based on the system-cybernetic methodology, which implies the use of combined models, methods and algorithms for narrowing the diversity of the external environment and

[3] For a real object, the set of “input” variables $\mathbf{x}$ and the set of «output» variables y can be either CV or MV, depending on the problem statement; the set DV can be mapped as $\mathbf{x}$ only.

expanding the diversity of the controlling side on the basis of proactive control of the structural dynamics of the considered man-machine systems [9, 10, 12].

4. Evolution of DM tasks in the creation of model-centered IIMS components

The analysis has shown that the creation of Advanced Process Control (APC) and Real Time Optimizer (RTO) on Real EAO is evolutionary, as a targeted request from business users emerges to improve the efficiency of individual CO and/or process lines [2, 3, 9, 10]. However, in practice, the formation of plans for their implementation is often spontaneous, without a deep methodological justification of the sequence of implementations, component composition of APC/RTO, and extensive coverage of technological objects.

The obligatory technical condition of APC creation is the readiness of components of information CV/DV/MV -flows of L1-level to be included into control models of L2-level, which is actually one of the stages of "brightening" CO as BB and redistribution of control functions between DM and IIMS. The condition of RTO creation is the presence of a group of n CO in the technological line, controlled by their own APCs, the operation of which should be determined by a single production and economic target function. For industrial EAOs, such targets include, for example, maximum productivity, production margin, minimum energy consumption, etc., as well as their combinations.

Fig. 4 presents a generalized map of the evolutionary transformation (or, in other words, development management) of different types of IIMSs depending on the complexity of DT and control models, the saturation of information flows handled by automatic OT/IT subsystems, and the number of EAO components covered.

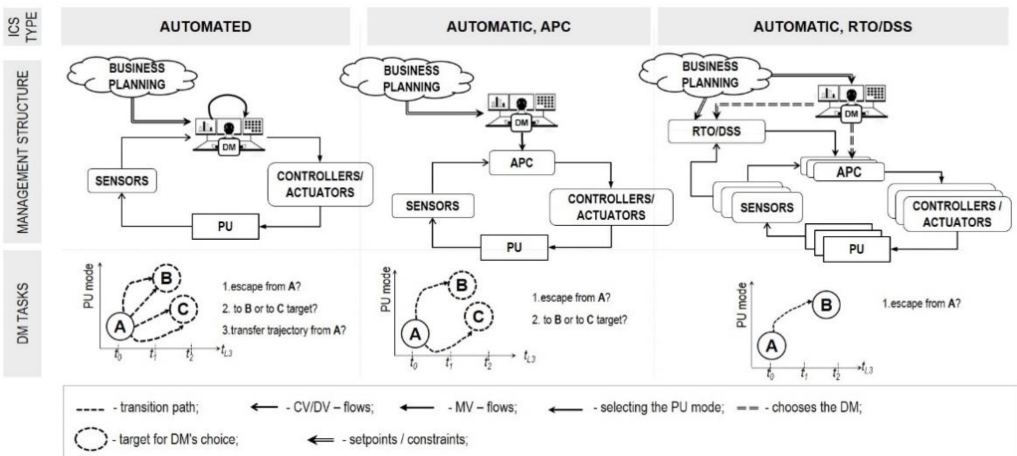

Figure 4: Types of IIMS, structures of their construction, management tasks to be solved, place and role of DM

Fig. 5 shows the qualitative graphs obtained in [9] and reflecting the influence of typical modes of IIMS operation, which are at different stages of evolutionary complexity, on the cost of products:

1) the upper graph shows the modes of CO operation when maintaining the target "Process Indicator", characteristic of the modes "Manual," "Automated," "Automatic, APC," and "Automatic, RTO/DSS."
2) the lower graph shows the specific Cost levels that correspond to the CO operating modes displayed in the upper graph.

Both graphs together illustrate how the dynamics of the evolutionary increase in IIMS complexity from "Automated" to "Automatic, RTO/DSS" increases the so-called "Cost margin".

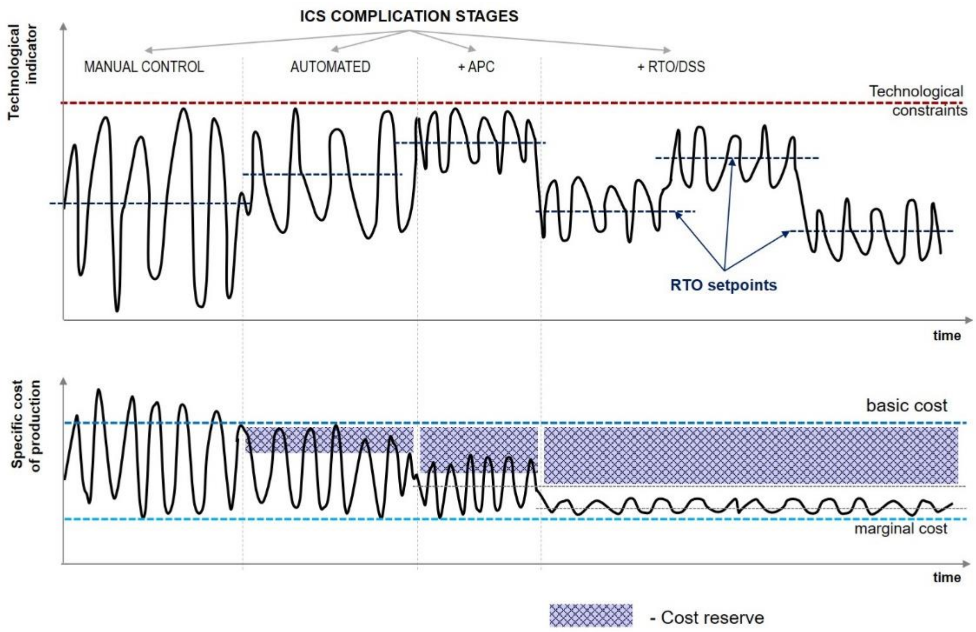

Figure 5: APC (L2) and RTO (L3) are cost management tools as a factor of VAb

The presented correspondence between the IIMS complexity category and the "Cost margin" for a CO (in real production - a group of n CO) implies the possibility to keep its level consistently minimal for the longest possible period of time. This possibility is provided by the IIMS ↔ CO complex, which automatically reconfigures the operating modes of $CO_{1...n}$ to keep Cost at the lowest possible levels following changes in the external conditions for EAO by means of RTO/DSS + APC as tools.

The graphs presented in Fig. 5 show that managing the evolutionary increase in complexity of the IIMS ↔ CO complex allows for the eventual effective implementation of measures to maintain EAO key performance indicators (e.g., Cost) at the required target level. In this case, the generalized EAO performance indicator, as which we consider the VAb indicator, also becomes manageable, since the Cost indicator will be a component of it.

5. Conclusions

The paper presents the results of further development of the complexity management methodology. As promising approaches to solving the problems of multistage redistribution of DM functions of prospective automated control systems for complex technical objects, it is proposed to use the full range of classical and complex predictive modeling. This approach will allow not only to describe at the constructive level difficult to formalize processes of operator control of technological processes, but also to relate the generalized indicator of VAb of EAO and its IIMS to the private performance indicators on the basis of the original fuzzy-possibility convolution [12]. The obtained results can be used in the creation and modernization of advanced monitoring and control systems of complex agro-biotechnical objects. First of all, when redistributing the functions between the agronomist and IIMS.

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