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FORECASTING THE DEVELOPMENT OF COMPLEX SYSTEMS ON THE BASIS OF SIMULATION MODELS

The paper considers theoretical and applied problems of the elaboration of simulation models for prediction and optimal development of generalized production systems that create material products and services. An essential difference of this work from the analogues consists in that model of development is viewed not as a reflection of the real object development but as a standard to create a new object. Accordingly, the technical system development process is viewed as a parallel interrelated development of the virtual and real systems. The system of models that simulate interrelated development of the system and its model is built.

Key words: *prediction, optimal development, simulation model, working model, fuzzy model, metamodel, generalized production system, vectorization.*

Problem statement. Formally**,** many of the modern technical systems have no statistics, i.e. it is sufficient to have long stability intervals and corresponding statistical series. In recent years, development is becoming more innovative. There is a class of models that are not observable in the popular modeling science – models-hypotheses, models-projects for systems that have not been created yet. Large volumes of manufactured products require modeling as a means of planning and prediction. Constantly there are situations when large batches of cars, laptops and food products appear to be harmful and dangerous. It is natural to eliminate such risks at the stage of simulation modeling of a new product, new technology, new production system. Modeling of the development is a field of mathematical modeling that lacks an effective and specific problem statement. Book [1] still remains an example of a rational approach. It considers the properties of the developing systems, formalized representation and study of which requires creation of new models of dynamic systems. A new class of dynamic models based on nonlinear integro-functional equations with prehistory is introduced; the problems of modeling the distribution of resources between sectors are investigated.

Problem statement. The work is aimed at the creation of models to be used in the decision making support systems. The term development is a polysemantic one. We will stick to environmental interpretation. Actually, the problem is to break through the traditional paradigm: "a model is a reflection of the modeling object properties" that are important for the researcher. For development processes a model is a standard for the object, virtual reality, the essential features of which should be reflected in real production systems The situation when an imitation model is elaborated first and then the object is created is a rule rather than an exception in engineering practice. Simulation model of an enterprise development process must reflect not only the current state of the modeling object but also possible future states among which optimal and impermissible ones are searched for.

The choice of basic model of the generalized production system

Today a simulation model is not complete without a comprehensive simulation model of the external environment. Therefore, the following solution is chosen: we simulate not only given production but the entire system of producers of a certain segment, e.g. cosmetics, spaceships, airliners, buses. We also include the models of choosing and learning the consumers into the system of models. The latter is determined by the fact that globalization and hyper proposal are the main problems for production systems today. Thus, the model of an enterprise is imbedded into the model of the system belonging to the class of "N producers, M products, K consumers" systems. Such approach could be considered to be a specific case of the invariant imbedding method. The MNK system model is formed as a set of models, ordered by a three-level decomposition of the "full model" into functional, structural and reduced submodels. In this work the optimum aggregation method is used as one of the methods for obtaining reduced models that enables replacement of the production element system by an equivalent optimal element. [4, 5].

The last point of the basic model conception is as follows: instead of building the models – statistical data approximations, we build models, based on the fundamental laws of the subject area, on the mechanisms that generate the observed distribution of characteristics of elements in the systems of producers. Statistical data are involved at the stage of model verification. This methodology belongs to Forrester [2, 3]. Usefulness of the proposed concept of the production system basic model and the possibility of its implementation were verified by the created complexes of basic models and simulation results. The simulation models are intended mainly for active prediction, search for desirable yet rare development processes that have not been observed in reality and taking careful inventory of the numerous catastrophic development options that have not been also observed so far. No direct analogs of the proposed models were found in the available contemporary literature.

A way of solving the problem. At present, such methods and technologies are required, that enable creation of new models for new problems within 2 -3 months rather than 20-30 years. The chosen concept of a generalized working model of the "producers – products – consumers" system allows a substantive discussion of the problem of "simulation object – development model" interaction process using definite models. This gives rise to a new level of simulation: creation and analysis of the metamodel of MNK systems – the process of changing the MNK system models in time.

Two classes of processes in the "model – object" system

Unlike the models that represent real existing objects or processes, innovative development models belong to different pragmatic classes. Let us call these classes as follows: 1) descriptive models describing an existing real object; 2) prescriptive models that prescribe what a future object should be. Fig. 1,2 present schemes of the processes of the two classes [6]. These plots are calculated by the first-approximation models. These models are intended for transforming a verbal description of the development processes into the quantitative model at the very beginning of elaboration process. "The mechanism" that lies in the basis of this model is "probabilistic growth restricted by random laws of probability and fuzziness distributions".

Fig. 1 represents the following scenario: a production system is adjusted and produces goods steadily. Arrows show information exchange between the object and the model.

The scenario represented in fig. 2 is as follows. For an innovative project a simulation model is created that starts giving information for the model correction and refining the object design. At the beginning of the production system creation solutions of many problems are found using the model, information exchange is performed as well as mutual adaptation of the model and the object. The model achieves a satisfactory level of adequacy.

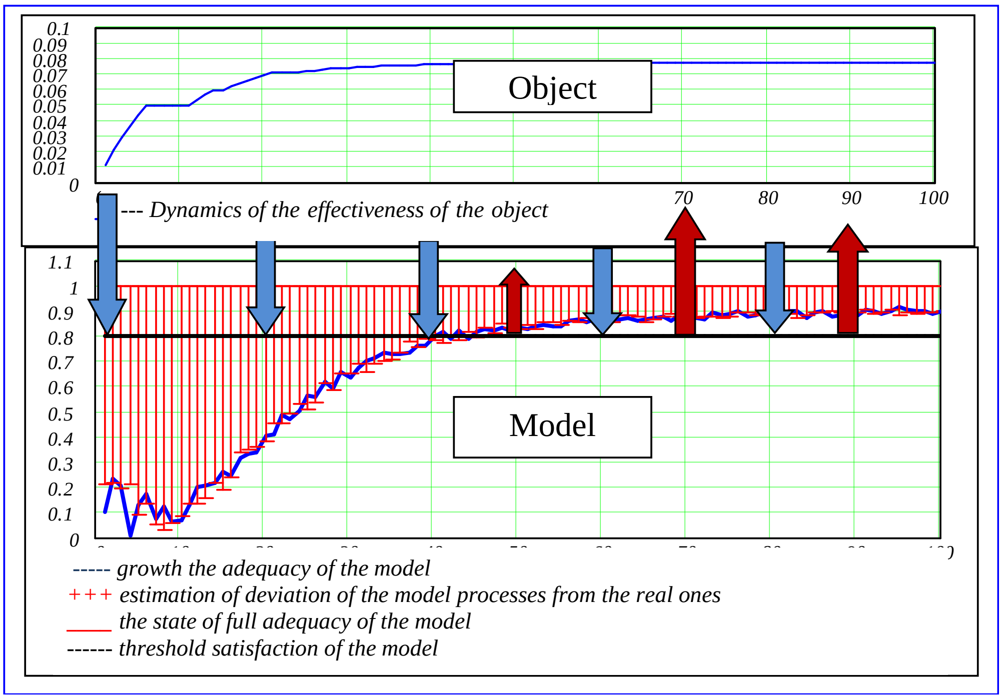

Fig.1. The scheme of the “existing object model construction” process

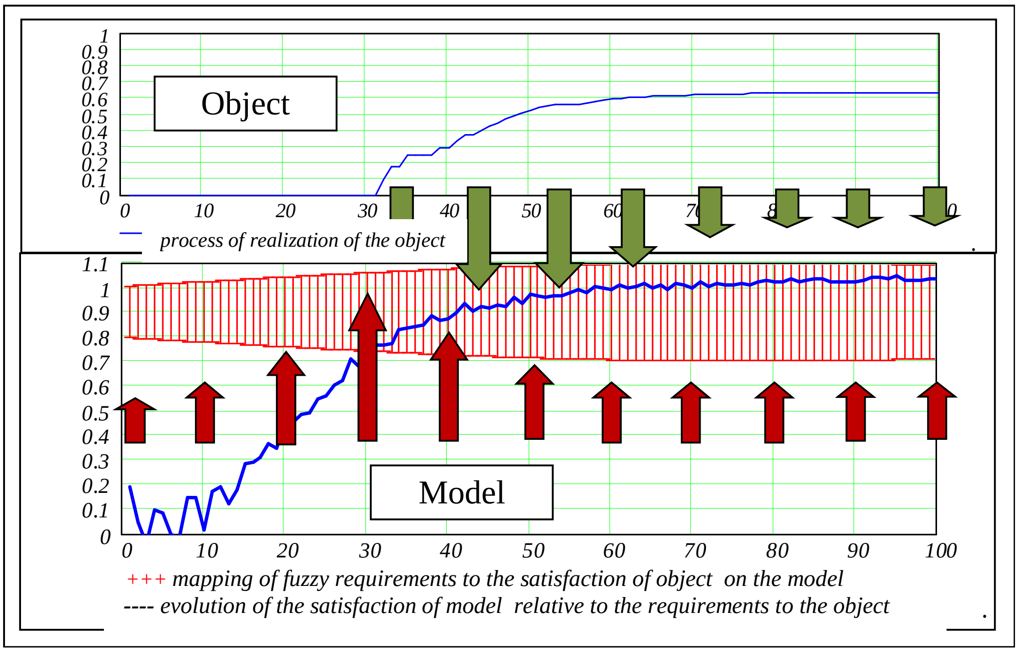

Fig. 2. The scheme of the “ construction of the new model for the new object” process

In the construction of mathematical models for new objects numerous uncertainties and disturbances dominate. At the same time, multiple processes of learning and development are observed. Into the second-approximation model we introduce such factors as “novelty” and “mastering” given by the coefficients $\beta 1$ and $\beta 2$ correspondingly. These coefficients are normalized: $0 \le \beta 1 \le 1$, the value $\beta 1 = 0$ corresponds to novelty of the engineering system while $\beta 1 = 1$ – to the absence of novelty; the range for real systems: $0.80 \le \beta 1 \le 1$. Similarly, for mastering: $0 \le \beta 2 \le 1$, $\beta 2 = 0$ – «instantaneous” mastering, $\beta 2 = 1$ – absence of mastering, for real systems $0.80 \le \beta 1 \le 1$.

Deterministic model of the “model-object” system development

In the first approximation of the development model construction we gave qualitative description of the informational interconnections of the model and the simulated object. In the second approximation we detalized these connections and build deterministic quantitative models of the connections. Fig. 3 shows the diagram of these connections.

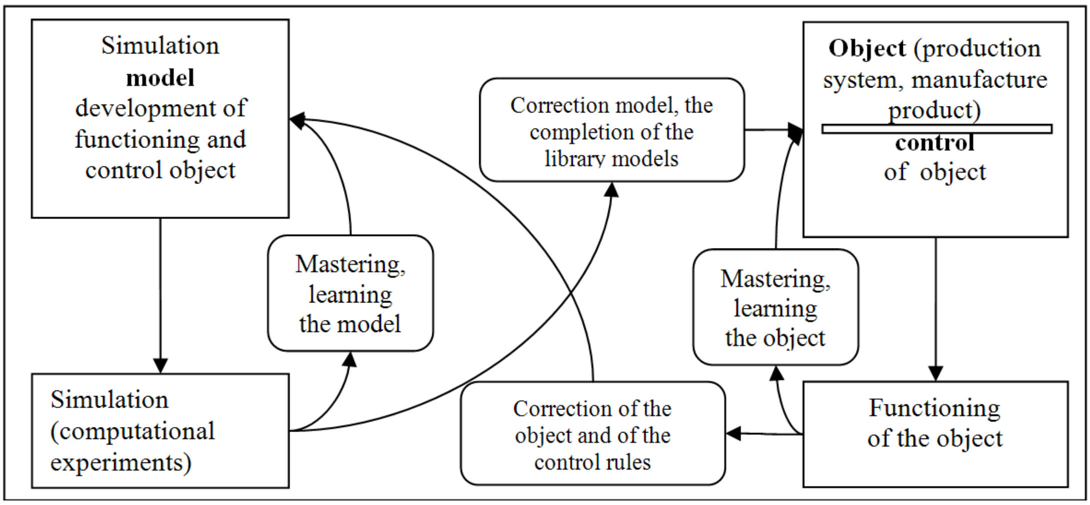

Fig. 3. Diagram of the informational exchange in the “model-object” system

Deterministic continuous model of the production system model construction is elaborated on the basis of the diagram shown in fig. 3. Variables and functions: $x1\,(t)$ – level of the model satisfiability, $0 \le x1(t) \le 1$; $x2(t)$ – level of the production readiness for manufacture products, $0 \le x2(t) \le 1$, $fmm(x1(t))$ – function of the influence of the achieved level of the model on the model growth rate; $fpm(x2(t))$ – function of the influence of production on the model level rate; $Inm(t)$ – the development costs rate. The model of the object model development is given by

$$\frac{d}{dt}x1(t) = fmm(x1(t)) \cdot (1 - x1(t)) \cdot Inm(t) \cdot fpm(x2(t)). \qquad (1)$$

Deterministic continuous model of the production system development. Variables and functions: $fpp(x1(t))$ – function of the influence of production on the production system level rate; $fmp(x2(t))$ – function of the object model influence on the production system level rate; $Inp(t)$ – the rate of costs for the production system creation. The model of the production system development is given by:

$$\frac{d}{dt}x2(t) = fpp(x2(t)) \cdot (1 - x2(t)) \cdot Inp(t) \cdot fmp(x1(t)). \qquad (2)$$

Deterministic model of the “model-object” system. We create working models that are run in the mathematical package environment. One and the same expression may have different definitions in this environment. Let us introduce designations for the right-hand part of the equations (1) and (2):

$$F\,\mathrm{mod}(x1, x2, fmm, fpm, VPm) = fmm(x1(t)) \cdot (1 - x1(t)) \cdot Inm(t) \cdot fpm(x2(t)), \qquad (3)$$

$$Fprs(x1, x2, fpp, fmp, VPp) = fpp(x2(t)) \cdot (1 - x2(t)) \cdot Inp(t) \cdot fmp(x1(t)), \qquad (4)$$

where fmm, fpm, fpp, fmp – functions of feedback and cross-links in the system; VPm, VPp – vectors of the model parameters: "first the model – then the object”. Let us write difference equations of the system:

$$\begin{pmatrix} x1_{k+1} \\ x2_{k+1} \end{pmatrix} := \begin{pmatrix} x1_k \\ x2_k \end{pmatrix} + \begin{bmatrix} F\,\mathrm{mod}(x1_k, x2_k, fmm0, fpm0, um, k) \\ Fprs(x1_k, x2_k, fpp0, fmp0, up, k) \cdot (k \succ) 40 \end{bmatrix} \cdot \Delta T. \qquad (5)$$

Fig. 4 shows examples of the development processes obtained using model (5). They are: weak cross-links, 2 – strong influence of the object on the model, 5 – strong influence of the model on the object, 3,6 – creation of the model with different intensity of cross-links.

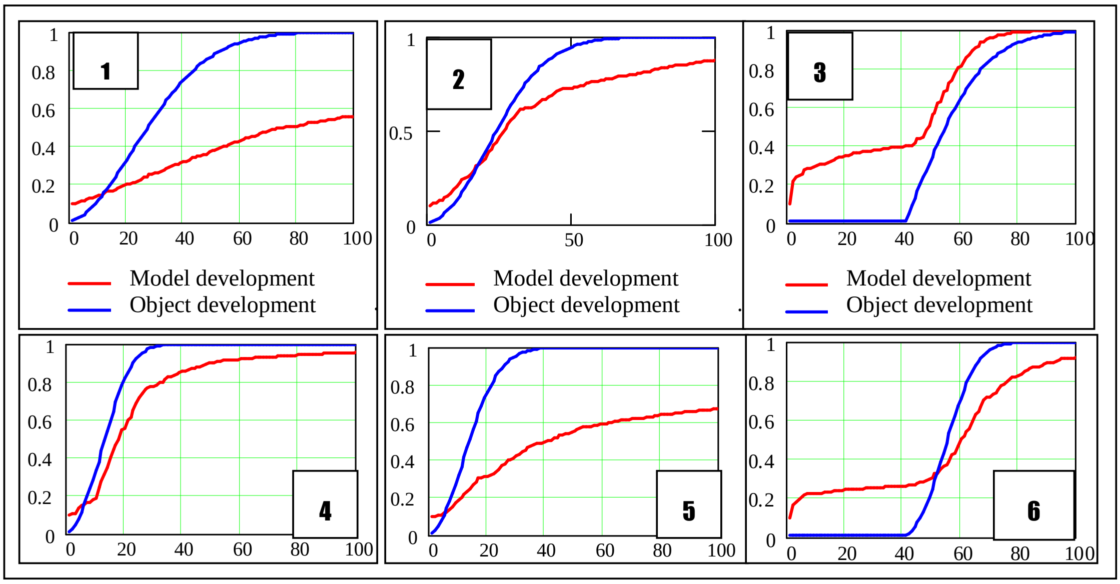

Fig. 4. Examples of the “model-object” system modeling

Taking into account the realities of the creation and development of new production system has led to the new statement of the problem of development process modeling. As the object of the development process a “model-object” system is considered. A basic working model of such system is built. The obtained simulation results correspond to the empiric data. The proposed approach and model correspond to the trend of simulation model and production system integration.

On the basis of the deterministic model we create and study a model based on fuzzy logic. The model of the model construction process is not an orderly hierarchical level of the model of a distributed production system, i.e. a metamodel. A distinguishing feature of modeling the innovative development processes consists in the following: first a model is created – a way to fast, inexpensive and safe testing of the development variants. A detailed complex model of functioning and development of the production system as an interpretation of the abstract development model is built. In the framework of this paper, the metamodel is a metaprocess of the model system development, its final state being a satisfactory realizable model of the distributed system innovative development.

Software programs are recognized as a type of industrial products. In fact, models-predictors are type of industrial products – there is such sector as a “model business”. At the stage of product manufacturing the link between the model and the object is quite a concrete one: the model is a replacement of the object when dangerous testing and search for new solutions is performed. At the production system level “the model of production system operation – the production system” links are probabilistic and fuzzy.

Practice requires answers to two questions:

– Which variant to choose: to start with production system construction or to create a simulation model first and then, on the basis of simulation results, to create the production system quickly and accurately;

– to what extent the model is adequate to the future system.

The models of this work are intended for answering these questions.

An example of this research implementation is production of agricultural machinery for small farms at an enterprise of the defense sector. Provided that this production is compatible with the available technological base of the enterprise, the former leads to a considerable increase of its efficiency. But demand for such production is essentially uncertain and short-term while designs and technologies of small agricultural machinery must be constantly updated. Without rational development management such by-production is guaranteed to cause losses. Optimal risk management gives guaranteed average profit. Therefore investigation of the links in the "model-object" system is practically important while theories give rise to a new approach toward the development as to the process of co-evolution of the model and the object.

Technology of the system fuzzy model construction

Links in the 'model-object" system are mainly informational, probabilistic, fuzzy, non-linear, but they have quite accurate verbal description. Metamodel of the development process was built in three stages:

– development of separate models of the object development and of the model development;
– development of deterministic model of the "object-model" system;
– development of probabilistic model of the "object-model" system.

Technology for designing probabilistic and fuzzy influence functions is elaborated:

– influence function $fp(X)$ is defined in the area $0 \le X \le X\max;\ 0 \le Y \le Y\max;$

– distribution of probabilities $dp(X)$ or of fuzziness $df(X)$, are determined by the dependence of distribution parameters on variables *X*, *Y*:

$$dpr(X) \Rightarrow dpr(X, Vpp(X, Y)); \quad dfz(X) \Rightarrow dfz(X, Vpf(X, Y)), \tag{6}$$

where *Vpp*, *Vpf* are vectors of the parameters of corresponding distributions.

Operators (program modules) of transition from deterministic to probabilistic function are assembled

$$Y = fp(X) \Rightarrow fpf(X, Y), \tag{7}$$

where X, Y – values of input and fuzzy initial variables. fpf – a normalized probabilistic (membership) function. Fig. 5 shows an example of the simulation results.

Composite "model-object" systems are aggregated one-dimensional models of the object and model development, their state variables being the levels of the model and the object completeness. The next stage of the research and development is the construction of two versions of the closed model from the class of MNK models.

On the basis of the fixed sequence of stages of the system creation process we elaborate a detailed metamodel of building simulation model of the "producers – products – consumers" production segment. This model simulates functioning of each producer, product and consumer. Dimensionality of testing systems was: 10 producers, 100 products, 1000 consumers.

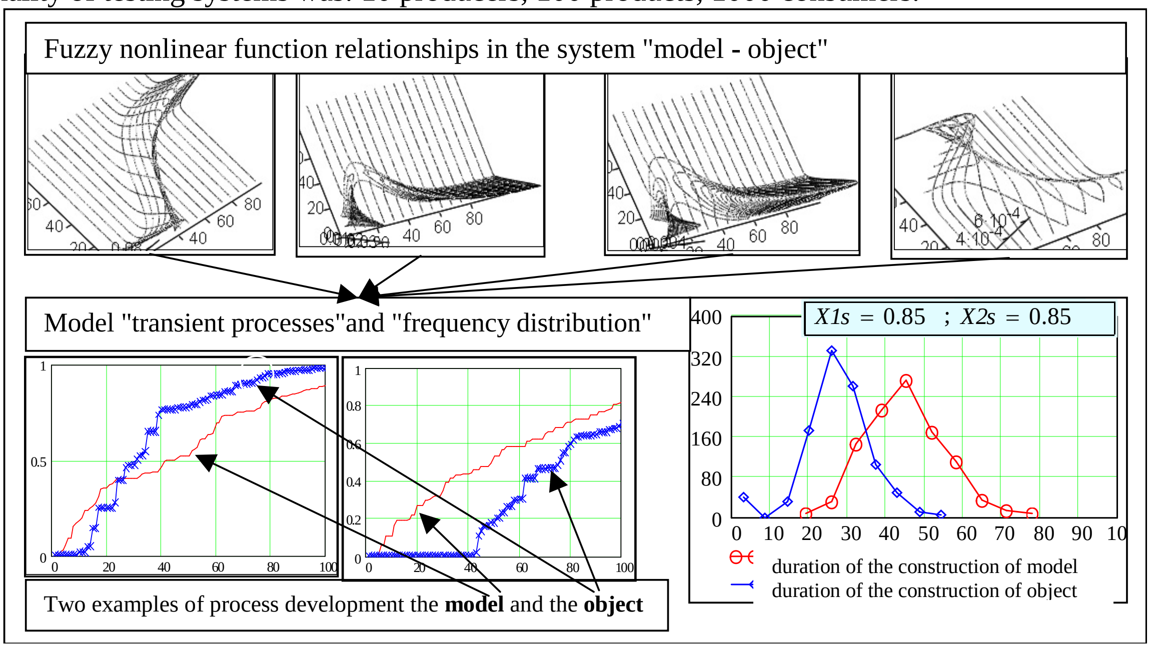

Fig. 5. Fuzzy metamodel of the development process. An example of simulation results

Registration and control of each product and each consumer functioning is a routine practice in many segments of production: aircraft manufacturers, autocarriers receive on-line information; at their own supermarkets manufacturers receive data about each of the buyer having a card. This information is used for analysis, prediction and planning. Those data become more informative and reliable being simultaneously represented in a simulation model. A production system that does not study its users, teach them and learn from them is doomed to degradation.

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