From Classical Systems Thinking to Modern Dynamic Systems Theory: Beyond the System Modelling, Analysis and Behaviour Interpretation

PhD. stud. eng. inf. **Bogdan CIORUȚA**[1,2*], MA stud. **Alexandru LAURAN**[3,4]

[1] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Department of Informatics, Office of Informatics, 62A Victor Babeș Str., 430083, Baia Mare, Romania; bogdan.cioruta@staff.utcluj.ro

[2] Politehnica University of Bucharest, Faculty of Applied Sciences, 313 Splaiul Independenței, 060042, Bucharest, Romania

[3] University of Stavanger, Faculty of Science and Technology, Kristine Bonnevies vei 22, Stavanger, Norway

[4] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Faculty of Science, 76 Victoriei Str., 430122, Baia Mare, Romania.

Abstract: *In many practical cases the excitations acting on a system or structure are random in nature, and as a result the response of the system or structure can no longer be satisfactorily described and quantified. From Classical Systems Thinking to Modern Dynamic Systems Theory, beyond defining and understanding the conceptual delimitations of system, respectively the system structure, properties and classification, there followed a series of papers that focus on the system analysis, modelling and behaviour interpretation. In the same context, the mathematical model of a system - as a set of mathematical relationships and equations that allow the description of system behaviour, input-output or input-state-output transfer - is presented. A wide range of models associated with the systems, based on which the behaviour of the systems is analysed and interpreted, are also presented.*

Keywords: *Dynamic Systems Theory, system modelling, specific system behaviour, model analysis.*

1. Introduction

In many practical cases the excitations (as part of perturbations) acting on a system or structure (physical, real) are random in nature, and as a result the response of the system or structure can no longer be satisfactorily described and quantified, in deterministic way [1]. Thus, the excitement induced by the unevenness of the road on a car moving at a constant speed (Fig. 1), earthquakes, turbulence in air or water, the action of wind or waves are just a few examples of excitations (although at first glance they are considered simple events and / or phenomena) which by their nature give the systems and structures with which they come into contact a random character.

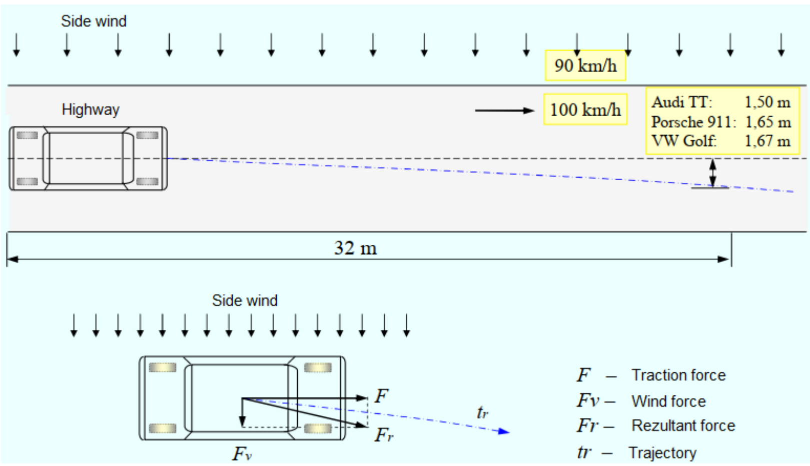

Fig. 1. Schematic representation of the excitement induced by the side wind on a car moving

As far as systems theory is concerned, this is still a very current field of science; many articles have been published in this field in specialized magazines and many books in prestigious publishing houses. For this reason, no matter how perfected the modern means of information, it is

practically impossible to keep up-to-date information in this field, to select and write this information, starting from definition and classification in a form easily accessible to the general public [2, 3].
Writing about a field of great relevance, such as systems theory or, as the case may be, dynamic systems [4, 5], is, from this point of view, a great risk, because by its nature the information is, at least, at least partially outdated at the time of publication. Aware of this shortcoming, we tried to arouse the interest of the general public for a current field of science, through the synthetic exposition of the main results obtained - see an example in Fig. 2 [5].

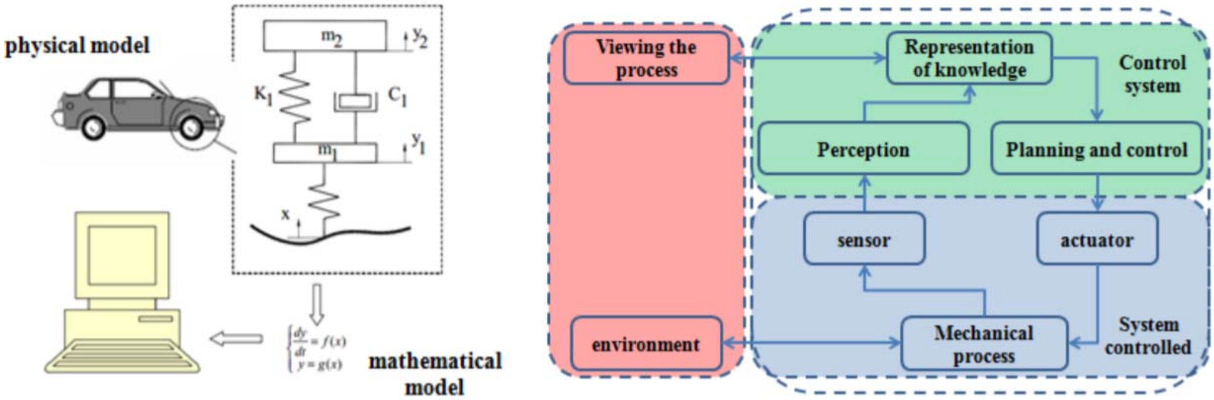

Fig. 2. Schematic representation of dynamic model analysis in relation to Dynamic Models Theory

Without being a popularization study, this material presents in addition to a series of mathematical statements, which are still taught in some of the faculties of technical higher education, with reference to systems theory and their characteristics. Systems theory, together with its consequences, is reflected in current technical sciences, and not only, as a new point of view, as a new integrative approach. Until recently, some researchers believed that the secrets of nature, and implicitly of the associated shadow technique, are in the microcosm and competed to discover elementary particles of matter (carriers of energy and information), while others have sought in the macrocosm, in the world of galaxies, black holes and other formations in the vast universe, and both leaving the environmental world in which we still live. Both considered that they were at the top of modern research, not taking into account the research of those who dealt with the phenomena of the environmental world.
This paper is part of the introduction to Dynamic Systems Theory and analysis of their behavior, being dedicated to familiarizing the reader with the diversity of fundamental concepts and development stages specific to Dynamic Systems Theory, respectively with a review of definitions and characteristics of existing systems in the literature [6, 7]. Also in this study found a natural place and a presentation of the properties that systems can meet, respectively a non-exhaustive classification of models, starting from the systems they represent in an abstract form, depending on their linearity. , the reporting to the time variable, the number of input-output variables, the behavior over time or taking into account other aspects. Also, the issue and the need to study dynamic systems are reviewed, as well as the implications of the analysis of the dynamic behavior that the considered systems may have.

2. Modelling, analysing and interpreting the behaviour of a system

The behavior of a system in dynamic regime (which includes the steady state and the transient regime) can be described with the help of a mathematical model, consisting of algebraic equations and differential or differential equations, as the system is continuous or discrete time. In the general theory of systems, as we have mentioned, two distinct ways of representing systems in the time domain are used: by equations of type I-O (input-output) and by equations of type I-S-O (input-state-output). As such, the mathematical model of a system is set of mathematical relationships and equations that allow the description of system behavior, input-output transfer or input-state-output [8-10].

A dynamic system (memory system) can be associated with a dynamic model - for the characterization of the dynamic operating mode, and a stationary model - for the characterization of the stationary operating mode. The stationary regime can be of static type (when the system variables are constant in time) or of permanent type (when the form of variation in time of the system variables is constant - of ramp type, of sinusoidal type etc.). Next, we will consider the stationary model as being associated with the static stationary regime.
Static systems models (without memory) and stationary models of dynamical systems consist of algebraic equations, while models of dynamic systems consist of differential equations (for continuous systems) or equations with differences (for discrete systems).
The dynamic model, by reference to the static model (see Fig. 3) [3] on the other hand, also includes the stationary model, the latter can be obtained from the former by a convenient customization (by canceling the time derivatives of the variables - to continuous systems, respectively by matching the values of each variable at all times - to discrete systems).

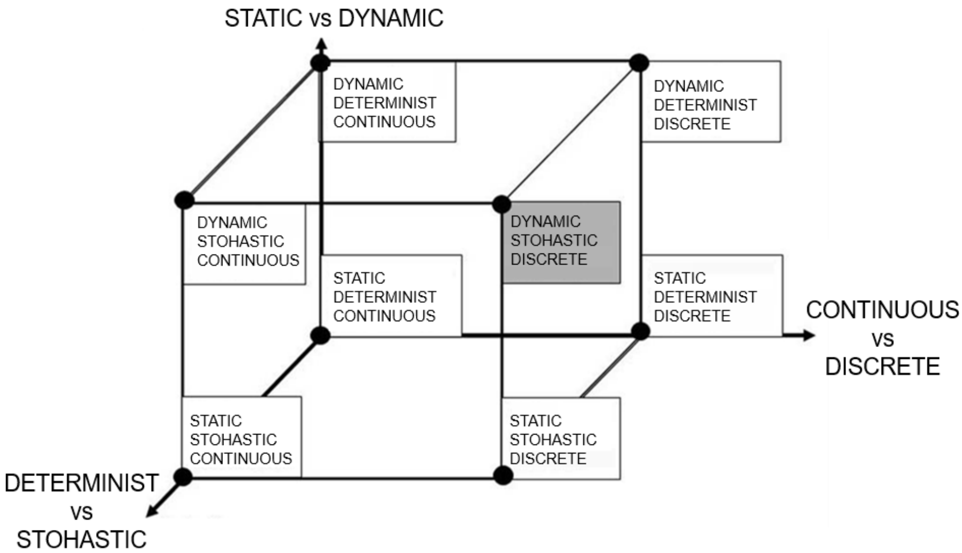

Fig. 3. Schematic representation of dynamic models in relation to static models

The stationary model (static type) does not contain the time variable. Linear systems correspond to linear models (consisting of linear equations), and to nonlinear systems - nonlinear models (which contain at least one nonlinear equation). In most practical applications, to simplify mathematical formalism, systems with weak nonlinearities are associated with linear or linearized models on portions of the working field.
The modeling of a physical system, ie the operation of obtaining the mathematical model, can be performed by analytical, experimental or numerical methods. Simulation is the operation of describing the behavior of a system based on its model. The simulation accuracy is given mainly by the accuracy and precision of the mathematical model. Regardless of the method, the modeling operation is based on taking into account working hypotheses, with a simplifying role. According to the way of choosing the simplifying hypotheses and the degree of their concordance with the real phenomenon, the obtained model is simpler or more complex, reflecting the physical reality with a greater or lesser degree of precision.
The analytical modeling of the technical systems is performed based on the general and particular laws that govern the specific physico-chemical phenomena of the real system (the law of conservation of mass / volume / energy / impulse / electric charge, the laws of physico-chemical balance etc). Experimental modeling (also called identification) involves performing direct tests on the physical system, allowing either global identification of the system (in the case of black box systems) or only determining the value of some parameters of the model, when knowing the structure and shape of the model (from analytical modeling).
Numerical modeling combines analytical and experimental methods and procedures. A variant of mixed modeling is one in which the shape of the model is determined analytically, and some unknown parameters or with a high degree of uncertainty are determined experimentally.

In the field of technical sciences, as mentioned, experiment and observation are essential aspects for a system that is developed iteratively. Ultimately, the elaboration of a theory represents the construction of a verbal or mathematical model of reality. The model is therefore, in these conditions, the representation of knowledge, of the essential aspects of a system in a usable form. The model is a simplified, approximate representation of the real system. It is usually neither possible nor necessary to make a detailed description of all internal mechanisms. It is enough for the model to mimic, to behave close enough to the real system.
There are several types of models (see Fig. 4 and Fig. 5), namely: physical models (empirical or small-scale - for example, a technology is developed in the field of chemistry, a micro pilot, the technological process is tested on this physical model and conclusions are drawn), phenomenological models (conceptual - the respective systems are described by certain laws), functional models (formal - the system is represented by functional relations, functional schemes) and mathematical models (analytical).

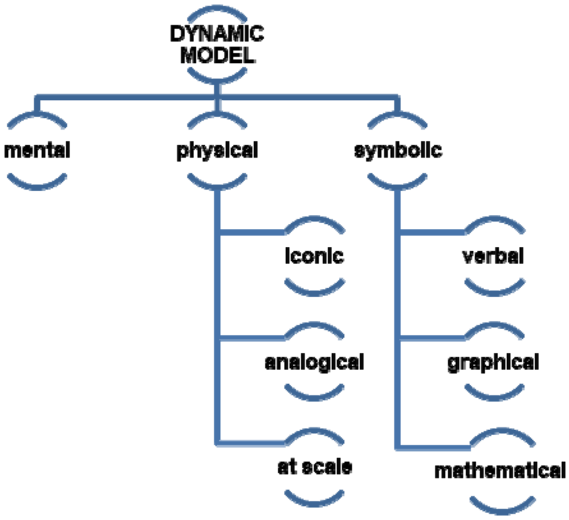

Fig. 4. Schematic representation of dynamic models' classification (I)

The model must be in a usable form (which is not an end in itself). It is a basis for analysis, decision making and in this sense the model must be as small as possible. If the number of simplifying hypotheses considered is large, then the model obtained is simple, robust, easy to process and interpret, but less accurate.

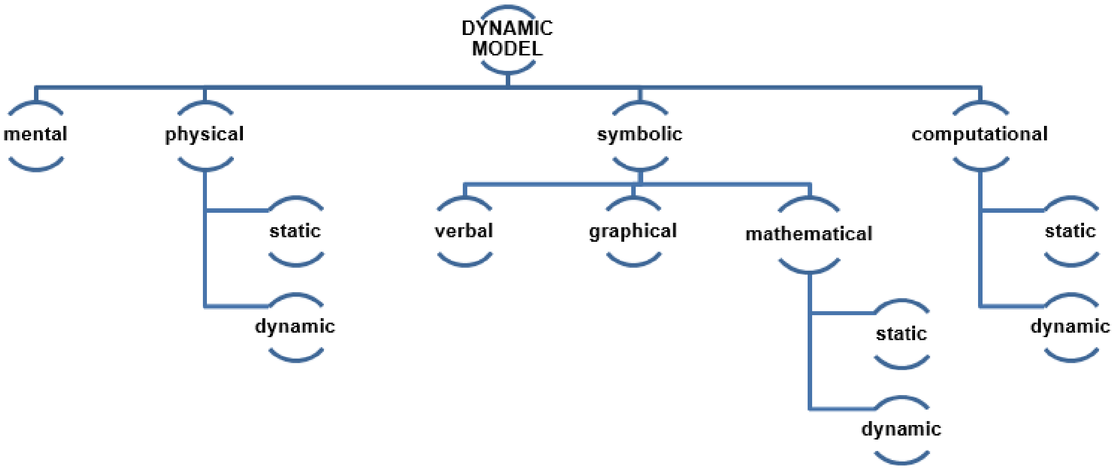

Fig. 5. Schematic representation of dynamic models' classification (II)

Even very complicated models, regardless of the classification they fall into (see Fig. 6), are not recommended, due to the lack of accuracy in determining some parameters, the impossibility of analytical calculation, rounding and truncation errors that occur in numerical processing, etc.

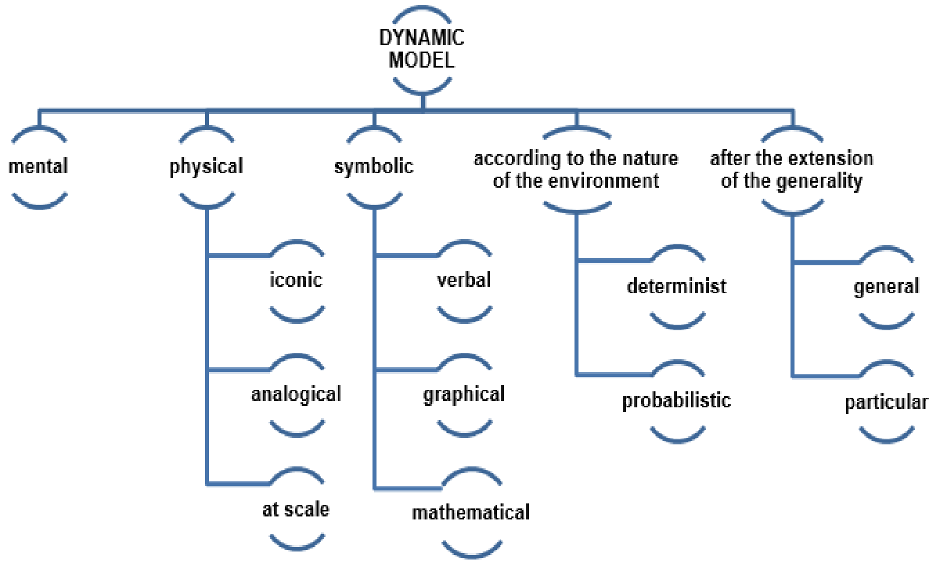

Fig. 6. Schematic representation of dynamic models' classification (III)

The model is a material or ideal object, which replaces in the research process the original object, keeping some essential characteristics (geometric, physical, dynamic, basic functional), important for the research process; depending on these characteristics the model can fall into different classes of models. The ideal modeling has a theoretical character. When certain sets of symbols are used for modeling, the modeling is called symbolic. Schemes, graphs, formulas, etc. may appear as symbols. Under these conditions, we say that mathematical modeling involves researching the object through a model formulated in mathematical terms and notions, using mathematical methods.

Mathematical modeling uses simplified mathematical representations of real world systems, processes, or theories. Mathematical models are created to facilitate the understanding, prediction and control of a system. A mathematical model is symbolic and is used to express ideas and clarify problems. A good model is a faithful replica of reality. The validation of the model implies the confirmation of the simplifying working hypotheses, of the quality of the experimental data through the obtained results and the conclusions drawn. Mathematical modeling is used successfully in extreme situations, when experimentation is too expensive, too dangerous or virtually impossible. The synthesis of an experiment in a mathematical model and its use instead of the experiment is the real success of this activity.

The mathematical model is a fundamental working tool for an engineer. It consists of a set of mathematical relations able to correctly describe the interdependence of process variables. By mathematical relations is meant any abstract means capable of quantitatively describing the interdependence of variables such as: equations, inequalities, tables, diagrams, chemical equations, computational subroutines or even computational programs.

Deterministic models are made up of property conservation equations to which the constitutive equations and the equations specific to the phenomenon and terms of the equations are attached. The complexity of these models and the practically insurmountable difficulties in solving them limit their applicability. The development of computational techniques and numerical methods for solving systems of differential equations, representative of this type of models, synthesized in high-performance computational algorithms provides, mainly, predictive character to these models.

Statistical models are models with simple mathematical expression, which explains their successful use in practice (see the examples presented in Fig. 7 and Fig. 8). It represents the mathematical synthesis of a practical experiment and for this reason their use is made only within the limits within which the experiment took place. Any extrapolation is not recommended.

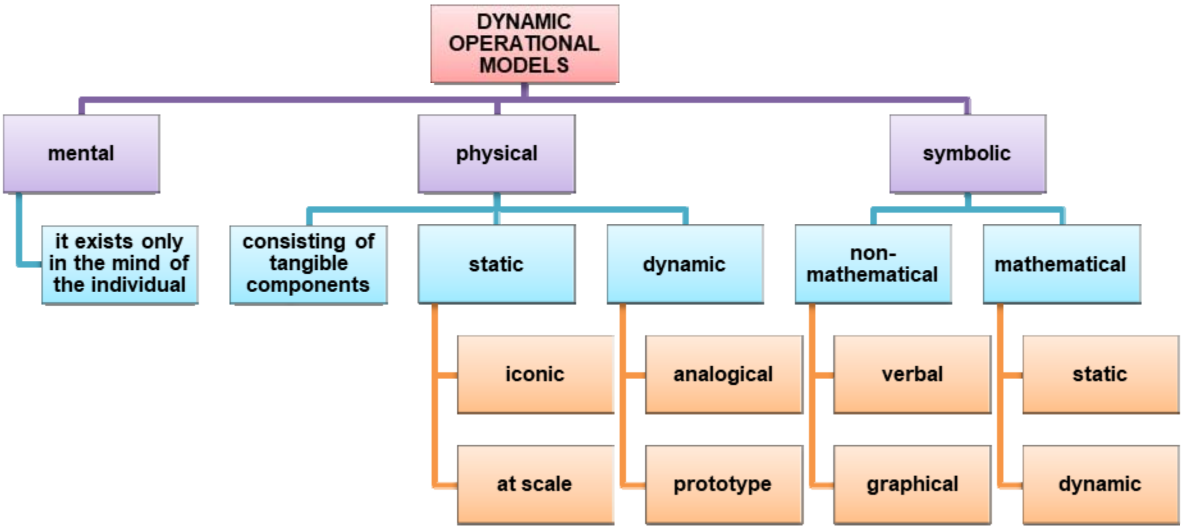

Fig. 7. Schematic representation of dynamic models' classification specific to operational research

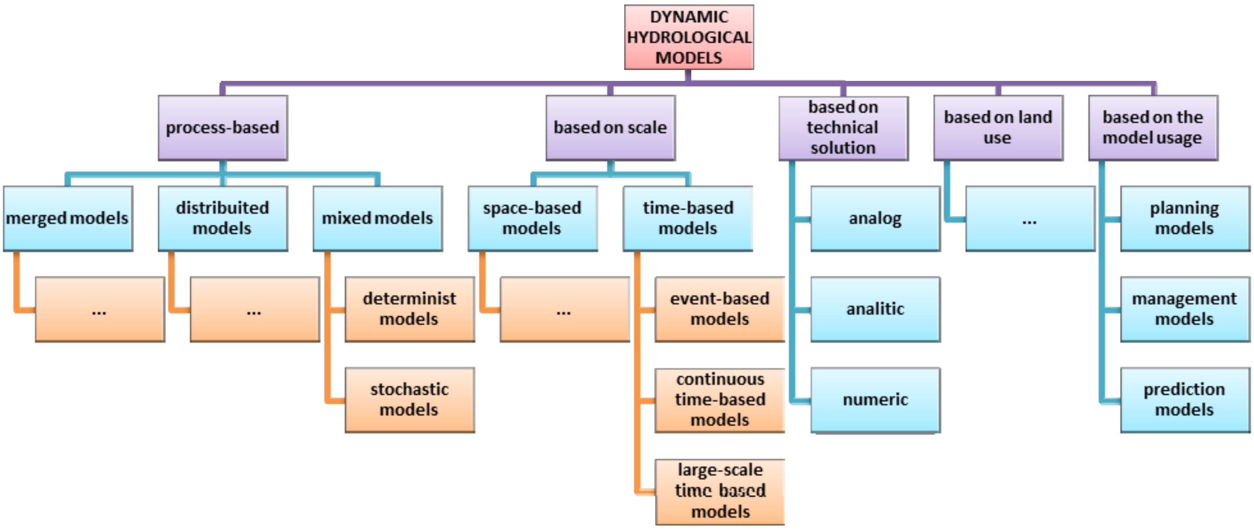

Fig. 8. Schematic representation of dynamic models' classification specific to hydrological research

The mathematical modeling of operations and in general of the processes of the surrounding reality is almost always accompanied by the existence of two opposite tendencies: on the one hand it is sought that the model reflects as accurately as possible the real process, and on the other hand, it is desired to obtain a model. as simple as possible, allowing the complete solution of the problem. Resolving this contradiction is equivalent to finding the balance between "oversimplification" and "overcrowding".

3. Systems behavior analysis - object of study and methods of investigation

The analysis and methods themselves, of analysis of the behavior of dynamic systems (with reference mainly to mechanical systems), as well as of the random vibrations associated with them have known a continuous development, lately, due to the high needs of design of structures and equipment. superior functional performance and high reliability to the extremely complex requirements to which they are subjected during operation. Examples of such stresses are those caused by the turbulent flow of fluids, the dynamic loads produced by the action of seismic movements, wind or waves, or the excitations induced by the unevenness of the runways.

A common feature of these types of requests is the impossibility to describe their evolution, in a deterministic way, due to the behavioral dynamics of the whole system, an aspect that gives rise to concepts such as white box, gray box and black box. The dynamic behavior of mechanical systems with random parameters is described by stochastic differential equations whose treatment depends essentially on the way in which the random factors intervene:

- differential equations with random initial conditions - important role in statistical mechanics, statistical thermodynamics, a priori analysis of spacecraft trajectories etc;
- differential equations with random coefficients - used in the study of systems whose parameters have imprecise values due to inherent material or execution imperfections or vary randomly as in the case of the mass of material on a conveyor belt;
- differential equations in which the random part enters as a non-homogeneous term - representing the external perturbation applied to the system as a random function of time (random process).

The last category of differential equations have the widest field of applications, being used in modeling the dynamic behavior of most mechanical structures encountered in practice (road and rail vehicles, ships, aircraft, civil and industrial construction, machinery, machine tools, etc.).
The whole approach of system analysis methodologies is based on the idea of the existence of possibilities for continuous improvement and improvement of the performance of any system, through an activity of analysis of the existing system and design of a more efficient system. To achieve this goal, system analysis uses a set of methods to achieve the specific stages of each methodology of analysis and design of systems, which make the transition from the physical model (real) to the mathematical model.
By its nature, system analysis uses the systemic approach method, which is based on the concepts of general systems theory and logically combines the system analysis stage with the synthesis one, as well as a series of methods specific to the stages necessary to develop the new system. such as:

a) modeling method - uses a set of statistical-mathematical techniques, heuristic techniques, in order to determine an isomorphic representation of objective reality.
b) simulation method - technique of testing, evaluation and manipulation of a real system through computer experimentation of mathematical and logical models in order to observe and study the dynamics of system behavior in the future.

Depending on the problematic area it addresses, the diagnostic analysis can be general, when considering the whole system, and partial or specialized, when analyzing one or some of the basic areas. An essential element in the diagnostic analysis is the analysis of information in order to know how the system works and its state.

c) computer methods - ubiquitous in the analysis and design of more efficient systems, in general, as well as for the realization of expert systems and support systems for decision support, in particular.

To achieve its objectives, system analysis uses or combines some of these methods for any of the methodologies used. Choosing the most suitable models and the appropriate modeling technique is an important aspect.

4. Conclusions

Because most natural and technical systems are nonlinear dynamical systems, ie systems characterized by the presence of chaotic (non-deterministic) behavior, the study, respectively their definition and characterization, the classification and the analysis of the control possibilities require the use of the most diverse working methods. There are suitable methods of modeling, simulation, analysis-diagnostics - mostly informative, current methods and with the possibility of approaching some multicriterial analysis sequences.
Mechanical dynamic systems used in the technique for over a century have the mathematical formalism of input-state-output. It refers to dynamics involving many state variables that make modeling difficult in itself. Current work techniques - program sequences, software, applications - make it possible to create more and more fidelity representations, and application results increase

the interest of research for dynamic systems in many fields of activity to limit negative effects and dysfunctions, both in inside the system considered, and in the external environment.

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