Lecture: Modern methods for solving problems in management based on scientific modelling approach

Ivan Mihajlovic
University of Belgrade, Technical faculty in Bor
imihajlovic@tf.bor.ac.rs

1. INTRODUCTION

What is technology: Body of knowledge from different scientific fields which helps us to solve some problem or fulfill some of our needs?

What is technological process: predefined set of activities, allocated in space and scheduled in time, which are transforming input to output parameters enabling development of products or services which solve some problem or fulfill some of our needs.

Most of operational processes (technological and business processes), especially in industry, are presenting very complex systems defined with large number of constituting elements and their interrelations.

About systems:

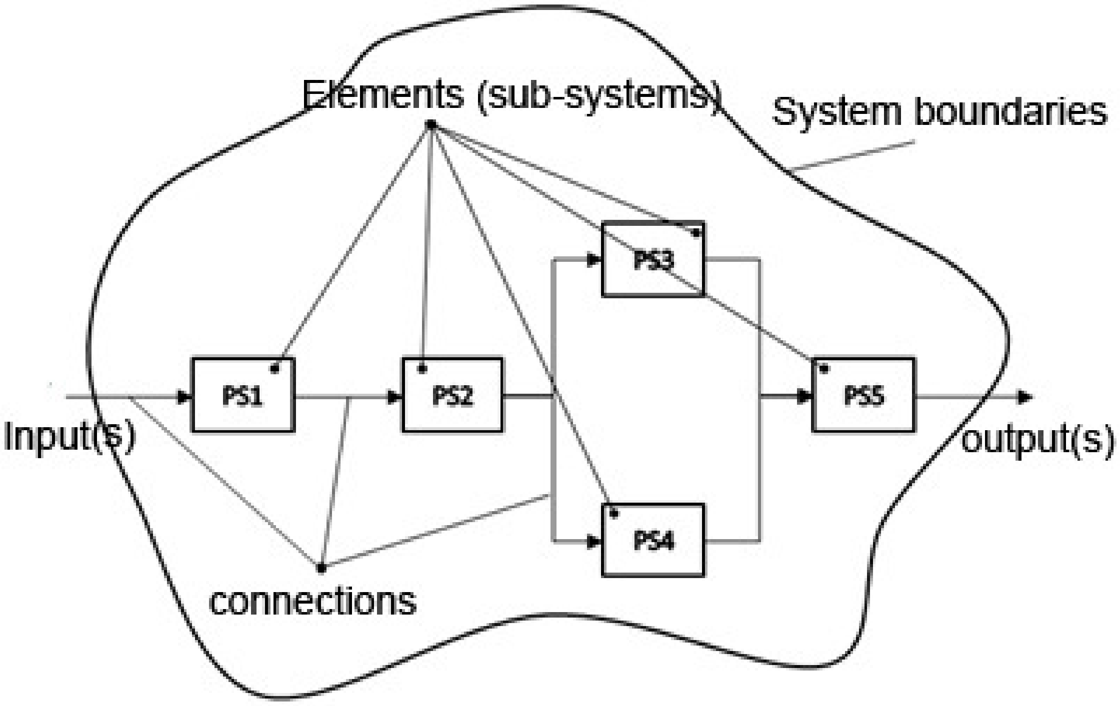
What is system?

Answer:
Simplest definition: “system is assembly of interactive elements”

Another **"a set of objects or elements in interaction to achieve a specific goal."**

More complex definition: “system is assembly of elements or processes correlated with relations, with common purpose of existence (common goal). Elements can be material, idea, information, functions, living creatures, business activities, …..”

General representation of a system is:



What examples of systems can you think of? What is the function of a system?

The function of any system is to convert or process energy, information, or materials into a product or outcome for use within the system, or outside of the system (the environment) or both. Indeed, if a system is to survive, it must save some of the outcome or product to maintain the system.

Why is this important for modeling of complex operations processes?

There is a scientific approach in contemporary science, called the systematic approach.

The science which is dealing with the analysis of nature, technical or social phenomena using the systematic approach is the Systems theory or (**General systems theory**).

Before general systems theory, the science was relaying on René Descartes, scientific methods.

The first great philosopher of the modern era was René Descartes (1596-1650), whose new approach won him recognition as the progenitor of modern philosophy.

Descartes's pursuit of mathematical and scientific truth soon led to a profound rejection of the scholastic tradition in which he had been educated.
It has been said that both modern philosophy and modern mathematics began with the work of Rene Descartes. His analytic method of thinking focused attention on the problem of how we know (epistemology), which has occupied philosophers ever since. Descartes was educated at the renowned Jesuit school of La Fleche where he was taught philosophy, science, and mathematics. He earned a law degree and then volunteered for the military in order to broaden his experience. When his duties allowed he continued his studies in mathematics and science. Eventually he became dissatisfied with the unsystematic methods utilized by the previous authorities in science, since he concluded they had not "produced anything which was not in dispute and consequently doubtful". The only exception to this was in the field of mathematics which he believed was built on a "solid foundation" . Medieval science, on the other hand, was largely based on authorities from the past rather than observations in the present, therefore Descartes decided to conduct a personal plan of investigation.

Much of his work was concerned with the provision of a secure foundation for the advancement of human knowledge through the natural sciences. Fearing the condemnation of the church, however, Descartes was rightly cautious about publicly expressing the full measure of his radical views. The philosophical writings for which he is remembered are therefore extremely circumspect in their treatment of controversial issues.

After years of work in private, Descartes finally published a preliminary statement of his views in the *Discourse on the Method of Rightly Conducting the Reason* (1637). Since mathematics has genuinely achieved the certainty for which human thinkers yearn, he argued, we rightly turn to mathematical reasoning as a model for progress in human knowledge more generally. Expressing perfect confidence in the capacity of human reason to achieve knowledge, Descartes proposed an intellectual process no less unsettling than the architectural destruction and rebuilding of an entire town. In order to be absolutely sure that we accept only what is genuinely certain, we must first deliberately renounce all of the firmly held but questionable beliefs we have previously acquired by experience and education.

The progress and certainty of mathematical knowledge, Descartes supposed, provide an emulable model for a similarly productive philosophical method, characterized by four simple rules:

1 The first rule was never to accept anything as true unless I recognized it to be evidently such: that is, carefully to avoid precipitation and prejudgment, and to include nothing in my conclusions unless it presented itself so clearly and distinctly to my mind that there was no occasion to doubt it.
2 The second was to divide each of the difficulties which I encountered into as many parts as possible, and as might be required for an easier solution.
3 The third was to think in an orderly fashion, beginning with the things which were simplest and easiest to understand, and gradually and by degrees reaching toward more complex knowledge, even treating as though ordered materials which were not necessarily so.
4 The last was always to make enumerations so complete, and reviews so general, that I would be certain that nothing was omitted.

This quasi-mathematical procedure for the achievement of knowledge is typical of a rationalistic approach to epistemology.

In fact, Descartes declared, most of human behavior, like that of animals, is susceptible to simple mechanistic explanation. Cleverly designed automata could successfully mimic nearly all of what we do. Thus, Descartes argued, it is only the general ability to adapt to widely varying circumstances—and, in particular, the capacity to respond creatively in the use of language—that provides a sure test for the presence of an immaterial soul associated with the normal human body.

But Descartes supposed that no matter how human-like an animal or machine could be made to appear in its form or operations, it would always be possible to distinguish it from a real human being by two functional criteria. Although an animal or machine may be capable of performing any one activity as well as (or even better than) we can, he argued, each human being is capable of a greater variety of different activities than could be performed by anything lacking a soul. In a special instance of this general point, Descartes held that although an animal or machine might be made to utter sounds resembling human speech in response to specific stimuli, only an immaterial thinking substance could engage in the creative use of language required for responding appropriately to any unexpected circumstances.

The apparently global scope of Descartes' speculations might lead some to conclude that his epistemology demanded the rejection of all authority, including the Bible. In point of fact, he considered himself a good Catholic and with respect to the "truths of revelation" he clearly stated, "I would not have dared to ... submit them to the weakness of my reasonings"

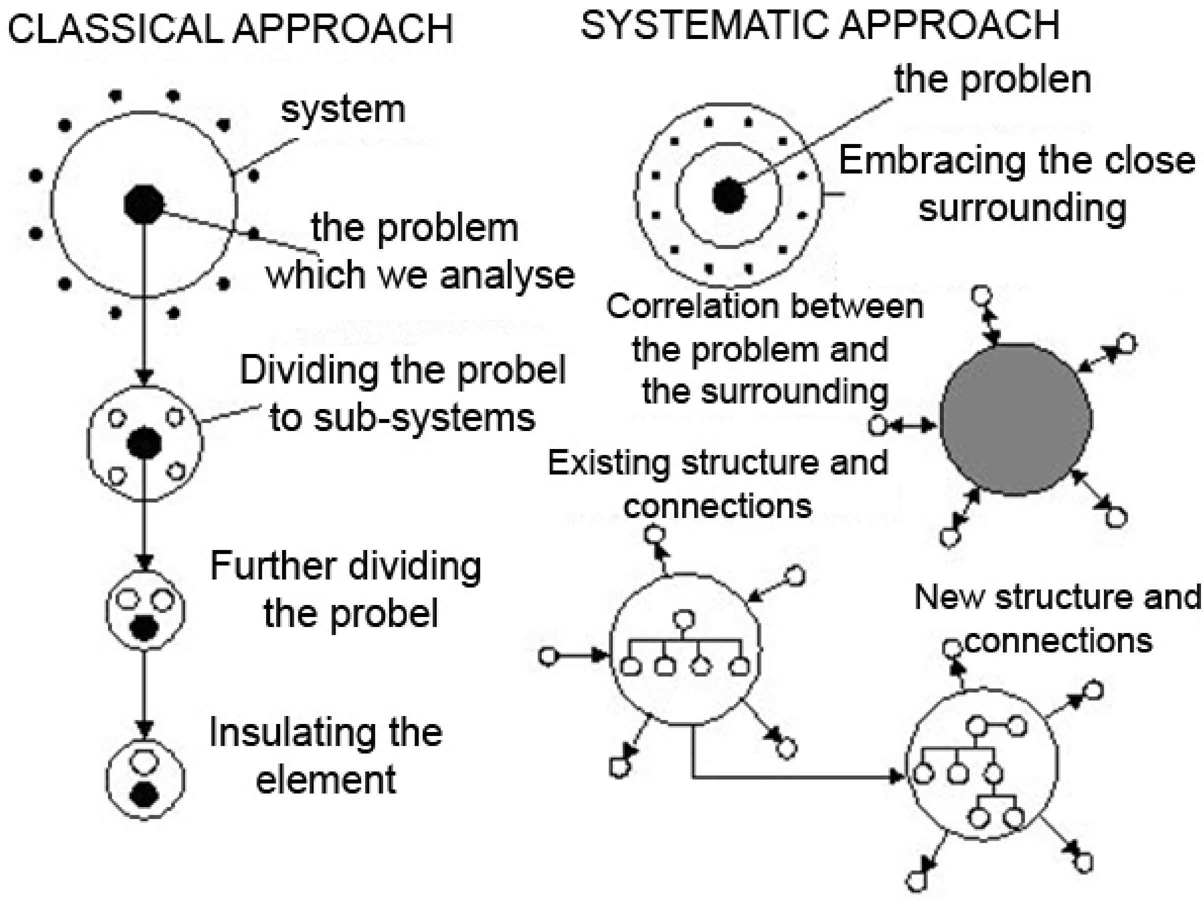
After him complete modern science was based on two assumptions:

1. The first one is that each system could be decomposed on single components and that each of the components can be analysed independently of all others
2. The second one was that the compounds can be linearly addet to each other to explain the whole of the system.

Is it true?

- *<u>Systematic approach</u> is regarding each element as a part of a system but at the same time as a part of a surroundings.*
- The core of systematic approach (systems analysis) is that the surroundings is having crucial importance on observed system.
- If there is no influence of the surroundings, each system would be a ideal one.

Example ship.



Explain it on the example of business system in a company (function structure with a employee working in marketing)

Top management
R&D marketing production logistics accounting sales ......

Systematic approach in system theory (in contemporary science) is this way based on system thinking, which is the basis of GST. There are 7 main principles of system thinking:

- P1: Everything is a system or a subsystem (idea, material, energy and information)
- P2: Probabilistic observation of the world
- P3: Complexity of the nature and the systems
- P4: Synergism
- P5: Dynamical observation of appearances
- P6: Holistic observation of the systems
- P7: Relativity of each appearance (Entropy)

Entropy is a measure of the systems disorder…
What is the most natural behavior of each systems Order or Disorder. Each system tends to become as disordered as possible. The anarchy is the most natural state of the society. We must have work to prevent it. If we close the system, its entropy would grow until it breaks down from insight.

Also there are four assumptions that transfer some appearance in to the system:

1. First assumption is that the appearance is defined as a system
2. Second appearance is that this appearance is always in interaction with the surroundings, newer isolated.
3. Third assumption is that behavior of that appearance is always nonlinear
4. Fourth assumption is that ultimate goal is continual improvement of its functionality.

GENERAL SYSTEMS THEORY GST

- *Scientific discipline which investigate different phenomena independently of their specific nature and the origin. It investigates:*
    - *Inter correlation of the elements*
    - *Structure*
    - *Organization*
    - *Functionality*
    - *Reactions of the systems*

Biologist **Ludwig von Bertelanffy** was the first who introduced GST as a scientific field in 1928. **He felt the need for a theory to guide research in several disciplines because he saw striking parallels among them. His hunch was that if multiple disciplines focused their research & theory development efforts, they would be able to identify laws & principles which would apply to many systems. This would allow scholars & scientists to make sense of system characteristics such as wholeness, differentiation, order, equifinality, progression & others. With a common framework, scientists could better communicate their findings with each other & build upon each other's work.**

He believed that over time, what was discovered would come to be applicable to life in general.

Another purpose of General system theory is eliminating the redundancy in science and to search for similarities in concepts and procedures between different scientific disciplines. This way it tends toward integrated systems theory.

This concept is also not complete new one. Similar approach – form the aspects of physics was proposed by A. Einstein (1879 –1955) in his unfinished work: “The theory of everything”.

Its claim was: Einstein's dream of proving there is only one fundamental force in nature: Electrical, magnetic and gravity fields are actually only one.
http://phys.org/news/2013-02-furthers-einstein-theory.html

Another genius who shared the same idea as Einstein was Genrich Altshuller.

- TRIZ

Теория Решения Изобретателъских Задач

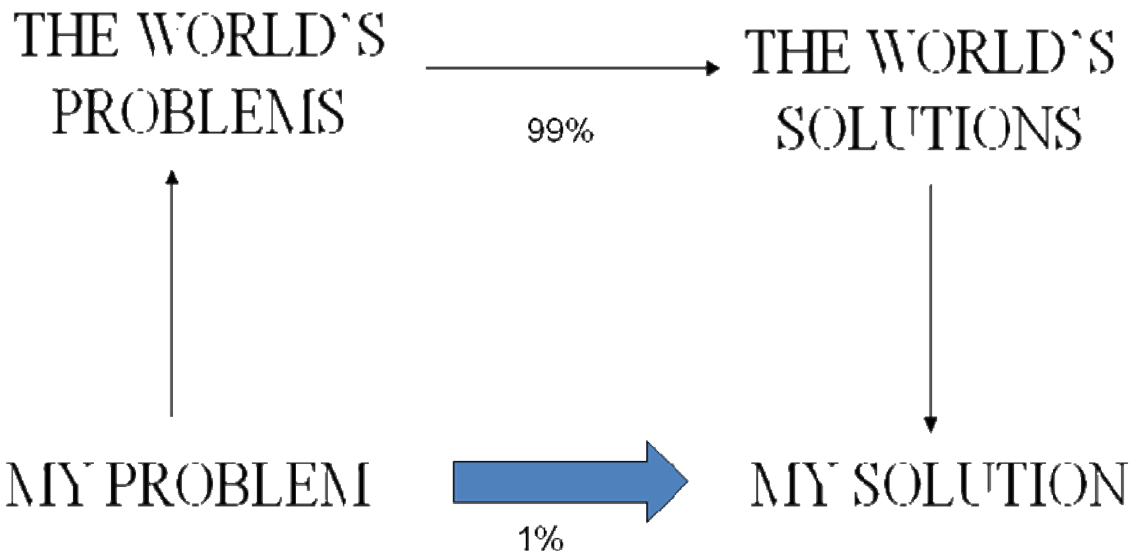
Also known as TIPS in Western society
Theory of Innovative Problem Solving) http://www.mazur.net/triz/

- TRIZ (a Russian abbreviation for the Theory of Solving Inventive Problems) was originated by the Russian scientist and engineer Genrich Altshuller. In 1948, Altshuller started massive studies of patent collections. His objective was to find out if inventive solutions were the result of chaotic and unorganized thinking or there were certain regularities and patterns which governed the process of creating new ideas and inventions.
- After investigating approximately 400.000 patent descriptions, Altshuller found that only 0.3% of all patented solutions were really new, which meant that they used some newly discovered physical principle – such as the first radio receiver or the first film photo camera. The remaining 99.7% of inventions used some already known physical or technological principle but were different in its implementation.

According to TRIZ

Levels of Inventiveness.

Level	**Degree of inventiveness**	**% of solutions**	**Source of knowledge**	**Approximate # of solutions to consider**
1	Apparent solution (quantitative system change)	32%	Personal knowledge	10
2	Minor improvement (qualitative system change)	45%	Knowledge within company	100
3	Major improvement (innovation to invention)	18%	Knowledge within the industry	1000
4	New concept (Pioneering invention)	4%	Knowledge outside the industry	100,000
5	Discovery	1%	All that is knowable	1,000,000



THE WORLD`S PROBLEMS

99%

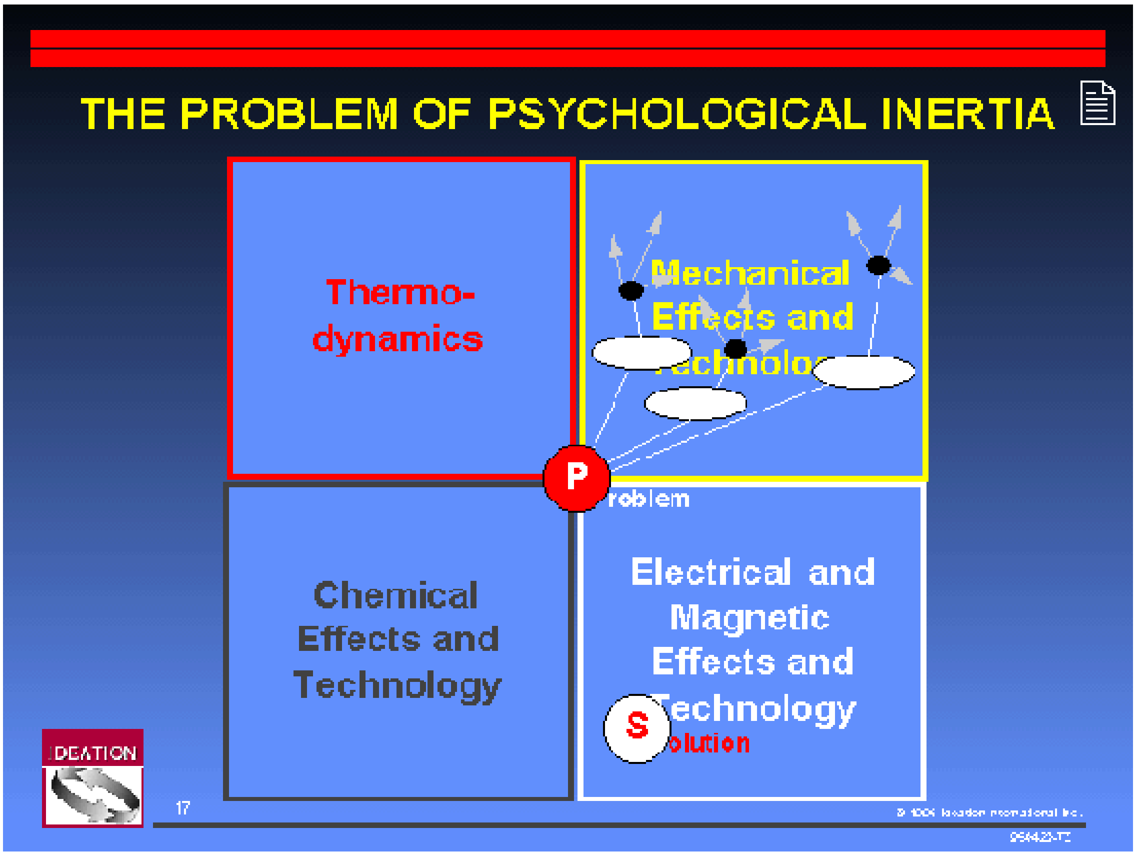
THE WORLD`S SOLUTIONS

MY PROBLEM

1%

MY SOLUTION

Ideal Solution for your problem May Be Outside Your Field



THE PROBLEM OF PSYCHOLOGICAL INERTIA

Thermo-dynamics

Mechanical Effects and Technology

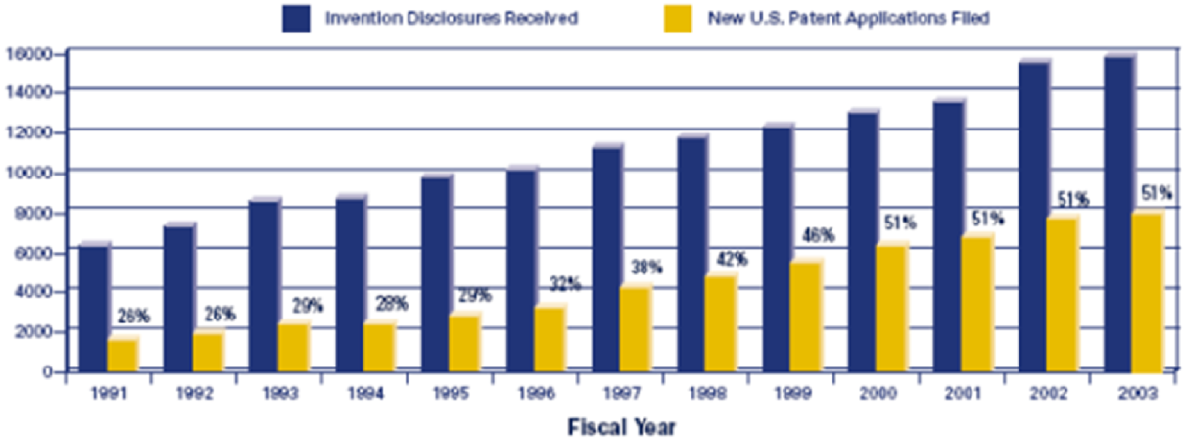
Problem

Chemical Effects and Technology

Electrical and Magnetic Effects and Technology

Solution

Besides this, Genrich Altshuller was also dealing with theory of invention.



Source: Thursby, Georgia Tech

- The number of inventions is always higher than the number of application fields

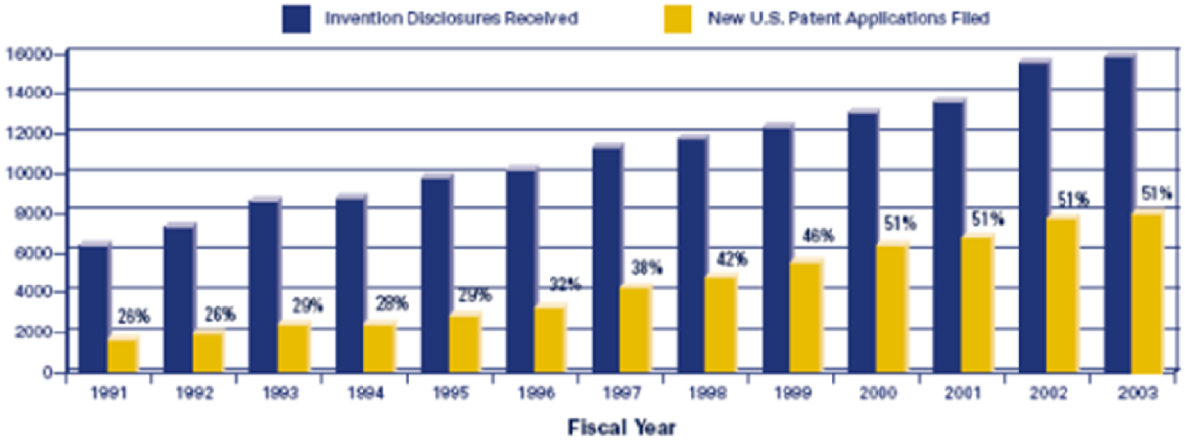
Why ?

- **Answer:** Genrich Altshuller **in his book** And Suddenly the Inventor Appeared:
“If somebody invent completely new technological system while the old one is still active, the route to success and public acceptance is very long and difficult. The problem which is a lot in front of its epoch is most difficult to be solved. The most difficult part is to prove that this new system is possible and necessarily. The inventor must be careful because too advanced design can be unaccepted by the public. Sometimes, it is better strategy to introduce few subsequent improvements”.

- Example1: radar *(sonar) during World War II, which give info about enemies airplanes and ships.
- Is it useful?
- Some captains did not want to install radars. When they realized that the number of enemy airplanes is twice as many as they could assume (without using radar), they started to believe that the radar is actually attracting the enemy plains. / this is very usual resistance to new technology that is natural human behavior
- Alternating Current (AC)
- Is it useful ?
- Tesla: Direct current (DC) to Alternating Current (AC)

- Old technology didn’t achieve planned financial effects to be replaced by new one.
- Inventor Died in bankruptcy in New York hotel

Now get back on a track and GST



Source: Thursby, Georgia Tech

The number of application fields (yellow) is, on the other hand, growing faster than the number of inventions (blue)

Why?

The answer is TRIZ and GST

- The 99.7% of inventions used some already known physical or technological principle but were different in its implementation. Different field of application of the same system.

More than 50 years after Bartalanffy (during 80ties), the work in understanding systems has evolved to the point that we incorporate many of the concepts into our everyday language. We speak of a health care system, a family system, body systems, information systems, banking systems, political systems, etc. One of the reasons we do this is because the amount of knowledge & information available has increased tremendously during this time period. We cannot know all there is to know. We seek some way of ordering what we encounter to avoid being overloaded with information. We

focus in on small areas of knowledge rather than trying to comprehend the whole.

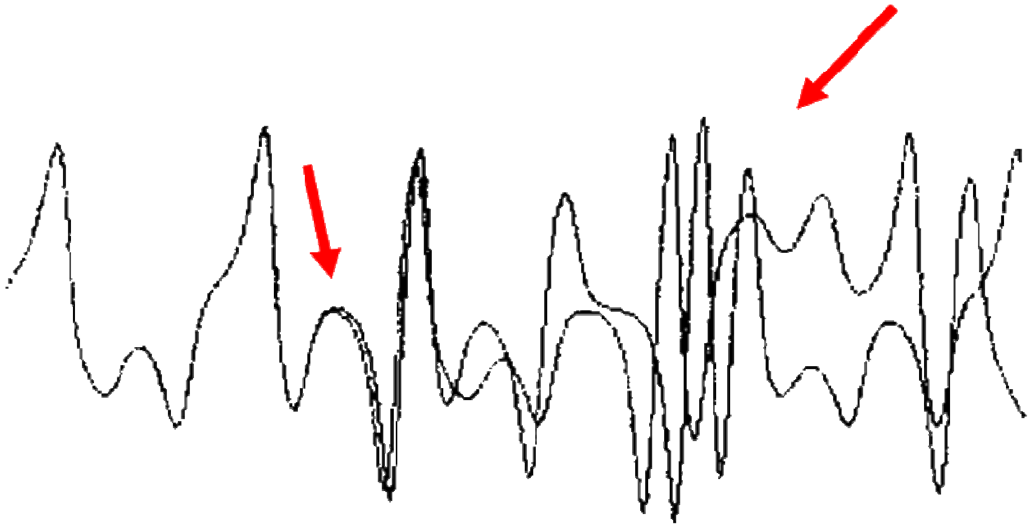
CHAOS

Contemporary development of the GST is relying on the modern investigations in the field of the Chaos theory. The chaos theory is one of the crucial evidences that systematic approach is actually better than Descartes.

About the chaos theory ?

It started **with Edward Lorenz**- and famous *"butterfly effect"*

Meteorologist - pioneer (modeling the weather data in 1963 based on the data from the 1960).
How does meteorology work, we measure weather data in the past to use it to predict the temperature in the future.
Example of the temperature prediction, based on the past measurements. He built his computer model to predict temperatures. He introduced the data in the form:
0.506
This resulted with mistake:



When compare:
The value of 0.506
With the value of 0.50612

The difference is only: 0.00012

If we measure temperatures on daily bases on **5** minutes intervals:
Now: 365 days * 24 * **12** = 105120 measuring intervals.

At the end of the year, the mistake in measurement is: 0.00012 x 105120 = 12.6144 ^{O}C

This way, instead of 0 degrees in December, our model would predict 12.6^{O}C. Somebody will go swimming, he would be disappointed.

However, most famous theoretician of a chaos theory of today is of course: **Stephan Hawking**. During 80ties he introduced Chaos Theory in to the scientific systems theory. This way actually the end of Von Bartelanffy –s approach. Officially Glajk proposed inclusion of the chaos theory with the chaos theory phenomena, which are beyond usual human opinion and observations. Before this, traditional predictive models always accounted for smaller or less errors in calculation, and this was the only explanation of so called „random fluctuations“.
It can be concluded that the chaos, the same as the GST is exceeding the divide between the scientific fields, it brings together the scientists from the scientific field which were completely opposite in the past.
Nowadays the Chaos theory is incorporated in many nonlinear modeling approaches, which are mostly relaying on nonlinear statistic approaches. As the most important is the **Fuzzy Logic.**

Back on the operations systems
If placed on the level of general system theory (GST), each of complex process could be defined as a complex system with one or more output variable and large number of input variables. Still on the level of GST, optimization of such systems is actually consisting in obtaining desired value of output variable (variables) which should be inside the defined outlying levels. This could be achieved in two ways. First way is based on control and regulation of input variables (both controlled and disturbances), which is based on defined controller unit of the system. The second way is based on possibility to perform controlled and designed changes on the structure of the system in question.
However, considering the complexity of the systems, both methods require adequate model of the investigated system which would be the basis of its further optimization. This is because the controller unit is actually defined as inversion of mathematical model equation of the object of control and, on the other hand, the change of the structure inside the real system can be too expensive if it is not based

on prior model based experiments. Also, it could lead to wrong reorganization of the system structure.

Considering that in operations management, there is a belief that absolute optimization of any system cannot be achieved, each system should be the object of further optimization in the future. If defining an adequately accurate model of the system, it could be used as a tool for another iteration of optimization, considering that it can result with prediction of output values based on different scenarios and combinations of input variables.

Accordingly, development of accurate model of the operations (technological or business) process is of essential importance in contemporary operations management, considering that this is enabling much easier way of the process parameters acquisition, which is of crucial importance for complex systems optimization. Operations management complexity, dealing with the contemporary technological processes, is additionally increasing during the 21st century. The reason for this should be found in the fact that contemporary technological processes require optimization of not only the technical – technological and economical, but the ecological aspects of the processes, as well. Successful operations planning and optimization of any of contemporary technological processes is supposing preparatory defining of the process model, comprehending all technical, economical and ecological parameters at the same time (Mihajlovic et al., 2011). At the bottom line, the most important aims of the system (process) modeling can be listed as follows: Using the model instead of real system to achieve system parameters; Avoiding the risk of experiments on real system; Obtaining the results of prediction whose analysis should enable effective operational management and optimization of the real system; Lower expenses resulting from model, instead of system, optimization.

Accordingly, selection of the most appropriate modeling approach, of the real technological process, is of crucial importance in achieving these aims. This paper is dealing with the development of the algorithm that can be of use to decision makers when selecting the most appropriate modeling approach for technological processes. The algorithm is developed based on previous experience in modeling of real technological systems.

2. BACKGROUND

Besides intensive development of the modeling methods, in different fields of science and technology, it can be stated that unique classification of all types of models isn't developed yet. Having this in mind, general classification is placing all models in one of two groups: the class of symbolic (in most cases numerical) and the class of real (physical, material) models. Having in mind such general classification, the object of the research presented in this paper is actually the symbolic models, e.g. numerical models. Symbolic models are describing the object, process or appearance on some of languages (symbols) characteristically for the objects nature. To further explain the symbolic language, it should be started from the fact that each scientific field developed its own symbolism during its historical evaluation. The first language used to describe each scientific discipline was, of course, verbal language. Next scientific language was the language of mathematics pronounced by its symbolic abbreviations, relations and logical dependences. Starting with James Watt and his centrifugal "fly ball" governor, which was the first system of automotive regulation, the development of contemporary mathematical modeling started (D'Auria, 1879). However, since Watt was practitioner, inventor and engineer, he was not the one who developed the first mathematical model of this first dynamic system controller unit. Actually, the first theoretic who described this system using numerical model was James Clerk Maxwell (1868). He wrote a famous paper "On governors" that is widely considered a classic in feedback control theory and is used as inspiration for researchers, even today (Zheng-Ming and Wei-Ren, 2007). Subsequently, further research was conducted on the field of dynamic system optimization and control, starting with Routh (1877) and Hurwitz (1895) who investigated the stability of linear systems, in parallel with Lyapunov (1892) who introduced modeling of nonlinear systems for the first time, over Lorentz (1966) and his famous butterfly effect up to contemporary investigations present in recent research (Hawking, 1998; Wu and David, 2002; Golden et al., 2012; Perera and Soares, 2013, and many others).

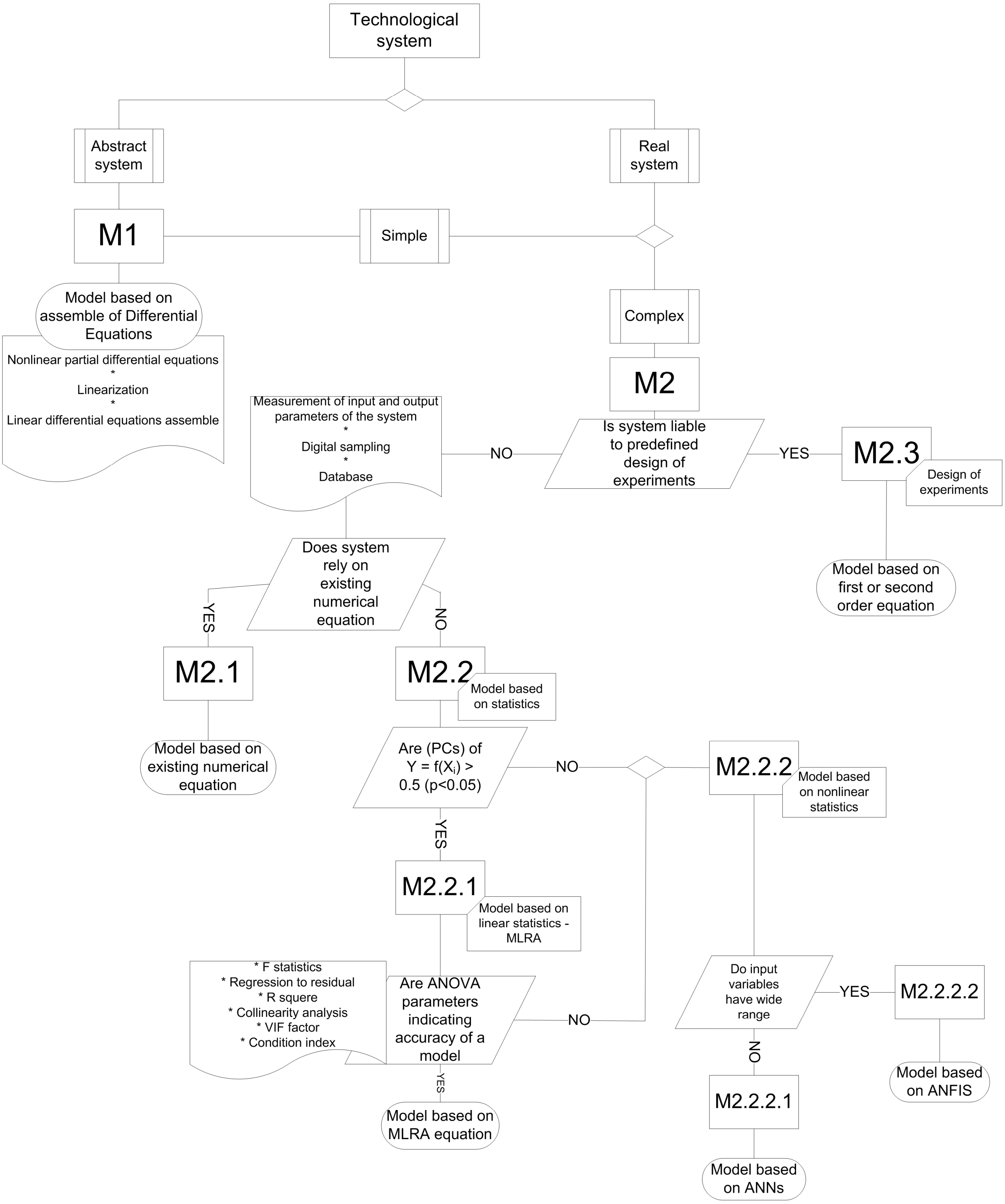
For a while in history of mathematical modeling, each scientific and technical field developed its own language of the symbols. However, resulting from the intensive development of informational technology, the possibilities for modeling different appearances are strongly increasing. This again leads to the certain standardization of symbolic models and their broad application which leads to generality of computer simulation and modeling implementation. Accordingly, mathematical language once again becomes major modeling tool. Each scientific field is subsequently adjusting its symbolism to standard mathematical expressions (Mihajlovic et al., 2009).

2.1. Complex process numerical modeling approaches

Aware of the fact that mathematical model has to mirror the real technological process as better as possible, as well as the cognition of the limits to which contemporary mathematical apparatus can reach; the question of level of real process idealization arises. Accordingly, primarily characteristics of the process should not be neglected, on one hand, while mathematical model should not be too complex, on the other. Too complex mathematical model is lingering the subsequent mathematical analysis. Also, complexity narrows the applicability of the model on a small surrounding of an equilibrium point of the system. Accordingly, the first modeling technique, that will be denoted as (M1) in following text, is based on the assumption that the mathematical model of an object is presented in the form of differential equations assemble. With systems, presented by differential equations assemble, the structure of the model is emerging directly from the known theoretical background and scientific validity of the system. For M1 modeling approach, as a precognition, it is necessary to know the structure of the investigated system and nature of the system reflected in some physical law that describes its behavior. Subsequently, the solutions of the differential equations assemble can be obtained using the computer simulation after introducing standard input signals. Then, the real system (the object of control) is induced with the same input signals while the output (response) of the system is measured. Comparing the results of the differential equations solution with the outputs of the real system, the conclusions on validity of constructed model can be brought. On the other hand, since there is no real linear system existing in the nature, success of this modeling approach is based on differential equations linearization, in the surrounding of an equilibrium point. This is resulting with difficulties of complex systems modeling, which can have more than one stabile state and this way many equilibrium points (Weir, 1991; Brown, 2007; Đorđević et al., 2010; Mihajlović, 2011). The real system's dynamical behavior is additionally aggravating this modeling approach. Subsequently, this modeling approach is mostly applicable for simple real (physical) systems and, of course, for abstract systems before their construction.

The second modeling approach, that will be denoted as (M2) in following text, is based on experimentally obtained, or measured, functional dependences of the real object under the non stationary regime. Using the measured output of the system, obtained after introducing predefined input signals, mathematical model of the object can be defined. In this case it is not necessary to know the structure of the system (relations among the elements, number of elements and their characteristics), neither the physical law of its behavior. In this approach, it is sufficient to collect the outputs, after introducing predefined inputs to the system and this way to form a data base which can be used for further modeling procedure. This is why, this type of modeling, is called a “black box modeling” (Taylor et al., 2003; Giraldo-Zuniga et al., 2006; Mihajlović et al., 2009). This type of real process modeling is attaining more and more application in the operations management, because of the practical reasons based on its applicability. In this paper, both M1 and M2 approaches will be discussed on practical examples of different technological systems modeling.

Further modeling approaches (M1 and M2) could be divided in following subcategories:



2.2. Example of technological process numerical modeling: