Systems Theory applied in Intelligent Transport Systems

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Contents:

1. Introduction

Systems Theory represents a significant theoretical backgrounds for any professional undertaking within the branch of ITS. There are several approaches to elaborating this kind of theory.

For engineering purposes (i.e. also for ITS) the classical approach: GTS – General Theory of Systems which is based on ideas of Karl Ludwig von Bertalanffy [1] and his co-workers is probably the most beneficial. A purposeful source of knowledge on the internet is [2]. An excellent review of fundamental Systems ideas is provided in the works of G.J. Klir [3, 5]. Both innovative and thorough insight into the engineering utilizations of Systems ideas is presented by J. Vlček [4].

Systems Science within its application areas means **solving problems / tasks**. Accordingly this Chapter is "task-based" as well.

Efficient handling of Systems ideas implies at least functional knowledge of specific mathematic tools, such as:

Linear algebra [6]; Theory of graphs [7] ; Petri Nets [9]; Decision tables [9]; Mathematical Analysis [10]; Fourier and Laplace Transforms [11]; Clusters analysis [12]; Statistics and Probability[13];Fuzzy sets [14], Theory of Games[15], Multi-criteria Decision - making [16], *(specific references are given only as examples)*

2. Basic Concepts of Systems Sciences

Systems sciences originated as self-contained branches of Science in the first half of the last century. That was the way the scientific community responded to:

- Over-specialization of particular scientific subjects
- Lack of mutual correspondence and understanding among scientists not only of the distant, but even the neighboring branches of science
- Rediscovering basically the same laws and knowledge in distinct branches of science

Systems Sciences point out the **holistic (**i.e. whole-oriented) approach against **reductionism** that had been dominant and successful till the Descartes era. Systems Sciences have their unique

- Subjects of study
- Data and knowledge
- Meta-level,

As a result, Systems Sciences fulfill all the requirements of the full-fledged Science.
It is also possible to develop them in a way to equally accomplish the requirements relating to:

- Practical purposes
- Measurability
- Ability to be algorithmized
- Ability to be standardized
- Ability to be proved by evidence
- Efficiency

Consequently, they have also all the characteristics of the engineering branches of science.
The evolution of Systems Sciences has been catalyzed by the significant advances in

- Systems Thinking
- Mathematics
- Computer Science

The progress of Systems thinking could be documented since the Ancient era. Aristotle's proposition: „**The whole is more than a set of parts**" is often mentioned in this case, e.g.

Mutually independent pieces of knowledge from the fields of biology, physics and social science in the first two decades of the last century played probably the decisive role in the process of Systems Sciences formation.

It was evidently proved that **the relations / interactions are often more important for the "function" and "comprehension" of the selected object, than the nature of the respective parts of the same object**.

It was also proven in successive steps that in such cases it was possible to find similar, analogical processes in qualitatively completely different objects.

The progress in Mathematics and Computer Science formed an important methodological and instrumental frame for the rapid evolution of Systems Sciences. Moreover computer technology made it possible to use a less precise approach – the experiments with mathematics models, rejected by mathematics purists, which were quite successful in engineering applications.

Systems Sciences proved competent in coping with an “organized complexity“, heterogeneity and openness. Many branches of human activity, above all transportation, telecommunication and consequently ITS, belong to these categories.

The basic notion is a **SYSTEM**

This concept is intuitively understood as a “set of things and their mutual relations “.

There is as well someone (a subject) who identifies the System.

The role of a subject (investigator) is (in a rather provoking manner) stressed in Gaines ´s definition: “System is any entity an investigator recognizes as the System“. A*ccepting this definition one has to carefully define the process of Systems recognition / identification.*

Dictionaries as a rule define System as a Set of things (natural or artificial ones) joined together into a complex whole.

Portal [2] definition of System is as follows: “Systems are sets of entities, physical or abstract, comprising a whole where each component interacts with or is related to at least one other component and they all serve a common objective”.

More thorough definitions of a System also need deeper knowledge and therefore we will be concerned with them later.

The structuring of Systems features transects the classical branches of Science. An illustrative example should be a “Klir´s matrix“[3]. In the first (classical) dimension are shown Systems of physical…, biological…, technological…, transportation,… economical,…social,… juristic,….ethical,…environmental… nature, i.e. classified under the semantics, in the perpendicular (Systems) dimension are referred Systems of abstract,…general,…or interpreted nature.

Table 1: Klir´s matrix (adopted from [3])

Classification of Systems by “thing-hood” Classical Science perspective ↓	**Classification of Systems** by “System-hood” (degree of abstraction) **Interpreted** ← **General** → **Abstract**															
physical																
chemical																
......																
biologic																
......																
technical																
......																
environmental																
....																
social																
....																

Systems could as well be classified taking into account the way of their build up.

Mathematic Systems theories represent the **deductive** approach. Most general and well elaborated is **MTS**, (Mathematic Theory of Systems)

The System is introduced as relation of abstract sets V_i.

$S := V_1 \times V_2 \times .. \times V_i$ (× means Cartesian product) (1)

MTS can cope with input / output Systems, Time Systems and Goal Systems. Very complex phenomena should be studied in "Complex Systems" which are defined based on the set of Systems.

Mathematic Fabric of Systems Theories displays many advantages – unambiguity, accuracy, generality…Arguably, one disadvantage could be certain "remoteness from practical life". (To be frank I would rather translate this phrase as intellectual and mathematic difficulty.) A less controversial disadvantage is the lower flexibility which is the consequence of the axiomatic build up. This disadvantage is more serious then we can guess as the typical feature of many Systems are their uncertainty or even their "softness".

An Inductive Approach is characteristic for the original **General Theory of Systems GTS** [1]**.** Society for General System Research (SGSR) was founded in 1954 in order to follow these 4 objectives:

1. To investigate the isomorphism of Concepts, Laws and Models from various fields and to help in useful transfer from one field to another.
2. To encourage development of adequate theoretical models in fields which lack them.
3. To minimize the duplication of theoretical effort in different fields.
4. To promote the unity of science through improving communication among specialists.

Not just the whole of particular Systems Science has to be based on deductive approaches. It is often purposeful to take advantage of the utilization of particular deductive attempts. It is quite often the case, therefore we can find an important parts e.g. within the Theory of Automata, Circuits Theory, Theory of Games, Computer Science and in Systems Analysis as well, that have typical deductive fabric. ***Cybernetics*** has more specific contents which is focused on "control and communication within living beings and machines".

Similarly, several branches of science and technology have significant aspects of system-hood, e.g.: Control Theory, Theory of Finite Automata, Theory of Circuits and Nets, Theory of Games, Theory of Decision-Making, Computer Science (Informatics), **ITS** (Telematics), Operation Research, Automation, Theory of Transportation Systems Analysis (SA) and Systems Engineering. The fabric of these sciences is mostly a constructive one.

3. Systems Identification Task

This task is the initial one but on the other hand it is also very complex and far reaching, interacting with several further tasks. This implies that quite frequent re-entries to this task in the course of this text are to be made.

3.1 Systems Identification - an Intuitive Approach

Scenario:

- Subject (investigator) interacts with certain Object. As a result of these interactions he is gradually able to recognize a set of variables on the Object. There are obviously 2 classes of these variables: a support (space, time, species, generation…) forming certain reference within which the changes of states of basic variables (comprising the so called base) occur. The outcome is → **Source System.**
- The next phase is a trial to separate variables into the input and output ones and the specification of environment – a neighborhood being a source of the input variables. This phase obviously comprises also the placement of subject (as a rule to the neighborhood). The positive outcome of this trial is → **Directed System** while the negative one is **Neutral System.**
- When a Source System comprises the actual states of variables within the support the → **Data System** is identified.

The next steps of Systems identification are as a rule:

- Evaluation of variables (continuous / crisp / fuzzy)
- Introduction of levels of distinguish
- Finding out specific relations within the system which are **invariant against transforms of support.**
- Specification of the rules which control generation of the states of System. → **Generative (rule based) System.**

An Introduction of the Levels of Distinguish is an extraordinarily important step in the course of systems identification. Generally, one is not able to state a priori, when this step is to be performed, either in the very *beginning, continuously during the identification, or iteratively in several steps. We do not have enough knowledge and tools for the exact introduction of the concept of levels of distinguish. That is why an intuitive presentation of this concept following scheme in Fig.1. has to suffice.*

An important concept within the Systems theory is a **Behavior**. An intuitive meaning of this concept is a succession of states of variables in a fixed state of neighborhood.

The **Structure** is a set of relations / joints among the parts of System.

Specification of **Structure** means de facto a display of joints (i.e. ordering) of the Systems parts (Fig. 2).

Two lemmas could be derived:

L1: Behavior does not imply Structure.

L2: (Structure AND State of System AND State of Neighborhood) implies Behavior.

Whole – part implications:

The simple fact that a System is composed of parts results in the existence of connections / joints among these parts.

As these parts are generally of heterogeneous nature, the joints perform the role of homogenization "claimer" to facilitate the existence of both the structure and behavior of a System (See Interface Task).

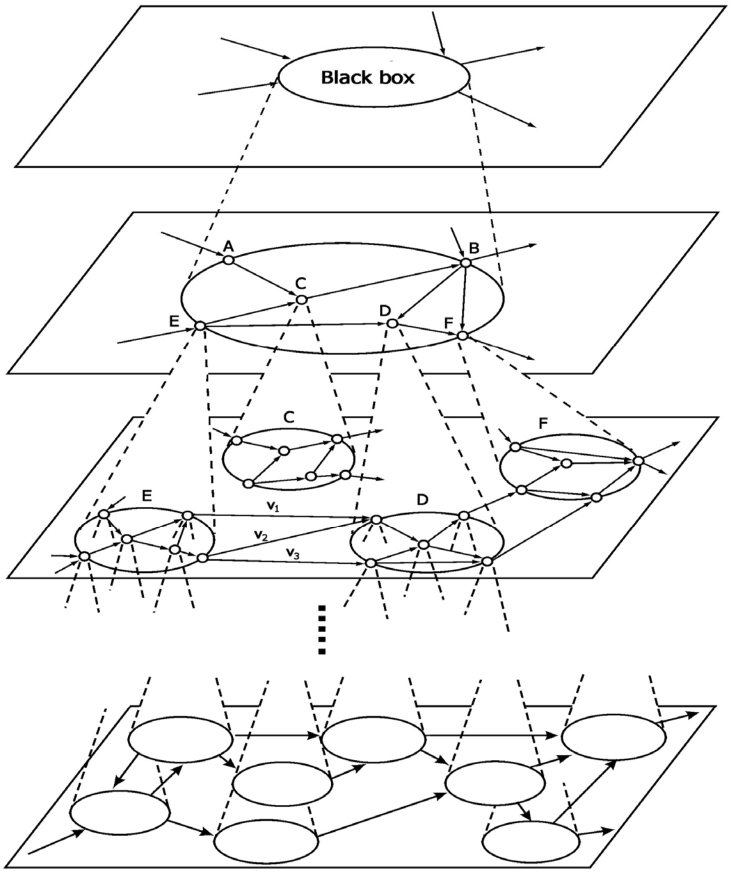

Fig.1. Illustration of the concept of Levels of distinguish (adopted from [17]).

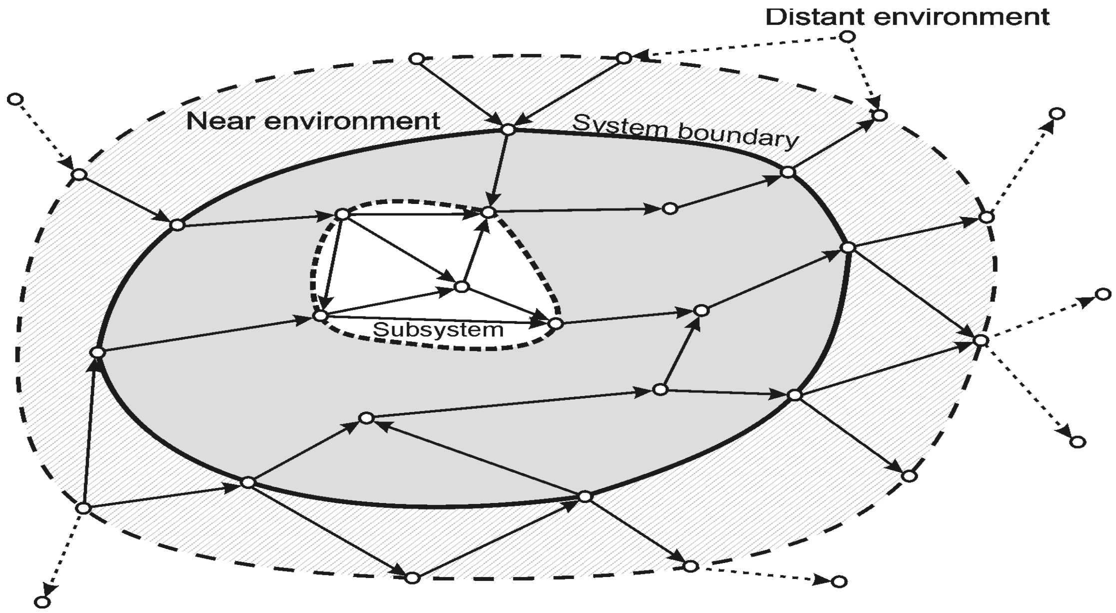

Fig.2. Schematic sketch of an introduction to Structure – Oriented Graph (adopted from [17]).

3.2 Systems Identification – Elaboration of Concepts

An object is as a rule changing in time (i.e. evolution). "Snapshot" of an object expressed in base variables could be identified with the **State** of the System.

State Space $S := L \times V$; L is the set of Systems variables, V is the set of domains of these variables (2)

Behavior of the System can be then identified as $\rightarrow$ Set of Trajectories in State Space

Causality of the (Time or dynamic) Systems express the feature of the System in which any state is independent on future states.

Elements of Systems

The separable parts of Systems, (the Elements of the System first of all) can preferentially be expressed (in Time Systems) as Finite Deterministic Automata:

$A = (X, Z, Z_0, Y, \alpha, \beta)$; (3)

Where as X,Z,Y are finite non-empty sets of inputs, internal states and outputs respectively; Z_0 (subset of Z) is the initial state of automaton;

$\alpha := Z \times X \rightarrow Z$; (4)

$\beta := Z \times X \rightarrow Y$; (5)

Both (mapping) functions **(α, β)**, do not generally act instantaneously but with certain delay, therefore they generate the dynamics of an element / automaton

Structure, Structural Systems

Structure can be defined as the set of elements and doubles of elements from the same set,

$St = (A, (a_i, a_j))$; (6)

$i, j = 1,2,\ldots\ldots.n$; $A \in (a_1, a_2,\ldots a_i \ldots a_j \ldots a_n)$;

while doubles of elements express the existence of relations.

System can be then identified as evaluated structure

$S = (A/F, R/P)$; (7)

where A is a set of elements / automata;

$A = (a_k)$; $k = 1\ldots\ldots.n$;

F is a set of functions **α, β** of elements;

F = **(α_k, β_k)** defines the ability of system.

R/P is a set of relations between all existing doubles of Systems elements expressed in relevant parameters P.

The ability of system is fully accessible solely in the case of regular interfaces.

State of the Structural Systems

State of the element a_i in time t can be defined as a quadruple of sets (in simple cases vectors): inputs IN_i; outputs (also values of elements) OUT_i ; internal states Z and a state of internal function f_i

$$val\ a_i\,|_t = val\ (IN_i,\ OUT_i,\ Z_i,\ f_i)\,|_t \qquad (8)$$

Discrete time has been introduced, therefore:

$$IN_{i,\ t-1} \rightarrow (\ f_i\ ) \rightarrow OUT_{i,t}\ ; \qquad (9)$$

symbol :(f_i) express that transformation is realized through function f_i .

Thus: State of the system is a set of states of the composing elements.

Respective state-space has its dimension equal to the number of states. If the metrics is introduced, then the state –space is the metric space, of course.

If the condition of regularity is fulfilled, then an output – the value of the element a_i – becomes in the same time the value of the input of the consequent element a_j :

$$OUT_{i,t} = IN_{j,t}; \qquad (10)$$

The change of the state of element a_i can initiate the transition of (at least one) successive element a_j

An **event** occurred.

$$u_j:\ OUT_{i,t} \rightarrow IN_{j,t} \quad \text{or} \quad t \rightarrow t + 1; \qquad (11)$$

Transition

Transition is de facto any change of state which manifests itself as the change of the value (or function) of the elements.

Transition could be further subdivided as follows:

- Full closed (state – space is not changed)
- Constricted closed (state – space is irreversibly reduced)
- Open (State – space can be gradually extended)

Under different criterion:

- Definite
- Multivalent (incl. Stochastic)

Process

The succession - chain of events is a process. These categories of processes are introduced:

- Serial (a single succession of events)
- Parallel (two or more events take part in the same step of time)
- Mixed
- Alternative (an event u_j is followed either by the event u_{ka}, or the event u_{kb}. The choice of the alternative is a result of certain condition testing.

Behavior

The set of the all **possible** processes is denominated as a magnitude (M).

The set of the all **activated** processes from M is then → **behavior**

Important subsets of behavior:

- γ - goal oriented (goal seeking) behavior
- δ - species / type focused behavior (taken down as a genetic code)

Identity

is the constructive characteristics of a System reflecting the acceptance of the System by its Neighborhood / Environment (See Identity Task).

Extended Inductive Definition of System [4]

$S = (A/F, R/P, M, \gamma, \delta, I);$ (12)

where (A/F,R/P) is the core of this definition (system as an evaluated structure) while (M, γ, δ, I) is the technical and epistemological extension.

Metrics:
The set of elements and / or states could be understood as metric spaces (and corresponding System as the Metric System) if there is defined **distance** of two elements a_i, a_j ; resp. two states s_i, s_j.

The distance (d) has to fulfill these conditions:

- $d(a_i, a_j) = 0 \Leftrightarrow i = j$
- $d(a_i, a_j) = d(a_j, a_i)$ ***symmetry***
- $d(a_i, a_k) \leq d(a_i, a_j) + d(a_j, a_k)$ ***"triangle inequality"*** (13)

(i, j, k are natural numbers).

Distances of Systems Elements have to be defined for all identified parameters of respective Systems joints.

3.3 Recommended Sequence of Systems Identification

1. Choice of the level of distinguish of the whole.
2. Choice of Systems Elements (nomination or generation; valid for the near / structured neighborhood as well)
3. Allocation of functions to the elements.
4. Definition of coupled pairs of elements, definition of Systems joints, definition of Systems structure, introduction of metrics.
5. Identification of alternative processes – i.e. area of adaptability of the System.
6. Specification of the conditions which are to be fulfilled to activate the processes from the neighborhood.
7. Stating and utilization of the rules for identification of strong functions and compactness.
8. Identification of identity.

(The meaning of items 5 – 8 will be explained in further Chapters - tasks)

3.4 Systems recording

There are several ways how to record System. The choice of suitable record depends mostly on degree of uncertainty (shortage of information) of respective System.

- Natural / artificial (e.g. programming) language
- Tables (of elements, relations, architecture, etc.)
- Figures and schemata (including time diagrams, flowcharts, etc.)
- Logical expressions or schematics
- Mathematical methods of description (graphs, sets, nets, functions, matrices, equations, algorithms, etc.)
- Use of analogon (similar, equivalent system)

3.5 Model - System Relationship

System can be identified as a specific kind of model in which the relation Original – Model is "controlled homomorphism", or "almost isomorphism". It comes to the fact that the Subject (Identificator / Modeler) firmly controls the deviation of the model from isomorphism. The necessary simplification procedures are to be properly chosen [3].

3.6 Ensuring Systems Existence

Interpreted Systems have to reflect the qualities which are familiar from the reality. These features affect time-life of respective System as well. They express human experience that nothing can perpetually cumulate or disappear within the System. Probably the simplest expressions of these qualities are generalized Kirchhoff laws:

$$\Sigma_{\forall i}\ (IN_i+OUT_i) = 0 \qquad (14)$$

***Nothing** neither disappears nor emerges per se in any Systems element or subsystems (with input IN and output OUT).*

$$\Sigma_{\text{for every closed path inside the System}}\ (IN_i - OUT_j) = 0 \qquad (15)$$

Nothing can be gained or lost moving on circular path inside the System.

3.7 Specific types of Systems / Models

Complex Systems / Models are characteristic of "emergent phenomena" – new, often unexpected qualitative features which result from the complexity beyond our abilities of computing / modeling (i.e. "trans-computability"), OR heterogeneity of elements / Systems parts, OR uncertainty. In general case of complex heterogeneous Objects even the basic characteristics of Systems or Systems parts are not fully feasible. Then the concept of Alliance [18] could be utilized.

4. Interface Task

An important condition both for the very existence of System and the seamless running of processes within the System is the regularity of joints among any parts of the System. To ensure the regularity of joints the interface of respective the Systems parts is to be analyzed.

Interface at the basic level is defined as the fictive cut between two joined parts of the System.

It is recorded by the set of relevant variables and their values on the output and consequent input.

Regularity of the interface then means the equivalence (or one to one predefined correspondence) both the sets of variables and the respective values (domains, intervals) of these variables [19].

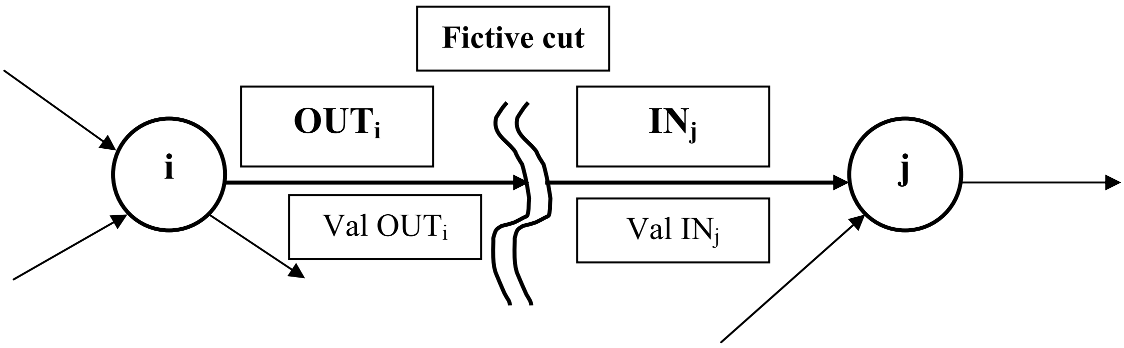

Fig.3. Scheme of Interface of Systems elements i and j.

$$OUT_i \approx IN_j\ ; \qquad (16)$$

$$\text{Val } OUT_i \approx \text{Val } IN_j\ ; \qquad (17)$$

(for all identified joints i,j within the System).

Ensuring Systems regularity implies:

- Finding out irregular relations of interfaces
- Regularization of these relations
- Projections of implemented actions into the coherence requirements, i.e. check of System's regularity, as any intervention into the System could result in unexpected and nonlocal System's changes.

Alternative approaches of interface regularizing:
1. Modifying the function of the input or output element of the irregular joint
2. Inserting conversion element (i.e. automaton) into the respective joint
3. Using substitutability of parameters
4. Finding such elements within the system that can either supply the missing demand or consume surpluses
5. Reconstruction of the System as a whole.

5. Systems Structural Tasks

These tasks have general aims to investigate potential capabilities of system‘s structure and / or possibilities and impacts of structural changes.

In these tasks the fundamentals of the knowledge of the Theory of the (oriented) graphs [7] are commonly used, e.g.: Dijkstra's algorithm, Floyd's algorithm, Danzig's algorithm, Ford-Fulkerson's algorithm, Sorting algorithms, Theorem on Features of the Powers of Adjacency Matrices…

The initial idea of this type of tasks solving is to express the Systems Structure in the form of oriented graph and then to utilize the firmly established fabric of the Theory of graphs.

These tasks are usually articulated as follows:

- Path tasks
- Antecedent and subsequent elements finding task
- Feedback identification task
- Finding elements or relations with specific parameters
- Flow network task
- Systems decomposition and integration task
- Systems goals task

5.1 Path Task

This task enables:

- Finding all possible paths between any two elements
- Path‘s length assessment
- Finding path with predefined parameters (e.g. the shortest, the longest, of the specific length, ...)
- Tracing path of certain length
- Finding set of all paths in the system

To solve this task in general the Sorting algorithms and / or the Theorem on Features of the Powers of Adjacency Matrices, i.e.: "Non-zero coefficients in the i^{th} power of adjacency matrix determine the existence and amount of paths of the length i between any oriented doubles of elements", can be successfully applied. On the other hand the utilization of specific algorithms (Floyd's, Dantzig's, Dijkstra's) can be more efficient in many particular tasks [7].

These following relations are introduced:

- Systems element ⇔ node
- Systems relation / connection ⇔ arc
- Systems path ⇔ graph path
- Systems structure ⇔ Oriented graph

5.2 Antecedent and Subsequent Elements Finding Task

This task can be transformed into the Path Task taking into account the following relations:

- Antecedent elements = elements on paths leading **into** certain element.
- Subsequent elements = elements on paths leading **from** certain element.
- Generation = the length of the path that connects reference element with its antecedent or subsequent.

Then finding antecedent and subsequent elements task takes directly advantage of these results of Path Task:

- Subsequent elements to the element i, j-th generation can be found in the j-th power of adjacency matrix (S^J) in i-th row. Indices of the columns with non-zero value in the i-th row show the subsequents.

- Antecedent elements to element i, j-th generation can be found in the -jth power of adjacency matrix (S^J) in i-th column. Indices of the rows with non-zero value in the i-th column show the antecedents.

5.3 Feedback Identification Task

Feedback is of vital importance for the very existence of many Systems. Life of beings, operation of automatic devices or robots, behavior of environmental and social systems or even the evolution is based on this concept. On the other hand untreated, improperly acting feedback can cause many problems – instability of system, oscillations or even a „deadlock".

That is why feedback in Systems is to be „under supervision / control of the Subject or (super) System".

Feedback Identification Task can be transformed into the Path Task as well, taking into consideration the relation:

- Feedback of the length **j** is in the respective graph of Systems structure represented as closed path. Therefore feedback of the length **j** is identified in respective j^{th} power of adjacency matrix of the graph as nonzero element in the main diagonal.

Whereas both the Systems environment and the Systems resources are not commonly displayed in Systems structure, eventual feedbacks going through the environment or resulting from resources utilization is to be identified separately.

5.4 Finding elements or relations with specific parameters Task

This task can be in general successfully solved using sorting algorithms.

5.5 Flow Network Task

An ability of Structured Systems to transfer certain quantity between two specified Systems elements has great user – oriented impact. An efficient tool in this case is specific part of the theory of oriented graphs – a flow network. Powerful algorithm within this theory is the Ford-Fulkerson's algorithm.

5.6 Systems decomposition and Integration Task

To overcome unmanageable complexity of a System as a whole quite often a decomposition of the Systems structure can be done. Only binary relations are suitable candidates for decomposition. There are 4 basic kind of decomposition:

- Topological
- Functional
- Semantic
- Hierarchic

Quite often these four basic kinds of decomposition are pragmatically combined.

Whether any kind of decomposition is applied, 3 postulates should be met:

- Integrity - i.e.: The System before and after decomposition remains the same.
- Consistency – i.e.: No part of the System is isolated.
- Balance – i.e.: Decomposed parts are of comparable (not too different) complexity.

The Criterion of <u>topological decomposition</u> is the minimum number of joints of decomposed parts, or minimum sum of weights of these joints. To fulfill this criterion various modifications of Ford - Fulkerson's algorithm are successfully applied.

The criterion of the <u>functional decomposition</u> is: Decomposed parts – Subsystems have to be carriers of Macro-functions. Identification of macro-functions can be done via the concept of levels of distinguish. This decomposition is significantly dependent on the Subject's point of view; nevertheless it is frequently used as it reflects the aspect of minimal inference to Systems processes related to the level of decomposition.

The criterion of <u>semantic decomposition</u> is: The elements of decomposed part – Subsystem are carriers of pre – defined feature. This type of decomposition is de facto set up on the basis of the categorization of Systems elements. As a rule, sorting, clustering and fuzzy clustering algorithms are frequently utilized.

<u>Hierarchic decomposition</u> is the decomposition of hierarchical structure. The graph of hierarchic structure is tree. It implies, that 2 basic approaches to the hierarchic decomposition become effective: on (hierarchic) levels or on branches. The second attempt is an analogy of functional decomposition while the first one holds the basic features of semantic decomposition.

Systems Integration means a substitution of a subsystem by a constructed System element. This task consists of two phases. The structural one is a plain transposition of a subsystem with a particular element. The constructive phase means the creation of the Systems element (i.e. automaton) which has the same functions as the input – output behavior of the deleted subsystem. Generally this is a complex and hard-to solve problem.

5.7 Systems Goals Task

The goal of the System generally can be:

- Specific state of the System
- Specific state of neighborhood or initiation of certain processes within the neighborhood
- Certain processes in the System defined in qualitative, quantitative and dynamic parameters.

Goals Classification

Systems goals can be classified according to various criteria:

- According to the length of the Systems path: the near goals and the distant ones.
- Tactical, operational and strategic goals.
- Goals achievable / unachievable. Goals can be achieved if there is a path to the goal state and if there are sufficient system resources.
- According to the allocation:

The outer goal is allocated to the neighborhood. It means either setting the neighborhood to a pre-defined state or the initiation of specific process within in the neighborhood. Expressed simply, this means a 'supply' of some entity from the system into the surroundings. The internal goals of the system are allocated to the interior of the system. They represent dynamic balance of the set of the goals of its components and subsystems. As a result, they are of conflicting nature. The ordering goal is the first of the nonlocal, holistic system goals. Its achievement is mediated by "ordering" / "self-ordering" processes, which are generally of “minimax” character and are therefore within the class of “strong processes”. An example can be known from cybernetics as homeostatic process. The goals of this category imply that the control processes and system resources are managed in such a way that resources are optimally spent. Keeping track of this objective ensures the survival of the system, even under selective pressure. Further understanding of the nature of this type of system provides an objective introduction to cybernetics.

Species survival goal (conservation of genetic code) is the second category of non-local goals.

This class of goals is closely related to the behavior of the system in relation to genetic code. In Systems theory, this goal was established under the influence of biology, its characteristics are nevertheless generally systemic.

Enforcement of identity goal is the last category of non-local goals, which are given explicitly. It is further explained within the Identity task. Conflicts between goals and categories of goals respectively are very frequent. An opposite case – coherence of goals is a rare yet very interesting Systems phenomenon.

Goals sources:

The Systems goals sources can be identified:

- inside the System
- in the near neighborhood
- in the far neighborhood

Methods of goals generation

These methods should be put into the group of decision-making processes.

In systems sciences however, we must take into account that we are able to answer questions like: "How and why just these states were chosen to become goals?" Or "Who designed these Systems goals and how exactly?"

Methods of goals generation can be divided into these groups:

- exact, "hard": characterized by rigorous rules. They use logical and mathematical approaches, mathematical modeling, and operations research,
- exact "semi-hard": the rules-making goals continue to be exact, but they are based on the methods of coping with uncertainty, such as fuzzy approaches, genetic algorithms and neural networks,
- soft: methods based on subjective experience (heuristic approach, "brainstorming").

6. Cybernetics Essentials

Cybernetics was characterized by the most famous of its founders, Norbert Wiener as "the Science of Control and Communication in living beings and machines". The other Systems sciences have common core concepts with cybernetics, such as: the concept of automaton, structure, transition, information / signal, entropy, feedback. Feedback is a key concept of cybernetics. Higher control methods are not conceivable without the feedback and communication with no feedback has significantly reduced semantics. In cybernetics is customary to work with both continuous and discrete variables (including time).

6.1 Control

The first component of the cybernetics definition is control.
Control: = consciously chosen sequence of events (to achieve a specific goal), or:
Control: = consciously selected goal process.

There are two basic classifications of control. The first one is of explicit and implicit control. For explicit control it is at least in principle possible to distinguish between a controlling subsystem (i.e. controller) and a controlled part of system, while for implicit control such distinction has no real meaning.

The second type of classification is valid only for explicit control. It is based on topologies of joints / feedbacks.

Direct control

In the diagram Fig. 4 we can distinguish the controlled part (a system or object "o ") and the controller 'r'. Both are identified as elements (automata), or (sub) systems.

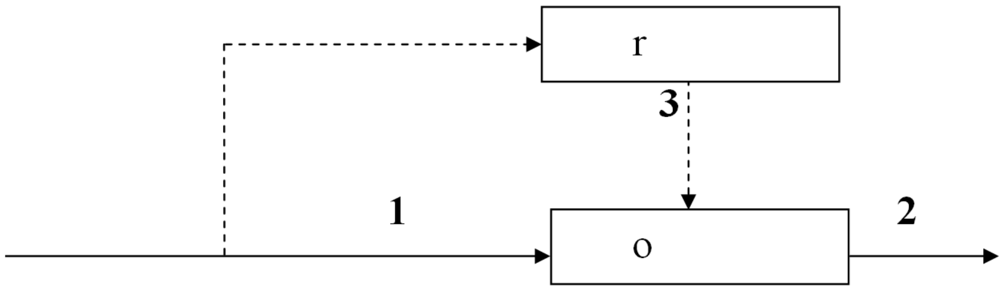

Fig. 4. Direct control

Systems part "r" acts on "o" with control links "3". Output "o" marked "2" is usually what is of interest. The scheme is seen as this output is a 'product' of System, on the other hand it is not available in the sense that the Systems part “r” has no information about its actual parameters and values. There is no explicit feedback. For this reason, this class of control can be used only if the output “2” is made sufficiently reliable and robust. A typical case is a binary control.

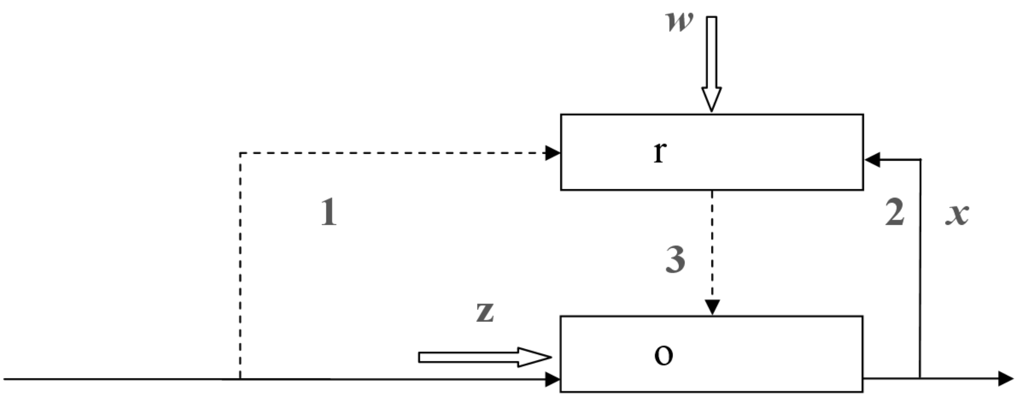

Fig. 5. Feedback control

Control based on deviation - Feedback Control

This is a basic and simple class of feedback control. In this case, the output "2" (its value is "x") acts on the control part “r” . The output value is compared in “r” with the current reference value "w". Depending on the "processed" difference (x - w) "r" ("r" in this case is also called the controller) creates value, which is transmitted to the control link "3", and operates "o".

Control based on deviation, i.e. the simplest case of feedback control, has to be discussed in greater detail in order to comprehend qualitative characteristics of this process. First, the variables are to be re - marked as usual in the theory of control. This way of marking is based on the history of constant - value control. This simple case of control is quite widely used in applications (e.g. thermostat, speed regulator). The input "z" in this sense is a disturbing signal via which the neighborhood acts on the System. The variable "w" corresponds to the initial settings of the subsystem “r” and therefore it expresses the required value. Output "x" can be derived e.g. via the transfer graph method:

- transfer of control: $x/w = ro/(1+ro)$ (18)

- transfer of disturbance: $x/z = o/(1+ro)$ (19)

If the relevant functions (processes) of elements (subsystems) r, o, s are linear, the relevant transfers can be expressed in the form of Laplace images. Generalization of the value of "w" into the time variable is then non – problematic. Further, the quality of the control and process dynamics "w → x “ (i.e. transfer x/w) is to be identified. This control can be further broken down under criteria:

- Linearity: linear / nonlinear
- Continuity: continuous (also analog) / discrete
- Determinism: deterministic / stochastic / fuzzy

The "classical" deterministic linear continuous control is further pragmatically classified by the type of controller:

P: control variable y is directly proportional to the difference (x - w).
PI: control variable y is directly proportional to the (x - w) and integral of the (x - w).
PD: control variable y is directly proportional to the (x - w) and derivative of the (x - w).
PID: control variable y is directly proportional to the (x - w), derivative, and integral of the (x - w).

An important feature of the feedback control is its stability. A measure of stability can be the output behavior in a "sufficiently long" time, i.e.:

$\lim_{t\to\infty} x(t) =$ $0 \Rightarrow$ **control is stable** (20)

$\infty \Rightarrow$ control is unstable

$(0,\infty) \Rightarrow$ control is neutral

The quality of the control process can be evaluated with reference to different criteria. The most frequent is the criterion of the minimum integral of the deviation square.

Reliability of the control process can be determined as reliability of any process.

Availability of feedback control can be as well evaluated as the availability of any process, i.e. the frequency of occurrence of states when the process is activated in proportion to the number of requests to activate the process.

Optimization of the control implies:

(i.) Determination of the optimality criterion
(ii.) Specification of the process (including determination of the activation conditions) that best meets specified criteria.

Adaptive Control

It is a higher degree of feedback control. The information of controller “r” is enhanced utilizing an input "1" (dashed arrow entering the controller "r" in Fig.5.). The potential result is better dynamics, quality and stability of control.

Interactive Control
In comparison with previous case the inner coupling of "r" and "o" further increases. Through the added inner links the regulator "r" obtains detailed information on object "o". It also helps to improve the qualitative and quantitative characteristics of the control process.

Control with prerequisites (utilizing genetic code)
Control process is supplemented by the variable which express the distance of the respective state from the genetic code of the System.

Control with self-learning
In addition, we can identify the output - input loop in controller "r" in the structure. It expresses in a simplified form the possibility of storing information about the history of control processes, i.e., "gaining experience".

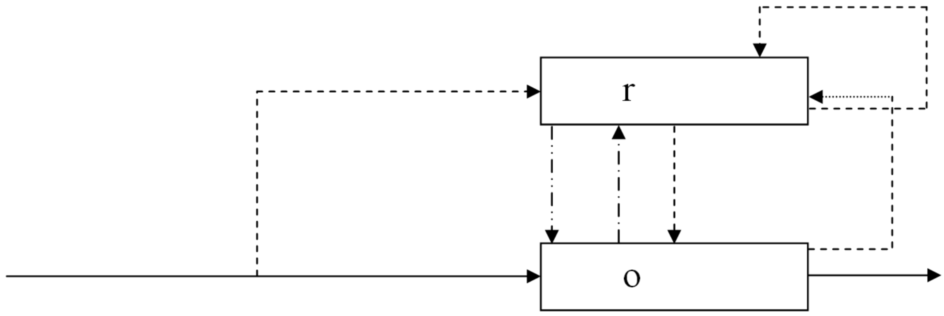

Fig. 6. Control with self -learning

At the end of this paragraph an important law (known as the "Law of the Requisite Variety" - William Ross Ashby) that connects the areas of communication and control is briefly discussed.

We suppose that perturbation enters the input of System, which obviously causes an increase of output uncertainty if the processes of control are not active. You have probably noticed that the control reduces the uncertainty of the system as a whole. The output "2" in Fig. 5. is, (in spite of the input perturbation - in the case that control processes are active) in better defined, less uncertain state. To exemplify the constant - value control suppresses the active perturbations significantly at the output of System. Only small fluctuations (caused by the imperfections of control) remain. This knowledge can also be re - formulated so that the processes of control actively filter the disturbing signals entering the system.

The natural question, of what the limits of active filtering are then arises:
(i) Active filtering is not effective if there are insufficient resources. This conclusion is quite understandable, though quantification can eventually be complicated.
(ii.) Active filtering fails if the value of the disturbing signal is so high that it causes System failure. Again, the conclusion is obvious and from our point of view it does not require further analysis.
(iii.) Active filter fails if there is insufficient information on the disturbing signal state changes (i.e. changes in the dynamics of the environment). It deals with the case of the Law of Requisite Variety.
In a simplified formulation this law can be expressed as follows:
(a.) Uncertainty removed in the process of control is bound above by the quantity of information shared between the controller and the environment.
Or:

(b.) The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate for. Even this restriction of the active filtering in terms of human experience can be easily understood. To coin an example if the controller is able to accept and process such as an average of 10 bps, it can hardly be expected it would be able to eliminate a perturbing flow of 20 bps.
What is noteworthy is the fact that this law is valid for any system and arbitrary type of control.

6.2 Logic Systems

Historically, a theory of logic systems is a constituent part of cybernetics. Currently, this part of Systems theory is distributed to several almost autonomous Systems sciences. The most important one of them is Computer

Science (CS). CS is an essential component of ITS, and it is discussed at length in the other chapters of this book. Therefore, these issues are not being dealt with herein.

6.3 Communication

Communication is generally understood as the transfer of information. Information during this process changes its carrier (signal), code, or even modifies the information structure via either removing redundancy (compression) or, conversely increasing redundancy (security). In case there is a priori information of the recipient state, communication can also extract (Shannon) information from data.

The focus of cybernetics is not the plain "telecommunications" side of information transfer but rather the study of the forms of information expressions and transforms, languages and specific issue of a process initiation (e.g. control) utilizing language constructs.

Cybernetics generalizes and further elaborates the concept of signal systems originally established in biology and psychology. We are tackling the problem of how a specific event initiates a process. These categories can be distinguished:

- The first signal level, which is characterized by direct processes initiation. The initial event directly "triggers" the process. The concept of a reflexive level is borrowed from biology.
- The second signal level, which is characterized by mediated initiation of processes. Specific event invokes the creation of a language construct in the relevant language, then possibly follows a translation of this construct into another language, and eventually follows the interpretation of the construct and subsequently the initiation of the process.
- Signal level "One and half", which is characterized by the modification of the trigger event by certain internal premise. Internal premises are expressed via the attraction of strong processes in System behavior. In linguistic terms, this corresponds to the phenomenon known as homonymy. Particular languages mutually differ in semantics.

A language is essential in communication.

6.4 Language

Language is above all a basic tool of communication between people. This so-called natural language is the most perfect known communication tool and communication / information processing environment respectively.

For Human - Machine or Machine – Machine communication artificial languages have been developed. They do not possess the expressive potential of natural language, however they display a simpler form, unambiguous syntax and semantics and as a consequence, better conditions for the implementation of the one – to - one translation from one language to another.

In recent years, the so-called pragmatic language were introduced, which formally deal with the communication between man, or computer on one side and "less intelligent" - information simpler machine than the computer, on the other side. An example could be the two-way communication between car and driver. It is usually an example of the "One and half" signal level. The properties of these languages are nonstandard and not yet sufficiently explored [20]. These languages are likely to be significant even for communication between biological objects.

The components of language in general are:

- alphabet - a set of basic symbols
- syntax – a system of rules by which (higher) symbols – syntactic constructs- are derived
- semantics - meaning / content of the syntactic constructs.

Alphabet, along with syntax, form grammar. Grammar is a system that generates the structure of language. Grammar is defined as the set:

$$G := (N, T, W, P), \text{ where:} \tag{21}$$

N is the set of nonterminal symbols
T is the set of terminal symbols (alphabet)
W is the initial non-terminal symbol $V \subset N$
P is a set of associative / rewriting rules.

Semantics can be distinguished into these classes:
• axiomatic (fixed assignment)
• compiler oriented (the meaning of the construct is determined via translation between languages)
• operationally defined (the meaning of the construct / object is generated as a logical function of sub-objects)
• denotational (the meaning of the construct is generated in the process of real language use – e.g. natural languages).

The formal similarity of the definitions of grammar and automaton is no accident. It can be proved [21], there is an isomorphism between the language and automaton. This result has two strong consequences:

(i.)The system can be equivalently recorded as the set of languages; (multi-language) and the set of rules of their mutual translations.

(ii.)The real object can be recorded in language.

6.5 Homeostasis

Biologists have probably first noticed that the living creatures obtain energy, substance and information from the environment. On this basis a number of control processes which generally have the aim of maintaining the "internal environment" within the limits in which the creature survives well is activated. This is achieved via a well balanced and mostly feedback set of control processes minimizing deviations. Similar situations have been identified in social units, environmental wholes and then even in certain inanimate objects (crystals resisting to changes in temperature, and such like). The existence (life) of such objects is accompanied by their high arrangement, therefore by low (configuration) entropy. The Second Law of Thermodynamics, the law of universal scope in the real world, in its more general formulation states that each (i.e. even the open) system tends to entropy increase. An observation that certain objects in reality remarkably well "survive" in an organized - low entropy - state, indicates that the chaotizing tendency of the Second Law of Thermodynamics is effectively eliminated by the multidimensional "active filtration of perturbations" i.e. homeostasis. This objects feature can be naturally reflected in the Systems identification. Within Systems we therefore can find the specific goals and goal oriented "anti-entropic" processes, focused both on the ordering of an individual and the survival of the species.

6.6 Artificial Intelligence (AI)

AI is now a well constituted science field that originated within the framework of cybernetics. In its context, and in a broader context of the Systems theory, it has further evolved.

The essence of AI is illustrated here just as a set of typical tasks:

a. identification - recognition of varieties
b. optimization
c. search of goals
d. (self) adaptability
e. control of parallel processes
f. communication with the neighborhood (including the ability to understand vague expressions)
g. understanding in general
h. identity control
i. self-consciousness

7. Behavior Tasks

7.1 Review of Concepts

Behavior **:=** set of processes active within the System in a specified time interval AND in a given state of the neighborhood;

$F = \cup_{\forall i} F_i$

Process **:=** sequence (chain) of events OR trajectory in State – space;
State of the System **:=** Set of actual states of Systems elements;

State of the System (reduced meaning) **:=** Set of actually Active System elements;
Event **:=** Change of the state of Systems element OR change of Systems structure OR step of external time;
Partial behavior (F_i) **:=** Subset of processes activated for pre – defined (fixed) vector of Systems inputs (I_i).

7.2 Basic Model of Behavior

Key step to the solving of this task is a decomposition of the behavior as a whole into the partial behaviors F_i. (This decomposition is not universally applicable.)
The problem can be efficiently solved via this correspondence: System → Graph (Table 2) for each partial behavior:

Table 2. To solve the basic model of behavior this transformation of a System into a Graph can be used.

System	Graph
State	node
event	Edge (arrow)
process	path

Adjacency matrix of this graph for the respective partial behavior F_i is the Matrix of partial behavior D^i.
Quite often this Matrix is transposed into whole State – Space. The resulting Matrix (of higher dimension) is called the Standard matrix of i^{th} partial behavior $\mathbf{SD^i}$.
Set of all Matrices of partial behavior or $\mathbf{SD^i}$s represents the behavior of the System as a whole.
All paths in this set represent all the processes within the respective System, i.e. behavior.
A practical problem arises if the Set of Matrices of partial behavior (or SD^i) for analyzed system is to be identified.
There are two basic approaches of obtaining these matrices:

- Experimenting with the System
- Modeling the System with appropriate tools, for example with Petri Nets or Decision Tables.

The example of the use of Petri Net is based on this correspondence:

System	⇔	**PN**
Set of elements		Set of Places
Activity of an element		Token at the Place
Event		Testing condition of transition
Input combination Ii		Initial position of tokens
Partial behavior D^i		Transition graph
Initial state		Root of the transitions graph

7.3 Extended model of behavior

Analysis of behavior utilizing solely the Basic model of behavior could not be efficient in all tasks as it needs quite often a cumbersome transformation of the Systems. The extension of this model can be taken into account directly:

- Parameters of the Systems joints
- Certain aspects of System functions without any further Systems transformations, e.g. for these tasks:
  - Behavior in time scale

- Resources needed to the carrying out processes
- Reliability of processes.

General Procedure:

1. Construction of the Basic model; make – up of the set of matrices of partial behavior D^i
2. Finding out the processes in the basic form
3. Completing the description of processes with selected parameters of joints and / or Elements functions (substitution out from Systems model – i.e. Interpreted System)
4. Insertion of the values of input parameters (out of the near neighborhood).

Examples:

Time Analysis

The activation of any Systems Element is assigned a defined time interval (i.e. delay within the selected Element). To analyze any chosen process with respect to time it is necessary to find out all the activated paths in the Systems structure. Then the duration of a respective path is cumulated step by step. As a rule the path of specific duration (min., max, predefined…) is then analyzed in detail (the so called "critical path").

Structure of the System (Table 3):

Table 3. Structure of analyzed System

S	I	2	3	4	5	6	7	O
I		**1**	1		1			
2				**1**			1	
3								1
4						**1**	**1**	
5						1		
6								**1**
7								**1**
O								

Table 4. Time delay τ in respective Systems Elements

Element	I	2	3	4	5	6	7	O
τ (s)	5	20	13	6	8	9	10	11

Concurrently activated joints: I-3 AND I-5; 4-6 AND 4-7; 6-O AND 7-O (this information is needed for the construction of PN). ***PN:***

⇓

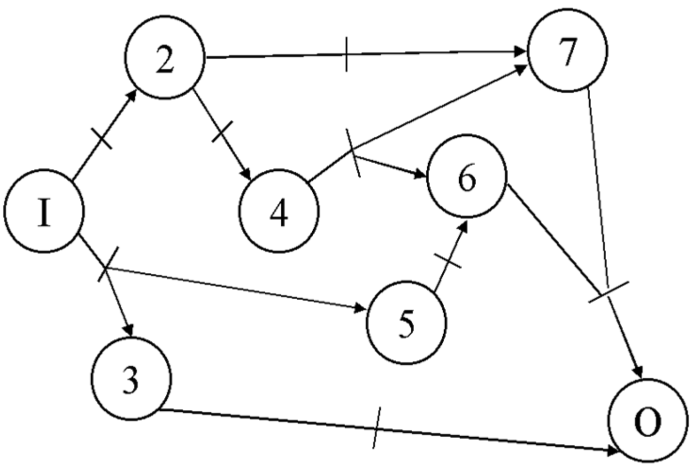

Fig. 7. PN construction

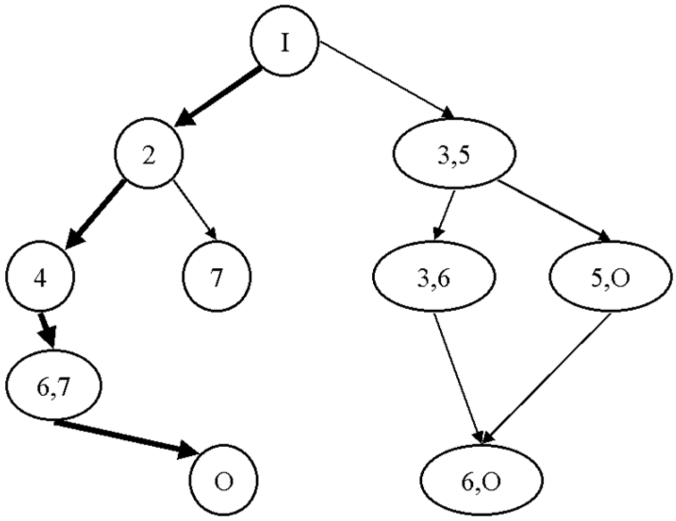

Fig. 8. Transition graph (only for I=1 is reasonable):

Table 5. Partial behavior

Single partial behavior is obtained:

D^1	I	2	4	7	6,7	3,5	3,6	5,O	6,O	O
I		**1**				1				
2			**1**	1						
4					**1**					
7										
6,7										**1**
3,5							1	1		
3,6									1	
5,O									1	
6,O										
O										

Analysis of the process chosen (**I → 2 → 4 → 6,7 → O)** with respect to time duration:

To be able to analyze time relations the adjacency matrix of the sub-graph which is activated in the course of chosen process must be found.

The frame algorithm of acquiring this sub-graph:

In successive steps check all the events of the process under investigation in the respective matrix of partial behavior.

For each event which take part in the chosen process in matrix Di**:**

→ Mark in the adjacency matrix of a respective System **S all the rows** corresponding to the active elements prior to this event.

→ Mark in the adjacency matrix of a respective System **S all the columns** corresponding to the active elements next to this event.

In the crossing points of marked rows and columns in the matrix of neighborhood **S confirm the ones,** if they occur there.

The set of confirmed "1"in the matrix **S** represents an activated sub-structure.

Table 6. Identification of activated substructure (1 - confirmed joints, 0 – non-confirmed joints)

	I	2	3	4	5	6	7	O
I		**1**	0		0			
2				**1**			0	
3								0
4						**1**	**1**	
5						0		
6								**1**
7								**1**
O								

Chosen process activates these paths in the Systems sub-structure:

i. Y – 1 – 2 - 4 - 6 - O

ii. Y – 1 – 2 – 4 - 7 - O.

Times expenditure of the execution of the chosen process can be determined by the insertion of the data from the table of delays.

For the respective paths these values are obtained:

i.: 51; ii.: 52.

Duration of the process is usually identified with the length of the longest - the most time consuming (critical) path.

Analysis of the cost of process execution.

Cumulative approach:

- Each Systems element is assigned a certain cost of activation
- Cumulative parameter of the cost of process is calculated step by step during the course of process.

Utilization of the “source”(bank):

Structure of the System is supplemented with (real or fictitious) element or sub – system “source” (Bank)

- Prior to any activation of the element in the course of the process this element “claims” requisite resources in the “source”.
- Resources are consequently allocated to the element. (In the opposite case the follow - through of the process is modified by some condition.)
- Costs are traced in the “source” (Bank).

Analysis of process reliability:

Generally the probability of process execution is analyzed.

Frame procedure:

- Allocate activated sub-structure.
- Determine probabilities of the execution of the functions of pertinent elements (for given variety of Systems inputs).

Probabilities of implementation of particular states or processes are identified as follows:

Series ordering (chain):

For mutually independent probabilities of elements the probability of failure - free process **P** is equal to the product of particular probabilities of failure – free functions of elements $\mathbf{p_i}$. If the condition of mutual independency is not fulfilled, the respective conditional probabilities are to be taken into account.

$$P = \Pi_{\forall i}\, p_i \qquad (22)$$

Parallel ordering:

The probability of failed process **Q** is equal to the product of probabilities of failed functions of elements $\mathbf{q_i}$.

$$P+Q=1\ , \qquad (23)$$

$$q_i+p_i=1\ \big|_{\forall i}\ ,$$

$$Q=\Pi_{\forall i}\, q_i$$

7.4 Parallel behavior task

More processes mean more elements functions active in the same interval of time:

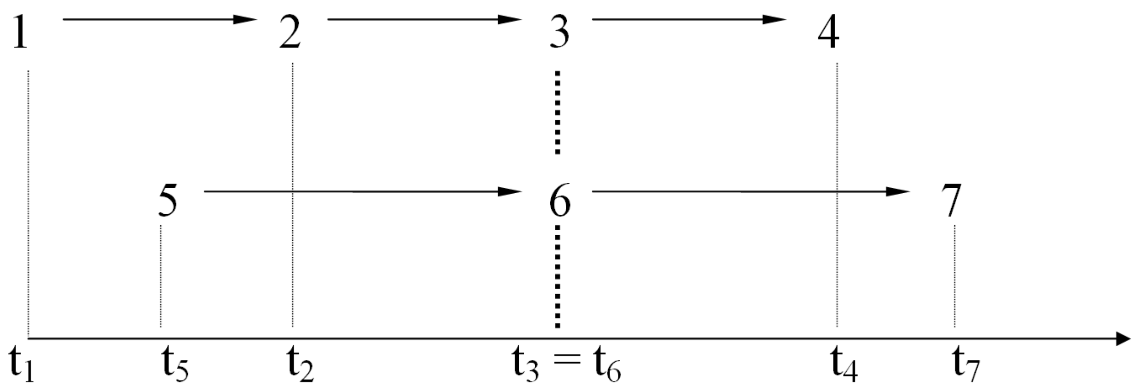

Fig. 9. Scheme of parallel running of processes in time

The task is usually solved in time diagrams which schematically depict the activation of elements in the run of time

Time diagrams:

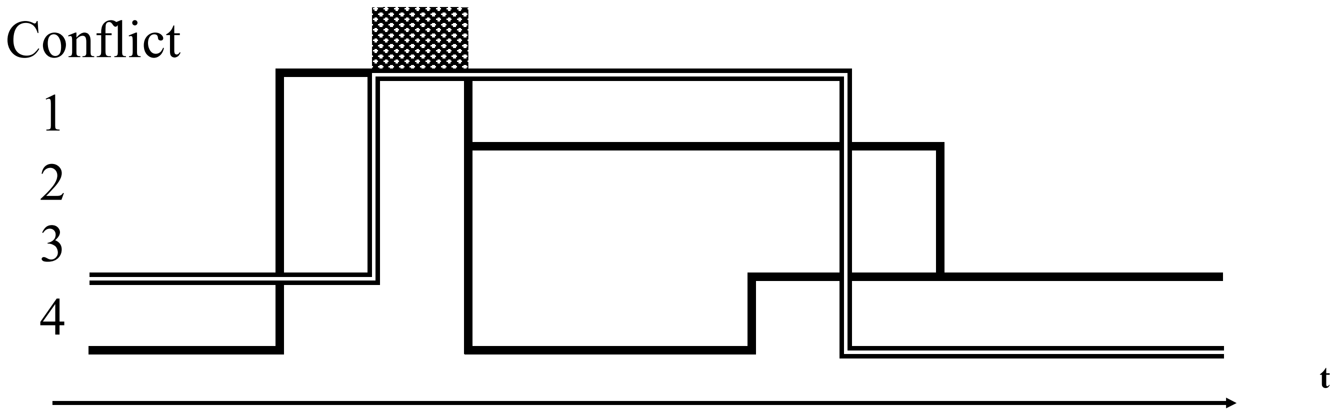

Fig. 10. Time diagram

7.5 Alternative Behavior task

Alternative process – conditional branching of at least one State-Space Trajectory

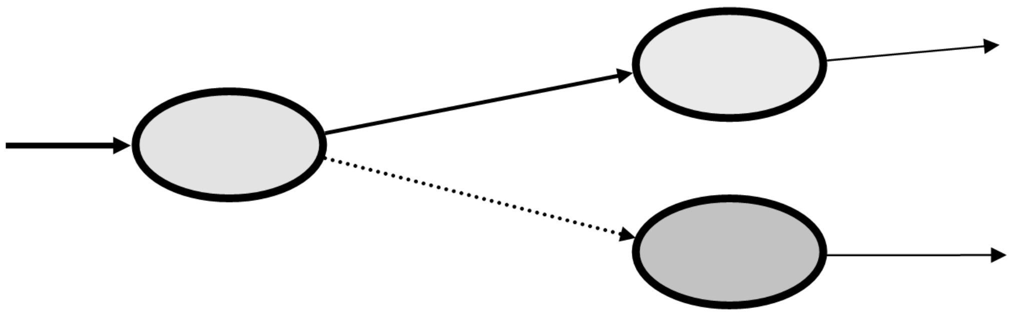

Fig. 11. Branching the trajectory in State- space

Modeling of alternative processes :

- Logical expressions / functions
- Systems of Logical equations

- Combination of Petri Nets (**PN**) with the above stated attempts or **DT**
- Decision Tables (DT)
- Cluster Analysis (**CA**).

7.6 Genetic Code (CG) Behavior Task

A significant feature of complex Systems is the different efficiency of certain classes of processes. Generally there is a class of "strong processes" which are relatively highly efficient (they hold "minimax characteristics"), while other processes are not so efficient. If strong processes are relatively frequently initiated the overall efficiency of the behavior of a respective System is also high. This fact could be recognized as competitive advantage within the frame of Systems Universe.
Crisp definition of GC:

GC is a trace of typical behavior: $F_T = \cap_{\forall i} F_i$, (24)

Model (compare basic model of behavior): $\cap \forall i \; SDi$ (25)
Nevertheless obviously (for complex System): $\cap \forall i \; SDi = \emptyset$ is valid (26)
This trivial result is not obviously plausible.

Not such strict introduction of typical behavior is possible if the majority functions or fuzzy matrices are utilized.
Fuzzy attempt:

1) Find $\mathbf{W} = \cup_{\forall i} \mathbf{SD_i}$ (universe of processes; $W = \{w_{jk}\}$) (27)
2) Determine $\mathbf{G} = \cap_{\forall i} \mathbf{SD_i}$ (28)
3) Identify, whether G contains any process as a whole. In the positive case the crisp typical (strong) behavior has been found. Its trace is crisp GC. End. - If not, go to: 4).
4) Introduce threshold $\xi \in <0,1>$
5) Construct fuzzy matrix with membership function

$\mu : \tilde{G}_\xi \; \{w_{jk} \in W \mid \mu(w_{jk}) \geq \xi\}$ (29)

and go on analogically as in 3).
Gradually tune the value of the threshold till manageable number of the whole processes is obtained.
Respective transition graph / trace of the matrix of this graph express GC.

7.6.1 Classes of behavior in relation to the genetic code (qualitatively)

1) Ideal behavior. It has consistently zero deviation from the genetic code. Behavior tracks the goal. In practice this behavior is rare.
2) Standard behavior. Small deviations arise from the GC, with the possibility of returning to the path of GC. It follows the goal, but requires control of the goal behavior.
3) Adaptive behavior. Pose considerable deviation from the trajectory of GC. There is the possibility of returning to a trajectory of GC at a price: either changes the parameters on the same structure or structural changes (introduction of new elements and joints). It allows achieving the goal of reduced efficiency (due to additional costs such as energy, time ...... the adaptation).
4) Mutation behavior. Variations arise from the GC trajectory of no return. There is a possibility to ensure overall consistency and integrity of System with an acceptable change of GC and with a change in goals. System can maintain the basic attributes of the goal behavior. In this case a change of the structure is quite frequent. Based on the analogy with the biological sciences we can specify resulting System as a different kind.
5) Degenerative (faulty) behavior. System is unable to maintain the goal, in some cases even losing a good sense of goal behavior. It disrupts GC irreversibly and leads to the disintegration of the System. For this behavior, we can distinguish two versions:
a) The uncontrolled (sudden or gradual) degradation b) Controlled System termination (apoptosis).

7.6.2 Analysis of deviations from the GC (quantitatively)

This task can be solved solely in the metric state-space. The deviation from GC is evaluated as a distance of two trajectories (or two sets of trajectories). The first one is the trajectory of ideal behavior while the second one is the trajectory of deviated behavior. This distance should be associated with a pertinent set of parameters such as time or expenses.

8. Systems Architecture Task

Architecture in a general sense could be introduced as a constructed teleological system model of the object of interest with two key features:

- Existence within specified (abstract) space
- Execution of a defined or identified systems function.

Architecture can also be constructed as a weighted unification of a triple of system models (See scheme in Fig. 12):

1. **O**bject (what)
2. **I**nfrastructure (where, when – in relation to a higher system)
3. **A**im (how, why – in relation to the subject – Systems analytics).

Common understanding of architecture prioritizes the second point.

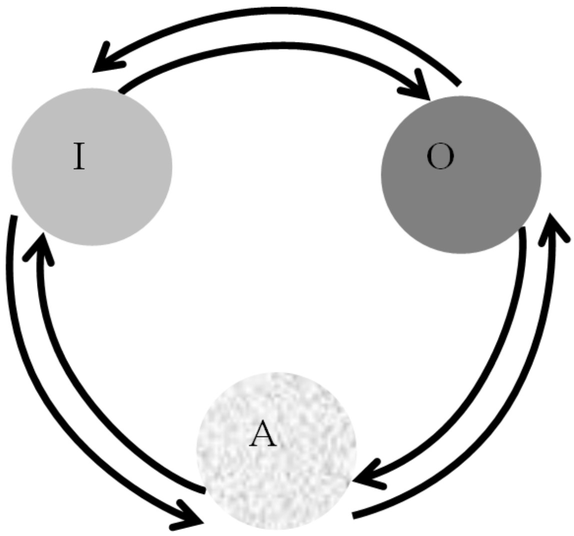

Fig. 12. Scheme of the construction of architecture.

More frequent pragmatic division of architectures introduces several points of view:

- General
- Logical
- Physical
- Object – oriented
- Topological

Etc.

9. Interoperability Task

This concept is quite frequent in the European context. It is defined within European standards as well. Unfortunately, there are many subtly differing definitions that are mutually hardly compatible and they can be distinguished at different levels as well. Interoperability of railway interlocking systems is defined quite accurately while e.g., interoperability of telecommunications systems could be understood in a slightly different manner.

Evidently the dominant feature of interoperable systems is the reliability (of representation) of the standard execution of strong systems processes.

If the problem is analyzed at a suitable level of distinguish, interoperability could be understood as a unique feature of the system in which acceptable degradation of all the Systems interfaces which participate in the execution of strong processes occurs. The concept of interoperability is therefore equivalent to the at least "weak regularity" of interfaces between strong systems elements. The specific European problem is the interoperability of the existing systems (for example of telecommunication or transportation nature). From the existing "menu" of regularization procedures only the insertion of conversion element is feasible. That is probably why achieving of the interoperability in the European context is so difficult and quite often also uneconomical task.

10. Identity Task

Systems identity is the entity, introduced by Vlček et al. [4] to express (in as compact form as possible) the relation of the complex system with its neighborhood.
The identity is defined at two basic levels: (A) Internal, (B) External.

(A) Level is constructed in the dimensions of type, uncertainty and relative weight of goal – oriented processes.
(B) Level is expressed in the dimensions that reflect the impact of the system on the neighborhood.

Quantitative construction of Identity forms a 7 dimensional vector of the components:

1. "Tuning": $\mathbf{Tu = \Sigma IF_R / \Sigma IF}$, where $\mathbf{\Sigma IF_R}$ means the number of all regular interfaces in the respective system, while $\mathbf{\Sigma IF}$ means the total number of interfaces in this system
2. "Type": $\mathbf{Tp = \Sigma\delta / M}$, where $\Sigma\delta$ means the number of strong processes in the system of interest, while **M** means systems magnitude (*i.e. the cardinality of the set of Systems processes*).
3. "Goal - weight": $\mathbf{Gw = \Sigma\gamma / M}$, where $\Sigma\gamma$ means the number of goal - oriented processes in the system of interest, while **M** means systems magnitude.
4. "Goal – stability": $\mathbf{Gs = 1 - D(\gamma)}$, where $\mathbf{D(\gamma)}$ means the averaged dispersion of goal - oriented processes in the system of interest.
5. "Extrovert orientation" : **Ex = OUT / (IN+OUT)**, where **OUT** is total number of output states (i.e. the sum of the output boundary element states of the system of interest) while **(IN+OUT)** is total number of the states of the system boundary elements.
6. "Importance" (for the higher system HS) : $\mathbf{Im_{HS} = OUT\ \delta / \delta_{HS}}$, where $\mathbf{OUT}\ \delta$ is the number of output states of the strong processes of the system of interest, participating in the same time in the strong processes of the higher system HS, and δ_{HS} is the total number of strong processes of HS.
7. "Coherence of goals" (with higher system HS) : $\mathbf{Cg_{HS} = OUT\ \gamma / \gamma_{HS}}$ where $\mathbf{OUT}\ \gamma$ is the number of output states of the goal - oriented processes of the system of interest, participating in the same time in goal - oriented processes of the higher system HS, and γ_{HS} is the total number of goal - oriented processes of HS.

The Identity of an object (original) can be constructed in two steps:

Object $\rightarrow$ specific constructed system $\rightarrow$ Identity [19]

11. Systems Reliability Task

The knowledge of the processes analysis and control in complex systems remains still <u>unsatisfactory</u> in spite of significant and continuous progress in Systems Sciences and Systems Engineering.

There are several factors affecting this situation the most significant being the following ones:

- Unavoidable and omnipresent **uncertainty** which is marked by different causes and modes. Uncertainty could be identified both at the levels of original / object and system / model.
- Complexity of the effects on systems **interfaces** [22].
- Vague identification of the relevant information subsystems and significant ("strong") information processes.
- Holistic nature of the systems resulting in poor efficiency or even the non-relevance of available, mostly reductionistic approaches.

That is probably the reason why soft methodologies are widely and more or less successfully used [23].

On the other hand, soft methodologies are too subject – sensitive and suffer from serious disadvantages:

- They cannot be expressed in regular algorithmic way.
- It is very frequently impossible to measure their efficiency or even to mutually compare the different results obtained.
- The results cannot be transferred and generalized.

Strong demand for alternative "non – soft" approaches is therefore obvious.

An unavoidable prerequisite is an introduction of the core concepts.

- Reliability,
- Homogenization, and
- Information Power.

11.1 Reliability

11.1.1 Reliability of the system element or a system as a whole in the finite deterministic automaton (FDA) representation can be defined as a **probability of the correct carrying out of the respective FDA mapping functions.**

An obvious scheme may be determined as follows:

- Choosing reference FDA functions.
- Defining / discovering (based on an experimental background) the probability of an event that the respective FDA function follows this chosen reference.

The second step is often a very difficult one.

11.1.2 Reliability of a system can be defined in several ways [24].

From the pragmatic point of view the following scheme is often preferred:

- Choose the process of interest.
- Choose the reference characteristics of this process.
- Define / discover (based on an experimental background) the probability of the event that the chosen process follows the reference characteristics.

Strong and goal seeking processes are frequently of interest. Obviously the second and the third steps are both difficult and tedious.

Specification of reliability at this level requires the knowledge of:

- Systems structure
- Detailed course of the chosen process
- Particular reliabilities of the systems elements activated in the course of the process.

This concept of **Systems Reliability** is an equivalent to the **Probability of reference execution of a certain chosen process.**

11.1.3 Reliability of Complex Heterogeneous Systems (e.g. Hybrid Systems, Systems Alliances or Virtual Systems) holds some specific features:

- Vague identification of a strong process of reference,
- difficult determination / measurement of particular systems elements reliabilities,
- non-regularity of significant systems interfaces,
- strong coupling among particular systems elements resulting in complex expressions of particular reliabilities as conditional probabilities,
- significant systems uncertainty.

That is the reason why the concept of Systems Reliability being expressed in terms of probabilities becomes impractical or even useless. Instead of it the **distance** of two processes in state-space, i.e. the reference process and the actual one, can be used as a measure of reliability. An alternative approach (*prediction diagnostics*) is based on the measuring of the distance of the process from the boundary of the “region of acceptability” in state - space.

The concept of **Structural reliability** is introduced for the lastly mentioned cases [24].

11.2 Homogenization

An effective dynamical process of homogenization of the heterogeneous whole has important consequences for the:

- integrity of the whole
- existence of the object inside the environment
- structural properties of the whole
- dynamics of the whole with respects to the environment

All these factors form conditions for either the sustainable growth of the whole, or to the controlled decline of it.

Heterogeneity of the real object has its origin in:

- the variability of the abundance of basic components of reality: mass, energy and information (M,E,I) [25-28],
- differences in metrics,
- effect of hidden states or variables, resulting in uncertainties,
- variability of the conditions of the activation of alternative processes.

Uncontrolled heterogeneity results in loss of the parts of the whole and, under the stress of an environment, the disintegration of the whole.

Four levels of homogenization have been recognized so far [27].

11.2.1 Technological level.

At this level the process of homogenization can be reduced to the control of acceptable intervals of variables / parameters. This type of homogenization de facto means the regularization of interface. The task at this level can be solved within the framework of system analysis. The macro - description of the process is characterized by decrease of configuration entropy.

11.2.2 Macro-physical / chemical level.

The process of homogenization on this level means balancing of the interactions between an object and its environment.

For a case of limited interaction between an object and the environment and for the thermodynamic description a typical situation could be expressed by relations between Energy and enthalpy versus entropy, the temperature being a parameter.

This attempt can usually help to solve the stability of heterogeneous physical and chemical objects. Different possible approaches to the chosen macro-state result in uncertainty.

A far-reaching generalization of this approach could be rendered if the validity of the ternary equivalence M-E-I *(mass – energy – information)* is accepted. [25,26]

11.2.3 Biological level.

Homogenization of a whole is a result of an interplay of the object and its environment as well. The important factors of the process at this level are:

- Competition of several objects for the resources in the environment
- Ability of duplication or multiplication of (at least one class of) objects.
- Two or more objects co – exist inside common environment.

A typical process of homogenization has three distinct phases:

Reproduction $\rightarrow$ Occupation of Environment $\rightarrow$ Homogenisation

A problem of stability of systems being homogenised by this process arises. Homogenisation via reproduction is connected with an enormous decrease of configuration entropy, which is a typical marker of potential instability.

Systems tasks: Dynamics of Identity is an effective tool for the analysis of homogenization processes at this level. Process of homogenization of the whole is characterized by smooth dynamics of identity [28]. Branching of the dynamic trajectory of identity reflects the emergent phenomena, for example, reproduction. Modern and efficient attempts to the homogenize and control complex Systems, based on concepts of intelligent co – operating agents or holons fall within this level.

11.2.4 Social level. The information expressed in a set of languages is the most important factor in the process of homogenization at this level. Respective languages of certain parts of a whole differ in their alphabets, grammars and semantics. Consequently, a multilingual character of information exchange between parts of the object / system and environment arises. The quality of multilingual translation is a natural measure of a degree of homogenization. The integrity of the whole is causally derived from the completeness and efficiency of translation. An important aspect of multilingual translatability in systems is “utilizing of limited resources, and / or limited time to disposal”. Specific case of this approach is “dynamic translation”. Its nature should be characterized as a dynamic, quite often iterative or repetitive process of translation, typical for dynamic optimizing of its (frequent) alternative transition. This approach is usually demanding in terms of the consumption of (systems) resources. On the other hand, it does not generally result in excessive decrease of the configuration entropy – a positive marker for the expected object / system stability. This is the reason why this approach to homogenization is quite frequently chosen for objects of very high degree of importance.

11.2.5 Hybridization of levels. There are certain wholes that consist of objects of several described levels, or their heterogeneity is of multi-dimensional nature. This is the case of transportation. Several dimensions should be distinguished, for example the energy (cost) / substrate / vehicle / road / user / owner. In these cases the mutual ability of translation ("translatability") among objects of all levels and dimensions is required. That is the reason why there is a general demand for universal tools of homogenization. It is obvious that a strong requirement for universality could be met by means of general introduction of the concepts of object language translation in a multi – lingual environment. An introduction of the languages of physical objects or technical artifacts could seem rather unusual, but there are no valid objections. Respective languages are to be studied, recognized, understood, and introduced into common use.

11.3 Information Power

A concept of Information Power (IP) has been constructed in order to study the problem of systems response to the certain information or to the information flow[20,27]. Sound understanding of this concept is a necessary prerequisite for further analysis. The concept is quite complex. That is why the introduction of IP should not be too condensed.

11.3.1 Information Field

Information exchange is anchored in reality. The reality is a System composed of three entities $\mathbf{R} \in (\mathbf{M}, \mathbf{E}, \mathbf{I})$. (*M…mass; E….energy; I…. information)* These elements are mutually irreducible, but there are relations of equivalence among all of them. Within the area of competence of informatics the equation

$\mathbf{I_R} = \mathbf{I_M} \times \mathbf{I_E} \times \mathbf{I_I}$ is valid.

($\mathbf{I_M}$, $\mathbf{I_E}$, $\mathbf{I_I}$ are information reflections of M, E, I, respectively while × means Cartesian product).

Information could act as a trigger of action. The problem of an origin of relation between information and (physical) action resulting alternatively in decrease or increase of Systems entropy is nowadays just partially solved [29].

11.3.2 Specific Subtasks of Messages Interpretation.

IP can be assumed as an interpretation of a message.

Interpretation can then be recognized to be a "translation" of information into the states or functions of the original system.

A message can be assumed to be shared information; containing conscious intent of the system state change or an activation of some functions of an original system which is built in the very construction of information.

The tasks are intended to solve:

- Reflections of the aim on the model (information).
- An allocation of the aim to the original objects the state of which is to be changed, or the function to be activated.
- A measure of acceptability of a message by the original object.

Problems could arise, either

- singular, or
- global (e g., in social dimension).

Reflections:

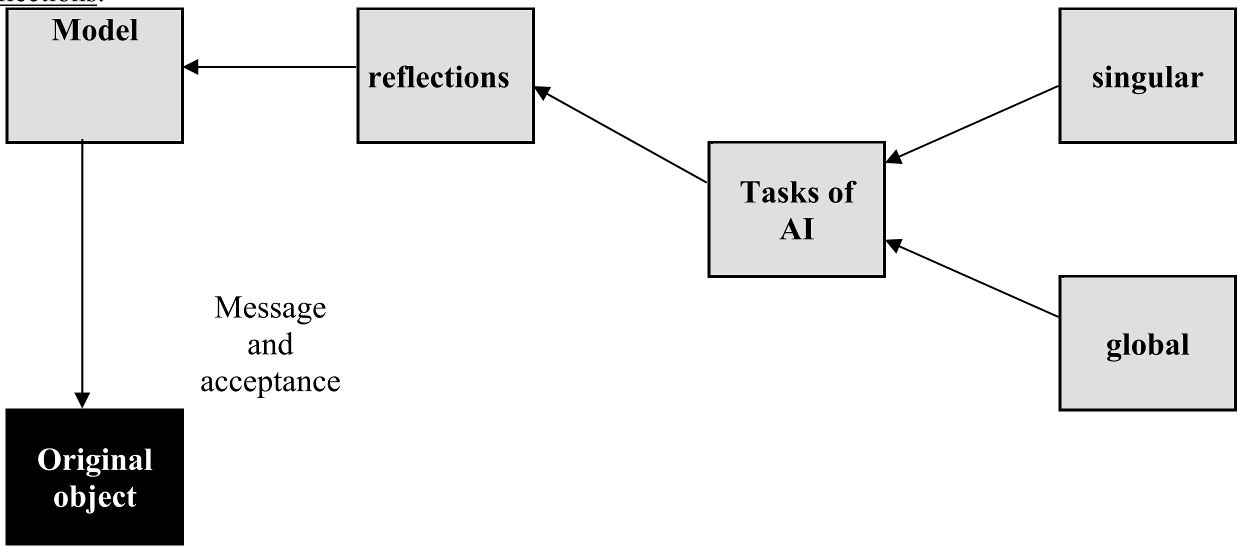

Fig. 13. Scheme of the representation of model aim

Allocations:

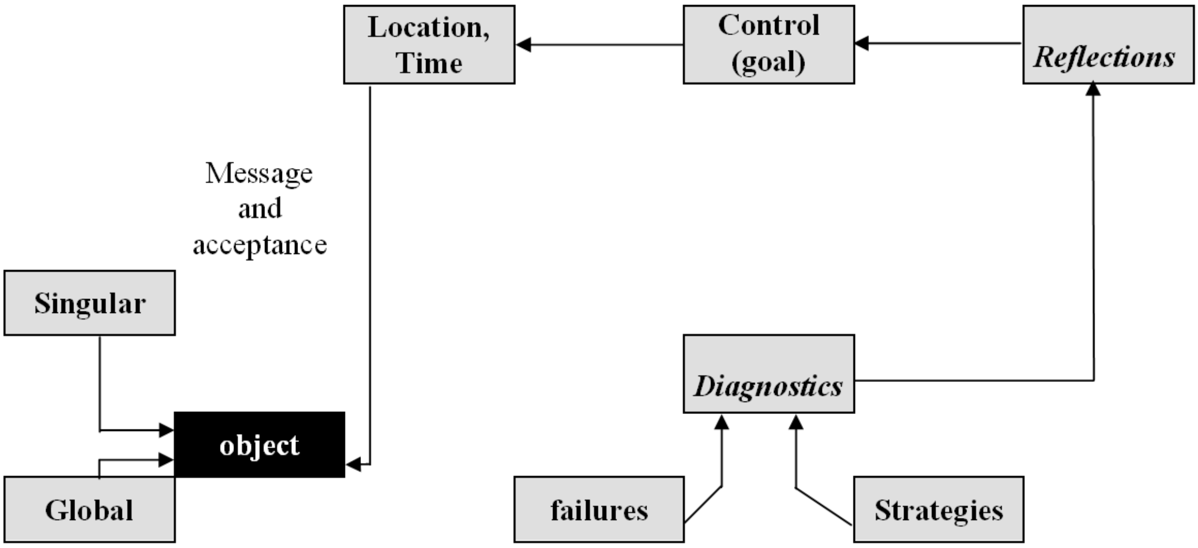

Fig. 14. Scheme of the allocation of the aim to the object

Acceptability:

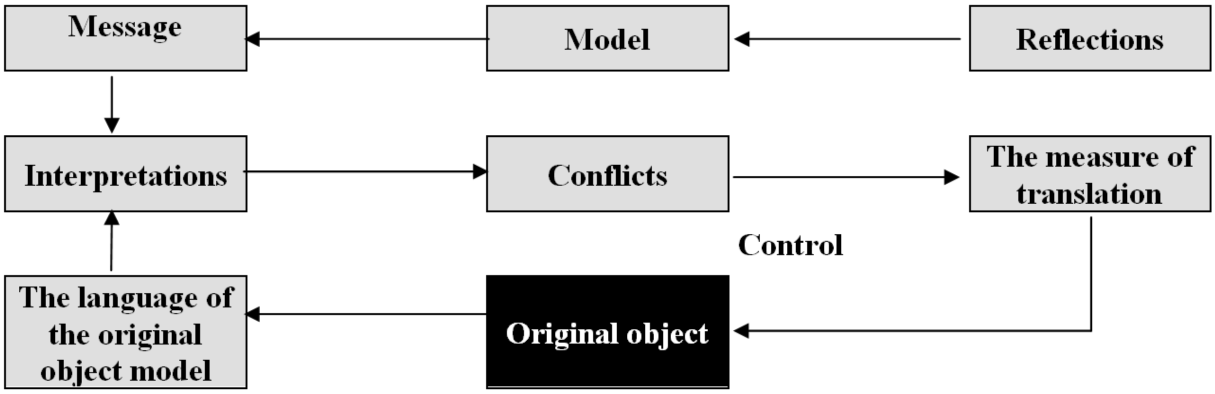

Fig. 15. Scheme of the acceptability of the message for the object

Integrated task:

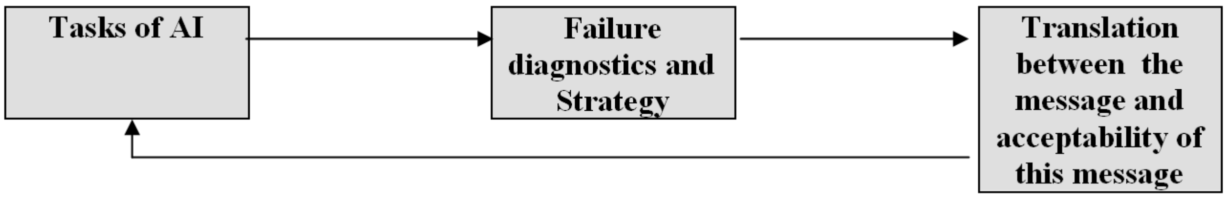

Fig. 16. Integrated task

11.3.3 Definition

Information power (IP): (measurable entity in state space **(M, E, I),** analogical to the basic type of automaton)

$$IP := I \times S_0 \rightarrow S_k, \text{ where } S_0 := (M, E, I) \qquad (30)$$

Value of IP: $|\mathbf{S_0 - S_k}|$ (31)

The alternatives of the evaluation of IP (in semantics M, E, I):

- transitions of states in state space
- changes in the contribution of $\mathbf{S_0}$ to identity
- changes of knowledge (epistemological scale)
- **IP** can also be distinguished in grades of **quality** of **I** (data / information / knowledge /.. etc.).
  Quality of IP lies within the interval between total chaos and ideal order.

11.3.4 Relation of IP and Systems time

A basic problem of systems response to certain information can be (at least in principle) solved by utilizing re – interpretation of Shannon´s concept of information, if the system is identified without explicit structure - as an automaton.

For the more frequent situations the structure of system is recognized, Shannon´s approach is not adequate, and the utilization of the concept of IP becomes fruitful.

The measurable global effect of IP on the system is the change of the flow of System time.

Flow of System time is defined as a sequence of system events.

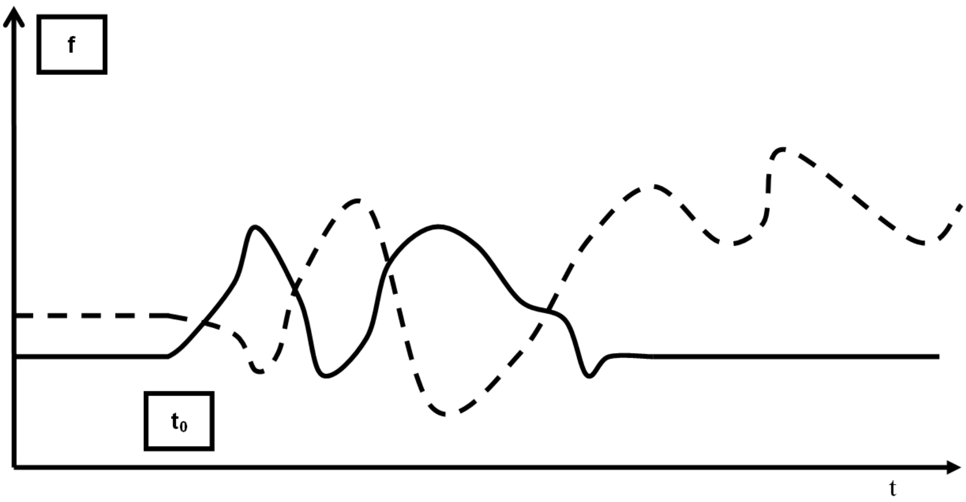

Fig. 17. An example of the system time response to the information accepted in (external time) t_0. Solid graph: time – limited response, dashed graph illustrates either chaotic behavior, or the activation of control process. (f is time dependent frequency of events)

The response of the system to certain information is a change of the instantaneous frequency of events. The response can be limited or unlimited in time. The later case can be either a result of chaotic behavior, or the result of activation of a control process.

11.3.5 Information action

Information action (IA) is a slightly modified concept to the IP. IA is also a weak analogy to physical action. The value of IA can be (in principle) easily calculated as the sum of "excessive events" triggered by the input information.

An advantage of IA in comparison with IP is that IA can be directly associated with the efficiency of the translation of pertinent System Multilanguage.

The disadvantage of IA is that it cannot be easily utilized if the response of the System on the triggering input information is unstable.

11.3.6 Relation IP / ordering

Substantial output of IP analysis should be the determination of the sign of ordering function of IP.

Comprehensive solution of this relation is feasible making use of "phase information" which is contained e.g. in wave function [29]

11.3.7 Approaches to the IP analysis

There have been two basic approaches to the IP study so far:

- Multilanguage approach
- Structured approach

The Multilanguage approach is based on the notion that there is equivalence between an automaton and a certain language [21]

The respective chain of thoughts could be as follows:

- Structured System is composed of ordered (connected) elements
- The elements are identified as automata
- Multilanguage composed of particular languages can be associated with the System
- Structural System relations and relations System – Neighborhood as well define the constraints to the syntax of this Multilanguage and to the rules of the semantics transformations.
- IP (more accurately IA) is a measure of the efficiency of Multilanguage translation.

This approach is quite universal. The main problem of this approach from the application perspective comes from the fact that the incomplete and uncertain grammars of these languages are very often met. Neither a theory, nor a set of typical tasks with these groups of grammars have been elaborated into a sufficient depth.

A multilanguage interpretation can be complete, incomplete or alternative. IP is mediated in at least two languages:

- Language of the respective system
- Language of environment.

The structured approach means dynamic analysis of:

- Functions of elements
- Structure of System, inclusive respective sensitivities
- Regularities of Important complex interfaces.

11.4 IP Reliability

The analysis of IP means at the basic level the analysis of reliability and efficiency of processes of the System that is activated by input information.

If the structured approach to the analysis of IP is chosen, the most important task is the regularization of interfaces which are activated in the strong processes of the System.

Suitable model of Complex interface in the environment with significant uncertainty is constructed on the basis of the concept of Fictitious Deterministic Automaton (FDA).

11.4.1 Interface as a fictitious system element

For a complex interface (IF) it seems advantageous to introduce the IF as a fictitious system element ($\mathbf{A}^{\mathbf{FIF}}$). The advantage of this approach is anchored in the richness of the concept of system element, which is generally defined as an automaton. For the sake of simplicity the finite deterministic automaton (FDA) is usually chosen. FDA can be described by a triple of sets **IN, Z, OUT** – inputs, internal states and outputs, respectively (In the set of internal states Z is further defined a specific subset – initial internal state $\mathbf{Z_0}$.), and a double of (mapping) functions: α, β. Function α transforms the Cartesian product (IN x Z) into the set of internal states Z. Function β transforms the Cartesian product (IN x Z) into an output set OUT.

$$\text{FDA:= (IN,Z, } Z_0\text{,OUT,}\alpha, \beta); \ \alpha: (\text{IN} \times \text{Z}) \rightarrow \text{Z}, \quad \beta:(\text{IN} \times \text{Z}) \rightarrow \text{OUT}) \tag{32}$$

The fictitiousness of the IF element reflects its important features:

- No demands on systems resources, and
- No transformation of base variables or parameters, i.e. no consumption of time to carry out the functions.

It is worth mentioning here, that these features are strictly valid only for a regular IF, while any disturbances of regularity can equally harm these features.

Probably the simplest introduction of a **regular** IF as a fictitious systems element $\mathbf{A}^{\mathbf{FIF}}$ is:

Z is an empty set,

α is any arbitrary function without any demands on the system resources (in fact α is meaningless),

β transforms IN into OUT, $\boldsymbol{\beta}$**: IN→OUT**, the transformation being an equivalence for all the parameters (components) of the sets (vectors) IN, OUT respectively : **OUT = IN.**

To describe the impact of irregularities and uncertainties, a slightly modified model of IF is more suitable:

Let OUT = $\{a_i^{OUT}\}$ be a set of parameters a_i^{OUT} ; Let IN = $\{a_j^{IN}\}$ be a set of parameters a_j^{IN};

Let Z = $\{a_k^{Z}\}$ be a set of parameters a_k^{Z} ; $Z_0 = \{z_{0k}\}$; (i, j, k, natural numbers),

$$\boldsymbol{\alpha}\mathbf{: Z := Z_0} \qquad\qquad \boldsymbol{\beta}\mathbf{: OUT:= (IN \times Z)}$$

For regular IF the respective $\mathbf{A}^{\mathbf{FIF}}$ has obviously the features: i = j = k; $Z_0 = \{z_{0k}\} = \{1\}$

$$\text{Regular interface: } A^{FIF}\text{: } Z_0 = \{1\}; \alpha: Z_0 \rightarrow Z; \beta: (\text{IN x Z}) = \text{OUT}; \dim(\text{IN}) = \dim(\text{Z}) = \dim(\text{OUT}) \tag{33}$$

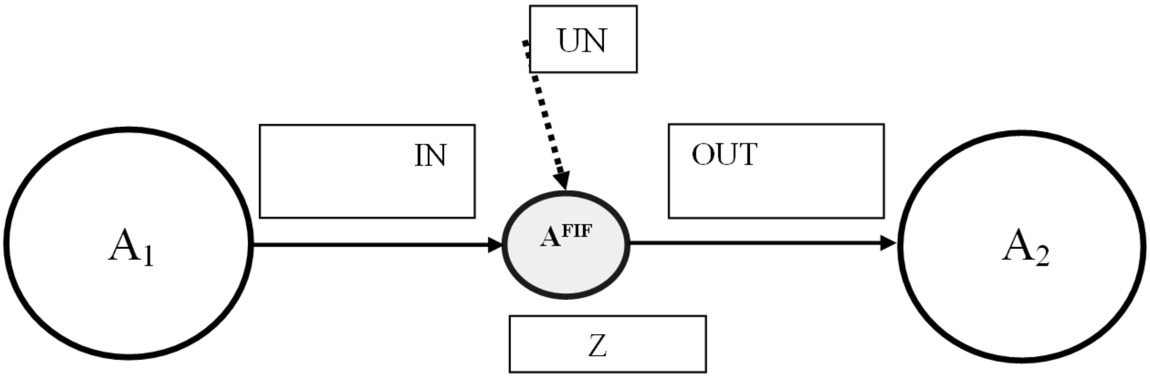

Fig. 18. Schematic sketch of regular interface identified as a fictitious system element.

11.4.2 System Uncertainty

Uncertainty (in Complex Systems substantial and almost omnipresent) has many "resources" and aspects. Any effective analysis of complex systems reliability can hardly be done without a thorough evaluation of the impact of uncertainty on the system. Thus, this is not a question uncertainty being in the focus of the contemporaneous systems science.

At the beginning of a further study methodological problems arise of "incorporating" uncertainty into the system. A significant majority of authors localize uncertainty into:

- Systems (or system elements) **functions / processes,** or
- systems **structure**, eventually to
- systems **neighborhood**.

The localization of uncertainty into the IF is not frequent. Nevertheless, the author believes this is the only approach which could help us to illustrate certain nontrivial aspects of the task. To model IF we have primarily chosen an attempt described in chapter 11.1. (Interface as a fictitious system element) in which uncertainty "enters" the initial state Z_0.

11.4.3 Specification of the Subtask

The aim of the further part of this Chapter is to analyze the combined effect of the dimension and uncertainty of chosen IF within the system with respect to the reliability of the defined processes. The task is structured to the following main steps:

A. Reliability of a single (non-interacting) IF
B. Reliability of interacting interfaces.

11.4.5 Reliability of the non-interacting IF

is directly connected with the regularity of this interface. The respective relation is defined as follows.
Reliability of regular IF is equal to 1.

Rel (Reg (IF)) = 1; (34)

To specify the impact of irregularity we have to turn back to the chosen model of interface.
Assume further the same dimension of sets IN, OUT and Z,(i = j = k).

To simplify the following discussion let us suppose Z_0 is a vector, the components of which can be either 1 or 0. For the regular IF the vector $\mathbf{Z_0 := \{1,1,1,....1\}}$.

The impact of uncertainty (resulting in possible IF irregularity) could then be expressed in the simplest possible way as the existence of zero components in Z_0.

α: $\{\mathbf{a_i^Z}\} := \{\mathbf{z_{0i}}\}$ **i.e.** $\mathbf{Z := Z_0}$

β: $\mathbf{a_i^{OUT} := u_i\, a_i^{IN}; u_i = 1}$ **for** $\forall$i, for that $\mathbf{a_i^Z = 1}$, else $u_i = \aleph$, where $\aleph$ is the number of undefined real value in interval $0 \leq \aleph \leq 1$. (35)

Verbally: All the components of the input vector IN for which the corresponding components of initial internal state Z_0: $\mathbf{z_{0i} = 1}$ are directly mapped into the respective components of output vector OUT: $\mathbf{a_i^{IN}}|_{(zoi = 1)} \rightarrow \mathbf{a_i^{OUT}}$, while these components of input vector IN for that the corresponding components of Z_0 : $\mathbf{z_{0j} \neq 1}$ are mapped into the component $\mathbf{a_j}^{OUT}$ which has the value ℵ, uncertain without any a priori knowledge within the interval ⟨0,1⟩.

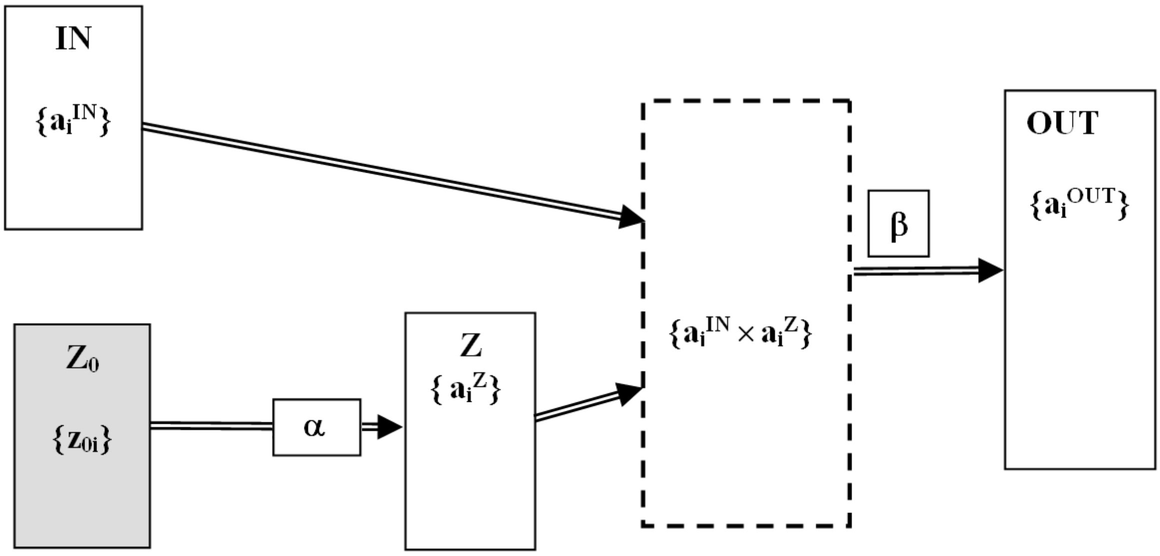

Fig. 19. Model of IF function (IF represented by fictitious finite deterministic automaton)

For example: For IN:= $\{a_1, a_2, a_3\ldots a_n\}$, and Z_0:= {0,1,0….1} ⇒ OUT =$\{\aleph a_1, a_2, \aleph a_3\ldots. a_n\}$.

Assuming the length of vectors IN, OUT, Z, Z_0 is **n** and there is **m** components of Z which are not equal to 1, **m** could naturally be an absolute measure of IF irregularity, while the relative measure of IF irregularity can then be introduced as rir := m/n. (36)

Reliability of irregular IF could be expected to be a monotonous, non-increasing function of the rir. As the reliability (from its original definition) is probability, it is purposeful to define it within the interval ⟨0,1⟩.

Rel (Irreg (IF) = Rel(rir) (37)

This consideration does not take into account the concept of "**acceptable degradation of IF**" (quite important for pragmatic reasons) which is quite often used within the body of Systems Analysis. This concept reflects the experience of analytics that minor irregularities of IF could often imply (in real or interpreted systems) no measurable effect on the reliability of the respective processes. The nature of this phenomenon can be linked with the redundancy of input parameters/variables (IN), and consequent possibility to reconstruct the correct values of the disturbed vector components in OUT. To introduce this aspect of the task into the model the threshold parameter ξ can be defined and the impact of uncertainty is then quantitatively expressed assuming the variable $\mathbf{z_{0i}}$ ⟨0,1⟩ . The function α in the model is modified, as well:

α: **If $(z_{0i} + \xi) \geq 1$ then a_i^Z:= 1, else a_i^Z:= $(z_{0i} + \xi)$,** while β remains unchanged:

β: **a_i^{OUT} : = $u_i a_i^{IN}$; u_i =1 for** ∀i, for that **a_i^Z=1,** else u_i = ℵ, where ℵ is undefined real number in interval 0≤ℵ≤1.The further results of the previous chapter remain unchanged. (38)

11.4.6 Generalization of the model for interacting interfaces

This model of IF could be generalized assuming that interfaces within the respective system interact. The interaction means for our purposes that the measure of irregularity **rir** of the IF under study can be modified by irregularities of the other system interfaces. The generalization is based on the idea that instead of taking into consideration only the initial state vector $\mathbf{Z_0}$ of the IF under study (as it is done in the chapter 3.1.) the analogical vectors of neighboring IF in the same system are to be considered as well. The function α is in this case of significantly more complex nature, mapping the Cartesian product of initial internal states vectors of all the interacting IF into the internal state Z of IF under study. Let the index of IF under study be **p** ∈⟨1,q⟩ and e =1,2….q. Then:

α_p: Π $(\mathbf{Z_0})_e \rightarrow \mathbf{Z_p}$; where Π_q means Cartesian product of q sets and the arrow "→" means a certain mapping rule; i.e.: (z01×z02×…..×z0q) → z1, etc. (39)

Simplified version of this case illustrates the complex nature of the generalized task:

Assume two interacting interfaces, IF_1 and IF_2. The first one let be under the study.

Z_{01}:= (1,0); Z_{02}:= (1,0,1); The relations are two-valued ones.

Respective (degraded) Cartesian product ($Z_{01} \times Z_{02}$) = ((1-1), (0-1), (1-0), (0-0), (1-1), (0-1));

Let us further define α_1: {(1-1):= 1, (0-0):= 0, (0-1):= 0, (1-0):= 0}, then $(Z_{01} \times Z_{02})'$:= (1,0,0,0,1,0), and $(Z_{01} \times Z_{02})''$:= $\mathbf{max}|_{\mathbf{dim\ Z1}}\ \mathbf{(comp((Z_{01} \times Z_{02})'))}$ = (1,1). (40)

Then Z_1= (1,1) and therefore this IF is regularized.

For a slightly different definition of α_1: Z1:= Z_{01}<u>AND</u>(max (comp$(Z_{01} \times Z_{02})'$) the IF remains irregular one. (41)

This generalization makes it possible to utilize the proposed model of IF for both interacting and externally controlled interfaces. This feature is important especially in complex hybrid systems and system alliances.

11.4.7 Geometric re-interpretation of the model

- Let the analyzed IF consist of **n** mutually independent variables / markers. Then its dimension is **n.**
- Let all the variables of IF be renormalized. Then, in geometrical view, IF could be supposed to form **n** dimensional compact body.
- Let <u>uncertainty</u> enter solely the studied IF, not the system as a whole. It modifies **m** variables/parameters of Z_0.

These assumptions should be expressed geometrically as the reduction of the n - volume of the IF, extracting from the core the outer shell in the sense that the OUT is completely uncertain. (See Fig. 20.) For the sake of simplicity, the same coefficient **rir := m/n** of the reduction for any dimension of the IF n – volume is then utilized. (42)

11.4.8 Model analysis

Our problem is now reduced to a purely geometrical task [30]:

- Let the "n-volume" of the **IF** be $\mathbf{V_{IF}}$
- Let the "n-volume" of the core be $\mathbf{V_{CORE}}$

Then the constructed variable **v** = $\mathbf{V_{CORE}}$ / $\mathbf{V_{IF}}$, being a function of **n**, **(v = v(n))** is an effective measure of the "weight" of the (regular) core for the given **n**.

The expressions for **v(n)**, for Euclidean space, spherical shape of IF and fixed γ, **ε,** respectively is as follows:

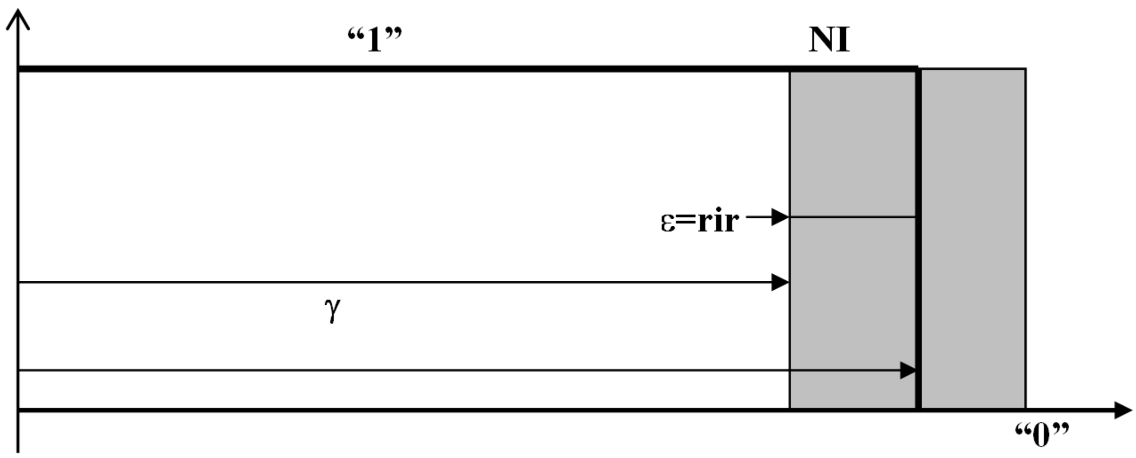

Fig. 20. Central cut through renormalized IF. "1" denotes full regularity, "0" denotes full irregularity of IF and NI denotes non-identified (i.e. totally uncertain) area of IF. ε=rir ; γ≤1; ε + γ= 1

<u>n - Sphere</u> of radius 1.

$$v(n) = \gamma^n$$

Let us show some values for γ = 0.9 (quite moderate value of uncertainty):

n	0	1	2	3	4	5	10	20	30	50
v(n)	1	0,9	0,81	0,729	0,656	0,590	0,349	0,121	0,042	0,005

Generalization should be done: **The n-volume of the core of IF for non-zero uncertainty is significantly decreasing the function of the IF dimension n.**

11.4.9 Discussion of the combined effect of IF dimension and uncertainty

From this model the following should be concluded:

In presence of uncertainty the increase of the dimension of the IF significantly reduces the relative weight of its regular **core**. This effect impairs the conditions for the reliable function of IF. For n > 10 the IF (for quite moderate level of uncertainty $\gamma = 0.9$) has relatively too high a proportion of potential irregularity for practical purposes. That is probably the reason why system analytics following the experience and intuitive background try to keep the number of markers (and therefore the dimension of the IF) as low as possible. (*This approach has also some remarkable links with epistemology, for example with the old, famous and scientifically very useful principle of "Occam's razor": "Frustra fit per plura, quod potest fieri per paociora"(It is futile to do with more things that which can be done with fewer). , or later his successors: "Entia non sunt multiplicanda praeter necessitatem"(entities must not be multiplied beyond necessity) William Occam (Ockham) (1285(?)–1349))*

Another way of improving the conditions for achieving the regularity of IF is to (re)construct it as robust as possible. It means that the acceptable degradation of the regularity of the respective IF, (expressed by the coefficient ξ**)** is to be sufficiently high. Within the artificial part of the system it could be done quite easily. The redundancy in codes or artificial system elements should be utilized, as well as time redundancy or sophistical means of predictive diagnostics. But this way is of controversial value for a "man – machine" IF, as it often assumes in fact the reconstruction of both interfacing parts of the respective system.

A specific discussion is required for the class of interacting IF. In this case the effect of IF conjugation could emerge. This effect could either degrade or improve the regularity of the respective IF.

Another possible approach is the construction of combined IF variables which may help to reduce the dimensionality of the respective IF consequently. This approach is promising if the variables of IF are mutually dependent. A problem then arises with the **geometric interpretation** that is important for the presented approach to the IF regularity task. The author decided to evaluate the potential of **fractal geometry** for this purpose, but no satisfactory results have been obtained yet.

Both the presented generalized model and its geometric reinterpretation could help to study and understand certain aspects of the IF behavior in complex systems and systems alliances. The effect of interaction of interfaces in complex systems and systems alliances could cast new light upon the problem of why certain multidimensional interfaces with significant degree of uncertainty "work" quite reliably in spite of the opposite results of analysis and models. The analogy with the behavior of neuron synapses is probably of deeper nature. From the coarse level of distinguish, this problem is reduced to the synergy of the structure and data redundancy, and therefore can hardly be successfully investigated.

11.5 Reliability in Information Systems.

Information is considered to be an important constituent of reality. Reality is determined by information relations between mass M and energy E. Information processes arise among mass, energy and information.

Information processes should be determined by a set of qualities the most important of them being:

- Information content,
- Information flow and
- Information power.

Information flows exist between sources and users of information. They are mediated by sources of the information flows. (Telecommunication systems, media).

Information processes are performed through some information operations (or combinations of operations), such as:

- Recognition of information,
- Translation of information,
- Interpretation of information,
- Coding / decoding,
- Aggregation and clustering,
- Filtering,

- Information sorting and storing, prediction,
- Activation (utilizing information to change the state of the object within which the information system "works").

Whichever relation among mass, energy and information is considered, the mutual ability of translation / interpretation is of growing importance.

Translation of information during the course of information operations can be processed only with a limited degree of accuracy. The concept of translatability should be introduced for this quality. It is possible to show that for finite real system and for finite densities of M.E.I:

$$\text{Translatability} \leq 1.$$

This statement means that errors are natural phenomena in the course of all information translation processes in real systems. Error – free translation in reality would be achieved only scarcely, in limited interval of time, on very specific occasions.

The spectrum of errors or failure causes is very wide, from probabilistic fluctuations of some minor elementary entities to human mistakes at meta-level.

11.6 Reliability of Complex Heterogeneous Systems

In Complex Heterogeneous Systems owing to the significant degree of uncertainty neither the Multilanguage, nor the Structural Analysis could be done correctly, eventually real information value of such analyses could be poor (*This notion is a manifestation of "Zadeh's principle": The more complex the system under study is, the lower is the number of certain non-trivial statements that could be made.*).

To coin an example it might be impossible to distinguish, if the change of the frequency of system time is the manifestation of the ordering or chaotization.

From the engineering point of view it seems to be obvious that the reliability of the systems transition to the chaotic processes is nonsensical.

As a result, either sophisticated concept of structured reliability must be introduced, or the shift to a higher degree of abstraction should be attempted.

11.7 Reliability of IP – system abstraction

System approach to the reliability of information power is more complex. Reliability subjected to the proposed study is the reliability of a model, following the scheme:

$$(M,E,I) \rightarrow I(M,E,I) \quad (43)$$

What kind of a model is it? It has to be both the model of the object reliability and the model of system features of the object. Reliability of the model is then introduced as the probability of isomorphic relation: OBJECT $\leftrightarrow$ MODEL in these systems features.

System features of the original (real) object could be determined within the framework of Systems Theory as dynamic goals:

- Location inside both the specified space - time interval and state –space area (Systems Reliability Theory defines this area as the "Region of Acceptability".).
- Strengthening or at least conserving of the position of the object in a (dynamically changing) environment.

To study and to determine these goals, Systems concepts of Architecture and Identity and to some extent also "European" concept of Interoperability could be utilized.

11.8 Construction of Systems Approach to the Reliability of Information Power

Systems constraints:

- "Location in space-time and state-space" and
- identity

could be integrated into the concept of identity of architecture.

Systems constraints:

- "Location in space-time and state-space" and
- interoperability

could be integrated into the concept of interoperability of architecture.

The respective sequences of representations are then:

Object → Architecture & Identity → Identity of Architecture

or

Object → Architecture & Interoperability → Interoperability of Architecture

Reliability of Information Power could be then recognized alternatively as:

- Reliability (of representation) of the Identity of Architecture
- Reliability (of representation) of the Interoperability of Architecture.

The first construction is more powerful and accurate. It is the consequence of the rich and more accurate semantics of the concept of Identity. Let us accept it.

Reliability of IP could be then decomposed into (the representations of) three components:

- model of space-time.
- model of the evolution of identity.
- model of the evolution of strategic state of identity.

Reliabilities of these models (and also the reliability of their chaining) could then be deduced from the reliability of translation (interpretation) of the respective Multilanguage, and this concept could be further related with the completeness of grammars. The reason is obvious: These models originate in the respective system Multilanguage.

Gross scale understanding of the problem could be gained if the $\Re$ function is introduced and utilized.

The $\Re$ function is the difference of (actual) identity and strategic identity of the system of interest.

$$\Re = Id\ (t) - StId\ (t) \tag{44}$$

From the mathematical point of view $\Re$ is a well-defined function. Both actual and strategic identities are vectors of the same dimension. Time evolution of strategic identity is usually slower than the evolution of actual identity. Both these variables depend on time.

The ordering effect of IP is expressed in the approaching of $\Re$ function to zero.

$$\lim_{t\to\infty} \Re = 0$$

Time evolution of $\Re$ expresses at this higher level of abstraction reliability of IP.

The Situation is schematically illustrated in Fig. 21.

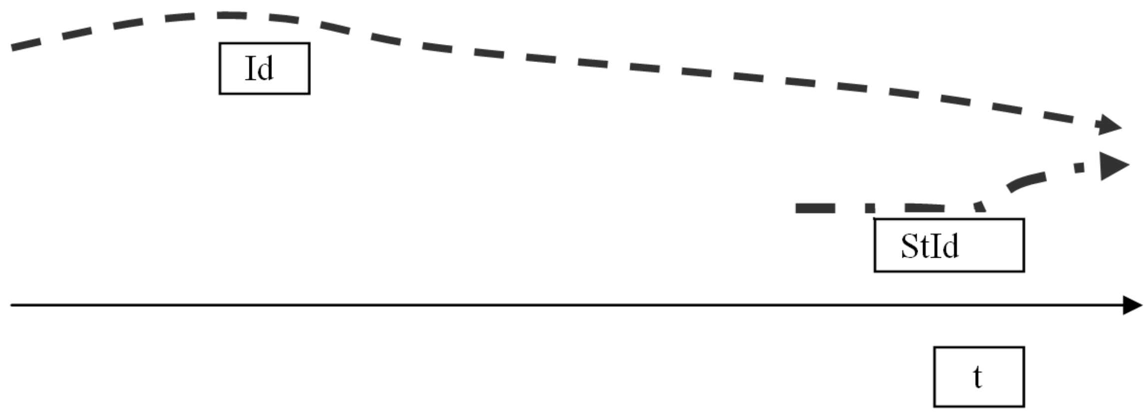

Fig. 21. Scheme of time evolution of Identity & Strategic Identity (active ordering effect of IP).

11.9 Discussion

At the Interpreted System level, the Reliability of Information Power is defined as a probability of a specified change of System time which is a response to input information. This definition cannot help us to distinguish whether Information Power has ordering or disordering effect on the System of interest.

To avoid this shortcoming, a transition to the higher level of abstraction is done. This step results in the analysis of a certain representation of the information power reliability. This shift implies additional prerequisites – such as the introduction of concepts of Systems Architecture, Identity or Interoperability. On the other hand this transition can help us to define the Reliability of Information Power via the concept of Reliability of the Representation of Identity of Architecture, and also to quantify it by the speed of the approaching of the difference between an actual Identity and Strategic Identity to zero.

The serious problem of potential chaotic behavior of systems in an information field has been partially solved by utilizing the evolution of $\Re$ function. This result is a consequence of the fact that the concept of strategic identity, constructed with the aim of supporting chaotic behavior, is nonsensical from the engineering point of view. (An assumption that the difference between identity and strategic identity decreases in the course of time is an important system goal for "well – designed" systems.)

This success is neither complete nor final. Chaotic behavior of the system in an information field remains possible as a consequence of poor identification. This is however a common problem of Systems sciences.

12. Alliances Task

12.1 Introduction

Systems analysts as well as managers, scientists, or even the officers and politicians feel the lack of suitable tools for modeling large heterogeneous objects or nets. There are many examples of such objects in various areas of human activity, for example transportation or information nets, human beings controlling some technical artifact, neural and limbic systems within the body, etc. The soft methodologies widely used until now lack the ability of quantitative evaluation and they are not able to tackle the essential uncertainty in a controlled manner. That is why the study of new attempts is needed.

The task of modeling of complex heterogeneous objects challenge the application of methodologies which are suitable for the analysis and synthesis of wholes consisting of almost autonomous freely joint parts / modules.

The "classical approach" is based on the concept of "*Hybrid Systems*". Well established methodologies are elaborated for these situations. A basic characteristic of a hybrid system is as follows:

There are two mutually distinctive classes of parts within the modeled whole.

The first one "lives" (i.e. evolves its dynamics) in continuous (external) time, while the second one „lives" within a discrete time scale, either the external one → synchronous timing; or even based just on the sequence of events → asynchronous timing. Relevant methodologies are frequently used for systems representing computer control of continuous objects (e.g. technology)

The first generalization of this approach is based on the analogous attempt relative to the other variables of the systems base besides time.

The second, far reaching generalization makes use of the concept of Identity [4,18]. The hybrid system is then defined as a specific system consisting of at least two subsystems with mutually differing Identities.

Quite frequent approaches utilize the concepts of **autonomous cooperating agents or holons.** These approaches are effective for modeling of the wholes which are composed of distinguishable homogeneous or heterogeneous parts, usually holding essential intelligence. The study of agent methodologies is at present the focus of scientific community (see for example IEEE Transaction on Systems, Man and Cybernetics Part C in the period 2006 – 10).

In this Chapter an alternative approach is presented, which is matched mostly to the tasks where both the structure and the behavior of the respective parts/ modules are of highly heterogeneous nature and/or these parts are identified with significant uncertainty, or these parts are notably variable in time.

The presented approach is applicable as a considerably powerful tool for analysis and synthesis namely of the transportation system alliances, which almost always are principally of heterogeneous nature. This approach can also be used for the improvement of our understanding of the functioning of complex neural networks and other information structures operating in the human body and for modeling these objects. It allows respecting also the aspects of time and other independent variables and aspects of the sensitivity of respective alliance functions to changes of their parameters as well. Consequently this approach opens the way both to the finding the reasons of critical and dangerous situations and to the operation optimizing of the considered structure.

12.2 Essentials of the Theory of Systems Alliances

The concept of systems alliances was proposed already in 2001 by Vlček [4]. In his approach, an alliance of two or more parts / modules originates as:

- a product of random encounter
- an outcome of processes of contamination and immunity
- a construct.

The alliance should be identified as follows [18]:

- set of systems or automata or autonomous parts (modules, partial systems);
- hybrid set of cooperating system
- virtual system.

Generally the alliance holds neither the common characteristics of species (genetic code), nor the common goals, or common identity, i.e. it does not have to be identified as a System. Components of alliance have to be autonomous; they must hold well defined interfaces.

On the other hand they do not require to be identified as Systems or automata. The membership of components within the alliance is typically the dynamic one. Holistic goals in alliances, if any, are generally mediated by their members.

The principles of the alliance formation have been explained through utilizing the concepts of information power (IP) and of multilingual translation efficiency respectively[20, 27]. An illustration of basic phenomena resulting in the emergence of alliance could be based on the concepts of interface sharing (IS), and of irregularities conjugation (IC) as well. [22]

Synergic phenomena of IS and IC are so significant that they could be used as the definition characteristics of the alliance. An emergence of these phenomena results in the improvement of the regularity of the interfaces either mutually among the modules / systems which take part in the alliance or between the alliance as a whole and its neighborhood (environment, forming together with considered alliance the super– system SS). The secondary effect is an improvement of the efficiency of the resources utilization.

Interfaces (IF) are in fact the only parts of alliances being firmly under control and identified in detail.

Interfaces within the alliance can be modeled by the fictitious deterministic automata. These models make it possible to take into consideration the uncertainties which could be linked with the irregularities of interfaces. The same models are capable of presenting the irregularities conjugation as well. Similar models can also represent the effects of alliance control.

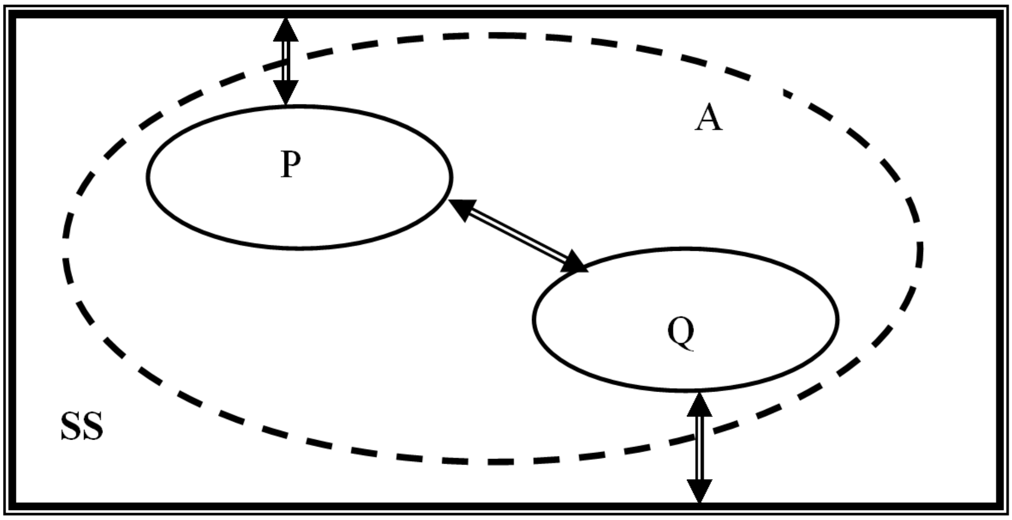

Fig. 22. Schematic sketch of Systems alliance, consisting of two parts - "Amoeba model"; (P and Q are constituent elements - modules of alliance A; SS represents Super – System, i.e. the environment the alliance exists within, the arrows indicate various types of relations between parts)

A more sophisticated model of alliance interface can be based on the concept of quantum–like subsystems [29]. Superposition of states or even the entanglement concepts are suitable tools for recording non - orthogonal interface parameters and resulting phase sensitivity of the respective IF.

12.3 Alliances and Information Power:

- The forming and existence of an alliance is causally joined with the reception and processing of information (*The concept of Information field is occasionally introduced in this context.*). In the dissipative environment it is the condition sine qua non for the plain existence of alliance.
- The impact of the information received can be measured utilizing the concept of IP which is defined as the integral response of the alliance Systems time to the information received.
- At this level we cannot distinguish whether the resulting effect is the randomizing or the ordering one. In alliances it means whether or not the sharing of interface increases or decreases its regularity (It can be distinguished at the higher level of abstraction and within the frame of constructive approach only [27].).
- The results of experiments on various real objects (laser cooling, control of traffic, social preferences…) support the idea that the ordering can easily flip into chaos, and vice versa. The results are very sensitive to "phase" i.e. to the actual time delay within which the information received is transformed into the running of system time.
- This knowledge resulted in the trials of constructing "phase sensitive" systems modeling methodology which would be able to incorporate this effect. It is probably not accidental that this methodology has some significant similarities with the models of quantum physics [29].

12.4 Models of Interfaces in Alliances

To represent the impact of irregularities, uncertainties or control, the model based on the concept of an automaton can be utilized.

Assume the "standard" (Mealy type) finite deterministic automaton (FDA), which is defined as follows:

$A := (IN, Z, Z_0, OUT, \alpha, \beta)$,

Where:

IN is a set of input states $\{a_j^{IN}\}$,

Z is a set of internal states $\{a_k^{Z}\}$,

OUT is a set of output states $\{a_i^{OUT}\}$,

Z_0, $(Z_0 \subseteq Z)$ is an initial internal state $\{z_{0k}\}$, (i, j, k, are natural numbers),

α, β is a double of "mapping" functions,

α: $(IN x Z) \rightarrow Z$ …input function; β: $(IN x Z) \rightarrow OUT$…output function;

For the purposes of interface modeling, the simplified version of an automaton, a fictitious deterministic automaton $\mathbf{A^{FIF}}$ is often suitable. $\mathbf{A^{FIF}}$ holds reduced (simplified) mapping function $\boldsymbol{\alpha}$:

$$\alpha: Z_0 \rightarrow Z, \tag{45}$$

while the next components of the finite deterministic automaton definition remain valid.

For regular interface the respective $\mathbf{A^{FIF}}$ has the features: $i = j = k$; $Z_0 = \{z_{0k}\} = \{1\}$; (*i.e.: $z_{0k} = 1$ for $\forall k$*);

$\alpha := Z_0 \rightarrow Z$; $\beta := IN \times Z \rightarrow OUT$; $\dim(IN) = \dim(Z) = \dim(OUT)$

For irregular IF :

α: $\{a_i^Z\} := \{z_{0i}\}$ i.e. $Z := Z_0$

β: $a_i^{OUT} := u_i\, a_i^{IN}$; $u_i = 1$ for $\forall i$, for that $a_i^Z = 1$, else $u_i = \aleph$, where $\aleph \in \{0,1\}$; for binary case it is uncertain vector of zeroes and ones (*For example: For $IN := \{a_1, a_2, a_3 \ldots a_n\}$, and $Z_0 := \{0,1,0 \ldots 1\} \Rightarrow OUT = \{\aleph a_1, a_2, \aleph a_3 \ldots a_n\}$..)*

(46)

Briefly: All the components of the input vector IN for that the corresponding components of initial internal state Z_0: $\mathbf{z_{0i}} = \mathbf{1}$ are directly mapped into the respective components of output vector OUT: $\mathbf{a_i^{IN}} / _{(z_{0i} = 1)} \rightarrow \mathbf{a_i^{OUT}}$, while these components of input vector IN for which the corresponding components of Z_0 : $\mathbf{z_{0j}} \neq \mathbf{1}$ are mapped into the component $\mathbf{a_j^{OUT}}$ which is uncertain without any a priori knowledge.

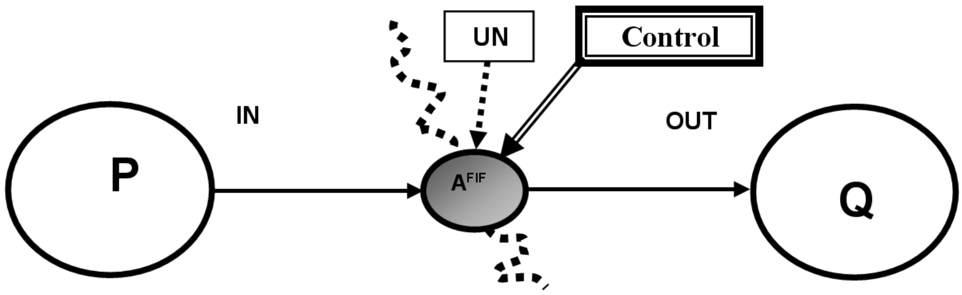

Fig. 23. Fictitious Deterministic Automaton (A^{FIF}) model of interface

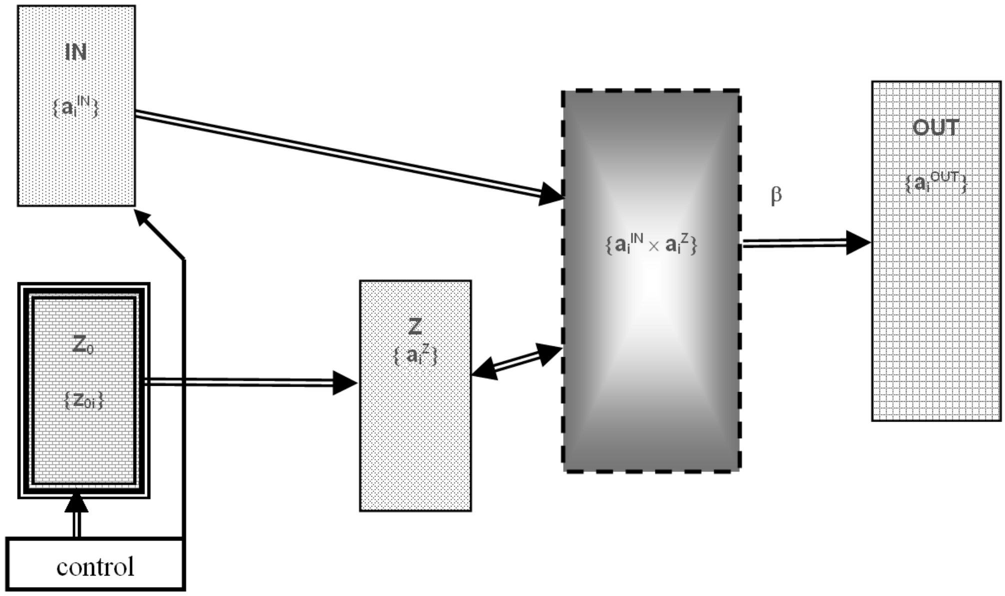

Fig. 24. Fictitious Deterministic Automaton (A^{FIF}) model of interface (IF) - State schematics.

<u>Generalization of the model for interacting interfaces or control</u>

This model of IF could be further generalized assuming that certain (neighboring) interfaces within the respective subsystem or alliance component interact, or they are externally controlled. This means for our purposes that the measure of irregularity of the IF under the study can be modified by features of other (*neighboring*) interfaces or control sets. The generalization is based on the idea that instead of taking into consideration only the initial state vector $\mathbf{Z_0}$ of the IF under the study the analogical vectors of neighboring IF in the same subsystem / alliance component or control sets are to be considered as well. The function α is in this case of significantly more complex nature, mapping Cartesian product of initial internal states vectors of all the interacting IF + control sets into the internal state Z of interface under study.

This generalization makes it possible to utilize the proposed model of IF for both the interacting and externally controlled interfaces.

For even more complex alliance interfaces the models of a full– featured automaton (both the Mealy and Moore types) or the hard (structured) systems could be eventually utilized.

An important factor is to be emphasized in this consequence: Respective automata or hard systems, of whatever type they might be, which are used for the alliance IF modeling <u>must be completely defined and identified</u>. Any utilization of the concept of alliance implies a detailed identification of relevant interfaces.

12.5 Alliance Control

The control within alliances has its inherent specifics:

1. There is possibly a weak analogy of systems hierarchical relation in the alliance.
2. The control within the alliance could be carried – out solely via interfaces.
3. The effect of the control approves itself as a change of the relevant interface. This change is causally transformed into the efficiency of the running of the processes passing through the relevant interface.

4. This effect can be recorded (within an equivalent language description) as a change of the efficiency or completeness of pertinent grammars.
5. The effect of the interface conjugation reflects the implicit component of control (self-regulation / self-organization).
6. Dynamics of the IF control seem to be the critical element. If the change of the IF induces a significant change in the running of processes (i.e. it is connected with intrinsic information power), the resulting effect is highly "phase sensitive" [29]. Chaotic behavior or alliance decay is to be expected without very fine-tuned control of the phase component.
7. Generally, for the respective model of alliance the results of control process represent the changes of inputs in the course of processes running. The stability of the processes is endangered if the Information power of the control, i.e. the change of the alliance time *(which is measured in the number of alliance events)* is of the same order as the alliance time of the longest processes passing by the interface.

To study the control processes within the alliance the schematics provided in Fig.22. - Fig. 24. could be slightly modified. Interfaces are to be explicitly expressed via a pair of finite deterministic automata as it is depicted in the Fig. 25.

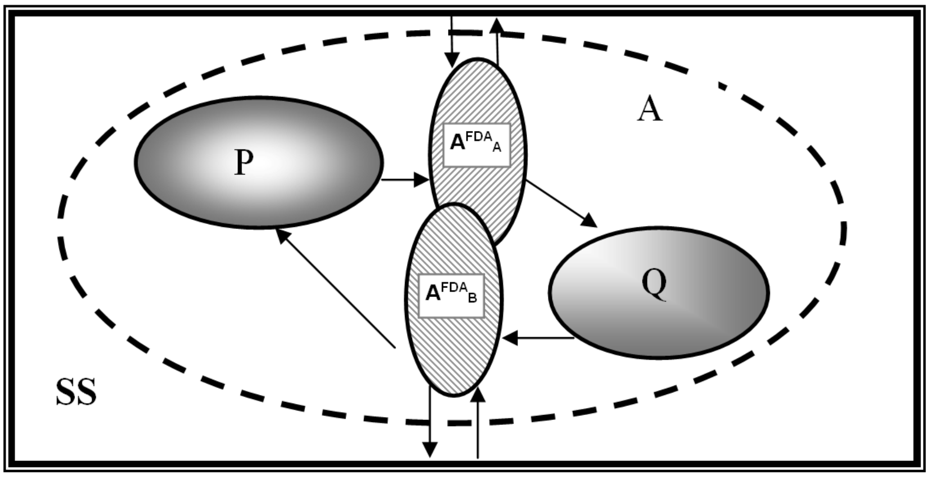

Fig. 25. Transformation of Fig. 22 to show the pair of interfaces $A^{FDA}{}_A$, $A^{FDA}{}_B$. These interfaces are modeled by a pair of automata which share parts of their state spaces and generally case they have also mutually related their mapping functions α, β. SS (super-system) represents the system of higher order which cannot generally be fully identified.

This model is quite powerful to represent the majority of important phenomena within the alliance interfaces, but it also maintains an evident pragmatic disadvantage – too many parameters / values are required to record shared parts of state – space and / or the mapping functions.

Therefore a simplified version of this model is presented. In this case the pair of automata (Fig. 25.) shares only certain parts of the internal state-space (Z) of both automata. (Compare Fig. 26. – all the shaded areas except the Z_A and Z_B , Z_{0A}, Z_{0B} respectively are to be omitted.). The finite deterministic automata definition of Alliance interface is then as follows:

$A := (IN_A; Z_A, Z_{0A}; OUT_A; \alpha_A; \beta_A)$

$B := (IN_B; Z_B, Z_{0B}; OUT_B; \alpha_B; \beta_B);$ (47)

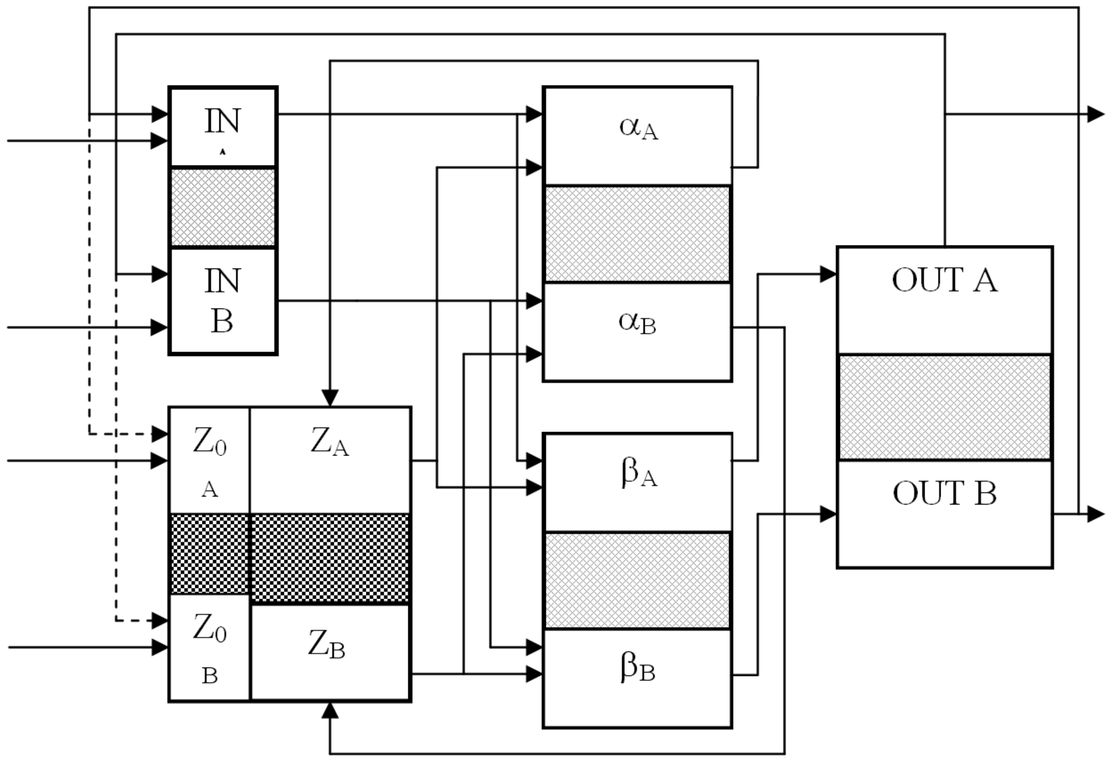

Fig. 26. State schematic of the alliance interfaces consisting of two joined automata and their connections with super–system (SS) Shared parts of the respective automata state spaces and/or their mapping functions are x – shaded. (- stressed for internal states Z) The respective alliance consists of 2 modules P, Q and exists within the SS (see Fig. 25.).

where:

$IN_A \cap IN_B = 0$; $OUT_A \cap OUT_B = 0$;
α_A ,α_B , resp. β_A ,β_B are not correlated;
and

$$Z_A \cap Z_B \neq 0 \; ; Z_{0A} \cap Z_{0B} \neq 0. \tag{48}$$

This approach has been utilized until now for the studies of alliance interfaces modeling for objects: HEV – Hybrid Electric Vehicle, Driving Car Simulator Laboratory and quite frequently [24] for the studies of the alliance: driver - car.

Fabera in [32] demonstrated that the transformation of the pair of finite automata with shared inputs to the pair of automata with separated inputs sharing their sets of internal states Z is generally feasible.

12.6 Conclusions

The theory of system alliances is an efficient approach which is matched mostly to the tasks where both the structure and the behavior of the respective parts / modules are of highly heterogeneous nature and/or these parts are identified with significant uncertainty, or these parts are notably variable in time.

This approach is applicable as a considerably powerful tool for analysis and synthesis namely of the transportation system alliances, which almost always are principally of heterogeneous nature. This approach can also be used for an improvement of our understanding of the functioning of complex neural networks and other information structures operating in the human body and for modeling of these objects. This Chapter is focused on the modeling of alliance interfaces. The model of an interface consisting of a pair of finite deterministic automata sharing a part of their internal state space is presented. This model of alliance interface can be successfully implemented in the study of typical phenomena in complex heterogeneous object with significant degree of uncertainty.

13. Soft Systems Tasks

13.1 Overview of basic concepts

Hard System is the System with a recognizable, explicitly expressed structure.
It can be modeled by formal tools, to:
• recognize and identify Systems structure
• recognize and identify System dynamics
• solve System analysis tasks
• design the System.

Soft system [23, 19] is a system which:
a) can hardly be identified
b) it does not have a firm structure.

Criterion of "hardness" or "softness" of the system is not its physical nature, but the degree to which the system can be objectively recognized and described via formalized tools. Thus, it is the degree of our ability to deal with Systems uncertainty.

"Softness" results from intractable uncertainty.

Typical examples of soft Systems are Systems of social and socio – economic nature or Systems - projects in the fields of science and technology.

Considerable subjectivity and incompleteness of recognition is characteristic for soft Systems. As a result, current formal tools are of limited use.

13.2 Sources of Systems uncertainty

are worth to be analyzed in detail. They could be classified as follows:
(a.) Significant influence of the remote System neighborhood.
Remote System neighborhood has an unknown structure and state space, it is commonly recognized as an automaton with unknown definition components.
(b.) Scarcity of available information on the System and / or its surroundings, namely:
- structure of the system
- (initial) state of the system
- states of the Systems interface.

This information shortage is as a rule caused by:
- Systems complexity (combinatorial or algorithmic respectively) and resulting trans-computability
- Shortage of resources in the area in which Systems analyst operates such as time, energy or financial resources. It is a reflection of obvious and fairly well documented finding that information and knowledge are not gratis)
- Reduced abilities of a System analyst (knowledge, skill and erudition of the analyst are not unlimited).
(c.) Processes fragmentation.

This is due to possible situations where the dynamics of the neighborhood is faster than the duration of strong processes in the system. Processes in this case are either modified "on the fly", or System during the activity of the process under analysis does not accept new inputs. In both cases, the possibility of the correct analysis of the processes and relations system / environment is significantly distorted.
(d.) Quantum uncertainty is indeed the fundamental one, but it is seldom the significant factor in the context of common Systems theory, as quantum Systems are generally not treated within the frame of Systems methodologies.

13.3 Comparison of "hard" and "soft" methodologies

Hard Systems Methodologies:
– are classic tools of Systems Engineering
– have extensive and proven apparatus based primarily on the tasks on the system, on the tasks of operation research, on applied parts of mathematics, computer science and systems theory
– their main advantages are: portability, relative (and conditional) objectivity, verifiability, the abilities to be algorithmized and automatized

– disadvantage is a certain risk of distortion of the task content (i.e. semantic) resulting from the fact that "hard" tools are rather aggressive, as the "hard" image of the problem solved is often adapted to the syntax of the formalized tools
– further disadvantage is their de facto non-applicability in the already discussed cases of high complexity and / or uncertainty.

Soft Systems Methodologies:
– emphasize the need of complete knowledge and capturing objects and their properties, even at the expense of a formal accuracy view
– portability methods are possible only by the examples (which can be used only as a model, not as direct instructions to a solution)
– disadvantages are: Methodological inhomogeneity, which makes it impossible to determine the level of the (often also uncertain - soft) criteria compliance in order to quantitatively (by formal methods) demonstrate the correctness of results
– They are rather pragmatic practices derived from experience in solving specific problems, but there are also generalizations of empirical techniques and their theoretical refinement and subsequent generalization.

System Engineering utilizes both types of the above mentioned methodologies in well balanced ratio. Projections of the 80's, claiming that the rapid progress and success of the "semi-hard" approaches (probabilistic and fuzzy attempts, methodologies based on neural networks or genetic algorithms) predicted early termination of the soft Systems approaches totally failed to come true. The main reason was that Systems Engineering expanded its scope to a very complex and heterogeneous socio - technical, environmental and global Systems in which different sources of softness could be found simultaneously. Furthermore, it came about because many of analyses and decision making were carried out in the situation of real shortage of available resources within the environment or Systems analyst. There is no compatibility among the "hard" and "soft" tools of system methodologies up till now. This weakness of Systems Engineering is being gradually solved rather than via the elimination of either soft or hard tools, by finding and developing new methodological means in order to enable compatible co-existence, mutual complementarity and further co – evolution for them. First, examples successful to some extent in this direction may be "soft architectures" proposed and gradually implemented in the area of transport telematics (ITS). They combine soft and hard Systems methodologies inter-operably, however, not yet fully compatibly. At the end of this paragraph I wish to mention one pragmatic, and seemingly obvious observation that is, nevertheless often overlooked: Any system "harden" in action that results from the analysis. The action at the moment of initiation is fully determined - hard. The (next) "softening" can then successively occur with the accumulation of uncertainty.

13.4 Soft systems analysis techniques

There are two most popular techniques, intended to be mainly used in decision making situations:
- SWOT analysis
- Force Field Analysis

13.4.1 SWOT Analysis

It is often used in planning the structural changes in the System, as it is known from the portfolio analysis. Working area in which the analysis is carried out has a typical quadrant structure:

Buy new car?

Strengths	Weaknesses
Better drivability greater operational range the joy of a beautiful new product better social status	considerable investment higher insurance costs
Opportunities	**Threads**
higher reliability and safety cheaper operation lower maintenance costs lower environmental burden greater durability	excessive burden on the budget hidden defects theft envy of people from the neighborhood unfulfilled expectations

Fig. 27.

IV. quadrant	**S**	-	Strengths
I. quadrant	**W**	-	Weaknesses
III. quadrant	**O**	-	Opportunities
II. quadrant	**T**	-	Threats

SWOT analysis is usually used to obtain an indicative picture of the situation in two time periods, the present and in the expected future (after changes). It is done utilizing a brainstorming attempt. This analysis is often used in the initial stages of a project of company strategy.

13.4.2 Force field analysis

This technique is used when planning changes in the system. It consists in the identification and evaluation of positive and negative forces acting in favor and against the system in a particular situation. Positive forces "push" system to the desired changes/goals. Negative forces "push" the system towards an undesired side or hinder necessary changes. According to the predominance of one or more others the changes are successful or unsuccessful.

Procedure:

a) the definition of the problem and the desired changes and goals

b) identification of the processes - inhibiting or facilitating the achievement of objectives.

The applied forces are displayed graphically as vectors acting positive against negative ones. The lengths of arrows indicate the weight of particular factors/forces.

Example:

Using force field analysis for decision making whether to build a highway from point A to point B:

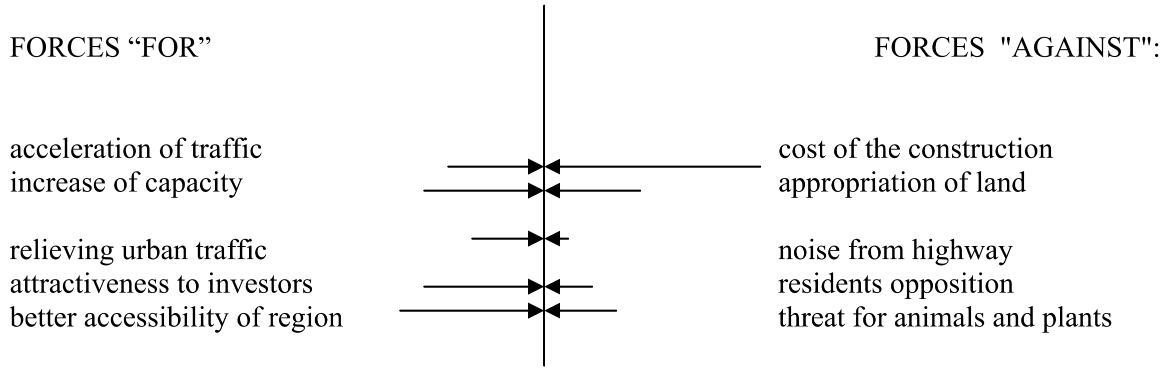

Fig. 28. An example of Force Field Analysis

13.5 Soft Systems Methodologies (SSM)

These methodologies are in essence the recommendations and procedures resulting from the experience and generalization of the Soft – Systems tasks in practice.

13.5.1 Action research - Jenkins

This methodology is often used for the analysis of large projects of technical or socio – technical nature. It contains the following basic stages:

1st Systems Analysis
2nd Systems Project
3rd Systems Implementation
4th Systems Operation.

The actual methodology is further subdivided into:

1st Systems Analysis

a) the recognition and formulation of the problem - getting a clear picture of the nature and probable and desirable benefits of its solutions
b) organization of the project - the right composition of the team
c) definition of Systems and subsystems - the clear definition and description, including flows and information links
d) defining a superior System (Super-system) - to define the role of the Super-system within the higher level frame and the definition of mutual joints
e) defining the goals of Super-system - the goals of Super-system have a direct impact on the system in question and are superior to the studied System
f) defining the goals of the System under analysis - these goals are defined with respect to the host Super-system so as to avoid conflicts
g) determining the total economic criterion – It should be clearly and directly related to the goals of the system for ease of evaluation
h) collecting data and information - for the future modeling and prediction of the future evolution.

2nd Systems Project

A key role in this stage is to define an interface between the project participants in all relevant parameters including time.

These processes are of interest:

a) the anticipation – it is used in each project, together with an estimate of prediction accuracy
b) modeling and simulation - first to construct the simplest model; that is gradually detailed (especially for key subsystems); then with the help of simulations the expected outcomes based on actual inputs are identified and the most appropriate strategy for the management of project is searched out
c) optimization – it is joined to the choice of objective function definition and to model inaccuracies and uncertainties

d) management - to ensure the ability to cope with unforeseen problems with the implementation to the real world.

3rd Systems Implementation

includes the following steps:
a) the elaboration of documentation and its approval - to prepare a document containing a timetable and recommendations on the principle of the critical path
b) Construction of the System - including the creation and verification of specific software and hardware for the early implementation of control and optimization algorithms.

4th Systems Operation
(including the so-called "operational research")

This stage can be detailed into phases:
a) the initial operation (this operation must be preceded by training of personnel and transfer of user documentation)
b) the retrospective evaluation of the project (allowing some re-optimization of the System and transfer of the experience into the future)
c) (new item explicitly not considered by Jenkins) useless or destroyed or obsolete System recycling.

13.5.2 Checkland Soft- Systems methodology [23]

This methodology stems from common human knowledge that for the situation under analysis there are many possible points of view, so it is difficult to define boundaries and goals of such a situation. The main components of this methodology are shown in Fig. 29.

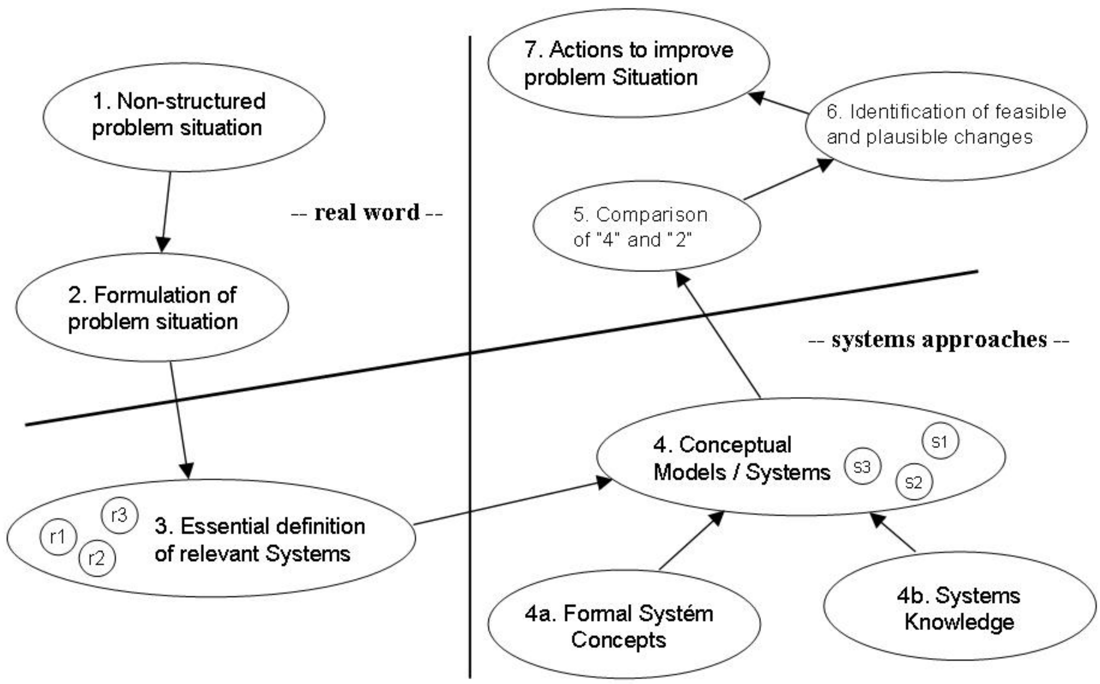

Fig. 29. Checkland Soft Systems Methodology

Phase 1: Situation considered problematic

Phase 2 : Problem situation (analysis) expressed The backgrounds is a picture of the problem situation as possible in the neutral form, i.e. so-called "rich" (colorful) picture of reality ("Rich Picture"). (Early attempts to

define the System lead to a flattening and depletion of the picture, and in most cases to the assumption of an existing arrangement as well.)
These 2 phases of the analysis are completed, if the following questions can be answered:
1st What kinds of resources are used in activated processes?
2nd How is the planning of these processes done?
3rd What is the organizational structure?
4th What is the neighborhood and what is the Super-System?
5th Which way the processes are managed and monitored?

Phase 3: The basic definition of relevant systems;

This phase includes defining the position and the intermediate joints of (relevant) systems, which are related to the problem. The fundamental definition of the relevant systems must reflect the aspects identified as CATWOE:

C (customer) - the one who can gain, benefit or lose from the system or from the running of its processes respectively
A (actor) - who performs relevant activities within the System
T (Transforms) - what inputs are transformed to what outputs
W (weltanschauung) - what a view of the world makes this System an important one
O (owner) - the one who can cancel / remove the System
E (environmental constraints) - as determined in a given environment, the system is what it is.

Phase 4: A structural model represents a fundamental contribution to the creative solution of the problem. It defines the reality of the conceptual model based on "conceptor" / systems analyst ideas (creating ideas about how things should be).

Phase 5: Comparison of conceptual models with the results of the problem analysis. It contains the results of the comparison and potential changes agenda.

Phases 6 and 7: Design and implementation of changes includes feasible and desirable Systems changes of the arrangements, processes and procedures and their implementation.

CATWOE analysis - example:
Definition of sea rescue services.
The basic definition of the relevant System:
It is a System managed by two components (government and charities), which should exist and coordinate volunteers and professionals who seek by appropriate means to rescue people at risk at sea.
CATWOE analysis:
***C** - endangered people in the sea*
***A** - volunteers and professionals involved in emergency services*
***T** - transform of the people at the risk to the people in safe*
***W**- for the society is desirable and in line with the social paradigms to avoid loss of life, loss of health and human deprivation in the sea*
***O** - charities and government*
***E** - variable climatic conditions and other dangers at sea*

13.6 Meta-level Process Model for Systems Analysis of Soft Systems - NIMSAD.

This model is a kind of framework that was developed as:
1st a tool for understanding systems analysis and synthesis
2nd a meta-level model for evaluating existing and emerging methodologies
3rd an instrument, indicating a logical approach to Systems analysis in an unfamiliar environment.

Components of the NIMSAD model:

a) Stage 1 - entry into the "real world"

This stage deals with the Systems analyst entry in that part of reality, which is a carrier of the problem. The stage is difficult to describe, it contains the setting up of relationships between analysts, carrier of problem and client.

b) Stage 2 - understanding the situation of interest.

To tackle this stage Systems analyst uses his knowledge of the system concepts, models and theories. An important entity in this context is the ability of perception, communication, reflection and abstraction as well as the ability of Systems analyst to establish contacts (sociability).

c) Stage 3 - Diagnosis ("Where are we now")
This is an explicit expression and processing of the data from stage 2.
Recommended tool in this stage is the fictional “freezing” of the dynamic situation. Thus a static expression of identified elements and their interrelationships can be achieved obviously, with the risk of eventual reduction, which could stem mostly from an insufficient recognition of the causal relationships over longer time periods.

The latter are 2 models:

1st diagnostic model 1 (DM1) displays the logical structure of roles, inner structures, flows, processes, functions, and such like.

2nd diagnostic model 2 (DM2) shows the situation in terms of real entities such as people, documents or products

d) Stage 4 - Outline of the forecast (“what we wanted to get and why”)
At this stage the client's expectations are defined and analyzed, the prognosis model is constructed to express the difference between the desired state and diagnosis.

e) Stage 5 - Systems Analysis
Creating a conceptual view forecast (desired state) on the basis of diagnosis (current state). In particular, the analysis of the distance between current and desired states is carried out. In addition, identification and critical examination is done of the elements and relations of DM1, that had prevented the current situation, and were transformed into the desired state within the frame of given Systems resources.

f) Stage 6 – the project of Systems "logic"
The logical elements and relationships that are considered necessary to achieve the desired state are identified. This stage is also called a logical project forecast (PM1). Then PM1 is compared with DM1.

g) Stage 7 - physical projects,
This is a selection of “ways and tools" for the physical realization of PM1.

h) Stage 8 – Implementation
The final "action", which implements the results of the previous stages.

References:

[1] von Bertalanffy, K. L.: (1968) General System theory: Foundations, Development, Applications, New York: George Braziller, , revised edition 1976: ISBN 0-8076-0453-4

[2] Portal: Systems science http://en.wikipedia.org/wiki/Portal:Systems_science

[3] Klir, G. J.: (2001) Facets of Systems Science, 2nd edition, Kiuver Academic/ Plenum Publishers, New York: ISBN 0-306-46623-6

[4] Vlček, J.: (1999) Systems Engineering (in Czech: Systémové inženýrství) CTU in Prague ISBN 80-01-01905-5

[5] Klir, G.J.: (2006) Uncertainty and Information, John Wiley & Sons, Hoboken, New Jersey ISBN 13-978-0-471-74867-0

[6] Kolman, Bernard; Hill, David R. (2007), Elementary Linear Algebra with Applications (9th ed.), Prentice Hall, ISBN 978-0132296540

[7] Bondy, J.A.; Murty, U.S.R. (2008), Graph Theory, Springer, ISBN 978-1-84628-969-9

[8] Petri, C.A. Reising, W., (2008) Petri Nets, Scholarpedia, 3(4):6477; http://www.scholarpedia.org/article/Petri_net

[9] Borysowich,C., (2007), Building Decision Tables, http://it.toolbox.com/blogs/enterprise-solutions/building-decision-tables-15903; http://openrules.com/docs/man_rules.html

[10] Rudin, W., (1976). Principles of Mathematical Analysis. McGraw-Hill Publishing Co.; 3rd revised edition, ISBN 978-0070856134

[11] Beerens, R. J. et al., (2003) Fourier and Laplace Transforms, Cambridge University Press, ISBN 0 521 80689 5

[12] http://www-users.cs.umn.edu/~kumar/dmbook/ch8.pdf; http://en.wikipedia.org/wiki/Cluster_analysis

[13] http://www.analyzemath.com/statistics.html
[14] Dubois, D., Prade, H., Fuzzy Sets and Systems, (1980) Academic Press ISBN 0-12-222750-6
[15] Fudenberg, D., Tirole, J., (1991) Game Theory , MIT Press, ISBN 0-262-06141-4
[16] Ling Xu, Jian-Bo Yang, (2001) Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach, ISBN: 1 86115 111 X; http://php.portals.mbs.ac.uk/Portals/49/docs/jyang/XuYang_MSM_WorkingPaperFinal.pdf
[17] Veselý, J. (1982) Systems Tools of Management (in Czech: Systémové nástroje řízení) Institut řízení, Prague,
[18] Votruba, Z., ed. (2009) Theory of System Alliances in Transportation Science ICS CAS & FTS CTU in Prague; ISBN: 978-80-87136-08-9
[19] Votruba, Z. et al. (2004) Systems analysis (textbook in Czech: Systémová analýza) CTU in Prague
[20] Brandejský T., Moos P., Novák M., Vlček J., Votruba Z.: (2002) Information Power (in Czech: Informační výkon, CTU in Prague; (abridged: Votruba, Z., Moos, P., (1999) Information Power, Proc. CE&I Conference Herl'any, Slovak rep.)
[21] Hopcroft, J., Ullman, J.: (1969) Formal Languages and their Relations to Automata, Addison-Wesley, Reading, Mass., U.S.A.
[22] Votruba Z., Novák M., Veselý J. (2004) Reliability of Interfaces in Complex Systems, Conference TRANSTEC Athens
[23] Checkland, P., Scholes, J.: (1990) Soft system methodology in action. Chichester. John Wiley.
[24] Novák M., Faber J., Votruba Z.: (2004) Problems of Reliability in Interactions between Human Subjects and Artificial Systems, NNW Monographs, Prague
[25] Stonier T.: (1990) Information and the Internal Structure of the Universe, Springer
[26] Prigogine I., Stengers I.: (1984) Order out of Chaos, Bantam Books, Toronto,
[27] Votruba Z.: (2005) Reliability of Information Power. CTU in Prague: 32 p., ISBN: 80-01-03186-1
[28] Brillouin L.: Science and Information Theory, Academic Press, New York, 1956
[29] Svítek M.: (2006) Dynamic Systems with Reduced Dimensionality, Monograph NNW, No. 6, Prague; ISBN 80-903298-6-1
[30] Votruba Z., Novák M., Voráčová Š.: (2003) Problem of dimensionality in predictive diagnostics, Neural Network World, vol. 13, No. 4,.
[31] Votruba Z.: Systems Ideas for Transportation, invited plenary lecture, WSEAS. Conf. Malta (September 15, 2005)
[32] Fabera V.: (April 11, 2009) The Transform of the Pair of Finite Automata with Shared Inputs to the Pair of Automata, (in Czech) ; Vlček Seminars CTU, Faculty of Transportation Sciences, Prague,