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THE RESEARCH PROCESS FOR THE PRINCIPLES OF COMPLEX SYSTEM DESCRIPTION WITH THE REFERENCE TO THE ENERGY GENERATION SYSTEM

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When we want to study the problem in the system, we would like to know what to start with and where. This knowledge is especially valuable when the system is complex. The study of a system and in particular a complex system requires a coherent way of system description which in result discloses the key problem and paves the way for the solution.

The objective of the study, which we would like to initiate by this paper, is to research the easy to apply rules for the complex system description. These rules will address the problems of the system's complexity which will be disclosed applying the approach presented in this paper.
The particularity of our approach is the way to identify and to formulate the key problems of the system's complexity. The starting point for the identification of the problems is the group of the system study tools including e.g. System Dynamics, IDEFØ, OTSM-TRIZ methods. Through the study of these tools it is possible to disclose the problems addressed by these tools and also the problems arising due to the interaction between the tool and the user applying it.

The whole process of the research is being recorded using the model of contradiction as a formulation of a problem and the network of contradictions as a tool to picture the interrelations between problems. The network of contradictions which is one of the OTSM-TRIZ concepts is applied here as a way to obtain the single page overview of the research process and also as the powerful platform for the further research towards the principles of complex system description.
The main solution of the presented study are first interim results presented as a network of contradictions constructed from the disclosed problems of system's complexity. The problems interconnected in the network are valid for the real complex system of the energy generation system for the urban area including CHP plants, applied by us as a reference case study. In further research we are going to show that addressing the problems of system's complexity identified here, it is possible to describe the complex system using a few simple to apply principles. After performing further research, the practical result will be the decrease in the data treatment expenses e.g. time, computing capacity, human involvement.

Keywords: System analysis, Complex systems, Network of Contradictions, OTSM-TRIZ.

Introduction

The description of a complex system with the necessary and sufficient number of details, necessary according to the objective of the study, is a problem faced in many processes e.g.: decision making, problem solving, modeling and design [1]. Research on complex systems is a recognized need [2] and the description of the complex system focusing on the right problems according to the goal, is one of its fundamental difficulties. Data-efficient and appropriate description of a system saves the expense in treatment of the information noise and stimulates concentration on the objectives. In practical application, the minimum description tailored to the objective, saves time in data computation, exposes the reason to the problem, supports the recognition of the information pattern, stimulates and enhances the perception of the studied system. Eventually it makes the system controllable. That means the possibility to manage maximum of the system's uncertainties in order to decrease threats.

The objective of the research initiated in this paper is to formulate the principles to describe and to study complex system. In order to do this, in the first step we have to identify the problems of the system's complexity which in the further study will be addressed by the principles.

In this paper we propose a systematic research process for disclosing the problems of system's complexity which are the obstacle in the appropriate description of a general complex system for the purpose of the e.g. problem solving process. We extract and select these problems using as a resource the difficulties addressed in the selected group of existing system study tools. A similar way has been utilized in order to extract the principles of forecasting in [3] and factors of cognitive complexity in [1]; both ways used existing system study tools as a base for their research. The exploration process presented in this paper goes beyond the identification of the set of problems; they are being linked into a network in order to picture the mutual relations. The organization into the network of contradictions adapted from OTSM-TRIZ technologies (Theory of inventive problem solving; TRIZ is the Russian acronym usually applied for. OTSM is the Russian acronym usually applied to indicate the General Theory of Powerful Thinking) provides a systematic way to organize the knowledge [4] about the problems of system's complexity. On the one hand the network is a mean to organize the results from the research; on the other hand it is a platform to formulate the principles of complex system description respecting the problems' relations with each other.

In order to validate the interim results obtained in the presented research process, the constant references to the case study of the example are being made throughout the research process. The case study concerns the complex system which has to be appropriately described to form its model representation. The individually adapted study of this complex system will introduce the innovative technological change of the way how the model describes the complex system. New rules for the model construction will, in the result, help to improve the productivity of the system.

Observations

In the study of a system[1], the chosen level of complexity in system's description should be enough to perform the study from the beginning to the end. The usual practice shows that the descriptions, used during the problem solving process, apply too many details. Why is it difficult to present the system with enough but not too many details? This problem can be expressed in the form of a contradiction. On the one hand we would like to have many details because we don't know what will be necessary in a long run and also in order to deal with maximum number of uncertainties in order to get our target. On the other hand we would like to have a few details in order to be not overloaded with facts, information and data. Low number of details helps also to reduce expenses to treat noisy information, to be able to identify what is signal and what is noise, to be able to support the perception of a system.

In order to describe this problem, it is proposed to follow the study of the question with the reference to a practical case example. The example case concerns the construction of the model of the energy generation system including power stations, heating stations and cogeneration plants (Heat and Power Cogeneration CHP). The problems interesting for us arise when the system is operated in the day-ahead energy market conditions. At the liberalized energy markets e.g. in Finland, Sweden, Denmark, Norway and Germany, the short term energy generation strategy is shaped according to the energy price reached at the trading session one day before the delivery day, which is the 'day-ahead' of the trading day. These conditions overload the reasoning capacity of the decision maker (DM) at the energy generation company (GENCO) because of the short available time for decision and complexity of the system. DM has the energy generation utilities and buying/selling contracts at the national or regional energy exchange (e.g. EEX in Germany, Nord Pool in Scandinavia) at his/her disposal. For the convenience of DM the system is represented in the model operated by the decision support and optimization software packages e.g. SPPA-M3000 Power Portal by Siemens AG, e-terrageneration by Areva, BoFiT by ProCom GmbH. The model of the local energy generation system, operating in the conditions of the day-ahead forecast, is optimized several times e.g. 10, in order to verify one concept of the production scenario. Here arises the problem of the expense of the computation time which shares the total time of decision, with the time for the decision making conducted by human DM. For the precise results the model should contain description of all elements[2] representing the local energy system in order to obtain precise production strategy, however each piece of data causes the increase in the optimization computing time which is a limited resource. The contradiction in this case: there is a need to describe the model of the energy generation with many details in order to obtain precise production strategy and there is a need

[1] System - a group of independent but interrelated elements comprising a unified whole [Wordnet a lexical database for the English language. Cognitive Science Laboratory Princeton University]

[2] Element - component: an artifact that is one of the individual parts of which a composite entity is made up; especially a part that can be separated from or attached to a system [Wordnet a lexical database for the English language. Cognitive Science Laboratory Princeton University]

to describe the model with few details in order to get more production scenarios and to have time for decision making. The problem with the excessive number of data being in conflict with the short time for their utilization is common and points to the need to have only the most important data, only the data exactly key to the decision, the data, called also, critical-to-X where X stands for our goal.

The great number of data is produced usually due to the utilization of the analysis process with the unconscious application of interim synthesis when the reasoning capacity becomes overloaded [1], [5]. The need for the interim synthesis is also visible in the research process presented in this paper, where at the stage 5 (Figure 1) appears the summary in the shape of the network of contradictions. Application of the network of contradiction and its study are the reasons why the name of analysis is not applied referring to the proposed research process. The following steps of the research process (Figure 1) are the elements of the study. It leads to understanding and not only to analysis[3], which is one of the ways to make the study by the means of decomposition into constituent parts and research of the mutual relationship or value. The study presented here as the research process includes the parts of analysis, synthesis, evaluation and reasoning. Therefore throughout the paper the research process will be referred to as the study and not analysis.

The problem of the appropriate description of the analyzed system is closely linked with the problem study approaches. The way to describe the system forms a base for the application of the particular way to find the solution e.g. the concept of system study proposed in the System Dynamics [6], System Operator [7], IDEFØ. However the user of problem solving approach tends to use too many details and overuses the particular tool. Moreover, application of more then one approach, inside single study process, multiplies the number of excessive information.

Here one faces with the problem of appropriate system description. We would like to analyze the system in order to introduce the technological change into it e.g. new way to represent the CHP (Heat and Power Cogeneration plant) model; however there exist several ways to describe it. As the system is complex, the user performing the analysis, tends to apply more system study approaches in border of the same analysis in order to treat maximum of aspects of the complex system. This way of analysis is time consuming, includes many overlapping operations and excessive data [8]. At the opposite end to the combination of many system study tools, there is the single unique method adapted to the particularities of the complex system under study. On the way to this target, the unique, individually adapted method, we propose, the research process to gather the problems of system's complexity stopping us in the study of a system. To identify these problems it is proposed to extract them from the system study tools e.g. problem solving tools, system analysis tools and to map them by the means of the network of contradictions linking together the problems presented in the form of

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[3] Analysis - the division of a physical or abstract whole into its constituent parts to examine or determine their relationship or value [Collins English Dictionary. 8th Edition first published in 2006 ©]

contradictions. The source of information about the system study tools includes the tool's description and the experiences of the tool's application.

The objective of this paper is to present the process of collection of the problems of system's complexity appearing in the description and study of complex systems. The process of problem collection and mapping is performed according to the following scheme. (Figure 1)

The way to study the problems of the system's complexity proposed in the research process presented in this paper is classified as methodological reductionism [9]. It has a certain edge over the classical reductionism approach. The methodological reductionism deals with the following contradiction in the need to combine the use of reductionism and holism. It is desired to use reductionism because it is possible to apply the tools for studying familiar to the western engineering culture; however some features referring to the whole are missed. If the system is described in the holistic way (system approach) the way of studying familiar to the western engineering culture does not work but the unobvious properties can be revealed. The advantage of the methodological reductionism is that it keeps the reductionism way of study, but it does not claim that it is possible to study in this way everything relevant to the whole. The expression 'familiar', used in the above presented contradiction, refers to the Western culture of engineering way of thinking and not to the Eastern culture which is considered to be holistic.

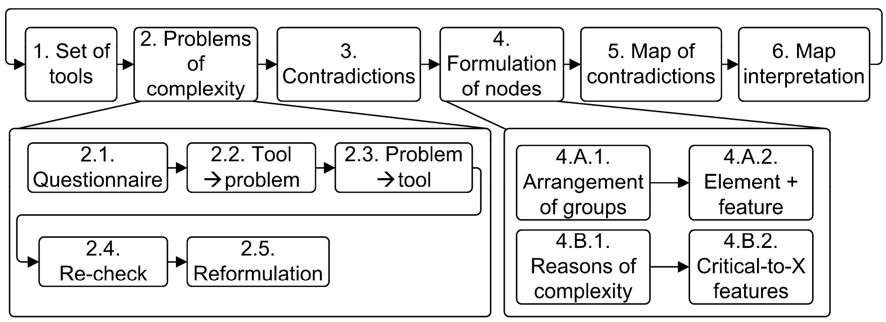

Figure 1. The research process of the problems of the system's complexity presented in this paper - scheme.

The methodological reductionism is also well suited to conduct the research for principles regarding the limitations of human perception; it supports reductionism but underlines the need for holistic reviews of processed knowledge, which are necessary for the human. The efficient study comprise of expansion and conversion cycles in the treatment of knowledge. The approach of the methodological reductionism with respect to human limitations points out the need for the summary at step 6 or 7 [5] from start. This is the one level where the proposed research process deals with the limitations in human perception, by the introduction of the knowledge conversion provided in this case by the means of the network of contradictions. The second level, where we are going to deal with limitations in the human perception, is the future formulation and utilization of the principles to deal with the problems in the study of complex systems. In the perspective, the application process will be designed to suit the human user, then developed to provide a greater and greater support to the human expert and finally to replace the human in the decision making process.

The reason why the limitations of the human perception appear to be in the focus of our research process, is because in fact the complex systems are complex due to the two features joint together: applied descriptions and limitations in the human perception [1] and not due to the nature of systems.

Description of the stages in the research process

Collection of the set of tools is the first stage of the research process. (Figure 1) The preferable set considered for the research for principles should be enough to deal with a real project. It is also better when the set contains tools of various origins in order to increase the variety of problems of system's complexity which are addressed in these tools. In the presented research process we use tools which had been applied in the study of the system of problem i.e. energy generation system [8]. The question, if the chosen tools are necessary and sufficient to study the case, for instance the CHP system [8], is in fact the question that we intend to answer with the results from the research process initiated by this paper. In other words the objective is to be able to assemble the tools from the already known techniques or to create new tools, in the form of the easy to apply rules, and principles which are necessary and sufficient for the study of practical case.

Step (2.) focuses on the extraction of problems of system's complexity from the system study tools by the means of the questioner collecting data about each tool. Initial description of problems is formed using the information from the tool's instructions and weak points of applied tools identified through the experience of their application. Disclosed problems undergo four redefinitions in order to make them more stable and to eliminate the repetitions, overlapping or neglect. During the redefinitions the number of problems is being reduced thanks to the elimination of the expressions doubled by the similar wording. The reduction of the number of problems is continued in the following step (3.).

Formulation of the contradictions in step (3.) is a key phase on the way to map the problems. Information included in the contradiction precise [4]: name of the element concerned by the problem, the feature describing the element and the parameters evaluating the effect on the desired need behind the problem. The formulation of the contradictions stimulates deeper rethink. The need to name the element and evaluation parameters exposes the close relations of some problems and stimulates the generalization e.g. one contradiction replacing two previous expressions.

The structure of the contradiction is used in the step (4.) to create the nodes of the net of contradictions. Two kinds of nodes are necessary, 'element + feature', related to the name of the problem and 'critical-to-X feature' linked with the problem's reasons.

Step (5.) is the construction of the net of problems. The link between two types of nodes ‘element + feature’ and ‘critical-to-X feature’ has a value referring to the feature in the ‘element + feature’ node. In order to match to the model of contradiction, the value of the links coming out of the ‘element + feature’ should be opposite in pairs.

The interpretation of the network at step (6.) gives a benefit at three levels: it presents an interim summary for the preceding stages of the research process; it is a tool for amelioration of the research process and the platform for the further research; it also appears to mark the point in our study where there is a need to converge the knowledge from the passed steps in order to use it in further research.

The closing loop from stage (6.) back to stage (1.) signalizes the feedback of the research process. (Figure 1) The observation of the results obtained at the stage (6.) provides the information about e.g.: the critical-to-X feature which have not been linked to, in the current network or the lack of the critical-to-X feature, when we identify the need for links from the ‘element + feature’. In this case the broader set of tools may be required. In order to check the consistency we apply also at each stage, the back loop to the preceding step of the research process. (These loops are not pictured on Figure 1)

The description of the research process is supported with the references to the study of the energy generation system.

The research process

The set of tools – Step (1.)

The set of tools used as a resource is a set of 23 system study tools collected in [8]. (Table 1) For the purpose of the PhD thesis, the tools were chosen among the recognized system study tools. The set of 23 tools had been selected according to the needs of the particular study of the energy generation system with CHP plants working in the day-ahead energy market conditions. These instruments belong to different categories i.e.: method, technique, rule, concept and they address specific problems of system’s complexity, which they are designed to solve. In this way the selected set of 23 tools gives an opportunity to describe different problems of complexity.

Table 1. List of the analysis tools used in the analysis

#	Name of the tool	#	Name of the tool
1.	System dynamics	13.	Agents theory (Multi-agent systems)
2.	IDEFØ	14.	Evolutionary design
3.	System Operator (Multi Screen Scheme of Inventive Thinking)	15.	Theory of Constraints

4.	Energy flow analysis	16.	KJ method (Affinity Diagram)
5.	Analysis of Initial Situation (AIS)	17.	C-K theory
6.	Bottleneck Analysis	18.	UML (Unified Modeling Language)
7.	(ARIZ Group) Problem redefinition	19.	IDEF3
8.	(ARIZ Group) Step back analysis	20.	(Evolution Law Group) Pace of development in different parts of the system
9.	(ARIZ Group) Model of contradiction	21.	(Evolution Law Group) Level of development analysis
10.	Construction of the network of problem	22.	(Evolution Law Group) Harmonization analysis
11.	Construction of the network of contradictions	23.	Analysis of Life Cycle
12.	SWOT (Strengths, Weaknesses, Opportunities, Threats)		

ARIZ – Algorithm of Inventive Problem Solving

Notion of the system and problem of system's complexity

The objective of step (2.) of the research process is to construct the first set of the problems of system's complexity addressed with the system study tools.

The problems of system's complexity, we are searching for, does not refer to any particular physical system. The problems are defined here on the system itself; system defined as the elements linked together by mutual relations. The set of problems of system's complexity forms itself the system of problem. It is a group of interrelated problems to perceive the group of interdependent elements.

The specific of the problems of system's complexity can be presented referring to the example of the complex system i.e. the energy generation system in the urban area with the CHP plants. In the case study, the model created for the real physical system of the energy generation is an input to the modeling and optimization software called BoFiT made by ProCom GmbH. The BoFiT is representative software in the category of GENCO operations management. The model in BoFiT is the system of elements representing energy production utilities together with the energy and fuel trading options [10]. (Figure 2a) The problem to perceive this system is faced whenever there is a need to change the model and to setup it with the data for the optimization of the current production task (24h of the following day). The group of data which is critical to the result of optimization concerns among others: electricity load, heat load, energy trading strategy, state of the generation units. These sets of data are allocated to the elements in the model following the overall scenario set up by the DM. This scenario is going to be tested in the model's optimization. In order to show how the problems of system's complexity arise before eyes of DM, let's keep the structure of the BoFiT model but without the technological details. For instance, the steam turbine ST3 in the BoFiT's model (Figure 2a), after the simplification, is described by inputs 'i1', 'i2' and outputs 'o1', 'o2' (Figure 2b). Before respectively: steam pressure, control, steam pressure, capacity in MW. The operational constraints in the form of characteristic are kept.

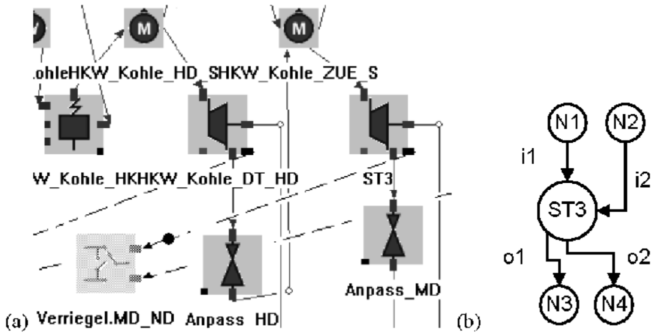

Figure 2. Model in BoFiT (a) and simplified system (b); (Nn- nodes)

Now the user attempting to perceive this system, faces the system as a phenomenon with the features of the system which examples are listed below. The examples from the energy generation system are used here in order to facilitate the comprehension.

Example list of the system's features:

--Number of links e.g.: inputs and outputs required to model a steam turbine.

--Number of clusters e.g.: energy generation stations in the urban area form the separate clusters.

--Distant, inter-cluster links outside one process e.g.: interaction of processes at the heat and power cogeneration plant (CHP).

--Feedbacks e.g.: increasing auxiliary production from small units is inefficient comparing to the startup of the large, more efficient unit.

--Dynamically changing elements e.g.: electricity demand, energy price.

The features of the system stand before the DM or any other user willing to study the complex system. Then the combination of these features with the observer and his tools causes the complexity to arise in many different ways. One way refers to the existence of the features themselves; some of the links or elements may exist but not be pictured in our system e.g. they are not considered factor in the forecasts. Other way for the complexity to appear is the observer, his limited perception and the limited capability of his tools. Observer, even with the hardware support, does not capture or keep the record of all links, all feedbacks and all dynamic relations. We are not able to keep all of these data and even if we are to store the data, it is not possible to use them on the short notice required for the day-ahead production strategy. Thus the complexity arises due to the simplified regions in a system with approximated characteristics. Another source of complexity to the user is the chosen way to learn, to study the system. The last part is the most important. Here is the place for the innovation in the technology to study the complex systems using the individually adapted method working data- and time- efficiently, even on the limited perception or computation power on the user's side.

Identification of the problems of system's complexity - Step (2.)

The identification of the problems addressed in the tools for studying systems (system study tools) is done on the basis of on the revision of instructions and application experiences of each tool. Description of the problems is done first in the regular text. In our example the list contains 40 problems. The difficulties in system description identified as addressed in one tool are also verified whether they are addressed by any other tool. These reversed and repeated questions are formed into five sub-stages of the Step (2.). (Figure 1)

Stage 2.1. – Questionnaire collecting the information from tools' documentation and from the application experiences in [8]. Question: What is this tool designed to do? (23 tools)

Stage 2.2. – First formulation of the problems addressed by the tools. Question: What problem is this tool designed for?

Stage 2.3. – Reorganization of information to answer for the question: Which tool does address this identified problem? (List of 40 problems)

Stage 2.4. – Recheck – Formulated problems are checked if they have been addressed in any other tool. Question: Does any other tool from the set also address this problem?

Table 2. Example of pros & cons summary for some selected tools

#	Name of the tool	Pros	Cons
13.	System dynamics	Formal, computer modeling enabled, feedback loop thinking, dynamic factor underlined	Construction based on redefinitions, main aim is problem analysis and not system analysis, modeling is subjective, construction highly dependant on user
14.	IDEFØ	High formalization, stimulus for the definition of mechanism and control	It does not support dynamic functions.
15.	System Operator (Multi Screen Scheme of Inventive Thinking)	Easy syntax and semantics, quick construction	High personalization, does not support variable time pace between described stages
16.	Energy flow analysis	There is a given scheme to fill in with data	It is a system study tool, the user has to form conclusions himself working at several stages in the given scheme.
17.	Analysis of Initial Situation (AIS)	Easy procedure of application,	No tool to work out the

		several tools included, diversification of thinking process	conclusion and to collect information is included into this kit.
18.	Bottleneck Analysis	Overcoming mental inertia, focus on the next bottleneck causes change in the mindset.	No hints about the solution.
19.	(ARIZ Group) Problem redefinition	Repeatable application	No particular technique
20.	(ARIZ Group) Step back analysis	Indications about potentially useful features and resources applied in other known solutions.	Indication refer to solutions which were created for different situation conditions.
21.	(ARIZ Group) Model of contradiction	It is a model.	User has to be aware of different sorts of contradictions i.e.: administrative, technical, physical.
22.	Construction of the network of problem	Easy syntax and basic semantics	Construction depends on the user; detailed construction expands too much and then requires fragmentation.
23.	Construction of the network of contradictions	Identification of key problems.	Advanced interpretation requires the knowledge of the construction process.
24.	SWOT (Strengths, Weaknesses, Opportunities, Threats)	Simple syntax	There should be at least 2-3 positions in each category.

Stage 2.5. – Reformulation of the problems of system's complexity, with the objective to eliminate the formulations doubled by wording. At this stage the list of problems in our example was reduced to 28. (Table 3)

Table 2 provides a short insight into the list of pros & cons for the tools used in [8]. This list especially benefited to the Stage 2.1. of the research process.

Contradictions - Step (3.)

In order to unify the form for all problems of system's complexity it is proposed to use the model of contradiction as a problem expression. The contradiction states the problem as a conflict between two values of a feature describing the element [7] (p.26-36). The value of a feature is described by the control parameter (CP) [4] (Figure 4). The two evaluation parameters describe the positive and negative state, in the reference to the unsatisfied need, at both values of the CP. In each contradiction, evaluation parameters indicate, that two positive evaluations are possible only when, contradictory, both positive and opposite values of CP are achieved at the same time.

The names of the problems of system's complexity, from our case study, transformed into the contradictions are presented in Table 3.

Table 3. Problems of System's Complexity

#	Problem of system's complexity	#	Problem of system's complexity
1.	Number of Redefinitions	15.	Distribution of research activities e.g. in parallel
2.	Completeness of the problem formulation	16.	Number of approaches
3.	Percentage of described resources	17.	Distribution of the scope
4.	Dynamic changes in characteristic	18.	Number of partial solutions in the system
5.	Homogeneity of system's development	19.	Number of oriented links
6.	Number of Natural selection parameters	20.	Number of elements/functions linked
7.	Number of constraints	21.	Scope of the Particular situation conditions used for description
8.	Number of procedures for guided exploration	22.	Relevance of the described problems
9.	Distribution of the detailed descriptions	23.	Scope of the pattern for initial recognition
10.	Number of guidelines' characteristics	24.	Rules in the systematic collection of information
11.	Formalization of approach	25.	Evaluation of recognized nodes e.g. leverage points
12.	Number of connection categories	26.	Scope of the system's perception
13.	Inter-cluster relations (Hidden Feedbacks)	27.	Number of elements' groups united by the functions
14.	Number of cross-level links	28.	Number of elements categorized by tool/function

Formulation of nodes - Step (4.)

The nodes of the network of contradictions: 'element + feature' linked to 'critical-to-X feature' are formulated thanks to the structure of the contradiction model which can be read in two directions. From left to right it presents the element addressed in the problem and problem's feature with conflicted values. From right to left, it gives the indications about the reasons to the problem. Since all described problems are problems of complexity, the reasons to them are critical-to-X standing for the description of the complex system. Description of the nodes is performed in the two parallel sub-lines marked on Figure 1 as (4.A.j.) and (4.B.k.).

Arrangement of groups - (4.A.1.)

The groups are formed on the basis of the common genre of the elements addressed in the contradictions. Thanks to the arrangement in groups it is possible for the user to perceive the higher number of problems of complexity. Six groups have been formed in our research for the problems of system's complexity i.e.: Problem definition, Approach, Pattern of recognition, Construction and operation of knowledge base, Relations, Nature of the system.

'Element + feature' - (4.A.2.)

Construction of the 'element + feature' is split into two parts. The name of the 'element' is taken from the name of the groups formulated at step (4.A.1.). As for the name of the feature, it is selected from the CP of the problems belonging to the group. The feature itself comes originally from the contradiction model. Eventually all the names of the groups appear in 'element + feature' bound with selected CPs e.g. in Table 4 problems P13 and P14 are the origin for the single 'element + feature.'

Table 4. Construction of the 'Element + Feature' Nodes

Group	Feature, CP	Name of the 'element + feature'
1.	2.	3.
Relations	P12 Number of connection categories (Feedback)	Relations – classification
	P13 Inter-cluster relations (Hidden Feedback)	Relations – distant links
	P14 Number of cross-level links	Relations – distant links
	P19 Number of oriented links	Relations – classification

The practical example of the 'element + feature' node named 'Relations – distant links', constructed in Table 4, can be the link between utilities belonging to clusters in different processes of the energy generation system. For instance, the start-up of a gas turbine has an influence on the economic-efficiency of auxiliary boilers operation. Let's have the closer look at this case. The advantage of a gas turbine is a short start-up time e.g. 5 minutes from start initiation to the minimum load [11]. This feature is an edge over the steam turbine which needs approximately 2h. The quick start of a gas turbine is used to satisfy the surge in the electricity demand. However at the same time the gas turbine unit produces the heat energy in the combined cycle from the exhaust gases. In this situation this new source of heat energy is more economic then the auxiliary boilers fuelled by oil which may have been in operation before the decision to start the gas turbine block. From the physical system point of view boilers and gas turbine belong to different processes bound only by the final product e.g. electricity and/or heat, but here they have the distant mutual link as it was described in this example situation.

Another 'element + feature' listed in Table 4 is: 'Relations – classification'. The practical example of this 'element + feature' can be all relations which exist within one group defined by the function performed by the elements e.g.: circulation of energy carriers like hot water, electric current, steam, fuel. Other example for classified relations is the circulation of money as profits from the energy sale and means to buy energy sources in the form of fuel or energy committed at the outside producer in order to fulfill our obligations stated in energy contracts. The relations can be classified also on the base of the function performed by the group of utilities. For instance the auxiliary boilers for heat production are related to the boilers for the steam turbine sets. Both kinds of boilers produce the heat for the district heating (DH) but their operation is related to each other and auxiliary boilers are used only when the boilers from the steam turbine set are unable to provide enough of heat. This kind of relation belongs to general decision making in the operation of the CHP plant.

Another ‘element + features’ formed in the same research process is called ‘Approach – spread over the system’. The two-piece construction of the name tells that this is the element from the thematic group ‘Approach’ and the describing feature is the ‘spread over the system’. In the reference to the generic system, this ‘element + feature’ indicates the importance of the existing approaches which propose the ready pieces of tools e.g. models, concepts or techniques, to study the complex system. In this particular node of the network of contradictions, the ‘element + feature’ underlines the feature of the approach deciding on the approach’s concentration on the region of the studied system. For instance: Affinity Diagram (KJ Method), problem redefinition, bottleneck analysis and Causal Loop Diagrams construction are, at least initially, concentrated on the region where the initial problem is localized; whereas e.g.: System Operator, IDEFØ, Theory of constraints, are decentralized in their approach to the system study. Additionally, much depends also on the user of the approach, the way how he/she applies the tool. In this study, in place of experience from the tools’ application we employ the practice acquired in [8].

What is the particularity of the ‘element + feature’ introduced above, called ‘Approach – spread over the system’ translated to the case of the energy generation system? The size of the energy generation system’s model requires the utilization of the system study tools addressing in the systematic way the elements belonging to distributed parts of the system. For instance, in order to operate the energy generation system in the economic-efficient way it is necessary to consider all the technological parameters of generation utilities e.g. start-up times, energy-efficiency, sort of fuel and their coordination in time, plus the grid restrictions and energy buying/selling contracts availability. The specific features of these parts of the system are decentralized, however their elements take part in the system study included into the decision making process. Therefore the approach has to be spread over the system in the uniform way in order to disclose the pattern for the recognition of the elements key to the study; and the approach has not to be spread in the uniform way, e.g. concentrated in the region of the initial problem in order to find out the precise indications how to form the pattern of recognition and to limit the number of processed data.

Reasons of system’s complexity - Step (4.B.1.)

We use the working hypothesis that there are two deep reasons of system’s complexity, these are: limitation of the human perception abilities [5], [12] and the chosen method to learn [1].

Respectively, in the reference to the artificial world, it is possible to say about the limitation of the time-efficiency in algorithm's computation and the limitation of applied algorithm as such.

Reasons of complexity in the study of the problems of system's complexity are a step closer to the system; at the one end they come from the deep reasons: perception's limitation and learning method. At the other end they are directly related to the problems of system's complexity described at stage (3.). (Figure 3) The indications for reasons of complexity are taken from the evaluation parameters used in contradictions. These parameters state, why positive or opposite value of the CP are desired in order to satisfy the need. Positive P1(+), P2(+) and negative P1(-), P2(-) description of the evaluation parameters refers to reasons to the problem described in the contradiction (Figure 4). If we take a closer look at the factor 'evaluation parameters from contradictions' on Figure 3, it is possible to recognize it also as the 'learning method'. Therefore the scheme on Figure 3 presents the two similar origins, closer to the source, deep reasons on the left and closer to the studied practical system on the right.

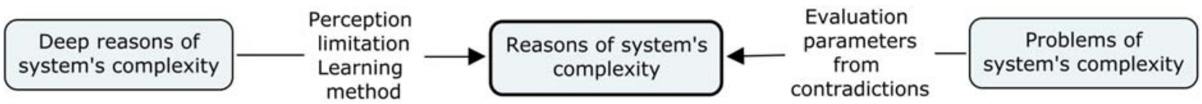

Figure 3. Reasons of system's complexity – the origins

Critical-to-X feature - Step (4.B.2.)

The critical-to-X features are the end elements in the network of contradictions, because the 'elements + feature' are linked to them via the features' description values. However, at the same time, for the whole study, the critical-to-X features are the middle element on the way to the X - the description of the complex system appropriate to the objectives of study. In order to formulate the critical-to-X features it is proposed to use the 'reasons of system's complexity' described in the preceding step (4.B.1.). Additional support is provided by the observation of the evaluation parameters P1, P2 in the 28 corresponding contradictions (column 2. in Table 5) and the name of the CP (column 1. in Table 5). The fragment of the table constructed in the Step 4.B.2. corresponding to one contradiction (Figure 4), is presented in Table 5.

Observing the thematic groups formulated at Step 4.A.1 it is possible to notice that there are the critical-to-X features formulated from the contradictions belonging to several thematic groups e.g. 'Limitation of data' and other critical-to-X features originated from the contradictions belonging to a single thematic groups.

In case of the problem presented in the contradiction on Figure 4, one of the critical-to-X features is in general, the amount of data, and particularly the excessive data. This critical-to-

X feature appears in several thematic groups and it is called ‘Limitation of data.’ Another critical-to-X feature, from the same contradiction, is based on the parameter P2, its name is ‘Encoding & Decoding’. This critical-to-X feature is characteristic for the thematic group ‘Approach’; it appears in 3 out of 8 contradictions in this group. Both of features linked in the contradiction are crucial, critical to the description of the complex system. The formulated critical-to-X feature is checked against other formulations in order to eliminate the expressions doubled by wording. Finally in total, out of the 28 initial contradictions, the group of 7 critical-to-X features is formulated. The number 7 is close to the number of 6 groups of contradictions formed at stage 4.A.1. and it also fits the limitation of the human perception, 7+/-2. Therefore the formulation of the critical-to-X features should be reviewed carefully.

Concerning the problem from Figure 4, the critical-to-X feature ‘amount of data’, as in other contradictions, is bound together with another critical-to-X feature - ‘encoding & decoding’ (Table 5). This one to one relation is noted thanks to the step by step description made in the reductionism way for each of 28 contradictions in our study. However the global view is missed and information about the mutual relations is hidden in the detailed one to one studies. In order to make the conversion of the knowledge and to provide the interim global view, the utilization of the network of contradictions is proposed. The net of contradictions is used in order to observe and study maximum of the relations e.g. links to the critical-to-X features ‘limitation of data’ and ‘encoding & decoding’. Immediately other question arises - What are the other mutual connections in the network of contradictions? The knowledge about relations between problems of system’s complexity and technology to exploit this knowledge will be very valuable. Thanks to the information about the interconnections between problems in the network, it will be possible to better fit the principles. In this way the principles will aim at the critical-to-X features linked from the main ‘element + features’ respecting also the interconnected ‘element + features’ directly linked to other critical-to-X features.

The formulation of the critical-to-X feature ‘encoding & decoding’ calls for the additional explanation. It refers directly to the solution used in order to deal with the limitation of the human perception. The human reasoning process requires the cycles of conversion and expansion of pieces of information. These pieces of information, called chunks are gathered in the sets of 7+/-2. Then our reasoning moves on, expands looking for new chunks. The set of chunks can be also expanded to recover the information in the further steps of reasoning [5], [13]. The process of encoding is performed in order to convert the acquired information into knowledge, clean the noise information and then to move further in the study. The system study tools use different solutions for the conversion e.g. construction of Causal Loop Diagram (CLD), utilization of System Operator (SO). Then the converged knowledge can be used in the further study. In case of need of more precise data the already converged knowledge can be decoded and used at the given time e.g. comparison of CLD with the CLD archetypes [14], development of the SO for the other parts of the system. The ‘encoding &

decoding' feature is critical to keep and move the knowledge around the complex system's study process.

At this point one may pose the question - How it has been decided that these features are critical-to-X and not the others? This decision is a consequence of the preceding stages in the research process (Figure 1). The critical-to-X features are formulated from all collected problems of the system's complexity which are in the contradictions at Step 3. Up to that step the problems of system's complexity have been already reformulated and re-thought at least 6 times i.e. 5 times at Step 2. and during the formulation of the contradictions at Step 3. Step 4.B.1. has an objective to facilitate the final disclosure of the critical-to-X features. The classification of the feature as the critical-to-X is done on the basis of the steps in research process (Figure 1) which provide an intense selection among the problems of system's complexity. Therefore the features extracted from the problems in the form of contradictions formed at Step 3. are considered as significant and critical-to-X.

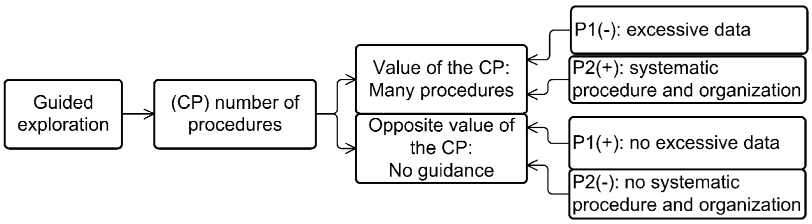

Figure 4. Contradiction Pr8 (Problem 8) – Guided exploration.

Table 5. Elements Used in the Formulation of Critical-to-X Features (Problem 8)

Name of the problem of complexity – Control Parameter (CP)	Evaluation parameters of the contradiction (Desired change in brackets)	Reasons of complexity	Critical-to-X features
1.	2.	3.	4.
Pr8. Number of procedures for guided exploration	P2: Organized pattern application (+)	Systematic procedure in encoding in order to have easier decoding	Encoding & decoding
	P1: Number of excessive data (-)	Excessive data in the guidance procedures	Limitation of data

The network of contradictions - Step (5.)

In order to have a system view of all identified problems of system's complexity and their mutual relations, it is proposed to link them into the network of contradictions. The construction of the network is a mean to check the correlation of recognized problems and the consistency of the study. For the construction of the network we use the knowledge modeling kit IHMC CmapTools. The network is built on the principle of the contradiction; therefore it pictures problems and also maps the interconnections [15] between problems. (Fig. 4) Altogether the network of contradictions is also a tool to work out the basis for the formulation of the easy rules to identify the appropriate level of complexity in the system description of a general complex system.

Interpretation of the net - Step (6.)

There are three general ways how we can use the network of contradictions. One way is to utilize it as a summary to the presented research process presented in one place and on one page. The network presents the 'elements + features' (marked as empty frames on Figure 5) linked by the positive and negative values of the features to the critical-to-X features (marked as frames filled in black on Figure 5). The strong point of the network is that it stimulates and pictures the links from many different 'element + features' to single critical-to-X feature. These links are possible to be noticed in the reductionism way of study but they are better visible in the holistic view as in the constructed network. The weak point of the network is that in order to learn about the information and reasoning behind the links it should be assisted by the glossary or description supporting all links in the network. In the further work on the network we are going to add more system study tools at the source and check out how many new elements of the network will appear.

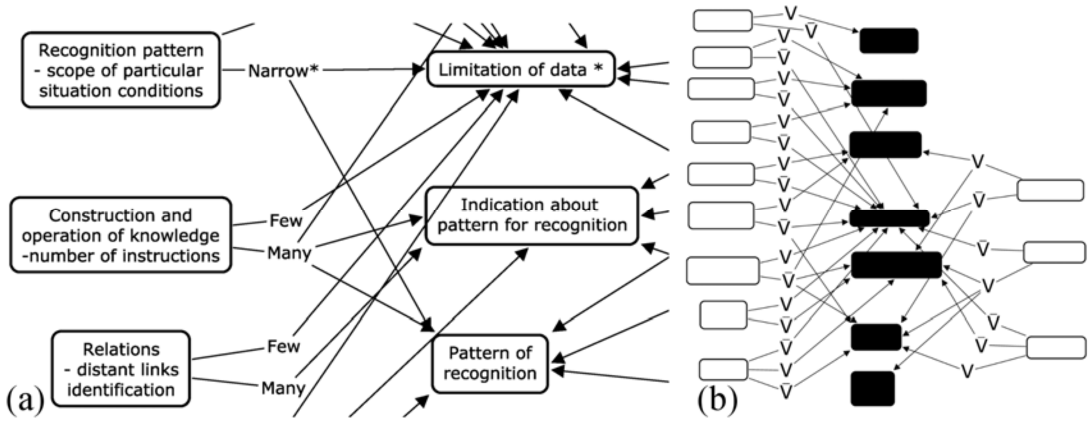

Figure 5. The network of contradictions: (a) fragment, (b) overview.

Second way to use the network is to study the net with the objective to ameliorate it e.g. revise nodes with single link, they may be an indication that there are missing elements in the network. The network of contradictions constructed as a result of the research process presents the interim holistic view on the problems of system's complexity. The network in its current state may be incomplete, some links or elements may be missing, and therefore the network will be studied in order to increase its internal consistency. The strong point of this path of the network's development is the increased interconnectivity and new elements; the weak point is the high number of links which should be described and studied when we use the network in the third way.

The third way to proceed with the net is to employ it as a platform for the further research on the problems of system's complexity. The third way will be continued in the further research in order to formulate the principles for complex system analysis. Using the network of contradictions we are ready to pose the following question: What is the system study tool or what is the principle of the system description and study, which applied to the complex system will successfully deal with the problems of system's complexity presented in the interlinked form of the network of contradictions? The interim result of our research is the structure which will be used in the further research to examine the existing system study concepts or if necessary it will become a mean to construct the successful principles from the beginning.

Conclusion

We made the first step on the way to formulate the principles to describe and study the complex systems by the formulation of the problems of system's complexity. With the applied principles, the difficulties in the description of complex system, formulated in the presented research, will be addressed directly, eliminating the excessive information in the system study and description process. This will build the straight way to the description of the complex system regarding the given objective.

Referring to the practical application in the modeling of the energy generation system, the utilization of principles will point out the necessary and sufficient data according to the objective of the model construction thus cutting out the excessive data. Operation of the limited number of data reduces the size of matrix standing behind the model. Decreased matrix means the less time expenses for the matrix's computation and more time for decision making.

Thanks to the research process proposed in this paper we identified and selected the problems of system's complexity. The problems have been extracted from the existing system study tools. Expression in the form of contradictions improved consistency in the numerous and overlapping initial set. The construction of the network of contradictions successfully mapped the problems presenting the interconnected and consistent structure.

The network of contradictions gives us the summary of the research process and it is also the platform for the further research. At the current stage the network can be already used to examine whether the proposed tool or principle, for the complex system study, addresses successfully the problems which will be encountered in the study of a complex system.

The presented on-going research prepared the basis for the change of technology in the construction of the model representation for the energy generation system in the urban area. The problems of system's complexity, which will be faced in the course of preparation of such a model, have been disclosed. These problems will be addressed by the principles which will be formulated in the further research. Focus on the problems critical to the objective will supply the essential and sufficient elements for the model construction.

Our assumptions are based on the following two ideas. One, the existing methods for problem solving and problem analysis are solutions, but we are not sure for what problems. That is why we study the problems. This idea was expressed by Russell Ackoff in the following way: 'We fail more often because we solve the wrong problem then because we get the wrong solution to the right problem'. Second idea, from the basis of our assumptions is the utilization of the 'System thinking'. The system approach uses two basic ideas. One, the objectives should be examined before considering the ways to solve the problem. Second, one should begin with describing a system in general terms before proceeding to the specific.

In the next phase it is planned to broaden the set of analyzed tools, verify the existing system study tools against the updated network of contradictions, formulate the principles for the complex system analysis and verify them on the practical examples of complex systems e.g.: spaceship 10E7 parts, aircraft 3·10E5 parts, automobile 4·10E4 parts [16].

References

[1] D. Batra, "Cognitive complexity in data modeling: causes and recommendations," *Requirements Engineering,* vol. 12, pp. 231-244, Oct 2007.

[2] S. H. Strogatz, "Exploring complex networks," *Nature,* vol. 410, pp. 268-276, Mar 2001.

[3] J. Scott Armstrong, *PRINCIPLES OF FORECASTING: A Handbook for Researchers and Practitioner*. Boston / Dordrecht / London: Kluwer Academic Publishers, 2002, pp. 849.

[4] N. Khomenko, R. De Guio, L. Lelait, and I. Kaikov, "A Framework for OTSM-TRIZ Based Computer Support to be used in Complex Problem Management," *International Journal of Computer Applications in Technology,* vol. 30, pp. 88-104, 2007.

[5] G. Miller, "The Magical Number Seven plus or minus Two: Some Limits on Our Capacity to Process Information," *Psychological Rev.,* vol. 63, pp. 81-96, 1956.

[6] G. Richardson and A. Pugh, *Introduction to System Dynamics Modeling*. Waltham: Pegasus Communications, Inc., 1981.

[7] G. Altshuller, *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*. New York: Gordon and Breach Science Publishers, 1984.

[8] M. Słupiński, "The method for analysis of the complex system : Application to the strategy of the energy production in the heat and power co-generation plant " Strasbourg, Wroclaw: University Louis Pasteur Strasbourg, Wroclaw University of Technology, 2007.

[9] "Reductionism," in *INTERS – Interdisciplinary Encyclopedia of Religion and Science*, G. Tanzella-Nitti, P. Larrey, and A. Strumia, Eds.

[10] M. Scheidt, T. Jung, and P. Malinowski, "Integrated power station operation – BoFiT and Vattenfall Europe case study," in *The European electricity market EEM-04*, Lodz, Poland, 2004, pp. 89-97.

[11] J. Xia and R. Antos, "SGT6-5000F (W501F) 3 million hours fleet operational experience," in *POWER-GEN International 2006* Orlando, FL: Siemens AG, 2006.

[12] J. M. Flach and R. R. Hoffman, "The limitations of limitations," *Ieee Intelligent Systems,* vol. 18, pp. 94-97, Jan-Feb 2003.

[13] F. Gobet, P. C. R. Lane, S. Croker, P. C. H. Cheng, G. Jones, L. Oliver, and J. M. Pine, "Chunking mechanisms in human learning," *Trends in Cognitive Sciences,* vol. 5, pp. 236-243, 2001.

[14] P. M. Senge, *The Fifth Discipline: The Art & Practice of the Learning Organization*. New York: Doubleday Currency, 1990.

[15] D. Kucharavy, R. De Guio, L. Gautier, and M. Marrony, "Problem mapping for the assessment of technological barriers in the framework of innovative design," in *International Conference on Engineering Design, ICED'07*, Paris, France, 2007.

[16] A. Grubler, *Technology and Global Change*. Cambridge: International Institute of Applied System Analysis, 2003, pp. 32-33.