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**APPLIED COMPUTER SYSTEMS**

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**LIETIŠKĀS DATORSISTĒMAS****COMPLEXITY MEASURE WITHIN A CONTEXT OF  
STRUCTURAL MODELING**

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*Complexity, structural modeling, graph connectivity, nodes, links*

**1. Introduction**

Nowadays the complexity of systems, structures, and processes in different branches is growing up. The intense of rapidly growing complexity has led to the making investigations on understandings of what it is really means system to be complex. We want to understand complexity with an aim to reduce this complexity. It is well-known that the more complex system is the easier way is to destroy it [1]. To understand what can be done on reducing complexity one has to be able to measure it. Measuring is essential to engineering. If you cannot measure something, you have not engineered it.

The study of complex systems (originally called Complex Adaptive Systems) as a distinct and recognizable discipline has been ongoing for more than three decades [2]. During this time many viewpoints and opinions have been proposed. There are also different ways how complexity is being defined but there are no many valuable approaches how the complexity can be measured. Examples of complex systems include biological systems, ecological systems, societies, as well as the systems that humans create and use. From the viewpoint of engineering science the system complexity can be measured depending on how collective properties arise from the properties of parts [3]. More generally, it refers to how behavior at a larger scale of the system arises from the detailed structure, behavior and relationships on a finer scale, where cause and effect relationships for the system as a whole are often not obvious.

The author explores how the structural modeling approach can be applied for the measuring the properties of a system structure and detecting the overall complexity of the system. In common this approach defines the measure as the set of all of the specific and instant relations among the parts, objects of a system. In the work there is discussed about the common researches on systems evaluation and the efficiency of applications of structural

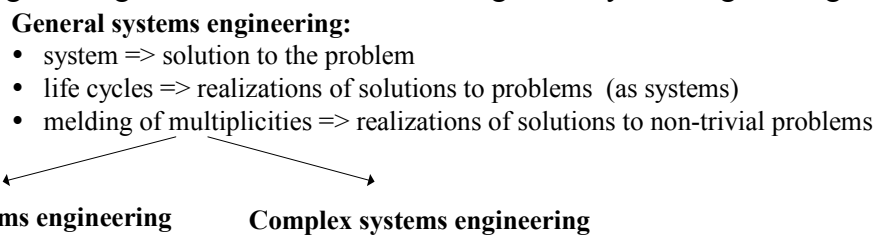
modeling technique, where issues about various systems quality characteristics are stressed on. There is also discussed about the theoretical aspects of structural modeling qualitative and quantitative analysis. Particular interest is devoted to the structural complexity measure which is one of the quantitative characteristics. This measure can serve as a good indicator which could show the common correlation of results. Also the scale of conceptualization is assumed as to be very important. The process of analysis is based on direct and indirect connectivity of the system's objects.

## 2. Complex systems engineering

Complex systems engineering” contains three terms [4]:

- Complexity
- Systems
- Engineering

Fundamentally, we're talking about an engineering activity centered on complex systems. But each of these concepts must be correctly defined and understood. In literature [5] complex system engineering is recognized as a second branch of general system engineering:



The differences between Traditional System Engineering and Complex System Engineering can be understood as differences in the way that a system is (or should be) conceptualized; as differences in the life cycles that account for their realization; and as differences in the multiplicities that must be melded, and how the melding is accomplished. Traditional systems engineering is appropriate for managing the decision making processes of individual autonomous agents in complex systems. Complex systems engineering must be added when multiple autonomous agents must a part of any solution and/or when multiscale analysis becomes essential to a sufficiently complete characterization of an evolving problem and its solution [4].

### 2.1. Complexity evaluation

Complex systems evolve and so measuring the evolution of complex systems is essential to complex system engineering. Different methods, approaches and techniques are considered for managing this not a simple task of systems complexity evaluation.

There are many definitions one can find to define a concept of a system and a complex system and most of the relevant literature is a discussion about systems with little attention given to defining the term. A complex system can be characterized as one whose development and maintenance is complex, one whose behavior is complex, or usually both [6]. A system is a construct or collection of different elements that together produce results not obtainable by the elements alone [7]. The Encyclopedia Britannica defines a system as a regularly interacting or interdependent group of items forming a unified whole. The IEEE defines a

system as a collection of interacting components organized to accomplish a specific function or set of functions within a specific environment. Bar-Yam [8] suggests that complexity is strongly related to the number of possible states of a collection, or its complete description.

In [9] there is discussed also about different viewpoints concerning to the statement of can the system be classified as complex or not. The approaches to understanding the complex systems states (among other opinions), that the world can be seen as objects having attributes and that what we can physically see and measure is what is truly real. Also in [9] is mentioned well-known Kolmogorow complexity and approach which proposes that system's complexity can be measured depending on time the (minimal) amount of time it takes to create the system. Another viewpoint is describing the system using rules as a notational system. There can be made gross general categories by the number of rules required to describe them. For example, to describe very large and complex systems one needs more than 1 million rules.

Irrespective of the definition or proposed approaches to be used two main aspects can be marked out:

- 1) components, elements, objects etc. the system under investigation consists of;
- 2) existing relations among these components, elements, objects etc.

Proceeding and examining a system's components and their interrelations one will be able to formulate a description of the system as a whole. An analysis of the interactions at the component level that yields a simple explanation of the apparent complexity of phenomena observed at the system level [2]. The intense interest arising in the study of complex systems has led to the necessity for developing of effective mathematical methods to make structural analysis of systems and measures of their complexity. The mathematical techniques of the complex system approach are include nonlinear dynamics, especially differential equations, difference equations and cellular automata, game theory, Markov processes, genetic algorithms, graph theory and time series analysis [9]. There is still no compact mathematical equation that would characterize the behavior of the system as a whole as a function of its components. Building a mathematical model of system is a very important precondition on the way of systems measuring.

Structural modeling approach can be an effective mathematical approach to complete this task while the reasoning here is based on a model of morphological structure which is transformed to graph where nodes depict objects within a system and links describe relations between objects. This approach lets us to develop a mathematical description of any (as technical as also non-technical) system in conditions of incomplete information [9].

### **3. Structural modeling approach**

The goal of structural modeling methodology is to provide the framework for systematic, domain model based knowledge acquisition, representation and processing based on a set of related structural models. The focus of this approach is on different systems with physically heterogeneous elements, which interrelation ensures different kind of flows existing in the system (like information, physical, descriptive, etc. flows). Four aspects are taken into consideration: systems structure, behavior and functions, and causal knowledge, that is, a specification of a modified behavior caused by structural changes in the system under consideration [10]. The important advantages of structural models are their ability to capture both shallow knowledge (expert's experience) as well as deep knowledge (understanding of cause-consequence relationships between input and output variables of the components), and to support inference of new knowledge [11].

According to [12] structural modeling refers to those modeling activities in which the intention of the modeler is to embody the geometric rather than the algebraic, and of describing form rather than calculating or measuring quantitative output. A key aspect of structural modeling versus modeling without the adjective structural is one of emphasis; emphasis on qualitative structural (geometric, topological etc.) aspects rather than on exact numerical or statistical properties of the systems being modeled.

As it was already told any system consists of elements and relationships between these elements. The model of morphological structure that essentially represents connectivity information about a system is used to support the structural reasoning. Structural reasoning is based on the analysis of direct and indirect connectivity of the system's objects using graph theory methods. Direct connectivity is described by structural equations. A general form of a structural equation is as follows [11]:

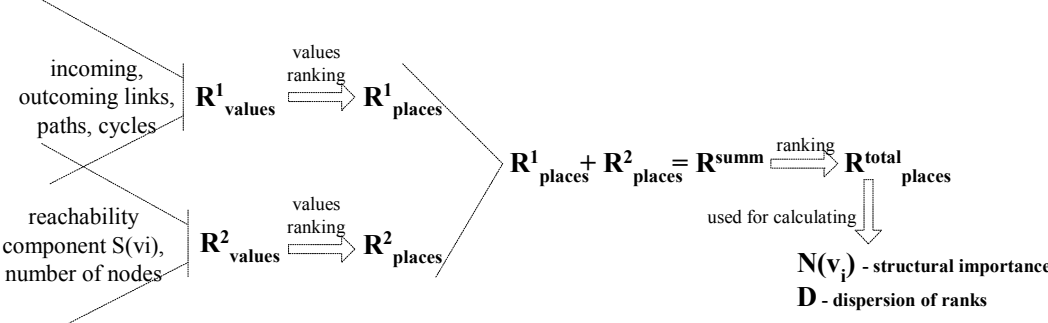
$$\text{flow}_1(\text{IN}) + \dots + \text{flow}_n(\text{IN}) = \text{flow}_1(\text{OUT}) + \dots + \text{flow}_m(\text{OUT}).$$

Hence, each structural equation represents knowledge about relationships between input and output flows of the corresponding object.

**3.1. Complexity components in structural modeling**

In order to methodically analyze anything, basic concepts are needed to explicitly and consistently center what are considered to be the pivotal aspects of the analysis. Measuring complexity of the structure (and thereby of the system) consists of two main components:

1. Qualitative analysis of the structure: here the evaluation of the structural importance is used to appreciate the quality of the structure in the sense of its potential reliability. The process of qualitative analysis is depicted below (see Figure 1).



**Figure 1. The process of the qualitative analysis**

The logical base for reasoning is as follows: the structure would be more reliable if the ranks of objects would differ less among themselves because there would not be functionally overloaded components.

2. Quantitative analysis of the structure: this component consists of many quantitative characteristics like diameter, radius, structural complexity, structural compactness etc. which are considerable only when we are comparing several structures.

Detailed description of theoretical bases for acquisition of all the characteristics in both components and the examples and conclusions of practical usage of the method are given in several publications [9][10][11]. Author wants to stress some important issues concerning to

complexity within structural modeling. One of the quantitative characteristics is structural importance of the structure. It is calculated according to [13] (see Formulae 1):

$$\rho = \frac{1}{m_1 m_2} \sum_{i=1}^{m_1} \sum_{j=1}^{m_2} \rho_{ij} - 1, \tag{1}$$

where  $m_1, m_2$  - the number of input and output nodes in the structure;

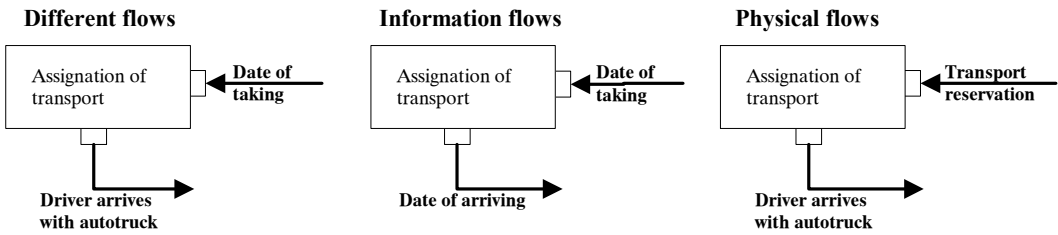
$\rho_{ij}$  - the number of different paths between the input/output node (i) to the deadlock node (j);

It states that the system is more complex if more paths exist between the input and the output of the system. The question arises – does the value of this characteristic correlates with the total evaluation of complexity where measures are taken from both components of analysis? Analysis of large scale systems/structures are of special interest here.

The second interesting question brought the process of analysis itself, not the individual characteristics within both components: what is the best way how to make a conceptualization of a system? This is briefly discussed in the following section.

**3.2. The scale of conceptualization**

As it was told in previous section the analysis has appeared the question about the conceptualization scale of a system. A primary goal of science is to compress phenomenological descriptions into concise abstractions and examine system’s components and their interrelations in the hope that in doing so one will be able to formulate a simpler description of the system as a whole [2]. One of the particular feature is various type of links in object’s inputs and outputs, namely, during the process one kind of flow is transferred into another kind of flow. The question here arises – can it be considered as acceptable when for object “assignment of transport” input is “date of taking” and output is “driver arrives with auto truck” – completely different flows. The first one can be concerned as information flow and the second one as physical flow (see Figure 2).



**Figure 2. Analysis of flows in objects inputs and outputs**

Therefore a question arises about the decomposition of the model into sub-models, where each sub-model contains only similar flows between objects. It means that usually a number of different objects exist within the system and their interrelations are heterogeneous. This could show the systems and their structure from the different viewpoints. In such a way a scale of conceptualization could be more precisely defined.

The number of scales in which the system can be decomposed also can serve as one of the characteristics in systems complexity evaluation.

## 4. Conclusions

Different methods, approaches and techniques are considered to manage the process of systems complexity evaluation. The use of structural modeling as an effective mathematical approach to complete this task is described here. The main advantage of structural modeling is that all needed data for analysis are captured in the systems structure itself, that is, no numerical data (statistics) are needed at all. Such important issues as connectivity and relations between system's elements are stressed on. As a result of this article two main issues can be noted: structural modeling as an adequate tool (among others) for complexity measuring and the second one is necessity of rules, advices for describing systems/structures in appropriate conceptualization scale.

This relevant structural modeling approach for obtaining conclusions about complexity of a system seems quite interesting, effective and reliable, in spite of the fact that the results are got in conditions of existing fuzziness and incompleteness of information.

Future work will be focused on building the form and common rules for structural modeling as a notational system. Decomposition of different system structural models will be made to get the feeling of effectiveness of such approach to systems complexity evaluation.

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#### **Survilo L. Sarežģītības mērs struktūrmodelēšanas kontekstā**

*Sistēmu, struktūru un procesu sarežģītība dažādās nozarēs aizvien pieaug. Sarežģītības pieaugšanas ātrums liek veikt atbilstošus pētījumus par to, ko tad īsti nozīmē sistēmai būt sarežģītai. Lai veiktu jebkādas darbības sarežģītības reducēšanas virzienā, sistēma ir jāspēj izmērīt, proti, jāzina kādi ir sistēmu raksturojošie raksturlielumi.*

*No inženierzinātņu viedokļa sistēmas sarežģītība var tikt mērīta atkarībā no tā, cik lielā mērā kopējās sistēmas īpašības korelē ar tās daļu īpašībām. Var arī teikt, cik stipri sistēmas īpašības mikro-mērogā ietekmē sistēmas darbu makro-mērogā, kur sakarības uzreiz nav saskatāmas.*

*Šajā rakstā tiek atspoguļots, kā struktūrmodelēšanas pieeja var tikt piemērota sistēmas struktūras mērīšanai, tādā veidā nosakot kopējo sistēmas sarežģītību. Vispārīgi runājot, tā piedāvā pieeju, kurā tiek pētīta objektu, sistēmas daļu specifisko un kopīgo īpašību attiecību kopa. Rakstā tiek diskutēts par vispārzināmiem pētījumiem, pieejām sistēmu sarežģītības noteikšanā un struktūrmodelēšanas lietojumu efektivitāti šajā kontekstā, uzsverot sistēmu kvalitatīvo un kvantitatīvo rādītāju nozīmi, kas tiek analizēti šajā pieejā. Īpaša uzmanība ir veltīta strukturālās sarežģītības kvantitatīvajam rādītājam un sistēmu konceptualizācijas mērogam. Analīzes procesa pamatā ir tiešās un netiešās saistības noteikšana starp grafa virsotnēm.*

#### **Survilo L. Complexity measure within a context of structural modeling**

*Nowadays the complexity of systems, structures, and processes in different branches is growing up. The intense of rapidly growing complexity has led to the making investigations on understandings of what it is really means system to be complex. To understand what really can be done on reducing complexity one has to be able to measure it.*

*From the viewpoint of engineering science the system complexity can be measured depending on how collective properties arise from the properties of parts. More generally, it refers to how behavior at a larger scale of the system arises from the detailed structure, behavior and relations on a finer scale, where cause and effect relations for the system as a whole are often not obvious.*

*This article explores how the structural modeling approach can be applied for the measuring the properties of system structure thereby detecting the overall complexity of system. In common this approach defines the measure as the set of all of the specific and instant relations among the objects and parts of a system. There is discussed about the common researches on systems evaluation and the efficiency of applications of structural modeling technique, where issues about various systems quality characteristics are stressed on. Particular interest is devoted to the structural complexity measure which is one of the quantitative characteristics and to the scale of conceptualization of the system. The process of analysis is mainly based on detecting of direct and indirect connectivity between objects within a system.*

#### **Survilo L. Мера сложности в контексте структурного моделирования**

*Системы, структуры и процессы в различных отраслях становятся всё сложнее. Быстрое увеличение сложности заставляет делать соответствующие исследования о том что на самом деле значит быть сложной системой, какие качества характеризуют это. Чтобы уменьшить сложность система должна бы измерима.*

*С точки зрения инженерных наук сложность можно измерять в зависимости от того, как от свойств отдельных составных производятся общие свойства системы в большем масштабе. Итак, как*

*поведение системы в маленьком масштабе меняется от свойств отдельных деталей структуры и их взаимоотношений в большем масштабе, где невооруженным глазом их взаимозависимость невидна. В этой статье описано, как подход структурного моделирования может помочь измерять свойства структуры. Таким образом возможно определить общую сложность системы. Этот подход определяет, в какой мере специфические и постоянные отношения между объектами, составными системы влияют на общую сложность системы. Процесс анализа основывается на нахождении прямой и косвенной связности между элементами системы.*