Knowledge structurization and implementation of the self-organization principle in the case of substantiation of conceptual properties for complex technical systems

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Abstract. The substantiation of the conceptual properties of complex technical systems (CTS) requires the use of knowledge of many engineering disciplines and the involvement of specialists from various subject areas. These properties are used for the implementation of the main functions, reliability and safety of CTS and can be substrate on the basis of the principle of self-organization. The technique of rule-based knowledge bases can be used for its implementation. The mechanism of self-organization involves the creation of a new computational structure for each object of investigation and interdisciplinary task to be solved.

Keywords: model, structure, self-organization, complex technical system, interdisciplinary task, knowledge base, rule-based model

1 Introduction

The substantiation of conceptual properties of Complex Technical Systems (CTS) at the initial stages of creation, which provide the principal possibility of implementing functions, reliability and safety, requires the use of knowledge of many engineering disciplines and involvement of specialists in various subject areas [1-3]. The properties of CTS are characterized by parameters of technical state, reliability and safety that change during CTS operation. These changes reflect the dynamics of properties and require the prediction of possible damage and planning adequate methods and means for monitoring and diagnosis. So, the problem of creating modern CTS has a transdisciplinary character and includes a set of interdisciplinary and disciplinary tasks. A significant part of these tasks can be solved on the basis of heuristics [4]. The effective use of expert knowledge, as well as the involvement of experts of related subject areas to the forming and solving problems, requires: improvement of methods and models for knowledge representation; development of knowledge bases (KB) and expert systems (ES); processing large amounts of information [5-7].

The most important technical solutions are substantiated at the early stages of the CTS creation on the basis of conceptual properties. In turn, the formation of these properties requires the combination of knowledge from different subject domain and a generalized formulation of interdisciplinary objectives and tasks. Thus, these generalized objectives and tasks allow to a wide range of experts to participate in the substantiation of new technical solutions. In this paper we make an attempt to present a set of interdisciplinary tasks for the substantiation of properties of technogenic safety IDT_{DS} and reliability IDT_{IL}. The principle of self-organization implemented in the form of rules and KBs is used as the basis. Thus, we expand the area of application of the self-organization principle [8-13].

2 The Conception of Self-organization Properties

One of the forms of implementation of the self-organization principle is the local rules [8]. So, we propose to use local rule-based models that reflect a set of relevant KB and computational modules (CM) intending for solving interdisciplinary tasks.

The principle of self-organization of CTS conceptual properties and their components and elements is a process of formation of properties providing effective functionality, reliability and safety on the basis of activation of relevant KBs and adequate rule-based models necessary for realization of algorithm of calculation. Missing or incomplete KBs and rules are created and supplemented directly in the process of solving problems by a team of experts, both related branches of knowledge, and with the participation of any expert. A special tool can be used for this purpose [14].

The mechanism of self-organization consists in the use of the "intelligent scheduler" that forms a set of relevant and adequate KBs and CMs. This set depends on the object of investigation and the certain interdisciplinary task and forms the self-organizing behavior [15]. The computational structure is determined by its own information space, including ontology of subject and problem areas, databases and KBs, as well as software [16-18].

The main interdisciplinary objectives and tasks for the formation of the properties of CTS at different stages of their existence and information levels are represented by local rules that determine the principal composition of the required KBs and rules.

The model of the transdisciplinary tasks that uses the principle of self-organization presented in figure 1, where $\mathbf{IDT_{DS}\ 1}$ - $\mathbf{IDT_{DS}}\ \boldsymbol{N}$ are the interdisciplinary tasks for stages of dynamics of the state to substantiate the safety properties for the discrete values of time (examples of IDSs: "to determine the nature and probability of possible catastrophic failures"; "to calculate the possible consequences"; "to calculate the risk", and etc.); $\mathbf{IDT_{IL}1}$ – $\mathbf{IDT_{IL}}\ \boldsymbol{M}$ are interdisciplinary tasks of the information level to substantiate the properties of structural, strength and physical reliability and other, and valid parameters of degradation processes; $\mathbf{IDT_{*ClS}1.1}$ – $\mathbf{IDT_{*ClS}}\ \boldsymbol{K.\ M}$ are interdisciplinary tasks of critical states classes.

Let's consider the content of KBs of the intelligent scheduler. The hierarchy of KBs corresponds to the hierarchy of selected tasks (Fig.1). These hierarchies are used for controlling the algorithms for creating and solving tasks:

KB_TDT → {KB_IDT_{IL1}, …, KB_IDT_{IL} M, KB_IDT_{DS}1, …, KB_IDT_{DS} K },

KB_IDT_{IL} i → { $KB\_IDT_{IL\ ClS}$ 1 i, …, $KB\_IDT_{IL\ ClS}$ K i},

KB_IDT_{DS} k → { $KB\_IDT_{DS\ Cls}$ k1, …, $KB\_IDT_{DS\ Cls}$ kM},

KBs for interdisciplinary tasks interact with KBs for disciplinary tasks:

KB_IDT* k i → {KB_DT* k i j}, where → – means the interaction, * – indexes IL or DS.

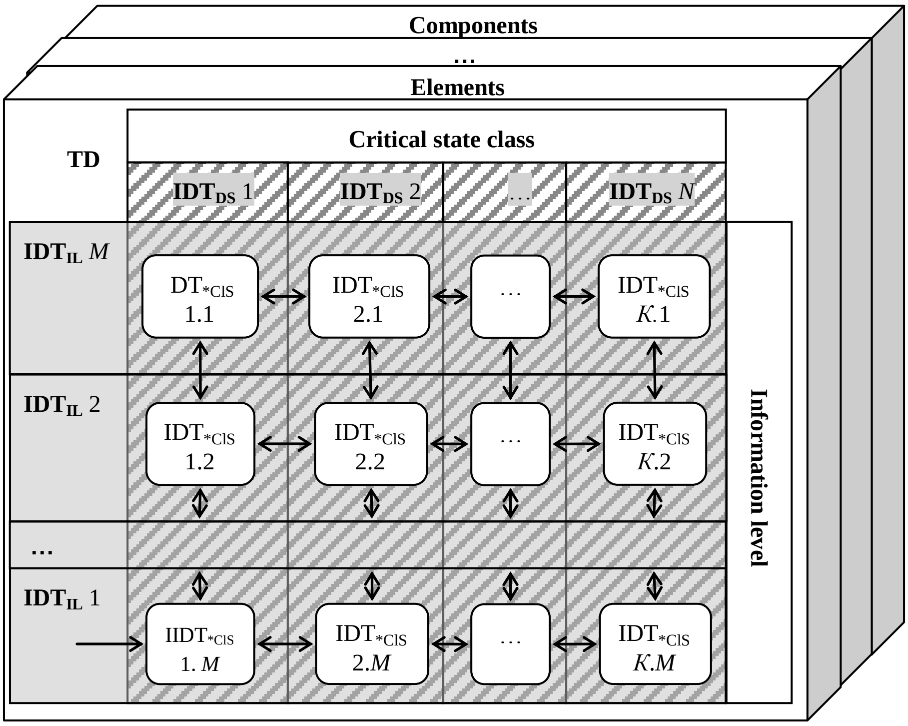

Fig.1. The model of the transdisciplinary tasks (TDT) for the substantiation of CTS properties

The objectives and content of the tasks without detail are presented in the table 1.

The knowledge bases listed provide:

- to define the hierarchy of subtasks for certain task;
- to formulate the task, i.e. to describe all elements, according to the proposed structure;
- to coordinate experts’ opinions for the hierarchy of tasks and the formulations of tasks;
- to define algorithms for solving tasks at all levels, etc.

KBs of the transdisciplinary task (TDT) describe the methodology for the design of new technical systems in general.

Let's consider examples of KBs for solving interdisciplinary tasks of different levels. Let’s solve IDT* 2.1, consisting of DT* 2.1.1 = {DT* 2.1.1.1, DT* 2.1.1.2, ...}.

These tasks are semi-structured and can be solved with the rule-based expert systems technique.

Table 1. A fragment of the model of the transdisciplinary task for the substantiation of CTS properties

<table>
<tr><td colspan="7">Transdisciplinary objective is to substantiate the properties of CTS
Transdisciplinary task (TDT) is to substantiate the properties of elements, components and CTS</td></tr>
<tr><td colspan="3" rowspan="3">Composition and structure of objectives and tasks</td><td colspan="4">Interdisciplinary objectives for the state dynamics stages are to substantiate safety properties that provide an acceptable risk for each state stage, IDO_{DS}</td></tr>
<tr><td colspan="4">Interdisciplinary tasks of the stages, IDT_{DS}</td></tr>
<tr><td>IDT_{DS}-1.
To substantiate the properties of safety in operational state</td><td>…</td><td>…</td><td>MDT_{DS}-4.
To substantiate the properties of safety in non-operational dangerous state</td></tr>
<tr><td rowspan="7">Interdisciplinary research objectives at information levels is substantiate the requirements of the state parameters, IDO_{IL}</td><td rowspan="7">Interdisciplinary task, IDT_{IL}</td><td rowspan="2">IDT_{IL}-1.
To substantiate the requirements for reliability that ensure properties of effective functioning</td><td colspan="4">To calculate parameters for functional properties of safety</td></tr>
<tr><td>for operational state
IDT_{*CIS}-1.1</td><td>…</td><td>…</td><td>for non-operational dangerous state
IDT_{*CIS}-1.4</td></tr>
<tr><td rowspan="2">IDT_{IL}-2.
To substantiate the technical requirements that ensure the requirements of reliability</td><td colspan="4">To calculate parameters for technical properties of safety</td></tr>
<tr><td>for initial state
IDT_{*CIS}-2.1</td><td>…</td><td>…</td><td>for failure state
IDT_{*CIS}-2.4</td></tr>
<tr><td rowspan="2">IDT_{IL}-3.
To substantiate the physical requirements that ensure technical requirements</td><td colspan="4">To calculate parameters for physical properties of safety</td></tr>
<tr><td>for fixed state
IDT_{*CIS}-3.1</td><td>…</td><td>…</td><td>for fracture state
IDT_{*CIS}-3.4</td></tr>
<tr><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td></tr>
</table>

KBs for IDT * 2.1 contains information about the possible sequences of solving its subtasks and recommendations for effective solving.

To solve any task the researcher has to create a KB by team of experts or to use the existing one. If the researcher wants to obtain new results for a task then he/she has to expand the existing KB.

Let’s consider IDT_{*CIS} 2.1: "to substantiate the technical requirements that provide the properties of mechanical reliability for the initial state", MDT_{*CIS}

2.1 $\subset$ MDT_{IL} 2.1. Now this task is solved by means of solving a set of disciplinary problems, one of which is the task: " to substantiate and choose the material" – DT_{IL} 2.1.1. This task includes subtasks DT_{IL} 2.1.1 = {DT_{IL} 2.1.1.1, DT_{IL} 2.1.1.2, DT_{IL} 2.1.1.3 …}, where DT_{IL} 2.1.1.1: "to prove the required strength of the material", DT_{IL} 2.1.1.2: "to substantiate the material residual life", DT_{IL} 2.1.1.3: "to identify material properties which can change during operation", and others. To obtain new results of collective solving of this disciplinary task, it is necessary to change the existing objective and algorithm by presenting them in the form of the interdisciplinary task $IDT_{IL\ ClS}$ 2.1.1, for example: "to substantiate the set of material properties to ensure mechanical reliability of the element is to select or create a new material". In this case, the previously formulated disciplinary problems will be solved on the basis of a single objective, in particular, in the aspect of mechanical reliability of the material, which will necessitate discussing the causes and possible consequences, that is, the causal complex of changes in the properties of the material and the object, and find a solution in this generalized aspect.

An example of a rule-based model of the set of KBs and CSs for $IDT_{IL\ ClS}$ 2.1.1 (the local rule of self-organization):

```
IF
The criterion of "leak before failure" must be provided»
(KB of fracture mechanics)
AND it is required to minimize the probability of through cracks
(KB of strength and resource at variable loads)
AND volumetric stress state (one tensile stress)
AND no stress concentration
(KB of strength under static loads)
AND variable loads (1 cycle / minute at high average cycle voltages)
(KB of  strength and resource at variable loads)
AND the medium temperature is not more than 300C0
(KB of long-lasting strength)
AND the technological environment is moderately active
(KB of corrosion resistance)
AND section thickness more than 30 mm
(KB of dependence of strength on scale factor)
AND the stress intensity Factor K1C is less than [A]
(a computational module)
AND the j-integral is less than [B] (computational module)
AND the fatigue crack growth rate is less than [G]
(computational module)
THEN
low alloy steel 30CrNiMoV8 or 25XCHBΦA or 15H1M1F
(BD of steels)
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Let's consider IDT_{DS} 2.1: "to calculate the parameters of the technical safety properties for the initial state". Now this problem is solved by solving a set of disciplinary tasks, one of which is the task: "to assess the risk of emergency in the operable initial state" - DT_{DS} 2.1.1. This task includes subtasks DT_{DS} 2.1.1 = {DT_{DS} 2.1.1.1, DT_{DS} 2.1.1.2, DT_{DS} 2.1.1.3…}, where DT_{DS} 2.1.1.1: " to substantiate the probability of brittle fracture of material in construction", DT_{DS} 2.1.1.2: " to substantiate the properties excluding the danger of brittle fracture", DT_{DS} 2.1.1.3: "to calculate the consequences of failure due to brittle fracture in the initial state", and etc.

To obtain new results for the disciplinary task: "to assess the risk of emergency in the operable initial state» DT_{DS} 2.1.1 = {DT_{DS} 2.1.1.1, DT_{DS} 2.1.1.2, DT_{DS} 2.1.1.3…}, we have to edit an existing objective and algorithm and present them in the form of interdisciplinary tasks $IDT_{DS\ ClS}$ 2.1.1, for example as followings "to substantiate the set of safety properties of the object in violation of operating conditions and deviation of the properties of the object from the technical requirements". In this case, the previously formulated disciplinary tasks will be solved in the aspects of technogenic safety and accepted properties of the object ($IDT_{IL\ ClS}$ 2.1.1).

This fact demands to discuss the possible causes and consequences, that is, the causal complex of safety violations at the initial state, and find a solution in this generalized aspect.

An example of a rule-based model for a set of KB and CSs of $IDT_{DS\ ClS}$ 2.1.1 (a local rule of self-organization):

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IF
Failure of the element may cause emergency
(KB of causes and factors of emergency)
AND the technological medium is dangerous
(DB of hazardous substances)
AND the element must ensure the tightness of the medium
(KB of ways to ensure tightness)
AND it is required to eliminate the danger of brittle destruction
(KB of fracture mechanics)
THEN
the criterion of "leak before failure" must be provided
(KB of fracture mechanics).
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Thus, the intelligent scheduler forms a set of relevant and adequate KB and CM for this task on the basis of the considered interdisciplinary tasks and their rule-based models.

3 Conclusion

The principle of self-organization is represented by local rules in the form of rule-based models reflecting the composition and purpose of a set of relevant KBs, which are necessary for solving interdisciplinary problems. Local rules are formed in accordance with the facts reflecting the objective of the task. The model of transdisciplinary task of substantiation of CTS conceptual properties is represented by a set of conceptual interdisciplinary tasks solved at the initial design stage. The main objectives and tasks for the formation of properties at different stages and information levels of the CTS existence are substantiated.

The principle of self-organization of CTS conceptual properties, components and elements is the process of forming properties that provide effective functionality, reliability and safety, based on the activation of relevant KB and adequate rule-based models. Missing or incomplete KB and rules are created and supplemented directly in the process of solving problems by a team of experts, both related branches of knowledge, and with the participation of any expert. A special tool can be used for this purpose.

Local rules implement processes of selection and interaction of KB and CM, which are designed for solving interdisciplinary tasks of different expertise and specialization.

The mechanism of self-organization consists in the use of the "intelligent scheduler" that forms a set of relevant and adequate KBs and CMs. This set depends on the object of investigation and the certain interdisciplinary task and forms the self-organizing behavior.

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