# Cognitive Flow Analysis

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***Abstract*— In the paper, the cognitive flow analysis is proposed as a method to integrate flows of matter, energy, and information in complex technical systems. Flow models are general and can be applied in many engineering tasks. We illustrate its capabilities for electronic equipment case study.**

***Keywords*— cognitive flow analysis; cognitive science; technical system; design**

## I. Introduction

Design methods are central in engineering activities. Many design methods have been proposed to formalize innovation and invention processes. However, till now a method that is suitable for any technical systems does not exist.

Moreover, a discussion about the correct definition for method is in progress. In [1], the description of design method has been introduced as follows: "a specification of how a specified result is to be achieved. This may include specifications of how information is to be shown, what information is to be used as inputs to the method, what tools are to be used, what actions are to be performed and how, and how the task should be decomposed and how actions should be sequenced".

It is doubtless, that information flow is crucial in engineering design. In [2], cognitive information flow analysis has been proposed. The technique uses both goal-directed task analysis and a modified cognitive work analysis. The main focus is on information flows.

However, in the end of the 20$^{th}$ century European researchers (Koller, Hubka et al.) [3, 4] emphasized, that three flows (information, energy, matter) have to be estimated in design process. In [5], the Information-Matter-Energy model has been introduced. It is crucial that information, matter and energy are linked. It is impossible to consider an element of the model independently.

In the paper, we propose a novel method Cognitive Flow Analysis that can be applied for flow analysis of different types: energy, information, and matter. It is remarkable that different elements of the model have common features and can be considered using the common method.

The rest of the paper is structured as follows. The next section reviews the related works in the field of engineering design. Section 3 presents our cognitive flow analysis. We discuss its application features for electronic equipment design as well. Finally, conclusions are derived in Section 4.

## II. Review of Related Works

Engineering design is a crucial element in engineering activities. Different understanding of engineering design as art or as science exists till now [6]. Some researchers (e.g. Hubka [4]) treat design research as a scientific discipline and seek general methods, while other researchers (e.g. Leyer) argue that designing is not a scientific activity and creative approaches have to be used [6]. In [7], systematic design and creativity were used simultaneously.

In [3], a general approach to engineering design was proposed. The main idea was that a system contains flows of energy/matter/information and therefore, all systems can be classified either a system of energy transformation or a system of matter transformation or a system of information transmission. Koller proposed a knowledge base related to the corresponding functions. However, current systems are much more complex and combine flows of energy, matter, and information to achieve the required functionality. Microelectromechanical systems (MEMs, microsystems) are examples of the systems [8]. Therefore, a novel approach is required to design the systems.

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In [5], the Information-Matter-Energy model for Cognitive Informatics has been discussed. It is crucial that Matter (M) and Energy (E) belong to the physical world (PW), while Information (I) can be used to model the abstract world (AW). In the Information-Matter-Energy model [5] the natural world represents a dual world. The natural world model is given as follows [5]:

$$NW \equiv PW \,/\!/\, AW = F(I, M, E), \tag{1}$$

where $/\!/$ denoted a parallel relation between two worlds: the physical and the abstract worlds; $F$ is a function that determines the natural world.

In [5], the links between *I-M-E* are given as follows:

$$I=f_1(M), \tag{2}$$

$$M=f_2(I), \tag{3}$$

$$I=f_3(E), \tag{4}$$

$$E=f_4(I), \tag{5}$$

$$E=f_5(M), \tag{6}$$

$$M=f_6(E). \tag{7}$$

Wang [5] have used the famous equation proposed by A. Einstein

$$\mathrm{E}=\mathrm{Mc}^2, \tag{8}$$

where $c$ is the speed of the light

$$c=3 \times 10^{8}\ m/c$$

for functions $f_5$ and $f_6$.

Cognitive information flow analysis [2] integrates goal-directed task analysis and a modified cognitive work analysis. The first method is able to satisfy dynamic situation awareness requirements. Cognitive work analysis allows to analysis the human work. A term *information item* has been proposed as a discrete data element abstraction. It is remarkable that the abstraction includes both physical objects and information reports. The proposed information flow diagrams show the flows of information through the system. Cognitive information flow analysis is a directed graph. Its nodes correspond to functions. The four information consumption types are represented by different edges styles. Edges are shown either as solid lines or as dashed lines. A direction of edges is shown either a single solid arrowhead or a double solid arrowhead. However, energy and matter transformation are not considered. Therefore, it seems to be useful to develop a cognitive approach that can be able to represent flows of energy, matter, and information simultaneously.

## III. Cognitive Flow Analysis

Cognitive flow analysis is a weighed directed graph

$$G=(V, E), \tag{9}$$

where $V$ is a set of vertices; $E$ is a set of edges.

Its vertex represents a subsystem. Its edge must have the source and the drain and represent a flow of energy/matter/information. The edge weight represents a transformation coefficient. Fig. 1 illustrates some particular cases. Fig. 1,a shows a linear cognitive flow analysis model for the case of similar flows. Fig. 1,b shows a parallel cognitive flow analysis model for the case of similar flows. All models represent a directed graph. The linear model represents a 2-regular graph. A parallel model represents a union of 2-regular graphs.

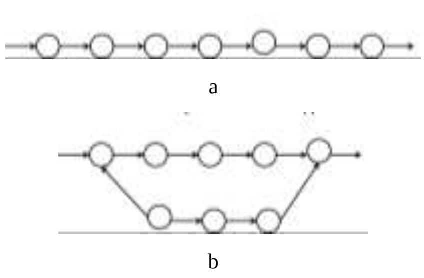
Cognitive flow analysis can be applied for different systems. Only time is independent variable. In despite of the generality of the proposed method, some restrictions exist. The method can be applied, if:

- the total energy of the system is constant;
- the mass of the system must remain constant;
- flows should be continuous;
- chaotic changes are not allowed;
- transformations between flows should follow the law of conservation of mass and the law of conservation of energy. The corresponding transformation coefficients are used.

The general operations that can be used are given as follows:

- discretization of continuous flows;
- division of a single flow to parallel flows;
- a speed of flow can be changed;
- a direction of flow can be changed.

It should be noted that in order to avoid energy losses a number of transformation should be minimal.

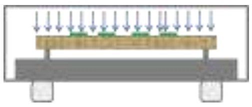
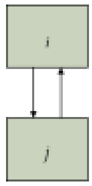
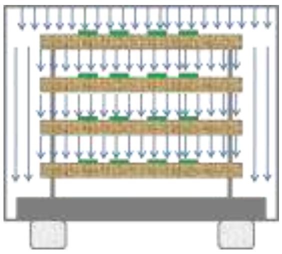
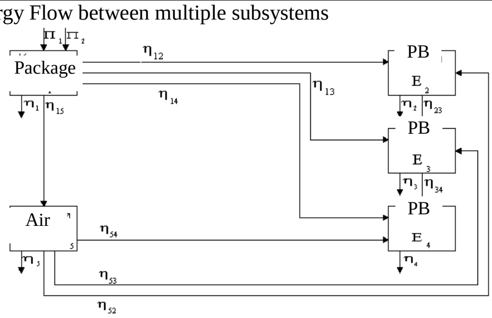


a

b

Fig. 1. Examples of cognitive flow analysis models. a) a linear flow analysis model, b) a parallel flow analysis model

TABLE I. ENERGY FLOW ANALYSIS IN ELECTRONIC EQUIPMENT

| **3D Model** | **Energy flows** |
|---|---|
|  | Energy Flow between 2 subsystems   |
|  | Energy Flow between multiple subsystems   |

In order to help a user to analyze flows of different types, we propose to mark edges showing energy flows in orange, edges showing matter flows in green, and edges showing information flows in black.

An algorithm of cognitive flow analysis application for systematic design is given as follows.

*Step 1.* Define all subsystems with flows through the subsystems.

*Step 2.* Classify types of flows (energy, matter, information).

*Step 3.* Define subsystems that should be controlled.

*Step 4.* Define flows that hinder the desired functionality.

*Step 5.* Transform flows and achieve the functionality.

We have chosen the design of electronic equipment as our case study to illustrate the cognitive flow analysis method capabilities. Table 1 shows energy flows between subsystems.

For the case of two systems (Table I, the first row) the corresponding equations are given as follows:

$$\frac{\eta_{ij}}{\eta_{ji}} = \frac{N_j}{N_i}, \tag{10}$$

where $\eta_{ij}$ is a transformation coefficient of flows from $i^{th}$ subsystem to $j^{th}$ subsystem; $N_i$ is a modal density of $i^{th}$ subsystem.

For the case of 5 systems (Table 1, the last row) the corresponding equations are given as follows:

$$\begin{aligned}
&(P_1 \oplus P_2)/\omega = \mathrm{E}_1(\eta_1 \oplus \eta_{12} \oplus \eta_{13} \oplus \eta_{14} \oplus \eta_{15}) - \mathrm{E}_2\eta_{21} - \\
&-\mathrm{E}_3\eta_{31} - \mathrm{E}_4\eta_{41} - \mathrm{E}_5\eta_{51};\\
&0 = \mathrm{E}_2(\eta_2 \oplus \eta_{21} \oplus \eta_{23}) - \mathrm{E}_1\eta_{12} - \mathrm{E}_3\eta_{32};\\
&0 = -\mathrm{E}_1\eta_{13} - \mathrm{E}_2\eta_{23} \oplus \mathrm{E}_3(\eta_3 \oplus \eta_{31} \oplus \eta_{32} \oplus \eta_{34}) - \mathrm{E}_4\eta_{43};\\
&0 = -\mathrm{E}_1\eta_{14} - \mathrm{E}_3\eta_{34} \oplus \mathrm{E}_4(\eta_4 \oplus \eta_{41} \oplus \eta_{43} \oplus \eta_{45}) - \mathrm{E}_5\eta_{54};\\
&0 = -\mathrm{E}_1\eta_{15} - \mathrm{E}_4\eta_{45} \oplus \mathrm{E}_5(\eta_5 \oplus \eta_{51} \oplus \eta_{54}).
\end{aligned} \tag{11}$$

where $\mathrm{E}_i$ is the energy of a subsystem; $P_i$ is a power of input signal; $\eta_i$ is a coefficient of energy losses in the flow.

In the general case, the corresponding equations are given as follows:

$$\mathrm{E}_i = \mathrm{f}\lfloor (P_1 \oplus P_2); \eta_i; \eta_{ij} \rfloor; \eta_{ij} = f(N_i); \tag{12}$$

It is important that eigen frequencies are important in the analysis. They can be calculated using CAD tools, e.g. ANSYS [9].

Fig. 2 shows the correspondent cognitive flow analysis model for the energy flow between 2 subsystems (Table I, the first row).

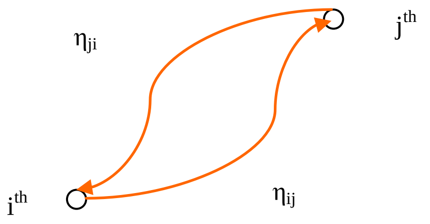



Fig. 2. Examples of cognitive flow analysis models

The proposed graph model allows to calculate relations between flows using graph metrics and compare a role of each vertex in the whole system.

However, flows of different physics should be calculated separately. Therefore, a hierarchical and multiphysics approach has to be used. Many 2-regular graphs are used for multiphysics applications. A hierarchical approach allows to expand cognitive flow analysis methods for nanosystems design [10] using multi-level representation [11].

Finally, our approach is in line with physical effects and the unified theory of intelligence [12]. It is sufficient to satisfy for Leyer's concern that creativity should be taken into account and use scientific advantages of systematic design.

Our approach simplifies system design and visualizes relations between different subsystems and different flows. It can be easily incorporated in interactive manuals, e.g. as in [13]. Visual analytics methods can be applied to define bottlenecks in the system and then find in a scientific manner a better design decision.

## Conclusions

In the paper, we have proposed our approach to formalization of engineering design. Several approaches to engineering design have been discussed in detail. It was shown that flows of energy, matter, and information have to be considered simultaneously.

The cognitive flow analysis model based on graph theory has been introduced and reviewed. An application of the method for electronic equipment design is discussed. It is obvious that visualization of relations between subsystems allow to review the system as the whole object. The bottlenecks can be defined by a visual control and some design efforts to eliminate the bottlenecks can be applied in a scientific manner.

It is remarkable that in despite of differences in physic effects flows of energy, matter, and information can be managed as an abstract item. Therefore, the information item [2] can be expanded as *a flow item* that can be used in multiphysics applications.

A graph representation of a system containing many subsystems is not trivial task. Therefore, for the cases a hierarchical approach is preferable.

These areas will be addressed in our future research.

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