Integration of Flow and Functional Analysis

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Flow analysis is an effective tool for analysing technical systems in TRIZ. It is a good complement to functional analysis (FA), as it allows to identify problems not identified by other means of analysis.

Nevertheless, until now:

- There is no accepted methodology for conducting flow analysis.
- No information from FA is used in flow analysis.
- The results of flow analysis and FA are integrated only when building the causal chain of undesirable effects.

This paper attempts to consider flow analysis as a special case of functional analysis: flows in a technical system (TS) are considered as a special case of components of the TS that have important features.

The functional relationship of flows to other ('stationary') components of the system is considered: to source, channel, receiver and control system of the flow, which form a functionally complete technical subsystem.

The proposed approach opens up the following possibilities:

- The possibility of applying well-established functional analysis techniques in flow analysis.
- Partial integration of the processes of flow and functional analyses.
- Identification of components interacting with the flows to be improved.

Problem Statement

The practice of flow analysis is highly effective. A properly constructed flow model can identify problems that are poorly detectable by FA tools. The reason is clear – FA takes almost no account of information about the spatial structure of the TS being analysed. But the flow model intuitively takes this information into account. The functional model (FM) is a "snapshot" of the TS taken at a given point in time. But this completely or almost completely ignores the dynamics of the TS. When building a FM of the system at work, one has to go to all sorts of tricks or simply has to disregard the "canonical purity" of the description. A typical example: component 1 – moves – component 2. When strictly following the rules of composing the FM, such a formulation is no longer correct, as it implies different positions of the components at different time.

The introduction of flows into the FM removes this kind of difficulty by **treating flows as dynamic components of a system** whose lower system level components move in space under the influence of static components. However, unlike FA, to date flow analysis is clearly unsatisfactory formalised. In fact, there is no unified methodology for conducting it. In addition, there are no tools for exchanging information between FA and flow analysis models. The two analyses are carried out independently and their results are combined only when the causal chain of undesirable effects is built.

There have been repeated attempts to combine the two instruments. One of the most elaborated methodologies is described in A. Kashkarov's dissertation [1]. Unfortunately, his proposed methodology is quite cumbersome, which completely kills one of the main advantages of flow analysis – its intuitive clarity and transparency.

This article discusses approaches that allow for the integration of FA and flow analysis without losing these inherent merits.

Choice of a Methodological Prototype

To continue the discussion, we select one of the existing variants of flow analysis methodology as a basis for further improvement. Apparently, the relationship between flow analysis and other TRIZ tools is best described in O. Gerasimov's dissertation *Technology of Selecting Tools for Innovative Design basaed on TRIZ-FVA* [2]. However, this description is very brief, which makes it difficult to use in practical work.

In addition, this description uses a number of concepts introduced within ZRTS[1] (flow analysis appeared as a development of one of the laws of ZRTS – the Law *Improve the Efficiency of the Use of Flows of Matter, Energy and Information*). It is useful to recall the history of the emergence and development of this law.

The precursor of the law is the law of minimal energy conductivity of systems formulated by G. Altshuller [3]. In the course of development of the system of ZRTS this law remained practically unchanged for a long time (from 1975 to 2002, judging by dates of publications). In particular, in [4, p. 56] the law is briefly mentioned as part of the law of increasing coherence in systems; in Salamatov's book [5] the law is reproduces almost verbatim.

In V. Petrov's book [6] the law is considered as an increase in specific energy saturation of systems and is a sub-trend of the law of system transition to the micro-level. But here it is no longer considered as requiring a minimal necessary level, but as a line of systems development.

In the work of S. Litvin and A. Lyubomirsky [7], the law is completely revised and considered as "law of increasing the efficiency of matter, energy and information flows".

It is not difficult to see that both V. Petrov and S. Litvin, A. Lyubomirsky have, in essence, a completely new law, not so much developing the predecessor but located nearby:

[1] ZRTS – Laws of Development of Technical Systems.

- Firstly, this formulation of the law refers not to a system to be constructed, but to ways of improving an already viable system.
- Secondly, [7] significantly extends the range of flows considered with "energy flows" to "matter, energy and information flows", i.e. to all kinds of flows existing in the system.

In doing so, the description of the law is not so much a trend (a line of development) as a list of mechanisms (essentially recommendations to improve flows in the system). The list of mechanisms is quite extensive at 42 items, structured by type of flow and divided into two groups, implying "changes in the conductivity of flows" and "changes in the efficiency of flows". It is this version of the law and its recommendations for conducting flow analysis that we will choose as prototype for future work.

What are we Going to Improve?

First of all, definitions. A serious shortcoming of most theoretical work in TRIZ is the lack of attention to notions and definitions. In particular, S. Litvin and A. Lyubomirsky formulate four main trends of this law (parasitic flows, as a special case of harmful ones, are described almost word by word as harmful ones):

- Improve the efficiency of use of useful flows.
- Reduce the damaging power of harmful flows.
- Increase the conductivity of useful flows.
- Reduce the conductivity of harmful flows.

The first two trends are obvious to triviality and trivial to complete non-instrumentality. But it is also completely impossible to argue with them. Of course, it can be useful to formulate obvious things explicitly as axioms, and this has been done.

But there are serious problems with the other two trends.

- Increase the conductivity of useful flows.
- Reduce the conductivity of harmful flows.

First of all, **conductivity of flow** sounds similar to the concepts of **resistance <u>of</u> electricity** or **conductivity of water in a pipe**. But we have, after all, to talk about conductivity of flow **channels** (paths) ("resistance of the **conductor** <u>to</u> electric current"). It is not a matter of simple matching of words, but of distinguishing substantially different categories previously mixed in a single term.

So first let's try to clarify some key terms. In this paper

- We call **a flow** such a movement of material objects, energy or information in a system in which individual parts of the flow move according to the same law one after the other (part of the flow may move in a supersystem, but the key is its presence and movement in the system in question).
- We call the **flow source** the component of the system that generates the flow and sets its initial parameters.

- We call **flow channel** the system component which defines the path of the movement of the flow (the channel may be distributed in space, and may have no clear, unambiguous boundaries).
- We call the **consumer** the component of the system which is transformed by a given useful flow, or one that is directly damaged by the harmful flow in question.

Add Diagram

Notes:

A. The above formulations are not absolutely general for all conceivable cases, but are sufficient for applied purposes (analysis of TS and elaboration of proposals for their improvement).
B. The assignment of elements of a system to one or another of the defined components are not unconditional and are determined by the specifics of the task to be performed.
C. In many systems, the flow is the object of transformation, not the subject. Accordingly, the "consumer" is the subject and should more properly be called the "transducer" of the flow. However, for the needs of practical flow analysis there is no significant difference, so we omit this peculiarity from further consideration.

This formulation separates four types of system components that functionally significantly differ in relation to the flow in question:

- the flow itself, as the subject of the transformation,
- the source of the flow,
- the channel for holding/limiting/directing the flow,
- the consumer – a component that is directly affected by the flow by changing at least one of its parameters.

In terms of "subject – function – object", the channel transforms the flow, the flow transforms the product. An essential detail is that a minimum FM consists of a flow element and a channel. Source and consumer may not be included in the FM.

The complexity of the model (introducing new additional elements) only seems to exist. The explicit introduction of a component which was previously implied by default

- simplifies the analysis of the model,
- reveals a direct, unmediated link between the flow model and the functional model, and also between the flow model and ZRTS.

In particular:

- In the flow model it is possible to operate with other components of the system (source, channel, consumer).
- In the functional model, in addition to the components appear all of the flows in question.
- The four system components (source, flow, channel and product) can be explicitly aligned, the components are specified by which the manageability of the flow (source and channel) can grow, etc.

In the proposed formulations also the pairs of trends are mentioned quite clearly:

- Improving the efficiency of the use of useful flows **by the consumer**.
- Reducing the damaging power of harmful flows in relation to **other elements of the TS**.

BUT:

- Increase the conductivity of **channels** of useful flows.
- Reduce the conductivity of **channels** of harmful flows.

In this formulation, trends become much clearer. Thus:

- the incompleteness of the current wording of the law becomes apparent,
- the second pair of trends is still highly objectionable.

Simple examples:

- The useful flow of fuel in an internal combustion engine (ICE). If the conductivity of this flow channel is increased, additional fuel flows into the combustion chambers which will result in incomplete combustion, which in turn will lead to a number of serious problems.
- Useful flow of hot water or steam in the heat exchanger. Increasing the conductivity of this channel heat will be removed from the system, although we need the opposite.
- The harmful Joule heat flux from the passage of electric current through an electronic circuit when the conductivity of this flow channel is reduced will additionally heat up the board, although again the opposite is required.
- If the conductivity of the conductor in the useful flow of electric current in a light bulb is increased, it will result in a change in its rating and beyond a certain limit the lamp simply burns out.
- If the conductivity of the useful flow of a semi-finished product to some kind of actuator (to the consumer of the flow) rises above a certain limit, the consumer will become overstocked and/or a store as buffer has to be introduced.

Of course, there are different ways to paraphrase this. A typical way to overcome these ambiguities in a flow or ZRTS analysis is to say "in this case there is a different sub-trend ...". However, **these kinds of clauses (and even the need for them itself) drastically reduce the instrumentality of the method**.

Of course, increasing the conductivity of the flow channel is often very useful. The techniques for such an increase are detailed in the current version of the law and remain true and certainly useful. The same goes for cases where the channel conductivity is reduced.

The proposed refinements to the concepts, while seemingly simple, make it possible to significantly improve the effectiveness of flow analysis.

An Algorithm to Conduct the Analysis

The following logic is proposed for conducting a flow analysis.

1. Build a flow model using the existing prototypical methodology.
2. Identify the flow deficiencies as recommended.
3. Clarify the identified deficiencies, identify their type:
   - Inadequate parameters and functions of the flow
     - Inadequate and harmful flow functions
     - Excessive expenses for the functioning of the flow
   - Inadequate parameters and functions of the channel
     - Inadequate and harmful channel functions
     - Excessive expensesfor the formation and functioning of the channel
4. ONLY for the identified problematic areas of the flow we construct refined flow models, in which we explicitly separate the flow itself and the channel.
5. Based on step 4, we construct a functional model for the components associated with the problematic flow and conduct a standard FA. (As a matter of fact, this is a standard and widely used technique by practitioners: to build a detailed FM at a deeper system-level for the problematic part of the system identified by the model at the higher level.)
6. To eliminate the deficiencies identified in the construction of the FM according to point 5 use the recommendations of the law to improve the efficiency of matter, energy and information flows. In doing so, it is convenient to make use of the classification of flows and of trends which are characteristic for different types of flows. An attempt at such classification and trends is given in [8].

Conclusions

Suggested approach:

- It is not a direct combination of the two methodologically quite different tools. Essentially, the proposed approach allows for the application of well-established and repeatedly proven techniques and methods of functional ANALYSIS to a convenient and illustrative flow-based MODEL.
- It is easy to apply and can be quickly mastered by practitioners being familiar with either FA or flow analysis. The approach can be applied by specialists, familiar with different variants of both FM and flow models. It is no secret that real-world models are constructed a little differently by each professional. Therefore, a rigidly prescribed algorithm may not be suitable for many practitioners.

Of course, it would be tempting to fully merge the two models, as was done, for example, in [1]. But at the output we get a very cumbersome model, overloaded with both information and graphic elements. The proposed approach allows, in our view, to obtain sufficiently weighty results with not too much effort.

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