The methodological basis and the technique for objectifying logical results of systems analysis in production sphere

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Abstract. Significant weight of subjective models used in the systems analysis is discussed. It reduces degree of correctness (coherence and completeness) of planning and managerial decisions as results of the systems analysis in the production sphere and causes costs of production in the decisions realization. That is why a methodological basis for decision-makers objectifying the systems analysis results is so urgent. It is based on the original system-goal approach, logical and linguistic models of goals, semantic model of structure of goals and semiotic model of reasoning about goals. Three main tasks for objectifying the results of systems analysis are set. Schemes, the main procedures, instructions and examples for the task solution are given.

1. Introduction

More than half of the century has passed since the first publications ([1], [2]) about systems analysis (SA) and this methodology was used for collaborative planning and managerial decision-making in problem situations. A key method of systems analysis is the development of a specific structure of goals (a goal tree) by experts and decision makers. Taking into account that goals are a logical basis for synthesis of a system [3], this structure of goals (SG) contributes to substantiation of decisions on the system of goals achieving (SGA). It contributes but does not provide to substantiation, due to a subjectivity of goals, their structure as well as rules that experts and decision makers use for creating SG. In the methodological terms, this subjectivity, to a certain extent, is due to polysemy of concepts ‘problem’ and ‘goal’ as well as uncertainty of SG-properties and rules for analyzing and structuring goals. In the technological terms, it is due to uncertainty of goal-wordings, professional and mental heterogeneity of experts and decision makers. These and other factors lead to incorrectness of SGs revealed during goals achieving.

The first man-machine realization of systems analysis that reduced the level of SG-incorrectness was named as PATTERN (Planning Assistance Through Technical Evaluation from Relevance Number) [4]. In order to provide SG-correctness, PATTERN prescribes to experts working out a normative forecast (the scenario of development of the analysis object) and a forecast of development of science and technology. After the SG-elaboration, experts estimate importance and mutual usefulness of the goals as well as the ‘state-period’ of their achieving. Further, a computer processes the estimates obtained, and experts carry out the final specification of the SG. Unfortunately, this and most other (reviewed in [4]) techniques and SA-means (e. g. [5–10]) used to improve quality of SGs, have no means for revealing subjective incorrectness in SG and SGA [11]. To solve this problem, the system-goal approach and original semiotic methods for objectifying the logical component of systems
analysis in production sphere were outlined in [12, 13] and defined in [14–17]. Using these means allows us to expand systems analysis methodology and develop a corresponding technique for objectifying logical results of systems analysis.

The paper is devoted to the methodological basis and the reliable technique, which provide objectifying the systems analysis logical component and results obtained from using it by experts and decision makers.

2. Three tasks of systems analysis
In [13], an approach to objectifying the logical component of SA and its results is refined, and the following stages in a process of decision making in a problem situation are identified:

- analysis, setting and structuring goals to elaborate a SG;
- analysis–synthesis functions, components and structures of a SGA to achieve goals of the SG.

Taking into account, that in production sphere the goals (subjective in their nature) are usually ‘negation’ of the corresponding problems (objective in their nature), a stage of problem analysis added for ‘initial’ objectifying the goals in the following SA-scheme:

analysis of problems and elaboration of a structure of the problems (a SP) → analysis of goals and elaboration of a SG agreed with the SP → analysis–synthesis of a SGA agreed with the SG.

The concept of SG- and SGA-analysis–synthesis objectifying is based, on the one hand, on subjective models of goal analysis and rules for a SG -development and, on the other hand, on the original objective semiotic models of goals, a SG, reasoning about goals and well-known mathematical models of decision-making [4].

2.1. Formulations of the systems analysis tasks and schemes for objectifying results of their solving
The first task. Analysis of problems and elaboration of a correct SP. Given: a problem situation in a production sphere. Required: to elaborate a logically correct and complete SP corresponding to the situation.

For this task solving, the following scheme is proposed:

scrutiny of a problem situation, identification and preliminary analysis of problems →
→ working out a catalog of the problems and determination of causative links between them →
→ elaboration of a causative structure of the problems and definition of the main problem →
→ analysis of the main problem and elaboration of a SP.

The procedures for this scheme realizing are considered in [19, 20].

The second task. Analysis of goals and elaboration of a correct SG agreed with the SP. Given: the SP. Required: to elaborate a logically correct and complete SG to solve the problems and thereby eliminate the problem situation.

For this task solving, the following schemes are proposed:

(a) elaboration of a SG based on the SP.

According to this scheme, a structure of goals that is isomorphic to the structure of problems that has been elaborated at the previous stage of systems analysis, and the goals of the SG which are the results of wordings (by a method of the corresponding problems ‘negation’), are defined. The method is suitable if wordings of the problems clearly express shortcomings in the sector of production sphere;

(b) determination of the main goal → elaboration of a SG, starting with the main goal.

According to this scheme, the main goal determined by ‘negation’ of the main problem in the SP;

(c) goal setting and preliminary analysis of goals →
→ elaboration of a catalog of the goals and determination of causative links between the goals →
→ elaboration of a causative structure of the goals → analysis of the causative structure of the goals and definition of the main goal → analysis of the main goal and elaboration of a SG.
Using of the most detailed scheme, similar to the scheme for elaboration of a SP, is advisable in the case of a large uncertainty of the problem situation and problems.

The procedures for these schemes realizing are considered in [13, 19].

**The third task.** Analysis–synthesis of a SGA agreed with the SG. Given: the SG. Required: to define and group together the SGA-functions, to determine the SGA-components corresponding to the SGA-functions (Fig. 1) and, according to the well-known methods [4], organizational structure of the SGA.

| A goal wording | The function(s) in the goal wording | The SGA functional group | The SGA functional component | The SGA structure |
|----------------|------------------------------------|--------------------------|-----------------------------|------------------|
| 1              | 2                                  | 3                        | 4                           | 5                |

**Fig. 1.** The heading of the table ‘The SGA goals, functional components, structure’

The procedures for the task solving are considered in [13, 20, 21].

Indicators and criteria estimating correct solving of these tasks of systems analysis and correctness of their results are proposed in [15].

3. **The methodological basis for objectifying results of the systems analysis tasks solving**

The original means for objectifying the solution of the tasks of logical systems analysis are proposed in [13–18]. They are: linguistic and logical means for a goal description, graph-semantic models of the production sphere thesaurus, SG, the semiotic system of reasoning about goals.

3.1. **Linguistic and logical means for a goal description**

Goal wordings in the Russian language are usually represented by two types of infinitive sentences (Inf):

- simple Inf (e.g.: ‘to develop fish processing machinery’);
- expanded Inf (e.g.: ‘to develop machinery and technologies for production of products from fish’).

In accordance with the law of goal setting and achieving [13], the original two-level linguistic model of a goal formulation is realized on the first level as the specific seven-phrase role frame ‘means-result’

\[
\text{\langle \langle actor (S1) > \langle technology-1 (A1) > \langle technics (S2) > \langle object-1 (S3) > \rangle} \\
\text{\langle technology-2 (A2) > \langle place (O1) > \langle object-2 (O0) > \rangle,}
\]

in which the roles (italic font) are represented in the nominative scale.

For example, the linguistic model of the goal wording ‘to develop machinery and technologies for production of products from fish’ looks as

\[
\text{\langle \langle technics to develop machinery > \langle object-1 fish > \langle technology-2 to develop technologies >} \\
\text{\langle object-2 products >.}
\]

A more compact corresponding model looks as

\[
\text{\langle \langle S2 to develop machinery > \langle S3 fish > \langle A2 to develop technologies > \langle O0 products >.}
\]

Every role of the frame ‘means-result’ is replaced by a relevant basic or derivative object. Unlike the basic object, the derivative one is detailed by a phenotype (the second level of the linguistic model). In general case, the phenotype is realized by four kinds of properties (P): functional (FP), nominal (NP), characteristic (CP) and physical (PP). Here is an example:

\[
\text{\langle \langle G S2 machinery PP stage . development > \langle S3 fish >} \\
\text{\langle G A2 technologies PP stage . development > \langle O0 products >.}
\]

where the role phrases represent properly goal marked by the sign ‘G’.

Thus, two-level structure of a goal wording obtained by the macro-writer (the role frame ‘means-result’) in which every role may be replaced by basic object (BE) or derivative one detailed by the micro-writer (the phenotype), in which every kind of properties may be replaced by basic properties (BS)). Besides, the role phrase in the frame ‘means-result’ may be a context of goal.
The two-level linguistic model is realized in the language of a goal \( L \) [13, 16]. \( L \) is specified by the two-level regular context-free grammar supplemented by the rules of inter- and intra-phrasal semantic context of a goal-wording [17].

A logical description of a goal is an implicative formula obtained by the certain transformation of the corresponding \( L \)-description of a goal.

3.2. Graph-semantic notions of the thesaurus and structure of goals
A semantic graph as a model \( M \) of the subject field (production sphere) thesaurus defines the basic semantic relations between the basic objects and basic properties that support SG correct elaboration. The other semantic graph as a SG model supports correct presentation of the structure of goals (unlike formal relations in a graph, the semantic relations in a semantic graph are supplemented by their own names, such as ‘whole-part’, ‘genus-species’, etc.) [13].

As a condition for deducibility of the subgoal \( c_{\beta i} \) (i = 1(1)\( l \), where \( l \) is the number of subgoals of the bush of the semantic graph of goals) from the goal \( c_\alpha \) (the ‘root’ of the bush of this graph), semantic relations of direct subordination are defined. The logical correctness of the bush of semantic graph on height is compared with the indicated deducibility.

As a condition for deducibility of the subgoal \( c_{\beta i} \) (i = 2(1)\( l \), from the subgoal \( c_{\beta 1} \), the correct semantic correlation between \( c_{\beta 1} \) and \( c_{\beta i} \) must be revealed. The indicated deducibility is associated with the logical correctness of the semantic graph of goals on the width.

To deduce a complete set of subgoals, the semantic relation of the completeness of the bush of the semantic graph of goals is determined. Justification of the completeness of the bunch of goals is carried out in accordance with thesaurus knowledge about the subject field. The completeness of the semantic graph of goals is determined by the completeness of all its bushes.

3.3. The semiotic system of reasoning about goals
The reasoning about goals is realized by the semiotic system (model) \( S \), which is given by eight components, the first four of which determine its formal subsystem \( F \), and the next four – the mechanism of changing \( F \) in the process of functioning \( S \) [13]:

\[
S = < T, B, A, P, \Psi_T, \Psi_B, \Psi_A, \Psi_P >
\]

Definition of BEs with their roles, BSs with their types and such relations between them as ‘whole-parts’, ‘genus-species’, etc., and their representation in a thesaurus-type model provide openness and easy customization for a specific sector of the production sphere.

The set of constant axioms of the system \( S \) includes the axioms of propositional logic, the axioms of the logical theory of change, partial causation, and absolute evaluations.

The set of the variable axioms of the system \( S \) is given by schemes expressing the patterns of goal analysis and assignment, which become axioms when only such names of semantic relations are substituted into them, the indices of which form sets that are compatible and fixed in the subject area, determined by the \( M \).

The current formal subsystem \( F_i \) of the system \( S \) carries out the sequential inference (denoted by \( \Rightarrow \)) from the goal \( c_\alpha \), subgoals \( c_{\beta 1}, c_{\beta 2}, \ldots, c_{\beta n} \), defined by experts and decision makers. Inference realized in two (for the current bush of the semantic graph of goals being formed) directions – in depth and width:

\[
c_\alpha \Rightarrow c_{\beta 1} ; c_\alpha \Rightarrow c_{\beta 2} ; c_{\beta 1} \Rightarrow c_{\beta 2} ; \ldots ; c_\alpha \Rightarrow c_{\beta n} ; c_{\beta 1} \Rightarrow c_{\beta n} ; \ldots ; c_\alpha \Rightarrow c_{\beta n} ; c_{\beta 1} \Rightarrow c_{\beta n} ; \ldots ; c_\alpha \Rightarrow c_{\beta n} ; c_{\beta 1} \Rightarrow c_{\beta n} ; \ldots
\]

where \( i = 1(1)\( m \), \( m \) – the number of subgoals of the ‘root’ goal \( c_\alpha \) of the current bush;

\( w \) – the number of conclusions, determined by the number of subgoals, the content of which satisfies the semantic completeness of the formed bush of goals, \( w = 2m \);

\( C \) – the set of added goals inferred by \( F_i \) to provide the bush completeness (with the exception case when \( C \) is empty).
4. Elements of the technique for objectifying results of systems analysis in production sphere

Consider the main elements of the technique to solve the logical tasks of systems analysis and examples of using them in one of important sector of the production sphere.

4.1. Instructions for goals L-description

Instructions applied are the following:

1) highlight judgment in the goal-wording. In accordance with the macro-writer of $L$, compose a goal description from $n$ role phrases (nominative sentences), $n \geq 1$. Do not use in the nominative sentences: conjunctions and prepositions listed in Table 1; pronouns, adjectives and participles in the subjective function; adverbs, particles, interjections; elliptical structures; abbreviations other than those specified in the list. Fragments of goal wordings prohibited in the $L$ should be replaced with their semantic equivalents made up of permitted parts of speech;

2) mark by means ‘G’ a role phrase describing a proper goal in a $L$-description of a goal;

3) arrange an inter-phrase ordering in accordance with the micro-writer of a $L$.

Table 1. Rules for converting a goal formulation into a goal description in $L$

| Goal wording | Goal description in $L$ |
|--------------|-------------------------|
| CONJUNCTIONS: connecting and contrasting (AND; AND … AND; ALSO; AS … AS): | |
| between role phrases | Do not include, as they express the attitude of role phrases ‘means’ composition |
| between properties (in a phrase) | Do not include, as they express the relation of properties composition in a role phrase |
| between infinitives (in a phrase) | When indicating at the stage of the life cycle of an object, add the corresponding name and value of PP-property to the role phrase |
| targetable (between phrases): TO; SO AS TO; FOR, etc. | Usually, they point to the role phrase ‘a final object’; in case of an indirect result, delete this phrase |
| PREPOSITIONS (in a phrase): OF | Typically refers to the role phrase ‘an initial object’ |

4.2. Some examples of corresponding linguistic and logical descriptions of goals

Let we have the goal with wording ‘To create an automated equipment and develop a technology for producing products from fish’ (designate it as $\alpha$), which directly subordinates a goal ‘To develop automated equipment for producing products preserved ‘Trout in oil’ (designate it as $\beta$) and a goal ‘To create an automated equipment preserving products from zander’ (designate it as $\gamma$). $L$-description of $\alpha, \beta, \gamma$ we correspondingly designate as $\alpha', \beta', \gamma'$:

$\alpha' = \langle < G S2 equipment CP automated > < S3 fish > < G A2 technology > < O0 products PP stage of life cycle . produced > >,$

$\beta' = \langle < G S2 equipment CP automated PP stage of life cycle . development > < O0 products CP1 preserved NP ‘Trout in oil’ PP stage of life cycle . produced > >,$

$\gamma' = \langle < G S2 equipment CP automated FP preserving PP stage of life cycle . development > < S3 zander > < O0 products CP1 canned PP stage of life cycle . produced > >$,

where $S2, S3, A2$ and $O0$ are codes of the roles in the frame ‘means-result’ (codes $S2, S3, A2$ signify the kinds of means in the production sphere, accordingly: $technics, object-1$ (an initial object), $technology-2$ (a production technology); code $O0$ signifies $object-1$ (a result of processing operation, namely its final object).

Designate logical descriptions corresponding to linguistic descriptions $\alpha', \beta', \gamma'$ as $\alpha'', \beta'', \gamma''$:

$\alpha'' = Gf_{a3} \land f_{a4} \land Gf_{a5} \supset f_{a7} ,$

$\beta'' = Gf_{b3} \supset f_{b7} ,$

$\gamma'' = Gf_{g3} \supset f_{g7} ,$
\[ \gamma'' = G f_3 \land f_4 \supset f_7 \]

where \( f_\omega \) (\( i=3, 4, 5, 7 \)), \( f_\eta \) (\( j=3, 7 \)), \( f_\kappa \) (\( k=3, 4, 7 \)) – \( i, j \) and \( k \) are the numeric codes of the names of the role phrases of the frame ‘means–result’, codes 3 (\( S2 \)), 4 (\( S3 \)) and 5 (\( A2 \)) designate the names of means, code 7 designates the result in the corresponding L-descriptions of \( \alpha', \beta', \gamma' \).

4.3. *The simplified example of results of analysis-synthesis of SGA*

Two particular results of analysis-synthesis of the SGA are shown in Table 2.

| L-description of a goal | FP and CP1 properties in L-description of a goal | SGA functional group | SGA component |
|------------------------|-----------------------------------------------|---------------------|---------------|
| \( (\alpha') < < G S2 equipment CP automated > \) < S3 fish > < G A2 technology > < O0 products CP1 produced > > | CPI produced | Producing fish products | Fish processing plant |
| \( (\beta') < < G S2 equipment CP automated PP stage of life cycle . development > \) < O0 products CP1 preserved \( NP \) ‘Trout in oil’ PP stage of life cycle . produced > > | CPI preserved \( NP \) ‘Trout in oil’\( \Rightarrow \) \( S3 \) trout | Preserving fish | Fish canning (preserving) workshop |
| \( (\gamma') < < G 3 equipment CP automated FP preserving PP stage of life cycle . development > \) < S3 zander > < O0 products CP1 canned PP stage of life cycle . produced > > | FP preserving CP1 canned \( S3 \) zander | | |

Logical-linguistic analysis of the bush of the goals \( \alpha, \beta, \gamma \) (more exactly, their logical \( \alpha'', \beta'', \gamma'' \) and linguistic \( \alpha', \beta', \gamma' \) descriptions), using possible, in the subject field, basic strategies (Fig. 2) (‘whole–parts’ of goal phrases on the macro-writer level of the L-descriptions; ‘genus–species’ of phrases ‘technique’, ‘object-2’ and their basic objects on the micro-writer level of the L-descriptions) proves correctness of this bush of SG.

![Fig. 2. Basic strategies of analysis-and-synthesis of goals](image-url)
5. Conclusion
Due to the use of the technique proposed for objectifying the logical component of systems analysis in the production sphere, experts and decision makers solve the assigned logical tasks more successfully [22–24]. The results of the proposed methodological basis and the appropriate techniques used in a number of sectors of the production sphere show that their application in the systems analysis of problem situations significantly (up to 10%) reduced non-production costs in this sphere.

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