Methodological approach to digitalization of management processes in automobile and road complex

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Abstract. In order to successfully accomplish the tasks of digitalizing control processes in the road complex integrated into a focused process, new generations of control systems — intelligent control systems (ICS) [1]. In the future, ICS should be able to independently develop a goal, implement the decision-making process for an action, provide the necessary set of functions to achieve a goal, predict the values of system indicators as a result of actions and compare them with real data, providing feedback in the system and adjusting the control procedure [2]. However, ICS that implement the abovementioned functions are complex software systems designed for automatic decision-making in the operational management of complex systems and processes. It should be noted

1. Introduction
To successfully accomplish the tasks of digitalizing control processes in the road complex integrated into a focused process, new generations of control systems are actively developing today — intelligent control systems (ICS) [1]. In the future, ICS should be able to independently develop a goal, implement the decision-making process for an action, provide the necessary set of functions to achieve the goal, predict the values of system indicators as a result of actions and compare them with real data, providing feedback in the system and adjusting the control procedure [2]. However, ICS that implement the abovementioned functions are complex software systems designed for automatic decision-making in the operational management of complex systems and processes. It should be noted
that full-fledged ICS for automatic control are still under development. However, the implementation of individual functions of the ICS in the form of systems that allow us to evaluate and implement actions in changing environmental conditions is possible in the form of dynamic control systems (DCS). The DCS is a tool that allows for given initial data on the state of the system and changes in informational environmental conditions that are random in nature, to compare the parameters of the possible and real results of the action, to develop optimal solutions that help achieve the goal of the control system. To do this, the necessary database and the mathematical apparatus for solving the tasks should be formed in the DCS. The functions of the DCS are also the assessment of the results of solving the problem, the formation of the parameters of the possible result of the system, the adoption of the control decision, process modeling to evaluate the solution of the problem [3].

2. Problem Statement
Depending on the goal that the DCS faces, the knowledge base, algorithms for solving a problem, making a decision, developing a control may have a different idea, which, in turn, depends on the nature of solving problems. Accordingly, it is possible to form various types of DCS, depending on the approximation of their functionality to the ICS. The general structure of the DCS with the use of simulation methods for obtaining solutions (DCS of the first type) is shown in Figure 1. The model of this structure assumes that the actual data accurately reflect the described processes, only in this case a reliable solution to a problem can be obtained in accordance with the statement and specification.

![Figure 1. The structure of DCS of the first type](image-url)

Based on the generated control algorithm transmitted to the database, a control action is generated. Before this action arrives at the control object, its effectiveness and consistency can be assessed using various methods used depending on the degree of uncertainty of information situations in the
environment being studied. For ICS tasks, this is the most difficult case – the uncertain state of the research environment [4, 5].

As a rule, in this case it is possible to resort to the use of expert models based on the knowledge of experts – specialists in this problem area, or methods of decision-making theory. What is one of the main problems in the design of DCS of a higher level of approximation to the ICS (second type) is that the task of choosing the necessary apparatus for describing decision-making processes and building on its basis a decision-making model that is adequate to the state of uncertainty in the environment becomes important. It is possible to use the combined DCS of the first and second type, where the knowledge base combines the description in the form of rigorous mathematical formulas with expert information, as well as the mathematical methods of finding a solution with non-strict heuristic methods [6]. But when developing a DCS of this type, the following problems may arise:

- The determination of the knowledge base structure and the principles of its formation.
- The need to develop new and adequate use of well-known theories and methods to describe processes in the system.
- The need to develop ways to formalize and organize the process of implementing decisions.
- The need to develop algorithms and software.

It is important to note that a DCS must have the property of adapting to dynamic changes in the environment of a process under study, the ability to introduce new elements and relationships into the description of situations, change the rules and strategies for the operation of objects in the decision-making process and develop control, work with incomplete, fuzzy and contradictory information etc. [7].

3. Materials and Methods

All known decision-making methods imply an iterative application of synthesis, analysis and estimation procedures [8]:

- Synthesis includes the formation of a certain set of requirements described in the language of functioning. The synthesis is most effective while using both ascending and descending actions, and the results of applied research and the possibility of using known technologies are taken into account.

- Analysis of system solutions includes calculating and predicting the value of parameters depending on technical or informational characteristics. In all cases, information on physical processes and phenomena, technical information as well as economic information stored in databases is used. System analysis and operations research are necessary steps towards evaluating system design options, but the required adaptation of appropriate models and methods to the characteristics of the subject area is required. In general, the use of analysis is a necessary but not a sufficient component of the decision-making procedure on the choice of a project version of a system.

- Evaluation implies that each solution option (or alternative) is evaluated in comparison with other options, and also checked for compliance with the requirements of interested parties. Evaluation of each of the options is carried out after receiving information about its characteristics. Characteristic data not related to design decisions are external factors that are used in relation to all options to be evaluated. Each option is subjected to a final assessment with the selected optimal indicators, after which a final decision is made.

The iterative use of the synthesis – analysis – evaluation triad is a fundamentally important feature of decision-making methods. The application of one method or another begins with the recognition of the needs of interested parties and the determination of their requirements, which are then transformed according to certain rules to obtain an initial description of system solutions. In the future, the description of the system is refined and detailed; moreover, at lower levels of the system hierarchy, the system engineering process is already used recursively, which allows achieving a high level of concretization in the description of the system. Using the method “synthesis – analysis – evaluation” allows us to describe and build a system, providing a gradual reverse transition from the level of detailed description of the components to the general structure of the system under study.
The decision-making process consists of a number of stages (steps). At the initial stage, it is necessary to identify a problem, a problem situation or determine the subject area in which decision-making is required. The term "decision" has many semantic meanings. These may be actions to solve problems, leading to some kind of result, the consequences of which must be assessed. Under a solution we can also understand some objects or systems requiring evaluation. A solution is also different options, alternatives, opportunities regarding actions and objects. The solution is also called the process of finding the best option in a sense, and this option itself.

At the next stage, it is necessary to substantively describe the subject area, to identify the goals of decision-making and also the limitations. Next, we need to collect and analyze detailed information about the subject area. In some cases, it is necessary to build a model, determine the range of alternatives (options) of decisions, perform decision generation and formulate a decision-making problem.

At the next stage, decisions are made based on the selected (developed) methods. Evaluation of solution options, their comparison, classification, ranking and selection of the most preferred one are carried out. And finally, the final phase is related to the implementation of the decision and the assessment of its consequences.

In decision theory, subjects are identified that affect the different stages of decision making. First of all, this is the decision maker (DM), that person or group of people who makes the final choice. The owner of the problem, an expert as well as a decision consultant can be highlighted.

The properties of the subject area, the conditions for the functioning of decision support systems can be different. Depending on the completeness and initial data, decision-making problems can be well-structured, weakly structured, and unstructured. For well-structured tasks, data are formulated in quantitative form, for weakly structured tasks, they contain quantitative descriptions with the dominance of qualitative and uncertain factors, for unstructured tasks, data are presented in the form of a qualitative description of the initial factors and the interdependencies between them. The choice of decisions can be made in conditions of certainty, risk or uncertainty.

Under certainty, the initial data and consequences of each alternative solution are known.

Risk conditions occur if the probabilities of alternatives to solutions are known or the law of the distribution of their probabilities is known. Then the task is reduced to the choice of statistical solutions. In turn, risk conditions can be defined as stochastic uncertainty conditions generated by random factors that, when they appear massively, have the property of statistical stability and are described by some kind of probability distribution law [9].

Uncertainty conditions under which the probability distribution law for uncertain factors is unknown are defined as conditions of statistical uncertainty. In turn, conditions of statistical uncertainty are divided into two types: first, with known distribution parameters (mathematical expectation, variance, and other characteristics of a random variable); secondly, with unknown distribution parameters.

If uncertain factors are nonrandom, do not have statistical stability, and are not described by any law of probability distribution, then it is impossible to obtain reliable information about these uncertain factors. And the probability of decisions related to the impact of these factors cannot be determined. In this case, we speak of conditions of non-stochastic uncertainty.

The following reasons for the occurrence of non-stochastic uncertainty in the choice of solutions should be highlighted:

- incompleteness and insufficiency of information about all factors of the problem of decision-making;
- fuzziness, ambiguity or inconsistency of allocation and description of the factors of decision-making problems.

In addition, the number of factors, variables, signs, indicators and criteria that determine the subject area can vary significantly. Информация об этих факторах может быть полной или частичной. Information on these factors may be complete or partial. Factors can be independent of each other or dependent. The dependence may be consistent or inconsistent. Indicators can be quantitative or qualitative, evaluated on different scales.
Decisive for the choice of solutions are models for evaluating indicators and choosing alternatives for these solutions. The structures of the models for evaluating and choosing decisions can be different, they might differ in “connectedness” between factors, and hierarchical assessment. The structure of a model is largely determined by the goals of choice and the criterion of the efficiency of decisions. There are various languages for describing selection problems in the form of: quality criteria, selection functions, binary relations, axiom systems [10].

It is advisable to use the language of binary relations or systems of axioms if the choice of solutions cannot be made unambiguously and is represented by vectors of criteria and restrictions, depends on the system of preferences of the decision maker, as well as on the conditions and relevant information that he possesses [11].

The most widely used languages for describing selection problems are the languages of quality criteria (efficiency) and selection functions. These description languages are focused on the fact that the initial set of decision alternatives is uniquely defined. And for making decisions, criteria for the effectiveness of decisions or a set of rules are used.

Under the conditions of one or a small number of criteria, complete certainty of the subject area, the methods of decision theory are well developed.

However, in conditions of a large number of incompletely defined, both qualitative and quantitative, interacting indicators that determine the subject area and also the complexity of objects that require an assessment to make decisions, classical methods and models of decision theory are often not applicable.

In such conditions, the construction of a domain model and the development of methods for evaluating complex multi-criteria objects, which can greatly facilitate the subsequent choice of an option, are of great importance.

4. Discussion of Results
   The main tasks of evaluating and choosing alternatives to solutions include the following:
   • evaluation of alternative solutions;
   • comparative assessment and ranking of many decision alternatives;
   • definition of strategies for evaluating decision alternatives;
   • determination of the values of particular indicators of decisions by given values of a generalized indicator;
   • search for the values of particular indicators that provide the required values of the generalized indicator;
   • search for the best solutions (values of particular indicators) providing the required values of a generalized indicator.

   Single- and multi-criteria methods for evaluating and choosing alternatives to solutions can be distinguished [12, 13]. In the single-criterion case, the following are considered known:
   • many alternatives to solutions (objects, options) – \( a_j, j = 1 \ldots m \);
   • assessment of alternatives according to the selected criterion (indicator) – \( p(a_j) \);
   • rule for choosing the best option:
     \[
     \max_j(p(a_j)) \text{ or } \min_j((a_j)).
     \]

   In the process of solving the problem of choosing the best option, an alternative \( a^* \) is determined, for which:
   \[
   p(a^*) = \max_j(p(a_j)) \text{ or } p(a^*) = \min_j((a_j)).
   \]

   Another case of the selection problem is the ranking of solution options in accordance with a variety of alternative estimates. More significant for practical use is the case of evaluating and
choosing alternatives according to many criteria. In the multi-criteria case, each variant \( a_j \) can be associated with a vector of the form:

\[ \{ p_1(a_j), p_2(a_j), \ldots, p_n(a_j) \}, \]

representing option estimates by criteria (indicators): \( p_1, p_2, \ldots, p_n \).

Further, approaches to comparing and choosing solutions can be divided into two large groups: reduction and not reduction of many criteria to one [14].

Methods based on non-reduction of multicriteria assessment problems and choice of solution options to one criterion, set as their task comparison of options based on assessment vectors for all criteria. Among the important factors taken into account when solving this problem, one can indicate the weight (importance) of the criteria, as well as information on the preferences of the decision-maker. Often these methods are used in another setting: the search for optimal solutions on a set of parameters that determine the decision-making conditions [15].

Among the methods of this group the following can be identified:

- method of dominance;
- method based on global criteria;
- lexicographical ordering;
- methods of mathematical programming;
- threshold methods;
- methods of the theory of multisets etc.

As a rule, the application of these methods is due to the independence of the criteria and their full certainty.

In the case of using methods based on the reduction of multi-criteria assessment problems and the choice of solutions to one criterion, the choice problem is solved on the basis of constructing an integral (generalized) criterion. For this, various methods of aggregation, “convolution” of indicators are used, i.e. the construction of various general indicators, primarily additive and multiplicative.

An additive generalizing criterion (indicator) is obtained as a weighted sum of estimates by particular criteria (indicators):

\[ p_{\text{add}}(a_j) = \sum_{i=1}^{n} w_i \cdot p_i(a_j), \quad j = 1, \ldots, m, \]

where \( p_i(a_j) \) is the assessment of the alternative \( a_j \) by the criterion \( p_i \), \( w_i \) is the weight (importance) of the criterion \( p_i \).

The multiplicative criterion is defined as:

\[ p(a_j) = \prod_{i=1}^{n} p_i(a_j)^{w_i}, \quad j = 1, \ldots, m. \]

However, the above expressions do not always adequately reflect the characteristics of the tasks of assessment and choice, in particular, the interdependence, inconsistency of individual indicators.

The approach based on the convolution of many criteria into one is used in many methods of decision theory, among which the following can be distinguished:

- methods based on the theory of value, utility;
- methods of analysis of hierarchies;
- nonlinear convolution methods;
- methods of the theory of fuzzy sets [15].

The approach to multi-criteria assessment of complex objects, based on the reduction of many criteria to one, is attractive in that it reduces the complexity of such decision theory procedures as
comparison, ranking, classification and choice of options (alternatives). At the same time, the demand for the search for effective assessment methods that reflect the characteristics of the subject area and the preferences of a decision maker or the knowledge of an expert increases significantly.

An analysis of existing methods allows us to conclude that they do not fully reflect the features of the subject area, which are the uncertainty as well as the strongly interacting different-quality indicators and also the complexity of the objects being evaluated.

5. Conclusion
In contrast to the first type of DCS designed to find the optimal solution and based on rigorous mathematical methods and optimization models, the second type DCS is mainly focused on solving difficult formalized problems in the absence of complete and reliable information (Figure 2).

![Figure 2. The structure of DCS of the second type](image)

A DCS of the second type is designed to search for the optimal solution based on rigorous mathematical methods and optimization models (lack of reliable information). Naturally, one of the main problems in the development of a second-type DCS is the choice of an analytical apparatus for the algorithmization of decision-making processes and the construction on its basis of a mathematical model that is adequate to the studied area (semantically correct). However, as a rule, the main developments are carried out in the context of a deterministic interpretation of a single-criterion model with its inherent consistent decision-making scheme. As a result, the obtained models often have a significant share of subjectivity in decision-making and are inadequate to real practical processes characterized by non-determinism in the development of the situation in the research environment.

When determining the second type of DCS, it is necessary to focus on the computational-logical model for obtaining solutions. In this case, the information base should combine the description of processes in the form of a strictly mathematical apparatus with the information of experts, that is, form parallel branches of the search for a solution with their further synthesis. Therefore, mathematical
methods for finding a solution are combined with non-strict heuristic methods, and the weight (significance) of one or another system action is determined taking into account further testing of the model in practice. When developing a second-type DCS, it is necessary to overcome a number of difficulties associated with the need to solve the following problems:

1) formation and updating of the database;
2) development of new and adaptation of known theories and methods for describing information processes in DCS;
3) development of formal ways of organizing the application of the developed DCS (methodological support for practical implementation);
4) development of algorithms and software with data processing and obtaining results in parallel processes for developing optimal solutions.

It can be stated that the second type of DCS cannot be fully attributed to the ICS, since it has all the disadvantages of hybrid systems. The above difficulties can be removed by integrating mathematical modeling methods into a set of effective plans into the DCS, which should allow to build algorithms that provide optimal solutions for the implementation of applied control problems having minimal information about the state of the research object.

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