Using artificial neural networks when integrating the requirements of standards for management systems in QMS

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Abstract. The article is devoted to the features of the formation and implementation of integrated management systems, as well as a description of the experimental study of the applicability of machine learning methods in the process of integrating standards for management systems.

Keywords: ANN, integration, artificial neural network, quality, machine learning, system, QMS, standard, requirements, management, experimental study, empirical model.

Introduction

Modern enterprises operate in a dynamic, rapidly growing environment. The success of their activities is largely determined by the ability to maintain a high level of functioning and developing quality management systems. The most priority direction of improvement is the formation and implementation of integrated systems, which is due to the widespread use of international standards for management systems and market requirements [1].

According to GOST R 55269-2012 “Organization Management Systems. Recommendations for building integrated management systems ”, organizations that implement more than one standard should identify the elements of the systems that it implements as general and, therefore, establish uniform implementation procedures for them [2]. The ISO 72 manual applies a classification that is the basis for general management system requirements, and each item is discussed in more detail. Many requirements established in the standards and technical conditions are common and can be practically included in one common management system. From this, it follows that reducing duplication of work, because of combining two or more systems, makes it possible to significantly reduce the overall volume of the management system and increase the system effectiveness. [3].
Figure 1. The integration scheme of the requirements of several standards for management systems

According to the figure, these systems can be integrated into the form most acceptable to the organization and the duplication of work can be reduced to a minimum, if the various requirements for the management system are systematized with consideration of the basic requirements in general. This provision applies to all management systems, regardless of whether they are the official standard for the management system or are less formal systems that are part of the overall enterprise management system [3].

Thus, the process of integrating the requirements of standards for management systems is accompanied by the solution of the classification problem regarding the compatibility of individual requirements of several standards, as well as the degree of compliance of these standards with each other.

As a rule, the process of integrating several management systems is laborious and time-consuming in most cases. Because it is necessary to study the requirements of several standards at once, to identify general and specific requirements, and to carry out a set of measures for organizing and implementing IMS. Besides, it is necessary to monitor the relevance of each standard within the functioning and further development of IMS, as well as to use methods and management tools that do not contradict the requirements of any standard. In the case of individual enterprises, this may be the reason for refusing to implement an integrated management system. As the main tool for classifying the degree of compatibility of individual standards and reducing labor costs, it is proposed to consider using machine-learning methods, namely, artificial neural networks (ANN) of direct propagation.

Using neural network programming allows achieving high accuracy of output parameters when solving tasks of classification and regression [4-5]. The basic principle of the work of ANN of direct propagation is to calculate weighting for the regressive dependence by iterative processing of the training sample.

An empirical mathematical model and plan for the experiment were developed to study the applicability of this approach. It is supposed to use the results of expert evaluation of the compatibility of selected standards as initial data. The implementation of the empirical model is a software package, the main purpose of which is to find the response hypersurface by solving a mathematical optimization task, as well as determining the specific configuration of ANN that provides the highest classification accuracy. The study of using a similar approach in the field of the calendar-network planning of R&D projects is given in the relevant publications [6-7].

Let us consider the experimental research plan in more detail.
Research

The first stage of the research is the most responsible and consists of the preparation of a training set (TS). This stage consists of the following steps:

1. Choosing standards and their items.
2. Formation of a table of expert assessment of the compatibility of the requirements of selected standards.
3. Defining the degree of compatibility of requirements by an expert method (performed for each pairwise combination of the requirements of all integrated standards).
4. Creating a reference book of words used in the paragraphs of the standards included in the training set.
5. Converting the data of the summary table of expert assessment to the format used in machine learning [12-14].

The following requirements are met when selecting standards and their items (step 1):

- TS should consist of items of standards that have a high learning ability:
  - Has to be items of different versions of the same standard.
  - Has to be standards relating to the various activities of the enterprise (various types of products).
  - Has to be standards with the crossed set of requirements.
  - TS should include both mutually exclusive and complementary requirements.

Data sampling should be determined on the basis of expanding the reference book of words used in the wording of the requirements of the standards included in it. It is assumed that compliance with this principle expands the limits of applicability of the trained neural network to a larger set of standards and, as a result, the activities of the organization [15-18].

All possible pairwise combinations of requirements of the selected standards are written into the table as rows when preparing the table of expert assessment (steps 2 and 3), so that the total number of rows is equal to the square of the sum of all the selected requirements. After that, the compatibility assessment of a specific combination of requirements of standards is defined for each row of the table by the expert method. The maximum score is indicated for lines that represent the repeated combination of the requirement “with itself”. The scale of acceptable values of the estimates has to be chosen in advance from the set of real numbers.

The completed table of expert assessment is as follows:

| Standard name | Item | Score | Item | Standard name |
|---------------|------|-------|------|---------------|
| ISO 9001:2015 | 8.5.6 Control of changes | +1 | 8.5.1 Change management | ISO/IEC 20000-1:2018 |
| ISO 45001:2018 | 10.2 Incident, nonconformity and corrective action | +7 | 10.2 Nonconformity and corrective action | ISO 14001:2015 |
| ISO 14001:2015 | 6.1.2 Environmental aspects | 0 | - | ISO/IEC 27001:2013 |
| ISO/IEC 20000-1:2018 | 4.1 Understanding the organization and its context | +9 | 4.1 Understanding the organization and its context | ISO 45001:2018 |
| ISO/IEC 27001:2013 | 6.1 Actions to address risks and opportunities (6.1.1 General) | +5 | 6.1 Actions to address risks and opportunities (6.1.1 General) | ISO 9001:2015 |

In the next step (step 4), a separate reference table is created, into which all unique symbolic combinations (words) used in the wording of the chosen set of requirements are entered. Each character combination is assigned a unique integer identifier (from 1 to \( n \), where \( n \) is the number of unique character combinations). The table - reference book of standards is created by a similar principle.

After that, the data is converted to the format (step 5) used in machine learning:
1. **Normalization** of expert assessments is performed. For this purpose, the following formula is used:

\[ V_{\text{norm}} = \frac{V_{\text{exp}} - V_{\text{min}}}{V_{\text{max}} - V_{\text{min}}} \]

where \( V_{\text{exp}} \) – expert evaluation, \( V_{\text{min}} \) – minimum expert evaluation within the table under consideration, \( V_{\text{max}} \) – maximum expert evaluation within the table under consideration, \( V_{\text{norm}} \) – normalized value used for neural network training. Thus, expert estimates are given to values from 0 to 1 in the process of normalization.

2. **Categorization** of the wording of requirements of standards is carried out. Empty array (vector) is created for each individual requirement. Then, the addresses of the cells of the array and the values that are written in these cells are determined, depending on the identifiers of words from the reference table, which are part of the wording of a specific standard requirement. As a result, the verbal form of recording the requirements of standards is iteratively reduced to a vector form, which is used to train the neural network and stores the contents of the requirements in coded form.

The order of the first phase of the study is as follows:

- Choosing standards and their requirements
- Formation of the table of expert evaluation
- Normalization of values of expert estimates
- Selecting the table - reference book of words
- Formation of the table - reference book of standards
- Wording of the requirements is reduced to a vector form
- The training set of data is prepared
- Evaluating the accuracy of training

**Figure 2.** The order of the first stage of the study

The main objectives of the second stage of the experimental study are:
1. Choosing the means of implementation (software, programming languages, software libraries) and hardware platform.
2. Choosing architecture and parameters of the neural network.
3. Choosing a learning strategy.
4. Development of software code.
5. Neural network training.
6. Evaluating the accuracy of training.
7. Checking ANN on the requirements of standards, not included in the training set
8. Analyzing results.

Choosing means of implementation and the hardware platform is not essential in the research process and may depend on various factors:
- Final requirements for speed and accuracy of calculations.
- The possibility of changing the existing hardware platform.
- Requirements for portability of the final software implementation of ANN.
- The amount of data (standards requirements) for operating a trained network.

The most important task is to find the optimal combination of architecture, parameters and network training strategies. Given the persistence of the training sample of data, in the process of the second stage of the study, it is necessary to vary the configuration of the network, the mechanism and the
number of training cycles. For this purpose, it is intended to develop a special software module that provides consistent and continuous learning of specified configurations of ANN with an intermediate recording of training parameters after each iteration of the cycle.

![Block Diagram of an Artificial Neural Network](image)

**Figure 3.** Block diagram of an artificial neural network

It is necessary to follow the rule when changing network parameters: the number of rows in the expert assessment table should be significantly greater than the number of regression coefficients (weighting coefficients of the neural connections).

Before learning, the rows of the TS table are randomly mixed. After that, the sample is divided into two parts:
- Data intended for directly learning the neural network.
- Data intended to assess learning accuracy.

The first part of the sample is used when training a neural network. At this stage, paired vector representations of the requirements of the standards are iteratively transmitted as input network parameters. In this case, the normalized value of the expert assessment, corresponding to the points of a specific iteration, is transmitted as a training output value.

The second part of the sample is used to assess the accuracy of training. At this stage, the rows of the table, not used at the training stage are used as the input parameters. After that, the accuracy of ANN is calculated using the least squares method by comparing the output values of the neural network and the values of the normalized expert estimates.

Analysis of each configuration is carried out after completion of training. The main criteria for choosing the best configuration of ANN and the corresponding learning algorithm are the classification accuracy of the degree of compliance with the requirements of the standards and the computational cost of the learning algorithm. Within further research, it is advisable to solve the task of optimizing the accuracy relative to the computational cost of the learning algorithm.

**Conclusion**

Thus, a trained neural network is supposed to define the degree of compatibility of individual requirements of different standards by calculating the matrix of estimates, which in turn allow an
analysis of the compliance of the requirements of different standards with respect to each other, as well as the regulatory documentation of the enterprise. The expected results include:

Exception of duplication of documents and information that in turn allows to achieve coherence of actions in the enterprise and to reduce functional disconnection.

Significant reduction in labor intensity and need for human resources.

Reducing the time to complete the task of analyzing the compliance of the internal requirements of the enterprise, as well as the requirements of the various management system standards.

The practical application of the proposed approach can be considered through the following signs:

- Adaptability. The neural network allows determining the degree of compliance with the requirements of any standards of interest, which allows using it in enterprises regardless of industry and business specifics.
- Scalability. The initial formation of a broad base of knowledge about the compatibility of the requirements of various standards allows, in consequence, using this neural network in many enterprises without the involvement of experts.
- Continuous development. When using a neural network in each particular enterprise, statistics are analyzed for the degree of compliance with the requirements of the standards. Based on this analysis, the program is adjusted and further re-analysis.

Thus, the developed neural network satisfies modern trends in the development of management systems and has wide practical application and undoubted advantages for any enterprise.

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