Intelligent quality management tools for digital production and knowledge management system for their application

A N Chesalin, S Ya Grodzenskiy, M Yu Nilov and Pham Van Tu
MIREA - Russian Technological University, Moscow, Russia

E-mail: chesalin_an@mail.ru

Abstract. Due to the evolution of the digital production technologies and the transition to the cyber-physical systems, new methods of controlling technological processes and managing business processes of modern enterprises are needed. In the article we investigate the problem of improving quality management methods for the organization and management of modern digital production. Various methods of quality management, both traditional and modern, are considered. The concept of digital production quality management based on artificial intelligence and information technologies is proposed. As a basis for the implementation of the intelligent quality management methods in the management of digital production we consider the development of a knowledge management system for their effective application.

1. Introduction
Modern quality management system (QMS), based on the requirements of ISO 9000, must also comply with modern production technologies - digital production, which is based on the use of end-to-end and additive technologies, including big data, artificial intelligence, internet of things, robotics, quantum technologies; distributed registry systems; virtual and augmented reality technologies.

The quality management system of digital production should ensure compliance of production technologies with the requirements and ensure the highest quality of products. The most important aspect of digital production quality management is data mining, which allows to obtain the necessary information from a huge set of heterogeneous data of digital production. In this regard, the concept of quality management is proposed, based on the integration of tools for data mining into the traditional ISO 9000 quality management system and knowledge management system for its application.

In recent decades, the development of QMS is usually associated with CALS-technologies [1] (continuous information support for the supply and life cycle of products). The use of information technologies in production management, for example, for modeling business processes and creating electronic document flow, provides transparency and efficiency of quality management.

In the investigation we propose a set of seven intellectual methods of quality management with the knowledge management system for their application, which along with seven simple, seven new and seven newest methods of quality management should become familiar tools in the hands of quality specialists (engineers and managers) in the enterprises of digital production. For the development of digital production systems, it is necessary to develop and justify the concept of quality management system, which allows to ensure high quality of products through the use of intelligent management methods.
2. The concept of an intellectual control system of quality of digital production

The modern quality management system is based on the principles of TQM (Total Quality Management), one of the most important among which is the process approach. The concept of quality management of digital production should also be based on the mechanisms of intelligent business processes management with the use of modern information systems that allow to collect, store, process and analyze large amounts of heterogeneous data. In figure 1 the unified model of enterprises business processes consisting of top level processes is presented: the processes of the enterprise management, processes of a life cycle of production (a loop of quality) and auxiliary processes.

Intelligent quality management of the enterprise business processes should be based on the analysis of heterogeneous data arrays arising during the implementation of technological processes. Depending on the specific situation, it can be simple methods of quality control, new methods of quality planning, the latest methods of quality management [2]. The story of the seven simple tools is well known. In December 1967 at the Seventh Symposium on quality management, the features of the Japanese system that distinguish it from the West were named: participation of all levels in quality management, training of personnel in appropriate methods, the activities of quality circles, the use of statistical methods, a nationwide program for quality control.

Following these principles in Japan led to a mass movement for product quality. By 1979 the Union of Japanese scientists and engineers (JUSE – Union of Japanese Scientists and Engineers) brought together seven fairly simple methods of quality control (quality tools) based on the use of graphical tools for analyzing statistical data and do not require special knowledge, and therefore the mastery of them is not difficult even for ordinary performers. The main purpose of the "Seven simple quality control tools" is to identify the problem to be addressed as a priority. Seven methods presented in table 1.

Simple quality control tools (basic quality management tools that do not require special education and skills for their application) are based on the analysis of numerical data, which corresponds to one of the principles of Total Quality Management (TQM): "decision-making based on facts".

However, facts cannot always be expressed in numbers. In this regard, a set of quality planning tools (Seven new quality planning and management tools) has been developed by analyzing various kinds of data, such as verbal descriptions (verbal information), which need to be transformed into an interpretable form for making an informed decision. These tools are presented in the table 2, allow you to improve
the planning process and make optimal decisions in the shortest possible time. The collection of raw
data for new quality management tools is usually carried out with the use of brainstorming, assaults and
sieges, after which the collected data are analyzed in various charts.

The newest tools of quality management (presented in table 3) are called techniques that have become
widespread relatively recently, although some of them are known since ancient times. The peculiarity
of these methods is that they are based on a system approach to quality management and for their
application a team is formed and a leader is selected. With properly constructed (system) teamwork,
people together can achieve more than the sum of their individual achievements (this shows a synergistic
effect – the main value of teamwork).

Table 1. Seven simple quality management methods.

| Seven simple quality control methods |
|--------------------------------------|
| 1. The control paper (Checksheat)     |
| 2. Pareto chart                       |
| 3. Ishikawa Scheme                    |
| 4. Histogram                          |
| 5. Scatter plot (scatter chart)       |
| 6. Stratification (stratification)    |
| 7. The control chart (Shewhart)       |

Table 2. Seven new quality planning and management tools.

| Seven new quality planning and management tools |
|-----------------------------------------------|
| 1. Affinity diagram (Affinity Diagram)        |
| 2. Chart (graph) relations (Interrelationship Diagram) |
| 3. Tree diagram (decision tree))              |
| 4. A matrix diagram or quality table          |
| 5. Priority matrix (matrix data analysis))    |
| 6. Network diagram (Arrow Diagram)            |
| 7. Flowchart of the process and flowchart of the decision making process (process Decision Program Chart, PDPC) |

Table 3. Seven newest tools of quality management.

| Seven newest tools of quality management |
|-----------------------------------------|
| 1. Quality Function Deployment - QFD    |
| 2. Benchmarking                         |
| 3. Failure Mode and Effects Analysis - FMEA |
| 4. Analysis of the activities of the unit |
| 5. The system of "Zero defects»       |
| 6. System "Just in time", " Lean production»   |
| 7. Functional-cost analysis (Activity Based Costing-ABC) |

3. Intelligent quality management tools
It is generally recognized that quality management in the development and production of complex
systems is impossible without the use of a system approach, automation of all activities and effective
analysis of a huge array of data.

The next step in the development of quality management methodology that meets the spirit of the
time should be, in our opinion, the widespread use of artificial intelligence methods (especially machine
learning methods) and big data (referred to in the literature as Big Data).
For this reason, in addition to the tools listed in tables 1-3, in our opinion it is necessary to use methods that we propose to call "intelligent" and give in table 4. The need to apply intelligent methods in quality management based on complex data analysis (usually big data) is dictated by the requirements of digital production. Artificial intelligence techniques allow you to build complex predictive models, identify patterns, structure data, detect anomalies, etc., based on the analysis of a huge amount of heterogeneous data. It is obvious that the use of intellectual methods is difficult without proper education and training, and not always effective. In this regard, when solving the tasks, it is necessary to assess their complexity, importance and available resources. At the same time, it is obvious that the processing of large arrays of heterogeneous data carries such difficulties as: the data belong to different scales of measurement, may have fuzziness, vagueness, incompleteness, sometimes inconsistency and ambiguity, their value strongly depends on the speed of processing and timeliness of use. To make a decision in this case, such intellectual methods as fuzzy logic and game theory can be applied [3].

It is possible that the list of intellectual tools of quality management will be revised, but now this set of seven methods is an organic continuation of the development of quality management methods.

**Table 4. Seven intellectual tools of quality management.**

| Seven intellectual tools of quality management |
|----------------------------------------------|
| 1. Fuzzy logic                               |
| 2. Machine learning (including neural networks) |
| 3. Big data analysis (Big Data)              |
| 4. Game theory and multi-agent systems       |
| 5. Simulation (Digital modelling)            |
| 6. Evolutionary/bionic algorithms            |
| 7. Expert systems and DSS (decision-support systems) |

Accordingly, we can build the following sequence of development of management methods (figure 2).

**Figure 2. The sequence of development of management methods.**

In table 5 we show the problems arising in the management of business processes, and possible approaches to solutions based on intelligent methods with the indication of some works describing their experience.

It should be noted that intellectual methods of quality management are a part of system of quality management of digital production, and their application is possible only at the corresponding equipment of the enterprise by modern digital technologies.

**Table 5. Tasks that arise in the management of business processes and possible approaches to solutions based on intelligent methods.**

| Business processes | Examples of quality management tasks | Applied intellectual methods |
|--------------------|--------------------------------------|-----------------------------|
| 1 Management process | Stakeholder requirements analysis | Game theory [5, 6] |
| 1.1 Management process | Strategic / operational planning | Machine learning (regression analysis), Expert systems and DSS, Evolutionary/bionic algorithms[4, 13] |
|------------------------|---------------------------------|--------------------------------------------------------------------------------------------------|
|                        | Decision making under uncertainty | Expert systems and DSS, Fuzzy logic, Machine learning, Game theory[5, 6] |
|                        | Planning of internal audits      | Fuzzy logic, Expert systems and DSS, Game theory |

2 Life cycle processes

2.1 Marketing

| Stakeholder requirements analysis | Analysis of the feasibility/profitability of the contract | Game theory [5,6], Fuzzy logic |

2.2 Design and development

| Planning and control of development stages | Reliability analysis | Expert systems and DSS, Machine learning, Simulation modeling (digital twins) [7, 15] |
|                                           |                    | Fuzzy logic [9], Simulation modeling [14] |

2.3 Procurement

| Evaluation and selection of suppliers | Expert systems and DSS, Fuzzy logic |

2.4 Production

| Production planning | Control of technological processes | Capacity planning of equipment |
|---------------------|-----------------------------------|-------------------------------|
|                     | Expert systems and DSS [8], Machine learning Evolutionary/bionic algorithms[4, 13] | Machine learning (neural networks, cluster analysis) [14] |
|                     | Fuzzy logic                                        |

2.5 Verification and validation

| Product testing | Reliability assessment | Simulation modeling [11,12] |
|                |                       | Fuzzy logic, Machine learning (regression analysis), Simulation modeling |

2.6 Distribution/Logistics

| Evaluation and selection of transportation method and cargo carriers | Evolutionary/ bionic algorithms |

2.7 Repair and maintenance

| Component inventory planning | Fuzzy logic, Machine learning, Simulation modeling (digital twins) [15] |

3 Supporting processes

3.1 Supporting processes

| Process equipment maintenance planning | Fuzzy logic, ES and DSS, Machine learning [10] |
| Analysis of defects and deviations (anomalies) in the performance of technological processes | Fuzzy logic, Expert systems and DSS, Machine learning |

**Figure 3.** Intellectual quality management methods in the overall system of digital production.
Figure 3 shows the place of intelligent quality management methods in the overall digital production system. At the technology level, intelligent methods are used, but they are built into the appropriate solutions (intelligent sensors, machines, etc.), and do not belong to the methods of quality management.

At the level of production organization, intelligent quality management methods are used to monitor and control technological processes. With high digitalization, intelligent process control should be fully automated.

At the level of enterprise management, the use of intelligent quality management methods is the least automated and is associated with management decisions of varying complexity. It is assumed that the main application of intelligent quality management methods will be at this level. And in this regard, the knowledge management system is required, that allow the decision-maker to effectively make decisions aimed at the full range of tasks of the enterprise, both operational and strategic.

In the implementation of intelligent quality management methods in digital production, it is important to understand that it is necessary to apply intelligent methods systemically and for the relevant tasks. It makes no sense to use them in simple tasks, when it is enough to use simple methods of quality management, or when there is not enough knowledge to interpret the results - in this case, you can get the opposite effect from their application. Perhaps in the future, intelligent methods will be the universal "hammer" that will solve all the problems of digital production, but now their correct use in suitable tasks can give significant advantages and the highest efficiency of the decisions taken. To do this, it is necessary to implement a knowledge management system for the application of intellectual quality management methods.

4. Knowledge management system

To build an intelligent quality management system, the sequence is proposed (Figure 4). The application of intelligent quality management methods requires information technology for data analysis and a knowledge management system for their application.

The knowledge management system for application of intelligent methods needs to contain:

- a description of intelligent methods;
- their applicability in different situations;
- information technology and data necessary for their use;
- system interpretation of results;
- risks associated with their use, and etc.

Figure 4. The sequence of building an intelligent quality management system.

Setting requirements and developing a knowledge management system for the application of intelligent quality management methods is an actual task.

The development of this system should be implemented using best practices and applying standards in the field of knowledge systems.

We propose that the knowledge management system in the field of intelligent management methods should be based on the requirements of standards in the field of knowledge management and contain all stages of activities related to knowledge. Guided by CWA 14924-1-2004 "European guide to good practice in knowledge management", which highlights the following activities related to knowledge
management: knowledge identification, knowledge creation, storage, knowledge sharing, knowledge application, we offer the following systematic approach to organizing knowledge management activities based on the PDCA cycle (table 6).

**Table 6. Stages of activities related to knowledge management and proposed solutions.**

| Stages of activities related to knowledge management | Proposed solutions |
|-----------------------------------------------------|-------------------|
| 1. Applicability of knowledge - determining the need for knowledge | Survey of employees about the production tasks that can be solved, in which the use of intelligent methods is possible |
| 2. Knowledge identification - determination of the current level of knowledge and directions in the study of intellectual methods | Testing employees' knowledge in the application of intelligent management methods |
| 3. Creation of knowledge – identification of ways of learning knowledge | Creating working groups for the development and application of intelligent methods |
| | Conducting seminars on training in intelligent methods and software |
| 4. Storing and sharing knowledge – embedding knowledge in an organization | Creating a portal for learning intelligent methods (wiki pages) |
| | Development of manuals on the use of intelligent methods |
| | Creating handbooks for quick access with the necessary information |
| 5. Improvement of knowledge | Analysis of the effectiveness/ efficiency of the knowledge management system |

Solving all tasks at the specified stages using the knowledge management system will allow employees to effectively apply the proposed intelligent methods of quality management.

5. Knowledge management system architecture

We suggest using the client-server architecture of the system (figure 5), which is most appropriate based on the following considerations:

- minimizing duplication of functionality;
- reducing requirements for client machines (user computers/devices);
- storing data on the server increases system reliability;
- ease of making changes and updating information in the system;
- ease of access differentiation and data security.
We have developed the system consisting of seven modules, shown in figure 5, the use of which will allow you to effectively establish the use of intelligent methods in management. The knowledge management system developed at enterprises can consist of a different number of modules, and can also be integrated into existing management systems.

6. Conclusion
We have conducted the research of the development of digital production quality management methods, from seven simple methods to modern ones, and proposed the concept of intelligent digital production quality management system based on seven intelligent management methods, standards of ISO 9000 standards and information technologies. For the application of intelligent quality management tools, we have proposed a variant of implementing a knowledge management system and have described its tasks, architecture, modules, and advantages.

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