Models of fuzzy logic in the processes of verification of the required level of automation of technological processes research and production complexes

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Abstract. Improving the methodological apparatus for monitoring and analyzing the potential of technological processes of industrial enterprises, based on the identification of the level of maturity of processes, is the primary task of achieving a competitive state. The article describes ways to verify the processes of the main activities of the organization, using fuzzy logic models and criteria for achieving the required level of automation.

1. Introduction

Today, there is a production situation in which the threshold of the proximity of a new scientific and technological revolution is felt. This kind of phenomenon has occurred at different times and the main attribute of the proximity of this phenomenon is the process of changing terminology. In this case, the general production and industrial world is faced with the prospect of using industry 4.0 technology and related auxiliary interfaces to accelerate the process of integrating substitute innovations into the technological complexes of domestic enterprises.

In order not to remain on the margins of scientific and technological progress, a modern enterprise needs to monitor its own level of development, both in technical terms and in technological terms.

2. Materials and methods

Technological lag threatens high financial losses and as a result, the loss of the market segment that forms the main gross profit of the organization. In order to prevent such a situation, it is necessary to conduct internal technological audits to study the level of scientific and technological progress of the organization, as well as to understand the need for automation or the introduction of mechanization in existing processes. Such problems are widely described in various sources of both domestic and foreign authors [1-3] related to systems for monitoring production processes and tracking processes that affect the manufactured product. Transition processes during the change of technological patterns are the processes of reengineering, when it is necessary to completely reorganize the existing production cycles and achieve not only the development of a new technological line, but also to form the necessary competencies of the staff.

In practice, there are many enterprises in which their own research and production complexes use a mixed style of production organization: manual labor, partial mechanization, partial automation. Such decisions are made for reasons of mixed rhythmicity and are caused by unstable orders from customers or consumers of similar production systems [4-6]. To date, the experimental base of science has been
reintegrated into separate production complexes and has become part of the existing production and industrial organizations that are engaged in both scientific research and the execution of production orders.

However, in many similar production sites, manual labor still outperforms process automation in percentage terms. Therefore, in order to modernize the technological processes of research and production complexes and justify the re-equipment of production facilities, it is necessary to develop a methodology for assessing the need for automation of the main production processes. This technique will be useful in decision-making processes related to the development of organizational and technical solutions for problem processes and preparation for the synchronization procedure of the main production processes of the enterprise.

3. Methodology
There remains a rather serious problem with the description of the current situation within the research and production complexes. The main problem of classifying the level of automation of technological processes is the selection of indicators and criteria for conducting the procedure for evaluating the level of technology, personnel qualifications, and identifying advanced equipment.

In the process of preparing for the analysis of the need for automation of technological processes, a technological audit of the production system was carried out, and the characteristics of indicators for monitoring the level of automation were identified. Formed a scale of relations for the interpretation of the results (table 1).

| Parameter                          | Formula | Description of variables | Scale         |
|------------------------------------|---------|--------------------------|---------------|
| Progressivity of technology        | $d_{prog} = \frac{W_{prog}}{W_{gen}} \times q$ | where W prog. - progressive equipment, units, W total-total number of equipment, units. | Lowd< 1, middled =1, highd> 1 |
| Automatic equipment                | $d_{aut} = \frac{W_{aut}}{W_{gen}} \times q_{aut}$ | where W aut. - automatic equipment, units. | Lowd< 1, middled =1, highd> 1 |
| Obsolete equipment                 | $d_{ob.eq} = \frac{W_{ob.eq}}{W_{gen}} \times q_{ob.eq}$ | where W ob.eq. - obsolete equipment, units. | Lowd< 1, middled =1, highd> 1 |
| Age of equipment                   | $d_{10} = \frac{W_{10}}{W_{gen}} \times q_{10}$ | where W10 is equipment that has worked for up to 10 years | Lowd< 1, middled =1, highd> 1 |
| The specific weight of workers     | $d_{m} = \frac{P_{p,m}}{P} \times q_{m}$ | Where Rp. mech. the number of workers performing work in a fully mechanized way, P - the total number of workers. | Lowd < 1, middled =1, highd > 1 |
| performing work in a fully机械化 way |         |                          |               |
| The specific weight of the workers, | $d_{p,m} = \frac{P_{p,m}}{P} \times q_{p,m}$ | where Rp. mech - the number of workers engaged in manual labor. | Lowd < 1, middled =1, highd > 1 |
| the management of the automatic equipment |         |                          |               |
| Number of complex-mechanized       | $K_{c.m.w} = \frac{K_{com.m.w}}{K_{com.m.s}} \times q_{work}$ | where K com.m.w - the number of complex-mechanized workshops, K com.m.s - the number of complex-mechanized sections. | Lowd < 1, middled =1, highd > 1 |
| workshops, sections                |         |                          |               |
However, before engaging in the process of assessing the level of automation, it is necessary to come to an understanding of whether the process is ready for structural change. Assessment of process maturity and preparedness for possible innovation creates uncertainty understanding of the status of the process, what that process we have deployed or installed, and to identify the process must meet specific criteria that need to be set and measured. This problem will be solved by GOST R ISO / IEC 15504-2-2009, which clearly sets the maturity levels of the process and the rating components that characterize its potential.

The problem of boundary states between process levels is a well-known classification problem, which leads to a fuzzy situation in understanding the readiness of the process potential for the next step in the cycle of continuous improvement. Such cycles are the basis of the ideology of universal quality management and the principles of quality management [8-10], which prescribe to iterate the process of continuous improvement, using new methods to achieve an improvement in the quality level and the unification of all processes. Of course, this kind of action leads to destabilization of the working rhythm of the personnel of the structural unit and constant readiness for structural changes and innovation. As a result, the personnel ceases to perceive this phenomenon as significant results of management actions aimed at creating optimal conditions for the course of the work process. Therefore, a mechanism is needed to assess the potential of the process to understand the readiness of the entire process infrastructure for change.

### Table 2. The level of maturity of processes in the structural unit.

| Level          | Characteristics of the process | Rating               | Criteria                          | Intervals       |
|----------------|--------------------------------|----------------------|-----------------------------------|-----------------|
| Level 1        | Completed process              | Implementation of the process | Mostly or completely              | M or C - 50%-100% | UCL – 100% |
|                |                                |                      |                                   | CL - 75%        |                |
|                |                                |                      |                                   | LCL – 50%       |                |
| Level 2        | Managed Process                | Implementation of the process | Completely | C - 85%-100% | UCL – 300% |
|                |                                | Implementation management | Mostly or completely | M or C - 50%-100% | CL - 242% |
|                |                                | Working product management | Mostly or completely | MC - 50%-100% | LCL – 185% |
| Level 3        | Established process            | Implementation of the process | Completely | C - 85%-100% | UCL – 500 |
|                |                                | Implementation management | Completely | C - 85%-100% |                   |
|                |                                | Working product management | Mostly or completely | M or C - 50%-100% | CL - 427.5 |
|                |                                | Process Definition    | Mostly or completely              | M or C - 50%-100% | LCL – 355 |
| Level 4        | Predictable process            | Implementation of the process | Completely | C - 85%-100% | UCL – 700 |
|                |                                | Implementation management | Completely | C - 85%-100% |                   |
|                |                                | Working product management | Completely | C - 85%-100% |                   |
|                |                                | Process Definition    | Mostly or completely              | M or C - 50%-100% | CL – 612.5 |
|                |                                | Deploying the process  |                                    |                 |                |

\[
d_{\text{auth.1}} = \frac{K_{\text{auth.1}}}{K_{\text{total}}} \times \text{number of lines,}
\]

where \( K_{\text{auth.1}} \) - number of automatic lines, \( K_{\text{total}} \) - total number of lines.
The following ranked rating scale should be used to express the achievement levels of process attributes.

The ranked rating scale defined above should be expressed in terms of a percentage scale representing the degree of achievement [11].

### Table 3. Level Characteristics.

| Designation       | Interval              | Interval characteristic                                                                 |
|-------------------|-----------------------|----------------------------------------------------------------------------------------|
| N - Not reached.  | N - 0%-15% realization.| Evidence of the achievement of the process result or the appearance of process attributes |
| PA - Partially    | PA - 15%-50% realization.| Achieving the first goals of the process, performing the tasks or main functions of the process, documenting the process |
| M - Mostly        | M - 50%-85% realization.| Systematic iteration of the process and the presence of a process schedule for measuring the main attributes achieved at the output. Measuring the flexibility and viability of a process. |
| C - Completely.   | C - 85%-100% realization.| There is evidence of a complete and systematic approach to achieving and fully achieving a particular attribute in the process being evaluated. |

After you have formed an idea of the level of maturity of the process and its readiness for change, you can start solving the main problem. The first steps to reduce the tension are the task of forming a qualimetric scale for understanding the intervals of belonging to a certain class that characterizes the internal state of the process, in our case, the scale of relations allows you to form the interval n=0,....1. So how the core of the interval is clearly formed by clear ideas about the sufficiency of the indicator. According to table 1, three levels of need for automation are created: high need for automation, medium need for automation, low need for automation. The next step is to determine the boundary states using the fuzzy logic apparatus, which will provide a completely adequate solution for such situations. Table 4 shows a fragment of the decision rules for training the assessment system.

### Table 4. Characteristics of the indicators of the level of automation.

| Characteristics of indicators of the level of automation | Level (class)       |
|---------------------------------------------------------|---------------------|
| F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 |                        |
| Low | 0  | 0  | 0  | 0  | 0  | 0  | 0  | High need for automation |
| middle | low | 0  | 0  | 0  | 0  | 0  | 0  | High need for automation |
| high | middle | low | 0  | 0  | 0  | 0  | 0  | High need for automation |
| 0  | high | middle | low | 0  | 0  | 0  | 0  | High need for automation |
F1-Morally obsolete equipment, F2-The age of the equipment, F3-The proportion of workers performing work in a fully mechanized way, F4 - The number of complex-mechanized workshops, sites, F5-The proportion of workers operating a car. Equipment, F6 - Progressiveness of equipment, F7-Automatic equipment, F8-Number of automatic lines.

4. Results and discussion

Thus, applying various approaches to the description of linguistic variables, the potential of the technological process is investigated. It becomes possible to obtain a fuzzy solution based on the results of a technical or technological internal audit obtained after continuous monitoring of the course of the technological process [11-13].

However, there are different models used in fuzzy logic to describe the function of belonging a certain state of a process to the class that most fully describes all its internal characteristics. Such models are widely described in different sources and by different scientists [8-10]. It is necessary to identify the most suitable models for the situation under study, which are applicable to fuzzy state classification systems using the developed system training rules. The work provides an example of using the R programming environment, the R-Studio working environment, the main model for describing the membership function is the "trapezoid" model, figure 1.

![Figure 1](image_url)

**Figure 1.** The "trapezoid" model.

Figure 1 shows a fragment of the resulting assessment of the process potential for the object of research belonging to one of the following classes: K1 – High need for automation; K2-Medium need for automation. And the characteristic criterion F1-Obsolete equipment.
Figure 2. A piece of program code.

The rationale for choosing such a model is a significant interval in which the cores of the set that correspond to the process belonging to a certain class are clearly defined. The boundary values that intersect with other sets that characterize a particular class are also defined.

Table 5. Membership functions for fuzzy logic models.

| Level 1 (High need for automation) | Level 2 (Average need for automation) | Level 3 (Low need for automation) |
|-----------------------------------|--------------------------------------|-----------------------------------|
| $y = 0, \ x < 1$                  | $y = 0, \ x < 2.1$                   | $y = 0, \ x < 3.8$                |
| $\frac{x-1}{1.8-1.1}, \ 1 < x < 1.8$ | $\frac{x-2.1}{2.5-2.1}, \ 2.1 < x < 2.5$ | $\frac{x-3.8}{4.3-3.8}, \ 3.8 < x < 4.3$ |
| $y = 1, \ 1.8 < x < 2$            | $y = 1, \ 2.6 < x < 3.1$             | $y = 1, \ 4.3 < x < 5.1$           |
| $\frac{2-x}{2-1.8}, \ 2 < x < 2.2$ | $\frac{3.1-x}{3.5-4.1}, \ 3.5 < x < 4.1$ | $\frac{5.1-x}{6.7-5.1}, \ 5.1 < x < 6.7$ |
| $y = 0, \ x > 2.2$                | $y = 0, \ x > 4.1$                   | $y = 0, \ x > 6.7$                |

Practical applicability. As a result of applying such a model, technical experts, auditors, and decision makers get a sufficiently strong methodological tool that allows them to confidently say what potential the technological process under study has and determine the level of its maturity to form a judgment about the preparation of the technological process for structural changes. A fragment of the questionnaire for use in the audit is presented in Table 5. The methodology includes a fuzzy set model that allows you to stop the state of uncertainty in the inter-classification areas. In all of its properties, the levels of maturity of the processes described in detail in [8,9,10]. Conducting technical audit process in accordance with the analysis of the potential indicators from Table 1, it is possible to form a judgment on the level of need process automation.

Table 6. Fragment of the audit questionnaire [5,8].

| Analysis of the level of potential of the process |
|--------------------------------------------------|
| Specific weight of progressive equipment          |
| Progressive equipment                            | Total number of process equipment |
| 0                                                | 0                                 |
| Specific weight of automatic equipment            |
| Automatic equipment                               | Total number of process equipment |
| 0                                                | 1                                 |
| Specific weight of obsolete equipment             |
| obsolete equipment | Total number of process equipment |
|---------------------|-------------------------------|
| 0                   | 10                            |
| Specific weight of equipment age groups, up to 10 years | Total amount of equipment |
| 0                   | 1                            |
| The specific weight of workers performing work in a fully mechanized way | Total number of workers |
| 0                   | 3                            |

5. Conclusion
In this paper, we analyzed the existing models describing membership functions and selected such a function as a "trapezoid", which describes in more detail the core of the set of membership functions presented and most fully meets the tasks of clear control of interval values, which is demonstrated only by the trapezoidal membership function. The practical application of this methodology is necessary to make a decision on the modernization of existing processes in order to ensure the effective flow of the main activities, ensure their functionality and verify the effectiveness of their outputs, so the use of the practical methodology will allow you to obtain actual confirmation of the updated processes.

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