Model of optimal organization maturity management under conditions of interference and uncertainty

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Abstract. The article proposes a mathematical model of the optimal process for managing levels of organization maturity in the presence of interference in the source data. This work is a part of the solution to the more general problem of developing a system for managing the maturity level of business processes in an organization. Changes in organizational maturity of a company are described in terms of a managed dynamic system. It is shown that such a model adequately reproduces a number of effects in the behavior of the system of indicators of the organizational maturity of the company. The paper uses the method of analytical design of optimal Kalman-Leтов regulators (ADOR), as well as a recursive Kalman filter that estimates the state vector of a dynamic system based on incomplete and noisy data. The constructed model demonstrates plausible behavior in predicting the process of organizational maturity managing. Reproduces the effect of accelerated growth of controlled indicators defined as a priority in the model. Using the Kalman filter allows one to form a control action on the dynamics of organizational maturity indicators in such a way that the target values of maturity levels are achieved even under conditions that are significantly distorted when measuring the initial data. The proposed methodology for optimal management of the organization’s maturity level is demonstrated by the example of evaluating and forecasting the maturity level of one of the departments of a technical university.

1. Introduction
One of the most important management technologies in modern economic conditions is the management of business processes. The standards of the ISO 9000 family are based on the management of business processes, therefore, each enterprise developing a quality management system based on these standards must be guided by this approach. According to the ISO Survey study, the number of such enterprises in the world exceeded one million. From this fact it follows that the task of managing business processes is highly relevant. The process approach to management was first described in the work of Philip Crosby “Quality is Free” [1], its further development was proposed by Watts Humphrey [2]. The best practices of business process management are described in the BPM CBOK set of knowledge on business process management.

One of the important characteristics of enterprises carrying out business processes is their organizational maturity. In [3], [4] organizational maturity is defined as the degree to which the organization explicitly and sequentially implements practices or processes that are documented, managed, measured, controlled and constantly improved. The maturity of the organizational process can be measured using expert assessment, for example, in the form of a survey of stakeholders. The description of the maturity
management framework for business processes is presented in the international standards ISO/IEC 15504, ISO 9004, ISO 10014. The limitations of this group of standards is that they focus on questions of assessing the level of maturity, but do not contain formulas and algorithms for developing a solution to manage this indicator.

Among the methods for improving business processes are reengineering [5], continuous process improvement (CPI) [6], as well as a group of lean manufacturing methods (Kaizen) [7], [8]. In turn, the limitations of this class of methods consists in the fact that decisions on the implementation of measures to increase the efficiency of processes are made on the basis of assessing the expected financial result, but far from always taking into account the synergy of factors of the organizational environment.

The creation of an enterprise management system according to the level of organizational maturity as a target indicator allows, in the author’s opinion, to eliminate these restrictions in business process management methodologies.

In this paper, the solution to the above problem is proposed to be performed as follows:

- Describe the process of organizational maturity indicators growth in the form of a managed dynamic system.
- Carry out parametric identification of the obtained dynamic control system based on the available experimental data of the existing enterprise (in this work, one of the university departments).
- To develop an algorithm for optimal maturity level control for the constructed model using the Kalman-Letov method in a deterministic formulation;
- To develop an organizational maturity management model based on the Kalman filter to overcome the problems of noisiness and subjectivity of maturity assessment data.

The paper shows that the thus obtained model of a linear dynamic system in discrete time plausibly describes the dynamics of the business processes maturity indicators system in an enterprise.

It is shown that by setting the target parameters in the Kalman-Letov model, it is possible to obtain a maturity level growth path with a priority increase in the required maturity level indicators.

It is shown that the proposed method allows one to control the process of increasing organizational maturity in such a way that the target values of maturity levels are achieved even under conditions significantly distorted when measuring the current system parameters.

2. Methods

2.1. Used standard of organizational maturity

In this work, we use the standard ISO 9004:2009 “Managing for the sustained success of an organization — A quality management approach”.

The purpose of this standard is to assess the maturity of the organization’s processes as a whole in terms of achieving sustainable success. The standard contains tools for assessing process maturity. The system of indicators of the standard contains 6 main (top-level) factors of organizational maturity, respectively, to which the following sections are highlighted in it.

- Management to achieve sustainable success of the organization. This section describes the requirements for general management principles.
- Strategy and policy. This section describes the requirements for ensuring the realization of the mission, vision and values of the organization.
- Resource management. This section describes the requirements for the management of internal and external resources required to achieve short-term and long-term goals of the organization.
- Process management. The section contains requirements for ensuring pro-active management of all processes, including processes transferred to third-party implementers.
• Monitoring, measurement, analysis and study. This section contains requirements for monitoring, measuring, studying and analyzing the effectiveness of its activities on the part of the organization.

• Improvements, innovations and training. The section contains requirements for the organization's actions to ensure improvements (products, processes, etc.), innovations (development of new products, processes, etc.) and training of participants in the process as a basis for the effectiveness of other actions.

An assessment of the maturity level for each of the sections listed is given in the range from 0 to 5. These indicators, which evaluate the 6 components of the maturity level of the organization’s business processes in accordance with ISO 9004:2009, comprise the 6-dimensional vector of indicators of the managed system used in this paper.

2.2 Description of the organization business processes maturity level as an object of management

Imagine a set of indicators of organizational maturity as a set of managed parameters of the organizational system.

The decision maker in the organization (DM), solves the problem of increasing organizational maturity by controlling the investment of resources - the working time of employees, the resource of machines, materials. The investment of resources is roughly estimated by a single integrated indicator - their value. The decision-maker is responsible for the efficient use of these resources to ensure the organization's development goal of increasing maturity.

The following components are distinguished in the system for managing the levels of maturity of an organization’s business processes.

• Managed object – the maturity level of the organization’s business processes, described by a 6-dimensional vector.
• Management system - a person who makes decisions on projects for the implementation of management technologies.
• Controlled parameters – components of the vector of maturity level indicators.
• Control impact – the amount of resources invested in the improvement of management technologies.

2.3. Research hypotheses

In this paper, the following hypotheses were adopted.

• The maturity level of business processes is expressed for each factor as a non-dimensional value, taking values from 0 to 5. This value is the result of the enterprise’s self-assessment by internal experts.
• In the process of the enterprise’s activities, the level of a specific element of organizational maturity rises in proportion to the number of resources invested in the development of this element.
• Elements of organizational maturity influence each other; maturity level can change during the daily activities of the organization, as well as a result of changes in its corporate values.
• The following indicators influence the planning and implementation of the organizational maturity management process:

  • graph of increasing level of organizational maturity by elements over time;
  • resource costs (in monetary terms) for projects to increase organizational maturity.
2.4. Organizational maturity process management model

The essence of the proposed methodology is summarized below. A more detailed exposition is contained in [9]. Imagine a dynamic system that simulates the process of increasing organizational maturity in the form of a model in discrete time:

\[ x(t + 1) = x(t) + Ax(t) + Bu(t) + v(t) , \]

\[ y(t) = Hx(t) + w(t) . \]

Where:

- \( t \) – discrete time for the implementation of projects to increase organizational maturity \( t \in [0, T] \), where \( T \) is the duration of the projects in the planned periods (months, quarters);
- \( x(t) = [x_1(t),...,x_n(t)]^T \) – \( N \)-vector of organizational maturity values by elements, where \( x_i(t) \) – is the maturity level by the \( i \)-th element at the moment \( t \); \( N \) – their total number. In this paper, we will use the indicators of the upper level of the standard ISO 9004 [12] and, as noted above, \( N = 6 \);
- \( y(t) = [y_1(t),...,y_k(t)]^T \) – \( K \)-vector of observations, where \( y_i(t) \) – is the observed value of the \( i \)-th maturity level indicator at the moment \( t \); in this paper, \( K = N \);
- \( u(t) = [u_1(t),...,u_m(t)]^T \) – control \( M \)-vector, where \( u_i(t) \) is the control action by the organization in the form of investing money in resources for the implementation of organizational development projects at the moment \( t \);
- \( A = [a_{ij}] \) – \( N \times N \) – the matrix that determines the rate of change of maturity by elements due to factors of the internal environment of the organization; \( a_{ij} \) – the degree of influence of the maturity elements \( x_i \) on \( x_j \);
- \( B = [b_{ij}] \) – \( M \times N \) – the matrix that determines the increase in the level of maturity in the process of strategic development of the management system; \( b_{ij} \) – the degree of influence of the control action \( u_i(t) \) on the maturity level in the \( j \)-th element \( x_j(t) \);
- \( H = [h_{ij}] \) – \( K \times N \) – the matrix of observations, allowing to obtain an assessment of the level of maturity \( x(t) \) by the observed indicator \( y(t) \);
- \( v(t) = [v_1(t),...,v_m(t)]^T \), \( w(t) = [w_1(t),...,w_k(t)]^T \) – interference vectors affecting \( x(t) \) and \( y(t) \) respectively. It is assumed in the work that these are statistically unrelated random processes such as white noise with zero mean values and dispersion matrices, respectively \( V \) and \( W \).

The initial state of the system is a random vector with characteristics:

\[ M[x(t_0)] = x_0 , \quad \text{cov}[(x(t) - x_0)^2] = S_0 . \]

2.5. Initial data on the maturity state of organization processes

This work is the first attempt to assess and predict the growth of organizational maturity of the university management system. In our opinion, the proposed methodology makes it possible to obtain more adequate assessments of the university management system in comparison with the currently accepted procedures for assessing and accrediting a university.

The Institute of Informatics and Telecommunications of the Reshetnev Siberian State University of Science and Technology (IITC) was chosen as the organization under study. Initial data were collected in the process of self-assessment in the Institute’s Directorate. The self-assessment procedure was carried out in accordance with the standard ISO 9004. This procedure consisted of a survey of the organization’s experts on questionnaires contained in the standard ISO 9004-2010. Six experts were interviewed. Information was collected on the organizational maturity according to the results of 3 years of the Institute’s work for 2016, 2017, and 2018. It should be noted that well-known publications (for
example, in [10]) provide a methodology for assessing the maturity of higher education institutions, but there are no concrete results of such an assessment.

\[
x_{2016} = [2,000, 2,500, 2,000, 2,167, 2,000, 1,875]
\]

\[
x_{2017} = [2,167, 2,583, 2,333, 2,000, 2,667, 2,000]
\]

\[
x_{2018} = [2,700, 2,600, 2,800, 2,133, 2,533, 2,550]
\]

Such a volume of experimental data does not allow, unfortunately, to carry out statistically reliable parametric identification of the system. Linear interpolation of these indicators for shorter periods of time also does not solve the problem, since the data in the resulting masses are linearly dependent.

It should be noted that the problem of collecting reliable information about the maturity level of economic systems is fundamental. Such systems are characterized by:

- high dimension of the parameter space;
- fast variability of both parameters and system structure;
- long (compared with the time of variability) time lag of accumulation of system parameter values.

These three properties of economic systems in the aggregate make it difficult to carry out statistically reliable identification.

To overcome this problem, the following assumptions were additionally made.

- Model (1, 2) is simplified by reducing the increment matrix A to a diagonal form. This means that we neglect the relationship between different indicators of the maturity level, believing that each of the indicators changes singly and independently.
- The data were interpolated (4) at intermediate time points with an interval of one month based on two hypotheses about the dynamics of the maturity level of the company:
  - on the linear dynamics of maturity level indicators over time;
  - on the dynamics of maturity levels indicators in accordance with the exponential law.

The construction of the organizational maturity indicators growth dynamics models on the basis of accepted hypotheses made it possible to construct an approximate model for controlling this process.

### 2.6. Identification of organizational maturity management system parameters

Interpolation of the maturity indicators growth was carried out, which was assumed to vary exponentially in the intervals between annual values \(x_{2016}, x_{2017} \) and \(x_{2018}\).

The calculation was carried out in the MatLab system using the “fit” function with the interpolation setting “\textit{exp1}” on a grid of 24 steps with a step of 1 month. The last value corresponds to the end of the third (2018) year. It should be noted that the use of the MatLab system for calculations led to the use of formulas written in vector form hereinafter. Then, the dynamics of maturity level indicators were extrapolated to the 5-year interval according to the exponential law. Based on the calculations performed, the identification of the parameters of the control model (1) without interference was carried out. A detailed description of the solution to this problem is given in [9].

A matrix \(A\) was compiled (a matrix of maturity levels’ increments in formula (1)), based on the average values of the coefficients of increasing the maturity level in one step \(x_{i+1}/x_i\) for all components of the vector \(x\).

The “observer” matrix of \(H\), having a \(6 \times 6\) dimension is constructed on the basis of the assumption that the observation is carried out without distortion, respectively, is a unit matrix.

Matrix \(B\), having a dimension of \(6 \times 1\), is formed on the basis of statistics on the investment of resources in management tasks.
2.7. Optimal management of organizational maturity by quadratic criteria without interference

The model (1), identified in Section 2.6, allows to solve the optimal control problem with a quadratic quality criterion according to the Kalman-Letov method based on the equations of the control system (1), (2).

Control quality criterion (in discrete time):

$$J = x(T) \cdot \psi \cdot x(T) + \sum_{t=0}^{T} [x(t) \cdot Q \cdot x(t) + u(t) \cdot R \cdot u(t)]\Delta t \rightarrow \min.$$  (5)

As is known from [11], [12], the optimal control of system (1) with a quadratic quality criterion (5) is determined by the formula:

$$\Pi(t) = K(t)x(t),$$  (6)

where the gain factor $K(t)$ is a vector calculated by the formula:

$$K(t) = -R^{-1}B^T(t) \cdot P(t),$$  (7)

$P(t) –$ inverse time solution of the Riccati equation:

$$P(t-1) = P(t) + A^T(t)P(t) + P(t)A(t) - P(t)B(t)R^{-1}B^T(t) \cdot P(t) + Q, \quad P(T) = \psi.$$  (8)

Let us explain the meaning of the parameters included in criterion (5).

The matrix $Q$ determines the “price” of the organization’s costs for managing maturity levels.

The matrix $R$ determines the “price” of the organization’s costs for managing maturity levels.

$\Delta t$ is the time step of the discrete time grid of the model (month, quarter, year). In this paper, the value of this parameter is 1 and corresponds to one calendar year.

Using the MatLab system, 6 different growth options for organizational maturity were calculated for the model identified in Section 2.6. For each of them, based on formulas (6) - (8), the optimal Kalman-Letov regulator was constructed, and then the trajectory was calculated by formula (1). Each of these trajectories corresponds to the priority of one of the maturity indicators in accordance with the ISO 9004 standard. Priority is set by increasing the values of the matrix $\psi$ components corresponding to the priority indicators of organizational maturity.

The results of the calculations are given in [13].

2.8. Solving the problem of the organizational maturity increasing process optimal control considering interference using the Kalman filter

With a more general statement of the problem of managing and evaluating maturity levels than in clause 2.7, the interference and possible discrepancy between the actual value of the parameters and the calculated ones are considered. The problem is solved under the assumption that the initial state of the system $x(t_0)$ is a random vector with mathematical expectation $M[x(t_0)] = x_0$ and dispersion $S_0$, uncorrelated with $w(t)$. An “observer” is used to evaluate the state of the system. Here is “his” record in the discrete-time variant.

$$\bar{x}(t) = \bar{x}(t-1) + \bar{x}(t-1)(A - B \cdot u(t) - L(t) \cdot (y(t) - L(t) \cdot \bar{x}(t-1)), \quad \bar{x}(0) = x_0.$$

where $\bar{x}(t)$ is the state estimation vector, $\bar{x}(0) = x_0$, $y(t)$ is the observation vector, $L(t)$ is the matrix that determines the “observer” parameters. The optimal value of this matrix, providing a minimum of mathematical expectation of error $\varepsilon(t) = x(t) - \bar{x}(t)$ is determined by the expression:
\[ L(t) = -S(t)H^TW^{-1}(t), \] (10)

where \( S(t) \) is the solution of the Riccati equation:

\[ S(t+1) = S(t) + [(2A(t)S(t) - H^TW^{-1}HS^2(t) + V(t))]\Delta t, \quad S(0) = S_0. \] (11)

The “observer” (10), (11), (12) is called the Kalman filter [11], [14], [15]. The control problem in the formulation under consideration is to minimize the mathematical expectation of criterion (5). In this case, the optimal control is equal to

\[ u(t) = R^{-1}B^TP(t)x(t), \]

where \( x(t) \) is the optimal estimate of expression (9) obtained using the Kalman filter, and \( S(t) \) is the solution of the Riccati equation (11). Based on (10) and (11), the state estimate is determined by the formula:

\[ \bar{x}(t+1) = \bar{x}(t) + [(A(t) - B(t)R^{-1}B^TP(t))\bar{x}(t) - L(t)(y(t) - H(t)\bar{x}(t))]\Delta t, \] (12)

\[ \bar{x}(0) = x_0. \] Simultaneously with the solution of problem (11), (12), the value of the optimality criterion (5) is calculated.

2.9. Algorithm for solving the problem of the organizational maturity increasing process optimal control considering interference

As was shown above, the problem of optimal control of the organizational maturity increasing process considering interference using the Kalman filter is solved numerically in discrete time. The calculation algorithm for solving problem (5) - (12) is as follows.

- Problem (5) - (8) is solved in the inverse time on the interval \( t = T, \ldots, 0 \), and the values of \( P(t) \) are stored.
- The Riccati equations (10), (11) are numerically solved in direct time. The solution is performed on the interval \( t = 0, \ldots, T \).
- The optimal gain factor of the Kalman filter \( L(t) \) is calculated by the formula (10).
- As the observation values \( y(t) \) \( t = 0, \ldots, T \) are obtained, equation (12) is solved under the initial condition \( \bar{x}(1) = x_0 \), i.e. the optimal trajectory of the process on the interval \( t = 0, \ldots, T \) is calculated, and the optimal control action \( \bar{u}(t+1) = -R^{-1}B^TP(t)\bar{x}(t+1) \) is also determined.
- At the same time, the value of the quality criterion is calculated by the formula (5).

3. Results

In [23], using the MatLab system, 6 different options for the growth of organizational maturity were calculated. Each of these trajectories corresponds to the priority of one of the maturity indicators in accordance with the ISO 9004 standard. The priority is set by increasing the values of the components of the matrix \( \psi \) corresponding to the priority indicators of organizational maturity. Using the formulas given in Section 2.7 of this paper, we have constructed the Kalman-Letov controller and calculated the optimal controller, and for each of these options, based on formulas (6) - (9), the trajectories of maturity level parameters were constructed.

In this paper, control was calculated based on the observed values \( y(t) \) that passed through the linear “observer” \( H(t) \) and distorted by noise \( v(t), w(t) \). At each step, the Ricatti equation was numerically solved by formula (12) for the matrix \( S(t) \). Based on the calculation of \( S(t) \), the Kalman filter parameters \( L(t) \) were calculated using formula (11). Next, the trajectory of the controlled values \( \bar{x}(t) \) was calculated by the formula (13). Figure 1 shows graphs of changes in maturity level indicators for a system aimed at priority growth of maturity index No. 3.
Figure 1. Trajectories of indicators of the system maturity levels with priority on maturity indicator No. 3. (1 Maturity Level, 2 Estimated Maturity Level, 3 Observed Maturity Level).

4. Discussion

Figure 1 shows that when setting the priority for organizational maturity index $x_3$ over a 5-year time interval, its value reaches the fifth maturity level before all other indicators.

It can be noted that a system controlled by noisy observable data (“Observed maturity level” in figure 1), although it differs from the results of deterministic calculation $y(t)$ (“Maturity level” in figure 1), demonstrates a pronounced ability to return to the target path. This can be seen in the graph of estimated values of maturity levels $\bar{y}(t)$ (“Estimated maturity level” in figure 1).

5. Conclusions

Thus, the proposed methodology for planning and evaluating the process of the educational institution organizational maturity managing allows you to create a mathematical model of organizational development in terms of the dynamic systems control theory. The classical dynamic model of the control system allows us to describe the behavior of such an indicator of the organization as a level of its maturity. At the same time, the actual data on the dynamics of the organization's maturity level make it possible to identify the parameters of the control system.

It is shown that in this class of tasks a workable tool is a deterministic model of a control system in discrete time, using the algorithm for constructing the optimal Kalman-Letov controller.

The resulting model provides the construction of management paths for organizational maturity levels that correspond to the priorities of the decision maker in the strategic management process. The resulting trajectory ensures the primary achievement of the maximum values of maturity levels by priority indicators, reducing the management costs of less priority ones.

It is also shown that the use of the Kalman filter allows you to set up the management of organizational maturity indicators in the conditions of interference and estimation error. This property of the model has significant practical value in the face of subjectivity in assessing organizational maturity indicators by experts.

The proposed model is scalable from the point of view of the organizational maturity indicators detailed management. The same formulas allow you to manage organizational maturity indicators with varying degrees of detail in their decomposition using matrix mathematics in the MatLab system.

Further work may consist in developing methods for predicting changes in the time and cost parameters of business processes as a result of changes in organizational maturity indicators. The solution to this problem will allow us to reach an assessment of the investment effectiveness of measures to increase organizational maturity.

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