

Energy Costs of Production and Project Assessment

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Abstract: Corporation cycle of developing a project and its implementation in the production to minimize energy costs is considered. A hierarchical control system for this cycle is reviewed for harmonizing the interests of its elements taking into account the human factor. A procedure for a comprehensive assessment of project to diminish the energy costs of production is proposed. The key factor of such an assessment is the energy costs rating of existing production. The problem of determination of such a rating is formulated. Conditions for such determination are obtained taking into account the interests of the elements of the corporation responsible for production. These conditions are illustrated by the example of determining the ratings of energy costs of production in large scale corporation Russian Railways. An example of a comprehensive assessment procedure for projects to reduce the cost of energy production in this corporation based on these ratings is given.

Keywords: Modelling and decision making in complex systems, intelligent decision support systems in manufacturing, intelligent system techniques and applications, project, assessment, energy, costs.

1. INTRODUCTION

Innovative energy-saving technologies and tools are an integral part of any modern manufacturing. Recommendations for implementing innovative projects within the framework of the concept of the new industrial revolution INDUSTRY 4.0 are given by Kagermann et al. (2013). The architecture of innovative production management was discussed by Bauernhansl et al. (2014). There are separate decision centers for design and production. Each center is headed by a manager who has at his disposal the necessary resources. The project management subsystem should be integrated into the general corporation management system. A similar architecture has been tested, for example, in the production of microelectronics (Shishkin et al., 2001). To some extent, one can speak of a decentralized management system, in which the human factor plays an important role (Tsyganov, 2010). To avoid controversy, a coordinator is appointed at the corporate level. Its functions are the organization and regulation of the corporate cycle of research and development in the field of energy conservation. The coordinator is faced with the problem of harmonizing the interests of two diverse subsystems of energy conservation related to design and production. The complexity of this problem determines the relevance of the study of managing the corporate cycle of developing energy-saving projects and their implementation in manufacturing.

In accordance with the concept INDUSTRY 4.0, production management is based on the widespread use of elements of artificial intelligence such as adaptation and learning algorithms. For example, adaptive algorithms for sustainable

development were proposed by Borodin et al. (2004). The use of adaptation and learning algorithms in corporate cycle of development and implementation of innovations considered by Tsyganov (2018, 2019a).

Consider the control of the corporate cycle of development and implementation of innovations in the field of energy costs shown on Fig. 1. The Production Control Center (in short, the Center) is responsible for production, including energy costs for it. The Center for Energy Saving Projects (CESP) creates and implements new tools and technologies aimed at reducing energy costs for production (Fig. 1). The senior management of the corporation provides general guidance and expertise projects (Enaleev et al., 2019a,b).

To manage such a complex system, an intelligent decision support system is needed. Its main goal is to reduce energy costs for production. Thus, a key factor in decision making is determining true significance of innovation to reduce the energy costs of existing production. In the event that innovation is truly needed, a comprehensive assessment of alternative projects to reduce the energy cost of production will also be required. We offer a scheme for evaluating complex projects characterized by several indicators. Some indicators are not quantifiable. They can be evaluated expertly in rank scales only. The problem arises of obtaining an integrated project assessment based on the consideration of both quantitative and rank heterogeneous indicators. We propose a procedure for converting quantitatively measurable indicators to rank indicators. Based on the rank indicators, an expert convolution scheme for only rank indicators using matrices and a convolution tree is formed. Such a scheme makes it possible to take into account the incomparable characteristics of projects in the final assessment. In contrast

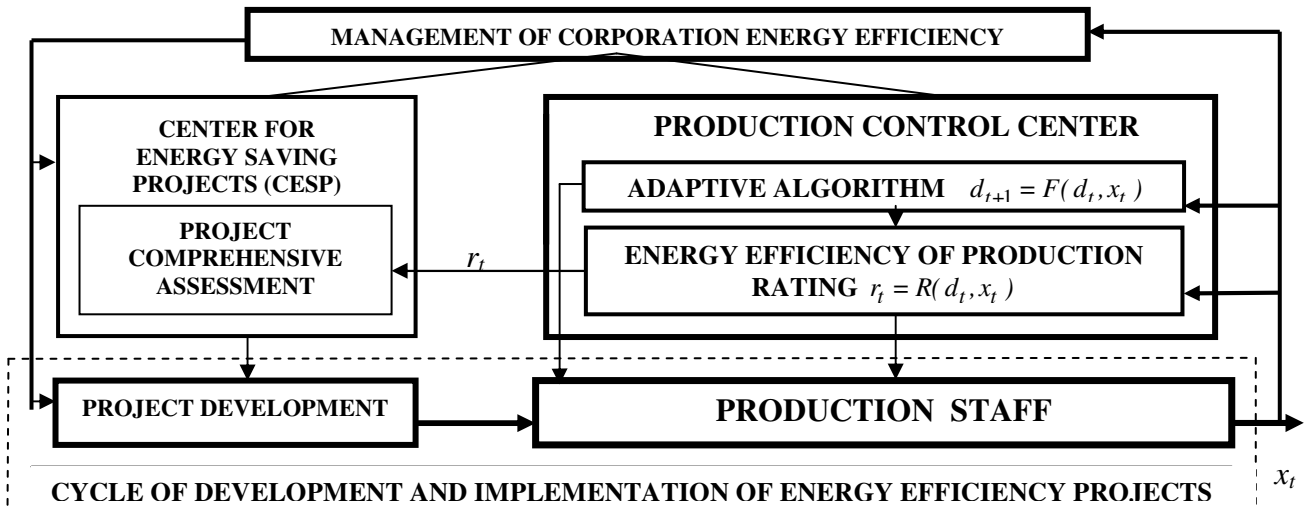


Fig. 1. The control structure of the corporative cycle of development and implementation of energy efficiency projects.

to the linear convolutions, which can evaluate the final estimates only for convex sets of criteria values, the proposed scheme allows us to evaluate the final indicator for non-convex sets of rank criteria. The proposed scheme develops the approaches of Burkov et al. (1993). It describes a method for converting continuous indicators into rank indicators and implements an algorithm for the formation of the final assessment in which the convolution structure based on the structure of the goal tree.

2. SIGNIFICANCE OF INNOVATION FOR THE ENERGY COSTS OF PRODUCTION

Consider the energy costs of production in value or kind (in particular, the cost of fuel, electricity, gas, etc.). Let the minimum energy costs for production (in short - the minimum costs) characterize the random variable m , $m \in M$. To determine the true significance of innovation in such a stochastic situation, the Center uses adaptive algorithm. Let's look at the ways of such adaptation with different awareness of the Center.

2.1 Monitoring minimum costs

Suppose the Center can observe m . Consider the task of determining one of two ratings - 2 (low energy costs) and 1 (high energy costs). To do this, we assign m to one of the two sets M_1 and M_2 which make up the set M , $M_1 \cup M_2 = M$. An incorrect rating leads to losses. The problem is to determine the separation of the set M , which minimizes average losses. For each unknown set M_1 and M_2 , we introduce loss functions $L_1(c, m) = m - vc$, $v < 1$, $L_2(c, m) = b(c - m)$, where c is an unknown parameter of the decision rule separating set M_1 and M_2 . Tsyganov (2019b) showed that the corresponding average losses $J(c)$ can be minimized using such an intelligent system technique as the adaptive algorithm:

$$c_{t+1} = F(c_t, m_t) = \begin{cases} c_t + \gamma_t v & \text{if } m_t < (b+v)c_t / (b+1) \\ c_t - \gamma_t d & \text{if } m_t \geq (b+v)c_t / (b+1) \end{cases} \quad (1)$$

where m_t is the value of random variable in period t , γ_t is adaptation coefficient, $c_1 = c^1$, $t=1,2,\dots$. Then Center can determine true energy cost rating:

$$r_t = R(c_t, m_t) = \begin{cases} 2 & \text{if } m_t < c_t(b+v)/(b+1) \\ 1 & \text{if } m_t \geq c_t(b+v)/(b+1) \end{cases} \quad (2)$$

The true rating r_t (2) corresponds to the minimum costs m .

2.2 Human Factor and Deficit of Information

We suppose that the Center do not know m_t , but can observe the energy costs x_t , $x_t \geq m_t$ (Fig.1). In order to determine the rating r_t , Center can use adaptive algorithm (1). Suppose the minimal costs m_t becomes known to production staff, who take advantage of this for own purposes. To avoid such undesirable activity of staff, tutoring mechanisms were proposed (Tsyganov, 2019c).

To determine the true significance of innovation to reduce the energy costs of existing production, consider the task of determining the rating r_t corresponding to the minimal costs m_t using the approach developed by Tsyganov (2019b). Suppose that the Center observes costs x_t , $x_t \geq m_t$, but the minimal costs m_t is unknown to it. Thus, the Center on the basis of x_t forms an estimate d_{t+1} of the parameter c_{t+1} using the algorithm (1):

$$d_{t+1} = F(d_t, x_t) = \begin{cases} d_t + \gamma_t v & \text{if } x_t < (b+v)d_t / (b+1) \\ d_t - \gamma_t d & \text{if } x_t \geq (b+v)d_t / (b+1) \end{cases} \quad (3)$$

$d_1 = d^1$, $t=1,2,\dots$. Also Center is using (2) to determine rating of costs:

$$f_t = R(d_t, x_t) = \begin{cases} 2 & \text{if } x_t < d_t(b+v)/(b+1) \\ 1 & \text{if } x_t \geq d_t(b+v)/(b+1) \end{cases} \quad (4)$$

In fact the rating f_t (4) is an estimate of the true energy cost rating r_t (2). Suppose that the higher is the rating f_t (4), the higher is the incentive for production staff. Suppose also that the minimal costs m_t becomes known to the staff before selecting x_t in period t , $x_t \geq m_t$. So the staff can choose x_t so as to maximize own objective function

$$V(d_t, x_t) = \sum_{\tau=t}^{t+T} \rho_{\tau} R(d_{\tau}, x_{\tau}), \quad (5)$$

where ρ is the discount factor, T is the staff foresight. The hypothesis of benevolence of staff in relation to the Center is supposed: if $m_t \in \underset{x_t}{\text{Argmax}} V(d_t, x_t)$ then $x_t = m_t$. The

Center is interested in true energy cost rating ($r_t = f_t$).

We show that if (3) holds, then f_t determined by (4) is equal to the true energy cost rating: $r_t = f_t$, $t=1,2,\dots$. The objective function $V(d_t, x_t)$ depends on ratings $f_{\tau} = R(d_{\tau}, x_{\tau})$, $\tau = \overline{t, t+T}$. By condition (4), as x_t grows, the current rating $f_t = R(d_t, x_t)$ does not increase. Further by (1), d_t does not increase with growth x_t when $\tau = \overline{t+1, t+T}$. Consequently, according to (4), the future rating $f_{\tau} = R(d_{\tau}, x_{\tau})$ do not increase with growth x_t when $\tau = \overline{t+1, t+T}$. So all terms on the right side (5) do not increase with growth x_t . Since $x_t \geq m_t$, then the maximum $V(d_t, x_t)$ is at $x_t = m_t$. Consequently, by virtue of the benevolence hypothesis $x_t = m_t$. Hence $d_t = c_t$, and from (1)-(2) it follows $r_t = f_t$, as required. This allows us to use (3) and (4) as the rating criteria.

We will illustrate the application of criteria (3) and (4) by the example of one of the characteristics of energy costs used in large scale corporation Russian Railways. There management quarterly observes the value of the specific energy costs per unit weight of the transported cargo per unit distance (SEC). The actual value of SEC s_t is matched with the corresponding plan p_t aimed on diminishing SEC. So the indicator x_t characterizing energy costs of production in quarter t , is calculated as the difference between actual and planned value of SEC: $x_t = s_t - p_t$.

To show the need for innovation more clearly, we will define four ratings of the energy costs of production - "Poor" (1), "Satisfactory" (2), "Good" (3), and "Excellent" (4). To assign such ratings, we consider the following two algorithms satisfying the conditions of the Theorem.

1. If the actual value of SEC s_t is greater that the plan p_t ($x_t > 0$), then the energy costs ratings 2 or 1 are assigned by (3) and (4).

2. If the actual value of SEC s_t is not greater that the plan p_t ($x_t \leq 0$), then the energy costs ratings 4 or 3 are assigned by analogy with (3) and (4):

$$r_t^* = R^*(d_t^*, x_t) = \begin{cases} 4 & \text{if } x_t \leq D_t \equiv d_t^* (b+v)/(b+1) \\ 3 & \text{if } x_t > D_t \end{cases} \quad (6)$$

$$d_{t+1}^* = \begin{cases} d_t^* + \gamma_t v & \text{if } x_t < D_t \\ d_t^* - \gamma_t d & \text{if } x_t \geq D_t \end{cases} \quad (7)$$

$d_1^* = d^*$, $t=1,2,\dots$. Combining (6) and (7) we obtain energy costs of production rating:

$$r_t = \begin{cases} 4 & \text{if } x_t \leq D_t \\ 3 & \text{if } 0 \geq x_t > D_t \\ 2 & \text{if } Q_t \equiv d_t(b+v)/(b+1) \geq x_t > 0 \\ 1 & \text{if } x_t > Q_t \end{cases}, t=1,2,\dots \quad (8)$$

Using (8), we can determine true significance of innovations in energy saving. The lower the rating r_t the more production needs innovations. In particular, the value $p_t + Q_t$ is the higher limit of the actual value of SEC s_t corresponding to satisfactory energy costs of production. If the value of SEC s_t is greater then $p_t + Q_t$, the innovations are required.

Note that the ratings similar to (8) can be defined for energy costs in kind (in particular, the costs of fuel, electricity, gas, etc.). All of them also can be used to determine true significance of innovation. The next step in decision making is a comprehensive assessment of alternative innovation projects to reduce the energy cost of production.

3. COMPREHENSIVE ASSESSMENT OF PROJECT ENERGY EFFICIENCY

Consider the problem of selecting energy efficient projects by the analysis of heterogeneous indicators set. To solve this problem, we will use the principles of a comprehensive project assessment proposed by Burkov et al. (1993) and developed by Korgin et al. (2017). The technique of the assessment includes the following five stages. Stage 1 consists in the formation of the most complete list of projects related to the technology field under consideration.

Stage 2 consists in compiling a list of indicators characterizing the projects under consideration. These indicators determine the diverse and possibly heterogeneous features of projects that are important for the assessment. It is necessary that the set of indicators fully reflect the goals of the organization for which we do the assessment.

At Stage 3, we form measurement scales for each indicator from the selected list. It seems rational to measure them in discrete scales since the indicators are significantly heterogeneous. For example, the discrete scales reflect the ratings "Excellent," "Good," "Satisfactory," and "Poor". In the presence of sufficiently accurate quantitative values of the indicators ratings can be determined based on appropriate

data processing. Otherwise, or in the case of a qualitative indicators the scales ratings are determined by experts.

At Stage 4, the order of pairwise convolution of indicators in the form of a convolution tree is established. Whenever possible we recommend when choosing indicators for pairwise convolution form meaningful characteristics of intermediate indicators. At Stage 5, we define the values of the convolution matrices corresponding to the vertices of the constructed tree. Burkov et al. (1993) proposed methods for moving from one convolution tree to another, including algorithms for converting convolution matrices that were defined for the original tree previously. Methods and examples of convolutional matrix construction are described by Korgin, N. and Rozdestvenskaya, S. (2017).

4. EXAMPLE: PROJECTS OF ALTERNATIVE ENERGY FOR LOCOMOTIVES

As indicated in Section 2, the key to determining the significance of innovation are the ratings of energy costs in existing production (8), which are regularly presented by the Center (Fig. 1). The analysis of ratings (8) in relation to the production of the large scale corporation Russian Railways showed that the most important innovations associated with the replacement of locomotive hydrocarbon fuels with alternative energy sources. Consider the use of the approach described in Section 3 for the formation of comprehensive assessments of projects using alternative types of energy for locomotives.

4.1. A Projects List

A review of the possibilities of using various fuel types for locomotives traction reveals the following options: synthetic liquid fuel; natural gas; solid fuel; hydrogen fuel cells; locomotive with a nuclear power. The list should also include promising innovative transport technologies: magneto-levitation and vacuum-levitation.

Synthetic liquid fuel. This refers to the use of all synthetic liquid fuels kinds obtained from plant materials. The main disadvantage of synthetic fuels is the lower calorific value in comparison with diesel fuel and, as a result, higher fuel costs. The problem is the development and implementation of fuel synthesis technologies and the provision of raw materials.

Natural gas. Its use is possible in compressed and liquefied forms. Tests have shown that the containers dimensions for compressed gas have greatly limited locomotive mileage, i.e. locomotives with a limited radius of action can use it (Volodin et al, 2002). The use of liquefied natural gas by locomotive traction is promising. The main problems associated with the use of liquefied gas are associated with both of cryogenic equipment and organization of production and supply of liquefied gas to railway transport.

Solid fuel. There is experience in creating gas-generating diesel locomotives and their operation on the railways. Coal gasification on transport gas generators is less efficient than

under stationary conditions (Volodin et al, 2002). The gas turbine locomotive operation on solid fuel can be carried out in two ways: on generator gas and on a pulverized coal combustion (Volodin et al, 2002). A gas generator locomotive requires greater productivity generator than diesel locomotives. For a gas turbo locomotive with pulverized coal fuel, the problem of improving the quality and completeness of solid fuel combustion is relevant. A gas turbine locomotive plant using pulverized coal requires preliminary preparation of pulverized coal. The combustion of pulverized coal leads to intense wear of the turbine blades. The main problems of using solid fuel for locomotive power plants are the need to increase efficiency engines, ensuring the reliability, service life of the gas generator and turbines, reducing additional costs for devices, storage operations, preliminary preparation of coal, and its loading.

Fuel cell locomotive. Hydrogen fuel cell engines have many advantages. However it is necessary to solve a number of complex problems: development of hydrogen storage technology; development of safety standards, storage, transportation, use, etc. creating a hydrogen infrastructure.

Locomotive with a nuclear power plant. The design of a locomotive with a nuclear power plant with a fast neutron reactor was developed in the 1980s. Options were designed for the layout of the power plant which can be used as a locomotive or a mobile power plant. Further work was discontinued. The creation and the use of such locomotives requires a large number of problems solution, primarily related to the safety of their operation and maintenance.

Promising transport technologies. Studies conducted to date show the promise of using magneto-levitation and vacuum-levitation transport technologies (Lapidus at al., 2017).

4.2. Indicators and Measurement Scales

The selection of indicators for the projects classification follows from an analysis of the organization's goals and an assessment of the degree of influence of the expected energy costs of the projects under consideration on these indicators. For clarity and interpretability of the classification system, if possible, it is desirable to use a limited number of indicators. Below is an example in which 6 indicators are set.

Table 1. The indicators list and their scales

Indicator	Indicator scale
1. Expected decrease in energy costs	1, 2, 3, 4
2. Technology security	1, 2, 3
3. Expected payback period	1, 2, 3
4. Capital investments	1, 2, 3, 4
5. Failure risk	1, 2, 3
6. Discounted reduction in energy costs over the life cycle	1, 2, 3, 4

The first indicator is determined by comparing the expected efficiency of the energy saving project per unit of cargo and unit of distance (z_i) with the forecast norms of this efficiency. These future norms are formed based on the current ranking

norms D_t and Q_t from (8), reduced by a coefficient k , $k < 1$. The value of the coefficient k is determined by experts. Thus, the rating of the first project indicator in period t is calculated similarly to rating (8) and is equal to:

$$r_t^1 = \begin{cases} 4 & \text{if } z_t \leq k D_t, \quad k < 1 \\ 3 & \text{if } 0 \geq z_t > k D_t \\ 2 & \text{if } k Q_t \geq z_t > 0 \\ 1 & \text{if } z_t > k Q_t \end{cases}, \quad t=1,2,\dots,$$

The second indicator determines the degree of security of the technology. A value of 1 means that security issues are not resolved; a value of 2 means a generally satisfactory level of safety and environmental impact, but there are deviations that can be eliminated without significant costs; a value of 3 means that the tool or technology for the project in question meets the safety requirements and environmental measures.

The third indicator characterizes the payback period after the anticipated start of the technology industrial operation. A value of 1 means a payback of more than 15 years; value 2 - payback no more than 10 years; a value of 3 means a payback of less than 5 years.

The fourth indicator characterizes the cost degree of creating an industrial design and the necessary infrastructure for the technology operation. A value of 1 means the amount of costs significantly exceeding the ability of the organization and interested structures to finance the project; 2 - the project requires significant investment by the organization and interested investment structures; 3 - the project can be carried out at the expense of large but acceptable investments; 4 - the project does not require large investments.

The fifth indicator characterizes the risks of project failure due to external and internal adverse conditions and insufficient justification of the reliability of the project: 1 - the risk of failure to fulfill is very high; 2 - moderate default risk; 3 - the risk of project failure is negligible.

The sixth indicator determines the energy costs characteristics of a product or technology during their life cycle taking into account the discounting of income. A value of 1 corresponds to a low cost reduction; 2 - a satisfactory cost reduction comparable to investments in the implementation of the project; 3 - good energy costs; 4 - reduction of energy costs significantly exceeds the costs of results project implementation. Also we take into account the rating r_t (8). The smaller is this rating the more important for the corporation to develop and implement an appropriate energy saving project.

Table 2. An example of the indicator values selection

Project	Indicator values					
	1	2	3	4	5	6
1. Synthetic liquid fuel	2	3	2	3	3	2
2. Compressed natural gas	3	3	2	3	3	3
3. Liquefied Natural Gas	4	3	3	4	3	4
4. Solid fuel	3	3	3	3	3	4

5. Fuel cells	4	3	3	3	3	3
6. Nuclear installation	3	1	2	1	1	2
7. Magneto levitation	3	3	2	3	3	3
8. Vacuum levitation	4	2	3	3	2	4

4.3. Convolution Tree

Experts establish the convolution tree structure (Fig. 2). To obtain an intermediate indicator it is advisable to choose indicators that are close in content, for example, a convolution of the 5-th and 8-th indicators (see table 1) characterizes the profitability of the project evaluated.

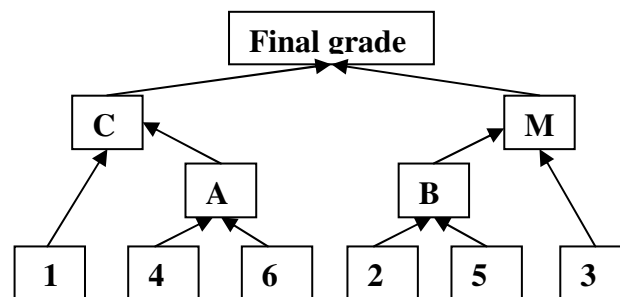


Fig. 2. The indicators convolution tree

4.4. Convolution matrices assignment and grades calculation

Tables 3-7 give an example of constructing convolution matrices. The first indicator entering determines the matrix line number, and the second indicator determines the column number. The values of the convolution matrix elements are established by experts at the stage of setting the estimation method for a given subject area, in this case, to assess the prospects of projects to create tools and technologies for using new types of energy for train traction.

Table 3. The convolution matrix A

Indicator 4	Indicator 6			
	4	4	3	2
	3	3	3	2
	3	3	2	1
2	1	1	1	

Table 4. The convolution matrix B

Indicator 2	Indicator 5		
	4	3	1
	3	2	1
3	3	2	

Table 5. The convolution matrix C

Indicator 1	Indicator A			
	4	3	2	1
	4	3	2	1
	3	2	1	1
2	1	1	1	

Table 6. The convolution matrix B

Indicator 3	Indicator B		
	4	3	1
	3	2	1
	2	1	1
	1	1	1

Table 7. The final grade convolution matrix

Indicator C	Indicator M			
	4	3	2	1
	3	3	2	1
	3	2	1	1
	2	2	1	1

The table 8 shows the results of the calculation of the valuation values for the projects under consideration. The final assessment allows arranging projects by priority.

Table 8. The calculation of intermediate and final grades

Project	Indicator values				
	A	B	C	M	Final grade
1. Synthetic liquid fuel	3	1	3	2	1
2. Compressed natural gas	3	3	3	2	2
3. Liquefied Natural Gas	4	3	3	4	4
4. Solid fuel	3	3	3	3	3
5. Fuel cells	3	3	2	3	3
6. Nuclear installation	2	1	1	2	1
7. Magneto levitation	3	2	3	3	3
8. Vacuum levitation	3	2	3	3	3

As follows from table 8, we reject projects 1, 2, and 6. Projects 4, 5, 7, and 8 require further research. We recommend project 3 for implementation. The above procedure for the preliminary selection of projects can serve as a decision support system using expert opinions. Proposed scheme may allow find more adequate estimates than by Technology Readiness Level (Mankins, 2009).

4. CONCLUSIONS

In order to constantly reduce energy costs in a large scale corporation, it is necessary regularly to realize the development and implementation cycle of projects. We modeled 2 stages of decision making in this cycle: determination the significances of innovations using the adaptive algorithm, and a comprehensive assessment of alternative projects. The significance of innovation is characterized by ratings and norms of energy costs. In a stochastic environment, they are calculated using the adaptive algorithm. However, production staff can take advantage of the lack of knowledge of management to achieve their own goals. Therefore, the calculated ratings and norms may not reflect the real possibilities of reducing production energy costs. The theorem shows how this can be avoided. Namely true ratings of energy costs of production can be determined

by establishing a direct relationship between them and staff stimuli. Further research may be related to the development of more sophisticated intelligent decision support systems for energy saving in the development and implementation cycle of projects in large scale corporations.

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