Construction of mathematical model of training and professional development of personnel support of additive production of REA

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Abstract. The article presents a model of training and advanced training of personnel support of additive production of electronic equipment components as a factor affecting the final quality of the product, which is a synergetic effect of human-machine interaction.

1. Introduction
A significant number of organizations and teams are involved in the problems of management of personnel support of science-intensive production of enterprises. Currently, the variety of aspects of the personnel of a modern industrial enterprise (organizational, educational, professional, social) imposes increased requirements for its training. Additive manufacturing is knowledge-intensive and is included in the list of critical technologies and to work with this technology requires highly qualified personnel. Modern trends in digital production, the Internet of things, aimed at the active formation of the industry of additive technologies, the use of these technologies is particularly promising in the production of housing elements of electronic equipment in which there is an acute problem of complication of the form of electronic devices and printed circuit boards, which require housing, taking into account their specificity and ergonomics, the use of additive technologies is relevant, because of their ability to take into account the features of the equipment at the design stage.

These circumstances determine the important role of additive technologies in the production of composite materials and ensure the proper level of quality that meets the requirements of the placed components of electronic equipment. In this regard, modeling of all aspects of activity and training is a complex problem, and the model itself can be so cumbersome that its use in the management of the training process will be difficult, and sometimes impossible.

2. The use of numerical simulation systems about polymers
The proposed mathematical model does not simplify the decision-making procedure and makes it possible to reasonably approach the development of alternatives and the choice of the best. The index of parallelism of work performance is determined by the formula:

\[ Y_n = 1 - \frac{\sum_{w=1}^{w} T_w}{\sum_{w=1}^{w} T_w, op} \]
\[ \sum_{i=1}^{n} T_{w,op} \] - the sum of the operations that make up an item;

\[ \sum_{i=1}^{n} T_w \] - the total duration of the production cycle of the product.

The index of parallelism of work performance is determined by the formula:

\[ V_w = 1 - \frac{\sum_{i=1}^{n} T_w}{\sum_{i=1}^{n} T_{w,op}} \]

\[ \sum_{i=1}^{n} T_{w,op} \] - the sum of the operations that make up an item;

\[ \sum_{i=1}^{n} T_w \] - the total duration of the production cycle of the product.

The integration indicator is calculated by the formula:

\[ C_{int} = \left( \frac{N_{KIS}}{N_{com}} \right) \times 100\% \]

where \( C_{int} \) – degree of integration of additive manufacturing;

\( N_{com} \) – total number of units/organizations;

\( N_{KIS} \) – number of production stages using additive technologies.

A documented procedure is developed, which extends to the acceptance control of the buildings of REA produced using additive technologies figure 1 [1,2].

**Figure 1.** Model of process of creation of the case of REA based on additive technologies with application of composite materials.

Work on the additive installation provides for direct interaction between man and equipment and requires, in addition to compliance with the technical parameters of the equipment, the task performed, also take into account the qualification of personnel who work on additive equipment, according to
sanitary and epidemiological rules 2.2.4.548-96, the result of the work of man and equipment is a finished product that does not require additional processing figure 2.

Figure 2. Experimental stand of work with polymers and prototyping of component base of REA.

In order to improve the efficiency of the personnel support of an industrial enterprise, it is necessary to develop a mathematical model, the structure and composition of which should determine the content and direction of theoretical and practical training (retraining, advanced training) of officials. In addition, the content of knowledge, skills and abilities of these officials objectively need to be constantly monitored in order to add new or reduce, and sometimes delete outdated or outdated information. The reason for such procedures is due to the natural desire to improve the company, the need to introduce innovative achievements of science and technology, as well as the limited time of training of personnel support of the industrial enterprise. With the use of the proposed model, it is possible to justify the order for the training of personnel in the object-subject area under consideration [6].

3. Mathematical model of training and advanced training of personnel support

The structure of the mathematical model of training of personnel support of the industrial enterprise is proposed to be presented in the form of the graph shown in figure 3.

The set of vertices $V_1, V_2, V_3, \ldots, V_r$ of this graph is put in correspondence with the set of elements of the training material. Under the item of learning material can be understood as a discipline, topic, or theme.

The set of vertices $S_1, S_2, S_3, \ldots, S_m$ of the graph corresponds to the set of official functions performed by officials.

Figure 3. The structure of model of the expert.
To a set of tops D1, D2, D3,..., Dq – a set of positions of the industrial enterprise.
Set of vertices R1, R2, R3,..., Rn – set of training requirements.
The arcs of the graph show:
\( \mu_{ij} \) - relationship between the elements of educational material;
\( \lambda_{ij} \) - connections of elements of educational material with service functions;
\( \beta_{ij} \) - connected elements of the educational material with the requirements for the training of officials;
the \( a_{ij} \) are the connection of utility functions with the training requirements of officers;
\( \gamma_{ij} \) - communication utility functions-post.
As follows from the description of the model structure, for its construction it is necessary to:

- To make (define) the list of positions of the industrial enterprise;
- Define a list of functions for each post;
- To develop (define) requirements for the training of specialist;
- Identify the elements of the training material and their characteristics;
- Identify all relationships between model elements.

As a result of construction of mathematical model of training of staffing of the industrial enterprise
the database in the form of relational model is formed. In this case, the set V1, V2, V3,..., Vr is formed
in the form of a directed graph \( G(V, M) \), in which the set of vertices V is aligned with the set of elements
of the training material, and the set of arcs M is the set of information links between them. To ensure an
effective training process, it is necessary to convert the original graph \( G(V, M) \) to the position of the
linear graph [2].

In this regard, the following optimization formulation of this problem is proposed. It is necessary to
convert the graph \( G(V, M) \) to linear, subject to all the relations of precedence, so that the total length
of the arcs takes a minimum value. Let's take an expression as a target function.

\[
L(Q) = \min \sum_{i=1}^{n} \sum_{j=1}^{n} (S_j(G) - S_i(G))d_{ij}q_{ij}
\]

under constraints:

\[
\sum_{i=1}^{n} F_i(G) = n
\]

\[
\forall \{s_i, s_j\} \in R(S_j(G) - S_i(G) > 0)
\]

where \( n \) is the number of sections in the structure of the training material;
\( F_i = 1 \) if \( S_i \) is included in the structure, 0 otherwise;
\( q_{ij} = 1 \) if \( S_i \) and \( S_j \) sections are adjacent, 0 otherwise;
\( d_{ij} \) - is the weight of the arc connecting the \( S_i \) and \( S_j \) sections.

To solve this problem, it is advisable to use the method of branches and boundaries. In this case, as
a method of branching the decision tree to choose a standard approach, and to find the lower bound to
determine the total length of the arcs of the graph [3].

It is proposed to determine the total length of the graph arcs by the formula [5,6]:

\[
L = L_1 + L_2 + L_3,
\]

where \( L_1 \) - is the total length of arcs incident only to fixed vertices;
\( L_2 \) - total length of arcs connecting fixed and non-fixed vertices;
\( L_3 \) - is the total length of arcs incident only to non-fixed vertices.
\[
L_1 = \sum_{i=1}^{q-1} \sum_{j=1}^{r-1} (x_{ij} - x_{ji})d_{ij}w_{ij}
\]
\[
L_2 = \sum_{l \in U, s \in P} (\min \{x_s - x_l\})d_{sl}w_{sl}
\]
\[
L_3 = \left( \sum_{l=1}^{q} n_1(n - q - l) + (r + 1) (m - \sum_{l=1}^{q} (n - q - l)) \right) d
\]

where

\(W_{sl} = 1\), if vertices \(s\) and \(l\) are adjacent, 0 is otherwise;

\(U\) – set of fixed vertices of a graph;

\(P\) – set of non-fixed vertices of a graph;

\[q = |U|\];

\(x_{sj} (x_{li})\) – the coordinate of the vertex \(s\) \((l)\) fixed on the \(j\)-th \((i\)-th\) place in the lattice graph;

\(d_{sl}\) – the weight of the arc’s incident to some vertices of \(s\) and \(l\);

\(m\) – the number of arcs that are not used when calculating \(L1\) and \(L2\);

\(d\) – the minimum weight of the arc.

We consider the solution of the optimization problem on the example of the discipline "management of innovative projects" direction 27.03.05 "innovation". For the development of educational material in this discipline it is necessary to study the previous disciplines of the curriculum. The relationship between the disciplines is presented in table 1 [5].

Table 1. Connection of the discipline "management of innovative projects" with other disciplines of the curriculum.

| Discipline | Name of Discipline | Previous disciplines |
|------------|--------------------|---------------------|
| V_1        | Mathematics. Mathematical analysis | V_1                 |
| V_2        | Management of innovation activities | V_1                 |
| V_3        | Mathematics. Probability theory and Mathematical statistics | V_1                 |
| V_4        | Informatics        | V_1                 |
| V_5        | Information Technology | V_3, V_4            |
| V_6        | Innovative management | V_5                 |
| V_7        | Innovative project Management | V_2, V_5, V_6       |

Graph \(G (V, R)\) for the discipline "management of innovative projects" is presented in figure 4.

The decision tree of the graph \(G (V, R)\) obtained by the branch and boundary method is shown in figure 5. Figures indicate the values of the lower limit- \(L\).

![Graph G (V, R) for the discipline «management of innovative projects»](image-url)
The optimal plan for placing the original graph figure 4 in a linear, presented in figure 6. Thus, the proposed mathematical model of training of personnel support of an industrial enterprise determines the content of training and justifies the need to change it (input, adjustment or removal). In addition, the solution of the presented optimization problem by the branch and boundary method figure 5 [7].

![Decision tree](image)

**Figure 5.** Decision tree.

![Optimal plan](image)

**Figure 6.** The optimal plan for placement of the initial graph in linear.

The developed model allows to find such sequence of passing of educational material (considering all relations of precedence) at which, the total length of arcs would take the minimum value.

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