Generation of project solutions on choosing of mechanical assembly production of the Industry 4.0 using operators of genetic algorithms

D A Zakoldaev¹, A V Gurjanov², A V Shukalov¹ and I O Zharinov¹

¹Faculty of Information Security and Computer Technologies, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, 49, Kronverksky Av., Saint Petersburg, 197101, Russia
²Stock Company “Experimental Design Bureau “Electroavtomatika” named after P.A. Yefimov”, 40, Marshala Govorova St., Saint Petersburg, 198095, Russia

E-mail: mpbva@mail.ru

Abstract. The current task of automatic generation of project solutions on choosing of the mechanical and assembly production of the Industry 4.0 smart factory is considered. Choosing of the mechanical and assembly production is a multi-criteria task, which is due to the variety of cyber and physical systems of different purpose. Choosing of the mechanical and assembly production requires to determine the space of project alternatives, find a suitable way of project solutions coding, and define the mechanism of the project solutions automatic generation. The chart of classes is presented which are the part of the automatic generation process of the project solutions on choosing the technological appearance of the Industry 4.0 production division. The way of coding the project solutions based on binary sequences is presented. The scheme of the general algorithm of the project solutions automatic forming based on genetic algorithms operators is presented as well.

1. Introduction
The current way of development of the modern mechanical engineering is [1] a task to project the mechanical and assembly production of an Industry 4.0 item designing company. The Industry 4.0 production company is a company functioning in an automatic mode using cyber and physical technological equipment and digital innovative technologies.

The Industry 4.0 innovative technologies are [2] cloud technologies, the industrial Internet of Things technologies, sensors technologies, technologies of Systems-to-Systems and Machine-to-Machine, technology of BigData and others. They are unified in the single information space of the company. The main advantage expected after the implementation of those technologies in the production process is the creation of a company which is capable to carry out a full production cycle of the item designing component manufacturing without human intervention.

The designing of such production is a complicated and multi-factoring task which must be solved with multi-parametric criteria of optimization. The proposed solutions [3] on how to choice the mechanical and assembly production of the Industry 4.0 are based on the mathematical operations of combinatorics that help to form a plurality of alternative project solutions. If the nomenclature of cyber and physical systems (CPS) [4–6] is big enough, and manufacturers and tactic and technical
specifications [7, 8] may differ, the forming space of project alternatives on how to choose the digital
distribution is going to be quite large.

To reduce the size of the project alternatives space and the time which is required
to find the best

solution, some new algorithms of automatic generation of project solutions must be obtained [9, 10]
based on the mathematical methods of the theory of probability. The most suitable for automatic forming
of project alternatives is the method of using mathematical operations of genetic algorithms. Genetic
algorithms [11, 12] allow forming the code combinations of project solutions to which
the special

operations of “crossing,” “mutation,” and “reproduction” can be used.

2. Project solutions formation principles
The chart of classes which participate in the project solutions automatic generation process on how to
choose the production division of an Industry 4.0 smart factory is given in figure 1.

Figure 1. The chart of classes which participate in the project solutions automatic generation process on how to choose the production division of the Industry 4.0.

The chart of classes is formed with semantic parameters transformed in mathematical units. The
initial data for forming the chart of classes is tactic and technical specifications \((x_1, x_2, ..., x_n)\) of cyber
and physical equipment. This equipment is given in figure 1 as models (brands) of equipment and names
of some equipment manufacturers. Mathematical folding

\[
e_{tajm}(x_1, x_2, ..., x_n), m = 1, 2, ..., M_j,
\]
of specific quality indicators of equipment can characterize a plurality of cyber and physical systems of
different purpose which are capable to support technological operations within the technological section \( i \), the production line \( j \) and the technological algorithm of the item designing component manufacturing \( a \).

Based on folding of the specific quality indicators of the equipment, the additive separable criteria \( f_k \left( e_{ajm} \right) \) of the quality of a production digital line (a workshop of a smart factory) in general are formed.

The plurality of project solutions is defined as a matrix \( e_{ajm} \) of the specific quality criteria for cyber and physical equipment. Each element \( e_{ajm} \) is given according to the quality criteria \( f_k \left( e_{ajm} \right) \), the value of which should not exceed the limit value of \( f_{\text{lim}} \left( e_{ajm} \right) \). The technological line of the Industry 4.0 cyber and physical production is given in figure 1 as a set of production machines complying with the closed cycle of production operations to manufacture an item designing component.

3. The methods of project solutions coding

The choosing algorithms of mechanical and assembly production suppose finding a project solution by searching through the whole tactical and technical specifications (TTS) and nomenclature of cyber and physical equipment. Such a way of generation of project solutions has the exponentially increasing calculation complication of the algorithm. Therefore, calculation of the parameters of the digital production workshop choosing, being done at the stage of projecting, may require a lot of time even when using a high processing computer (PC) which is a part of the designer automatic workplace.

Table 1. The coding principles of project solutions on how to choose the mechanical and assembly production of the Industry 4.0 item designing company

| \( i \), un. | Name of equipment | Equipment model | Equipment manufacturer | Code combination |
|-------------|-------------------|----------------|------------------------|-----------------|
| 1           | Printed circuit board (PCB) loader in line | 1 | 1 | C_1 0 1 0 — — |
|             |                   | 2 | 1 | C_1 0 0 1 — — |
|             |                   | 3 | 1 | C_1 1 0 0 0 — |
|             | Surface mount components installation machines | 1 | 2 | C_2 0 1 0 0 — |
|             |                   | 2 | 2 | C_2 0 0 1 0 — |
|             |                   | 3 | 3 | C_2 1 0 0 0 — |
|             |                   | 4 | 4 | C_2 0 0 1 — |
|             | Soldering automatic system of the double wave | 1 | 1 | C_3 0 1 0 0 — |
|             |                   | 2 | 1 | C_3 0 0 1 0 — |
|             |                   | 3 | 2 | C_3 0 0 0 1 — |
|             |                   | 4 | 3 | C_3 1 0 0 0 0 |
|             | PCB unloader from the line | 1 | 1 | C_4 0 0 0 1 0 |
|             |                   | 2 | 1 | C_4 0 0 1 0 0 |
|             |                   | 3 | 1 | C_4 0 0 0 0 0 |
|             | PCB washing system | 1 | 1 | C_5 1 0 — — — |
|             |                   | 2 | 2 | C_5 0 1 — — — |

To reduce the number of calculation operations, different ways of automatizing the searching of project solutions are used, which generally use a mathematical apparatus of genetic algorithms [11, 12]. The principle of coding of project solutions on how to choose the mechanical and assembly production of the Industry 4.0 item designing company is given in table 1. To code one unit of technological equipment (an equipment model of a particular manufacturer), a line of matrix \( C_i \) is used.
The plurality of project solutions of technological appearance of mechanical and assembly production of the Industry 4.0 item designing company may be expressed through such an equation:

\[
\begin{bmatrix}
1 & 0 & \ldots & 0 \\
0 & 1 & \ldots & 0 \\
\vdots & \ldots & \ldots & \vdots \\
0 & 0 & \ldots & 1
\end{bmatrix} = \begin{bmatrix}
1 & 0 & \ldots & 0 \\
0 & 1 & \ldots & 0 \\
\vdots & \ldots & \ldots & \vdots \\
0 & 0 & \ldots & 1
\end{bmatrix} = \begin{bmatrix}
1 & 0 & \ldots & 0 \\
0 & 1 & \ldots & 0 \\
\vdots & \ldots & \ldots & \vdots \\
0 & 0 & \ldots & 1
\end{bmatrix} = \begin{bmatrix}
1 & 0 & \ldots & 0 \\
0 & 1 & \ldots & 0 \\
\vdots & \ldots & \ldots & \vdots \\
0 & 0 & \ldots & 1
\end{bmatrix},
\]

where matrices \( C_i \) define the code combinations for the technological equipment of type \( i \), installed in digital production according to the principle of project solutions coding.

4. The algorithm of automatic generation of project solutions

Using operators “crossing,” “mutation,” and “reproduction” from the mathematical apparatus of genetic algorithms [11, 12] includes such a way of automatic generating of project solutions, where the project alternatives are formed randomly by choosing (using the generator of random numbers made with the software) the bit combinations of matrices lines \( C_i \) in a random way.

![Figure 2. The scheme of the general algorithm of automatic formation of project solutions using the operators of genetic algorithms.](image)

The scheme of the general algorithm of automatic formation of project solutions using the operators of genetic algorithms is given in figure 2. The base of the algorithm is the probability approach to forming the space of project alternatives. The names of the CPS samples are randomly excluded from the space of project solutions to compose a single technological line of the Industry 4.0 automatic production. These CPS samples receive a unique binary code.

The code is being modified randomly (bit units which characterize some equipment of CPS in the
position code change their location within the code). As a result, the new CPS choosing which corresponds to the technological line is being done. Due to this, the generation of project solutions on PC of the automatic workplace is being formed into the space of project alternatives.

5. Conclusion
Using the operators of genetic algorithms to generate project solutions cannot guarantee that the optimum project solution will be found when one can reach the maximum of the projecting object quality criterion (mechanical and assembly production of the Industry 4.0). However, it may significantly accelerate the machine reprocessing of the project solutions options because of the even (random) covering of the project alternatives space. The mathematical apparatus for generating of the project solutions can be given to the designer in form of the cloud service.

The optimal project solution for automatic generation of project alternatives on the base of the mathematical apparatus of genetic algorithms should be defined by the projecting purpose. The type of this purpose defines the rate of the algorithm correlation which is given in figure 2. The rate of the algorithm correlation determines the time which is necessary to comply a project procedure of searching for the suitable choosing of mechanical and assembly production of the Industry 4.0 smart factory.

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