The application of Krone model to describe the production facilities of the Industry 4.0 smart factories

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Abstract. An actual task is to synthesize project solutions of production facilities of the synthesis of Industry 4.0. Project solutions is based on the description of digital production and its functionality. The description must be based on the Krone model. The Krone models use morphological tables to create general descriptions. This approach supposes the modified model of Krone when the morphological tables are changed with mathematical matrices. A mathematical apparatus of algebra may create the automatic processes descriptions to generate project solutions to create a production facility of the Industry 4.0. A scheme of the Krone model components may interact where you can use multi-parameter criteria. You may generate a project solution to create a digital production facility with given optimal requirements. It is clear that the synthesis of the digital production model must be done after the creation of construction, program and technological documentation for an item designing component. A perspective way of digital production projection is a way of automatic generation of project solutions being done with a mathematical apparatus of genetic algorithms.

1. Introduction

Smart factories of the Industry 4.0 [1-3] projection is a good thing for item designing industry. Smart factories automatically perform the technological cycle of the item designing component manufacturing with unmanned production technology. The main production unit of a smart factory is a cyber and physical system [4, 5]. Today the market of cyber and physical systems (CPS) is formed and the manufacturers of automatic technological equipment propose their goods to clients. Each model of CPS has their own tactical and technical characteristics which influence the general outcome of the smart factory performance.

To project a mechanical and assembly production where project solutions are varied, some procedures based on particular mathematical criteria must be applied [6, 7].

In practice [8, 9] the projection of mechanical and assembly production has two approaches to project an item designing company. The first approach is to implement some quality criteria in project procedures to describe the activity of some technological lines and sections. The second approach which is more useful is to describe project procedures and objects as a single unit [10, 11]. This is used to implement the general methods to describe the components and functionality of mechanical and
assembly production of the Industry 4.0 to generate project solutions. The mathematical models of Krone will be appropriate for this task based on morphological analysis.

2. Production infrastructure of an item designing company of the Industry 3.0

Item designing components in the Industry 3.0 are done with technological equipment united in technological lines. There is special personnel for technological equipment maintenance which are engaged in the process in semi-automatic mode. In semi-automatic mode the human personnel is engaged in the following operations:

- putting blanks into machines (lathe, drill machines and others) and evacuating the manufactured component from the machines;
- putting PCBs (printed circuit board) in the input area of radio and electronic components placers or in solder trimming ovens inputs and later parts will be evacuated later;
- putting units into ultra-sonic baths of flux taken away with solder residue from the printed circuit board where the PCBs will be evacuated later from the baths;
- placement of units (radio and electronic modules) in the automatic working places checking sections to check out the working functionality of the items and etc.

So semi-automatic mode of item manufacturing supposes that human personnel to prepare technologically the operations and the key technological operations are done automatically. In this way the personnel is a part of the main technological line.

The hand work of specialists of different qualifications is just one disadvantage of the semi-automatic mode, but there are some more:

- the high percentage of scrap because of the low automatizing level of technological routes completion of item designing components manufacturing;
- the extended time required for an item designing component to be manufactured because works require high qualification and high expenses for the company;
- the necessity of good logistics for blank transferring (assembly units of the future components) to realize operation within a workshop or between workshops in the item manufacturing;
- the necessity of documents creation within an item designing company when drawings, text and other types of construction (CD), program (PD) or technological (TD) documentation will be used inside the company in its paper form, which is suitable for its perception and others.

3. The principle of automatic production creation

To increase the level of automatizing the manufacturing process and to transfer an item designing component to the automatic production mode, the company must implement:

- robotized cyber and physical systems to complete mechanical and physical and chemical operations automatically under the program control;
- new informative technologies which are capable to work automatically in item designing component manufacturing (technologies Systems-to-Systems, Machine-to-Machine, industrial Internet of Things (IoT), sensors, cloud technologies, BigData technology to process the vast amount of industrial data, augmented reality technology and other).

The companies which have such technologies and cyber and physical equipment today are known as the Industry 4.0 companies which have flexible automatic productions.

To implement the company infrastructure, the robotized transport system may create the company technological lines which may automatically transport the blanks within the workshops and produce the components. The completed assembly units will be stored in the storage (or from the storage) with robotized systems as well.

The Industry 4.0 companies with closed cycle loop manufacture the item designing components automatically and require good specialists with professional knowledge of:

- exploitation, maintenance, field running works and repairs of robotized cyber and physical systems of industrial purpose;
• the application of informative technologies in digital production and integration of technological processes automatic control systems including automatic systems of technological preparation production and others.

Unlike the item designing companies of the Industry 3.0, the personnel of the Industry 4.0 company is more like an auxiliary system of production. The personnel function in the Industry 4.0 is to monitor the functionality of cyber and physical systems and to monitor the technological operation completion state in the work chambers of cyber and physical systems. When necessary the personnel of the Industry 4.0 item designing company make decisions of situation management. The personnel access to the production data occurs through the technology of industrial IoT and cloud services.

4. Findings
The Krone model is a description of complicated technical systems and its components based on the mathematical apparatus of morphological analysis. The Krone model may be based on morphological tables which describe functionally sub-systems that compose the system and their algorithms. If such model describes an item designing company of the Industry 4.0, the morphological tables must have:

• the marks of cyber and physical systems of different manufacturers which are the part of an automatic technological line;
• the mathematical models of cyber and physical systems which describe the technological equipment functionality (the mathematical description itself is a discreet system terms of automatic control with random delay).

A Krone model for a smart factory of the Industry 4.0 is shown in figure 1 and includes a nomenclature of parts of the same type (sub-systems) where each element is manufactured in a distant place. In the Industry 4.0 it means that an oven of assembly and montage workshop for solder trimming can be done by two (several) manufacturers, but the product functionality will be the same. Oven specifications of different manufacturers are different and the quality value of assembly and montage workshop may differ, but the workshop consistency and its functionality will be general. This is the main idea of the Krone model for the production division of the Industry 4.0. The account of entire nomenclature for technological equipment which is available in the market with different tactical and technical specifications will create a space of project solutions of particular type.

Mathematical models of cyber and physical systems which is the second morphological table of the Krone model creates its own space of project solutions where project alternatives may differ in its grade of mathematical description adequacy to the real physical item. Discreet recurrent equations of different types may differ in accuracy of technological equipment description. The linear intent to describe cyber and physical systems is an origin of its own class of mathematical models which may add to the project solution space results.

The key point of the Krone model is the unification of two morphological tables where each one of them describes its own part of the production system of the Industry 4.0 item designing company. The scheme analysis given in figure 1 reveals that the rules aimed to unify morphological tables are defined with the item manufacturing route sheets and the description of some technological operations.

Route sheets and technological operations description copy the equipment in details and copy in the same way the technological process being done with that machine. So the route sheet of the manufacturing process in each moment is objective for two spaces of project solutions where each of them has its own morphological tables. A route sheet as a part of documentation for the item can be done only after project solutions works (the preparation of construction and program documentation). It means that a new item designing component in production requires new ways for cyber and physical systems to be self-organized keeping in mind the peculiar things of the technological operations.

The result description of the Krone model is:
• general list of components of digital production of the Industry 4.0;
• general description of digital production and its functionality which is a part of speaking plurality of project solutions.
Such form of describing a digital production is for item designing companies of particular type (optical item designing, radio and electronic item designing, mechanical production and others). General description of digital production functionality is good for the scheme stage of the new digital plant.

The final consistency of digital production where a particular type of items will be manufactured is carried out at the stage of work projection and by cutting the plurality of project solutions. The cutting of plurality requires some criteria based on the mathematical operations of doubling. The cutting criteria (optimal criteria) consider the technical task (TT) to project a digital production to define the quality of new plant activity. The speaking plurality cutting result is the project solution to describe a particular digital production which will be realized in the plant (smart factory).

5. Conclusion
The projection of mechanical and assembly production of the Industry 4.0 is an actual task for designing the item. To create smart factories which function automatically, some tasks must be defined and solved to synthesize complicated technical systems based on multi-criteria project solution optimization.

Traditionally the multi-criteria optimization requires the mathematical operation of doubling (additive and multiplying doubling) of private quality criteria of complicated technical system and comparison of the integral quality criteria with the functionality. To solve the projection task of mechanical and assembly production of the Industry 4.0, there is an approach based on multi-parameter criteria of Volkovich based on a step by step procedure of optimization. Volkovich criterion [6, 7] is in accordance with the mathematical apparatus of morphological analysis and can be adopted to project procedures of project solutions generation if the morphological tables will be changed with matrices.
The mathematical apparatus of vector algebra based on matrix algebra may realize project operation with the computer of the designer automatic work place, which helps to generate project solutions automatically.

Krone models are a good instrument for a designer to create a general description of mechanical and assembly production of the Industry 4.0 and its functionality. To automatize the generation of project solutions to synthesize the production of the Industry 4.0, there is the mathematical apparatus of genetic algorithms. Genetic algorithms may generate automatically project alternatives which are different in its consistency and quality criteria for production division (for example, production speed; a transfer of a unit given for the length of a technological line, etc.).

References
[1] Bonilla S H, Silva H R O, Terra da Silva M, Goncalves R F and Sacomano J B 2018 Sustainability 10(10) 3740
[2] Zuehlke D 2010 Annual reviews in control 34 129-138
[3] Lee E A 2015 Sensors 15 4837-69
[4] Zhang Ch, Jiang P, Cheng K, Xu X W and Ma Y 2016 Procedia CIRP 56 360-365
[5] Liu Ch, Jiang P 2016 Procedia CIRP 56 372-377
[6] Gurjanov A V, Zakoldaev D A, Shukalov A V and Zharinov I O 2018 IOP Conference Series: Materials Science and Engineering 327 022111
[7] Gurjanov A V, Zakoldaev D A, Shukalov A V and Zharinov I O 2018 Journal of Physics: Conference Series 1059 012010
[8] Radziwon A, Bilberg A, Bogers M and Madsen E S 2014 Procedia engineering 69 1184-90
[9] Gjelum N, Mladineo M, Veza I 2016 Procedia CIRP 54 158-163
[10] Kim J H 2017 Journal of industrial integration and management 2(3) 1750011
[11] Qian Zh, Yu Y, Fan G 2015 Applied mathematics & information sciences 9 1981-92