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The description of the Industry 4.0 cyber and physical production division based on Petri net models

A V Gurjanov[1], D A Zakoldaev[2], A V Shukalov[2], I O Zharinov[2]

[1] Director, Stock Company «Experimental Design Bureau «Electroavtomatika» Name After P A Yefimov, 40, Marshala Govorova St., Saint Petersburg, 198095, Russia
[2] Department of Computer Design of On-Board Computer Equipment, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, 49, Kronverksky Av., Saint Petersburg, 197101, Russia

E-mail: mpbva@mail.ru

Abstract. The Industry 4.0 production division base is cyber and physical systems. They function automatically using some additive technologies, the Internet of things technology, sensors technologies and etc. To project the cyber and physical production divisions they can use some mathematical models based on Petri nets. The Petri nets let describe and research discrete events processes which are a part of cyber and physical production division. A Petri net structure is given to describe production processes in the Industry 4.0 devices designing company. The Petri net model is done in the environment VisualPetri 1.2.

1. Introduction

The modern industrial production develops rapidly in the direction of new information technologies and equipment (cyber and physical systems) implementation in the devices designing components manufacturing technological processes. The actual point of company industrial capabilities transferring to working with the new technological equipment is the exchange of the automatized lines of component production for the robotized automatic lines. Such a transfer exists today as practical implementation of the ideas of «the fourth industrial revolution» which is widely known in the science literature under common definition Industry 4.0.

One of approaches how to create and research the digital twin of the Industry 4.0 devices designing mechanical assembly production is the approach when they describe the devices designing component (parts) using the oriented graphs model. The graph model of the adequate discrete events dynamics of the devices designing manufacturing process can be described using a general theory mathematical apparatus known as nets of Petri.

The Petri nets theory [1-3] and available means how to model discrete processes (events) can be used to describe a variety of discrete states of the Industry 4.0 [4-6] production division of the components manufacturing technological routes which have the following properties:

- manufacturing operations completion parallelism in different mechanical assembly production sections technological lines;
- manufacturing operations completion asynchronism in different mechanical assembly production sections technological lines;
- the hierarchy of component structure and its assembly algorithm which is based on the

technological difficulty increase of some assembly units.

The parallelism, asynchronism and hierarchy of the devices designing components manufacturing technological routes can be explained with some specific features of the Industry 4.0 devices designing company mechanical assembly production organization — systems of discrete events which includes:

- the incoming flow of materials and assembly units in separate production lines (component transferring inside the workshop with transport robotized system);
- state transformation of materials, components and parts in separate production lines and sections which is based on technological operation completion (for example, component unit automatic assembly, lacquering and anti-moisture covering application on a printed circuit board with installed components, component electrotyping which was obtained with some additive technologies application and etc.);
- floor plan and nomenclature of the engaged technological equipment to manufacture the component in the devices designing company mechanical assembly production sections.

So the task of the mathematical model of creation and research of the Industry 4.0 devices designing company mechanical assembly production based on the Petri nets theory is actual one.

2. Petri nets component to describe mechanical assembly production

The primary components of Petri nets graphical descriptions are:

- place (in several literatures they use some equivalents «position», «top»);
- transfer (sometimes they use equivalents «barrier»);
- connection (sometimes they use equivalents «arc»);
- marker (sometimes they use equivalents «chip»).

The figure 1 shows the typical components of Petri net which are used to describe devices designing company manufacturing processes.

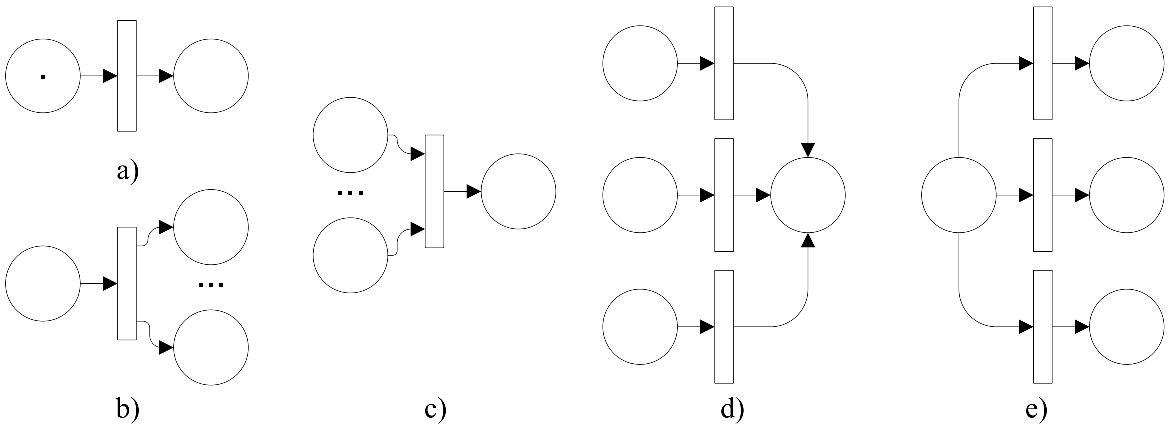

Figure 1. Typical components of a classical Petri net:
a) a net of a single transfer with one entering and one exiting places;
b) a net of a single transfer with one entering and several exiting places;
c) a net of a single transfer with several entering and one exiting places;
d) a net of three transfers with three entering and one exiting places;
e) a net of three transfers with one entering and three exiting places.

When they describe discrete events of mechanical assembly production processes the place of Petri nets is each production position in the workshop section and condition of manufacturing operation completion in this position. The graph shows the place of Petri net as a circumference.

When they describe discrete events of mechanical assembly production processes the transfer of Petri nets is the completion result of separate (or enlarged — which depends on the technological process research scale) technological operation. The graph shows the transfer of Petri net as a vertical rectangle («barrier»).

When they describe discrete events of mechanical assembly production processes the connection of Petri nets is component transfer (part, assembly unit, material, component and etc.) in the technological lines and production sections during component manufacturing. The graph shows the connection of Petri net as a graph arc — line (one ordinary or several repeated) with an arrowhead which connects several net components (place, transfer). The arrowhead direction is the component transfer direction (its assembly units) in the mechanical assembly production during its manufacturing in the devices designing companies.

When they describe discrete events of mechanical assembly production processes the marker of Petri nets is an object (component, part, assembly unit and etc.) on which the manufacturing operation is being done in a particular manufacturing position. The graph shows the marker of Petri net as a point («chip») which is located inside the circumference — place. The marker position in the place circumference is the initial state — the initial mesh of Petri net. In a single circumference there could be several marker points. If there are more than seven points than according to the rules of Petri net they show only the resulting number (the number of markers) inside the circumference.

The marker transferring from one circumference to another which means transfer completion is being directed according to the direction of the connection arrowhead (mingled states) which shows the component transfer in the production and which is the result of condition completion — a separate manufacturing operation in the devices designing component manufacturing technological route.

So the marker transferring (the marker transferring from entering place to the exiting place for corresponded transfer) in Petri net describes the dynamics of mechanical assembly production sections is a result of technological operation completion (a flow of events) of the general technological route component manufacturing and characterize the dynamics of manufacturing system behavior in the space of devices designing company states.

According to the general rule when completion is done the marker from its entering place transfers to its exiting place. The number of transferring markers is equal to the number of connections. The marker transferring can be done only if the number of markers in its entering place is equal or higher than the times of the corresponded connections «place-transfer». So two varieties provide the functionality of Petri net:

- a variety of step by step transfer completions which shows the completion of separate technological operations in the production;
- a variety of available Petri net meshes which number can characterize the transfer of materials, parts and components in the mechanical assembly production technological lines.

It is clear that after the completion of each transfer Petri net becomes an information similarity of discrete events manufacturing process for the Industry 4.0 devices designing company.

3. A Petri net model for the Industry 4.0 cyber and physical system

The Industry 4.0 devices designing company mechanical assembly production organization is based on the robotized cyber and physical systems automatic technological lines implementation. The industrial purpose of cyber and physical system according to its functionality manner belongs to the automatic control digital system class with a random delay. The property of system «digitalizing» can be explained with some digital components which work in discrete time with the principles of program control.

Cyber and physical system is realized [7] with a system of detectors (sensors technology), gears, controller and a feedback channel to provide control and quality of technological operations completion inside the system work chamber. Cyber and physical system random delay can be explained with the system support of the user remote access technology using the Internet of Things (IoT – Internet of Things) using protocols of guaranteed pings provision and remote storage technology to organize the control of system functionality [8-10].

It is clear that IoT technology application to organize the Industry 4.0 devices designing company production section is more profitable than the technology M2M (Machine-to-Machine) which is applied today in the Industry 3.0 companies.

The analysis of the IoT technology properties which is the base of cyber and physical system functionality shows that not only the physical channel of the manufacturing technological operations completion exists which is the purpose of that system but there is also parallel virtual flow where the technological operation completion is the parameter calculation of component digital model. The virtual flow is done on the level of IoT remote storage servers.

So each Petri net transfer on the technological process completion physical level is equal to the corresponded transfer on the cyber level. The figure 2 shows Petri net which corresponds to the cyber and physical system and includes the flow parallel structure of the Industry 4.0 devices designing company manufacturing process.

The transfers that shows the technological operations completion on the physical level in the figure 2 are shown as «barriers with fillings». The transfers that shows the technological operations completion on the cyber level in the figure 2 are shown as «barriers without fillings». The dot and line arrows show the correspondence of barrier and technological operation (on physical level) or barrier and component digital model (on cyber level) in figure 2.

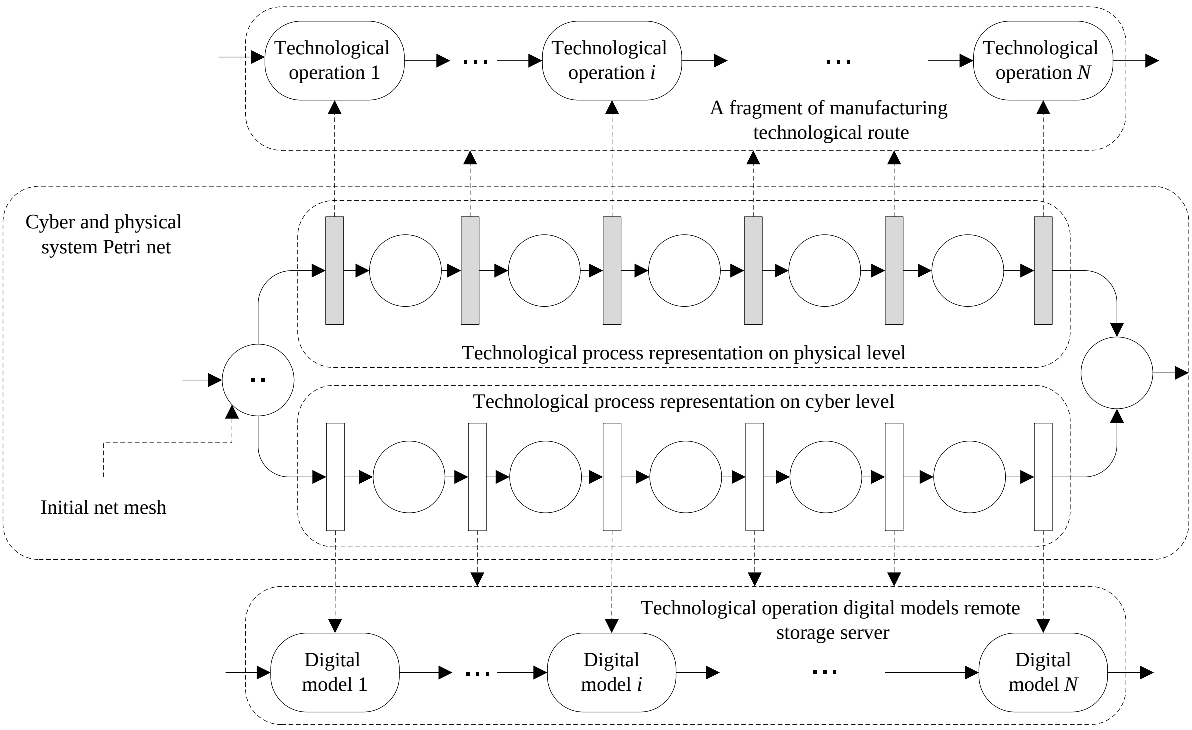

Figure 2. Petri net that shows technological process of the component manufacturing (part) with cyber and physical application in the Industry 4.0 production company.

Additionally to the process description of the Petri net cyber and physical systems shown in figure 2 where places on physical level are corresponded to:

- cyber and physical systems controller;
- the IoT wireless net controller to organize information exchange between technological equipment in a production section (workshop);
- the control command digital to analog converter which the controller sends to the work chamber gear where component manufacturing technological operation is being done (part);
- the cyber and physical system work chamber gear;
- devices designing component technological process manufacturing work chamber (assembly unit);

- the technological process completion state detectors and the technological equipment state detectors;
- an industrial data analog to digital converter which are received from the cyber and physical system sensors sub-system.

The marker location in the Petri net initial place circumference is according to the rule of the initial net mesh. The number of located markers depends on the initial functionality condition of a particular cyber and physical system and can vary. For example, for a robotized automatic component installer which is a part of the SMD (SMD – Surface Mounted Devices) section the number of the initial marker is equal to the number of the installing on PCB (PCB – Printed Circuit Board) radio devices components (resistance, microchips, capacitors and etc.) and one more (the PCB itself). For a 3D-printer (D – dimension) a single marker inside the place circumference is equal to the desired volume of metal powder which will be baked with a laser to manufacture a component which is a part of target device and etc. The figure 3 shows the generalized Petri net structure for the Industry 4.0 devices designing company mechanical assembly production description.

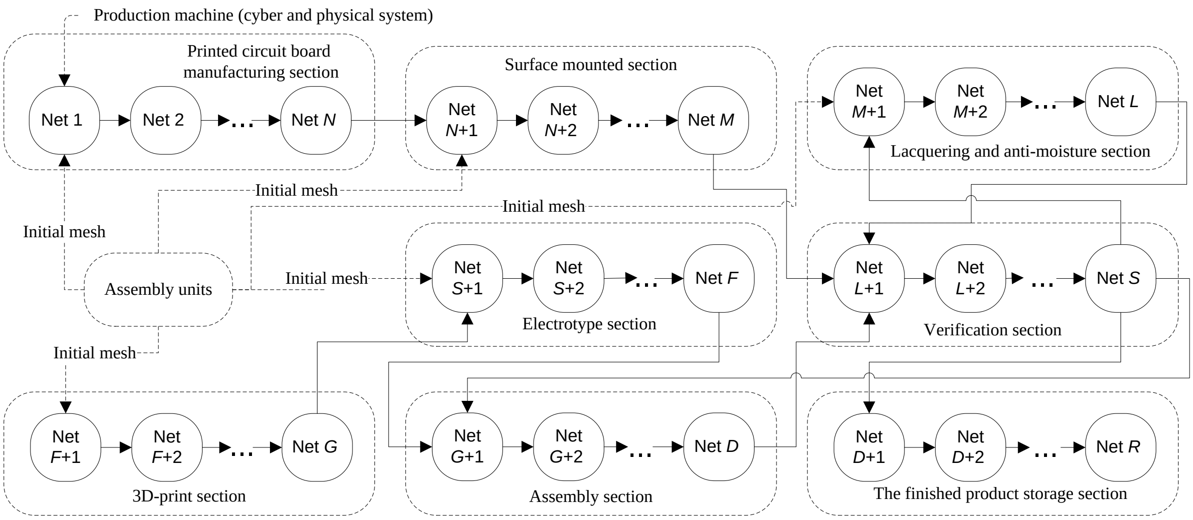

Figure 3. Petri net structure for the Industry 4.0 devices designing company mechanical assembly production.

4. Petri net modeling which describes the Industry 4.0 mechanical assembly production

For the available instrument research of the proposed Petri net and properties of the corresponded devices designing company mechanical assembly production on the level of discrete events there can be used several program environments and modeling instruments. The most popular instruments according to the practice are:

- Petri NetWork 2.0 has an advantage of easily usable graphical editor to synthesize a Petri net;
- The Petri Net Kernel 2.0 has an advantage of easily for user to apply some modeling instruments when they create a Petri net;
- HPSim has an advantage of included modeling time support in the modeling environment;
- VisualPetri 1.2 has an advantage to model several technological and business processes which are part of automatized (automatic) productions.

The instrument VisualPetri 1.2 is a program instrument with an open source-resource with a free code freely distributed in the internet with the license General Public License which explains its application to model Petri nets which describe the Industry 4.0 devices designing company mechanical assembly production in the initial project stages of the future digital company production sections. The figure 4 shows an example of the VisualPetri 1.2 modeling program work window of the discrete events system with a Petri net fragment to describe a cyber and physical system.

The Petri net discrete events analysis which structure is shown in figure 3 in the modeling

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environment VisualPetri 1.2 shows that the proposed Petri net structure option has the property of attainability which shows the possibility of practical tasks solutions which has the Industry 4.0 devices designing company mechanical assembly production.

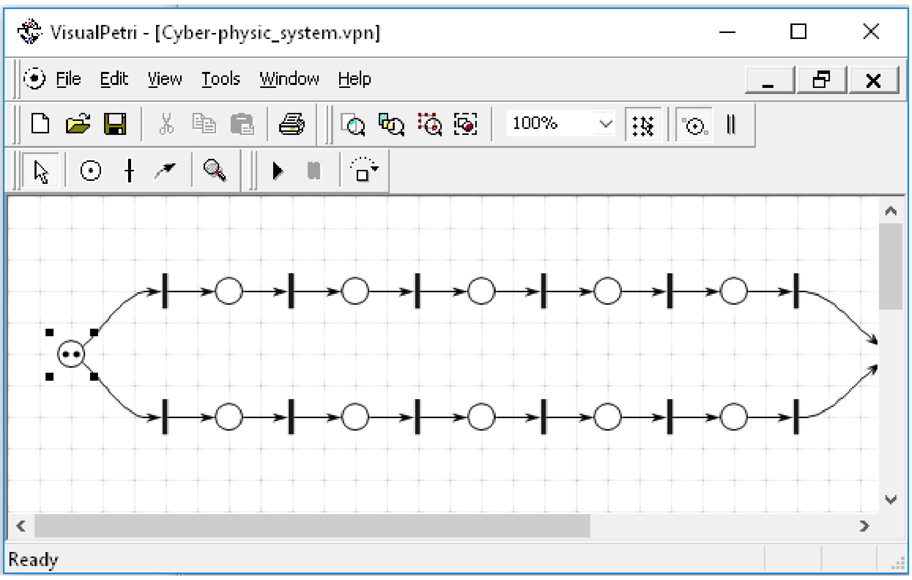

Figure 4. VisualPetri 1.2 modeling instruments work window of the discrete events system with a Petri net fragment to describe a cyber and physical system.

5. Conclusion

To research the Industry 4.0 devices designing company industrial processes on the stage of sketch and technical project it is necessary to create a digital twin of the mechanical assembly production. A mechanical assembly production digital twin can be a model which made graphically as a Petri net and with program support of matrix algebra mathematical apparatus and formal logic theory.

Petri nets modeling in the specialized imitation environments gives a chance to research process character of the discrete events states space which are part of the production and install possibility and practical significance of the digital industrial company practical realization on the base of the Petri nets approved basic properties (attainability, limitation, security, viability.

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