Building a business process management model for a «smart» enterprise

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Abstract. The article examines the possibilities of using Petri nets in the context of automated business process management of a «smart» enterprise. On the basis of the studied methodology, a system Petri net is built, adapted to «smart» production. The network architecture is clearly presented and deciphered in detail, events and transitions implemented within the framework of various functional subsystems of an industrial enterprise integrated into a single information platform are described. The proposed Petri net can help reduce the transaction and transformation costs of reengineering associated with the digital transformation of the enterprise.

1. Introduction
Modern manufacturing enterprises, focusing on improving the competitiveness and quality of products, process productivity, cost optimization and resource saving, invest in the development of automated systems, the construction of digital platforms, the key task of which is to minimize errors and failures in the operation of equipment, prevent defects, reduce the time to perform operations. In this context, the development of digital technologies allows us to build processes in such a way that the enterprise management system acquires the features of a network of data flows built on the principle of end-to-end business processes. Thus, the architecture of «smart» production is formed, which meets the needs of consumers and takes into account the interaction with suppliers.

Business processes of «smart» production are broadcast in the information environment of an industrial enterprise, the responsible person is always determined, the performers of each process are fixed, indicators for evaluating the effectiveness of processes are fixed, and acceptable parameters of processes and operations are indicated in relation to production processes.

Quite complex processes and reactions are typical for petrochemical industries, for which the automation of processes, the digitalization of control systems is a particularly urgent problem [1]. A network approach to enterprise management is possible by building a single information platform that integrates the business processes of the enterprise [2]. At the same time, the integration of information systems that support various business processes of an industrial enterprise makes it possible to standardize processes, operations, and documentation, taking into account the best industry practices [3].

In our opinion, the methodology of Petri nets, which is based on the theory of directed graphs and was studied in detail by J L Peterson [4], allows us to succinctly reflect the automation of «smart» production processes. The study and implementation of the capabilities of Petri nets is given wide attention by researchers. In particular, the scientific literature presents the results of the use of Petri nets...
for modeling the process of wastewater treatment at petrochemical enterprises [5], data sorting – parallel and asynchronous [6], prevention of chemical accidents [7], traffic flow management [8], etc.

Our research is aimed at building a model for managing the processes of an industrial enterprise in the context of production intellectualization based on a Petri net. All processes of «smart» production are based on the fundamental principle of digitalization – a systematic approach to managing the end-to-end flow of materials, information, and finance. In this regard, it is particularly important to build a business process model that comprehensively describes the most important aspects of the functioning of an industrial enterprise and is adaptable to the corporate information system. Thus, it is proposed to expand the array of scientific research in business process management and adapt Petri nets to the «smart» enterprise.

2. Materials and methods

The purpose of the simulation is to build a control system that ensures the organization of processes in the context of functional subsystems. Building models based on Petri nets serves as the foundation of software for automated process and operation management. The main elements of this methodology are the transitions of the \( T_n \), the positions of informing the \( P_n \), sequentially following each other in accordance with the logic of process management, as well as the marking functions.

In order to build a model of integrated management of «smart» production, such functional aspects of an industrial enterprise are considering as [9]:

1) management of the life cycle of the enterprise's production assets (planning; acquisition or development of production assets on their own; installation of production assets; operation and maintenance; decommissioning);

2) supply chain management (planning; procurement; production; delivery; return flows);

3) product lifecycle management (new product idea, concept; new product development; new product production; service; product disposal; product improvement);

4) order execution lifecycle management (order receipt; production planning; direct production; delivery of the produced product; invoicing; invoice approval);

5) management of the industrial production safety system (system planning; system design; operation; hazard detection; diagnostics of the identified hazard; system modernization).

3. Results and discussion

As a result, a system Petri net of the second kind is constructed, reflecting a certain hierarchy of sets of events (figure 1).

![Figure 1. Petri net adapted to «smart» production (built by the author).](image-url)
Let's denote the events taken into account by the proposed system (modeled by $T_m$ transitions):

$T_1$ – the order is placed in the enterprise information system;
$T_2$ – a production infrastructure development plan is being developed (if the necessary production facilities are not available);
$T_3$ – a decision is made to "buy or produce" in relation to production assets and components;
$T_4$ – work begins on the acquisition or manufacture of production assets, components;
$T_5$ – work on the acquisition or manufacture of production assets is being completed;
$T_6$ – operation of production assets begins;
$T_7$ – production process is suspended;
$T_8$ – a defective report is drawn up;
$T_9$ – an order is formed to write off the property;
$T_{10}$ – a decision is made to use the existing infrastructure (if the necessary production facilities are installed);
$T_{11}$ – confirms the availability of the ordered product in the required quantity in the finished product warehouse;
$T_{12}$ – the absence of finished products in the warehouse is detected;
$T_{13}$ – working documentation for a new product is being developed;
$T_{14}$ – a prototype is produced according to the developed working documentation;
$T_{15}$ – quality control of the produced new product is carried out;
$T_{16}$ – a new product is made in the ordered volume;
$T_{17}$ – the product is produced according to the available working documentation;
$T_{18}$ – the quality of the produced product is checked;
$T_{19}$ – order execution is suspended;
$T_{20}$ – the order is sent for shipment;
$T_{21}$ – the order is delivered to the consumer;
$T_{22}$ – invoice is issued for payment;
$T_{23}$ – a payment invoice is agreed upon;
$T_{24}$ – warranty service begins;
$T_{25}$ – the product is disposed of.

Let's list the conditions reflected in the model:

$P_1$ – the order from the client is accepted for processing;
$P_2$ – compiled for the development of production infrastructure;
$P_3$ – a decision has been made to acquire the necessary production assets;
$P_4$ – a decision has been made to produce the necessary production assets;
$P_5$ – resources involved (financial or production);
$P_6$ – required equipment installed;
$P_7$ – received a signal about a hardware failure;
$P_8$ – equipment operation is suspended;
$P_9$ – a decision has been made on the further operation or decommissioning of the equipment;
$P_{10}$ – a request was received to check the availability of the ordered product in the required quantity in the finished product warehouse;
$P_{11}$ – received a notification about the availability of the ordered product in the required quantity in the finished product warehouse;
$P_{12}$ – received a request to the production for the production of a new product that was not previously produced at the enterprise;
$P_{13}$ – approved working documentation for the new product;
$P_{14}$ – prototype received;
$P_{15}$ – the prototype has passed operational tests;
$P_{16}$ – product for the received order of a new product for the company;
$P_{17}$ – a request is received to the production for the production of the product according to the available working documentation;
P₁₈ – the product for the received order is made;
P₁₉ – manufactured products have passed quality control;
P₂₀ – a notification was received about the readiness of the manufactured products for shipment to the finished product warehouse;
P₂₁ – the order is ready for shipment;
P₂₂ – order is delivered;
P₂₃ – invoice for payment issued;
P₂₄ – invoice agreed and paid;
P₂₅ – notification of the occurrence of a warranty event.

The figure shows 3 element networks as part of a single system network:
1 – order execution lifecycle management;
2 – management of the life cycle of production assets of the enterprise;
3 – product lifecycle management.

In the first case, the automation mechanism covers the element network of product lifecycle management, the elements of the SCOR model of supply chain management, and the "order-to-cash" subsystem. In the second case, we are talking not only about the management of fixed assets of a "smart" enterprise, but also the mandatory inclusion of elements of the security mechanism for automated business process management systems of an industrial enterprise.

In addition, the constructed Petri net provides return flows. In the case of P₂₂ → T₂₀, returnable packaging may occur; in the case of P₉ → T₃, repair of failed equipment; P₂₅ → T₁₃ describes the process of improving a product with low demand.

Let us denote the general characteristics of the constructed Petri net adapted to "smart" production. It is temporary, as it is focused in particular on compliance with the schedule of processes and operations, regulated by strategic and tactical plans, enterprise standards, technological instructions and other documents. "smart" production aggregates a number of significant subsystems of enterprise management: management of fixed assets of an industrial enterprise, product, logistics, orders, protection system of production and automated systems [9].

Thus, the presented business process management model of a "smart" enterprise succinctly describes the architecture of the main functional subsystems of "smart" production. At the same time, this model does not include the level of operations to avoid complicating the perception of events and transitions. Of course, intelligent production requires the most accurate modeling of computerization and digitalization of the control system, taking into account all the details. This is the goal of enterprises interested in modernizing production and adapting it to the requirements of Industry 4.0. The Petri net (figure), taken as a basis, will provide a "smart" response of the information and communication platform of the enterprise to any deviations in business processes and prevent the occurrence of events that hinder development.

4. Conclusions

Thus, an analytical review of scientific research, the study of the methodology for building Petri nets allowed us to identify the absolute practical value of applying this type of modeling to the construction of the architecture of a "smart" enterprise. The proposed model based on the Petri net illustrates a complex interconnected system of processes that translates a logical sequence of events and conditions. The developed Petri system network of the second kind reflects a certain hierarchy of sets of events, where the priority functions are order fulfillment lifecycle management and product lifecycle management, providing-management of the lifecycle of the enterprise's production assets and ensuring the security of automated business process management systems of an industrial enterprise. The author's model can be taken into account in the digital transformation of industrial enterprises, the intellectualization of production and is a tool for designing a fundamentally new information platform of the enterprise. An adapted Petri net can help reduce the transaction and transformation costs of reengineering.
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