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Introduction

Digital transformation is becoming an essential topic for companies across the globe. Especially, this fact is connected to the upcoming fourth industrial revolution that leads to the development of the smart manufacturing [3]. Digital transformation and smart manufacturing are characterized by increasing digitalization and interconnectedness of products, value chains and business models. The industrial transformation is based on Cyber-Physical Systems (CPS) and the Internet of Things, "interconnecting the fabric and its entire production sphere with intelligent environment" [5].

Thus, modern companies have to adapt their businesses and operating models according to the digital transformation principles in order to stay competitive. However, while the vision of a future digital production environment is conclusively described and reasoned in respective literature, especially small and medium sized enterprises are facing challenges concerning the realization of digital transformation [16]. A study conducted by PWC conveys this assumption, by stating that 46% of the questioned companies see the biggest challenge in the vague roadmap and the lack of concrete advice as for fulfilling digital transformation [13].

Therefore, it is necessary to create comprehensive digital transformation framework which will allow companies to reshape current value propositions using digital technologies and systems properly and effectively [8].

Enterprise engineering as an approach to digital transformation

In this paper it is proposed a solution of problems concerning the realization of digital transformation by using principles and tools of enterprise engineering.

Enterprise engineering is a complex approach to creation, reorganization and transformation of companies that is based on the analysis of company strategy, business processes and information systems as a whole system [21].

Enterprise engineering approach is successfully used for different kinds of enterprise transformations because it allows determining the directions for the company development on the basis of strategic goals and identified weaknesses [22].

There are a lot of enterprise engineering methodologies. The most common of them are TOGAF, Zachman Framework, Gartner Methodology [20].

TOGAF was chosen for creation of Digital Transformation framework for Smart Factory because this methodology has the architecture development method and a lot of metamodels that can be used as the basis of digital transformation process [20].

Digital Transformation Framework for Smart Factory

Digital Transformation framework for Smart Factory was designed by enterprise engineering approach and analysis of leading strategic initiatives in the area of smart manufacturing and digital transformation. Namely, the framework consists of the reference model of Smart Factory architecture and Digital Transformation Realization Method. The reference model was developed by the metamodel of the enterprise architecture methodology TOGAF and digital transformation concepts. Moreover, TOGAF Architecture Development Method was suggested as the basis of Digital Transformation Realization Method.

Reference model of Smart Factory architecture

Most developed countries conduct research projects and create strategies in the sphere of smart manufacturing. For instance, Chinese strategy includes such priority points as the development of "smart" production equipment and the procurement of new age information technology [9]. In Europe there are a lot of research projects in the sphere of Internet of Things due to «The Seventh Framework Programme for Research» and others [12]. Moreover, a lot of consulting companies carry out different researches in this sphere [19].

However, it is worth noticing that Germany and the USA pay special attention to the implementation of digital transformation principles in manufacturing. Namely, the governments of these countries have developed strategic initiatives for the creation of smart manufacturing ("Industry 4.0" – in Germany, "Advanced Manufacturing" – in the USA) [11]. According to these strategic programs, smart manufacturing should combine information, technology and human ingenuity to bring about a rapid revolution in the development and application of manufacturing intelligence to every aspect of business [7]. It will fundamentally change the way the products are invented, manufactured, shipped and sold [13]. It will improve employees' safety and protect the environment by making zero-emissions, zero-incident manufacturing possible [13].

Programms and initiatives that describe main digital transformation principles are general and abstract enough [2]. So in order to provide companies with some kind of a roadmap a reference model of Smart Factory architecture was developed on the basis of these concepts.

The structure of the reference model was created by the TOGAF content metamodel. The basic elements of the model are business architecture, information architecture and technology architecture. For each type of architectures clear criteria, to describe the ideal state of Smart Factory architecture, were formed on the basis of digital transformation principles explained in government programs, initiatives and consulting reports.

Business architecture

- The Smart Factory ought to have customer-oriented culture [5].
- IT and business departments should work together in order to react on changes immediately [16].
- Operation business processes should be automated. Employees ought to focus on strategic and creative tasks [3].
- All decisions should be made on the basis of deep and operational analytics [19].
- The Smart Factory should increase digital channels [13].
- The Smart Factory ought to diversify product lines by digital products and services [13].
- Marketing should be predictive. Namely, marketing decisions should be based on analytics and forecasts [19].
- The Smart Factory should use globalization advantages to reduce costs, improve efficiency and increase market share [7].
- The Smart Factory should create and develop the innovation culture [10].

Information architecture

- The Smart Factory should have a centralizing information system that gathers and analyzes customer interconnection history from all channels [6].
- Data from all business processes ought to be integrated in one information system [11]
- The Smart Factory should provide employees with digital communication channels [4].
- The Smart Factory ought to use cloud computing in order to analyze big data gathered from different devices and sensors effectively [18].
- The Smart Factory should have capabilities towards Big Data processing [12].
- The Smart Factory ought to establish high level of cyber security. It is connected with the need of stronger protection for Internet-based manufacturing [9].

Technology architecture

- A manufacturing system ought to be smart [15]:

1. Cyber-physical systems;
2. Full automation;
3. Totally interconnected systems;
4. Machine-to-machine communication.

- A manufacturing system of the Smart Factory should be based on sensors. Sensors ought to have the following properties [4]:
  1. Zero default/deviation;
  2. Reactivity;
  3. Traceability;
  4. Predictability.
- The Smart Factory should use autonomous vehicles that allow to optimize the flow and to reduce costs [11].
- The Smart Factory should use robots with the following characteristics [18]:
  1. Real-time autonomy;
  2. Full transparency (contextualization, comprehensiveness, collaborative robot) on data reporting.
- The Smart Factory should produce smart products. Smart products are products that meet the following conditions [12]:
  1. Products can be tracked during each stage of the lifecycle;
  2. Products include the information about production process;
  3. Products can manage the production process autonomously.
- The Smart Factory should use smart materials. Namely, materials ought to be connected with all participants of the product lifecycle in order to create smart value-added products [12].
- The Smart Factory should use 3D printing for mass customization and rapid prototyping [18].
- The Smart Factory should use the virtual simulation for launching new products and processes in order to optimize costs and time [11].
- The Smart Factory ought to focus on mass customization. Mass customization has the following features [14]:
  1. Customer and marketing intimacy;
  2. Flexibility;
  3. Perfect match of customer's needs with mass production efficiency;
  4. On-demand manufacturing.

The main goal of this reference model is to describe the ideal architecture of the Smart Factory with the highest digital maturity level [19]. Therefore, companies can choose some of the criteria that are the most suitable for them and use it for digital transformation realization.

Digital Transformation Realization Method

TOGAF methodology includes Architecture Development Method (ADM) that can be used as a basis for digital transformation process. But for the implementation of digital transformation in Manufacturing it is necessary to adapt ADM by using the reference model of Smart Factory architecture.

So the process of digital transformation in Manufacturing can be the following:

Step 1. Describing basic components of the current enterprise architecture. According to the TOGAF methodology, basic elements are business architecture, information architecture, technology architecture.

Step 2. Analysis of the current architecture state for identifying advantages and weaknesses.

Step 3. Designing a goal state of the architecture by the adaptation of the Smart Factory architecture reference model.

Step 4. Creating a digital transformation roadmap including necessary steps for switching from current architecture state to goal state.

Framework validation

The developed framework was successfully tested on the Russian manufacturing enterprise in timber industry. Namely, the digital transformation roadmap was created by using Digital Transformation Realization Method and the adapted Smart Factory architecture reference model. The paper includes brief results of the framework validation.

According to the Digital Transformation Realization Method, the current enterprise architecture was described for the first time. Analysis of the business architecture consisted of the strategy analysis, product line analysis, organizational structure analysis and analysis of business processes. For example, in this paper the results of company business processes modeling are shown.

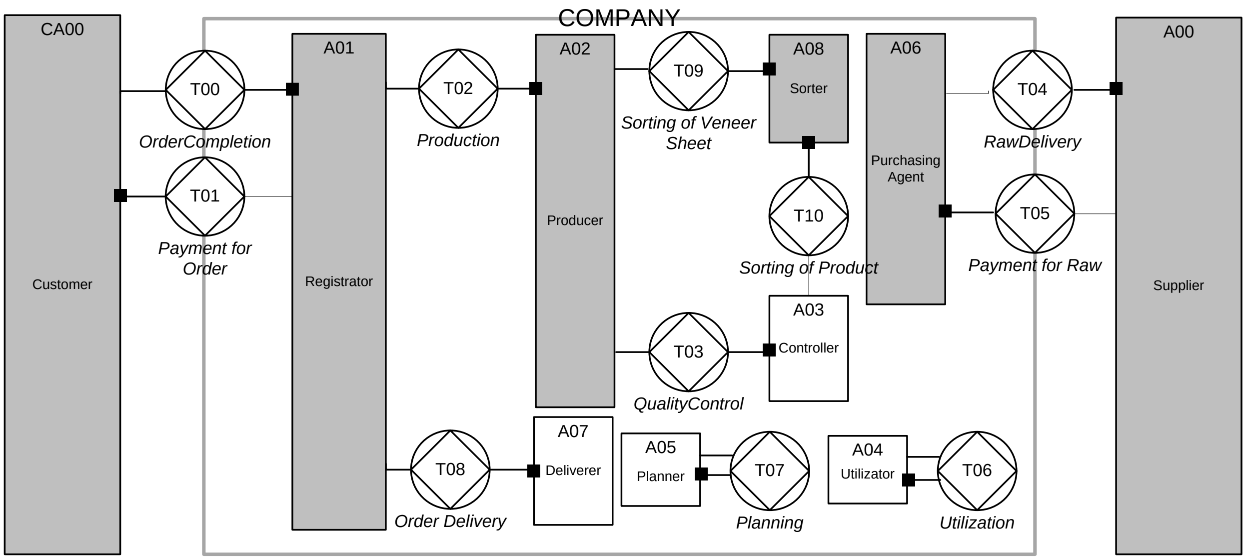

Fig.1 Core business processes of the manufacturing enterprise in timber industry

Transaction	**Result**
T00 Order Completion	R00 Order O has been completed
T01 Payment for Order	R01 Order O has been paid
T02 Production	R02 Product P has been produced
T03 Quality Control	R03 Quality control of Product P has been done
T04 Raw Delivery	R04 Raw R has been delivered
T05 Payment for raw	R05 Raw R has been paid
T06 Utilization	R06 Utilization U has been done
T07 Planning	R07 Plan P has been done
T08 Order Delivery	R08 Order O has been delivered
T09 Sorting of veneer sheet	R09 Veneer sheet S has been sorted
T10 Sorting of product	R10 Product P has been sorted

Table 1. Results of the transactions

Furthermore, all corporate information systems and technology infrastructure were described.

As a result of the current enterprise architecture analysis advantages and weaknesses were identified. For instance, the main strength of the current state is ERP system including data from all automated business processes.

The next step was to design the goal enterprise architecture on the basis of the reference model of the Smart Factory architecture. The reference model is some kind of general and universal model; thus, it is worth modifying this model before using for some company. For example, the criterion connected to the creation of smart products has been excluded because the company products are characterized by low level of science linkage. Moreover, the point about creation of the integrated and automated value chain was excepted because it is impossible to realize this criterion in conditions of the current country infrastructure. Furthermore, some points were added in the reference model according to the identified problems and company goals. For instance, one of the company strategic goals is an implementation of lean production concepts. So the adapted reference model includes the key directions for the company development.

Finally, a digital transformation roadmap was developed. The roadmap consists of local improvement suggestions that allow reaching the goal state of enterprise architecture and realizing the digital transformation. Some steps from the created roadmap are: an automation of the production process, an expansion of IT department, an implementation of the innovation culture and others.

Conclusion

In this paper research results towards digital transformation realization are shown. Namely, Digital Transformation framework for Smart Factory was designed based on the enterprise engineering approach and analysis of leading strategic initiatives in the area of smart manufacturing and digital transformation was carried out. The framework consists of the reference model of Smart Factory architecture and Digital Transformation Realization Method. The reference model was developed by the metamodel of the TOGAF enterprise architecture methodology and digital transformation concepts. Modified TOGAF Architecture Development Method was suggested as the basis of Digital Transformation Realization Method. The developed framework was successfully tested at the Russian manufacturing enterprise.

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