The 12th IEEE International Conference on Dependable Systems, Services and Technologies, DESSERT'2022
9-11 December, 2022, Athens, Greece

Combining of Digital Twin and Artificial Intelligence in Manufacturing Using Industrial IoT

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***Abstract*—The paper focuses on Digital Twin (DT) in Manufacturing using of Artificial Intelligence (AI) and Industrial IoT. According to the concept, the manufacturing includes three main units: equipment, personnel and processes. All data from these units are inherited to manufacture model (DT) and decision support system with the use of AI. DT data technology allows finding the required knowledge that can be interpreted and used to support the process of decision-making in the management of the enterprise. AI applications open up a broad spectrum of opportunities in manufacturing to add value by optimizing processes and generating new business models. The Landscape was described by a formal model to assure possibility analyze state and development of landscape in detail considering DT and other technologies. DT and IIoT implementation for simulation of real enterprise manufacturing were considered.**

Keywords—Digital Twin; Internet of Things; IoT, manufacturing; Artificial Intelligence; Industry 4.0

I. Introduction

Today the main activity of industrial enterprise includes processes that are determined by the goals and objectives of the business entity. Nowadays Ukraine is one of the counties in Europe, which has qualified ad well-trained IT-staff with the relevant competencies. There exist a lot of industrial high-tech solutions in different branches of manufacturing. The great potential for different IT-sectors, innovators and others is presented throughout Ukraine.

At the same time, the focus shifts to the DT in IoT in order to improve the decision-making process at the enterprise by providing information about maintenance and reliability as well as data on new products and increased efficiency of manufacturing.

The organization's DTs appear to create organizational processes models that allow real-time monitoring and process efficiency.

Besides, the production side has partial coverage (only a part of the information is collected from the equipment) in relation to Industrial IoT (IIoT). On the DTs side, there is only manual data entry. With the spread of IIoT industry and the corresponding increase in data processing there are opportunities for the use of AI.

The purpose of the study is to focus on conception, structure and application of DT in manufacturing using of artificial intelligence and industrial IoT and to show possibility of using the formal model to assure possibility analyze state and development of landscape in detail.

According to the concept the manufacturing includes three main units: equipment, personnel and processes. All data from these units is inherited to manufacture model (DT) and decision support system (AI).

II. Ukrainian State of the Art

The generally accepted concepts of enterprise security and safety management by combining these two interconnected functions in one concept are considered in [1]. The enterprise' general protection, where important data is stored, processed and transmitted, is impossible without combining the properties of security and safety management systems. There was presented and analyzed the three-level hierarchical integrated architecture model for the functional of security and safety management system, which includes the international standards requirements and principles of the cyber control. This concept is especially important at the present time with the rapidly developing of Industry 4.0 movement.

As a driver of Industry 4.0 movement the Association of Industrial Automation of Ukraine (APPAU) was established in 2011. The mission of APPAU is to develop the local market through the establishment of professional standards in the technical field and in the development of business.

For the European community of industrial automation will be interesting the main activities and tasks of APPAU [2-3]:

- consolidation and development of expert groups;
- harmonization and promotion of international standards (IEC/ISO) in the field of industrial automation and information technology;
- providing outline critical development problems and propose appropriate solutions;
- improving dialogue between various stakeholder groups (including researchers and university professors);
- development of high-tech communities and ecosystems in a cluster approach;

– promotion of innovation in accordance with developing countries;

– create and provide new services for community members and partners, including promotion and export.

Also, APPAU with the Association for Innovative Development of Ukraine formed the national movement Industry 4.0 in Ukraine [4-5].

It was positioned as a common platform for all high-tech segments in manufacturing.

The national movement Industry 4.0 is based on additional technologies such as IIoT platforms smart sensors, collaborative robotics, 3D/4D printing, artificial intelligence (AI), cybersecurity and safety, virtual and augmented reality, real-time location services, wearable technology, drones and others. Fig. 1 presents the Ukrainian landscape for technologies of the national movement Industry 4.0 [2].

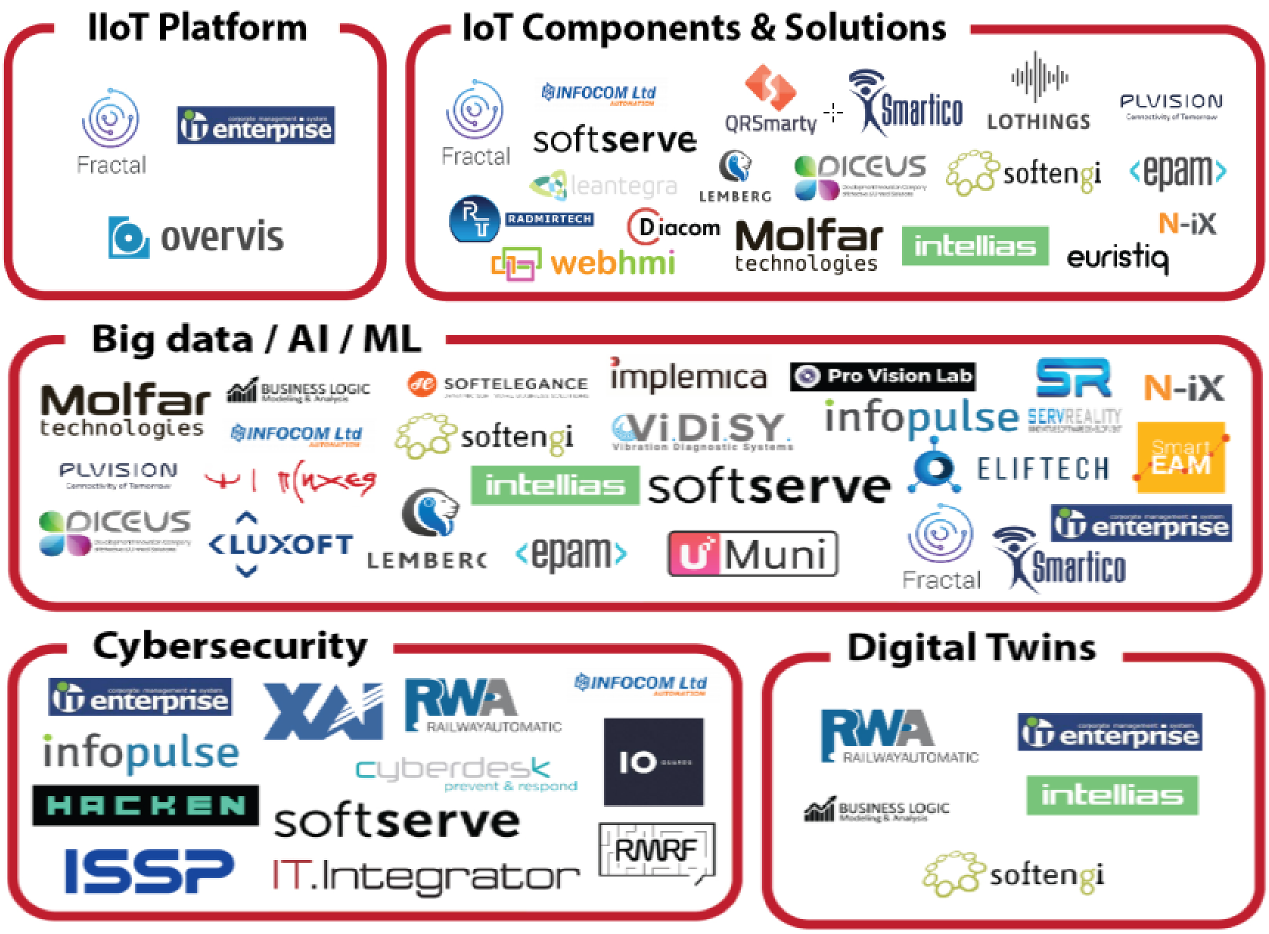

Fig. 1. Ukrainian landscape Industry 4.0 technologies (ver. 2.0) [2]

The Ukrainian company IT-Enterprise [6] is the leader of movement 4.0 in the category of IT companies and the leader in promotion 4.0. The company conducts many events, releases case studies, success stories, regularly supports APPAU in various events, such as market surveys, events and more. The Industry 4.0 movement includes application of IIoT.

According to APPAU IT-Enterprise has the largest coverage of Ukrainian customers – it is hundreds of companies and thousands of executives and industry specialists. Experts from Kharkiv Region Center Industry 4.0 as a part of APPAU (https://khci.eu.org/) which is a structural unit of National aerospace university "KhAI" (staff of Department of computer systems, networks and cybersecurity) by their actions influence the rapid development of technological progress to a new industrial revolution called Industry 5.0.

Among the main activities of KRCI are the following: networking, education and training services provider, education of the market, coordination and management of R&D activities.

In March 2018 the first Ukrainian Case Industry 4.0 is published implementation of the SmartFactory IT-Enterprise solution at PJSC "FED" [7]. This APS (Advanced Planning & Scheduling) solution is classic enough for World 3.0, contains at the same time elements for World 4.0 such as deep integration with ERP and MES, application of mobile applications, augmented reality and more [2].

The Joint Stock Company "FED" is manufacturing enterprise in Ukraine. The specialization of this company is the production and development of aerospace and general technical units. Its flight control systems are a decisive factor in ensuring the safety of aircraft and helicopters. The technical units of the company are successfully used in different European countries. The process approach to the organization of production has implemented in the company "FED". The main process is the quality assurance process. The connection between Equipment and Processes is through Personnel.

Current study would be instrumental to advance research in the field of digital technologies required to implement Industry 4.0 principles at high-tech industrial enterprises. Fig. 2 shows overall concept of the system.

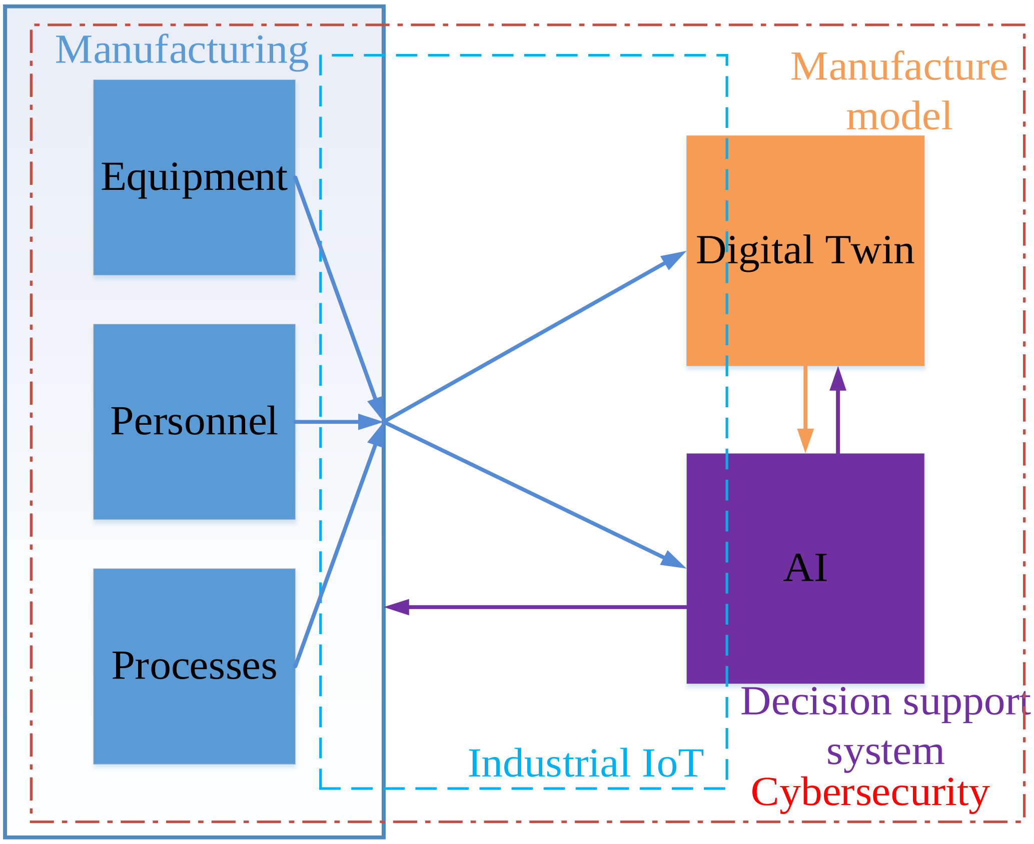

Fig. 2. Overall concept of the system

The collected data is sent to AI, which allows staff to make informed decisions quickly. DT is used for simulation of real enterprise manufacturing for training of personnel and modeling actions that helps optimize business performance.

III. DIGITAL TWIN IN MANUFACTURING

DT is a virtual copy of the real physical object, including its dynamics behavior in the environment. This technology, including simulation capabilities, has very attractive prospects in the industry, as it allows one to predict breakdowns, optimize service plans, and improve quality more accurately. This technology perfectly integrates with IoT, AI and Virtual and Augmented Reality [8-10].

Thus, DT is a digital representation that reflects a real object, process or system and it can also be connected to create twins of larger systems.

The “DT” concept is part of the Industry 4.0 movement and is designed to help enterprises more quickly detect physical problems, more accurately predict their results and produce better products [11-14].

The idea of DT goes back to computer ideas about the things design or online customer profiles, but modern DTs differ in four main ways:

– the model reliability with an emphasis on how they support specific business results;

– communication with the real world, for monitoring and control in real time;

– the use of advanced big data analytics and artificial intelligence to open up new opportunities;

– evaluate *what-if* scenarios.

DT data technology allows finding the required knowledge that can be interpreted and used to support the process of decision-making in the management of the enterprise [15-16]. The emergence of the concept of DTs was associated with the growth of digitalization of production processes, during which physical resources were replaced by digital.

An important role is played by Internet technologies as the IIoT [17-19] that provide communications between manufacturing and DT with AI. It is open the direct road to the creation of fully automated industries. Cybersecurity (and further cybersafety) plays and extremely important role during all operations [20-22].

Strategic advantage of DT is in significantly increased speed of technical decision-making process and reducing the cost obtaining the required product characteristics.

Having DT, it can be reduced the magnitude number of field tests, attempts of technical processes development - all that is connected with the manufacture of the real material part and its tests, the cost of which is much higher than the cost of mathematical modelling [19, 23, 24].

Current research activities on DT in manufacturing is going on the following topics:

1) DT of knowledge, skills and behavior of educational processes in Lifelong learning;

2) DT-based mobile control systems for smart building, cities, manufacturing;

3) DT of health.

IV. Artificial Intelligence in Manufacturing

AI is also used to improve performance and reduce downtime. Machine learning algorithms for manufacturing are shaped and tuned to the specific challenges of manufacturing – such as reducing losses, improving process stability, reducing downtime and anomalies [2].

AI applications open up a broad spectrum of opportunities in manufacturing to add value by optimizing processes and generating new business models (Fig. 3).

Examples of AI applications from current corporate practice are the predictive maintenance of production machines, the use of image processing technologies for the automatic sorting of items such as batteries or food or (customer) communication using text-based dialog systems (chatbots). An important success factor for the use of AI is a good quality database that already exists in the company. The use of AI applications requires a certain degree of advanced digital maturity of the company. In the production area, a digital sensor system has to be implanted in many applications along the production line. The development of AI applications requires the knowledge of data analysts and / or computer scientists. However, since this knowledge is not or only to a limited extent available to many companies, external services are a solution.

For example, cloud-based AI applications are already making it possible for medium-sized companies to book specific AI-based services in the modular system, for example cognitive services such as the image or face recognition or the conversion of speech into text.

Due to the extensive potential of AI-based applications, it is to be expected that the current competitive environment of manufacturing will change [20]. For example, in [25] on pattern recognition can be more and more autonomous and cost-effective through AI systems.

At the same time, AI systems improve the forecasting of customer wishes and thus enable new dimensions of an individualized customer approach. The result will be novel and user-focused business models. The focus is on "getting to know" the user (or an object, such as a machine) – the better the AI knows the user / machine, the more precisely services can be tailored or predictions made about their behavior and needs.

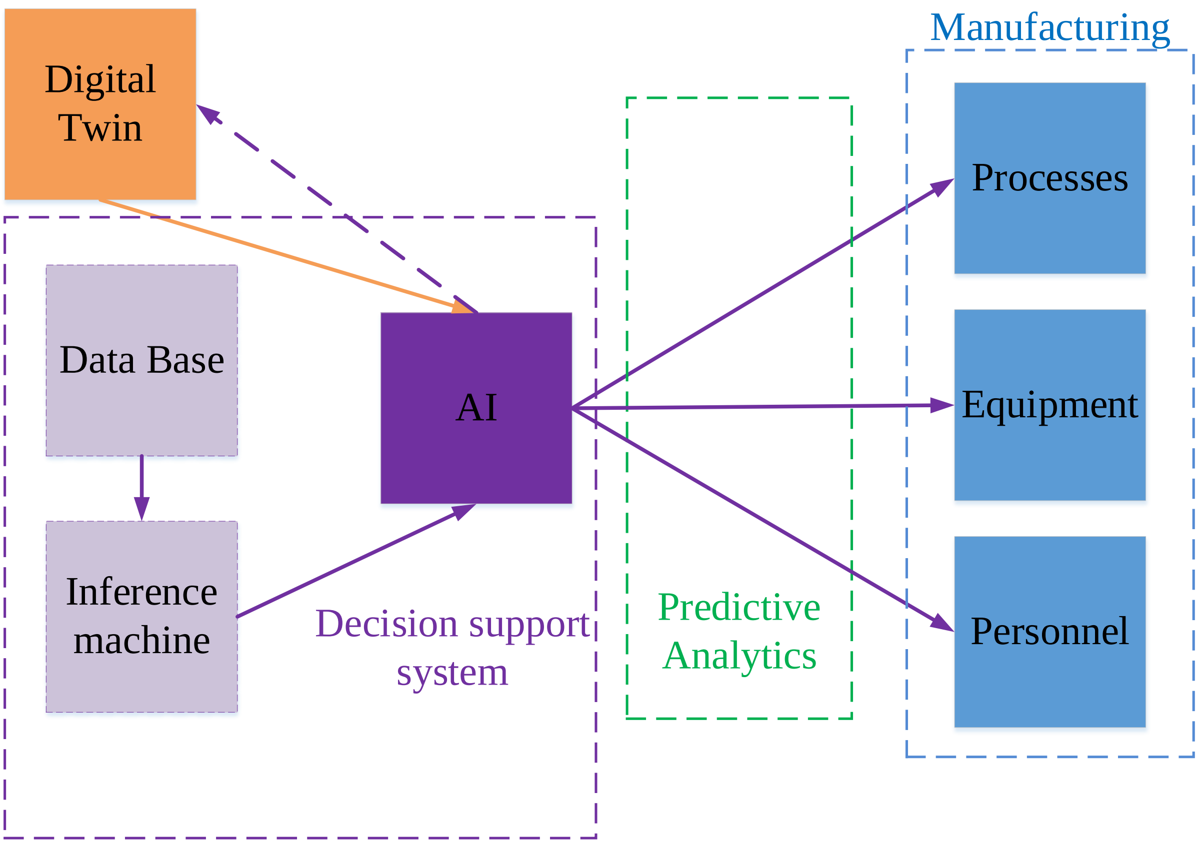

Fig. 3. Artificial Intelligence in manufacturing

Specifically for manufacturing companies with a limited database it is helpful to have cross-company access to platforms that bring together data from different sources and enable their exploitation. To leverage the power of AI systems, it is necessary to move from the currently often isolated in-house data silos to data platforms that lead to cross-industry collaboration and digital ecosystems. AI needs large number of training data. Generation of synthetic data based on digital models. Quality, representativeness and robustness of the training data is crucial for the success of AI. All relevant states of an object must be included.

For a state, all occurrences that can occur in the application must be included. However, AI does not require an analytical understanding of the problem to be solved.

Possibilities of using AI:

1) AI can be used to collect statistics (see production disruptions from the entire data set);

2) Considering critical options that are not provided for with the predictive analytics;

3) Analysis of a large amount of product data on the presence of inconsistencies.

Current research activities on Artificial Intelligence in manufacturing is going on the following topics:

1) Hierarchical and distributed neural networks-based system with combined relearning;

2) Big Data analytics for multi drone fleets-based monitoring of severe NPP/CI accidents;

3) Deep learning of neural networks for image recognition in space monitoring and manufacturing;

4) Machine vision of autonomous systems;

5) Expert systems for logistics based on fuzzy logic;

6) Text recognition using deep learning neural networks;

7) Application of AI for development and implementation of IoT for industry domains [26].

V. CASE STUDY

A. Landscape model application

A landscape (LS) is very important point to present and analyze state of the technology development in the country, the region, the industry branch and so on. This is especially important in the context of the Industry 4.0 movement, which is described by a lot of modern technologies such as AI, digital twins, IIoT and so on.

Usually LSs represent in arbitrary form many technologies of a certain type and enterprises (actors) involved in their research, development and implementation (see, for example Fig.1).

It's a big picture which can't be called a model and analyzed using formal technique.

We suggest to describe LS by a formal model to assure possibility analyze state and development of landscape in detail. This model is presented by the following expression

$$LS = \{Reg, Tech, Ent, t, M_{TT}, M_{ET}\},$$

where Reg – region or set of the regions, $\{Reg_i\}, i = 1,...,n;$

$Tech$ – a set of analyzed technologies, $\{Tech_j\}, j = 1,...,m;$

Ent – a set of region(s) enterprises, $\{Ent_k\}, k = 1,..., p;$

t – time or time slot, which is analyzed;

M_{TT} – mapping M: $T \to T$, describing connecting technologies;

M_{ET} – mapping M: $E \to T$, describing "coverage" of technologies by the enterprises.

This model can be detailed considering:

– different types of technologies, branches and so on;

– special metrics taking into account numbers n, m, p and cardinalities of sets $Reg, Tech, Ent$ and their subsets.

The set-theoretical model LS can be presented in other form using the graph with weighted nodes and links. For example, initial non-formalized landscape (Fig. 1) is described by the graph (Fig. 4). In this case:

– set of nodes is defined by set $Tech$;

– every node $Tech$ has metric of enterprises number, which develop the technology $Tech_j \in Tech, m = 5,$ and $\forall j : \exists \Delta Ent_j \subset Ent;$

– every link between $Tech_{j1}$ and $Tech_{j2}$ has metric of crossing subsets $Mor_{j1,2}$ of enterprises, which develop $Tech_{j1,2}$:

$$Mor_{j1,2} = |\Delta Ent_{j1} \cap \Delta Ent_{j2}|.$$

This model allows evaluating the most developed technologies and activity of various enterprises.

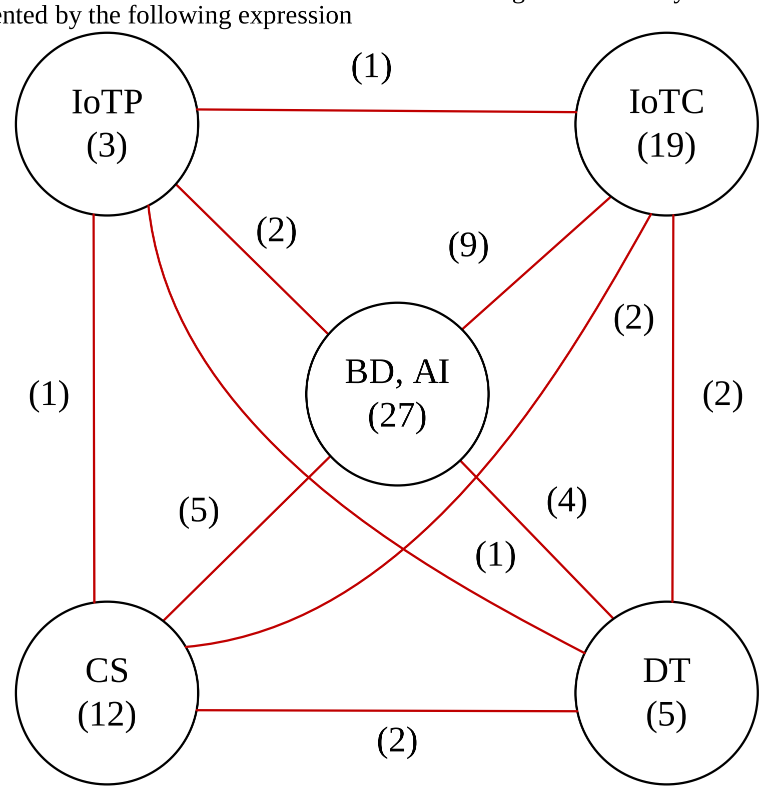

Fig. 4. The graph with weighted nodes and links of landscape

B. Digital twin and IIoT implementation

The considered technology of DT is actively used by the Joint Stock Company “FED” for simulation of real enterprise manufacturing for training of personnel and modeling actions that helps optimize business performance.

The DT of the logistic system of a manufacturing enterprise was developed using .NET programming technology. Nomenclature equipment of the manufacturing enterprise such as turning machines, circular grinding machines, gear hobbing machines and high-speed vertical milling machining center was represented as pictograms. This was done with the aim to calculate the optimal location of production facilities and transportation routes of products for maximum productivity.

The developed application allows the user to create a digital enterprise model to plan the optimal location of production facilities and to receive the most productive model for production.

The application performs the following functions:

1) Creating the required number of equipment;
2) Creating the necessary number of ways for movement of production units;
3) Ability to adjust the scheme during design;
4) The time and resources calculation for the manufacture and transportation of one unit.

VI. CONCLUSIONS

A special feature of the DT in manufacturing using the AI and industrial IoT was considered.

An important advantage of this technology, including simulation capabilities, has very attractive prospects in the industry, as it allows to more accurately predict breakdowns, optimize service plans, and improve quality.

Future research can be dedicated to development and implementation of DT-AI-IoT decisions for manufacturing especially aircraft and engine building, NPP Instrumentation and Control systems and so on.

Besides, we plan to specify and implement dynamical LS model and special tool to analyze movement Industry 4.0 in Kharkiv region, Ukraine and other countries to assess and compare key metrics, support decisions making for its successful and sustainable development.

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