Digital Transformation Revolution with Digital Twin Technology

Tolga Erol
Training and Simulation Technologies
HAVELSAN A.Ş.
Ankara, Turkey
terol@havelsan.com.tr

Arif Furkan Mendi
Training and Simulation Technologies
HAVELSAN A.Ş.
Ankara, Turkey
afmendi@havelsan.com.tr

Dilara Doğan
Training and Simulation Technologies
HAVELSAN A.Ş
Ankara, Turkey
ddogan@havelsan.com.tr

***Abstract*—Technologies were being developed in laboratories for military purposes in the past, and its spread in daily life was a result of a long-term process. However, because of the rapid spread of technological developments and the facilitation of information access processes, we can become aware of new technologies in a short time and shape our daily lives with the advantages of the use of these technologies. The Digital Twin concept, which is expected to cause changes in many areas of our lives in the near future, has entered our lives with the industry 4.0 industrial revolution and is defined as a digital copy of a physical system. Digital Twins have started to take place in our lives in other civil fields as well as in industrial and engineering fields, with the advantages they offer in terms of time and cost. We will discuss the current works and future opportunities in health, industrial, smart city management systems applications where this promising technology will be seen directly reflecting on daily lives.**

Keywords—Digital Twin, Digital Transformation, Industry 4.0

I. INTRODUCTION

The concept of "digital age", which is the expression of the era we are in, is defined as "the present time, in which many things are done by computer and large amounts of information are available because of computer technology" [1]. We live in an era where many things such as design activities can be edited, executed, designed, and tested in computer environments. In the past, while technology was produced and developed in laboratories for military purposes, its demilitarization and its spread in daily life took place as a result of a long-term process. However, it is now possible to be aware of technological developments occurring around the world with almost one click. In addition, the active effect of technologies into our lives and the widespread use of them can be seen as a benefit of the digital age.

"The imitations keep the originals alive." when we analyze the sentence in terms of technology; we encounter an innovative approximation to preserve, enhance and improve their originals which is Digital Twins. Digital Twin technology, which is often encountered with industry 4.0 and engineering fields, is health, transportation, energy, etc. preferred in the fields also. Using this technology, governments aim to increase their welfare and technological development levels by working in various fields.

When Gartner's 2019 "hype cycle for digital government technology" is examined, it is seen that the Digital Twin is the "innovation trigger technology" that triggers other technologies and is among the five technologies expected to have the most impact on government institutions in the next 5-10 years [2]. The results of the relevant research are shown in Figure 1.

Fig. 1. Gartner Government Technology Hype Cycle, 2019 [2]

The Digital Twin technology, which has a bright future in many fields of study and many studies and research activities continue to be carried out, can be expressed as a digitally modeled copy of an object/system that physically exists in the real world. Digital Twins consist of three basic components: the physical state of the system in the real environment, the state of the system in the digital environment, and the data that connects these two states. While sensors and Internet of Things (IoT) technologies are actively used in the transfer of physical assets to the digital environment, artificial intelligence and advanced machine learning techniques are used to learn the behavior of the physical entity from the created Digital Twin and to produce future predictions. The foresight help manufacturers determine their roadmap for predicting future failures and process improvement.

In smart city applications, city planning, and city security; in hospitals and health services; studies are carried out on the use of Digital Twins in production line processes, in the production of energy and energy systems, and in all kinds of system/product designs. It is expected that the Digital Twin technology will become more widespread, especially with the developments in technologies that have a large share in the creation of Digital Twins such as IoT. With the widespread use of technology, usage of this technology in our daily life for example, in transportation, traffic, security areas while leaving our house and going to work; when we go to hospitals, we will see that they are actively used in health services and processes such as diagnosis and treatment of diseases. Technological development and welfare levels are expected to increase as a result of the improvements provided by Digital Twin technology in the services actively used by many citizens in daily life. In this study, we will examine health, industrial and smart city management systems perspectives, which are among the civil and daily use areas of Digital Twin technology, and talk about important studies in this field.

978-1-7281-9090-7/20/$31.00 ©2020 IEEE

Then, we will explain our suggestions and predictions for the future regarding the areas in which we cover important works.

II. WORK DONE

We will examine the important Digital Twin solutions developed to make civil daily life more efficient under three basic frameworks: healthcare, industrial, and smart city management systems applications.

A. Healthcare Applications

As in many areas of life, the healthcare industry has become part of the digital world. With emerging technologies, new solution methods offer quality and reliable treatment processes, while also affecting the growth of the healthcare market. According to Markets and Markets' IoT in Health Market report, the global IoT in healthcare market size is expected to grow from USD 72.5 billion in 2020 to USD 188.2 billion by 2025, at a Compound Annual Growth Rate (CAGR) of 21.0% during the forecast period. Key factors driving the growth of the IoT in the healthcare market are the rising focus on active patient engagement and patient-centric care, growing need for adoption of cost-control measures in the healthcare sector, and growth of high-speed network technologies for IoT connectivity and increasing focus on patient-centric service delivery through various channels [3].

Fig. 2. Digital Twin for Healthcare [4]

We will discuss the studies conducted in the field of health for the Digital Twin by grouping them into the fields of the digital patient, pharmaceutical industry, and hospital.

Digital Patient

The US military announced an agreement with the University of Nevada to create virtual copies of its soldiers. X-rays, MRI, and ultrasound will be used to create a complete 3D digital copy of the soldiers' entire body down to the cellular level. The US military has stated that this is just the beginning. In the future, it has been reported that body parts will be created using 3D printing with the help of the Digital Twin to treat the injured and save their lives on the battlefield [5].

Philips and Siemens Healthineers have worked on the creation of the Digital Two of the heart in order to diagnose the problems that occur in the organs by modeling the organs in the human body early and to make an accurate diagnosis, and new studies are continuing. Philips created the "HeartModel", a personalized Digital Twin of the heart, which was an important step in progressing to the digital patient idea [6].

Digital Twin technologies, which are being developed for patients, are mostly aimed at establishing the accurate and early medical diagnosis and finding appropriate treatment methods, and it is expected that studies in this area will gain more importance.

Pharmaceutical Industry

Within the scope of Digital Twin technology, various studies are carried out in the field of health about how the medicines used to the patients should be patient-specific and how the cells in the human should be simulated. Making biological, vaccine, and other medical products derived from living organisms involves variable and difficult to quantify biochemical reactions, making automation difficult. Digital Twin technology helps speed up experimental processes, develop new manufacturing approaches, and automate complex chemical and biochemical processes. Takeda Pharmaceuticals has undertaken various initiatives to offer transformative therapies to patients around the world. It is usually a multi-stage and lengthy process that can take up to 15 years for a new medicine to become available. The company realizes this situation and switches to Digital Twin technology and biochemical reactions that are complex to model, with the help of techniques such as artificial intelligence and machine learning offered by the Digital Twin technology, realistic input and output can be predicted about reactions and accelerates existing processes [7].

In order to overcome challenges such as long production processes and long medicine release times in the pharmaceutical manufacturing industry, one of Atos and Siemens' global pharmaceutical partners decided to test an innovative solution created and developed through joint investment and business cooperation from the strategic global alliance of Atos-Siemens. "Process Digital Twin" has carried out a study that is a virtual copy of certain steps in the production process in connection with IoT sensors installed in the real factory. In this study, by matching virtual and physical representations of processes and using predictive models and real-time analytics, Atos and Siemens are helping authorities in rediscovering and making the pharmaceutical industry's production environment more efficient [8].

Although the use of the Digital Twin in the pharmaceutical industry has been set out to accelerate medicine production processes and reduce the use of animals as subjects, it is expected that there will be an increase in the fields of modeling vaccine or living organism behavior, discovering the genetic structure and examining the effects it can have on human health.

Hospital

An important example of the Digital Twin in hospital design is the study conducted for the infrastructure and layout of the radiology department of Mater Private Hospitals in Ireland. Due to the high patient demand, increasing waiting times, and experiencing various problems, the hospital aimed to find solutions to existing problems by modeling the workflow and processes of the current system in cooperation with Siemens Healthineers. In the light of the collected data and the 3D model of the department, the Digital Twin of the radiology department was created and various scenarios were tested, and various predictions and recommendations were obtained regarding the CT and MRI appointment times for the current problems of the department. With the information gathered from the Digital twin, the changes to be made in the planning and organization for the radiology department of the hospital were determined [9].

As mentioned in this example, with the Digital Twin applications to be used for many hospitals and health centers, it will be possible to reduce the workload of healthcare personnel and to provide health services to more patients in the fastest way. Although the Digital Twin studies for organizing the hospital organization are not widely seen today, we expect it to emerge as a new area to be addressed in the future due to the increasing need for it.

B. Industrial Applications

Since 1980, smart production has been defined as the intersection of artificial intelligence and production [10]. Intelligent manufacturing can actually be called the structure that analyzes data using advanced information and communication technology. Real-time data transfer and analysis of products are carried out in smart production systems. A simulation structure is created to increase the efficiency and quality of the products. Digital Twin technology is now also used for uptime, worker safety, and high-efficiency demands in operational activities and service processes. Digital twins are used in areas such as product design, production line design, and production process optimization. Digital twins are available in many businesses to increase product performance and efficiency. The Digital Twins allow companies to control their production processes, detect failures, and thus produce more efficient products [11].

Fig. 3. Digital Twin for Manufacturing [12]

Digital Twins can even help optimize supply chains, distribution and fulfillment operations, and even the individual performance of the workers involved in each. We will discuss the work done in automotive and various production lines.

Automotive

Tesla from the automotive industry uses a Digital Twin for every vehicle with a chassis number it produces. Tesla has the Digital Twin of every vehicle it sells. The sensor data in the cars are interpreted by artificial intelligence and it is determined whether there is any problem in the operation of the car or if it needs maintenance. Each vehicle continuously provides data flow to the Digital Twin through sensors. Many maintenance problems can be fixed by software updates to vehicles [13].

Maserati's Ghibli factory also uses Digital Twin technologies to increase production capacity. At the end of this project, the company stated that while the time for new product development was shortened by 30%, the time to market of the products decreased from 30 months to 16 months, and the number of cars produced tripled [14].

In Formula-1 races, where every second count, it is necessary to know as much as possible about the inner workings of the car. For this reason, Digital Twin technology is used to improve performance. He emphasizes to Matt Cadieux, a chief informant for Red Bull Racing, that design changes increase volume year over year, with up to 1,000 changes per week between races, and the biggest challenge in this process is the rate of change. A simulation used helps the driver and vehicle crew know in advance which adjustments can improve performance. Similarly, at the Future Lab at the Goodwood Festival of Speed, Siemens presented the Aston Martin Red Bull Racing RB6 Formula-1 car and its Digital Twin created with the help of innovative software tools [15].

In the automotive field, the use of the Digital Twin in both product and production line processes is expected to help save time and cost, as well as develop, test, and control and monitor autonomous vehicles that are planned to be used actively in the near future.

Production Line

Tire manufacturer Bridgestone has been using sensor data and enhanced Digital Twin simulations for R&D studies for several years to improve tire life and performance. The life of a tire is heavily influenced by numerous factors such as load, speed, road conditions, and driving behavior, and a Digital Twin gives the firm insight into how these interrelated conditions affect tire performance by simulating various driving conditions. It has been stated by the digital strategy and engineering directors that studies on the Digital Twin technology will continue in order to increase profitability, maintain competitive advantage and increase efficiency in terms of time [16].

Global consumer products manufacturer Unilever has launched the Digital Twin project, which aims to create virtual models in its factories. According to this project, IoT sensors and performance data placed on factory machines are input to machine learning applications for analysis [17].

Another factory where this technology is used is SpeedFactory owned by Adidas. The Digital Twin used in SpeedFactory ensures that the entire process is simulated, tested, and optimized before production. Thus, Adidas's factory has been made capable of customizing, fast and transparent production [7].

Borçelik, which produces in hot-dip galvanized steel, cold-rolled steel, and hot-rolled steel groups, which are industrial raw material inputs, has implemented a Digital Twin project by modeling its production lines and announced that they have achieved a 2.5% increase in efficiency thanks to this project [18].

The Virtual Plant 4.0 solution concept developed by Gizil Enerji was realized in Polisan Kansai Paint Factory. In this technology, after the Digital Twin of the product or structure is created, the product is designed in a digital environment, the production stages are calculated, the production lines are installed and the production is realized virtually at the end. When fully ready, real production is started. The company has stated that thanks to this technology, it can reduce the risk of error in production below 1% [19].

Kale Group stated that they started their digital transformation studies 2 years ago and that their companies accelerated their studies on the Digital Twin technology, which is very popular in the field of industrial production in

the world, and stated that the Digital Twin works for the production line will be activated by June 2020 [20].

Manisa Organized perform air-conditioning manufacturing household Industrial Zone Mitsubishi Electric Turkey Air Conditioning System Manufacturing Inc. "e-F@ctory" concept with smart and designed as a digital factory and Digital Twin application for real production line was carried out. Thanks to this application, flexibility, and efficiency are added to production without interfering with the production line. For example, an authorized person can simulate the production that he actually wants to do in the Digital Twin of the production line by changing only the parameter and how efficiently he will work when the targeted production is real [21].

Italy-based OCME company, which operates in the field of packaging machine manufacturing, uses the virtual twin application for its activities. Especially with a new system they created in the COVID-19 pandemic process, they established a virtually authorized model where the mechanical design and automation design operated systematically. OCME Communication manager Gabriele Folli believes that the Digital Twin solution is beneficial not only in terms of designing projects and in terms of new products for a specific product type, but also in their customization applications in the products, in the designs of some parts of the project based on customer-specific requirements. Mr.Folli explained that they realized that the use of the Digital Twin is making major changes made it easier to shorten the time to market the product and saves considerable time in the process of fine-tuning the machine before authorization. He shared that it is very important that all possible container and packaging formats can be simulated on the virtual model they designed and that the factory can have the final products as if they are actually working [22].

Recently, during the COVID-19 pandemic, many factories had to stop or slow down their activities for a while. In this period, the importance of digital transformation and automation in factories was once again understood, and fast and effective factory systems with minimal human intervention and contact became more important. The production line in the Digital Twin factories is expected to become an indispensable technology in the industrial field in the near and distant future, as well as being aimed at providing a maximum benefit by speeding up the design and business processes.

C. Smart City Management Systems

With the creation of Digital Twins of factories, machines, and processes, Digital Twin studies have also been initiated in smart cities and energy sectors, an area where investments have been increased. Creating and managing smart cities, making various plans on the city is directly related to the Digital Twin technology and will provide agility to planners especially in the projects and events planned to be made. In addition to these, various studies are carried out on energy efficiency and environmental regulation. We will discuss the work done under two main headings as smart cities and energy.

Fig. 4. Digital Twins of Smart Cities [23]

Smart Cities

Digital Twins are also used in smart city initiatives for applications that address traffic congestion improvement, urban planning, and much more. Singapore's Virtual Singapore initiative makes many things possible, from planning cell towers and solar cells to identifying traffic patterns and simulating pedestrian traffic. This system helps to make realistic planning in investments and activities [7].

In the scope of smart cities, the Republic of Turkey Ministry of Environment and Urbanism has announced that Digital Twin creation of 81 provinces. With the use of Digital Twins, illegal structures have been detected [24]. The Republic of Turkey Environment and Urban Planning Minister Murat Kurum announced that usage of Digital Twins can determine the number of buildings according to the range floor in the cities, the total floor area of the net as can be known, and building the number of buildings in the city center and the average height was passed can be recorded [25].

Building information modeling (BIM) is a process that starts with the creation of 3D simulations in many areas such as planning, design, settlement, and construction. With the buildings transformed into Digital Twins throughout the life cycle of the project, BIM is able to provide all the information needed in all construction stages. Nomoko is building a virtual environment to accommodate the world's Digital Twin. This platform will have geographic information in 3D space. For this project, Nomoko is referring to the idea of integrating different data, such as BIM and traffic information, into the digital twin of those regions to show directional and lag time information from their source [26].

Huawei, which is the world's biggest broadcast communications innovation supplier, has executed Trafficgo, a savvy traffic framework in Shenzhen-China, with the help of the nation's three biggest telecom administrators, and obviously, the nearby legislatures of Shenzhen. The framework essentially permits the making of a Digital Twin of the city and with the help of computerized reasoning to consequently oversee, coordinate, and anticipate the traffic of the city on the advanced twin progressively. The Shenzhen "Traffic Brain" project that is a collaboration between Huawei and the Shenzhen Traffic Police Bureau was announced at the Smart City Expo World Congress. The "Traffic Brain" depends on countless innovatively progressed applications, including facial acknowledgment for criminal offense location, traffic light planning streamlining, and auxiliary picture based criminal traffic offense id [27].

SmartWorldPro, Cityzenith's advanced Digital Twin software solution for buildings and cities, was chosen by the

state government of Andhra Pradesh to develop the state's bold new $ 6.5 billion smart city capital, Amaravati [28]. Powerful user capabilities make it easy to perform natural language project data searches, run AI or machine learning ROI analyzes on the fly, and visualize key results for a wide range of customers [29]. Purposefully designed for the AEC, Realtech, Proptech, and CRE industries, SmartWorldPro is the world's advanced Digital Twin platform that allows users to import, modify, monitor, analyze and correlate projects and asset data. The product has tools such as Single Glazed Prism Project and Property Data Dashboard view; 2D and 3D, Universal Data Import and Management, Twin Direct Import, and Conversion from BIM to Digital [30].

Although smart cities is a newly emerged field, states have realized the importance of this area and started to intensify their investments. Digital Twin technology systems play a big role in planning in the smart city sector. Desired planning can be made on the city and systems, and scenarios can be tested on simulations. Especially in cities, it will bring the use of the Digital Twin to prevent increasing complexity, to provide solutions to traffic problems, and to use it in environmental and urban planning.

Energy

Turkey has attracted attention when it has made a strategic alliance to offer the concept of Digital Twin examined together with the first digital service solutions for increasing the energy efficiency of Siemens and Turkcell in Turkey. Thanks to this cooperation, the software developed by Turkish engineers of Siemens will provide full integration with Turkcell's Smart Home Platform and reduce energy consumption [31].

Another example of General Electric and GAMA Energy Digital Twin agreements signed by Turkey's Central Anatolia's first digital power plant Combined Cycle Power Plant is. This agreement improves efficiency and productivity for the first time in a power plant in Turkey used cloud industrial software applications. General Electric's advanced digital solutions of the industrial internet operating system Predix, Asset Performance Management (APM), and Operation Optimization (OO), were installed at GAMA Energy's Central Anatolia Natural Gas Combined Cycle Power Plant with an installed power of 840 MW in Kırıkkale [32]. Using Predix, General Electric's software platform, engineers have developed digital twins of GE's gas turbines, steam turbines, and wind turbines. In this way, the turbines are able to rotate and position themselves according to the wind [14]. In addition, this Digital Twin can realistically simulate the temperature in various parts of the motors through virtual sensors [33].

Digital Twin is actively used in the energy sector of major companies around the world. In the coming years, it is expected that investments in the Digital Twin field will gradually increase in order to meet the increasing energy needs rapidly. With the spread of nuclear power plants, Digital Twins will be used to predict any risky situation.

III. Future Insights

A. Healthcare Applications

When the Digital Twin studies in the field of health are examined, there are many sub-themes in this field. Some of these are digital patients, the pharmaceutical industry, hospital systems, predictive medical methods, and so on. Especially considering Hippokrates' famous "There is no disease, there is a patient" aphorism, various studies are carried out in the field of personalized medicine, which has become increasingly important today [34]. Many of the Digital Twin studies conducted for this purpose have focused on digital patient and medicine production processes. For now, modeling some body organs, shortening the time to market the medicines, etc. purposeful studies are conducted. In these studies, a general model can be created, and if possible, some customizations can be made. By improving this situation, personalized models can be produced. In the future, it is anticipated that many organs in the human body will be modeled and the studies of these organs integrated with each other will be examined, and there will be improvements in medical diagnosis and treatment processes. In addition to accelerating medicine production and testing stages, vaccine development activities for a virus-related disease will be accelerated with the use of Digital Twin technology. For example, in the COVID-19 pandemic process, which started this year and is very effective all over the world, the treatment of the disease and vaccine production are the major needs. Numerous studies have been conducted in the field but unfortunately, the effects of vaccines on humans in the next 10 years cannot be fully predicted. With the use of Digital Twin technology, a large database can be obtained by creating twins related to the human body, and studies that are normally carried out on test animals and humans in laboratory environments can be performed on Digital Twins in a digital environment. Thus, acceleration can be achieved at the point of obtaining the study results. In addition, considering that early diagnosis and treatment are life-saving, regular checks on the Digital Twins of individuals in the field of preventive health services, problems that start to occur in the body, and appropriate preventive health programs will be made. With the digitalization of hospital systems, many patient procedures will be monitored remotely, and physical presence in the hospital only when necessary will both reduce the workload of healthcare professionals and help speed up health services.

B. Industrial Applications

Digital Twin technology is actively used in the design, development, production line, and modeling of business processes in the industrial field. Although Digital Twin applications are commonly used on various production lines, and the use of technology in processes in other areas is not common. However, as a result of the COVID-19 pandemic, digitization, and advancement of processes with minimum human contact has gained much more importance. In this regard, manufacturers in the industrial field need more automation and contactless solutions for developing and diversifying their supply chains, providing digital communication with customers, and working in a way that their systems are independent of human beings [22]. For this reason, it is aimed to restructure the processes and to ensure business continuity with the new structure to be created. Integrating multiple systems has also gained importance. Providing data tracking of the machines and equipment of many fabricated manufacturing companies in this field with real-time data, using product simulations in order to understand the errors that may occur and after the product is delivered to the customer for products with maintenance service, the data required for product maintenance are regularly in the cloud systems will be kept and examined by the producers. In addition, the use of Digital Twins will also become more widespread for maintenance services such as

automobiles, industrial machinery, and medical devices. In the near future, Digital Twins of all systems in between from the manufacturer to the end consumer can be created and processes can be saved in terms of quality, speed, and cost by preventing any disruption in the processes.

C. Smart City Management Systems

A smart city is an urban area that uses different types of electronic IoT sensors to collect data. Insights gained from that data are used to manage assets, resources, and services efficiently; in return, that data is used to improve the operations across the city [35]. In Digital Twin technology, assets are modeled by being fed with real-world data and helps managers, strategists, and city planners in the areas of control and planning. With developing technology, the need for energy also increases. Digital Twin technology can be used to detect risks, especially in nuclear power plants, which have high-energy generation efficiency and cause dangerous consequences because of accidents.

Digital twins, traffic planning, and general transport systems of cities; Preparation of emergency plans and determination of response methods in natural disasters such as floods, fires, and earthquakes; It can help governments detect pollution in the city and make landscaping. It can allocate resources, plan operations, and optimize traffic by having real-time information about any emergency. Using it by emergency responders such as firefighters, authorities can access a 3D model of the building in case of fire. With the help of augmented reality and artificial intelligence, firefighters can predict where people are and the behavior of the fire [36].

Thomas Frey, a senior futurist at the DaVinci Institute, a Colorado-based think tank, wrote in 2018 that 85 percent of all IoT platforms accelerating by 2022 will have some sort of Digital Twin monitoring program, and some cities have the benefit value of Digital Twin smart city technologies. draws attention to the fact that it will be a pioneer in proving [14].

In the field of tourism, in which regions the tourist density in the city is concentrated, the examination and regulation of the tourism activities of the city during festivals and holidays, and the monitoring of the controls in the cities with the transfer of instant data with the Digital Twins are among the scenarios that may occur in the near future. Efforts can also be made to ensure regular follow-up of historical artifacts and historical settlements and to take precautions for destruction or theft. During the COVID-19 pandemic process, the activities and movements of the citizens in the city can be monitored and various measures can be taken for public health and safety when necessary. However, it can be used by governments and police agencies to ensure city security and prevent crime. The Person of Interest television series, which was broadcast in the USA between 2011 and 2016 and written by Jonathan Nolan, is about a system that uses a sensor, monitoring, and artificial intelligence technologies to prevent crimes in USA [37]. These technologies, which can only be imagined in the years they were published or are thought to be realized in the distant future, may appear with similar applications in the near future.

Digital Twins can examine the visual simulations of the citizens living in that region regarding the environmental planning planned to be carried out in their region, and systems can be designed to receive information about changes such as traffic on the way to work that may occur [23]. Modules that they can give feedback for planning can also be added to these systems. In this way, the subtleties that the experts do not notice in the environment and city planning will be transferred to the experts by the people living in that region.

There comes a time when visualizing complex systems may require connecting more than one Digital Twin. It is also estimated that 75 percent of Digital Twins used by 2023 will integrate with at least five extremes [38].

IV. Conclusion

The Digital Twin studies in the civilian field are generally related to processes in the production and industrial areas, as well as a wide range of studies in the fields of health, smart cities, and energy. In particular, it is seen that the impact of the COVID-19 pandemic process negatively affects factory production lines. At this point, we can say that the digital twin technology offers an important solution to make factories that have stopped production lines or whose production capacity has decreased, to become independent from people, and to increase productivity. It is also expected that the Digital Twin applications for smart cities and hospitals in the field of resource management and planning, which are needed during the COVID-19 pandemic, will become widespread. We can say that the maturity level of technology will increase and its spread will accelerate with the increase in its use in areas such as health, industry, and smart city management. It will also become widespread not only in these fields but also in piloting, engineering, and medical education. With the increase in the number of successful applications, the eye-catching advantages promised by this technology will be obtained concretely, and a significant gain will be made at the point of digitalization. It is also obvious that significant gains will be achieved with the adoption of this structure in emerging countries, where digitalization is of great importance at the point of accelerating the development of the country.

References

[1] "DIGITAL AGE | meaning in the Cambridge English Dictionary," Cambridge Dictionary. https://dictionary.cambridge.org/dictionary/english/digital-age (accessed Sep. 30, 2020).

[2] Susan Moore, "Top Trends From Gartner Hype Cycle for Digital Government Technology, 2019 - Smarter With Gartner," Gartner, Oct. 17, 2019. https://www.gartner.com/smarterwithgartner/top-trends-from-gartner-hype-cycle-for-digital-government-technology-2019 (accessed Sep. 17, 2020).

[3] "IoT Healthcare Market Size, Share and Global Market Forecast to 2025 | COVID-19 Impact Analysis | MarketsandMarkets," Markets And Markets, Jun. 2020. https://www.marketsandmarkets.com/Market-Reports/iot-healthcare-market-160082804.html (accessed Sep. 17, 2020).

[4] "Applying Simulation Modeling to the Hospital Environment - Insights - GE Healthcare Partners," GE Healthcare Partners, Mar. 14, 2018. https://uscan.gehealthcarepartners.com/insight-detail/applying-simulation-modeling-to-the-hospital-envir (accessed Sep. 17, 2020).

[5] "Soldiers digital twins let US Army 3D print replacement body parts in battle – By Matthew Griffin Futurist and Keynote Speaker," Jan. 05, 2017. https://www.fanaticalfuturist.com/2017/01/digital-clones-will-let-us-army-3d-print-new-body-parts-in-battle-to-treat-injured-soldiers/ (accessed Oct. 02, 2020).

[6] Henk van Houten, "How a virtual heart could save your real one - Blog | Philips," Philips , Nov. 12, 2018. https://www.philips.com/a-w/about/news/archive/blogs/innovation-matters/20181112-how-a-virtual-heart-could-save-your-real-one.html (accessed Sep. 17, 2020).

[7] A. Mussomeli, A. Parrot, B. Umbenhauer, and L. Warshaw, "Digital Twins Bridging the physical and digital," Deloitte Insights, 2020. https://www2.deloitte.com/us/en/insights/focus/tech-trends/2020/digital-twin-applications-bridging-the-physical-and-digital.html (accessed Sep. 16, 2020).

[8] "Atos and Siemens introduce Digital Twin solution within the global pharmaceutical industry - Atos," Atos, May 18, 2020. https://atos.net/en/2020/press-release/general-press-releases_2020_05_18/atos-and-siemens-introduce-digital-twin-solution-within-the-global-pharmaceutical-industry (accessed Sep. 17, 2020).

[9] "Digital Workflow Optimization," Erlangen, 2018. Accessed: Sep. 17, 2020. [Online]. Available: https://static.healthcare.siemens.com/siemens_hwem-hwem_ssxa_websites-context-root/wcm/idc/groups/public/@global/documents/download/mda4/ntmz/~edisp/from_digital_twin_to_improved_patient_experience_case_study-05658034.pdf.

[10] Q. Qi and F. Tao, "Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison," IEEE Access, vol. 6, pp. 3585–3593, Sep. 2018, doi: 10.1109/ACCESS.2018.2793265.

[11] İlhan Veli Kocabay, "DİJİTAL İKİZLER GÖMÜLÜ GERÇEK ZAMANLI ÜRETİM YÜRÜTME SİSTEMİ TASARIMI: KİTLESEL ÖZELLEŞTİRME İLE ÜRETİM YAPAN BİR FİRMADA UYGULAMA," Hacettepe Üniversitesi, Ankara, 2019.

[12] "The Closed-Loop Digital Twin," Siemens. https://www.plm.automation.siemens.com/global/en/webinar/the-iiot-digital-twin/41614 (accessed Sep. 17, 2020).

[13] Arindam Sen, "Role of Digital Twin Technology in Future | HCL Blogs," HCL, Jun. 15, 2018. https://www.hcltech.com/blogs/digital-twins-bridging-gap-between-industrial-assets-and-digital-world (accessed Sep. 17, 2020).

[14] Thinktech STM, "Dijital İkiz Teknolojileri ve Üretime Faydaları," 2019. Accessed: Sep. 17, 2020. [Online]. Available: https://thinktech.stm.com.tr/uploads/raporlar/pdf/952019111434675_stm_blog_dijital_ikiz_teknolojileri.pdf.

[15] Hubertus Breuer, "The Future of Manufacturing | Digital Twin | Global," Siemens, Sep. 07, 2018. https://new.siemens.com/global/en/company/stories/research-technologies/digitaltwin/the-future-of-manufacturing-plm-red-bull-racing.html (accessed Sep. 17, 2020).

[16] Jerome Boulet and Hans Dorfi, "Phone Interview with Bridgestone Directors," Oct. 03, 2019.

[17] Jennifer Smith, "Unilever uses virtual factories to tune up its supply chain," Jul. 15, 2019, Accessed: Sep. 17, 2020. [Online]. Available: https://www.wsj.com/articles/unilever-uses-virtual-factories-to-tune-up-its-supply-chain-11563206402.

[18] "Verimliliğe direkt katkı sağlayan 3 ayrı proje hayata geçirdi," ST Otomasyon Dergisi, Jun. 20, 2020. https://www.stendustri.com.tr/otomasyon/verimlilige-direkt-katki-saglayan-3-ayri-proje-hayata-gecirdi-h106609.html (accessed Sep. 17, 2020).

[19] Ömer Temür, "Türkiye'nin ilk Dijital İkiz projesi Polisan'dan," Türkiye Gazetesi, Apr. . https://www.turkiyegazetesi.com.tr/teknoloji/614245.aspx (accessed Sep. 17, 2020).

[20] Musab Turan, "İbrahim Bodur vefatının dördüncü yılında değerleriyle anılıyor," Anadolu Ajansı, May 18, 2020. https://www.aa.com.tr/tr/sirkethaberleri/holding/ibrahim-bodur-vefatinin-dorduncu-yilinda-degerleriyle-aniliyor/657346 (accessed Sep. 17, 2020).

[21] Abdulkadir Günyol, "Uzaktan erişilen dijital fabrikalarla üreticiler rekabette öne çıkıyor," Anadolu Ajansı, Apr. 06, 2020. https://www.aa.com.tr/tr/sirkethaberleri/enerji/uzaktan-erisilebilen-dijital-fabrikalarla-ureticiler-rekabette-bir-adim-one-cikiyor/656648 (accessed Sep. 17, 2020).

[22] "Sanal İkizlerle Üretimin Geleceği," Dassault Systèmes, IDC, 2020. https://events.3ds.com/tr/future-of-manufacturing-virtual-twins?utm_medium=email&utm_source=promotional&utm_campaign=3dscomwebinarreplay-futureofmanufacturingwithvirtualtwins-emed_OP61985&utm_content=2020-07-local-webinarreplay-futureofmanufacturingwithvi (accessed Sep. 17, 2020).

[23] Carly Minsky, "Digital twins give urban planners virtual edge | Financial Times," Jan. 29, 2020. https://www.ft.com/content/15851b06-1b6f-11ea-81f0-0c253907d3e0 (accessed Sep. 17, 2020).

[24] Ayşe Şensoy Boztepe and Zehra Aydın, "'Kaçak yapılar dijital olarak takip edilip önlenebilecek,'" Anadolu Ajansı, Nov. 11, 2019. https://www.aa.com.tr/tr/politika/cevre-ve-sehircilik-bakani-kurum-kacak-yapilar-dijital-olarak-takip-edilip-onlenebilecek/1641413 (accessed Sep. 17, 2020).

[25] "Çevre ve Şehircilik Bakanlığı Türkiye'nin 3 Boyutlu Dijital İkizini Oluşturdu | Haber Sağlıkçılar," Haber Sağlıkçılar, Nov. 25, 2019. https://www.habersaglikcilar.com/cevre-ve-sehircilik-bakanligi-turkiyenin-3-boyutlu-dijital-ikizini-olusturdu.html (accessed Sep. 17, 2020).

[26] "NOMOKO | Mirror World Data," NOMOKO. https://nomoko.world/mirrorWorldData/ (accessed Sep. 17, 2020).

[27] Ahmet Duran, "5G Nasıl Daha Yaşanılır Bir Dünya Sağlayacak," Medium, Dec. 16, 2019. https://medium.com/türkiye/5g-nasıl-daha-yaşanılır-bir-dünya-sağlayacak-a16f81cbac2 (accessed Sep. 17, 2020).

[28] "Amaravati Smart City - Cityzenith - The world's most advanced digital twin software solution." https://cityzenith.com/customers/amaravati-smart-city (accessed Oct. 01, 2020).

[29] "About - Cityzenith - The world's most advanced digital twin software solution." https://cityzenith.com/about (accessed Oct. 01, 2020).

[30] "Features - SmartWorldPro - Cityzenith - The world's most advanced digital twin software solution." https://cityzenith.com/explorer/features (accessed Oct. 01, 2020).

[31] "Turkcell ve Siemens ortaklığıyla enerjide yüzde 30 tasarruf – Turkcell Medya," Turkcell, Oct. 10, 2017. https://medya.turkcell.com.tr/bulletins/turkcell-ve-siemens-ortakligiyla-enerjide-yuzde-30-tasarruf/ (accessed Sep. 17, 2020).

[32] "GE ve GAMA Enerji'den Türkiye'nin ilk Dijital Enerji Santralı! | GE News," General Electric, Feb. 09, 2017. https://www.ge.com/news/press-releases/ge-ve-gama-enerjiden-türkiyenin-ilk-dijital-enerji-santralı (accessed Sep. 17, 2020).

[33] "Improving wind power with digital twin technology | GE Renewable Energy," General Electric, 2020. https://www.ge.com/renewableenergy/stories/improving-wind-power-with-digital-twin-turbines (accessed Sep. 17, 2020).

[34] Aydın Erdem, Dünya ve Türk Tıp Tarihi. Ankara: Güneş Kitapevi, 2006.

[35] C. S. Lai et al., "A Review of Technical Standards for Smart Cities," Clean Technol., vol. 2, no. 3, pp. 290–310, Aug. 2020, doi: 10.3390/cleantechnol2030019.

[36] Esther Fuldauer, "What is a digital twin? A powerful tool thanks to the IoT," Tomorrow Mag, Apr. 05, 2019. https://www.smartcitylab.com/blog/digital-transformation/smarter-cities-are-born-with-digital-twins/ (accessed Sep. 17, 2020).

[37] Person of Interest. USA: Warner Bros, 2011.

[38] "Digital Twin Technology Benefits and Challenges," Identity Management Institute, Mar. . https://www.identitymanagementinstitute.org/digital-twin-technology-benefits-and-challenges/ (accessed Sep. 17, 2020).