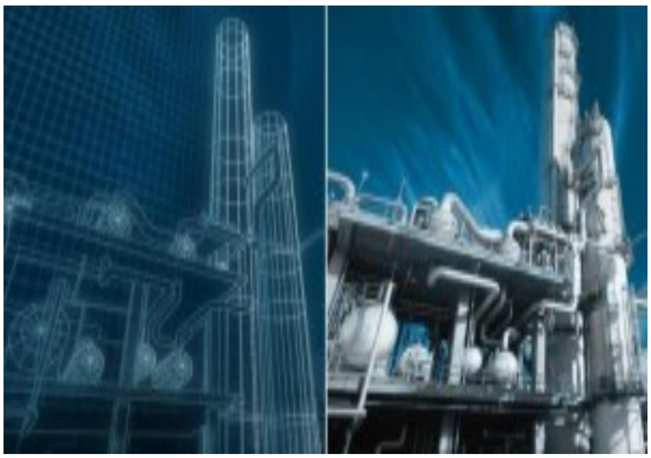

DIGITAL TWINS APPLIED TO OPERATIONS MANAGEMENT

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Executive Summary

The purpose of this report is to review the digital twin technology, its background, how it is used in various industries and what are its future implications.

The following points highlight some of the benefits that digital twin technology provides to various industries reviewed in this report:

- In the manufacturing industry, digital twins can help factories and plants in maintenance, quality and process optimization. They can be used to predict when a product will fail and perform preventive maintenance.
- In the logistics industry, digital twins can help in planning and managing global transportation infrastructure, warehouse management and tracking packages.
- In nuclear and aerospace industries digital twins can be used to reduce time spent in a hazardous environment or to train workers to handles emergencies in virtual space, so they are ready to meet any challenges that they face.
- In the energy industry, digital twins can be used to forecast demand and optimize the use of renewable energy or to make sure that there is no surplus electricity that is going to waste.

Key Takeaway:

Although digital twin technology is still in an infancy stage, and there are some challenges that it still has to overcome, its potential is huge. If looking at 25-50 years in the future, the digital twin technology is becoming a part of daily lives.

1.Introduction

1.1 Objective

In recent years, digital twin technology has been drawing an increasing amount of attention and recognized for its potential to benefits various industries. A digital twin is a computerized, constantly evolving, organic simulation model designed to mirror some physical systems in the real world (i.e., an airport, manufacturing plant, etc.) [1]. Digital twins are able to expose key insights into the real system that are not otherwise visible. For example, a digital twin can allow experimentations of hypothetical, risky scenarios or generate metrics that are not easily capturable in the real world. Digital twins have the potential to increase operational efficiency, act as a gateway to resource optimization, improve asset management, deliver cost savings, also to improve productivity and safety [1].

1.2 Approaches

This project aims to provide an overview of the digital twin technology in regard to its applications in various industries; the history of its developments, its status quo, and its future. Specifically, discussions are focused on the impacts of the digital twin technology on manufacturing, logistics, high hazardous environment, and renewable energy management, revealing its positive potentials and potential hurdles. Literature reviews are performed to provide professional insights, along with the use of industry case studies to supplement the discussions and substantiate the arguments. At the end of the report, recommendations are made, and future perspectives on digital twin technology are explored.

2. History of Digital Twin

Digital twins have been in use since the 1960s, mainly for computer-driven simulations by experts in highly specialized scientific fields. It was not until 1970 when NASA made innovative usage of its pairing technology on the Apollo 13 space mission [2]. When oxygen tanks aboard the aircraft exploded prematurely, NASA engineers tested possible solutions on a paired model of the aircraft from the ground prior to communicating remedial instructions to the crew stranded in space. Further developments on this concept took place soon after, including the integration of computer simulation with flight simulators in 1977 and the creation of AutoCAD (i.e., computer-aided design) in 1982. All this time, digital twin technology was limited to the defense and aerospace sectors due to its high cost, complexity, and mission-critical value. In 1985, however, the cost of simulation applications dropped, making them available to other engineering fields.

By 2000, simulation-based system design had become a mainstream, spurring the development of more sophisticated simulation applications. Despite these advances, it was not until 2002, when the concept of digital twins gained public recognition in Michael Grieves' presentation on technology at Michigan University [3]. He presented a PLM (Product Lifecycle Management) model, encompassing all digital twin elements such as the real and virtual spaces, virtual sub-spaces, data flow links from the real to virtual space, and information flow links from the virtual to real space. In the same year, McLaren Automotive created a digital twin technology for its M1 sports car to assist in product creation and performance forecasting [2]. Similar advances followed soon after, including the publication of USAF (US Air Force) and NASA papers on digital twins in 2011 and the 2015 wind farm initiative undertaken by General Electric Company.

From 2015 onwards, digital twins became seamlessly incorporated throughout the typical product lifecycle. Gartner even listed digital twins among its top 10 technology trends in 2017. With the advancement in IoT (internet of things) technology, a broad spectrum of firms is bound to enter the digital twin market, which is projected to register a 38% growth and exceed $26 billion in valuation by 2025 [2].

3. Findings

3.1. Digital Twin in Manufacturing

3.1.1. In Factories and Plants

Within factories and plants, the impact of digital twins spans in three areas – maintenance, quality, and process optimization [4].

In maintenance, digital twins bring in a predictive angle where their embedded machine learning algorithms analyze production data, detect anomalies, and forecast the RUL (remaining useful life) of various machines, equipment, and assets. As a result, machine repairs can be done at the most optimal time so as not to disrupt production. In addition, the technical teams are informed in advance about the right tools, spare parts, and the kind of maintenance that is needed.

In ensuring quality, digital twins can assist in identifying the probable sources of quality problems, thus ensuring their early mitigation before they cause costly defects in the manufacturing process.

Lastly, in process optimization, digital twins help in testing new ideas and processes without disrupting normal production. Specifically, digital twins facilitate the testing of assumptions using predictive analysis, the creation of digital twins that connect production systems to enhance traceability, and the real-time visualization of equipment behavior [4].

3.1.2. In Original Equipment Manufacturer

Digital twins also benefit OEMs (original equipment manufacturers) in three areas – production and design, products in the field, and future products [4].

In production and design, industrial IoT digital twins predict production failures for early resolution before they cause major breakdowns. Besides, they simulate improvements made on production parameters and facilitate testing of product behaviors under different design parameters without interrupting normal production. This way, digital twins promote efficiency in the production process.

Secondly, digital twins permit manufacturers to run diagnostics on products already deployed in the field. This way, the technicians do not have to visit the site and inspect the product manually to diagnose the problem, leading to significant savings in service costs while improving customer service and satisfaction. Configurations for new products can also be done remotely.

Lastly, digital twins for entirely new product designs can be created based on customer specifications and preferences, as well as insights obtained from the existing physical versions. The new digital model then informs the manufacturing process to create new products that not only meet the unique needs of the customers but also boost sales margins and competitive strength of OEMs.

3.2. Digital Twin in Logistics

Based on the DHL report of 2019, digital twins have five possible applications – packaging and container, shipment protection, warehouse and distribution centers, logistics infrastructure, and global logistics networks [2].

A. Packaging

In packaging, digital twinning can aid the conceptualization and testing of various packaging materials for durability and defects before they are deployed. The result will be lighter, more durable, and eco-friendly materials, which will reduce the dependence on the pollution-causing single-use packaging that most firms use. In addition, digital twins can continuously inspect reusable container fleets for damages or design flaws.

B. Shipment Protection

During shipment, the combination of product and packaging data obtained from their respective digital twins can help suppliers create optimal shipment and delivery conditions to prevent product damage during transit. The sensors shipped alongside sensitive or high-value products such as perishables and medications collect environmental data such as vibration, shock, humidity, and temperature, which are then transmitted to the shipment digital twin for simulation and identification of any weaknesses that could damage the products [2].

C. Warehouse and Distribution Centers

In the warehouse and distribution centers, digital twinning can help in designing the buildings and simulating their operations by combining data from the 3D models, IoT platforms, and inventory and operations departments. The advantages include the optimization of in-house space, automation systems (i.e., reducing energy consumption), and personnel productivity (i.e., using virtual reality training tools) [2].

D. Logistics Infrastructure and Global Logistics Networks

Digital twinning can be extended to other major logistics infrastructure such as container ports and cargo airports, which have more complex systems. The digital replicas monitor a variety of things, such as ship movement, weather patterns, and geographical data for higher operational efficiency. Lastly, the ultimate goal of digital twinning is to simulate the entire logistics networks, including land, sea, and air travel. This capability requires the integration of network digital twins with data from GIS (Geographic Information System) and autonomous vehicle technologies to obtain a global perspective of the supply chains.

3.2.1. Case Study: DHL Supply Chain

DHL is among the top logistics companies in the world and has been leading the pack in testing the integration of the internet of things technology in its warehouses through various partnerships. True to its name, the company has partnered with Tetra Pak to create the first-ever digital twin warehouse in the Asia-pacific market. The purpose of the digital twins is to facilitate cost-effective and agile management of physical assets and supply chain operations [5].

Tetra Pak is a global company that deals with food processing and offers packaging solutions. As part of its vision to ensure the availability of safe foods, the firm serves millions of customers through its outlets located in over 160 countries. Since Tetra Pak handles various products, the virtual representation of its physical warehouse will enable it to achieve round-the-clock monitoring and just-in-time resolution of productivity and safety issues.

The Smart Warehouse has six key elements that monitor internal operations.

1. It has systems for monitoring the temperature of the inhouse environment in real-time. Temperature measurements are crucial in ensuring the quality of the different food products stored in the Warehouse.
2. It monitors site movements and alerts the management in case of an unauthorized entry into controlled or restricted areas.
3. It optimizes space, thus reducing congestion, workload allocation, and resource planning on the warehouse floor. Space optimization is thus projected to result in at least 16% in efficiency gain [5].
4. It enables full traffic visibility that enables employees to slot packages easily into their allocated shelves of storage spaces.
5. It provides real-time operational data regarding the physical condition of packages and stock levels that not only assist supervisors in decision-making but also helps them in coaching their teams and improving the overall team performance.
6. It improves MHE (material handling equipment) safety due to the availability of proximity sensors that monitor over 1,000 designated locations in the warehouse [5]. IoT sensors have also been attached to equipment, robots, and autonomous vehicles that move

packages across the warehouse floor, thus improving their spatial awareness and reducing the chances of collisions. The system also has a container management solution that handles heavy containers, hence ensuring employee safety. Overall, DHL has installed a control tower that oversees the flow of outbound and inbound goods. This system ensures that inbound goods are offloaded at the correct time, sorted, and shelved within thirty minutes upon reception while goods bound for delivery are loaded for transportation within 95 minutes [5]. A seamless flow of goods is thus created, preventing delivery mistakes.

Through this initiative, DHL has demonstrated its capacity to leverage the wealth of knowledge and expertise it has gained through its global operations in meeting the needs of local customers. As a third-party logistics provider, DHL enables customers to outsource their logistics operations or management. The solutions offered by the firm include domestic transportation, warehouse management, packaging design and recycling, and service parts logistics [6]. The firm intends to replicate Tetra Pak's success in its future endeavors.

3.2.2 Challenges in Manufacturing and Logistics

Despite the advances in digital twins, specific challenges remain that hinder their adoption in manufacturing and logistics. First, the current logistics and manufacturing industries are highly fragmented, making it hard to create digital twins for global networks [2]. Firms differ in their levels of digitalization and organizational culture, thus creating considerable obstacles in supply chain networks and exchanging data. Second, most small firms lack the computing resources to adopt digital twin technology, which is also expensive to implement and deploy. Additional costs arise from the need to train employees and reorganize internal procedures and processes to accommodate the new working environment. Third, challenges remain in obtaining accurate virtual representations of physical systems either because of limited skills or poor data quality.

No digital twin created so far is a perfect replica of its physical counterpart because of the complexities involved in capturing the attributes of an asset. As a result, engineers usually make simplifications and assumptions in the models to balance the preferred attributes of the digital twin with the prevailing technical and financial constraints [2]. Poor data quality, on the other hand, arises because of inaccuracies, inconsistencies, and gaps in the product or systems data generated by most organizations.

Lastly, digital twins are likely to attract higher cybersecurity risks because of the magnified levels of disruption to entire manufacturing systems and supply chains. Digital twins particularly threaten the competitive strength of organizations because they store intellectual property on product design and sensitive customer information. Cyber attackers who obtain such information can use it for bad purposes such as identity theft, and fraud, to destroy a firm's credibility and reputation.

3.3. Digital Twin in High Hazardous Environment

Industries such as Nuclear and Aerospace operate in an environment that is inhospitable for human beings (i.e., radiation or sky/space). To operate in these conditions, companies spend millions of dollars to overcome the natural resistance and create tools and machines that allow humans to harness the resources in these environments.

Moreover, every time when changes or repairs have to be made or a new machine or equipment needs to be introduced, hundreds of thousands of dollars have to be spent in testing and making sure that it can operate under these conditions. Similarly, if an accident occurs in these environments then it can lead to catastrophic loss of lives, ecosystem, and revenues.

However, over the years technology has made great advances so software and sensors can be used to create digital twins of equipment, machines and the whole physical plants that are used in these industries. These digital twins can be used to experiment, test new products and consider the impact of hundreds of different variables and unexpected conditions in the virtual world before taking any steps in the physical world.

Digital twin technology can be used at any and all stages of the product life cycle. The following subsections show how digital twins are currently being used by these high hazardous industries at various stages of the product life cycle.

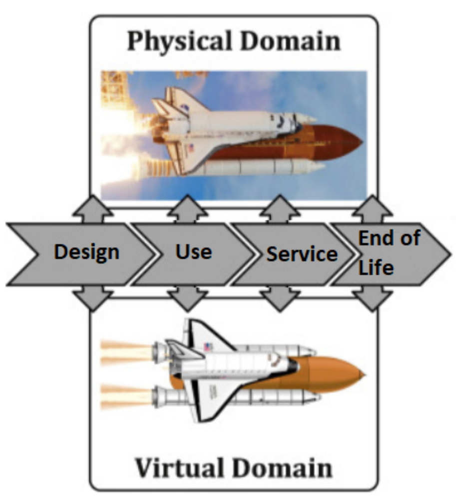

Figure 1 Digital twins can be used in entire product life cycle [7] .

3.3.1. Design Stage

The design phase starts from where knowledge, past experience, and mathematical/engineering principles are applied to build a product that would most likely meet requirements. However, for complex product design stage can become an iterative process where a design is created, followed up by a prototype development and testing to see if it meets the requirements. Then the process is repeated all over again until there is a product that meets the requirement.

In high hazard industries where a perfect product is required with a very small margin for deviation, the whole design process can be very complex and costly. For example, if the requirements are to design a new rocket ship that needs to be faster than the older model and instead of having four thrusters it needs to have five thrusters. Then to design this new rocket, a digital twin of the older model can be constructed to figure out the optimal location for locating the additional thruster and how it will impact the overall ship (i.e., how much more fuel is required, how the structure of the new ship needs to be redesigned and reinforced to handle the additional power, etc.) By using the digital twin technology, the design, testing and optimization of the whole ship can be completed in in the virtual space before building it physically.

In an interview, NASA leading manufacturing experts mentioned that digital twin technology plays a vital role in their organization and they don't build anything until they have first perfected it to meet the requirements in the digital space. Moreover, once the equipment has been built, they carry over its digital twin into operation phase so they can continue to monitor it [7].

3.3.2. Operations/Use Stage

Digital twin technology is most commonly used at the operations stage. A plant, equipment or machine operator can make use of the digital twin to test and find out the results of their tasks and operations in the virtual space before actually performing them in the physical world. Additionally, Digital twins allow companies to monitor the performance of their equipment and predict when it will fail, so they can safely take action in a timely manner.

General Electric (GE) and Assystem have created digital twin models that can be used to continuously keep track of a nuclear plant. The digital twin models produced by these companies can be used to reduce unexpected reactor trips, optimize fuel usage, and determine the optimal time to perform maintenance [8] [9]. Moreover, the GE digital twin model allows operators to quickly consider the outcome of different actions and select the most optimal course of action in real-time [10].

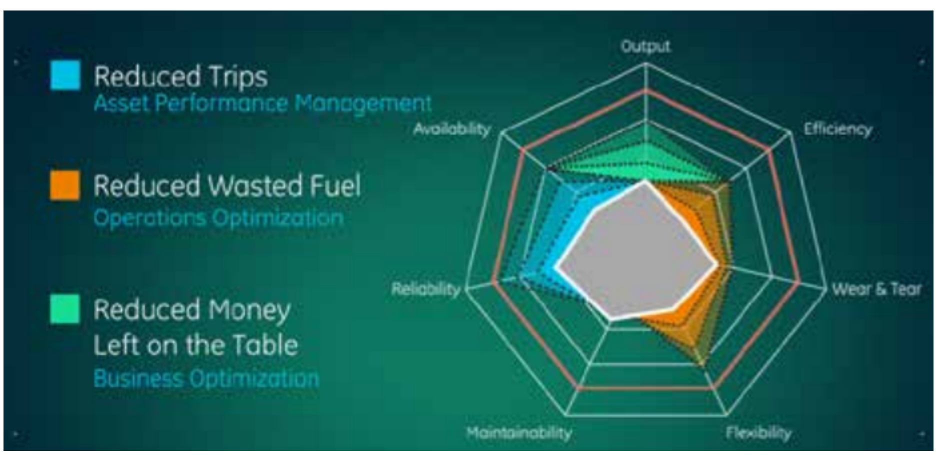

Figure 2: Plant operators can use digital twin models to find a balance between different priorities [9].

3.3.3. Maintenance Stage

Maintenance and operation activities are intertwined, as mentioned above the digital twin models developed by GE and Assystem allow companies to predict when a component in their nuclear plant will require maintenance. Similarly, Challenge Advisory created a digital twin system for AMVAC that allows them to monitor the health of their airplanes and determine the remaining life cycle of various components and when they will need maintenance. This saves AMVAC thousands of dollars as they do not need a ground crew to perform a routine physical check-up on airplane condition [11].

The U.S. Airforce has also created a digital twin software called Digital Thread for their fleet of planes. The Digital Thread system contains all information on each plane starting from the design stage, to manufacturing, operation, and maintenance. Along with providing notification of when a plane needs maintenance, it tells the maintenance personnel who is the supplier of that specific component and where they can procure it. The Digital Thread system is also connected to the technical support team so if the ground crew is having trouble diagnosing or solving a

Figure 3: A researcher from U.S. Airforce is showing how Digital Thread can be used [12].

problem, they can reach out to the support team which can see the real-time condition of the plane in virtual space and can help them in solving the problem [12].

3.3.4. End of Life Stage

A lot of companies are looking into using digital twin technology to manage the end of life stage of equipment (i.e., dismantling, recycling, and disposal). This is especially true of the nuclear industry where nuclear power plant decommissioning is a long and complex process with continuous radiation hazards. Sweco has developed a digital twin technology that can be used to create a digital twin of nuclear power plant for decommissioning. A lot of components at the nuclear plant emit radiation that drops to the safe handling levels over time. This digital twin allows companies to monitor the radiation levels and create an optimized dismantling plan, so they reach each component when its radiation level has dropped to safe handling levels. This digital twin also enables companies to get maximum value from the waste by ensuring that all components are correctly recycled or disposed of [13].

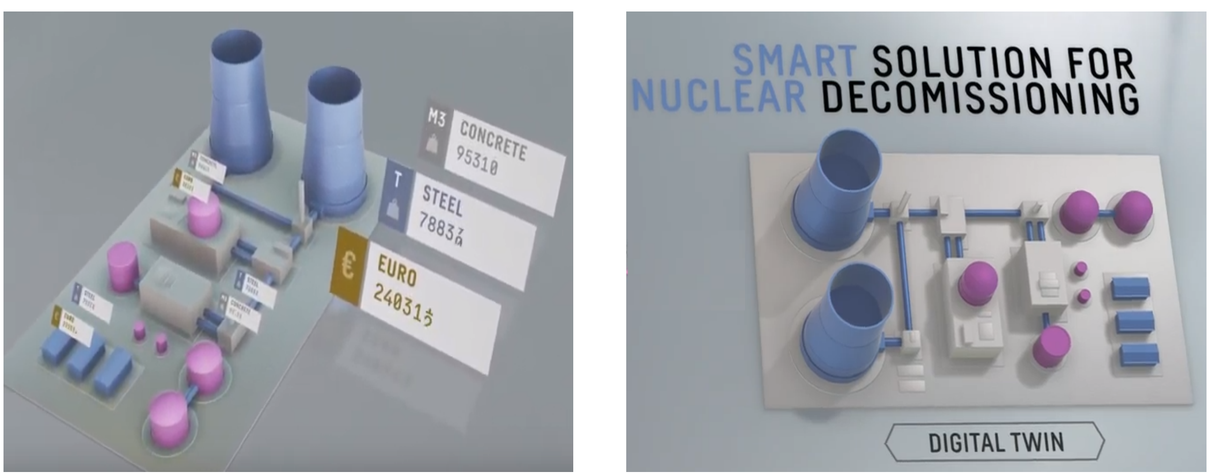

Figure 4: A digital twin model of nuclear power plant created by Sweco [13].

3.3.5. Safety

Although safety is not considered one of the design stages, it is the top priority for both nuclear and aerospace industries and one of the key driving forces that lead to the adoption of digital twin technology in these industries.

The following are a few examples of how the use of digital twin has improved safety in these industries:

- Emerson has created a digital twin simulator of a nuclear power plant that can be used to train employees on how to respond to emergency incidents. This system can also be used to plan for any unexpected incident that might occur when performing maintenance on a piece of equipment in the nuclear power plant [14].
- The Assystem digital twins used during nuclear power plant's operations minimize (and in some cases eliminate) the need for manual observations and measurements. This reduces the time that nuclear workers must spend in the radiation zone [10].
- SNC Lavalin has developed a digital twin for a nuclear power plant that can allow workers to do training and become familiar with a task in virtual space before they have to actually perform it in the field. This makes sure that workers can complete their tasks confidently and reduce their working in the radiation zone [15].
- Similar to SNC Lavalin, Circuitstream has created a virtual reality training platform for airside operators which gives them a chance to learn and practice in a safe environment without endangering their lives or damaging the equipment [16]

3.4 Digital Twin in the Energy Industry

The application of digital twin has witnessed an increasing trend in the energy industry over the past decade. To some extent, it can be attributed to the booming renewable energy sector as it has revolutionized the ways through which energy is managed. As a result, the digital twin technology came into play to facilitate seamless interconnections between the renewable energy industry and the convectional one.

3.4.1 Unique Features of the Renewable Energy Sector

In comparison with the conventional energy sector, the renewable energy industry has some unique features that pose challenges to its integration with the existing energy networks. Nevertheless, those features also provide fertile grounds for the development of digital twin technology. Specifically, renewable energy production is intermittent and weather-dependent, leading to gaps between production and demand [17]. Also, many large-scale solar and wind farm projects are deployed in regions where abundant renewable energy resources are available. However, those regions typically do not have a large population and thus high energy demands.

For example, the world‘s largest solar farm, the Noor Complex Solar Power Plant is located in the Sahara Desert and the world’s largest onshore wind farm, the Jiuquan Wind Power Base is located in the Gansu Province of China [18] [19]. As a result, renewable energy generation often leads to spatial gaps between generation and demand. In addition, unlike traditional energy generators that are typically clustered in large scale, renewable energy generators are usually scattered and are small in scale, adding variabilities to central grids [17].

3.4.2 Benefits of Adopting the Digital Twin Technology

The digital twin technology could benefit the renewable energy industry primarily in three ways. First, digital twins empower the energy suppliers with more controllability over the grid. Specifically, with all the energy generation systems interconnected and sharing real-time data, the digital twins make accurate predictions on the shifting demands on the grids, allowing energy suppliers to adjust power generation accordingly [17]. In contrast, under the current energy supply system, energy suppliers typically rely on historical data to forecast energy demand and plan generation capacity [20]. This usually leads to considerable discrepancies between generation and actual demand at the cost of financial losses.

In power grids, surplus electricity has to be dissipated from the grids to avoid damages. Ontario has been exporting its surplus energy to the U.S. or neighboring provinces such as Quebec at discounted prices, yielding net losses for the exported portion of energy [21]. Although the inaccurate prediction of demand is not the sole cause for the excess in power generation plight of Ontario, it does substantiate the potential of using digital twins to offer power suppliers more controls over the grid to narrow the gap between demand and supply, through accurate real-time forecasting.

Second, digital twin technology facilitates flexibility in the energy systems by implementing Power-X (PtX) measures [17]. Many industries use different forms of energy (i.e., electrical, heat, and etc.) for production. Since electrical energy is versatile and can be transformed into various forms, the digital twins enable seamless switch between primary energy sources according to real-time data analytics. For example, a steelmaking plant uses either electricity or natural gas for heating, when the digital twins anticipate excess energy supply in the grid, more power can be diverted for the heating purpose at the plant while curtailing the usage of natural gas.

As a result of higher controllability and system flexibility, digital twin also yields higher energy efficiency. Furthermore, the digital twin enhances system stability through early identification of abnormalities in the system. In particular, digital twin systems monitor the real-time working conditions of the energy system. If signs for abnormal conditions are detected, alters are triggered, prompting early intervention to reduce the risk of system failures [17].

3.4.3 Digital Twins in Wind Farms

Large scale wind turbine fleets typically feature high initial investment and operations and management (O&M) costs, especially for those located in remote areas such as offshore. Digital twins' capabilities to dynamically track performance and condition parameters, as well as automatic efficiency optimization, have made them increasingly valuable tools for wind energy investors [22].

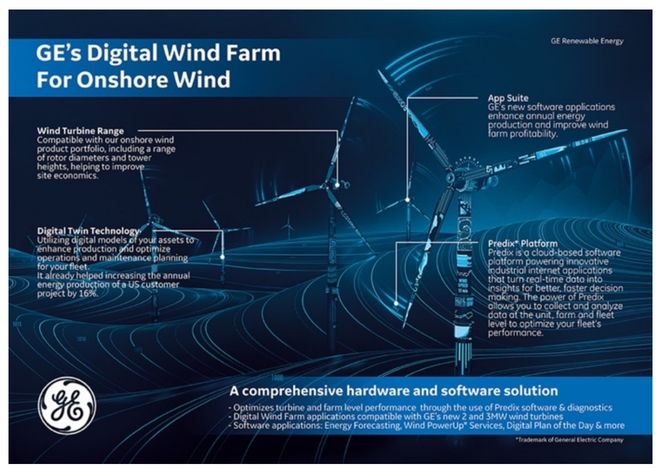

Figure 5 GE's Digital Wind Farm [22]

General Electric (GE) is one of the key players in the digital twin technology field for wind energy. According to GE, digital wind turbines have the following features.

1. They highlight access to real-time data and analytics of wind assets around the world. All the data collected from various sensors inside wind turbines are transmitted and processed on GE's could platform, Predix [23]. The digital twins use those data to monitor multiple parameters such as torque, vibration, blade pitch angels, etc. in the turbines and make adjustments according to the simulation results for optimized efficiency [24].
2. Digital twins allow early identification of anomalies in the systems, so preventive actions can be taken to avoid costly system damage and downtime [23]. For example, GE has developed a digital twin for the yaw motors in its Haliade turbines featuring virtual sensors to predict the temperature profiles in different parts of the motors to ensure certain adjustments for efficiency does not damage the motors [24]. According to GE, its digital twin solution for wind farms increases average energy generation by more 5% and reduces O&M costs by 10% [23].

3.4.4 Challenges of Digital Twins in the Energy Sector

Despite many promising potentials of the digital twin technology, its development and deployment also face many challenges. Those challenges can mainly be categories into security challenges and technical challenges.

3.4.4.1 Security Challenge

Digital twin technology, like many other IoT technologies, are prone to cyber-attacks. In digital twins, critical data no longer remains isolated in local domains; instead, data is shared online and become technically accessible without geographical constraints.

According to the World Energy Council's report on cyber risks, cyber risks can result in either physical or non-physical damages. The physical damages include the breakdown of critical machinery (i.e., wind turbines) or systems (i.e., energy grids) through malicious remote manipulations. Non-physical damages, on the other hand, involve data corruption, data or intellectual property espionage, etc. [25].

Although there have been no known cases of cyber-attack or data leakage incidents associated with digital twins up to this point, the worries about data security are sensible as consequences can be detrimental, and cyber-attacks are not farfetched. In fact, on December 23rd, 2015, the computers and data systems at the Ukrainian electricity distribution company were invaded by hackers, resulting in the disconnection of several substations and a 3-hour blackout [26].

As digital twins become more widely adopted in critical industries such as aerospace, manufacturing, logistics, and energy, more assets and processes can potentially be threatened. To cope with the cybersecurity risks, a management consulting company, Oliver Wyman, outlined a framework of management strategy that can also be applied to digital twins (Figure 6).

Figure 6 Cyber risk management strategy framework (A NEW APPROACH TO CYBERSECURITY LEVERAGING TRADITIONAL RISK MANAGEMENT METHODS, 2014)

Overall, the overarching strategy is to set universally recognized policies and standards in regard to cybersecurity. Cross-national governmental agencies and industrial organizations need to collaborate on cyber-security grounds through information sharing and personnel training etc. Detailed operational or design procedures need to be established in alignment with the policies and standards. In addition, the development of technology and physical infrastructure (i.e., enhanced data encryption mechanisms) need to follow suit.

3.4.4.2 Technical Challenge

The massive amount of data of various types is the foundation of a functional digital twin. On the other hand, however, the enormous amount of data also makes data transmission and processing challenging. The demand for real-time data requires high transmission speed and security, as well as low latency. While wired data transmission through fiber optics can meet the requirements, they require an extensive amount of infrastructure, which may not be viable in remote locations. Wireless data transmission is limited by its bandwidth and speed. The development of the 5G network exhibits promises to resolve data transmission issues [1].

In addition, there lacks universally accepted protocols and standards for digital twin data. Many firms such as GE and DNV GL develop their own proprietorial platforms, making cross-platform data integration beyond reach [27]. This hinders the development and deployment of digital twins because an individual firm is unlikely to excel in all aspects of the digital twin technology. In fact, the digital twin industry can follow the example of the telecommunication industry in establishing technical protocols and industry standards to make fertile ground for the development of a digital twin ecosystem.

4. Conclusion

In conclusion, digital twin technology plays a key role in various fields, and it can help a company achieve competitive advantages. Moreover, the digital twin is the future of designing and manufacturing a product, process, and service.

In the report, the team illustrates how companies can use digital twins to virtually predict things that would happen in the physical world. For example, companies can use digital twin technology to simulate experiments in high hazardous environment settings such as aerospace and nuclear.

One of the main benefits of using the digital technology is that it allows a better understanding of products in early stages, which could significantly reduce the various costs such as failure cost, design cost, and maintenance cost.

The team discussed several fields that can apply the digital twin technology, but there are many other industries out there that widely utilize digital twin technology such as health care, urban planning, and automotive industry. In general, the digital twin technology can be used as an idea generator to facilitate innovation. Moreover, it allows people to experiment various ideas without any constraints.

5. Recommendations

Although digital twin started its journey in the 1970s, it did not become mainstream until recently (in 2017). Hence there are still a lot of areas where it can be improved on, some of which are discussed below:

- A set of universally accepted principles that govern digital twin technology. This will help promote digital twin technology to other industries, and it will also make it easier to train people (in university or on the job) on how to develop digital twins.
- One thing that sets digital twins apart from other simulation models is the constant feedback data. Hence, it is necessary to make sure that this data is properly encrypted and protected to prevent it from being hacked or modified. A range of cybersecurity solutions already exists in the market which can be used by companies to guard their digital systems.
- Integrate digital twins with real-time decision making/operations processes. Data provided by the digital twin models can facilitate process optimization in real-time. This technology can be used in autonomous vehicles or in spaceships that are voyaging to Mars.
- Every product should have a digital twin model that follows it through its entire life cycle, similar to the U.S. Air Force's Digital Thread technology discussed above. When the first manufacturing company creates a product from raw material, it should also create its digital twin and share it with its customer down the line so they can build on it. This will allow customers to trace each product back to its origin and it will also help make sure each product is properly recycled leading to reduction in number of items that are sent to landfills.

- Manufacturing and logistics firms must work closely with their suppliers. Closer collaboration will facilitate quicker sharing of production and demand data for faster operations.
- Given the high cost and complexity involved in using digital twin technology, firms can start small by incorporating crucial technologies such as artificial intelligence, robotics, and IoT. These techs form the backbone on which digital twins are based, and will, therefore, provide quality data for creating the virtual replicas.
- Companies should gradually start educating their employees on digital twins since introducing the tech suddenly may disrupt normal operations or cause employee resistance. Managers are crucial in this transformation as they will not only guide and support their teams during the change process but also organize training sessions for reskilling or upskilling the workers who will be affected by the change. By the time digital twins are introduced, the workers will be adequately skilled and mentally prepared.

6. Actions / Way Forward

One of the most urgent issues that the digital twin technology developers need to resolve is the absence of universally accepted industry standards and protocols upon which future developments can be prompted.

Digital twin technology requires a complete ecosystem to thrive, and any individual cooperation is unlikely to excel in all aspects of the technology. Therefore, cross-industry collaboration is required. Digital twin industry can learn from telecommunication industry which faced similar issues in early stages. To ensure the compatibility of telecommunication technologies, key players in the market, which include telecommunication companies, chip and device makers, collectively established standards and protocols (i.e., 2G-5G standards) for technology development. This points out a feasible way for digital twin technology to follow suit.

While at the current stage, digital twin technology primarily focusses on industrial applications, their versatility, in fact, does not have boundaries. Last year, during the Chinese Spring Festival Gala, four TV hosts were joined by their digital twin models that were powered by artificial intelligence and were completely autonomous. This shows that there are hundreds of ways in which digital twin technology can be used to make lives simpler and safer.

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