POLITECNICO
DI TORINO

DIGITAL TWIN LEONI WIRING SYSTEMS EGYPT CASE

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Table of Contents

Table of Figure

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Many Thanks to my amazing supervisor Professor Luigi Benfratello who supported me during this stage of my life. He was always understanding. His words affected me and made me continue my journey. He told me: "Never give up and go back to your comfort zone, try to find some work here in Europe". And to my beautiful fiancé, who was always supportive and helped me in writing this thesis and was always there for me in sickness and in health.

Preface

For quite a long time, people have utilized pictures and models to assist them with handling complex issues. Extraordinary structures originally came to fruition on the designer's drawing board. Classic vehicles were formed in wood and clay. After some time, our displaying capacities have become progressively developed. PCs have replaced pencils. 3D PC models have replaced 2D drawings. Advanced modeling systems can simulate the activity and behavior of an item as well as its dimensions.

As of not long ago, there remained an unbridged partition between model and reality. No two produced objects are ever really identical, regardless of whether they have been worked from a similar drawing. PC models of machines don't advance as parts wear out and are replaced, as fatigue accumulates in structures, or as proprietors make changes to suit their evolving needs.

That hole is beginning to close. Filled by improvements in the digital reality, cloud computing, artificial intelligence, big data, and internet of things (IOT), the appearance of digital twins proclaims a tipping point where the physical and digital universes can be managed as one, and we can cooperate with the computerized partner of physical items much like we would the items themselves, even in 3D space around us.

Driven by the engineering, manufacturing, automotive, and energy industries in specific, digital twins are as of now making new value. They are making a difference to organizations in order to manage, visualize, monitor, design, and maintain assets more successfully. Furthermore, they are opening new business opportunities like the provision of advanced services and the generation of significant knowledge from operational information.

Experts have been searching and thinking about how digital twins will change traditional supply chains, and how the logistics segment may grasp digital twins to improve its own procedures. This report was made to answer the following questions:

■ What is a digital twin and what does it means for my association.

■ What best-practice models from different enterprises can be applied to logistics?

■ How will my supply chain change in view of digital twins?

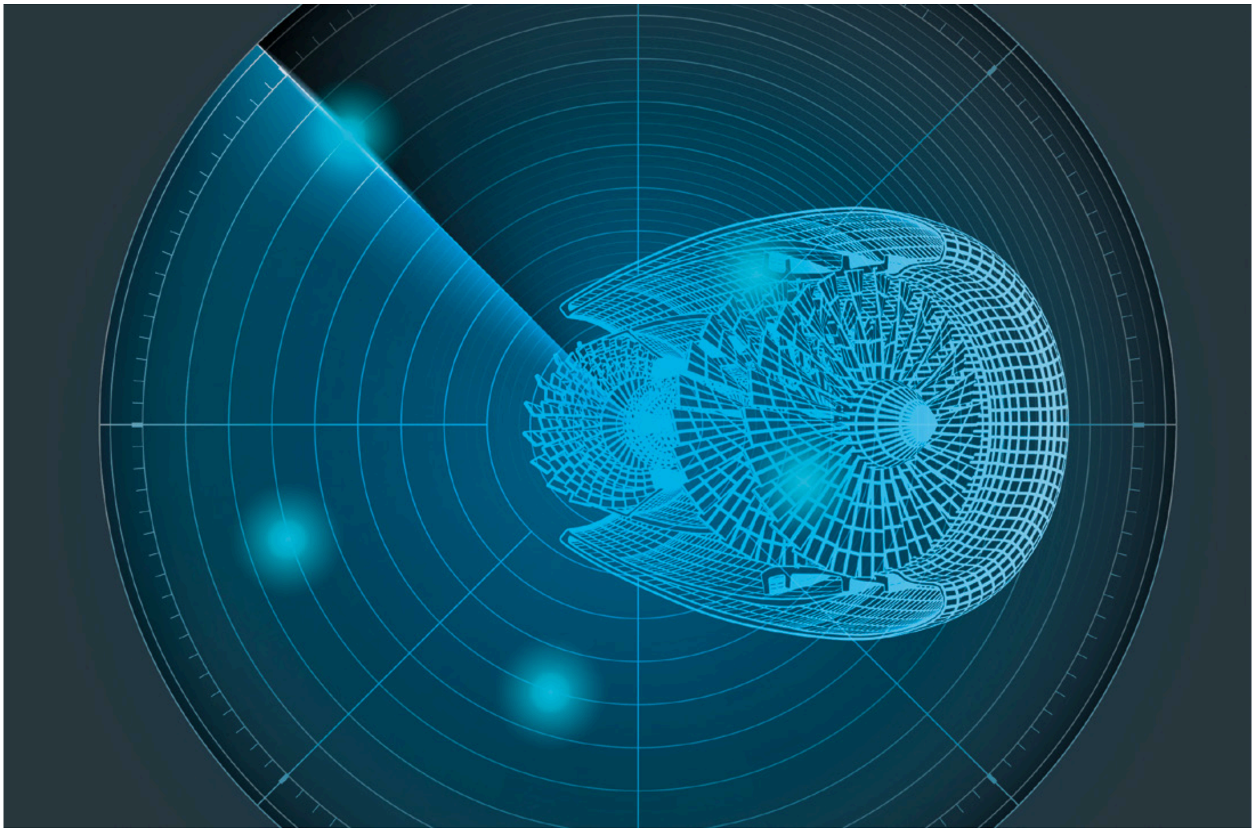
Looking forward, we accept that the use of digital twins through industries will drive decision making in the physical world. As a result, will drive critical changes in the activity of supply chains and logistics processes.

In the logistics business itself, digital twins will broaden the advantages of IoT already being applied today. They will bring further knowledge into the design, planning, optimization, and operation of supply chains, from shipments and individual assets to whole global supply networks.

Company profile

“LEONI is a global provider of products, solutions and services for energy and data management in the automotive sector and other industries. The market-listed group of companies has around 95,000 employees in 32 countries and generated consolidated sales of EUR 5.1 billion in 2018.

LEONI's largest customer group comprises the global car, commercial vehicle and component supply industry, for which the Company makes both standard and special cables as well as custom-developed wiring systems and related components. LEONI furthermore supplies products and services to these markets: data communication & networks, healthcare, process industry, transportation, energy & infrastructure, factory automation, machinery & sensors as well as marine. An integrated network for research & development, production as well as distribution and service give customers the assurance of tailor-made support at more than 100 locations around the globe. LEONI operates as a solutions provider with pronounced development and systems expertise.”



Chapter 1

1 Understanding Digital Twins

1.1 What is a digital twin?

As characterized by most industry investigators, digital twins are one of a kind programming portrayal of individual resources, processes, or systems that empower organizations to accomplish improved business results.

A digital twin can represent a functional asset (rotating equipment or including fixed), a component (engine, a pump, and so on.), a system of assets (a turbine, stream motor, MRI machine, and so forth.), or a fleet of assets (a wind farm, an aircraft, a combined cycle unit, etc.). The degree of portrayal is controlled by the focus on business results, e.g., lessening unplanned downtime of a compressor contrasted with optimizing power generation output.

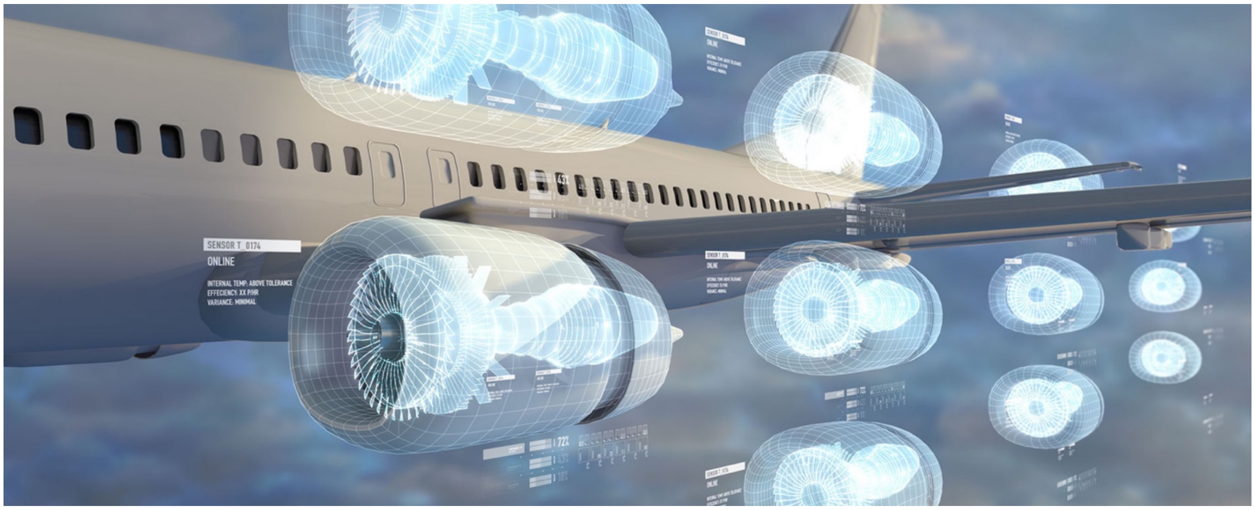


Figure 1: Shows different types of Digital Twin

1.2 THE DIGITAL TWIN COMES OF AGE

For a long time, researchers and designers have made numerical models of true items and after some time these models have gotten progressively complex. Today the advancement of sensors and system advances empowers us to interface already disconnected physical resources for computerized models. Right now, experienced by the physical article are reflected in the computerized model, and bits of knowledge got from the model permit choices to be made about the physical article, which can likewise be controlled with remarkable accuracy.

While the advanced twin idea has existed since the beginning of the 21st century, the approach is currently arriving at a tipping point where broad selection is likely in the not so distant future. That is on the grounds that various key empowering innovations have come to the degree of development important to help the utilization of digital twins for big business applications. Those advancements incorporate minimal effort information stockpiling and figuring power, the accessibility of vigorous, highspeed wired and remote systems, and modest, dependable sensors.

The utilization of a high-fidelity simulation or a direct physical replica to help the activity and upkeep of a benefit has a long history. NASA spearheaded a blending approach during the early years of space investigation. At the point when the Apollo 13 rocket endured noteworthy harm determined to the moon in 1970, NASA engineers had the option to test and refine potential recuperation methodologies in a matched module on earth before giving guidelines to the stricken team. To this day, matching - presently utilizing advanced models - stays a focal piece of the US space organization's system for overseeing space missions.

From the outset the intricacy and cost included in building digital twins restricted their use to the aviation and resistance segments (see the timetable in figure 2) as the physical items were high-esteem, strategic resources working in testing conditions that could advantage from reproduction. Moderately few different applications had the equivalent blend of high-esteem resources and difficult to reach working conditions to legitimize the speculation.

That circumstance is evolving quickly. Today, as a component of their ordinary business forms, organizations are utilizing their claim items to produce a great part of the information required to fabricate a digital twin; computer-aided design (CAD) and simulation tools are usually utilized in item improvement, for instance. Numerous items, including buyer gadgets, autos, and even family apparatuses now incorporate sensors and information correspondence abilities as standard highlights.

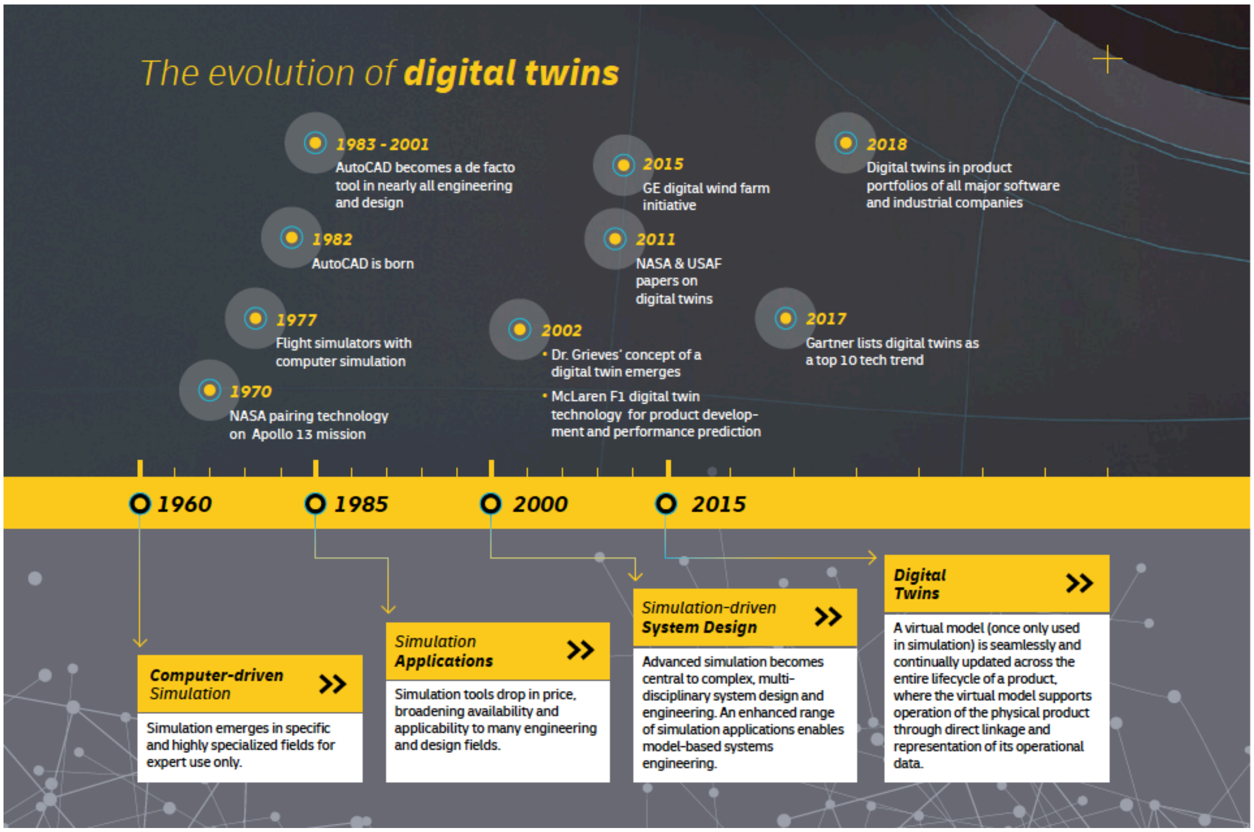


Figure 2: The evolution of digital twins. Source: DHL

As corporate enthusiasm for digital twins develops, so too does the quantity of innovation suppliers to supply this request. Industry analysts anticipate the digital twin's market to develop at a yearly pace of in excess of 38 percent over the following years, passing the USD $26 billion point by 2025.

A lot of innovation players have an eye on this conceivably rewarding space. The expansive scope of hidden innovations required by digital twins supports numerous organizations to enter the market, counting huge endeavor innovation organizations, for example, SAP, Microsoft also, IBM. These associations are well situated to apply their cloud computing, artificial intelligence, and enterprise security abilities to the production of digital twin arrangements. Moreover, producers of mechanization frameworks and modern gear, for example, GE, Siemens, and

Honeywell are introducing another period of mechanical hardware and administrations assembled on digital twins. Likewise, organizations offering item lifecycle management (PLM) such as PTC and Dassault Systèmes are holding onto digital twins as a central center innovation to oversee item improvement from introductory idea to end of life. Digital twin opportunities are also attracting the attention of start-ups, with players like: Cityzenith, NavVis, and SWIM.AI building up their own contribution's custom fitted to specific specialties
and use cases.

1.3 WHAT MAKES A DIGITAL TWIN?

Practically speaking with such a large number of various applications and partners included, there is no ideal accord on what establishes a digital twin. As our models show plainly later right now, twins come in numerous structures with numerous various traits. It very well may be enticing for organizations to ride the flood of intrigue in the methodology by appending a 'digital twin label' to a scope of previous 3D modeling, simulation, and asset-tracking technologies. In any case, this short sell the multifaceted nature of a genuine digital twin.

Most pundits concede to key qualities shared by most of digital twins. The ascribes that help to separate genuine digital twins from other kinds of computer model or simulation are:

■ A digital twin is virtual model of a genuine 'thing'.

■ A digital twin is extraordinary, related with a solitary, explicit example of the thing.

■ A digital twin stimulates both the physical state and conduct of the thing.

■ A digital twin is associated with the thing, updating itself in response to known changes to the thing's state, condition, or on the other hand setting.

■ A digital twin offers some incentive through investigation, representation, forecast, or improvement.

The scope of potential digital twin applications implies that even these characterizing characteristics can obscure in certain circumstances. A digital twin may exist before its physical partner is made, for instance, and continue long after the thing has come to the end of its life. A solitary thing can have more than one twin, with various models fabricated for various clients and use cases, for example, consider the possibility that situation arranging or foreseeing the conduct of the thing under future working conditions. For instance, the proprietors of manufacturing plants, medical clinics, and workplaces may make different models of a current office as they assess the effect of changes in layout or working procedures.

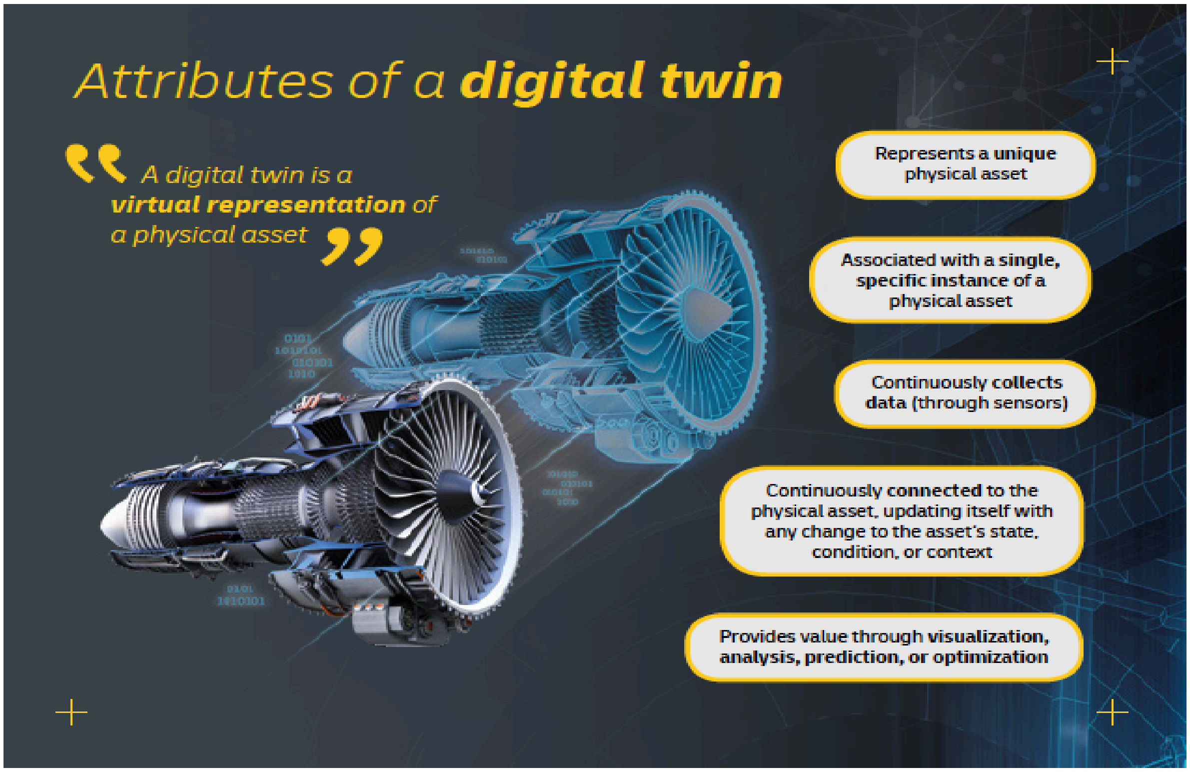


Figure 3: Characteristics of a digital twin. Source: DHL

1.4 UNDERLYING TECHNOLOGIES ENABLING DIGITAL TWINS

Five technologies are being developed in a complementary way to empower digital twins, to be specific the APIs and open standards, internet of things (IOT), artificial intelligence, cloud computing and digital reality technologies.

1.4.1 Cloud Computing. Developing, maintaining, and using digital twins is a compute- and storage-intensive endeavor. On account of the constantly falling cost of processing power and storage, enormous server farm systems with get to given by means of software-as-a-service (SaaS) arrangements presently empower organizations to procure precisely the computing resources they need, when they need them, while monitoring costs.

1.4.2 The Internet of Things (IoT). The fast development of IoT is one significant factor driving the reception of computerized twins. IoT advancements make digital twins conceivable because it is now technically and financially plausible to gather huge volumes of information from a more extensive scope of objects than previously. Organizations regularly disparage the multi-faceted nature and volume of information created by IoT items and platforms, requiring tools to help them manage and understand all the information they are currently gathering. A digital twin is frequently a perfect method to structure, get to, and break down complex item related information. Digital twins depend on a large group of fundamental innovations that are just currently coming to where they can be applied dependably, cost adequately, and at scale.

1.4.3 APIs and Open Standards. Closed, proprietary-by-design simulation tools and factory automation platforms are progressively turning into a thing of the past. Technology organizations made furthermore, secured their own information models, requiring escalated, ground-up programming improvement to manufacture framework from scratch for each new item.

Presently the accessibility of open standards and public application programming interfaces (APIs) has drastically streamlined sharing and information trade, making it feasible for clients to consolidate information from different frameworks and devices rapidly and reliably.

1.4.4 Artificial Intelligence (AI). Upgrades in the power and usability of advanced analytical tools have changed the manner in which organizations separate valuable bits of knowledge from big, complex data sets. Machine learning frameworks are empowering the improvement of frameworks that can settle on choices independently also as forecasts about future conditions depending on historical and real-time data.

1.4.5 Augmented, Mixed, and Virtual Reality. In request to use, expend, and adequately make a move on the bits of knowledge produced by a digital twin, it must be rendered either on a screen (2D) or in physical space (3D). Until this point in time, most digital twins have been rendered in two-dimensional space, as the regular figuring standards of today restrain us to shows on screens, PCs, and different screens. But increasingly, augmented reality is empowering us to show digital content in 3D. Furthermore, mixed reality permits us to collaborate with digital content in our current physical condition. What's more, virtual reality permits us to make altogether new situations to render digital twins in a profoundly vivid way, making the most extravagant utilization of, also, connection with the data.

While the above innovations – IoT, cloud computing, APIs, and artificial intelligence – give the fundamental detecting and handling framework required to make a digital twin, augmented, mixed, and virtual reality are the instruments for picturing digital twins and making them genuine to the client.

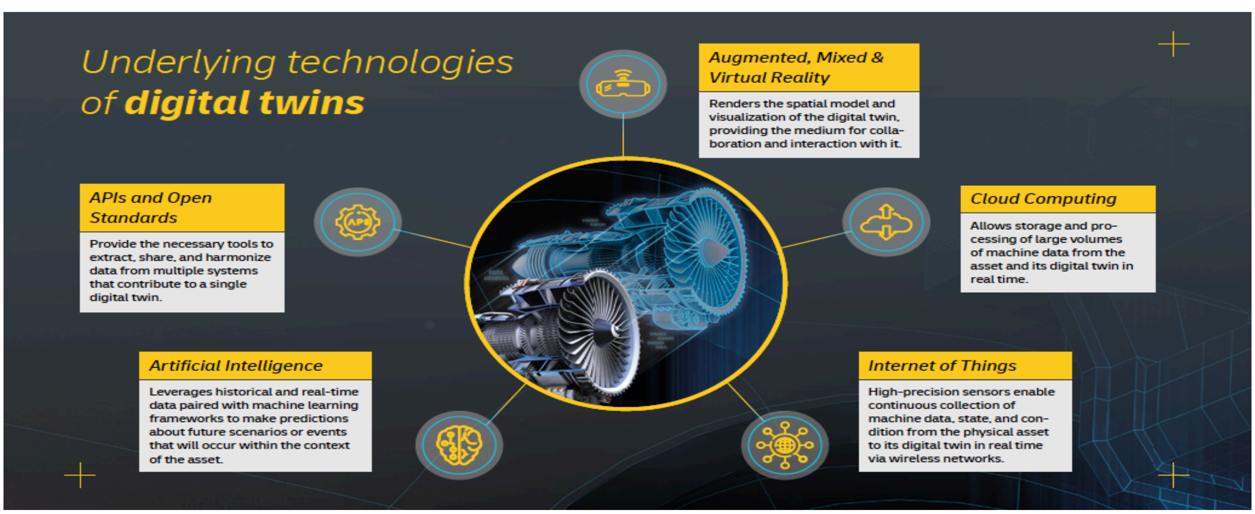


Figure 4: Technologies behind digital twins. Source: DHL

1.5 HOW DIGITAL TWINS CREATE VALUE

Digital twins can be utilized in various manners to increase the value of a product, process, user, or organization. The value available, and the venture required to catch it, are profoundly application subordinate. Most fall into at least one of the accompanying wide classifications.

1.5.1 Analytical Value. digital twins that incorporate simulation technologies can give information that is difficult to measure straightforwardly on the physical item – for instance data produced inside an asset. This can be utilized as an investigating device for existing asset, what's more, can assist with enhancing the performance of consequent product generations.

1.5.2 Descriptive Value. The ability to quickly picture the status of a resource by means of its digital twin is significant when those resources are remote or perilous – examples include off-shore wind turbines, spacecraft, power stations, a manufacturer-owned machines operating in customer plants. Digital twins make data increasingly open and simpler to decipher from a distance.

1.5.3 Diagnostic Value. Digital twins can incorporate diagnostic systems that utilizes measured or derived information to propose the most plausible main drivers (root causes) of explicit states or behaviors. These frameworks can be executed as unequivocal rules dependent on organization know-how, or on the other hand they may leverage analytics and machine learning approaches to derive relationships based on historical data.

1.5.4 Predictive Value. The probable future state of the physical model can be anticipated utilizing a digital twin model. One model is GE's utilization of digital twins in wind farms to anticipate power output, as delineated in figure 5. The most modern digital twins accomplish more than just anticipate the issue that may happen; they likewise propose the relating solution. Digital twins will assume a critical job in the improvement of future smart factories capable of making autonomous decisions about what to make, when and how, in request to augment consumer loyalty – and profitability.

Figure 5:GE's digital wind farm project

Early adopters of digital twins normally report benefits in three territories:

■ New business models

■ Data-driven decision making and
collaboration

■ Streamlined business processes

1.6 THE DIGITAL TWIN THROUGH THE PRODUCT LIFECYCLE

Since their beginning, digital twins have been firmly connected with product lifecycle management (PLM). Digital twins are currently utilized through the full product lifecycle, with a product's twin rising during the development process and evolving to support different business needs as a product advances through manufacturing, design, launch, servicing, distribution, operation and decommissioning.

1.6.1 Product Development. Information from the digital twins of past items can be utilized to refine the prerequisites and determinations of future ones. Virtual prototyping utilizing 3D displaying and reproduction permits quicker plan cycles, furthermore, decreases the requirement for physical tests as delineated in figure 6. During the configuration stage, tests with digital twins can distinguish conflicts between survey ergonomics, segments, and simulate product behavior in a wide variety of environments. Together these measures help to lessen improvement costs, improve the reliability of the final product and accelerate time to market.

Figure 6: Digital twins enable faster design iterations and rapid prototyping before going into production. Source: Forbes

1.6.2 Production. Digital twins encourage coordinated effort between cross-functional groups in the assembling procedure. They can be utilized to explain specifications with suppliers and permit plans to be improved for assembling and shipping. In the event that the association makes a digital twin with each item it makes, each model will fuse information on the particular parts and materials utilized in the item, arrangement choices chose by end clients, and procedure conditions experienced during generation.

Digital twins of production lines as delineated in figure 7 permit designs, procedures, and material streams to be tried and enhanced before another manufacturing facility is appointed.

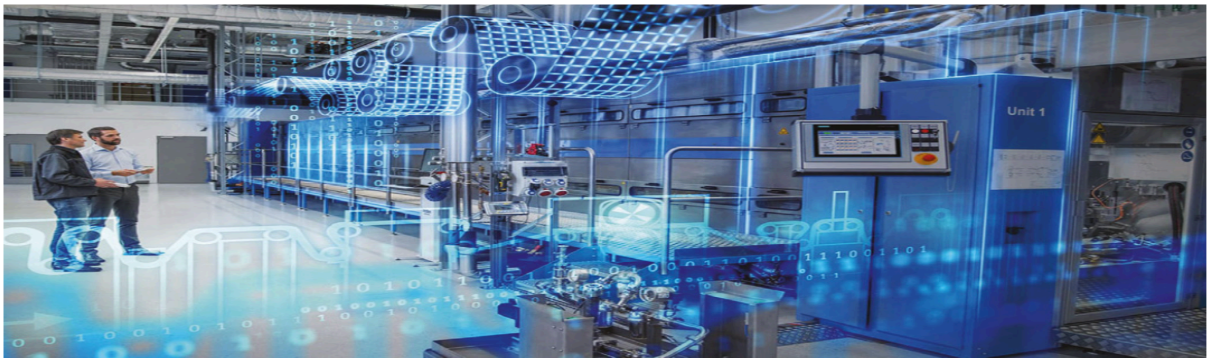


Figure 7: Siemens is applying digital twin technology to optimize processes within its production lines. Source: Siemens

1.6.3 Operate & Service. When the product goes under the control of the end-client, its digital twin keeps on accumulating information on its performance and working conditions. This information assists with supporting troubleshooting, maintenance planning, and optimizing product performance. As products are updated and adapted or parts replaced, the digital twin is fixed accordingly. Total data from various digital twins can be broke down to recognize use patterns also, enhance future designs.

1.6.4 End-of-life. At the point when a product is never again required by the client, digital twin information guides fitting end of-life activities. Information on the working states of explicit components give advice choices on whether to recondition, re-use, scrap, or recycle these products. Material information can help to decide fitting recycling and waste streams. What's more, the information collected by the digital twin during this procedure can be held for future investigation.

1.7 CHALLENGES IN APPLYING DIGITAL TWINS

There are critical difficulties to the widespread adoption of digital twins. Coordinating complex resources and their behavior digitally – with accuracy and in real time – can rapidly surpass financial and computing resources, organizational culture, and data governance capabilities. This area recognizes the hindrances that may be experienced when utilizing digital twins.

1.7.1 Cost. Digital twins require extensive interest in technology platforms, model development, and high-touch maintenance. While the vast majority of these expenses keep on falling, the choice to execute a digital twin should consistently be thought about to alternative methodologies that may give comparative incentive at lower cost. In the event that an organization is keen on a modest number of basic parameters, these experiences may be assembled more expense adequately through an IoT system dependent on sensors and a conventional database.

1.7.2 Precise Representation. For the near future, no digital twin will be an ideal portrayal of its physical counterpart. Coordinating the electrical, physical, chemical, and thermal condition of a complex resource is a very challenging and costly way. This will in general power engineers to make assumptions and simplifications in their models that balance the ideal properties of the twin with technical and economic constraint.

1.7.3 Data Quality. Great models rely upon good data. That might be a troublesome thing to ensure in digital twin applications which rely upon information provided by hundreds or thousands of remote sensors, working in demanding field conditions and conveying over questionable systems. As a base, organizations should create techniques to recognize and separate bad data, and to oversee holes and irregularities in product data streams.

1.7.4 Interoperability. Regardless of critical progress in transparency and standardization, technical and commercial hindrances to the trading of information remain. What's more, where a digital twin depends on simulation or AI technologies provided by a particular seller, it might be troublesome or incomprehensible to recreate that usefulness utilizing alternative suppliers, successfully bolting organizations into long haul single-provider connections.

1.7.5 Education. The utilization of digital twins will require staff, clients, and providers to embrace better approaches for working. That presents difficulties regarding change management and capability building. Organizations must guarantee users have the right skills and tools to communicate with digital twins and should be adequately inspired to make the vital transition.

1.7.6 IP Protection. A digital twin is a repository of intellectual property and know-how. The models and data fused into a twin incorporate detail of a product’s design and performance. It might likewise contain touchy information on client processes and usage. That makes difficulties around data ownership, data control, identity protection, and governance of data access by different user groups.

1.7.7 Cyber Security. Digital twins will be enticing focuses for digital hoodlums. The information interfaces that associate physical items to their twins give another purpose of section for malicious on-screen characters trying to disturb an association's tasks. Where digital twins play a role in the control of their physical counterparts, compromising a twin may have direct and potentially devastating real-world impact. Those attributes make effective management of digital twin cyber security a basic need, and one that will show new difficulties to numerous associations.

1.8 Why use digital twin?

Organizations must discover techniques to prevent the danger of potential item defects among their assets and future items. This bit of tech permits production costs to be limited, as organizations will spare costs when items are correct the first run. There is no requirement for costly physical tests or updates to the items or procedure. Research with makers has discovered that this idea will empower the decrease of development expenses of the up and coming age of machines by well over 50%. The highlights of the tech also give added certainty to support item performance and help complex choices, preventing expensive downtime to apply machinery and robotics.

1.9 Upcoming digital twin development features

The greatest and most energized advancement features that will be added to Digital Twin will be related with its precision and usability. So as to begin the phase of mass adoption, the idea must be affordable and simple to use for most organizations and entrepreneurs if the makers need to make their product a success. As far as explicit qualities and highlights that will be improved, it is normal that the entirety of the concentration is placed into the real-time accuracy of the feedback. Which means, that engineers are working on making the digital replica of the physical twin to respond to the changes that are made to the item quicker and with more accuracy.

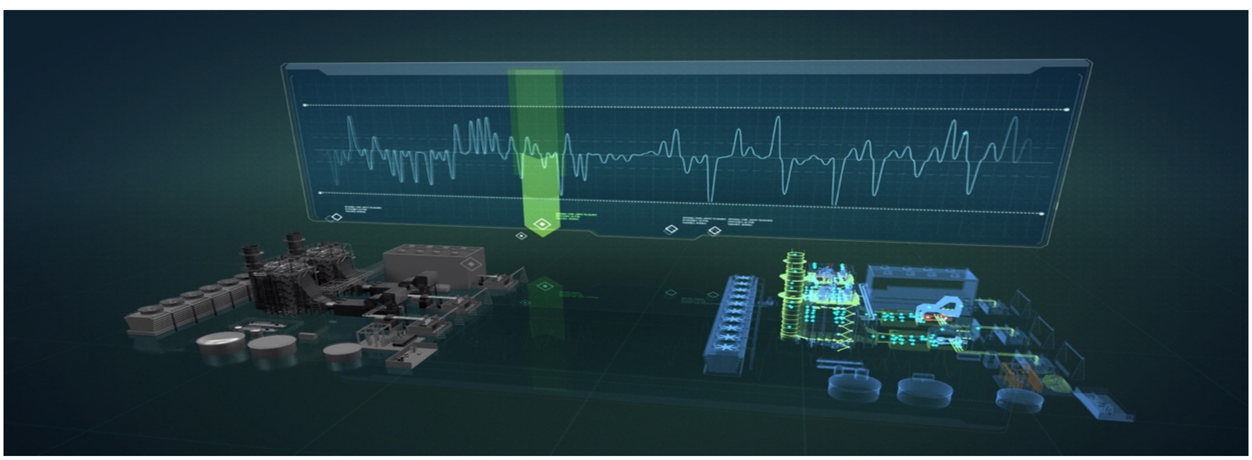


Figure 8: A Digital Twin system

1.10 Realizing digital twin value for GE case

"We've seen customers **increase reliability** from 93% to 99.49% in less than two years, **reduce reactive maintenance** by 40% in less than one year—contributing to significant maintenance cost savings, and **save $360K by predicting** a power outage in a gas plant. These kinds of results are what challenge our team at GE Digital to keep innovating and building more and more digital twins for customers.

So, while the digital twin serves as a proxy for the physical asset, system, or process in the digital world what makes a *digital twin unique and useful* is its ability to provide insights into current state, performance, and health of assets and processes as well as insights into future options to optimize assets and operations."

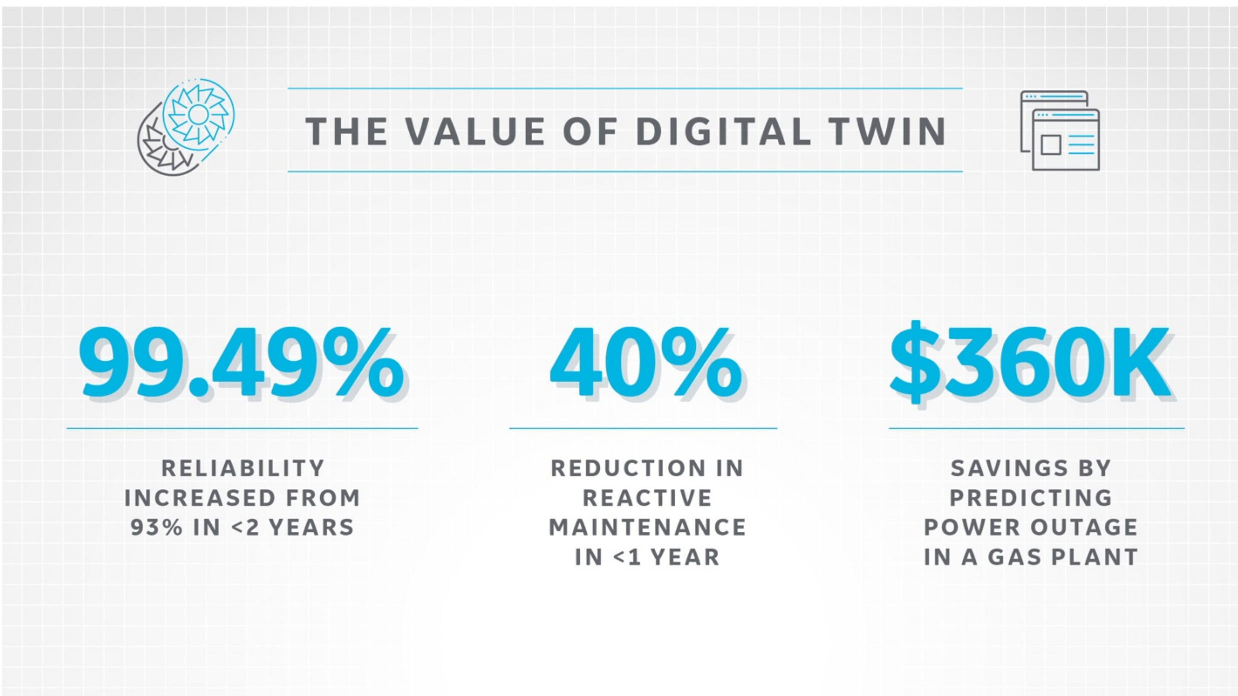
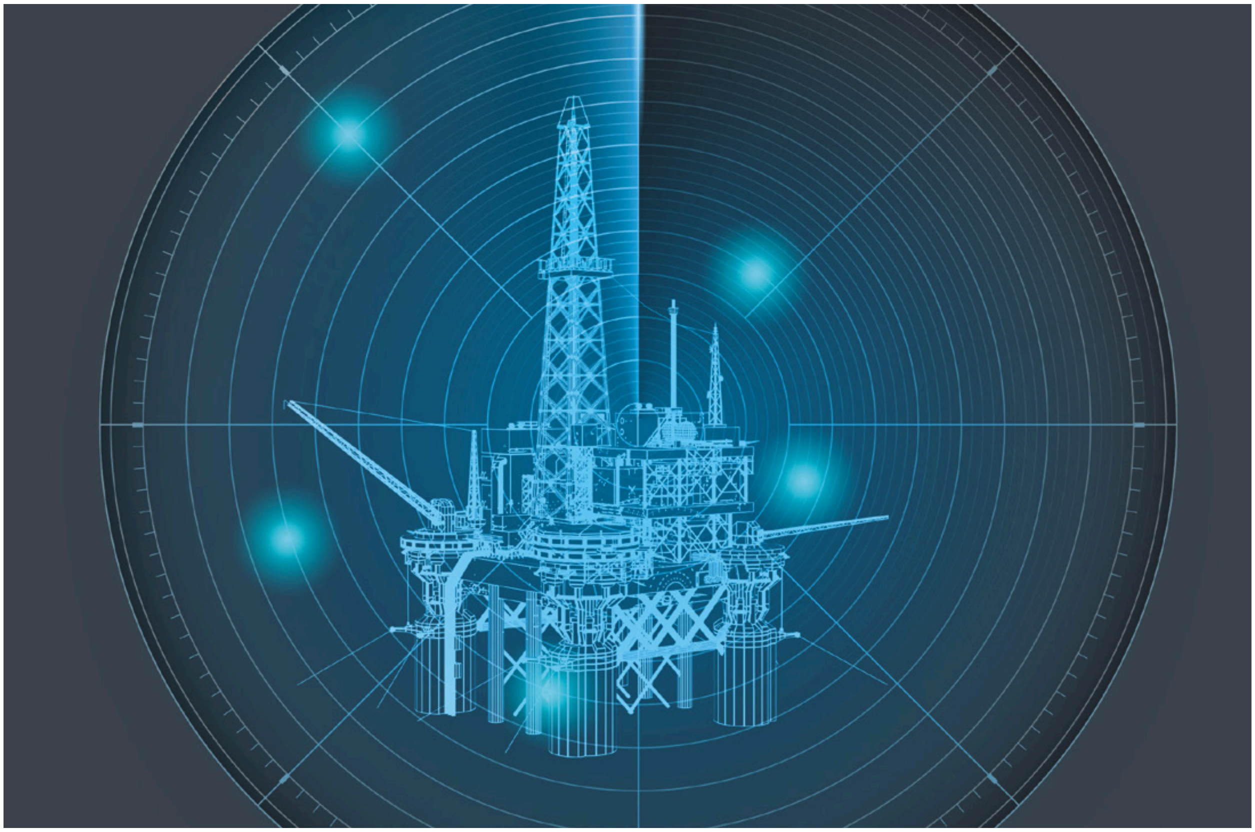


Figure 9: Shows Digital Twin Value for GE. Source: GE



Chapter 2

2 Digital Twins Across Industries

2.1 DIGITAL TWINS IN MANUFACTURING

Manufacturing tasks have been a specific area of focus for digital twin development. To some extent, that is on the grounds that industrial facilities are data rich environments in which core business is the generation of physical resources. Organizations make broad utilization of automation and robotics technology on production lines and numerous plants are embracing IoT and utilizing digital data to improve production performance. In high-efficiency fabricating there is a lot of significant worth in question. Indeed, even little upgrades to throughput, quality, or equipment reliability can be worth a great amount of money.

CNH Industrial, a worldwide maker of agricultural, industrial, and commercial vehicles, has utilized digital twins to optimize maintenance at its plant in Suzzara, Italy, where it produces Iveco vans. The organization worked with a specialist, Fair Dynamics, and a software supplier, AnyLogic, on a pilot task to improve the unwavering quality of robot welding machines on the plant's chassis line, as delineated in figure 10.

Figure 10: A digital twin of the Iveco manufacturing line helps drive better automated welding capabilities. Source: AnyLogic

While the task was incompletely planned as an innovation demonstrator, CNH also hoped to explain a genuine reliability challenge. Its welding robots depend on a flexible copper conductor named a lamellar pack to deliver electrical current to their welding heads. Be that as it may, these packs have a limited life and aggregated wear can make a pack soften, disturbing production and harming the robot. To decide the most proficient approach to keep up these basic segments, the organization fabricated a digital twin model of the line. Its model incorporates the various kinds of chassis and their related welding prerequisites, the automatic welding stations dispersed along the line, and the individual robots in each station. Information for the model is provided by the plant's production planning systems and by condition observing sensors fitted to every robot. simulation and machine learning, the digital twin gauges the likelihood of component failure. This framework permits the organization to run what-if possibilities comparing different operation and maintenance routines in order to optimize maintenance and spare parts expenditure while minimizing both planned and unplanned downtime.

Baker Hughes, a GE company that produces equipment for the oil and gas industry, has utilized technologies from its parent company to manufacture a complete digital twin of its plant in Minden, Nevada, USA. The model consolidates information from a large number of machines and procedures all over the facility, just as information on part deliveries from providers. By giving a thorough continuous perspective on production line execution, the digital twin helps managers and staff to discover improvement openings and respond rapidly to issues as they emerge. Baker Hughes says that the methodology has made a difference to enhance on-time delivery at what was effectively a high-performing office. Over time, the organization's aspiration is to twofold the rate at which materials course through the plant, with the assistance of proceeded advancement through the digital twin.

2.2 DIGITAL TWINS IN MATERIALS SCIENCE

The performance of physical products relies upon the qualities of their materials. Advances in materials science support huge numbers of the technologies we depend on today. Strong, lightweight materials are assisting with diminishing fuel utilization in vehicles, trains, and airplane. Furthermore, advantage from precisely detailed and prepared steel alloys. Be that as it may, the exact qualities of a particular piece of material is hard to decide. Testing can be damaging or require extraordinarily arranged examples, making it hard to embrace with real parts or in the production environment.

Digital twins may give an answer for this challenge. German programming organization Math2Market has created particular program for the simulation of an assortment of material properties. The organization's GeoDict programming models structurally complex materials including nonwoven ceramics, fabrics, composites, and foams. Utilizing AI-assisted image processing techniques, GeoDict delineated in figure 11 catches subtleties of the inside geometry of these materials from computer aided tomography (CAT) examines, electron microscopy, and comparative picture sources. It utilizes these material digital twins for a wide assortment of purposes, from strength and stiffness analysis to fluid dynamics studies that model the flow of liquids and gases through filters. Clients in the oil and gas industry are also utilizing the same way to deal with model courses through permeable shakes in underground reservoirs.

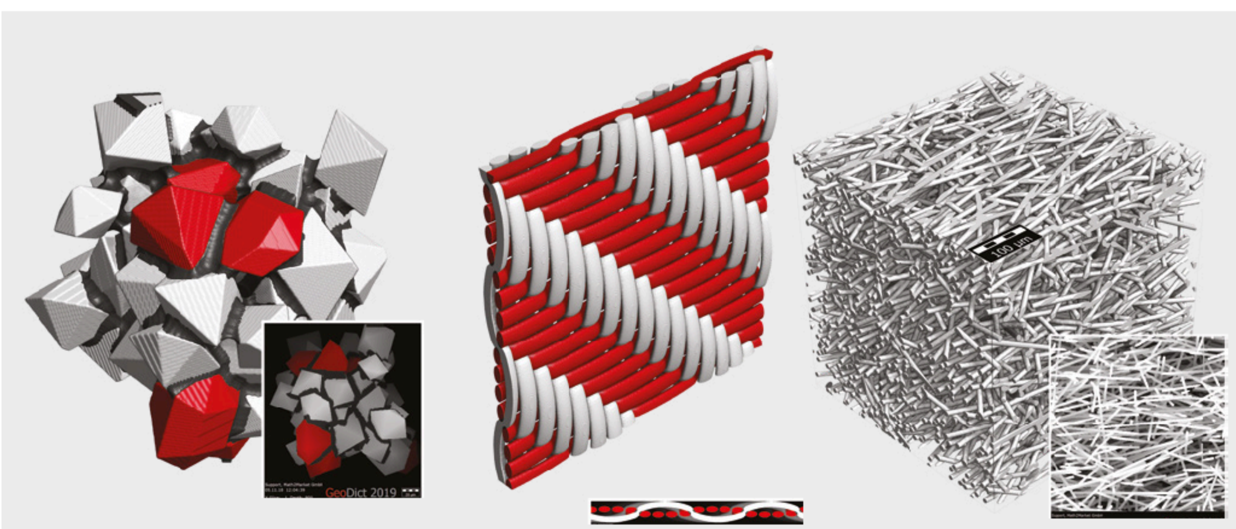


Figure 11: Material digital twins allow in-depth simulation of material properties. Source: Math2Mar

In the interim in the avionics industry, new materials are required in the journey for progressively lightweight, fuel-efficient, yet sturdier airplane. Figure 12 shows how the carbon-fiber composite fuselage of a Boeing 787 traveler airplane is successfully woven together at a production facility. Broad digital simulation and enhancement of the material composition was required to accomplish the weight and robustness required by the commercial aviation industry.

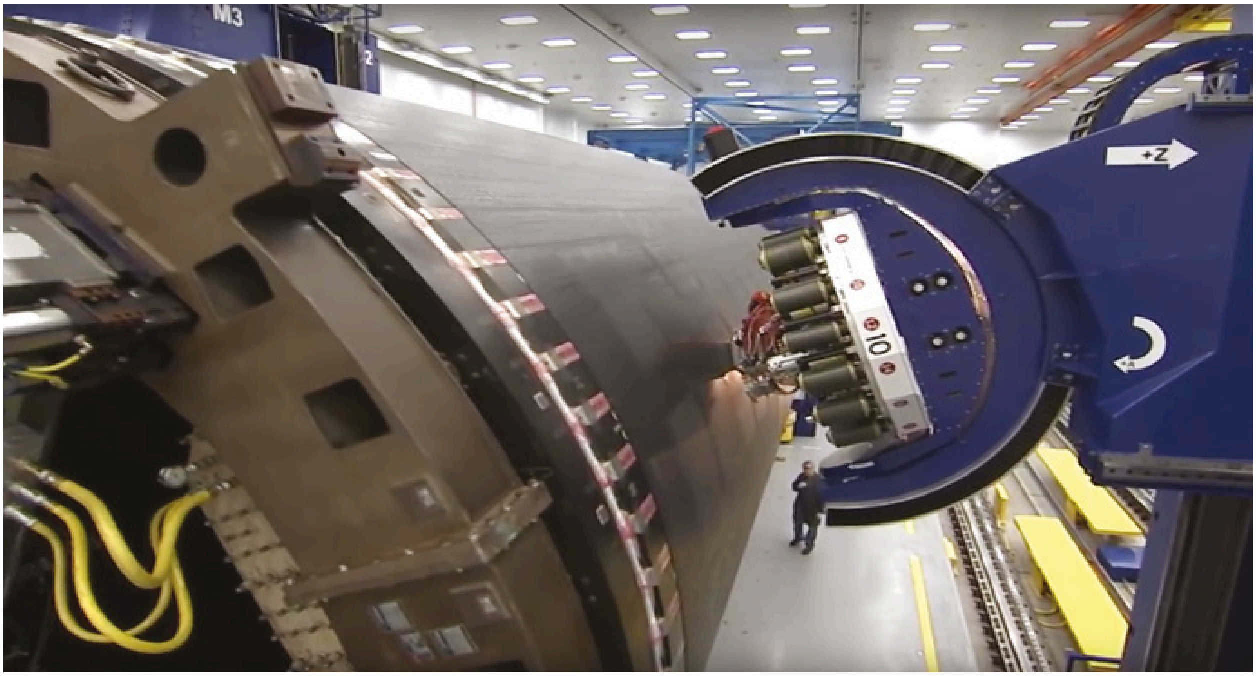


Figure 12: Simulating composite material performance

2.3 DIGITAL TWINS IN INDUSTRIAL PRODUCTS

Other than manufacturing, another important application for digital twin technologies is industrial products. This is to a great extent in light of the fact that the organizations with these benefits regularly seek after servitization systems and these require item uptime.

Digital twins support servitization by permitting these organizations to screen their items when they are in the client's hands. Digital twins empower effective maintenance strategies and remote diagnosis and repair. In a few applications, clients may even be ready to pay for the information or bits of knowledge created by the digital twins of the producer possessed resources.

Major aero engine producers counting Rolls-Royce, GE, and Pratt and Whitney are among the most progressive clients of digital twin innovations today. They are applying digital twins in new product development, in manufacturing and, of course, to assist the monitoring and support of engines operating on customer aircraft.

Digital twins are additionally coming into utilization on the ground. Compressed air systems manufacturer Kaeser Compressoren in the Netherlands has worked with SAP to build up a digital twin arrangement enveloping its whole deals and item support lifecycle, for instance. This framework goes about as a storehouse for records and information made during the specification and tendering process for a new installation, and the platform gives remote checking and predictive maintenance abilities.

2.4 DIGITAL TWINS IN LIFE SCIENCES AND HEALTHCARE

Analysts and clinicians over the healthcare division are investigating the capability of advanced twins, as well. Quite a bit of this inquire about displaying angles of the human body. Such models can assist specialists with understanding the structure or behavior of the body in more prominent detail, while lessening the need to perform obtrusive tests. Digital twins can permit complex operations to be practiced securely. They additionally can possibly speed drug advancement by permitting new treatments to be assessed.

'in silico'. Siemens Healthineers has created digital twin models of the human heart like the one in figure 13. The framework mimics the mechanical and electrical conduct of the heart, and utilizations machine learning systems to make remarkable, tolerant explicit models dependent on restorative imaging and electrocardiogram information. The Siemens teams is arriving at the end of a six-year study in which it made digital twins of 100 patients experiencing treatment for cardiovascular breakdown. At this stage, the group is just looking at forecasts made by the models to the results found in the patients, however future preliminaries could in the long run outcome in a job for digital twins in determination and treatment arranging.

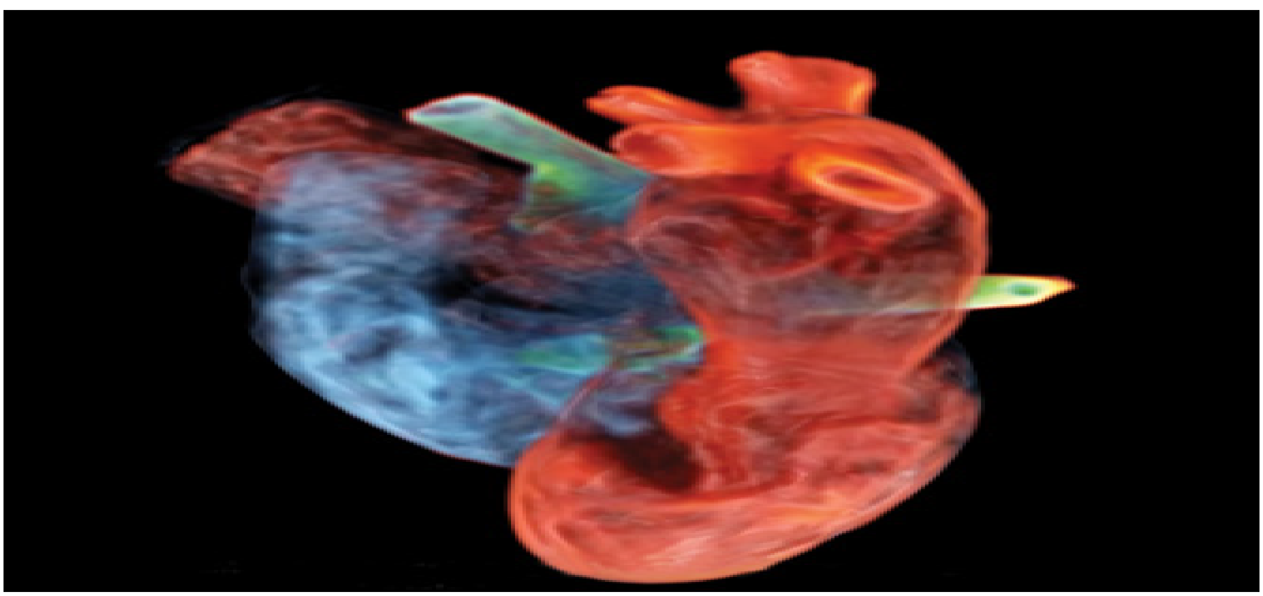


Figure 13: Digital twin of a CT scanner. Source: Philips

Medicinal gadget creator Philips has its own venture in progress to make a digital twin of the heart and the organization is investigating a scope of extra digital twin applications. In product development, for instance, it is utilizing modeling and simulation to test virtual models. Also, it is applying artificial intelligence methods to encourage remote help of complex equipment, for example, CT scanners that perform magnetic resonance imaging (MRI) like the one delineated in figure 14. Being used, a scanner may produce 800,000 log messages each day. Philips transfers that information from clients and investigations it to search for early notice signs of issues in its machines.

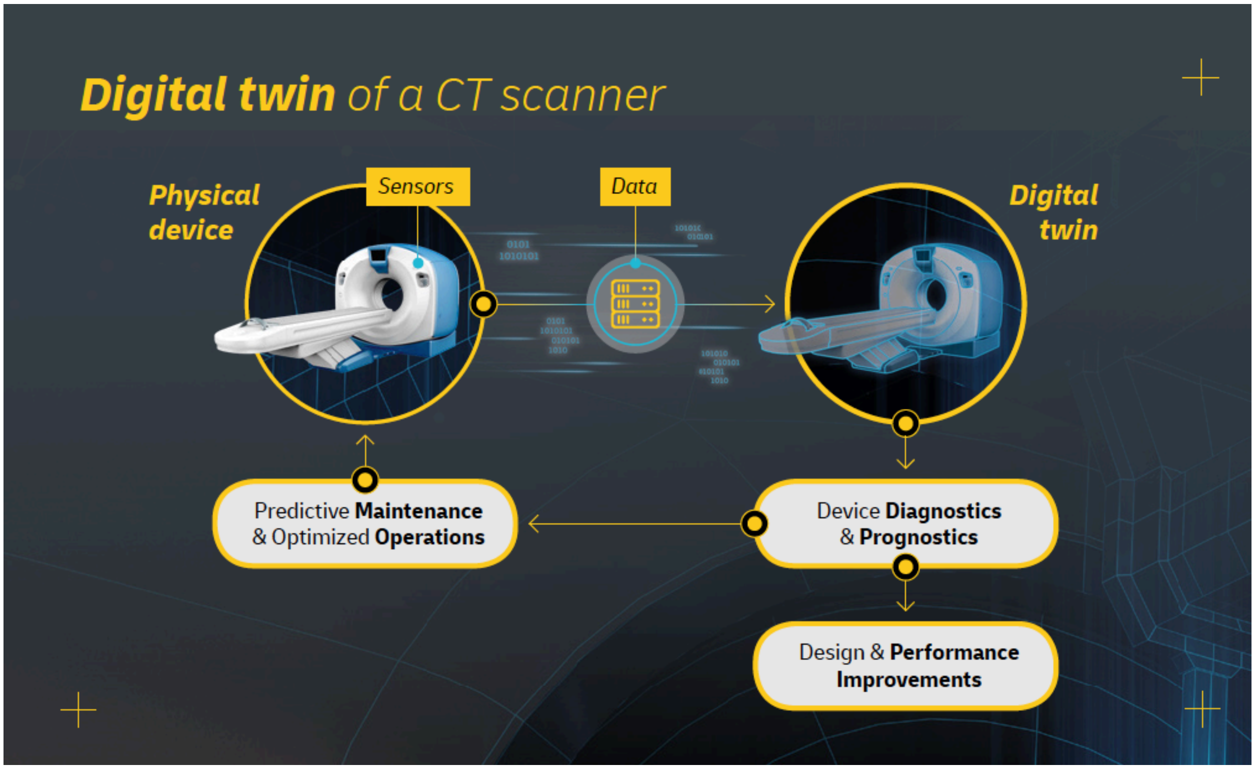


Figure 14: using digital twins to replicate human physiology allows us to understand and test the best potential therapy

2.5 DIGITAL TWINS IN INFRASTRUCTURE AND URBAN PLANNING

Estimated by the size of the physical objects they speak to, a portion of the present biggest digital twins are reproductions of physical foundation, for example, energy and transport networks and urban environments.

In the UK, rail hardware organization Alstom has assembled a digital twin to rearrange the administration of its train maintenance operations on the West Coast Main Line delineated in figure 15. One of Britain's busiest between city rail routes, the line associates London to Glasgow and Edinburgh by means of significant urban areas in the English Midlands and North West. Guaranteeing greatest accessibility of the fleet of 56 Pendolino trains is a consistent challenge.

Figure 15: Alstom leverages digital twins to optimize maintenance regimes and capacity in the UK. Source: Place North West

Alstom's digital twin incorporates subtleties of each train in the fleet, alongside their working timetables and maintenance regimes. It likewise models the accessible limit at every one of Alstom's five support terminals. Running inside the AnyLogic simulation environment, the model uses a heuristic calculation to plan maintenance exercises and designate them to the most suitable warehouse. Since the framework is associated to live data on train areas and planned movements, it can constantly adjust support plans to suit dire fixes. Operational issues may mean a specific train is somewhere else on the system when work is required. Maintenance planners additionally use the framework for imagine a scenario of the impact of changes to maintenance strategies and train timetables.

Finnish power transmission framework administrator Fingrid worked with IBM, Siemens, and different partners to assemble a digital twin of Finland's power network. The Electricity Verkko Information Framework, or ELVIS, consolidates eight various frameworks as portrayed in figure 16 into a solitary application, giving Fingrid with a steady, complete, and continuously updated model of its network. The digital twin is utilized in everyday grid activities, helping staff to manage power streams and assurance settings to fulfill need without over-burdening transformers or transmission lines. It also supports design and planning activities, permitting the administrator to simulate the possible effect of changes to grid setup or interest in upgraded resources.

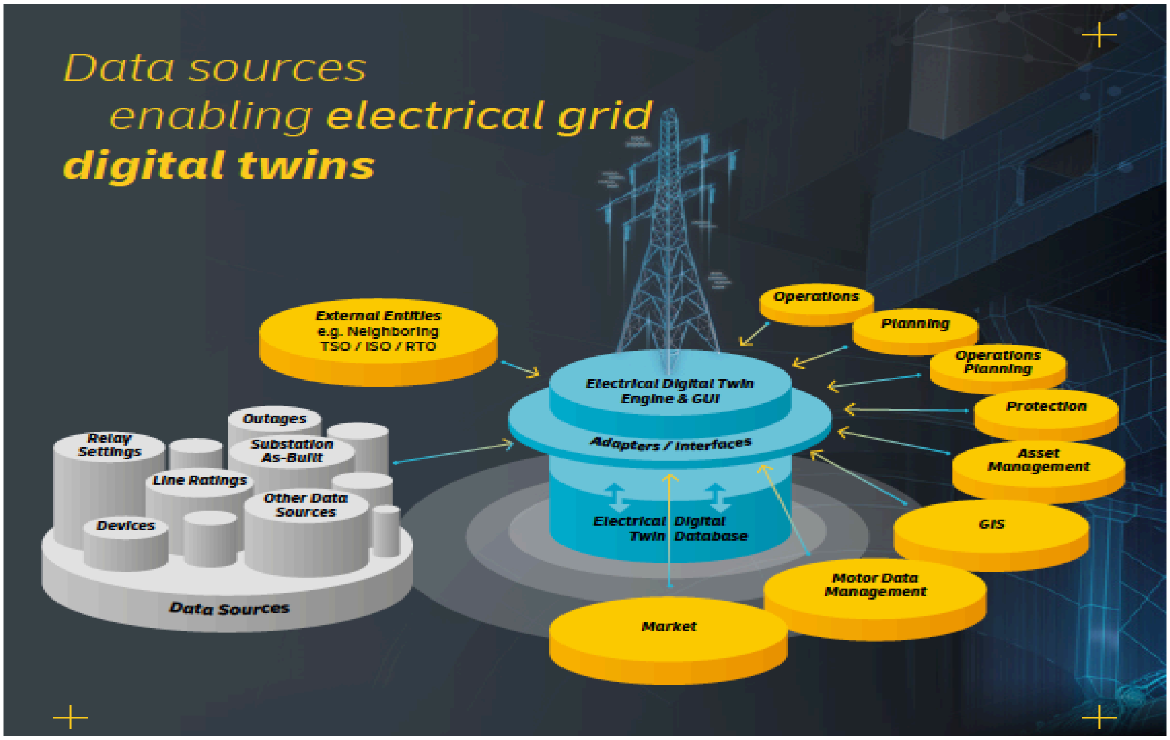


Figure 16: Data sources enabling electrical grid digital twins. Source: Siemens

In India, the territory of Andhra Pradesh is building up a digital twin of a brand new city. Planned by engineers Foster and Accomplices, Amaravati will fill in as the new state capital required after changes to provincial outskirts cut off the first capital, Hyderabad, into the new condition of Telangana. Amaravati has desire to become one the most digitally advanced urban communities on the planet, with development planning and operations all running on a single platform.

The underlying model of the digital twin appeared in figure 17, which uses Smart World Pro programming from Cityzenith, will be finished in 2019. During development, the platform will gather information from IoT sensors to screen natural conditions and the advancement of work. At last, the project’s backers state the framework will run the city's traffic and mechanize tasks for example, guaranteeing arranging applications consent to nearby guidelines.


Figure 17: A digital twin provides a rich single-pane-of-glass view of an urban project. Source: SmartCitiesWorld

2.6 DIGITAL TWINS IN THE ENERGY SECTOR

Energy production, regardless of whether by fossil fuels or renewables, includes enormous, complex resources, in remote areas. Those qualities are driving the investigation and selection of digital twins as a way to improve unwavering quality and wellbeing while monitoring working expenses.

In the offshore oil and gas sector, for instance, Aker BP utilized Siemens analytics technology in its Ivar Aasen venture off the Norwegian coast, appeared in figure 18. The success of the project, which diminishes labor necessities on the rig and optimizes equipment maintenance schedules, prompted a vital understanding between the two organizations. Under the understanding, Aker BP and Siemens will create digital lifecycle automation and performance analytics solutions for all future resources in the field.

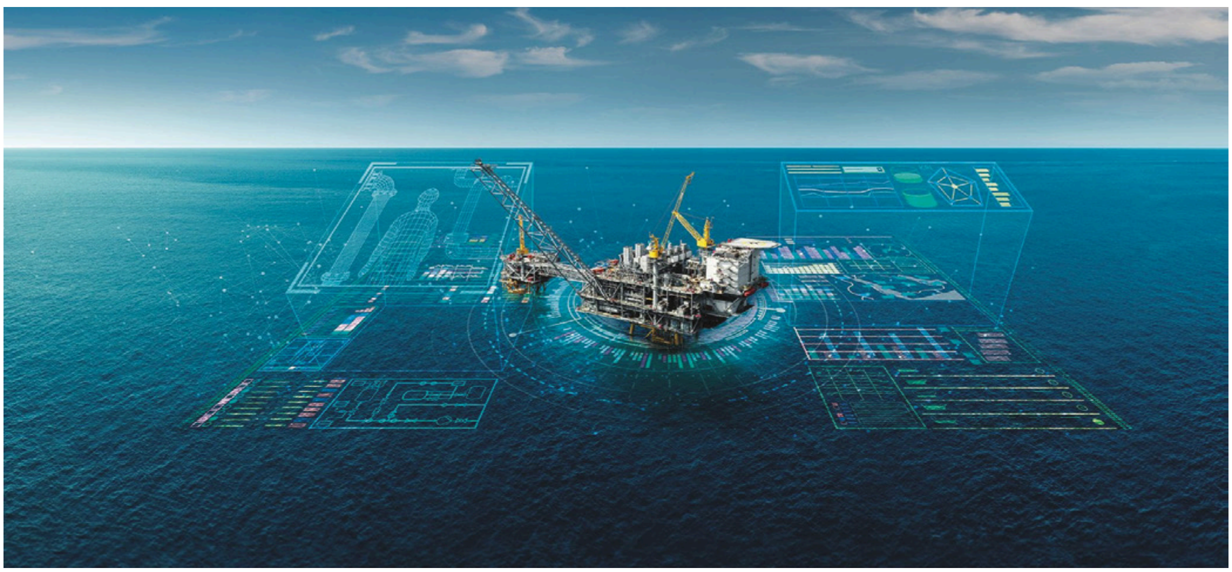


Figure 18: A visualization of the digital twin technology leveraged in the Ivar Aasen project. Source: Siemens

Somewhere else in the North Sea, Royal Dutch Shell is engaged with a two-year venture to build up a digital twin of a current offshore production platform appeared in figure 19. In the Joint Industry Project, the association is cooperating with simulation organization Akselos and building Research and development consultancy LIC Engineering to execute new ways to deal the structural integrity of offshore assets. The pilot venture includes the advancement of a basic model of the platform, which will utilize information from sensors to screen its wellbeing and anticipate its future condition.

Figure 19: Shell will develop digital twins of existing oil platforms to manage these platforms more effectively. Source: World Oil

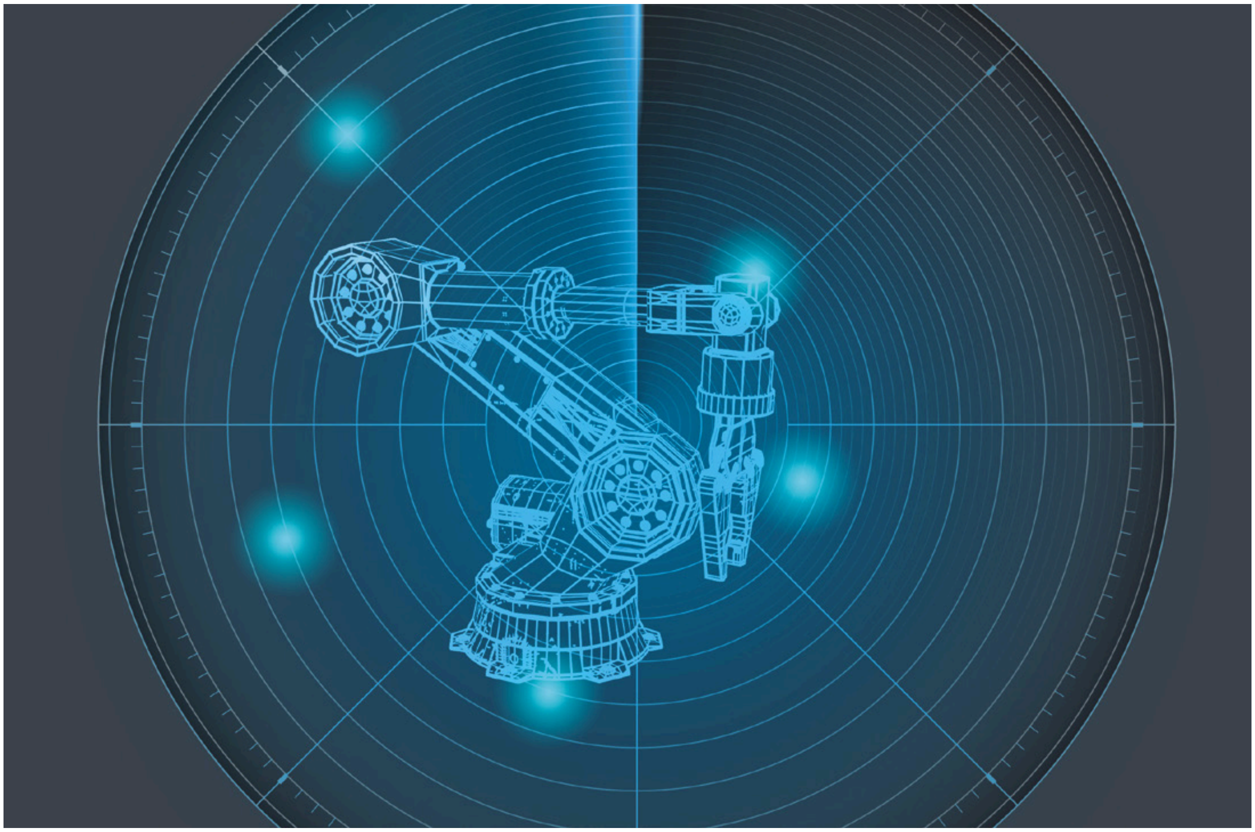
2.7 DIGITAL TWINS IN CONSUMER, RETAIL AND E-COMMERCE

Consumer products present an alternate set of chances and difficulties for digital twin technologies. Rather than a scarcely huge and complex resources, customer markets frequently include a large number of much simpler objects. So, players right now area have an alternate focus – they are investigating the improvement of digital twins that track the progression of items through supply chains, for instance, or building systems that can extract important bits of knowledge from amassed information delivered by huge quantities of similarly basic models.

Dassault Systèmes, a maker of 3D modeling and digital twin technologies, has worked with retail technology organization Store Electronic Systems to create digital twins of retail locations. In the system, a 3D model of a store's format is populated with information from electronic rack names like those in figure 20 to produce a detailed virtual representation of the store and its contents. Connections to the store's stock and point-of-sale systems update the model progressively to mirror the quantity of items loaded on the racks. Dassault says its methodology has various potential uses including applications that guide customers to the things on their list. The arrangement can likewise lessen stock-outs and help to improve stock formats.

Figure 20: Electronic store labels act as critical sensors to feed the digital twins of retail spaces. Source: SES

In retail and e-commerce applications, in the interim, organizations are creating progressively complex models of purchaser behavior. Information on past buys, web browsing habits, and social media movement is now being utilized by numerous organizations to target publicizing and promotions for explicit clients and settings. After some time, these models may advance into customer digital twins: complex, multi-attribute behavioral models that will endeavor to anticipate future practices and proactively impact buy choices.



Chapter 3

3 Digital Twins in Logistics

3.1 PACKAGING & CONTAINER DIGITAL TWINS

The overwhelming majority of products that travel through logistics networks do so in some type of protective enclosure. The business utilizes enormous amounts of single use packaging together with fleets of devoted or general-purpose reusable containers.

Designing, monitoring, and managing packaging and containers makes a number of difficulties for the business. The growth of online business, for instance, is driving up request, occasional volatility, and packaging variety. This, thusly, produces noteworthy waste and lessens operational effectiveness through poor volume use.

The use of material digital twins could help the advancement of stronger, lighter, all the more naturally well-disposed packaging materials. In endeavors to improve maintainability, organizations are investigating the use of a scope of new materials including compostable plastics and materials with a high level of post-consumer reused content.

Material digital twins, for example, those created by Math2Market could help organizations comprehend and anticipate the presentation of new materials in packaging applications. These twins can demonstrate material conduct under the temperature, vibration, and shock loads experienced in travel.

Digital twins could likewise support logistics players manage container fleets more productively. Reusable containers are an industry standard in numerous logistics streams and modes. They incorporate standard ocean holders, airplane ULDs, reusable cartons to ship vehicle parts between factories, and containers for nourishment and beverage delivery to retail locations and buyer homes.

Monitoring reusable holders can be troublesome. Not exclusively should organizations handle the development of holders from their last goal to where they are required straightaway, however they should likewise check for harm and sullying that may bargain future loads or present a risk to work force or different resources.

Developing 3D photographic advancements, for example, those created by German startup Metrilus, can quickly make a point by point model of a holder, permitting the robotized recognizable proof of potential issues, for example, scratches and breaks. That data could be joined with historical information on the container's movements to make a digital twin that illuminates choices about when a particular resource ought to be utilized, fixed, or resigned. Also, amassing such information over an entire fleet of containers could help proprietors to settle on ideal choices about fleet sizing and distribution, and recognize patterns that may show hidden issues, for example, an imperfection in container structure or unpleasant taking care of that happens at explicit focuses in the supply chain.

3.2 DIGITAL TWINS OF SHIPMENTS

Joining the contents of a bundle or container into its digital twin is the following sensible advance. On the off chance that a digital twin of an item to be delivered has just been made, information depicting its geometry can be gotten from its previous source, for instance. On the other hand, the item information can be created when the shipment is being ready, utilizing 3D examining and the same PC vision advances. Consolidating item and packaging information could assist organizations with improving productivity, for instance via automating packaging choice and container packing methodologies to advance usage and item insurance.

It is as of now basic practice to deliver touchy, high-esteem items, for example, pharmaceuticals and fragile electronic parts, with sensors that screen temperature, package orientation, shock, and vibration. The most recent variations of these sensors, for example, those created by Roambee, Blulog, Kizy and others consolidate sensors that offer a developing host of information focuses that permit constant information transmission during the advancement of a shipment.

A shipment digital twin would go about as a store for the information gathered by these sensors. Digital twin technologies could likewise permit this information to be utilized in new ways. A model that incorporates the warm protection and shock-absorbing attributes of the packaging, for example, could permit conditions inside the item be extrapolated from information gathered by outside sensors.

Figure 21: Digital twins of sensitive shipments will bring next-level visibility to the item and its packaging during transit. Source: Finnair Cargo

3.3 DIGITAL TWINS OF WAREHOUSES AND DISTRIBUTION CENTERS

Digital twins could have a critical impact on the activity, structure, and advancement of logistics infrastructure for example, warehouses, distribution centers, and cross-dock facilities. These digital twins could consolidate a 3D model of the office itself with IoT information gathered in associated warehouse platforms (figure 22), as well as inventory and operational information including the amount, size, area, and demand characteristics of each item.

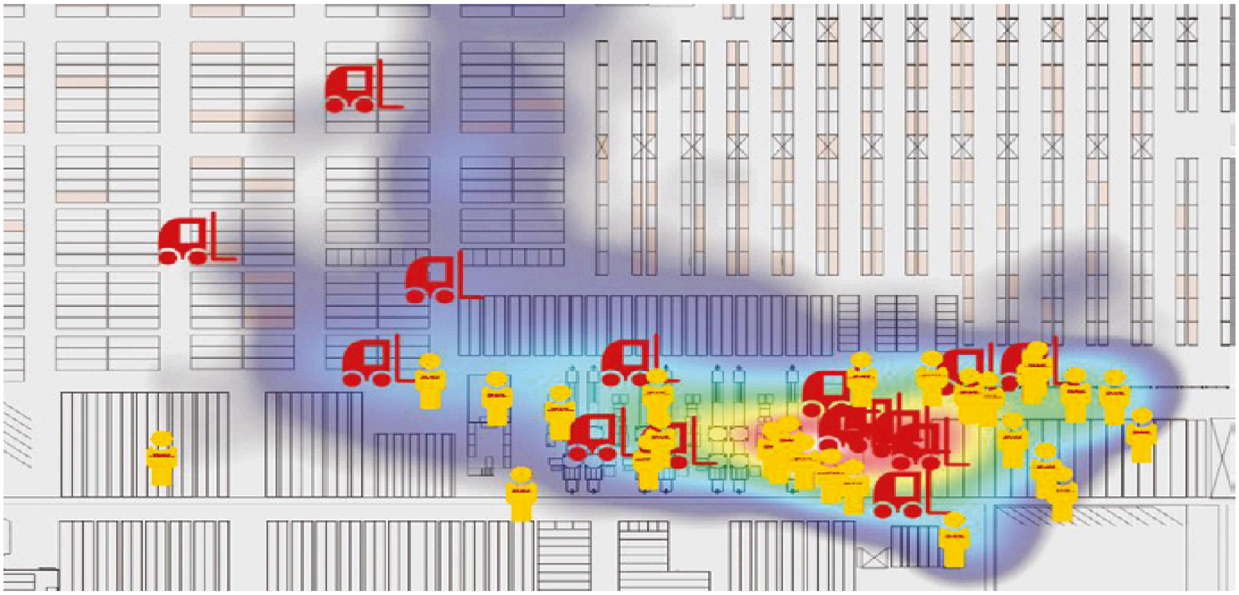


Figure 22: DHL uses heat maps based on internet of things technology to optimize operational efficiency and lay the foundations for safer working practices in warehouses. Source: DHL

Warehouse digital twins can support the design and layout of new offices, permitting organizations to optimize space usage and simulate the movement of personnel, products, and material handling equipment.

During warehouse activities, the digital twin can be continually updated with information collected from the different automation technologies that are getting more common in warehouses. These incorporate drone-based stock counting systems, automated guided vehicles, goods-to person picking systems, and automated storage and retrieval equipment.

Digital twins will likewise permit further optimization of the performance of these automation systems, for instance by utilizing sensor information, simulation, and observing technologies to decrease energy consumption while looking after essential throughput levels.

Comprehensive 3D office information can likewise be utilized to upgrade the productivity of warehouse personnel. Organizations can convey virtual-reality training instruments, for instance, or augmented-reality picking systems utilizing wearable gadgets such as Google Glass Enterprise Edition or Microsoft HoloLens – apparatuses that are previously being used today by DHL Supply Chain.

3.4 DIGITAL TWINS OF LOGISTICS INFRASTRUCTURE

Warehouses and distribution centers make up only a small amount of all logistics infrastructure. The progression of merchandise from sources relies upon the coordination of various components counting boats, trucks and airplane, request furthermore, data systems, and, most importantly, individuals.

This complex, multi-partner condition can be seen most unmistakably at major global logistics hubs, for example, load air terminals and container ports. At these offices today, the test of proficient activity is exacerbated by blemished frameworks for data trade, with numerous members dependent on offline forms that can be subject to mistakes and delays.

A task is currently in progress in Singapore to utilize digital twin innovations to address these issues. The Singapore Port Authority is working with a consortium of partners, including the National University of Singapore, to build up a digital twin of the nation's new mega hub for container shipping.

The digital twin methodology is as of now conveying benefits during the structure period of the Singapore project. The consortium is utilizing its digital models to facilitate the generation of potential designs, and it is utilizing simulation frameworks to assess diverse working situations.

Eventually, the Port Authority hopes that the digital twin will assist it with optimize management of the new office. Utilizing simulation, for instance, it will have the option to pick the ideal berthing area for a vessel of any given size, taking into account the assets, space, and staff required for loading and unloading activities, and the need to share those assets between various vessels at any one time.

While Singapore has a strong vision for the use of digital twins in large scale logistics infrastructure, a definitive achievement of any such activity relies upon the readiness – and technical ability – of all the partners in question. A 'living' digital twin of a port or air terminal will require each association utilizing the office to work and maintain a digital twin of its own resources and staff, and to share significant information continuously with other clients.

Figure 23: The already advanced Singapore port is about to get a major upgrade with digital twins. Source: CraneMarket

3.5 DIGITAL TWINS OF GLOBAL LOGISTICS NETWORKS

In logistics, a definitive digital twin would be a model of a whole system counting logistics resources as well as seas, railroad lines, expressways, avenues, and client homes and work environments. The possibility of such a sweeping twin is to a great extent a yearning for the logistics business until further notice. In any case, it is critical to conceive where the full acknowledgment of logistics digital twins may lead.

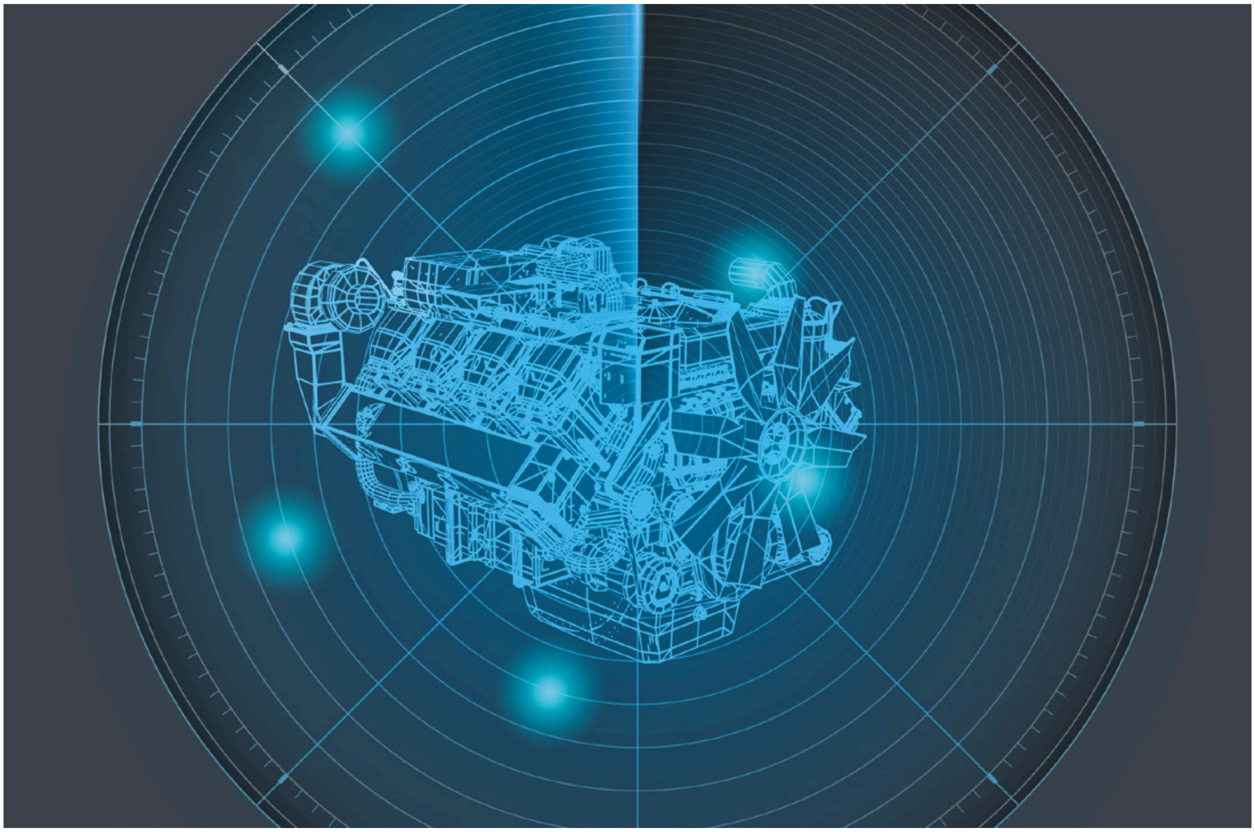
Figure 24: A visionary example of the elements involved in a digital twin of an entire supply chain network. Source: DHL

Geographic information system (GIS) innovation is advancing amazingly quickly today, empowered by progresses in satellite and aerial photography, and by on-the-ground digital mapping efforts. Interest for nitty gritty geographical information has been driven by numerous clients counting governments, service organizations, and navigation system providers. Most recently, the improvement of self-sufficient vehicle advances has quickened efforts to deliver incredibly point by point information of the globe. Self-driving vehicles and trucks are now being trialed on open streets, with 11 significant carmakers reporting intends to dispatch vehicles with independent capacities throughout the following decade.

Independent vehicles will change the accessibility of geographical information in two ways. They will require very point by point maps to work, and they will likewise perform mapping capacities themselves, gathering information from on-board cameras and from radio or light-based recognition and ranging system (radar and lidar methods) and afterward sharing that information remotely to constantly refresh and improve map databases.

Current GIS systems are considerably more than static digital maps. They can additionally consolidate dynamic information such as data on traffic speeds, street terminations and densities, and stopping limitations because of accidents and repair works. They can even incorporate the real-time location of explicit individuals and vehicles. logistics suppliers as of now utilize GIS information, utilizing it to design delivery routes, for instance, and anticipate arrival times dependent on blockage, climate conditions, and known delays at ports, air terminals, and border crossings. Digital twins of systems will likewise help suppliers to upgrade their traditional logistics systems, for instance by utilizing rich information on client locations,
demand patterns, and travel times to design distribution courses and inventory stockpiling areas.

Plainly these goals won't be simple to satisfy and likely are still years away from full usage. The greater part of the present digital twins is far less aspiring in scope however nevertheless present their users with challenges in terms of data quality, computing resource, precise representation, and governance. Here it is likewise essential to specify that the heterogeneous and divided nature of the logistics business will make it an exceptionally unfavorable condition for digital twins to flourish. It isn't yet evident whether those issues can be enough routed to empower the utilization of digital twins at really worldwide scale.



Chapter 4

4 Logistics Implications of Implementing Digital Twins

4.1 INBOUND TO MANUFACTURING

Quicker, increasingly adaptable assembling tasks will put new requests on inbound material streams. Digital twins will empower more items to be designed and altered to coordinate the particular prerequisites of individual clients, for instance, however satisfying that request will expand intricacy, with a more noteworthy number of part variations and the sky is the limit from there parts that must be overseen in a batch size of one.

Organizations should discover ways to deal with that unpredictability without trading off lead times, lessening transport efficiencies, or building high, expensive inventories. That will require care in the decision of supplier areas, alongside new ways to deal with transport and freight management. By pooling transport over numerous providers, for instance, organizations might be capable to build use in any event, when they require frequent deliveries and little request amounts.

Closer joint effort with providers will likewise be significant. Makers can encourage this by sharing demand forecasts – derived in part from digital twin data – earlier, and by working intimately with providers to comprehend the capabilities and constraints of their production processes. Providers, in the interim, can utilize approaches such as vendor-managed inventory (VMI) to give extra adaptability and incentive to their clients.

Figure 25: Digital twins will drive greater configuration and customization, and this will require more flexibility and better-quality control for fulfilling orders. Source: DHL

4.2 IN-PLANT LOGISTICS

The requests of digital twin-empowered manufacturing will likewise put new prerequisites on in-plant material streams. Organizations may need to adjust their processes for just-in-time delivery to lineside and their Kanban recharging systems to suit shorter lead times and higher product complexity. They will likewise need to deal with material and component related information with more rigor, to guarantee that the digital twins of the items they fabricate are related with the right batch codes or part serial numbers, for instance.

In some cases, adjusting manufacturing activities to oblige the necessities of digital twin-driven items and business models will require new ways to deal with the design of workstations and plant layouts. Organizations might need to change from batch processing to single piece flow, for instance, or adjust material storage and handling systems to adapt to more complex and variable material necessities. Digital twin innovations could help organizations to deal with this extra intricacy, by incorporating with advanced storage and handling systems, or through the use of AR advancements to assist staff with finding and pick parts quickly.

Figure 26: Digital twins will help optimize in-plant

4.3 AFTERMARKET LOGISTICS

Digital twins can possibly rethink the connection between item producers and their clients. With a digital twin, an OEM or a third-party service partner can screen an item anyplace on the planet. They can utilize that ability to offer a range of value-adding services to their clients, from remote help to predictive maintenance.

These new sorts of services will be profoundly subject to the adequacy of the supplier's after-market supply chain. Early admonition that a section is likely to fail is just helpful if a substitution is accessible for establishment at a convenient time. The supply and distribution of spare parts will turn into an undeniably basic component of the working model for some organizations.

To construct and work high-performing aftermarket logistics and support abilities, organizations will require to see precisely where their clients are, which items they are utilizing and how they work those items. They should consistently audit the situating and appropriation of spare parts inventory to ensure lead times that match their vows to clients.

Organizations will also need to connect parts distribution firmly with different components of their aftermarket and field service tasks. They may need to coordinate component delivery windows with the appearance of service experts at client sites, for instance, or utilize their vendors and wholesaler systems to provide after-sales services.

Aftermarket supply chains will also need to manage items toward the finish of their working life, regardless of whether that is worn, and broken parts expelled in service activities or complete items that are never again required by their unique clients. Digital twins can help organizations augment the potential estimation of end of- life equipment by pushing them to distinguish the specific type and content of equipment. Catching that worth may call for increasingly complex turn around logistics forms, coordinated with proper recycling, remanufacturing, and waste management systems.

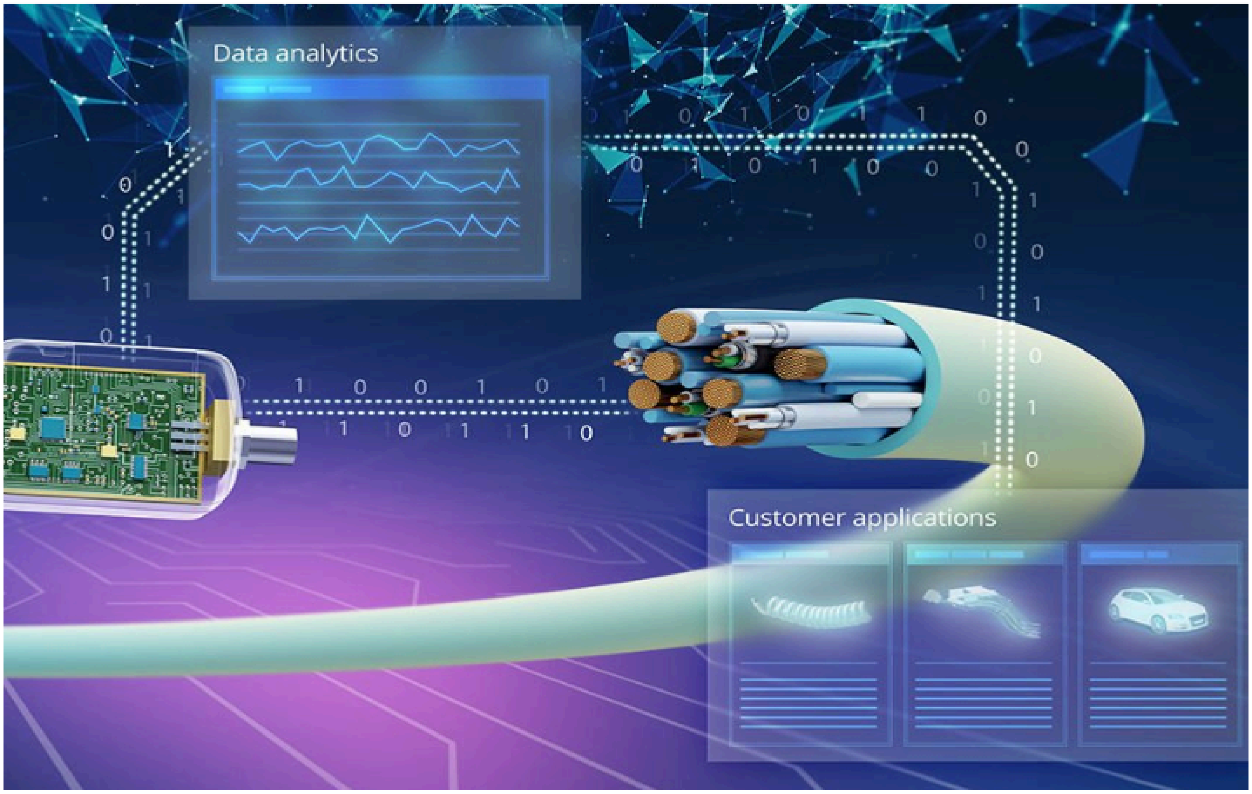
4.4 ORCHESTRATING THE SUPPLY CHAIN

By offering a progressively complete perspective on the presentation of items over their lifecycle, digital twins will permit organizations to take a progressively holistic, end to- end way to deal with the management of those items. Amplifying the through life estimation of items and related services will require a likewise holistic way to deal with supply chains.

Specifically, organizations should find more brilliant approaches to adjust inventory costs, availability, and lead times over their systems. That will expand the significance of full supply chain visibility, so they comprehend the area and availability of parts and materials in their inventories and those of sales channels, providers or suppliers, and distribution partners.

Ideal supply chain set up will also be critical, with provider and assembling logistics lanes, footprints, and stock areas arranged to help high service levels and guarantee organizations can meet the availability and reaction time guarantees they make to their clients.

At long last, supply chains should be versatile, with the capacity to maintain service levels even with disturbance, recover rapidly from significant occasions and react successfully to changes in demand.



Chapter 5

5 LEONI Wiring Systems

5.1 Global trends

Worldwide trends will impact individuals' lives around the world. They are set to assume a dominant role and represent the reason for LEONI's future exercises. Worldwide trends give the motivation to us to create items and innovations, which we deploy among our clients in light of technological development.

5.2 Industrialization & automation

5.2.1 Intelligent network in manufacturing

As the interest on adaptability and customization increase inside industry, the complexity of production consistently rises. In this way, intelligent interaction of systems with the most recent communications technology is known by the catchphrase 'Industry 4.0'. LEONI offers creative items and services in this field. Our portfolio reaches out from the cable to intelligent cable systems and smart services that furnish our clients with the most ideal help in their business.

5.3 Digitalization

5.3.1 LEONI is rising to meet the challenges of the digital era

"The digital transformation is happening, and it is now starting to pick up speed – and LEONI is in its center. Data and energy are changing our world. Following these megatrends, LEONI is taking steps forward from being an experienced cable producer to become a technology partner offering clients forward-looking energy and data solutions.
The goal: sustainable, intelligent and individualized solutions in addition to innovative value propositions for our clients and the world in the future.

Accordingly, our new LEONI vision is "Passion for intelligent energy and data solutions"!

In the future, we will be taking past technical product solutions and the knowledge on which these have been based over the last 100 years and combining these with new insights. These include active electronics, integrated sensor technology, embedded software, and the digital functional simulation for a wide range of client requirements and markets.

Our solutions:

LEONiQ – discover LEONI's new intelligent key technology"

5.4 LEONI EGYPT PLAN

Our goal at Leoni is to think more about our supply chain and how to digitalize it. I was responsible to search the internet in order to construct a report about Digital Twin to know:

■ What is a digital twin and what does it means for my association.

■ What best-practice models from different enterprises can be applied to logistics?

■ How will my supply chain change in view of digital twins?

Looking at the numbers and the cases from this report the mangers were impressed and so enthusiastic to apply such technology. However, there were some obstacles that must be concorded before applying such technology.

These obstacles were:

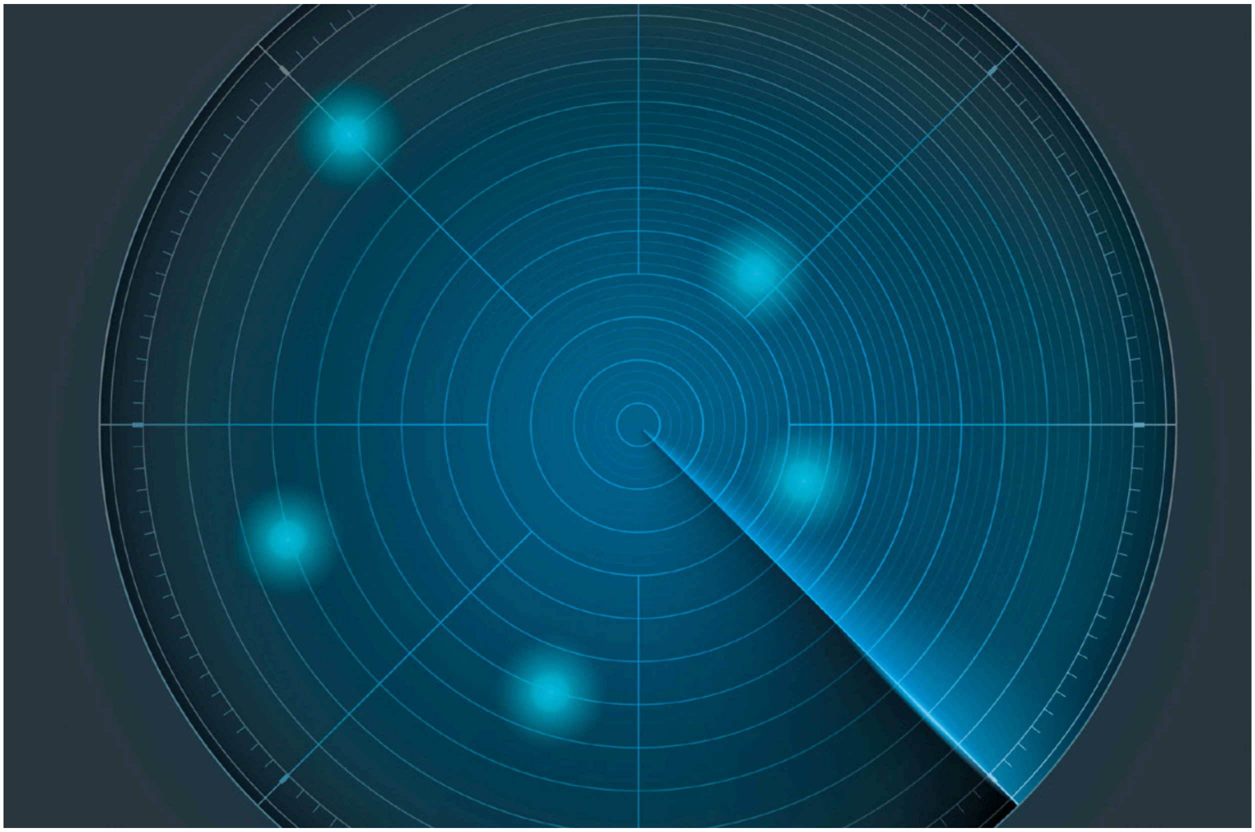
1- Cost
2- Education
3- Rules & Regulations
4- Plant and Warehouses modifications
5- Security

As a result, it was decided to apply the project on three stages.

Stage 1: Planning and Scheduling. They will plan the transition phase and how the work process is going to flow during this transition phase. Scheduling the transition phase giving dates on how each process of this process should take. Figuring out the total cost of applying this technology from the cost of equipment, cost of education, cost of authentications, and cost of modifications to warehouses.

Stage 2: Authentication and Deals. They will have to construct a meeting with the minister of defense, minister of interior, minister of trade, and mister of transportation. Because some of the equipment that will be use is banned from Egypt Like: drones for example. They will construct deals with companies to import the equipment needed, educate our personnel on using this equipment. Deal with cyber security companies to secure our servers and secure the data.

Stage 3: Ramp up. After Stage 1&2 they will start with the project and keep following up with the progress.



Chapter 6

6 Conclusion

In spite of the fact that difficulties and restrictions stay in computing resources, total cost, precise representation, governance, data quality, and organizational culture, organizations are advancing to defeat these obstacles. The advantages with digital twins will be improved results and incredible new plans of action.

Today, the engineering, manufacturing, energy, and automotive industries are driving the way in utilizing digital twins to deal with their most critical resources, followed by healthcare, the public sector, and even consumer retail. As the imperative advancements keep on getting more promptly available, the logistics area is just barely now starting its digital twin excursion and early instances of the first supply chain facilities and logistics center developed utilizing digital twins are starting to rise.

Maybe progressively significant for logistics experts to consider in the close term isn't the manner by which to use digital twins for direct coordination of supply chain activities, resources, and offices but rather how to advance the supply chain.

As digital twins give more prominent knowledge into and visibility of the current and future condition of a 'thing' – from a material surface to a critical infrastructure – more proactive choices can be made about dealing with the thing when sent in the field. For digital twins and their physical partners to cooperate ideally, there is a quickening requirement for logistics experts to improve responsiveness, availability, service quality, and delivery accuracy to guarantee the thing acts in ideal agreement with its planned design and performance.

Sources

AnyLogic (2018)
Alstom Develops a Rail Network Digital Twin
for Railway Yard Design and Predictive Fleet
Maintenance.
https://www.anylogic.com/digitaltwin-of-rail-network-for-train-fleet-maintenancedecision-support/

Deloitte (2018)
Expecting Digital Twins.
https://www2.deloitte.com/content/dam/insights/us/articles/3773_Expectingdigital-twins/DI_Expecting-digital-twins.pd

AnyLogic (2018)
Digital Twin of a Manufacturing Line: Helping
Maintenance Decision-making.
https://www.anylogic.com/digital-twin-of-a-manufacturing-linehelping-maintenance-decision-making/

Baron, K. (2018)
Seeing Double: Digital Twins Make GE and Baker
Hughes Supply Chain Innovators.
https://www.ge.com/reports/seeing-double-digital-twins-makege-baker-hughes-supply-chain-innovators/

Bluelog (2014)
Temperature Monitoring During Transport.
http://blulog.eu/nfc-data-loggers/

Carboni, C (2016)
The 'Connected Store' Reimagines Retail.
https://blogs.3ds.com/northamerica/connected-storereimagines-retail/

Centre for Digital Built Britain (2019)
Principles to guide the development of the National
Digital Twin released.
https://www.cdbb.cam.ac.uk/news/2018GeminiPrinciples

Cityzenith (2018)
Cityzenith's Smart World Pro Digital Twin Software
Platform Selected for New Capital City in India.
https://cityzenith.com/smart-world-pro-digital-twinsmart-city-india/

Copley, C (2018)
Medtech firms get personal with digital twins.
https://uk.reuters.com/article/us-healthcare-medical-technology-ai-insi/medtech-firms-getpersonal-with-digital-twins-idUKKCN1LG0S0

DHL (2019)
DHL Supply Chain deploys latest version of smart
glasses worldwide. https://www.dpdhl.com/content/dam/dpdhl/en/media-relations/pressreleases/2019/pr-smart-glasses-20190521.pdf

DHL (2018)
Artificial Intelligenge in Logistics.
https://www.logistics.dhl/content/dam/dhl/global/core/documents/pdf/glo-artificial-intelligence-inlogistics-trend-report.pdf

DHL (2018)
Servitization and Supply Chains.
https://www.logistics.dhl/content/dam/dhl/global/core/documents/pdf/glo-core-servitization-white-paper.pdf

DPDHL (2019)
Press Release: DHL Supply Chain deploys latest
version of smart glasses worldwide.
https://www.dpdhl.com/content/dam/dpdhl/en/media-relations/press-releases/2019/pr-smart-glasses-20190521.pdf

Digitwins Initiative (2018)
About the Initiative. https://www.digitwins.org/about-the-initiative

DNV GL (2019)
WindGEMINI digital twin for wind turbine operations.
https://www.dnvgl.com/services/windgeminidigital-twin-for-wind-turbine-operations-102853

DroneScan (2019)
Homepage. http://www.dronescan.co

Gartner (2018)
Top 10 Strategic Technology Tends for 2019.
https://www.gartner.com/en/newsroom/pressreleases/2018-10-15-gartner-identifies-the-top-10-strategic-technology-trends-for-2019

Gartner (2019)
How Digital Twins Simplify the IoT.
https://www.gartner.com/smarterwithgartner/how-digital-twinssimplify-the-iot/

GE Healthcare Partners (2019)
What's a Digital Twin? https://uscan.gehealthcarepartners.com/service-about/digitaltwin

Glaessgen, E.H. (2012)
The Digital Twin Paradigm for Future NASA and U.S.
Air Force Vehicles. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120008178.pdf

Grand View Research (2018)
Digital Twin Market Size Worth $26.07 Billion By
2025. https://www.grandviewresearch.com/pressrelease/global-digital-twin-market

Grieves, M (2016)
Origins of the Digital Twin Concept.
https://www.researchgate.net/publication/307509727_Origins_of_the_Digital_Twin_Concept

Howells, R (2018)
The Digital Twin Effect: Four Ways It Can Revitalize
Your Business.
https://www.forbes.com/sites/sap/2018/06/22/the-digital-twin-effect-four-waysit-can-revitalize-your-business/#576db0ca5835

Invirt Reality (2018)
Case Study: Vr Demonstrator For Logistics Training.
http://invirtreality.co.uk/dh-vr-demonstrator/

Kadleček, D. (2018)
Digital Twin. https://www-05.ibm.com/cz/watsonsolution-market/pdf/WSM_DigitalTwin.pdf

Kizy Tracking SA (2017)
End-to-end supply chain visibility in real-time,
anywhere in the world. https://www.kizytracking.com/

Lempert, P (2018)
Ikea Switches to Packaging Made From Mushrooms.
https://www.winsightgrocerybusiness.com/retailers/ikea-switches-packaging-made-mushrooms

Math2Market (2019)
GeoDict (landing page). https://www.geodict.com

Metrilus (2019)
MetriXFreight Smart Dimensioning.
http://www.metrilus.de

Microsoft (2019)
Hololens 2: Mixed Reality is ready for business.
https://www.microsoft.com/en-us/hololens

Philips (2018)
The rise of the digital twin: how healthcare can benefit. https://www.philips.com/a-w/about/news/archive/blogs/innovation-matters/20180830-therise-of-the-digital-twin-how-healthcare-can-benefit.html

Pomerantz, D. (2018)
The French Connection: Digital Twins From Paris Will Protect Wind Turbines Against Battering North Atlantic Gales. https://www.ge.com/reports/frenchconnection-digital-twins-paris-will-protect-windturbines-battering-north-atlantic-gales/

Roambee (2019)
Global on-demand goods and assets monitoring.
https://www.roambee.com

Roberts, F. (2017)
Shell joins digital twin initiative for offshore oil and gas assets. https://internetofbusiness.com/shelldigital-twin-oil-gas/

SAP (2018)
Kaeser Compressors goes cloud with the help of SAP cloud-based solutions.
https://www.sap.com/uk/products/digital-supply-chain/digital-twin.html

Siemens (2017)
For a digital twin of the grid.
https://www.siemens.com/press/pool/de/events/2017/corporate/2017-12-innovation/inno2017-digitaltwin-e.pdf

Siemens (2017)
Optimizing offshore production with Siemens Topsides 4.0 digital lifecycle solutions.
https://www.siemens.com/press/pool/de/pressemitteilungen/2017/power-gas/PR2017090415PGEN.pdf

Siemens Healthineers (2018)
From Digital Twin to Improved Patient Experience.
https://www.siemens-healthineers.com/news/msodigital-twin-mater.html

Leoni (2019)
https://www.leoni.com/en/company/global-trends/

Figure Sources

Figure 1: DHL (2019)
The evolution of digital twins.

Figure 2: DHL (2019)
Characteristics of a digital twin.

Figure 3: DHL (2019)
Technologies behind digital twins.

Figure 4: Harvard Business Review (2015)
GE's digital wind farm project leverages digital
twin technology to make predictions on power
output. https://hbr.org/resources/images/article_
assets/2015/07/GE-image-6.2.jpg

Figure 5: Forbes (2018)
Digital twins enable faster design iterations and
rapid prototyping before going into production.
https://blogs.3ds.com/perspectives/forbesmanufacturing-
digital-twin/

Figure 6: Siemens (2019)
Siemens is applying digital twin technology to
optimize processes within its production lines.
https://www.plm.automation.siemens.com/
media/global/en/Industrial-Machinery-Digital-
Twin-Image_1600x900_tcm27-55683.jpg

Figure 7: AnyLogic (2017)
A digital twin of the Iveco manufacturing line
helps drive better automated welding capabilities.
https://www.anylogic.com/digital-twin-ofa-
manufacturing-line-helping-maintenancedecision-
making/

Figure 8: Math2Market (2018)
Material digital twins allow in-depth simulation of
material properties.
https://www.math2market.
com/Showroom/structures.php

Figure 9: Spirit Aerosystems YouTube (2016)
Simulating composite material performance is
critical to ensure airworthiness.
https://www.
youtube.com/watch?v=oSRiovAiQkA

Figure 10: Philips (2018)
Digital twin of a CT scanner.
https://www.philips.
com/a-w/about/news/archive/blogs/innovationmatters/
20180830-the-rise-of-the-digital-twinhow-
healthcare-can-benefit.html

Figure 11: Siemens Healthineers (2018)
Using digital twins to replicate human physiology
allow us to understand and test the best potential
therapy conditions. https://www.siemenshealthineers.
com/press-room/press-videos/im-
20181204001shs.html

Figure 12: Place North West (2017)
Alstom leverages digital twins to optimize
maintenance regimes and capacity in the UK.
https://www.placenorthwest.co.uk/news/
alstoms-widnes-train-factory-enters-servicewith-
paint-job/

Figure 13: Siemens (2018)
Data sources enabling electrical grid digital twins.
https://new.siemens.com/global/en/products/
energy/energy-automation-and-smart-grid/
electrical-digital-twin.html

Figure 14: SmartCitiesWorld (2018)
A digital twin provides a rich single-paneof-
glass view of an urban project. https://
d2mpqlmtgl1znu.cloudfront.net/AcuCustom/
Sitename/DAM/016/Cityzenith_Amaravati1_
PR.jpg

Figure 15: Siemens (2017)
A visualization of the digital twin technology
leveraged in the Ivar Aasen project.
https://static.
upstreamonline.com/incoming/article1390297.
ece5/ALTERNATES/LANDSCAPE_600/
d66221a627d48c07a2d99bb9babae644

Figure 16: World Oil (2019)
Shell will develop digital twins of existing oil
platforms to manage these platforms more
effectively. https://www.worldoil.com/
media/9378/shell-ursa.jpg

Figure 17: SES (2018)
Electronic store labels act as critical sensors to
feed the digital twins of retail spaces.
https://
studiobruch.com/en/ses-imagotag/

Figure 18: Finnair (2019)
Digital twins of sensitive shipments will bring
next-level visibility to the item and its packaging
during transit. https://cargo.finnair.com/en/cargonews/
internet-of-things-logistics-kari-saarikoski

Figure 19: DHL (2017)
DHL uses heat maps based on internet of things
technology to optimize operational efficiency and
lay the foundations for safer working practices
in warehouses. https://www.youtube.com/
watch?v=ufmh0vrr3Fw

Figure 20: CraneMarket
The already advanced Singapore port is about
to get a major upgrade with digital twins.
https://cranemarket.com/blog/the-
worldstransshipment-
hub-automates-crane-operation/

Figure 21: DHL (2019)
A visionary example of the elements involved in a
digital twin of an entire supply chain network.

Figure 22: DHL (2019)
Digital twins will drive greater configuration and
customization, and this will require more flexibility
and better-quality control for fulfilling orders.

Figure 23: DHL (2019)
Digital twins will help optimize in-plant material
flows.