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Untangling the requirements of a **Digital Twin**

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CATAPULT High Value Manufacturing
UKRI Innovate UK

Foreword

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The term digital twin is gaining increased attention – Google trends indicate that over the past 5 years, the number of searches for the topic have increased by 400%. Recently, the Centre for Digitally Built Britain (CDBB) have released their report "The pathway towards an Information Management Framework" in which they look towards a Foundation Data Model. Our report, which is the output of several years' research into the field of digital twins, firmly supports the recommendations of the CDBB report.

However, there is still an underlying challenge before the achievement of a National Digital Twin, or any other common digital twin framework, and that is in its fundamental definition. The clarity required for this Foundation Data Model is hence presented within this report as a collation of our work into the constitute parts of a digital twin. Only by having a coherent framework for a digital twin can we hope to merge individual twins into what both the CDBB and the AMRC have termed a composite twin. Gartner (2020) suggested that by 2024 more than 50% of the individual digital twins in use would be acquired from OEMs and manufacturers as part of the product or equipment purchase and that in the same time frame 75% of composite digital twins will integrate data from individual twins. It is only through this integration and interoperability of different types of digital twins and their data that digital twins will deliver the full potential that they promise. This report hopes to help define this framework and to demonstrate how, by untangling the digital twin, the digital thread can be woven through your product, service or organisation.

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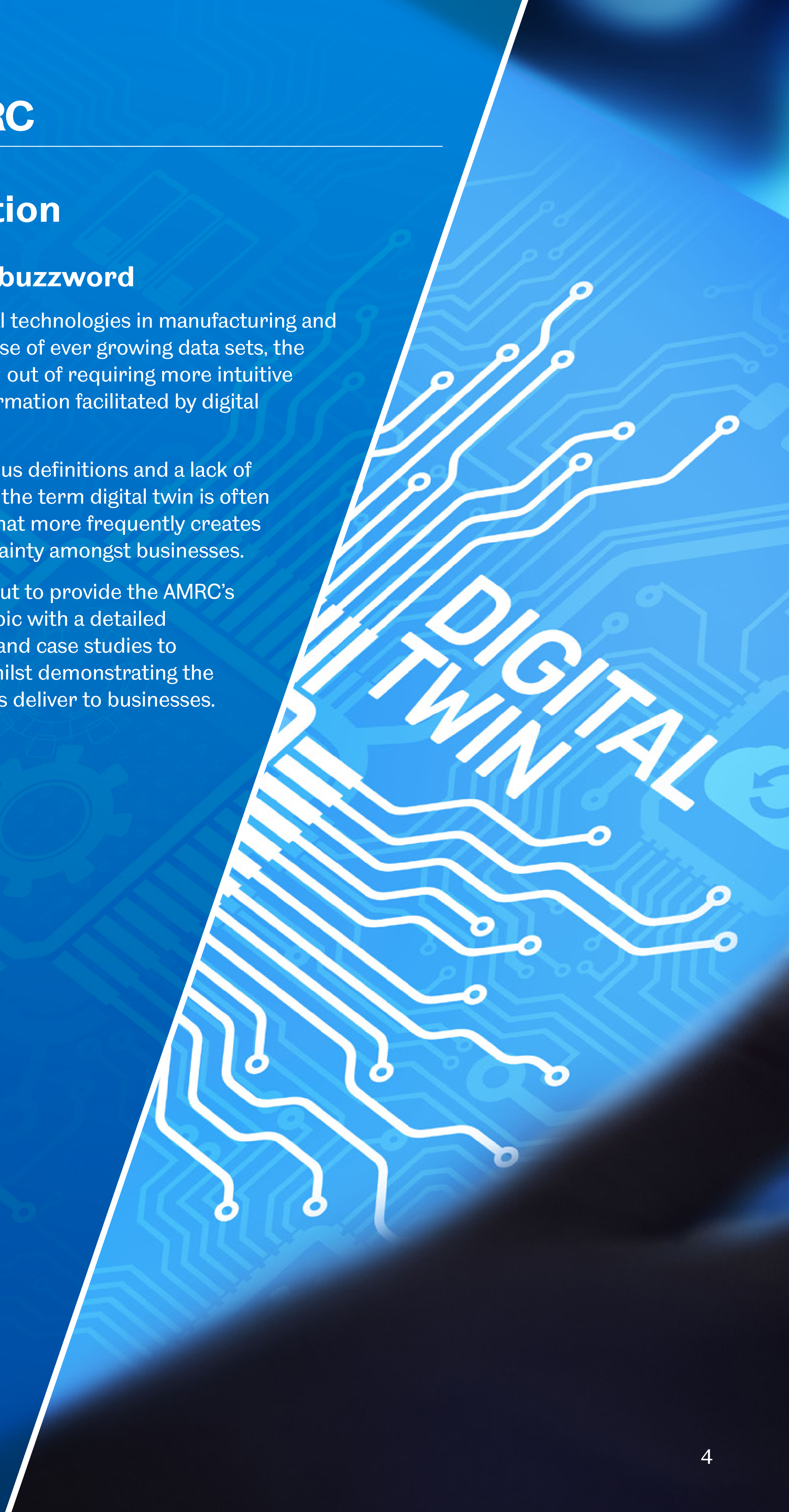
1. Introduction

Demotion to a buzzword

With the rise of digital technologies in manufacturing and the need to make sense of ever growing data sets, the digital twin has arisen out of requiring more intuitive ways to organise information facilitated by digital transformations.

However, with nebulous definitions and a lack of real-world use cases, the term digital twin is often seen as a buzzword that more frequently creates confusion and uncertainty amongst businesses.

This document sets out to provide the AMRC's clarification of the topic with a detailed definition, use-cases and case studies to alleviate confusion whilst demonstrating the value that digital twins deliver to businesses.

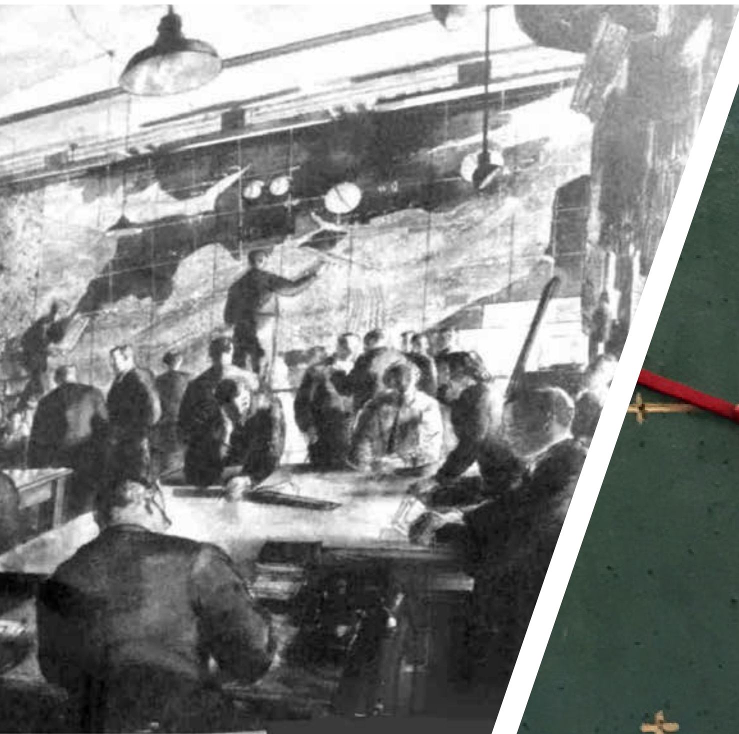


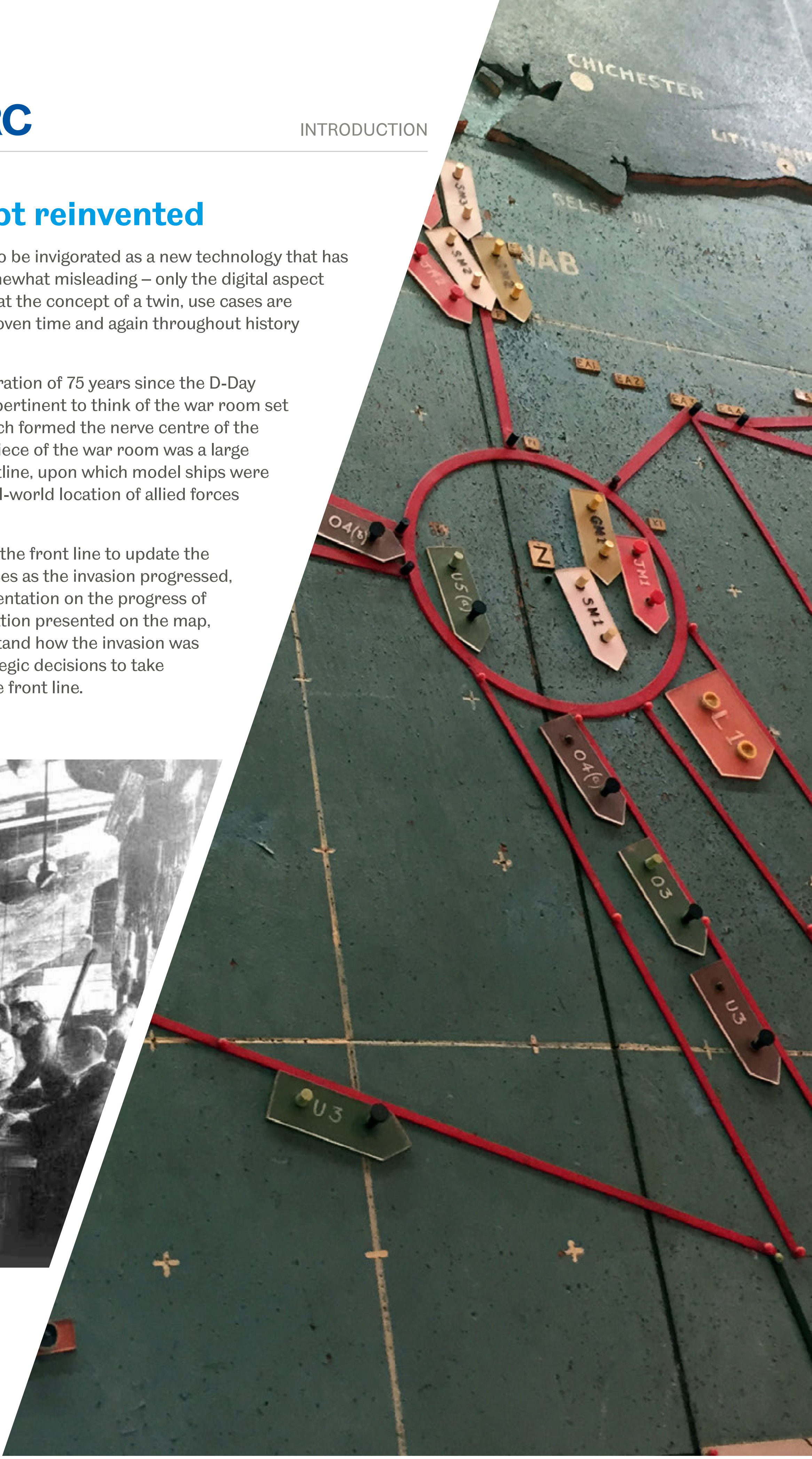
An old concept reinvented

Whilst digital twins seems to be invigorated as a new technology that has yet to be proven, this is somewhat misleading – only the digital aspect is new. Even briefly looking at the concept of a twin, use cases are common that have been proven time and again throughout history such as the example below.

With the recent commemoration of 75 years since the D-Day landings in Normandy, it is pertinent to think of the war room set up in Southwick House which formed the nerve centre of the allied invasion. The centrepiece of the war room was a large map of the Normandy coastline, upon which model ships were placed to represent the real-world location of allied forces crossing over to France.

Live data was radioed from the front line to update the position status of allied forces as the invasion progressed, providing a detailed representation on the progress of the battle. With the information presented on the map, commanders could understand how the invasion was progressing and make strategic decisions to take control of operations on the front line.





Neil Armstrong / Public domain

Going further through digital technology

When put in an historical context, the function of a twin becomes much simpler to understand – the twin aggregates and presents data from a remote system in an intuitive manner, facilitating further action. A digital twin is the same concept but improved through digital technology, allowing information to be presented automatically at speeds, accuracies and quantities that have not previously been possible. In the early stages of computing, a digital twin was only achievable in the high-budget environments of NASA control rooms and warship command centres.

What is causing the attention now is the decreasing cost of computation, advancements in sensor technology and improved network connectivity. In particular technologies such as the Internet of Things (IoT) are being enabled with cloud infrastructures. These combined are delivering improvements to manufacturing businesses of all shapes and sizes. This latter piece of enablement, the connectivity enabled through IoT, is already estimated by Gartner to have enabled 13% of businesses with an additional 62% in the process of adopting some form of digital twin during this year (2020). These types of deployments are also estimated to be seen by half of large industrial companies that will gain 10% improvements in effectiveness.

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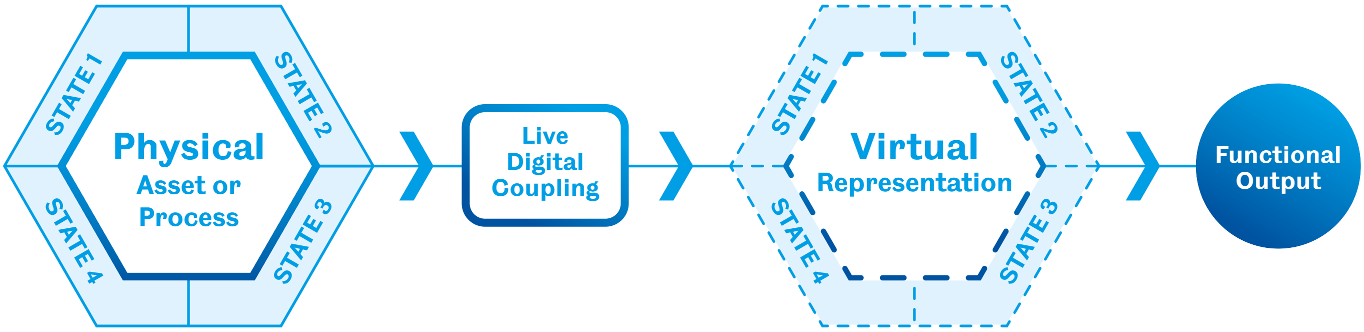
2. What is a Digital Twin?

A live digital coupling of the state of a physical asset or process to a virtual representation with a functional output.

How should a digital twin be defined?

There are a vast range of different definitions of a digital twin published in literature that often conflict with each other and are often sector specific. An isolated simulation is often seen as a digital twin, however this does not capture the intrinsic connection to something that physically exists. For this reason, the AMRC define a digital twin as above which is rationalised in the following sections.



The six highlighted components within this are further clarified to:

Live is when state information is available in a timeframe that is close enough to the underlying event. 85% of engineers surveyed* in late 2018 agreed that a digital twin would either replace or complement monitoring applications - a real time display and reporting of information.

Digital coupling is the transmission mechanism between data source(s) and data consumption method(s) using a digital carrier medium.

State is the particular condition the unique physical asset or process is in at a specific time.

Physical asset or process is an entity with an existence that has economic, social or commercial value. 94% of engineers surveyed* stated a physical aspect is a core requirement of a digital twin.

Virtual representation is an analogous description or logical model to its physical asset or process.

Functional output is information transmitted to a system or human observer that is actionable to deliver value. 74% of engineers surveyed from the same report* stated a representation is also a core requirement.

* Feasibility of an immersive digital twin - September 2018.
www.amrc.co.uk/files/document/219/1536919984_HVM_CATAPULT_DIGITAL_TWIN_DL.pdf

2.1 Breakdown

Although definitions and their explanations such as the previous have been stated in many articles, further analysis is seldom found to justify their importance.

Live

The data being used in a digital twin must be 'live', which for the purposes of a digital twin is that there is no appreciable difference between the state of the physical asset or process and its virtual representation at any given moment. This can be referred to as the capture latency. The justification for this is to ensure the output, typically a user, is able to make the same decisions and actions using the digital twin information as directly accessing the information at source. This is referred to as analysis and decision latency. Within this report, it is the combined latency including the capture, analysis and decision time to be quick enough to have a live connection.

When describing the concept of live many people will first think of live broadcast television, which is typically broadcast information being streamed without editing and interruption. This results in the picture that is being viewed identical to that of the events themselves. This definition for 'live' is not a fixed rule, but more an interpretation of a concept. However 'live' broadcasts are often delayed either by the limitations of transmission from one place to another or for pragmatic purposes, such as allowing for quick editing and censoring. How large this delay is before it is no longer considered 'live' information is not a definitive answer and typically based on the function and value of the broadcast.

Another aspect of 'live' is how often data is transmitted. A feed of a football score is considered a live stream of information, but how often the update is transmitted is also based upon the use case. For example, an update every minute, as each goal is scored or a single update upon the match finishing may all be considered the minimum amount of information to be considered live for different interested parties in the match.

These two factors, the delay between an event occurring and the information being received, and the regularity of updated information being transmitted, are more commonly referred to as latency and sampling rate. Regardless, both of these are key considerations for a live connection and highly dependent on the use-case. Ultimately, live does not require a high-refresh rate, or real-time, connection to enable a digital twin.

Importantly, a digital twin's capability to perform its functional output is inherently related to its environment. In particular, by changing a digital twin's environment it may lose its desired functionality and through this lose its classification as a digital twin. For example, a satellite in space may have a valid digital twin in Earth's orbit that is used to control its position and trajectory, which works effectively when the data is transferred with minimal latency. However, if this same satellite is moved to the outer solar system, the original implementation will now have a much higher communication latency and become functionally useless for control of the satellite.

A final consideration for data to be considered live is the intention to update the data to reflect changes in the state of the measured subject. A static snapshot cannot be considered 'live' even if it can be considered valid and up to date, as without the intention to retain parity between the real and virtual then a deviation between the two is possible at any stage.

Examples

A manufacturing process, such as machining an aluminium part on a machine tool, is a common connected asset that typically produces regular information at least once a second with a latency approximately 100 milliseconds to a shop-floor network.

A door that provides an update whenever it opens (from a closed state) or closed (from being ajar). This irregular timing of data transfer may result in no information for long periods of time, however is still considered live.

Glacial speed that is updated once a week is still valid due to there being no appreciable difference in the week timespan between the samples being taken defining the physical glacier by its virtual representation.

Live TV shown at 25Hz with a latency of 20 seconds. Although the refresh rate may be more than is required to still give the general progress of what is being broadcast, this again reflects the implementation detail rather than the definition being defined. However information being updated too slowly would lose the systems functionality and could no longer be described as live.

Digital coupling

The connection from the physical asset or process to its virtual representation must be digitally coupled, as opposed to analogue. An important distinction is the coupling encompasses the capturing of the data, communication method and end points such as transmission. Many deployed systems are already digitally coupled providing live data to other systems, as displayed in the examples below, however consideration should be made across the lifecycle of systems for all the different use cases to ensure availability of the information.

Security is the paramount consideration of the coupling mechanism as having information being distributed without appropriate security measures in place exposes vulnerabilities that could have a devastating effect on a business from data being compromised. Most data transmission protocols have some level of security, however these can range from basic password protection through to statistically impenetrable encryption. Security is a fine balance between pragmatism and safety, as added security increases the complexity of the system, hardware requirements and the need for specialised software and hardware systems.

Examples

Machine tool information being sent over a shop floor integration layer, such as an OPC/UA server.

IoT smart home devices exchanging information over a Wi-Fi connected message broker, such as power monitoring systems.

Weather stations capturing information by posting a web request to a cloud based database.

State

State is the description of the particular condition or circumstance the physical asset or process is in at a specific time. In a similar manner to live, the state description must be measured to an acceptable level of accuracy and uncertainty to not wrongly influence future decisions. This is dependent on use-case and should be handled on a case-by-case basis.

In addition, a state model requires supporting descriptions, typically through metadata, to provide context of the live state information. For example, an electric circuit that provides current measurement information about a wire will just provide a number, however the metadata of this would provide the context of it being measured in Amperes. Another example would be the context of what an integer state is to describe the current status of a system, for instance idle or being used.

Two key aspects are hence required to define the state:

1. The conditions that require describing, including the supporting descriptions through metadata information. Broadly, a physical asset will include properties such as: mechanical properties, electrical properties, and operational conditions whereas a physical process will include properties such as: timescales, processing time, and assigned resources.
2. The format that the state is described which is then transmitted over the digital coupling mechanism.

Condition Examples

A robotic arm which includes properties such as:

- Execution status, e.g. in program, stopped, emergency shutdown etc.
- End effector payload
- Joint positions

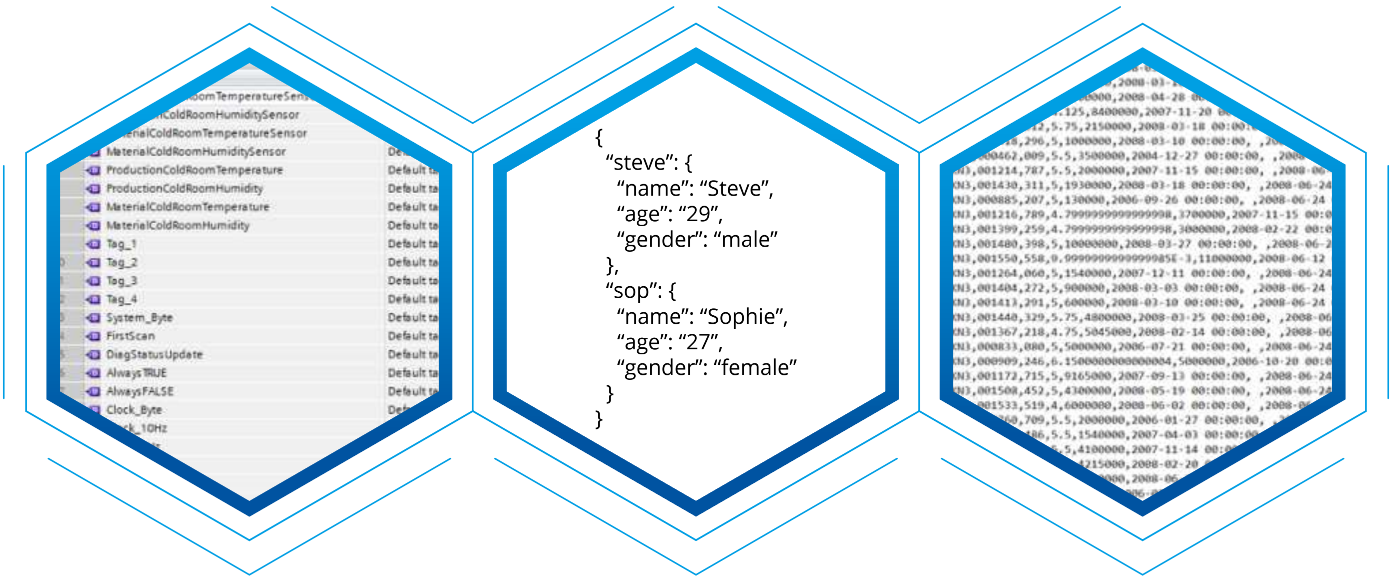
A shop floor process which includes information such as:

- Scheduled jobs
- Number of staff on shop floor
- Machine utilisation
- Number of items to be shipped

A supply chain which includes information such as:

- Current orders
- Market demand
- Parts produced per factory

Format Examples



Tag Tables - programmable logic controllers (PLCs) stored internal tags, or states, in data blocks for retrieval.

JavaScript Object Notation (JSON) is common for transferring data between a server and client that follows a lightweight language independent standard structure.

Data files such as CSV and Microsoft Excel that contain lists of information following headers located at the start of the document that collate records together.

Physical asset or process

Within this context, a physical asset is a tangible unique item or a physical process that is an established specific workflow. Both of these can be owned (i.e. could be turned into money) and have economic, social or commercial value from their ability to be sold, exchanged, or used. The physical asset or process is a fundamental key part of a digital twin that is sometimes overlooked or oversimplified; it is this unique existence of some "thing" exhibiting its behaviour in the real world and producing state information that is utilised and forms the start of the chain for a basic implementation of a digital twin.

Example Physical Assets

A wind turbine delivers commercial value from producing renewable energy.

A restaurant delivers economic value, but also commercial value to the owner and social value to patrons.

A car delivers commercial value to the company manufacturer and social value to owners.

Example Physical Processes

A brewing process that has commercial value to the company owner

A recruitment process that has commercial value to recruit the best for the new role

Shipyard logistics as part of a supply chain has economic value for distribution of goods and commercial value for its efficiency and competitive edge.

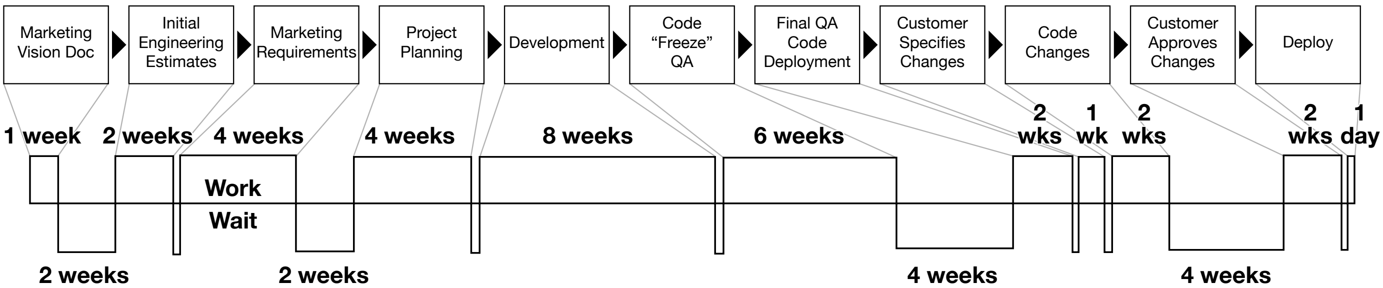
Virtual Representation

The virtual representation is the utilisation of the state information from the unique physical asset or process to its model. This is commonly envisaged as a virtual 3D model being updated from sensor information, however the scope is much larger to also encompass a bigger variety of structured documents such as schematics. Overall this requirement is more critically the representation of the state information in some way to maintain an accurate depiction so the functional output maintains its value.

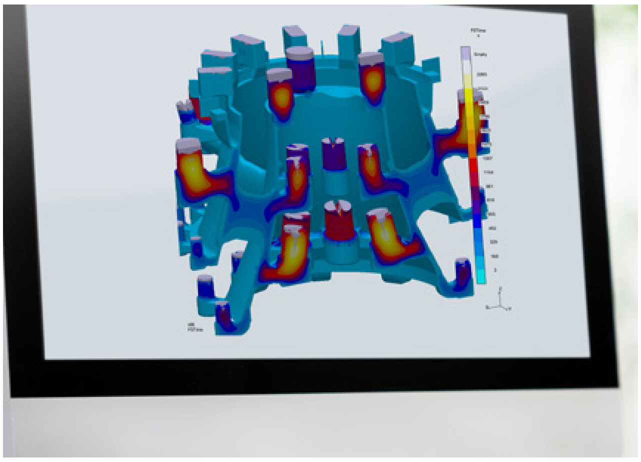
One typical characteristic is the ability to display this in a graphical format. This could be the previous example of a 3D model, however this is not essential. For instance, a mathematical model producing numerical outputs from the state information inputs is a virtual representation. Out of the surveyed engineers, only 45% stated a 3D representation was essential.*

In addition, a digital twin implementation only requires a selected region of interest of the physical item or process with its respective state information being used. For example, a digital twin focused on understanding a factory's energy consumption only requires power utilisation to be available.

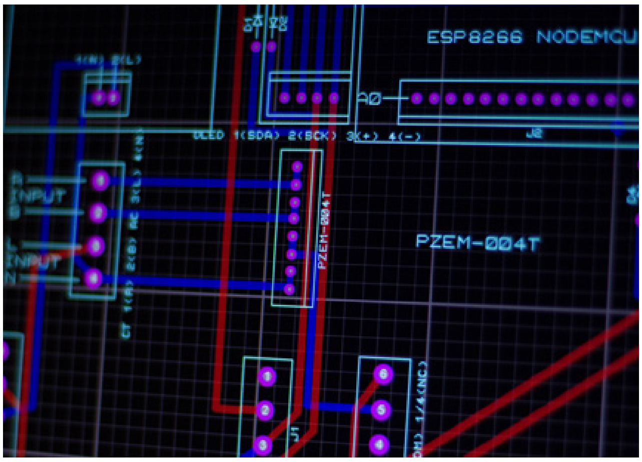
Examples



A value stream map of a software development process that captures value and non-value added segments.



SImulation of casting manufacture, to optimise designs that facilitate the production of components to the required specifications at the lowest cost.



A schematic of an electrical wiring system that models the expected behaviour given a set of inputs.

* Feasibility of an immersive digital twin - September 2018. www.amrc.co.uk/files/document/219/1536919984_HVM_CATAPULT_DIGITAL_TWIN_DL.pdf

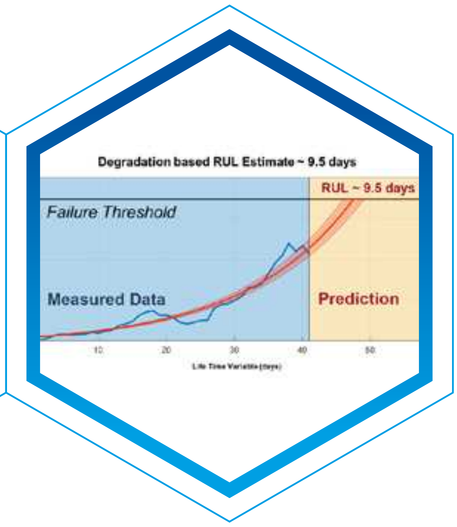
Functional output

The functional output requires actionable information to be available from the digital twin to at least one external system or human observer. Information is considered to be actionable if it allows for at least one informed decision to be made that adds either economic, social or commercial value to one or more stakeholders. For instance, information presented as a dashboard regarding the performance of a machine could provide an actionable output for scheduling preventative maintenance or automatic power monitoring could provide a daily report of which systems are just drawing idle power to save money.

Examples

Dashboards such as those from a car or machine tool to display information with dials or by showing warnings

Immersive environments, such as virtual reality visualisations, displaying the environment being captured from shop floor systems or asset monitoring for remote purposes, such as a production system or wind turbine.



A predictive model for the remaining useful life of a component that outputs when the component needs replacement.

2.2 Categorisation of a Digital Twin

Although the six components presented here are the minimum fundamental requirements of a digital twin, acting in essence as a checklist, this technology can be categorised for further developed implementations. It is important to first note that as digital twins cover a broad range of applications on top of the aspects already discussed within this report, defining well established categories to encapsulate all aspects of functionality may not suit all adoptions of the technology. Nevertheless, the functional output does fall into distinct maturities and is recommended to still use the previously established groupings identified by the High Value Manufacturing Catapult Visualisation and VR Forum (September 2018); supervisory, interactive and predictive.

These categories are defined as:

Supervisory – these are the simplest form of digital twin and display the live state of the physical asset or process to human observers. The value provided in this case is the ability for people to be able to act on the information provided. For example, a car driver may choose to stop at the next petrol station when the fuel gauge indicates that the car they are driving is low on fuel.

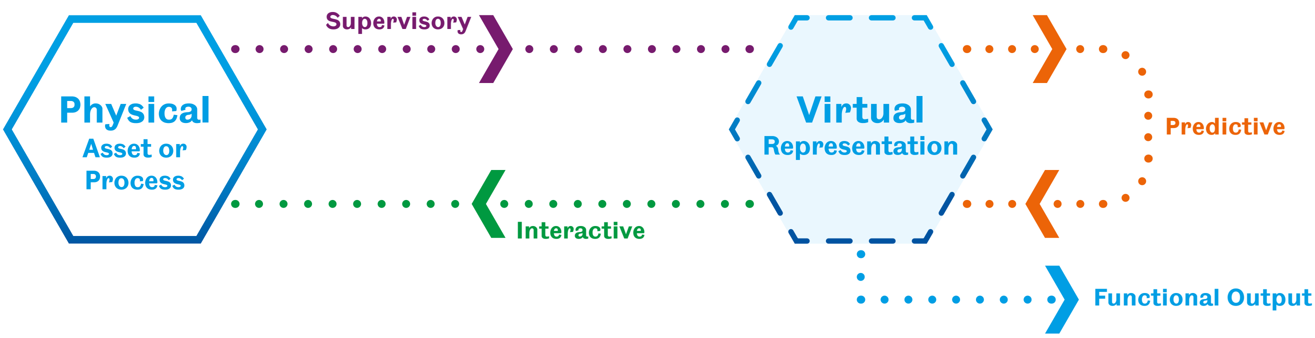
Interactive – the digital twin takes control of at least one aspect of the physical asset or process to achieve better performance from internal monitoring or more complex analysis. For example, a thermostat reporting the temperature in a room that has just gone above an upper threshold which in turn automatically requests the amount of heat being produced by the heating system to be reduced.

Predictive – this is the most complex type of digital twin that monitors state information over time to provide augmented information to the state information such as warnings and/or recommendations to a either a human observer or other digital system. Expanding on the supervisory example above, a car's fuel gauge could predict the remaining mileage based on current efficiency of the driving style. Whilst this may seem similar to the supervisory digital twin example, there is an important difference. In the supervisory case the driver has to rely on their own interpretation of the fuel gauge in order to decide whether or not they need more fuel whereas the driver in the predictive case is directly informed that they need more fuel within the stated millage which was information not originally available from the state information. Predictive, as with this example, often decreases the amount of human judgement required enabling better automation of systems.

Although there is some overlap between the three categories, a digital twin should be classified on its most complex functional output with a predictive digital twin considered to be the most complex and a supervisory digital twin considered to be the simplest. For example a farmer may build a digital twin of their crops to monitor their current health, enabling a supervisory digital twin. However, if an additional functionality was added providing the ability to automatically control the sprinkler system based on predicted rainfall it would now be described as a predictive digital twin, therefore a more mature deployment.

Composite Digital Twin?

A composite, or aggregate, digital twin has been gathering traction within this technology space to signify the digital twin is consuming information being provided by other digital twins. For example, a digital twin of a machine tool can be supervised by a human observer running the machine, however this same information can be consumed by a fleet manager alongside consuming all machine tool assets of that type. The fleet manager could use all the information to calculate the maintenance schedules of the machines to achieve the best performance that isn't possible with each machine individually. This concept is easily compounded again when maintenance schedules are in turn consumed by a digital twin of the whole factory and so forth.



2.3 Related Concepts

Related to the concept of a digital twin, several keywords are typically used that also require some clarification in the current context.

Digital Thread

With the growth of digital technology in our homes, businesses and everyday lives, interaction with systems that generate and store data in their own individual ways are ever-increasing. However, current systems produce "silos" of information that are not intended to be integrated together causing technical challenges in bringing together these data sources. The incentives to do this is often described as the "bigger picture" - to implement a system from different information sets that just hadn't been thought of yet. This challenge is common in many sectors, such as manufacturing, where the design, manufacturing, operation, maintenance, and disposal of products are all governed by disparate systems making through-life improvements very difficult to achieve.

The digital thread is the concept of providing traceability throughout a product's lifecycle across disparate systems. This is typically achieved by assigning an entity, asset or process with a unique identifier that is used to link the output from one system to the input of another, providing a connection between them and facilitating cross-system analysis.

Digital Shadow

Within this report so far, there has been no discussion of storing data as a requirement or component of a digital twin. Whilst it is quite feasible to only utilise live data straight away, and still be a valid digital twin, there is significant value to be gained in keeping data records to facilitate historical analysis.

By taking snapshots of state information over time and storing them alongside the planned activity, this information when analysed creates a digital shadow. This digital shadow allows for comparisons, in hindsight, between the previously desired or predicted state, and the actual achieved state. By performing this analysis, it enables the refinement of the operational and predictive models of the physical asset or process to continuously improve the future function of both the digital shadow and the predictive digital twin by better understanding what is occurring in practice.

By creating a digital shadow, it enables refinement and validation of the models underpinning a digital twin which has a number of advantages. Refinement increases the value in the digital twin to ensure the physical asset or process is functioning to its best. Validation increases the credence of the models when important decisions are being made whilst also ensuring it is taking into account the current trends and not invalid assumptions.

Finally, whilst a digital shadow is not mandatory for a digital twin, they can be invaluable for decision makers and businesses as a whole to achieve the most out of their assets or processes.

Digital Master

As presented within this report, the core requirement for the live connection of a digital twin is the single direction of communication from the physical asset or process to its virtual representation. However two-way (bi-directional) communication is often presented within other definitions due to including additional functionality above what is defined here as the minimum viable requirements of a digital twin - a supervisory digital twin.

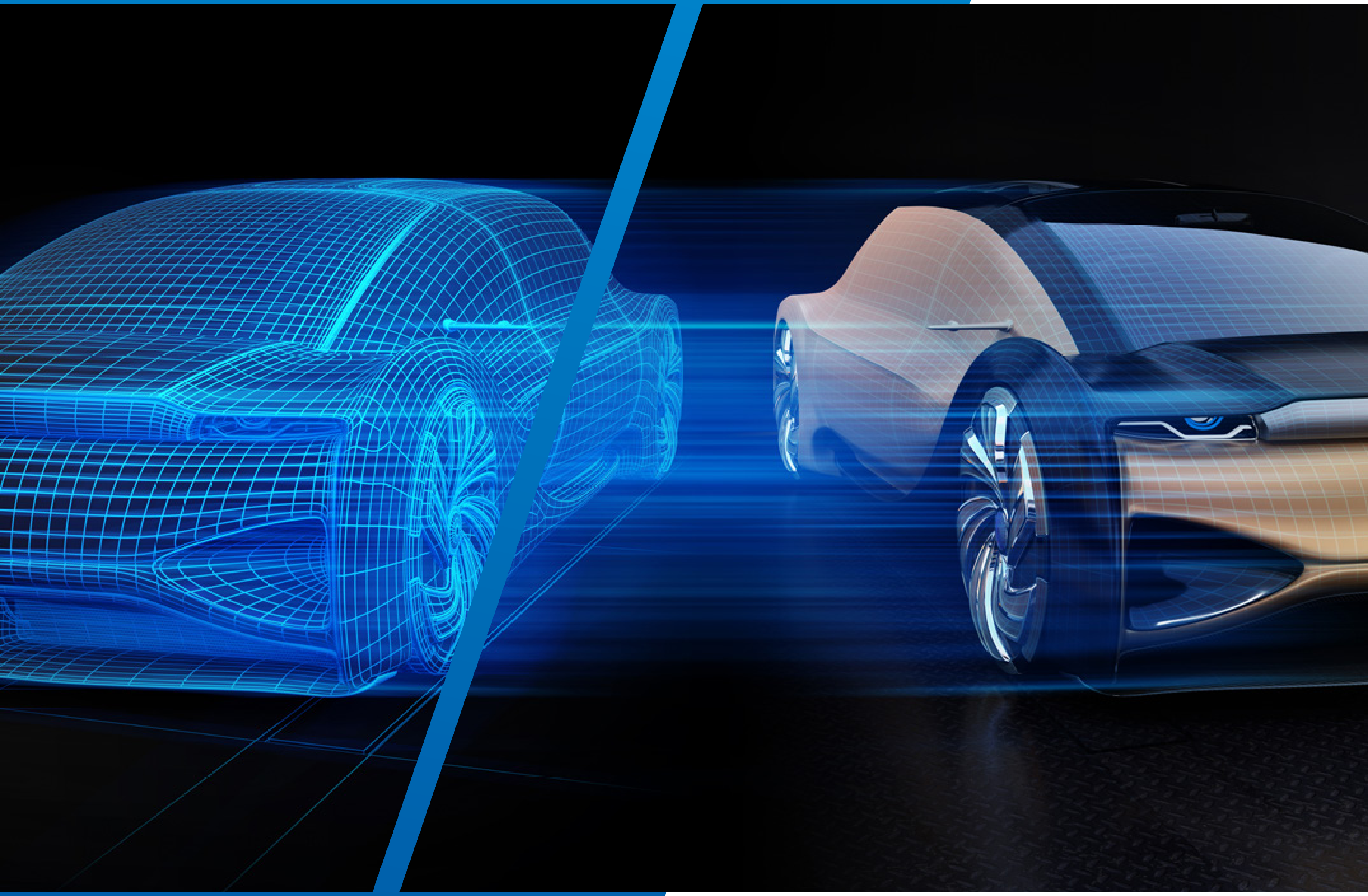
Two-way communication undeniably creates a significant enhancement above the baseline within this report, and due to this when a digital twin's functionality is extended to such an extent that it now incorporates controlling the physical counterpart automatically with no human intervention by analysis of live information it is considered a digital master. This is defined as such to signify the mastering of the real-world is now from the virtual space whereas a digital twin's mastering is the physical aspect in control of the virtual counterpart. A digital master will take live state information and augment its knowledge using its predictive digital twin and/or shadow to make automatic step-changes to improve the process where possible.

From the surface description this may appear as a standard closed-loop feedback control system, however the significance is the digital master will make incremental enhancements to have deterministically better performance for the same scenario. For example a quadcopter's digital master could be adjusting the control system to achieve better battery life from a wider knowledge range for the same flight performance whereas the traditional control system is only able to work within its known parameters to deliver flight.

Overall, the value of a digital master is to have the data rich systems self-managing utilising their base digital twin implementations to achieve the best performance.

3. Use-Case Drivers

Digital twin use-cases are almost endless covering a broad range of all aspects of our daily lives through to industrial applications across all sectors. However what underpins the value seen across these can be broadly split into three main categories that are explored on the following pages: asset, process and enterprise.



Asset

A physical asset's digital twin will receive live state information from the physical asset and typically be presented for users to act upon it. One of their main advantages is the functional output, such as a dashboard, which brings value immediately to the users who need it most as the information is now accessible anywhere at any time. However this deployment also enables a springboard effect by unlocking new value for future deployment iterations of itself or for other new deployments that can consume this information.

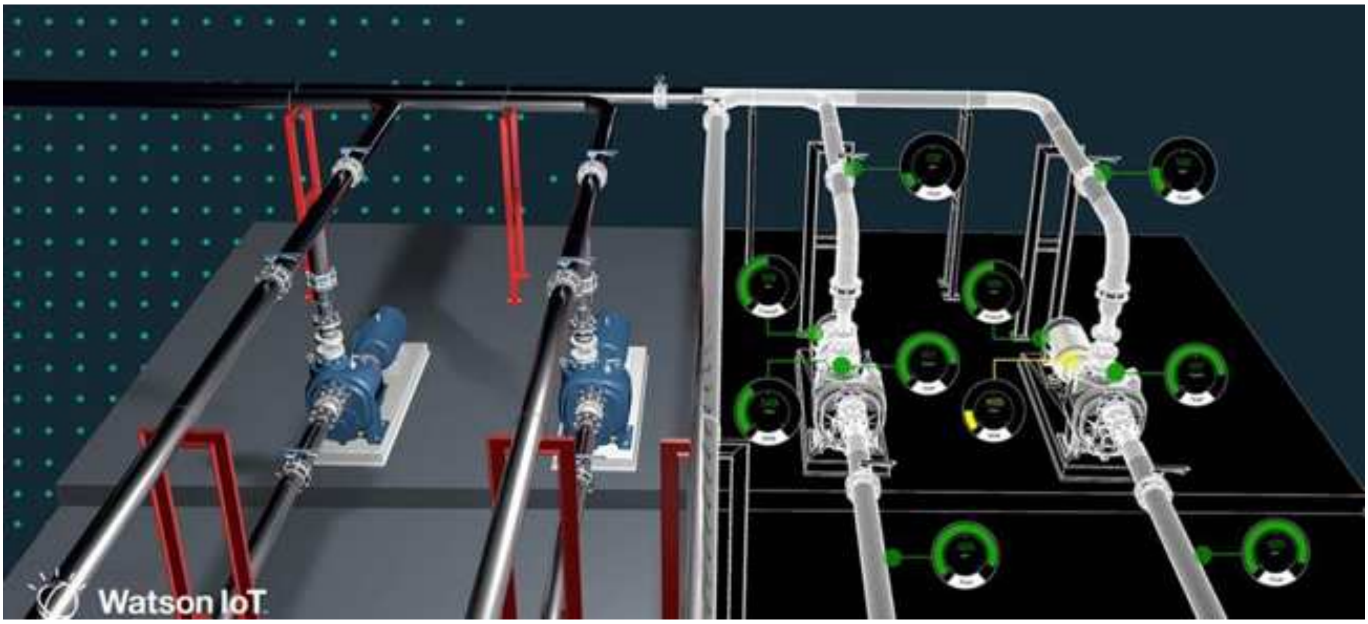
Although this category is often targeted first due to simpler implementations (such as health monitoring, productivity insights and warnings) they can mature into more advanced implementations utilising complex predictions and interactions between systems. A digital twin here with enough knowledge, understanding of itself and ability to interact with the required other physical assets and processes would enable 'lights-out manufacturing' environments, where zero human intervention is required during a production process.

Overall, creating asset digital twins are where obtainable value can be seen, such as productivity improvements. These foundational types also generate new opportunities, such as process digital twins driven from access to asset state information.

Process

A process digital twin utilises information from different information sources and typically includes one or more physical assets, with focus placed on their behaviour when an overarching process is carried out. These deployments often influence the respective asset digital twins for improved performance, for example, in a fleet management system.

Another key driver is the ability to identify insights providing value by inform decisions. Typical examples are production processes within manufacturing that are concerned with overall process performance, for example reducing costs and power consumption. The real value of a process digital twin arises when multiple data sources are employed in order to gain a deeper more fundamental understanding of assets. While it is feasible for a process digital twin to utilise just a single data source, it is recommended to ensure sufficient information is available from multiple streams to ensure the maximum value is attainable.

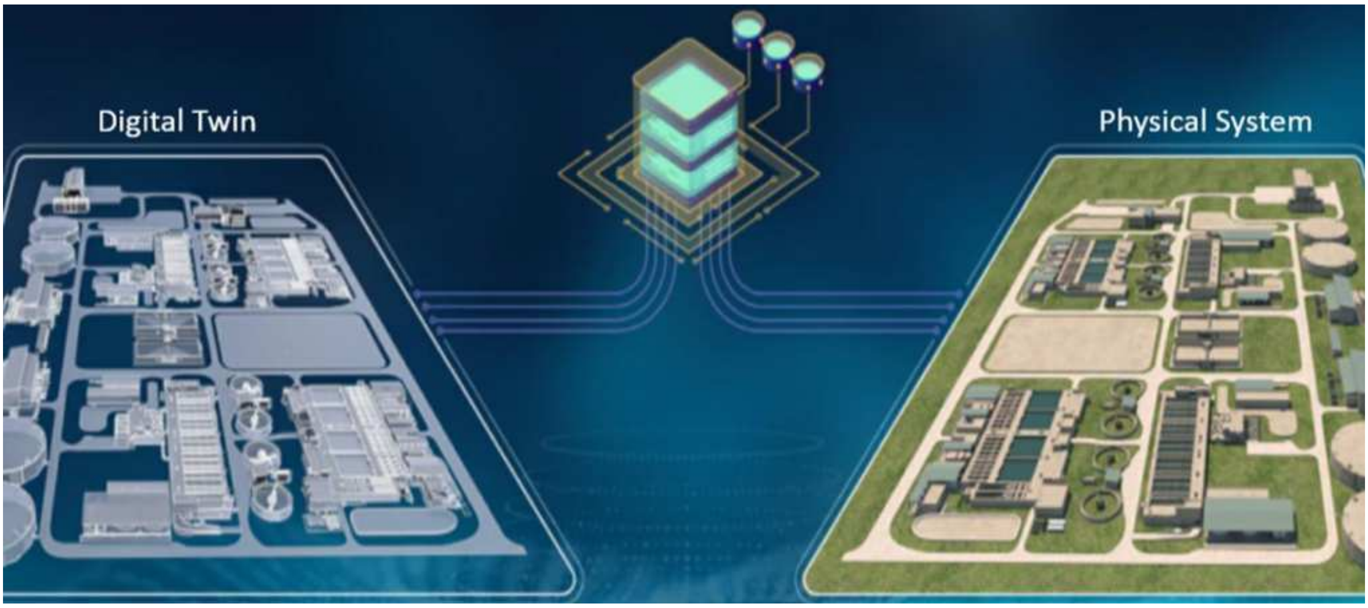


A physical assets' digital twin will receive live state information for users to act upon, whereas a process digital utilises information across sources focusing on the overall behavior of the system.

Enterprise

An enterprise digital twin utilises business-wide information to enable strategic decisions utilising asset and process digital twins across an organisation. These deployment types can be employed for a building, a certain location, or even world-wide. Key information will be from internal processes, business systems and external factors such as market demand to predict how to increase value, which for a business could be reducing overhead costs or executing strategic movements that affect the whole business with live feedback to assess the impact of their decisions.

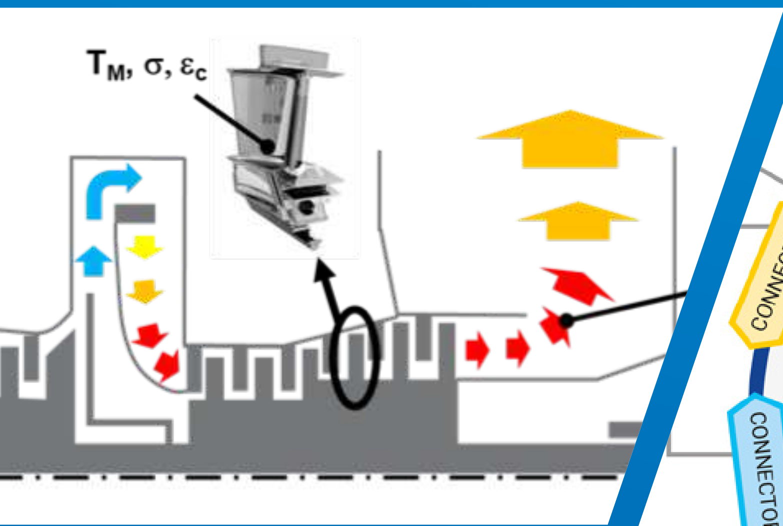
A characteristic of this category is the essential abstraction of information to the right level of detail. Whilst this may also be required to a lesser extent for both asset and process twins, the prospective amount of information at this level is magnitudes greater due to the amount of available information across all its sources. This has to be enabled through good enterprise data architecture and master data sources with the ability to drill down into the information sources when more detail is desired. This also enables practical human reasoning to aid comprehension when considering datasets this large.

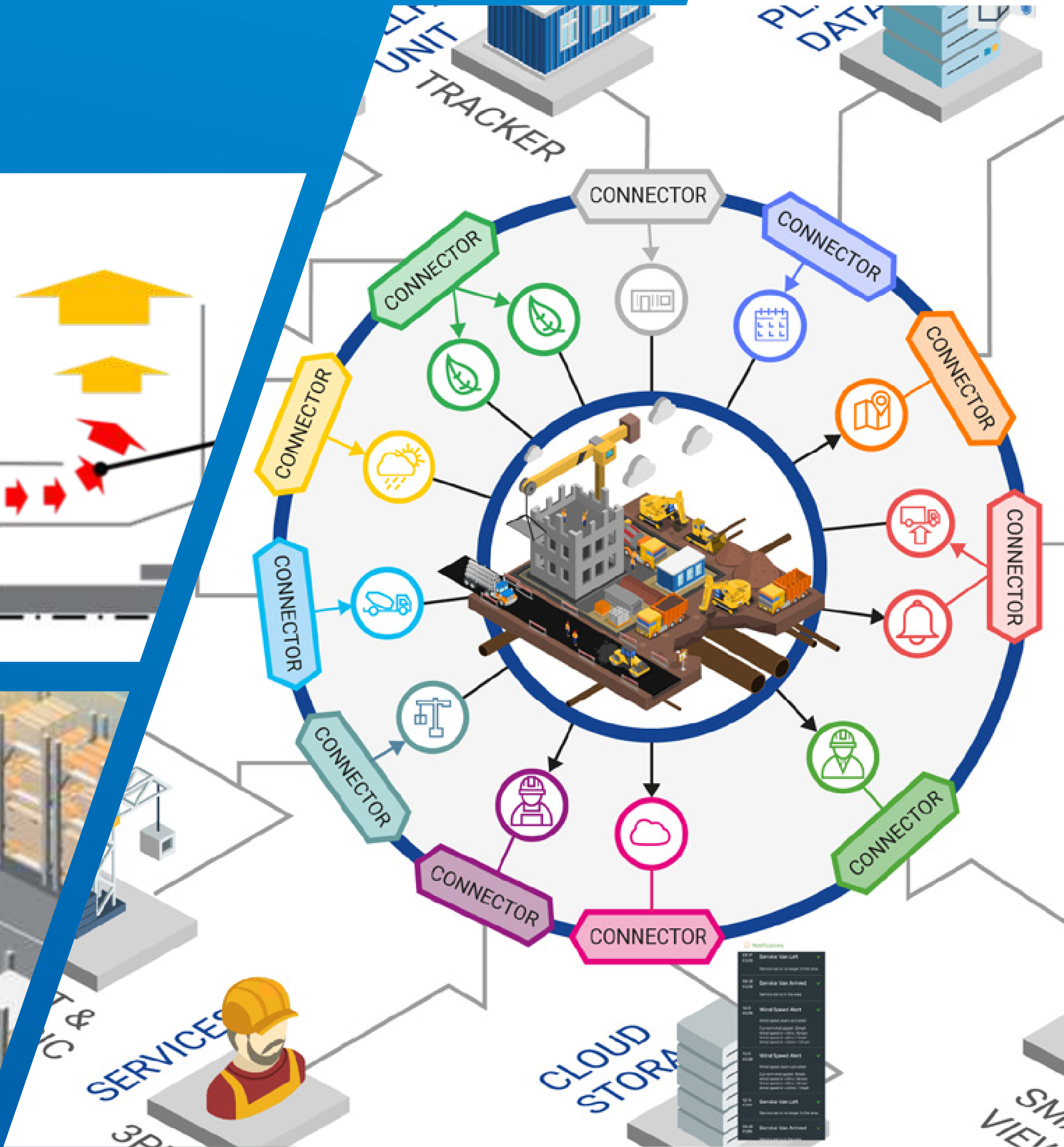


An enterprise digital twin enables key decisions across the buisness by utilising digital twins across the organisation.

4. Case Studies

The following case studies highlight the breadth and variety of applications that digital twins can be applied to from construction and rail, to power generation, to logistics. While not exhaustive, this provide a range of examples where deployments are adding value at the time of writing.





Case study

4.1 BAM Nuttall: The Learning Camera

Sector

- Construction
- Rail

Who Was Involved?

- BAM Nuttall - part of the Royal BAM Group of civil engineers and one of Europe's largest contractors.
- Iotics - a technology provider enabling digital twin deployment through their cloud-hosted service.

The Problem

- BAM Nuttall were working on a project involving the restoration of an existing railway bridge and required monitoring assets across the site. One of these was the site's compressor situated a mile from the site office. The uptime of this asset was critical and located in a hazardous area, which made health checks difficult and monitoring time-consuming.
- Live information from across site was not being utilised due to no standardised approach and no method of aggregating the data sources together to utilise relationships between the available information and assets.

Solution

- A standard web camera was used to train a machine-learning model on an attached edge computer, coined The Learning Camera. The device was programmed to recognise a scenario on site to provide an alert automatically so that someone can attend to the situation. For the compressor, this enabled the detection of the compressor display for detecting warnings such as a red warning light.
- A further development with Cranfield University enabled a digital twin of a site safety board for capturing changes in the state of the board. For example, it recognised if the first aid kit or fire extinguisher were taken away, and when they were returned allowing multiple notifications to be triggered as needed, such as to alert the site safety officer that there may have been an accident, as well as the purchaser to check on stock levels of the safety essential consumables.
- A computer dashboard driven by the Iotic Space platform was the key enabler to present previously disparate information sources collated together in a single environment. This included information

Continues...

A construction site's digital twin(s) would enable a single view all of assets and process across the site facilitating better decision making.

captured on-site as well as other local data sources, such as local weather feeds, to create a composite supervisory digital twin of the construction site. These additional local sources are processed for capturing significant events to drive notifications, such as wind speed being too high for equipment on site to work safely or when assets are idle for longer than a set time so that hired items can be returned to save money on the project.

Outcomes

- Developed and deployed a composite supervisory digital twin across a whole construction site that provided automatic notifications of warnings and issues.
- The technology deployed was low cost whilst still suitable for a hazardous construction environment.
- Utilised a scalable architecture to feed a dashboard and alert system for a range of assets with multiple sensors and cameras on a construction site.
- Iterating during the development was a key factor in the project's success. During the project the site safety board was augmented with a proximity sensor to alert if the board could be detected. This was important to distinguish if the board had been moved or something had been placed between the camera and the board - both situations which were flagged as dangerous for either not being where required or obstructing a person's access to the site safety board.

Benefits

- The Learning Camera read the compressor display panel; minimising workers' exposure to hazardous areas and bad weather.
- Automated alerts to notify the project team when equipment requires attention; reducing the regularity of health checks. Improved productivity through deploying technology to reduce time spent on non-value added tasks.
- Reduced risk though contractors spending less time in hazardous areas and bad weather.
- Reduction in menial jobs that took up a significant amount of time thereby impacting productivity.

Case study

4.2 Frazer-Nash Consultancy: Exploiting Data to Extend Asset Life

Sector

- Industrial power generation

Who Was Involved?

- Frazer-Nash is a leading systems and engineering technology company with over 850 employees. They're renowned for their work in the aerospace, transport, nuclear, marine, defence, industrial, power and energy sectors throughout the UK and Australia. The breadth of expertise and the insight they apply deliver successful outcomes.

The Problem

- Maintenance schedules of a large fleet of approximately 15,000 turbines is traditionally based around safe operating hours at their maximum design conditions to save sudden failure. However, all systems operate differently and inspection within maintenance procedures often replace parts that show no signs of damage.
- Repair and overhaul of a fleet is expensive for:
  - Operational costs due to downtime
  - Original equipment manufacturer costs for replacing high-value parts and inventory upkeep.
- The opportunity for this problem is with unit-specific maintenance schedules, however the complexity is in finding a balance between waste versus sudden-failure.
- The complexity of this problem is the lack of data points around a blade's local environment to reliably predict the blade's condition (T_M, σ, ε_C) from the known parameters of inlet temperature (T_2), outlet temperature (T_5) and shaft rotational speed (ω), displayed on the diagram.

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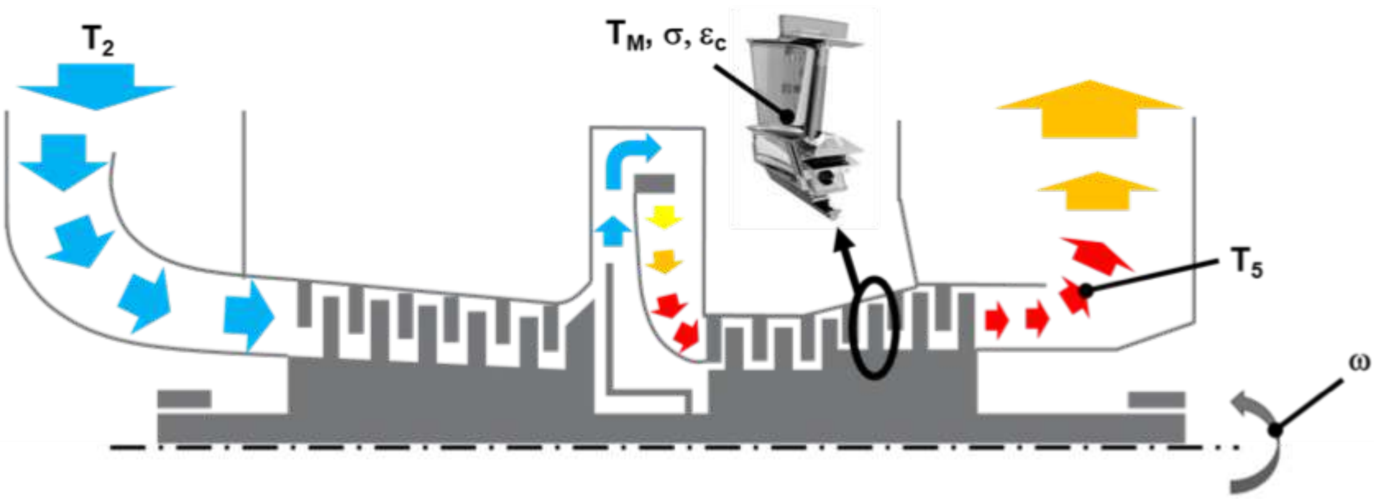
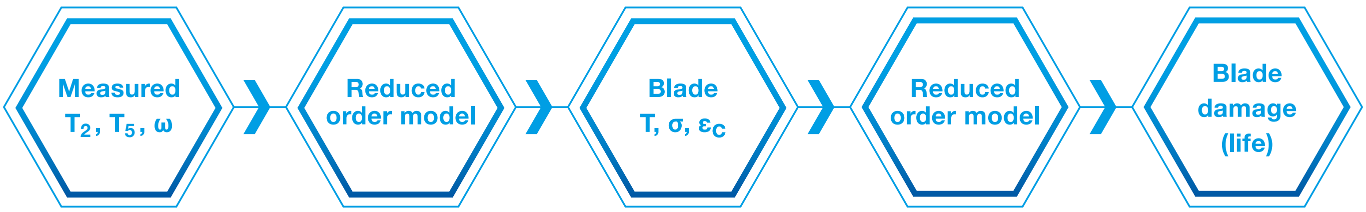


Using a digital twin to quickly and reliably predict unit-specific blade damage from engine monitoring data.



Chosen Solution

- Creation of complex mathematical models based upon a tiered system of testing, validation and complex physics from captured asset data utilizing probabilistic techniques to quantify the certainly in their predicted lives.
- Developed a digital twin relating the measured quantities, such as the temperatures of hot gases in the turbines, to the unmeasured local environment, operation and accumulated damage of the blades using the validated reduced order models for live predictions of remaining useful life of blades.

Intended Outcomes

- A competitive product in the market reducing the risk of failure and overhaul downtime across an engine fleet.
- Cost reduction through less waste and leaner inventory management.

Benefits

- The modelling and validation has achieved a reliable, tailored engine specific maintenance schedule.
- Deploying these models within their digital twin has provided a means of using live data from turbine control systems to determine maintenance schedules from estimated residual blade life across a whole fleet.
- Return on investment is to be realised in two years and with expected adoption five times that amount within five years.
- Exploration of the datasets is possible from live fleet information in addition to records of historical sensor data (digital shadow) to evaluate new maintenance and repair regimes.

Case study

4.3 DHL – Smart Warehouse Technology

Sector

- Logistics and Transport

Who Was Involved

- DHL Supply Chain worldwide supporting logistics and supply chain services for over 50 years reaching over 200 countries with 380,000 employees worldwide.
- TetraPak is a world-leading food processing and packaging solutions company that provide solutions for processing, packaging and distribution of food products serving customers in 160+ countries and has 24,000+ employees worldwide.

The Problem

- Warehouse efficiency is impacted by many factors, but the effect of small details can still cause large disruption if overlooked. Within this study, issues identified were around congestion, improved resource planning, workload allocation and site safety.

Chosen Solution

- DHL Supply Chain deployed a smart warehouse initiative for Tetra Pak to bridge its physical operations to a virtual representation to monitor the current status of all assets 24/7.
- This involved heavy utilisation of Internet of Things (IoT) technology with data analytics.

Continues...

Intended Outcomes

- Live site access monitoring with management alerts for controlled areas that have restricted access.
- Real time monitoring of environmental temperature systems due to the importance when dealing with food goods.
- Visibility of traffic movement for slotting optimisation.
- Real time operational data presented to supervisors to support more informed decisions for both day-to-day operations as well as coaching teams on how to improve their operational performance.

Benefits

- Warehouse supervisors can monitor 24/7 with real-time operational data to co-ordination of its live operations to resolve issues as they occur increasing productivity and safety of its operators by improving resource planning and allocated workloads.
- A conservative 16% efficiency increase by reducing congestion, improving resource planning and optimising workload allocations to ensure goods are shelved within 30 minutes of receipt, and delivery-bound goods are ready for shipment within 95 minutes.

Utilising IoT technology to enable real-time decisions across the warehouse which has increased efficiency, safety and productivity.

5. Implementation Strategy

From these previous case study examples it can be seen that many sectors are adopting digital twins as they provide savings through increased productivity, performance and reliability. This stepped approach addresses some of the key questions that should be asked whilst implementing digital twins.

1

Start with a use case.

Understand the fundamental problem and opportunities that exist that need to be addressed, including the business value. This requires breaking down the specific business context to be able to consider the strategic and performance goals.

2

Adoption and buy-in

Work with your clients, stakeholders, internal customers and managers to understand what they require of the system. Their buy-in will be crucial to the success of any projects implementation.

3

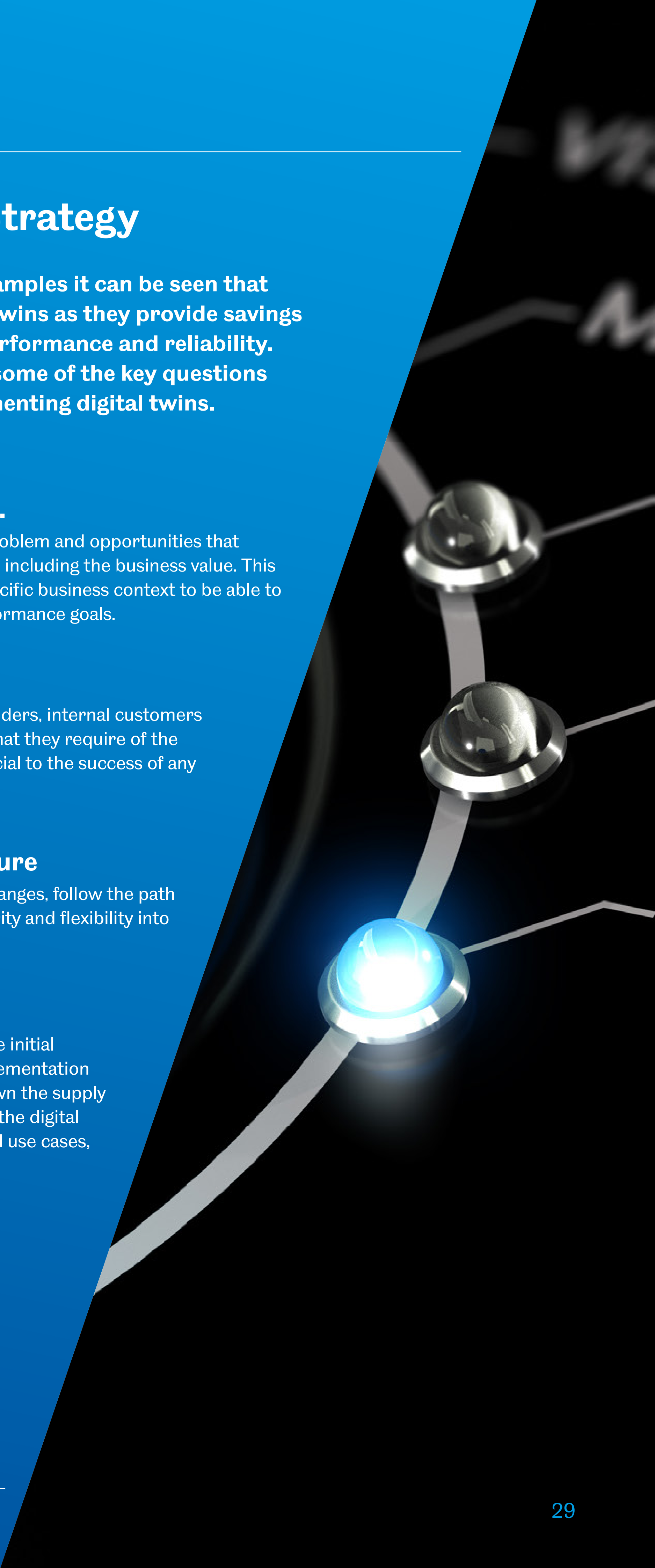
Design and architecture

Plan for the IT infrastructure changes, follow the path laid by others, and embed security and flexibility into the system from the outset.

4

Think long term

Extract maximum value from the initial investment by growing the implementation and sharing the data up and down the supply chain. Consider the life cycle of the digital twin through evolving needs and use cases, through to end of life.



5.1 Define the use-case

The use case is critical for addressing the root value of any improvement a business is looking to improve and always needs to be considered first, regardless of whether digital twins may or may not be the right solution. The use case determines potential solutions, which ultimately drives whether digital twins are the right technology for this problem.

Questions that should be addressed are:

- What is the value for the problem being addressed?
- What is the current map of the current product or process as a baseline?
- What KPIs can be reviewed both before and after to assess the impact?
- What ROI can be estimated due to the implementations?
- What is the functionality missing that would make the required improvements?

5.2 Adoption

End-users of new implementations are often overlooked, however step changes of any size of processes or technology critically depend upon the uptake by these collectives. None more-so than a large step change in what may be historical culture where "we've always done it this way". Although small refinements can make improvements, sometimes a new way of approaching a problem can completely revolutionise a business as a whole or even just a small sub-part of it. Therefore a major aspect of adoption should be the end-users.

Adoption of digital twins requires at least a review of: the output that they require, the granularity of the information and how multiple users all access the information. The output desires particular attention to avoid implementation for implementations sake. For example, implementing a system to notify someone to adjust a system rather than implementation of the systems to communicate together puts extra stress on the user.

However adoption should not just be considered from the bottom up, it also requires senior buy in for the approval of budgets, strategy, business direction etc. Due to the typical shift change associated with connectivity of digital twins, often business practices undergo a step change rather than incremental adjustments. Although decisions of this magnitude are high risk, several mapping techniques are available to breakdown the individual aspects such as TRL/MRL. This is typically considered standard for the embracement of new technology such as sensors, software platforms, systems across their whole lifecycle.

5.3 Design and Architecture

As with many advancements driven by new technology, the implementation and design are primarily driven by fundamental IT systems and technology. Having a solid backbone of IT systems is essential to deriving value without impacting the overall business. Considering that IT requirements are not fixed, and that use cases change, technology advances, and systems become obsolete, planning for these ongoing and growing demands is a vital step in the design and implementation of new technology.

By looking at existing systems, standards and best practice examples, it is possible to reduce the difficulty in design and implementation of a digital twin system. By implementing what has been proven, learning from the mistakes of others, and looking towards the future of data capture, processing and dissemination, it is possible to reduce the costs and complexity of digital twins, not just in the short term, but in the long term as well.

Many individual components that are required to enable digital twins already have active standards and as such it is recommended to use this wherever possible. Standards such as ISO 143206, is used to define 3D product definition data that is common across many industrial sectors. This will enable the value across lifecycles and supply chains to be maximised with the most compatibility possible.

Technologies such as the Building Information Modelling (BIM) are rapidly advancing within ISO 19650 as the international standard for managing information over the whole life cycle of a built asset. Standards such as these ensure that good practice can be readily adapted across all sectors. More generally the Reference Architectural Model Industries (RAMI) 4.0 defines the service-oriented architecture and supporting standards required and being implemented by Industry 4.0.

A major issue in developing IoT data capture systems is around data security. Designing security into the system from the concept through to delivery should be an integral part of any complex system such as a digital twin strategy.

Planning for implementation, growth and maintenance is another vital stage of the design. By creating a system which is accessible, easily maintained, and agile to future developments is essential to reducing ongoing costs and extracting maximum return on the investment.

5.4 Think long term

Implementing a digital twin is not a single implementation. Systems need to be updated as the processes and technology advance. By considering the nature of change at the concept phase, the flexibility and growth of the system can be designed in. A digital twin implementation is not an isolated phenomenon, and can be scaled, adapted and distributed.

It is possible to extract further value from your data and digital twins through augmentation, expansion and distribution. By incorporating the data and digital twins of up and down stream, processes can be improved with clear visibility of the benefits.

The University Of Sheffield. / AMRC Advanced Manufacturing Research Centre

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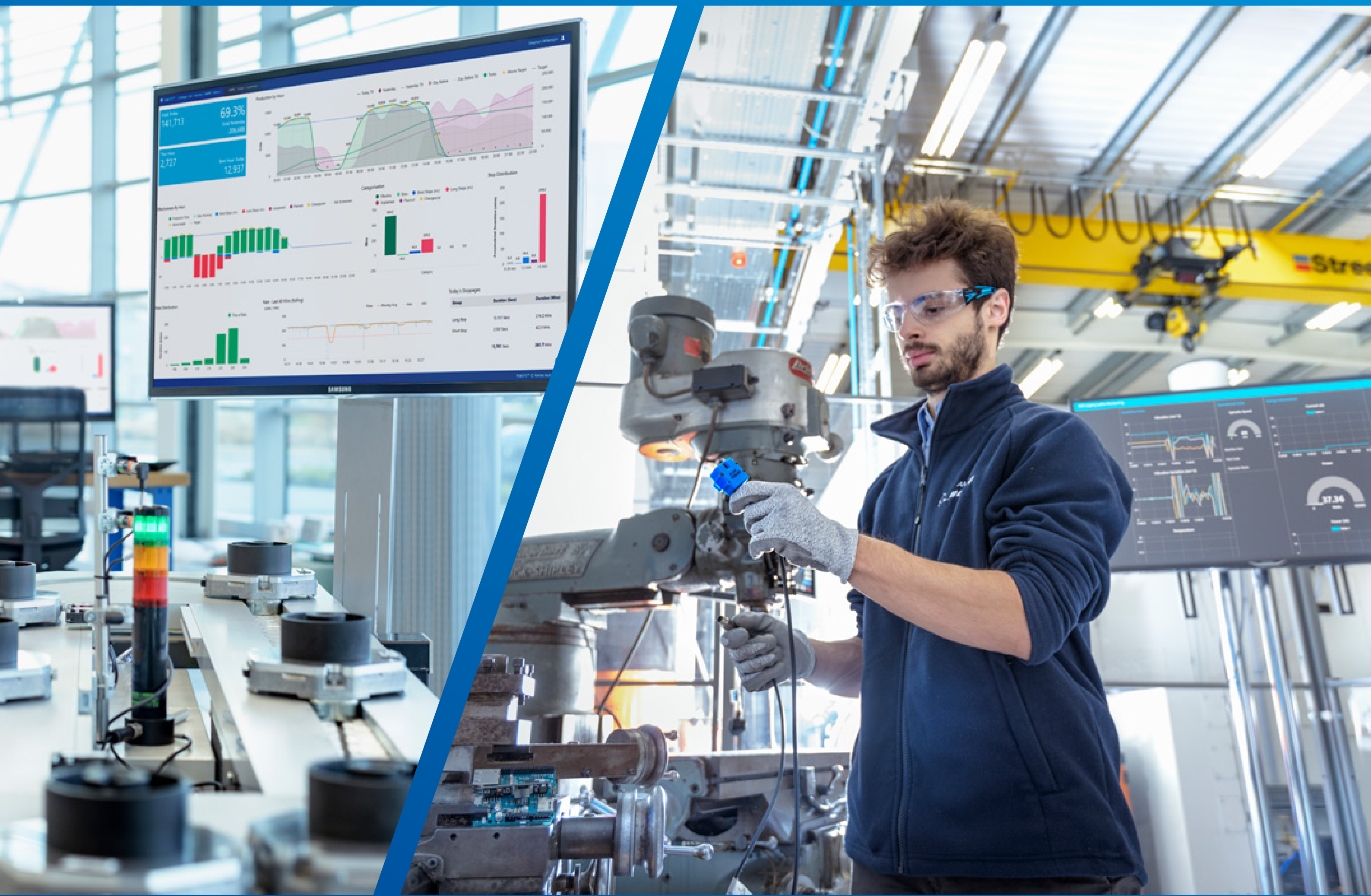

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