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DPLA
DIGITAL PLATFORM FOR LEAKAGE ANALYTICS

Demystifying Digital Twins

Emerging Technologies Quarterly Review: February – April 2024

Agenda

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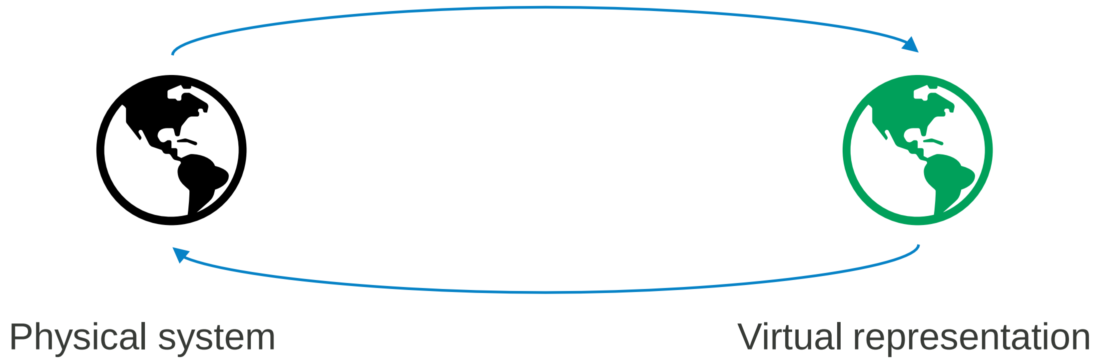
1.
Executive summary

Executive summary

Digitals twins (DT) are virtual models of real-world systems or objects. Their potential to improve monitoring and analysis of systems as well as simulate their behaviour under numerous scenarios is an exciting prospect for many applications.

The concept has developed since the 1970s but recent advances in sensor and analysis capabilities are enabling large scale digital twins to become a reality.

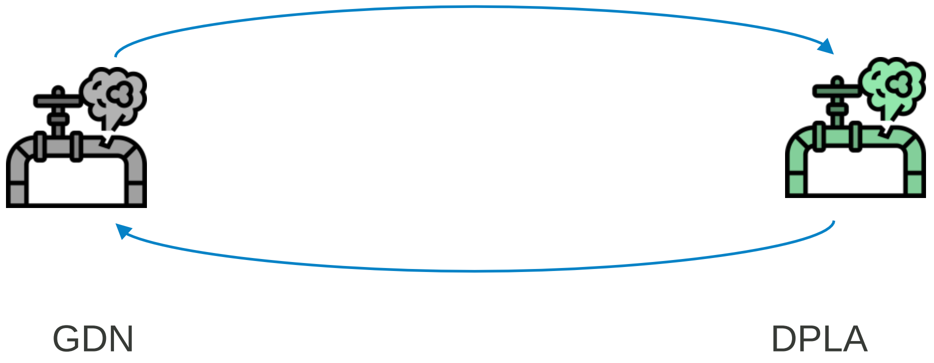
Despite their promise and popularity there are challenges to be overcome to implement the technology for new applications and optimise its benefits.



The goal of **DPLA** (Digital Platform for Leakage Analytics) is to create a virtual representation of Gas Distribution Networks (GDNs) which can detect the occurrence of leaks to **inform network maintenance and reduce emissions.**

This will involve combining operational data with advanced modelling approaches and novel sensor technologies to effectively detect leaks across the network.

The DPLA concept and implementation are intrinsically linked to DT technology with the **ambition to produce DTs of the UK GDNs.**



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2.

Introduction and background

History and development of digital twins

Digital twins (DTs) have a long and rich history where the concept, capabilities and accessibility have developed alongside technological advances. Currently, an estimated 75% of enterprises have adopted DT technology in some form, but there are still multiple opportunities for development and integration.

1970
NASA replicated the Apollo 13 spacecraft to train for and ultimately save the mission.

1990s
NASA continued to replicate Mars rovers to plan and adapt maneuvers on the surface of Mars from Earth.

2002
Dr Michael Grieves officially defined DTs in the domain of Product Lifecycle Management (PLM).

2000s
Advances in sensor technologies and real-time data integration enabled DTs to represent the current state of physical systems.

2010s
Advances in tools for simulation and analysis allowed DTs to effectively predict future scenarios.

2021
The global DT market was valued at $6.5 billion and expected to reach $125.7 billion in 2030.

Many attempts have been made to define the term ‘digital twin’ resulting in a range of definitions

With the rapid development and promise of DT technology, the term ‘digital twin’ became a buzzword with varying definitions across industries and many common misconceptions.

A **digital twin** is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity. – digital twin consortium (2020)

A **digital twin** is a virtual representation of an object or system designed to reflect a physical object accurately. It spans the object's lifecycle, is updated from real-time data and uses simulation, machine learning and reasoning to help make decisions. – IBM

A **digital twin** is a virtual model of an object, a system, or a process. It is connected to its real-world counterpart by a 2-way flow of right-time data, meaning it mimics it in all aspects. – NDTP

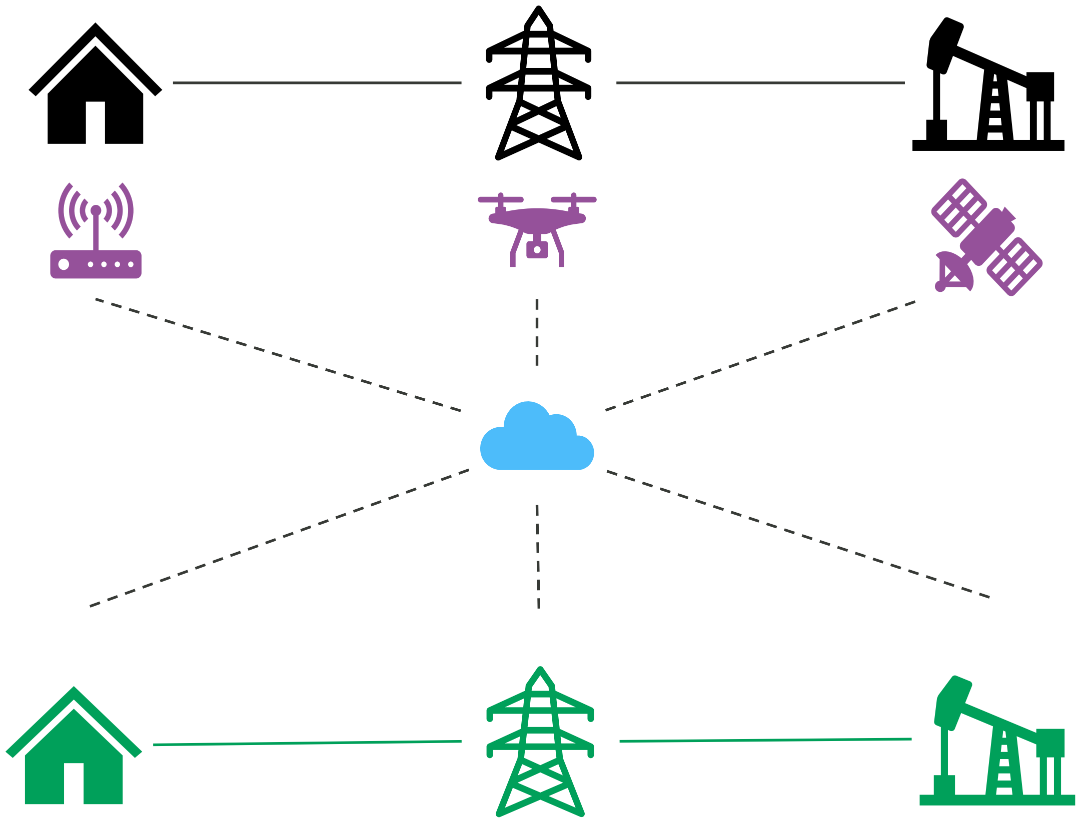
A **digital twin** is a virtual model of a physical object. It spans the object's lifecycle and uses real-time data sent from sensors on the object to simulate the behavior and monitor operations. – AWS

Digital twins provide virtual environments that mirror real world systems

Real-world system. This can vary in scale, but the parameters need to be defined.

Data feed. Representative data is collected from the real-world system, fed into the virtual representation and analysed to provide insights back to the real-world system

Virtual representation. The real-world data is used, in combination with some form of simulation and analytics, to provide a virtual representation of the real system.



Digital twins can improve operational efficiency, monitoring and decision-making capabilities with benefits to multiple stakeholders

Coupled with advanced AI/ML & User Environments, a Digital Twin is capable of…

Situational awareness
Establishing a highly detailed and accurate "common operating picture" of the physical twin in real-time

Understanding complex problems
Asking and answering questions (e.g. what, how, why, what if, etc.) about complex problems concerning objects/structures, processes, systems and people

Performing sophisticated analyses
Enabling real-time, historical and predictive analysis on a complex system

Generating insight
Generating new insights into the structure and function of objects/structures, processes, systems and people

Instilling trust
Establishing trust in the outputs through generating justifications and explanations understandable by users

Digital twins can vary in scope and scale so can be broken down into four types with increasing complexity

Component

Component twins are the basic units of digital twins. They represent a single but essential piece of a system. For example, a motor within a wind turbine.

Asset

Asset twins are made up of two or more components that work together. The interaction of the different components is virtually represented to produce performance data which can be analysed and used to inform decisions. For example, a wind turbine.

System

System twins represent how different assets work together and form a functioning system. The insights provided by system twins enable performance enhancements or improvements in efficiency. For example, a wind farm.

Process

Process twins show how systems work together and how the outputs of one system impact another. Originally developed to digitally reproduce an entire manufacturing facility, process twins could be used to model the interaction between multiple energy assets e.g. wind and solar farms.

A range of different technologies are essential to create digital twins

Sensors

Sensors are a crucial component of DTs as they **collect data** relating to different aspects of the system such as the **environment or performance**. This real-time data is essential for monitoring and providing an accurate representation of the real-world system.

The development of **advanced sensor technologies**, as well as the increase in their availability and affordability, has been a **key enabler** in the implementation of DTs.

Internet of Things

Although sensors are an instrumental part of DT technology, the **Internet of Things (IoT)** enables the **data** collected by various types of sensors to be **continuously streamed** in real-time and input into DTs.

IoT technology is **rapidly developing** and becoming more accessible across different industries, creating further opportunities for implementing DTs.

Software

Software is essential for DTs to take in and **analyse data** collected by the sensor networks, using it to **simulate the behaviour** of the physical counterpart.

Software can extend from traditional data analysis and simulation models to **machine learning** approaches. The development in this field is greatly increasing the capabilities of DTs.

Despite their promise as a transformative technology, the implementation and operation of digital twins comes with certain challenges

1. Technical and operational issues

Implementing and maintaining DTs requires robust IT infrastructure to handle the intake, analysis and storage of large quantities of data. Specialist knowledge is required for this implementation but also for the design and development of DTs. Therefore, SMEs with a range of expertise need to effectively collaborate. This infrastructure also requires large amounts of energy which increases the environmental impact of large-scale DTs.

2. Expectations vs. reality

Due to the buzzword status and promise of DT technology the realistic capabilities of implementations may fall short of expectations. The development of representative DTs, and their ability to provide insights, is heavily reliant on the quality of the data available. Unexpected variables in the physical system, i.e. ones that aren’t considered or measured, can also lead to reduced performance.

3. Complexity of implementation

As well as being challenging from a technological perspective, DT implementation has logistical complexities. Integrating DTs with existing systems can be difficult, especially since interoperability standards may not be fully developed and the insights may have broader implications, such as regulatory. Data security and privacy is also a key consideration as sensitive data must be protected from data breaches.

Recent technological development has the potential to impact the future of digital twins

Augmented and virtual reality

Integrating DTs with **AR** or **VR** technologies could enable stakeholders to interact with the digital environments in a more **immersive** and **meaningful** way. Engineers can train or practice operations in realistic scenarios that react in real-time. Decision makers can gain a more in depth understanding of data and potential outcomes of decisions.

In future, the integration of AR and VR with DTs will allow for **remote collaboration** through shared VR environments as DTs become part of the **metaverse**.

Artificial intelligence

The integration of **AI and ML** analytics into DTs enhances their **predictive capabilities**. Currently ML models are trained on a variety of scenarios and data defined by human practitioners. **Generative AI** has the potential to transform this process using large multi-tasking models which take in all data sources together to generate insights.

The potential of generative AI extends to providing chat bots which can assist in-field operations and respond to queries related to the system of the DT.

Cloud computing

DTs are reliant on large amounts of high-quality data and the processing power to analyse it. **Cloud storage** and **high-performance computing** allows data to be stored and processed in a **scalable** and **cost-effective** manner. Storing DTs in the cloud enables seamless integration with IoT devices for real-time data streaming and analytics.

Alongside these technical advantages, cloud-based DTs enable **collaboration** and pave the way for **interoperability** between DTs.

The implementation of digital twins has increased over recent years and now spans multiple sectors

Engineering and Manufacturing

Manufacturing and product lifecycle management are the original applications for DTs. Therefore, it is unsurprising that DTs in these areas are advanced. Unilever have DTs of multiple factories to improve operations, for example.

On the engineering side, projects such as the Turing Institute's Bridge Brother can be used to design and build innovative infrastructure.

Healthcare

The concept of personalised medicine has sparked the development of DTs in healthcare. The idea is that if a virtual model of a patient can be constructed then the results of different treatment scenarios can be predicted.
ELEM BioTech are developing this technology and currently have virtual models for cardiovascular and respiratory systems.

Energy and Infrastructure

There are many potential applications for DTs in energy ranging from predictive maintenance on individual assets to full scale grid modelling. General Electric currently use their Digital Wind Farm to optimise energy generation.

DTs are widely used in infrastructure to create smart cities. The Virtual Singapore Platform uses DTs of their city-state for urban planning.

Climate Change

DTs taking in weather and climate data can be used to predict the impacts of different emissions pathways and inform policy decisions.
Destination Earth is an initiative run by the European Commission aiming to build a full DT of the Earth by 2030. They are aiming to be able to simulate the physical and socioeconomic impacts of extreme weather events by mid 2024.

Biodiversity

Similarly to climate, the impacts of various interventions or emissions scenarios on biodiversity and ecosystems could be simulated using a DT.
Building a DT for this application is the focus of BioDT. BioDT is building several prototype DTs, with a range of partners involved, to model species interactions with humans, each other and how they may respond to environmental change.

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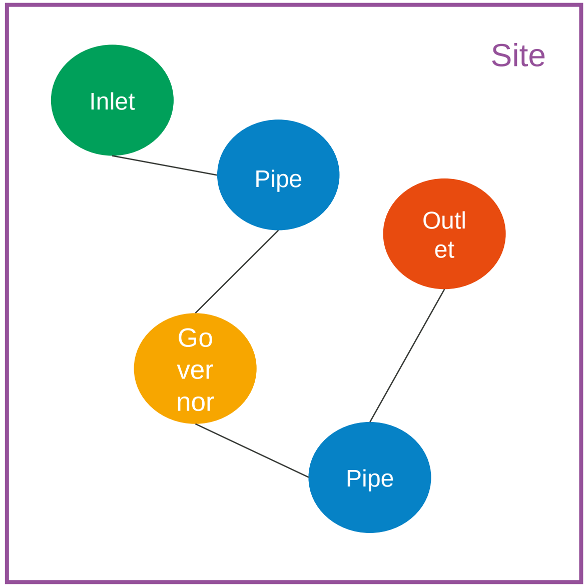
How digital twins relate to the DPLA

The DPLA project is developing building blocks for a full gas distribution network (GDN) DT from the asset level upwards

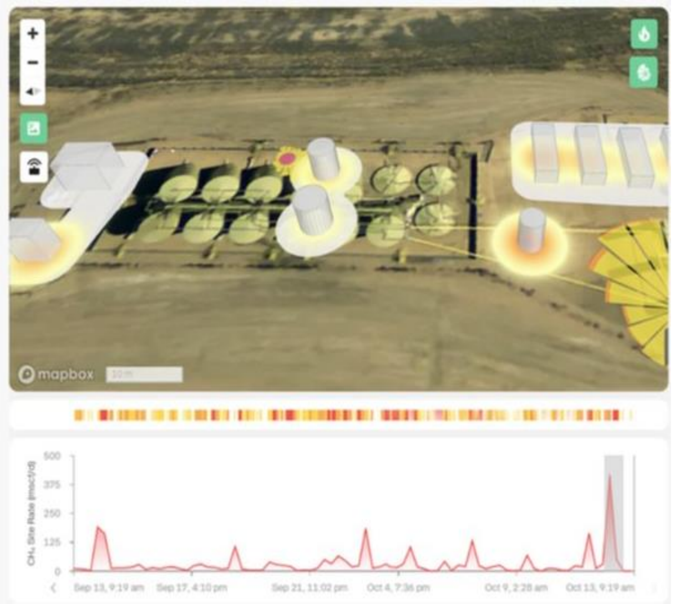
Network data relating to the layout and attributes of assets within a given site (e.g. an above ground installation) is being used to construct virtual site representations. The **operational data** (e.g. pressure, flow) is linked to these site representations to construct asset-level digital models of each site across the network at historical operating states.

IoT technologies (QUBE and Sensirion) to continuously monitor sites for leaks are being installed across a selection of trial sites. For the calculation of leak rates these technologies create a virtual representation of the site then pinpoint and quantify leaks in real time.

For the virtual site representations, the network data is converted into a **graph format** where nodes contain asset information, and edges represent connections.



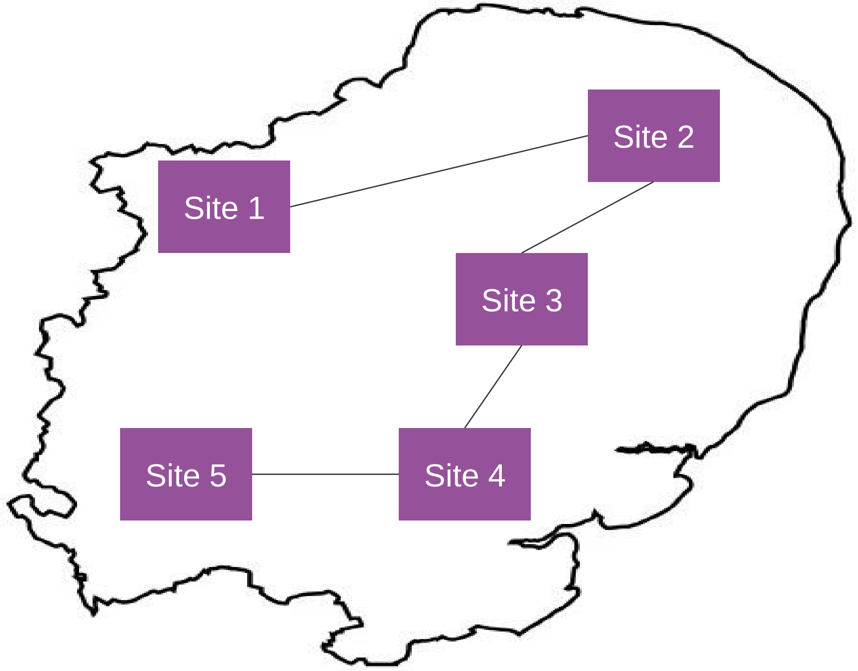
Real time site monitoring using **QUBE IoT** devices is displayed in their dashboard.



A virtual representation of the full GDN is constructed by linking the site representations

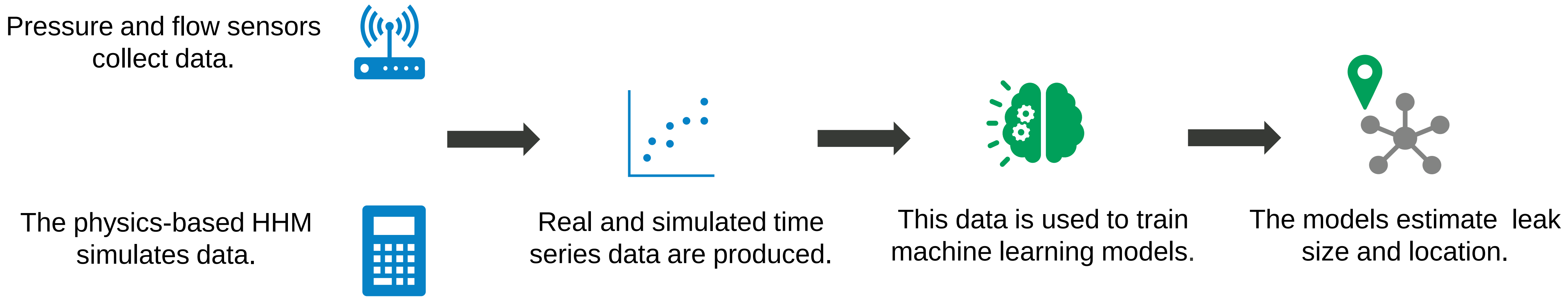
The virtual representation of the GDN forms the simulation environment for the **hybrid hydraulic model (HHM).** The HHM combines traditional hydraulic modelling with **machine learning** models and **operational data** to correct the parameters to more accurately reflect the real state of the network. The HHM allows the operating state (pressure, flow and temperature of gas) of the network to be simulated at any time and under any conditions.

The network level graph data structures are constructed by linking to the site level structures to provide the virtual representation of the GDN or Local Distribution Zone e.g. East Anglia.



Operational data and simulated data from the HHM will be used to train machine learning models to perform leakage analytics

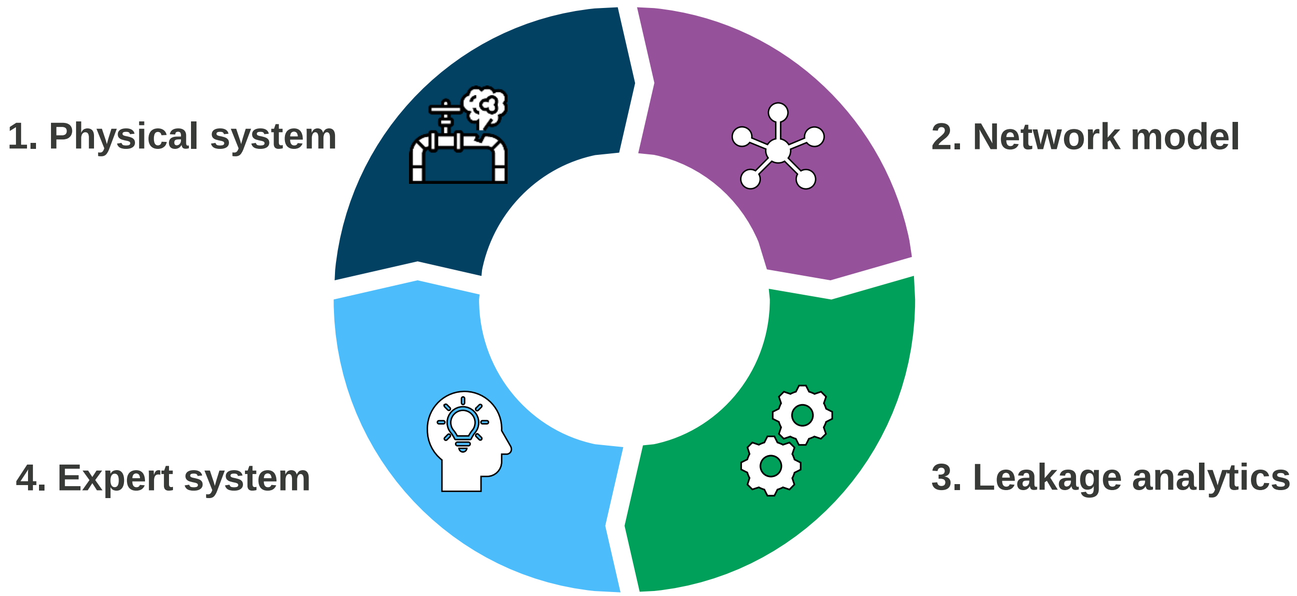
Pressure and flow sensors, installed for network monitoring, collect time series data at various points across the network. The HHM can be used to create synthetic time series data for pressure and flow. These datasets will be used both individually and in combination to train various ML models to detect, localise and quantify leaks across the network.



Leakage intelligence provided by the expert system will be fed back to the physical system to inform repairs, maintenance and reporting

Once the machine learning models have been developed and tested across the network we will build the **expert system**. The expert system will be a different form of model (which may include knowledge or rule-based reasoning and reinforcement learning) which takes the leakage predictions from the ML models and sensor technologies and combines them to give an **overall estimate for leakage**.

The outputs and insights provided from the expert system will then feed back to the physical system, completing the link between the virtual and physical systems.



The future development of DPLA will involve continually improving the models and adapting to changing conditions

Analytics development

Following the initial model development phase, the machine learning models will continue to be refined to increase prediction capabilities and create the opportunity for predictive maintenance.

Interoperability

The DPLA, and GDNs in general, represent a component of a larger system (i.e. the UK energy system). To optimise DTs, it is crucial that they can be used in conjunction with other DTs to model how different components of the system work together.

Frameworks for DT interoperability are currently being developed (e.g. Virtual Energy System, National Digital Twin Programme) and this will be a key consideration in the development of the DPLA.

Hydrogen

In efforts to reduce greenhouse gas emissions, alternative energy sources to natural gas (such as hydrogen) are being investigated. If assets are repurposed to transport hydrogen or a gas blend, the DPLA can be adapted to reflect this by altering the parameters used to drive the hydraulic model.

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Conclusion

There is still potential to be unlocked with digital twins, including many opportunities in the energy sector

The future of digital twins

With the development of new technologies and increased computing power, the opportunities for DTs are increasing.

In the **energy sector**, they have the potential to not only reduce methane leakage across gas networks, but to **optimise the entire energy system and inform the energy transition**.

Challenges to overcome

Although the future of DTs is bright, there are challenges to achieving their full potential.

To model full systems, DTs must be **interoperable** within a common framework, and with an increase in **data sharing** and **collaboration**.

The storage of large quantities of data and models introduces challenges both for ensuring **data security** and **sustainability**.

Is DPLA a digital twin?

The goal of the **DPLA** is to **revolutionise** the **leakage and shrinkage** model, a key component of which is the production of **DTs of the GDNs** across the UK.

Users will be able to interact with the tool to **visualise leaks, informing network maintenance and planning**.

This could be developed to **predict future leaks** or simulate operating network states with **different gas blends**.

Q&A

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