Department for Transport

FS38

Infrastructure Digital Twin Data Requirements for Whole Life Efficiency and Resilience

September 2025

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Introduction

Introduction

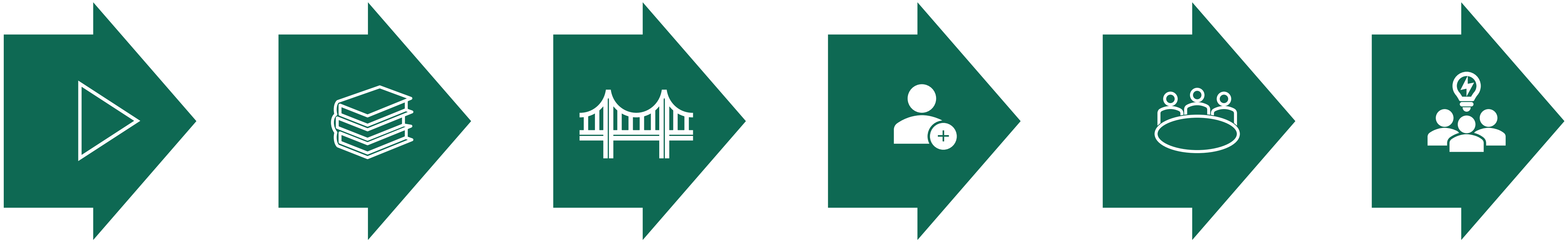
Background

This project focused on how whole life efficiency and resilience of infrastructure assets can be improved using digital twin technology.

The UK has a substantial number of infrastructure assets that face various risks, including aging, climate change, and other factors that affect their ability to function and their resilience.

Linked to these risks is uncertainty about the context shaping society and changing use of infrastructure systems and the availability of funding to commit that demands increased efficiency of assets.

The research used Futures methods alongside technical expertise following the process below to develop recommendations;



Inception

Definition of project expectations setting out this research methodology.

Literature review

A selective consideration of what insights of relevance already exist within published sources.

Asset and risk selection

Definition of a range of transport infrastructure assets and key risks to steer the research into data requirements.

Workshops

Two workshops with key stakeholders intended to explore uncertainty and risks and reveal key data requirements.

Interviews

Four conversations with experts associated with specific asset types for further consideration of digital twin prospects.

Conclusions

Presentation of key data requirements for digital twins of built infrastructure assets and challenges to implementation.

Introduction

Project objectives

The project identified the **key information requirements** for digital twins for built infrastructure by considering key **risks** to the resilience and maintenance of infrastructure, and what data can be used for mitigation.

The results provide a pathway to improving lifetime performance and resilience of infrastructure assets, to enable feedback loops for better design, and deliver efficiencies between Design & Build and Operate & Maintain using digital twins.

The project:

- Proposed a set of key **information requirements** for digital twins of built infrastructure.
- Explored how DTs may be **future proofed** against risks and uncertainties.

This project focused on the following questions…

Q1	What **work is being undertaken elsewhere** to improve the whole life efficiency and resilience of infrastructure by increasing the uptake of Digital Twin technology?
Q2	What **principles** should we use to guide and assure our approach to data collection?
Q3	What **information/data should be sourced** and included within the Digital Twin of a built asset for these resilience and lifecycle scenarios?
Q4	Which **resilience scenarios** are relevant to this work and should be considered for the future data needs?
Q4	What **issues/risks** (i.e., data sensitivity and liability) would be created or increased significantly by the implementation of the data requirements above?

Introduction

Project governance

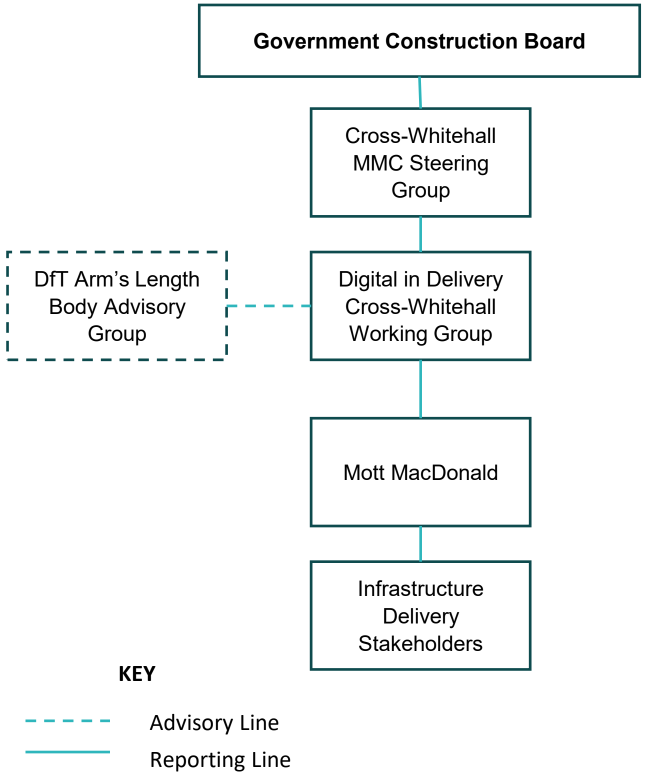
The project was led by the Department for Transport on behalf of the Cross-Whitehall Modern Methods of Construction (MMC) Steering Group under the Government Construction Board.

The MMC Steering Group endorsed an outline proposal to explore whole-life efficiencies of assets using digital twins In February 2024 and in June 2024 the Digital in Delivery Cross Whitehall Working Group (a sub-group of the MMC Steering Group) approved a detailed proposal.

The Department for Transport project team formed an Arm's Length Body Advisory Group (East West Rail, HS2, National Highways, Transport for London, Network Rail) to provide feedback on the proposal and the final report.

The work has been undertaken by Mott MacDonald and its partners as part of the 'futures support' provided to the Department for Transport by this consortium.

The final report was also been reviewed by the Transport Research and Innovation Board (TRIB) Infrastructure Working Group and the Infrastructure Delivery Stakeholders who attended the workshops.



Literature review

Literature review

The review of existing literature revealed the following key concepts

Infrastructure

- Infrastructure is a **complex network of interconnected systems** that we rely on for essential services, such as transportation, energy, water, and communication.
- To ensure infrastructure operates efficiently throughout its lifecycle, it must be **sustainable, secure, and resilient**.
- Embracing digitalisation, through integrating digital assets, such as data and algorithms, into physical infrastructure are key to maintaining its **long-term effectiveness and adaptability.**

Resilience

Resilience is “the property of a system to absorb, adapt to, or quickly recover from disruptive events”. The National Infrastructure Commission (NIC) has developed a **five-point framework**:

- Anticipate and be prepared;
- Resist shocks and stresses to prevent impact;
- absorb shocks and stresses to minimise impact;
- Recover through actions to quickly restore expected levels of service; and
- Adapt the infrastructure to be better prepared for the next time

Literature review

The literature has revealed the following key considerations regarding Information requirements.

Identify decisions that require information

- Information requirements stem from the decision-making required to meet organisational objectives.
- In turn, decisions are identified and consideration is given to whether sufficient understanding is in place for information requirement capture.
- Cook (2021) sets out a high-level methodology for identifying decisions that require information. This begins with developing a lifecycle activity model, followed by identifying associated relevant participants and the activities they face.

Understand types of and relationships between information requirements

- Information requirements can be categorised in a hierarchical way (ISO19650) with clarity over coverage and focus and interdependencies identified.
- Understanding the standardised view of information requirements, their different levels, and relationships between them is essential to enable an organised and structured method of capturing the information requirements, and ensure establishing a clear connection between strategic goals and the information collected and fed into a digital twin.

Identify information requirements

- Johnson et al (2022) tested a methodology to identify appropriate, relevant and effective Asset Information Requirements (AIRs).
- This methodology offers a systematic, robust way to link high-level organisational objectives to Critical Success Factors, Plain Language Questions, and finally, Information Requirements, with evidence trail.
- Such an approach needs to involve careful mapping of the real-world system - whether physical, social, economic, or a combination - by identifying its components, key variables, and boundaries.

Use systems thinking

- Understanding an asset as part of a system helps identify “key drivers and variables that determine asset behaviour in a given context (e.g. a flood event)”.
- It also helps capture interdependencies between parts of the system parts and the changes in the outer environment that can impact the system’s behaviour.
- Systems thinking also relates to the value of creating a timeline of the value of data across asset lifecycle, identifying who gets value where and when (see ISO 19650), and understanding the responsibilities of each stakeholder group at every stage.

Understand types of and relationships between information requirements

- Improving asset inventory data and it’s quality enables improved risk assessment. It is important to identify and categorise asset datasets (see ISO 7872: 2022) in relation to intelligent transport systems where four layers of information are identified; static, semi-static, semi-dynamic and dynamic
- See also ISO 37166: 2022 for examples of community infrastructure data, with suggested system-based method of categorisation, along with typical sources.

Specifications of information requirements

- Metadata allows users to assess the quality, source, and relevance of the information, enabling more informed decision-making and facilitating the integration of data across different systems and stakeholders.
- This can include requirement owner, requirement description, level of information need, acceptance criteria for information provided, supporting information for production of the information, and information exchange date.

Literature Review Methodology

An examination of some existing literature was undertaken understand the key considerations and challenge recognised within the field of asset management and digital twins, and to identify some case study examples of relevance

Literature Search

Definition of scope → **Keyword selection** → **Search execution**

- **Definition of scope**: Review Questions were formulated to explore key themes related to digital twins, infrastructure resilience, and lifecycle efficiency.
- **Keyword selection**: A set of relevant keywords was identified and used to retrieve results from Google Scholar and various search engines.
- **Search execution**: The search was conducted using the selected keywords, resulting in a comprehensive collection of documents that addressed the research questions.

Screening & Selection

Eligibility Criteria → **Known and Nominated Documents** → **Matrix Creation** → **Long List Creation**

- **Eligibility Criteria**: Retrieved studies were screened by reviewing titles and abstracts to assess relevance to the research questions.
- **Known and Nominated Documents**: Some of the selected documents were already known to the project team, while others were nominated by DfT based on their relevance.
- **Matrix Creation**: A matrix was developed to capture the initial review and screening results
- **Long List Creation**: A long list of 61 documents was created, representing a diverse set of sources that potentially addressed the key themes of the literature review.

Document Review and Prioritisation

Priority List Development → **DfT Review** → **Revised Priority List**

- **Priority List Development**: A list of 15 priority documents was created, ensuring it covered the various key questions and themes identified in the project.
- **DfT Review**: The proposed priority list was shared with DfT for review, ensuring alignment with project objectives.
- **Revised Priority List**: Following DfT's feedback, the priority list was revised to incorporate comments and recommendations.

Thorough Analysis of Selected Documents

Extracting Knowledge and Insights → **Priority List Development** → **Collaborative Analysis** → **Documentation of Outcomes**

- **Extracting Knowledge and Insights**: The 15 documents in the final priority list underwent a thorough analysis, focusing on extracting insights and answers to the research questions.
- **Priority List Development**: The analysis was guided by the open-ended "Review Questions".
- **Collaborative Analysis**: The analysis results were captured on a digital Mural board, facilitating a collaborative approach among the project team members.
- **Documentation of Outcomes**: The final outcomes of the analysis were documented, capturing the key findings and synthesised outputs derived from the literature review.

Literature review

The review of existing literature revealed the following key concepts

What is a Digital Twin?

The HMG National Digital Twin Programme defines a digital twin as the following…

*“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. This helps us test decisions before we make them and understand how different actions might affect the real world. However, it is essential that at all times, the real-world counterpart is able to continue to operate safely and securely without its digital twin”*

Such a ‘cyber-physical’ system enables simulation, visualisation and analysis and in turn collaboration (between stakeholders and within the supply chain) and optimisation that can improve decision making and unlock value.

What are Methods of Construction?

The cabinet Office has defined Modern Methods of Construction (MMC) as…

“a wide term, covering a range of offsite and onsite techniques. MMC provides alternatives to traditional methods and has the potential to deliver significant improvements in productivity, efficiency and quality for both the construction industry and public sector.

A joint government and industry working group have refined the term in the MMC Definition Framework to the following categories of Pre-Manufacturing (3D primary structural systems, 2D primary structural systems, Non systemised structural components, Additive Manufacturing, and Non-structural assemblies and sub-assemblies) and construction phase (Traditional building product led site labour reduction and productivity improvements and site process led labour reduction and productivity improvements)

Information-driven decision making

Ensure that the right information is available at the right time, to the right people and that the quality of the information is known and understood.

This involves understanding different types of information requirements and the relationships between them. It also involves defining the meta-data needed.

Systems thinking

It is necessary to recognise that infrastructure is considered as part of a system of systems and to manage it with a focus on the inter-dependencies between sectors.

Information requirements must account for the evolving global landscape-which will influence the capacity to prepare for and respond to risks.

Whole lifecycle view

A whole lifecycle perspective is crucial, where “each stage involves specific activities and information needs"

Outcomes focused

A people- and outcome-focused perspective is vital, “to ensure that data from assets and systems in the built environment is used to create value for the public good.”

Resilience framework

The National Infrastructure Commission resilience framework is a key text for identifying specific data and information * requirements.

** During the work reference has variously been made to information and data requirements. The distinction is more than semantic when following a sequence from data to information to knowledge to decision-making applying that knowledge. However, for the purposes of this project, attention is focused upon high-level requirements and as such data and information can be considered synonymous.*

Literature review

The literature review revealed key international case studies that demonstrate how digital twin technology can improve asset management and resilience.

Connected Places Catapult
Climate Resilience Demonstrator (CReDo)

“a pioneering project to develop, a digital twin across key services networks to provide a practical example of how connected-data and greater access to the right information can improve climate adaptation and resilience”.

Norway
Establishing ‘model-based’ requirements incentivises collaboration and innovation

Every discipline working simultaneously from a single 3D-model on the same common data environment has achieved the desired outcome of developing a culture of collaboration and unity.

New Zealand
the business case for improving resilience

The New Zealand Transport Agency has developed a methodology to build a compelling business case for enhancing resilience or creating a DT to improve resilience.

Canada
longer time-scale resilience planning

The Samuel De Champlain Bridge Corridor Project in Canada highlights the importance of long-term resilience planning for infrastructure, recognising that as timescales increase, the range of potential hazards and uncertainties amplifies.

Sweden
Multi-purpose value of a digital twin, and associated changes to operations

The case study of Virtual Gothenburg illustrates how a digital twin with the same underlying data and information can serve multiple purposes and deliver value to a range of stakeholders.

New Zealand enhancing asset lifecycle efficiency with purpose-driven digital twins

By gathering detailed, accurate data on road conditions, traffic, and environmental factors, the digital twin supports informed decisions at the right time, ensuring cost-effective asset management.

Literature review

The literature review has revealed further challenges to resilience and adaptation.

The *Delivering a Resilient Transport Network* report (2024) from the Chartered Institution of Highways and Transportation highlights **barriers to building resilience and adaptation**, which in relation to knowledge and data include: knowledge gaps and poor data integration; data set accessibility; and inadequate access to local weather forecasting models.

The report also points to several indications of the **repair costs associated with extreme weather**, underlining the importance of maintaining and future proofing infrastructure.

Although there is longstanding experience of dealing with physical assets, the same is not the case for dealing with equivalent aspects for digital twins which is an emerging technology. Endeavours like the Government & Industry Interoperability Group (GIIG) focussing on developing practical ways to enable efficient **information management,** can support creating and managing reliable information that will remain findable, accessible, interoperable, and reusable (FAIR). **Properties** have been identified as ones to consider and secure in the context of each piece of information handled by a digital twin.

Threat modelling is an important technique which should also be used to model and analyse a digital twin to better understand how it might be attacked or otherwise fail.

The **National Risk Register (2025)** identifies two primary categories of risks to infrastructure: chronic and acute. **Chronic risks** are long-term and persistent, developing gradually over extended periods while **acute risks** are characterised by their short-term and immediate nature. They often arise suddenly and unexpectedly.

Infrastructure asset type selection

Infrastructure Asset Type Selection

To define data requirements for efficiency and resilience a range of transport infrastructure assets were considered and four key examples selected to steer the research*.

Stage 1

A qualitative examination of the asset types focused on six aspects :

- Service importance
- Operational redundancy
- Exposure to external hazards
- Economic importance
- Social equity and vulnerable populations
- Interconnectedness and systemic importance
- Consideration was also given to prevalence and scale of asset types.

Stage 2

Within the project an initial list of eight transport and non-transport asset types was identified:

- Road with bridge
- Train station with track
- Airport terminal with runway
- Port
- Buried drainage pipework
- Vertiport
- Dam
- Nuclear power station

Stage 3

To arrive at a manageable set of four assets for the project, there were five points of consideration:

- Focusing on transport system assets (acknowledging the expertise at the disposal of those involved in the project);
- The distinction between nodal (a place) and linear (a corridor);
- Relevance to flows of people and flows of goods;
- Maturity of asset design
- Scalability of findings;
- The prevalence of an asset type in the overall system; and
- Importance of the asset in the system; and potential for insights on data requirements to sectors beyond transport.

** Assets examples were selected for the purposes of eliciting information requirements and not intended to represent a government priority list of key assets.*

Infrastructure Asset Type Selection

To define data requirements for efficiency and resilience a range of transport infrastructure assets were considered and four key examples selected to steer the research*. It should be noted that all assets would be understood as built infrastructure assets and can provide insights to sectors beyond transport.

Road with Bridge

Critical for surface transport connectivity for passengers, freight and emergency services, and vulnerable to extreme weather and physical wear.

Train Station with Track

Limited redundancy with potential for knock-on disruption across a network with adverse socio-economic effects, and with vulnerability to malicious attacks.

Airport Terminal with Runway

Critical to tourism, trade and global connectivity, and with vulnerability to extreme weather and little redundancy.

Port

Critical to import/export and supply chains, tourism, supporting economy and national security, and potential for significant loss of trade from closure.

** Assets examples were selected for the purposes of eliciting information requirements and not intended to represent a government priority list of key assets.*

Risks to infrastructure resilience

Risks to Infrastructure resilience

Defining useful data requirements to support resilience decisions requires an understanding of the type of risks infrastructure may experience over their lifespan.

The project recognised risks may be **acute** or **chronic**.

Acute risks arise suddenly and unexpectedly, causing immediate and localised damage.

Chronic risks are long-term and persistent, developing gradually over extended periods.

The research identified a set of **12 key risks** for consideration by stakeholders.

The selection process for choosing these is given on the next slide.

Acute Risks

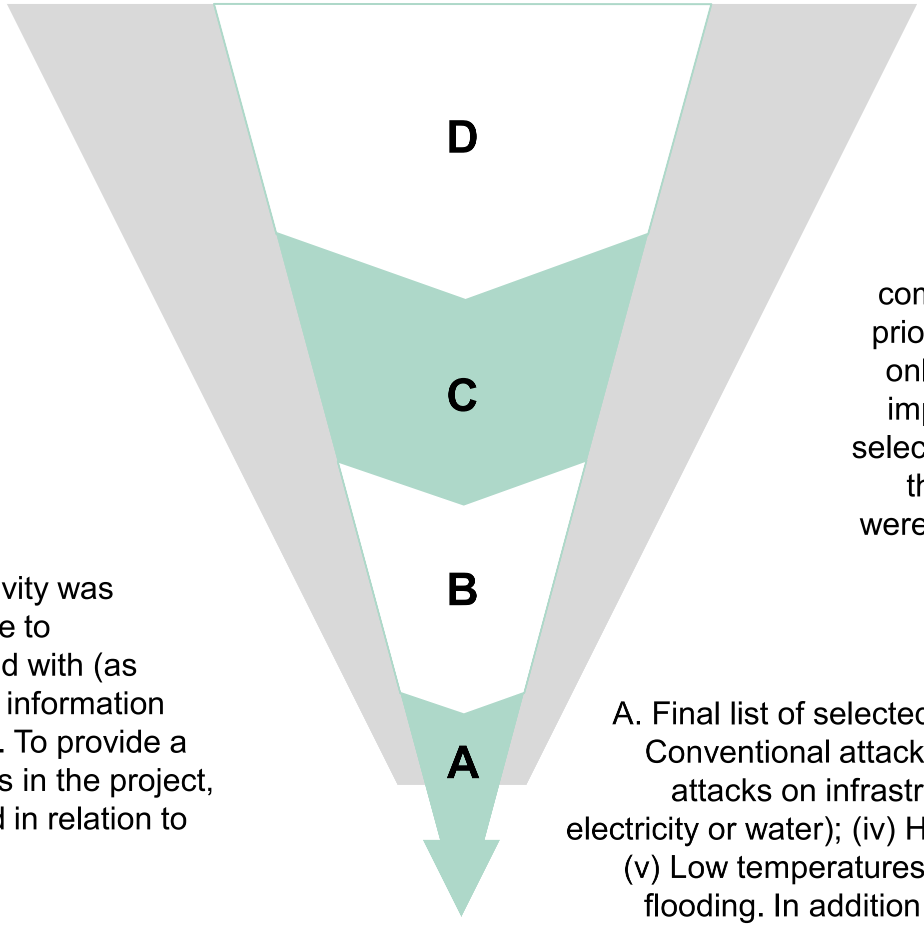
1. Conventional attacks on infrastructure
2. Cyber attacks on infrastructure
3. Failure of utilities (gas, electricity or water)
4. High temperatures and heatwaves
5. Low temperatures and snow
6. Surface water flooding

Chronic Risks

1. Changing nature of cybersecurity threats
2. Dependency on cloud platforms
3. Ageing infrastructure
4. Subsidence events
5. Low investment
6. Dependency on global supply chains

Risks to Infrastructure resilience

Key risks to be considered by the research were selected using the following methodology…



D. The UK's National Risk Register by the Cabinet Office (2023) focuses on **acute risks (2025)**. It lists 63 of these across various categories. The risks are considered in terms of likelihood and impact. For this project, the risks with higher combined impact and likelihood were prioritised. Further **chronic risks** were suggested by DfT based on cross-government expertise and considered in terms of their number and strength of connections with other risks.

C. The acute risks with higher combined impact and likelihood were prioritised. Within a subset of 19 risks only those 12 deemed to have direct impact on infrastructure assets were selected. Risks that were likely to have the same information requirements were rationalised, further reducing this down to a list of **six acute risks**

B. A set of 13 chronic risks with high interconnectivity was considered for this project and based on relevance to infrastructure assets and digital twin capability, and with (as above) rationalising those likely to have the same information requirements, three chronic risks were shortlisted. To provide a balanced representation of acute and chronic risks in the project, three further chronic risks were then also included in relation to infrastructure asset.

A. Final list of selected risks include: **six acute risks**: (i) Conventional attacks on infrastructure; and (ii) Cyber-attacks on infrastructure; (iii) Failure of utilities (gas, electricity or water); (iv) High temperatures and heatwaves; (v) Low temperatures and snow; and (vi) Surface water flooding. In addition to **six chronic risks**:(i) Changing nature of cybersecurity threats; (ii) Dependency on cloud platforms; (iii) Climate change; (iv) Ageing infrastructure; (v) Subsidence events; and (vi) Low investment

Baseline data requirements

Department for Transport

Baseline data requirements

For the four asset types addressed in this project, a **'baseline' data requirements profile was compiled for each asset .** This includes data requirements that would be relevant even before uncertainty and risk is explored further.

Baseline data refers to the essential foundational data of a digital twin, needed to model and operate the asset.

This includes data that represents the

- Asset's physical structure ('asset data'),
- Operational relationships and mechanisms within the system ('asset operational data'),
- Critical interactions between the asset and its external environment ('other data').

To generate the baseline data requirements, a **structured approach** was adopted rooted in systems thinking and purpose-driven analysis

- From a **systems-thinking perspective**, by defining the asset as a system with clear boundaries, this approach ensures a comprehensive understanding of its constituent parts, their interactions, and their environmental context, laying the groundwork for an effective and meaningful digital twin.
- The process was also **purpose-driven**. This informed the identification of relevant baseline data by prioritising information that directly supports decision-making and risk management.
- **Supervised use of AI** to complement human expertise and identify potential data requirements that might not have been initially considered.

Baseline data requirements

Road with Bridge

Asset data – asset information model.*

Operational data – structural health monitoring, maintenance and inspection records, traffic and operational data

Other data – weather forecasts and alerts, hydrological and environmental data, geotechnical data, drainage and water management systems data

Train Station with Track

Asset data – asset information model

Operational data – structural health monitoring, maintenance and inspection records, rail operations data, signalling systems data, track and infrastructure monitoring data, platform and station facilities data

Other data – weather and environmental data, hydrological and environmental data, safety and risk management information, geotechnical data, drainage and water management systems data, electrical systems data

Airport Terminal with Runway

Asset data – asset information model

Operational data – flight information and air traffic control systems, maintenance and inspection records, aircraft operations data, airfield lighting and signalling systems, runway and taxiway condition monitoring, terminal building and passenger safety data, passenger and baggage handling systems

Other data – weather and environmental data, risk and emergency management data, aircraft and passenger safety protocols, geotechnical and ground stability data, drainage and water management systems data, traffic and access control data, fuel storage and supply data

Port

Asset data – asset information model

Operational data – port infrastructure and structural health monitoring, navigation and marine traffic data, cargo handling and storage data, port security and surveillance systems , maintenance and inspection records, maritime and terminal operations data

Other data – weather and environmental data, maritime and safety regulations, tidal and hydrological data, geotechnical and ground stability data, environmental and pollution control, risk and emergency management data, drainage and water management systems data, port access and transportation data, electrical and utility systems monitoring

* According to ISO (2018) 19650, the asset information model (AIM) “supports the strategic and day-to-day asset management processes... It can also provide information at the start of the project delivery process. For example, the AIM can contain equipment registers, cumulative maintenance costs, records of installation and maintenance dates, property ownership details and other details that the appointing party regards as valuable and wishes to manage in a systematic way.”

Stakeholder engagement insights

Identifying stakeholders

Stakeholders were selected who could validate the risks and baseline data then define further requirements

80	DfT assembled an initial list of relevant stakeholder organisations.
38	The initial list was reviewed and shortlisted. This was based on relevant experience and expertise in four critical areas: digital twins; asset management with a focus on resilience and risk; procurement and construction; and digital built environment.
38	Final decisions on selection for participation were made by DfT, accounting for coverage of central and local government, different size companies across the supply chain, and academia

38 participating organisations

1. Autodesk
2. AECOM
3. Amey
4. Arup
5. Athenophilia
6. Atkins
7. Bentley
8. Buro Happold
9. Cambridge Centre for Smart Infrastructure and Construction
10. Cheshire East Highways
11. City Science
12. Colas
13. Connected Places Catapult (CReDO team)
14. Construction Leadership Council
15. Crown Commercial Services
16. Department for Education
17. East West Rail
18. England's Economic Heartland
19. Energy Security
20. Environment Agency
21. Homes England
22. ICG
23. Innovate UK
24. Infrastructure and Projects Authority
25. Kier
26. Ministry of Housing, Communities & Local Government
27. Ministry of Justice
28. Mott MacDonald
29. National Digital Twin Programme
30. Network Rail
31. National Infrastructure Commission
32. National Highways
33. NHS
34. SYSTRA
35. Transport for London
36. Transport Research Laboratory
37. Transport Research Innovation Board Infrastructure Working Group
38. WSP

Stakeholder workshops

90 minute Online on 14 October 2024

This introduced the project and its purpose and allowed participants to be able to offer their initial reactions.

Reviewing the chosen asset types and briefly considering related issues of relevance to data requirements and digital twin support.

Reviewing the 12 selected risks

In-person workshop on 21 October

This consisted of the following elements:

- Exploring possible future contexts for the chosen asset set
- Assessment of Risks
- Data Requirements

60-minute One-to-one interviews

These aimed to sense-check workshop insights on each asset type.

Each interview was semi-structured and intended to cover views on:

- baseline data requirements and further requirement associated with the risks identified earlier
- key considerations facing the asset owner and
- progressing beyond this project to consider a demonstrator of digital twin development in support of whole life efficiency of infrastructure.

Conclusions

Insight from stakeholders

Throughout the engagement activities further challenges to the implementation of digital twins for infrastructure were raised by stakeholders and these are summarised below.

Facing the realities of asset management

The reality in asset management can be that dealing with immediate operational challenges and constraints comes before addressing long-term performance.

Procurement approaches and priorities

Public sector procurement needs to become more programme-driven (whole lifecycle) rather than (only) project-driven. Fostering co-operation and long-term thinking for benefits realisation is challenging.

The complex nature of assets

Complex assets, such as airports, can have multiple stakeholder interests and responsibilities involved and the asset can evolve in form and function over time such that the asset and its digital twin face ongoing change.

A hierarchy of need from a digital twin

The first success from developing a digital twin would be resolving the frustration of 'where is the data?' then attention should turn to the purpose of the digital twin and a prioritisation of data needs.

Older, more complex, more problematic assets

It would be appropriate to consider the most complex version of an asset type that has multiple problem areas and transfer insights to less complex or problematic instances of the same asset type.

Changing digital capabilities and the importance of flexibility in data management

The demands upon and the capabilities of digital technology platforms to manage data continue to change.

Learning from across multiple assets of a given type

For a given asset type there is value in learning from tracking of performance of infrastructure across instances of this asset type to understand common issues and enable more pre-emptive and proactive actions in terms of the maintenance regime.

Taking a system view versus an asset view

There is importance in understanding the purpose of a system as well as the contributing purpose of a given asset and the inter-relation between the two.

Data requirements : Road with bridge

Workshop participants were provided with the 'baseline' data requirements and were asked recommend further data requirements for each asset to mitigate the prioritised risks.

- Data reflective of as-built and as maintained over time **composition and state of the asset**, and **design versus use capacity**
- Data on the **diarised history of developments** of the asset (including assumptions at the design stage (and their error boundaries), installation, refurbishment timelines, defect reporting, changes of use, accidents, alterations and changes of use, sensor uptime and reliability)
- Data on **responsible parties and warranty and insurance** details over asset's service life
- Data that helps in understanding the **asset's criticality** as part of the wider road network (that may in turn inform the relative importance this asset being prioritised for digital twin support in the interests of whole life efficiency)
- Data on the **changing bridge loadings** over time as the makeup of traffic and vehicle types changes, and related stresses, strains, thermal expansion and vibrations (and any indications of buckling or failures)
- Data on **flowing versus standing water**
- Data offering improved **detection of scour** caused by flooding
- Data from climate prediction models for **frequency and severity of future flooding** to pre-plan response interventions (and related business cases)
- Data on **asset's dependencies on power** (e.g. in support of signalling and traffic management)
- Data on **minimum service levels**
- Data on **disabled access**
- Data on **wider organisational approach** to the system in which the asset sits
- Data to populate asset **degradation models** to identify types of damage and urgency of treatment
- Data to **support evacuation plans** when the asset's functionality is disrupted
- Data reflective of **continuous monitoring**, beyond only visual inspections

Data requirements : Train station with track

Workshop participants were provided with the ‘baseline’ data requirements and were asked recommend further data requirements for each asset to mitigate the prioritised risks.

- Data on **asset functionality and usage** patterns (in terms of **how and why** it is used)
- Data on the **wider rail network and impacts** on the station from wider network disruption, as well as data on how station disruption could affect wider network functionality
- Data (linked to the above) that informs understanding of **asset criticality** (as for asset above)
- Data concerning **freight vehicle movements and flows of goods**
- Data on **station and walkway capacity**
- Data that is able to **relate risks to service provision**
- Data concerning **global supply chain** affecting timeliness of available materials for maintenance
- Data on **asset’s dependencies on power** (as above for previous asset)
- Data on **signalling system** operational status

Data requirements: Airport terminal with runway

Workshop participants were provided with the 'baseline' data requirements and were asked recommend further data requirements for each asset to mitigate the prioritised risks.

- Data that reflects a **diarised history of developments associated with the asset**
- Data that reflects an **inventory of key asset stakeholders**, and of **levels of expertise** that underpin use of a digital twin and support of decision making
- Data clarifying the **physical location and boundaries** to the airport
- Data on **asset utilisation and performance** (in the context of a slow to change physical asset and changing demands)
- Data to support **threat modelling** and **anticipatory scenario analysis**
- Data on the **variability of runway** in terms of its structural integrity and exposure to loadings and weather changes
- Data on **infrastructure and vehicles inventory to inform supply chain needs** for repair and renewal
- Data on **flooding and weather** that is both historic and predictive
- Data on **power usage**
- Data to monitor and model **interdependencies between different elements** that constitute the system that is the overall airport terminal with runway
- Data of an **anticipatory nature** to monitor and model for potential cyber attacks

Data requirements: Port

Workshop participants were provided with the 'baseline' data requirements and were asked recommend further data requirements for each asset to mitigate the prioritised risks.

- Data on **historical inspections** covering such things as cargo weights, frequencies of loading and failure incidents (in line with that above for airport)
- Data **monitoring quay walls** to understand loadings and stresses
- Data on **access channels** and **protective infrastructure** (breakwaters)
- Data on **network and communication infrastructure** that allows port to exchange information and coordinate operations efficiently
- Data about **the environment** including tidal flows, weather conditions, and underlying topography data (port depth) to ensure ship dock safety
- Data from **tracking** of port use in terms of vessel and cargo movements (quay asset utilisation)
- Data concerning **communications infrastructure** and **digital system backup** data
- Data on **compliance with health and safety** including relevant legal requirements and standards to inform constraints for modelling
- Data on **utilities**
- Data on **port interface and interactions with the wider system** affecting and affected by inbound and outbound movements
- Data on **facilities, transport links and logistics hubs** to ensure efficient movement of goods from the port to their final destination
- Data for **resilience modelling**
- Data on **tracking and profiling of personnel** at port to ensure security and support prevention of physical attacks and misuse of containers
- Data to support **handling of emergency situations and disaster recovery**

Reflecting questions set at outset of the project

Q1	*What **work is being undertaken** to improve the whole life efficiency and resilience of infrastructure by increasing the uptake of Digital Twin technology?*	Examples such as **CReDo** and case studies drawn from the **OECD infrastructure toolkit** illustrate the possibilities for creating improvement but also the challenging nature of doing so. More case studies demonstrating good practice were found here.
Q2	*What **principles** should we use to guide and assure our approach to data collection?*	Digital twins should have a clear **purpose;** an asset cannot be **considered in isolation from its wider system** and identifying data requirements should consider systems, whole life-cycle approach, future uncertainties, and the outcomes required at each stage.
Q3	*What **information/data should be sourced** and included within the Digital Twin of a built asset for these resilience and lifecycle scenarios?*	The project used **2050 explorative scenarios** to assess risks, asset vulnerability, and data needs for decision-making. While scenarios aid uncertainty exploration, the **process itself is key**. Baseline data challenges highlight the need for an adaptive approach to digital twin development over time.
Q4	*Which **resilience scenarios** are relevant to this work and should be considered for the future data needs?*	The project considered **four different asset types**. Key common baseline areas of data requirements are identifiable across different asset types. Further details on specific data requirements for each asset type were included. The project built upon such requirements to identify considerations and requirements in the context of uncertainty and risk.
Q5	*What **issues/risks** (i.e. data sensitivity and liability) would be created or increased significantly by the implementation of the data requirements above?*	The research revealed a range of issues: (i) insufficient data or inability to access data at the right time; (ii) the quantity of relevant data and effort required to sort it; (iii) managing data ownership and arranging right to access; (iv) how interoperable data would be in its existing state; and (v) user skills and availability of resources to maintain and update data throughout infrastructure lifecycle. Further risks may include a reliance on cloud infrastructure, interoperability dependencies and supplier lock-in, reliance on third-party platforms, and cyber attacks.

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