Delivered for

Department for Transport

Integrated Network Management Digital Twin

Economic Benefits Analysis Project

Summary Report

September 2024

Executive Summary

Integrated Network Management Digital Twin – Economic Benefits Analysis Project

Project Objective

This project has the central objective of quantifying the potential economic benefits of an ecosystem of federated digital twins dedicated to integrated transport network management. This ecosystem of connected integrated transport network management digital twins (IN-DT) could enable data sharing across organisational and sectoral boundaries, facilitating whole-system decision making to achieve better mobility outcomes for transport system users and operators.

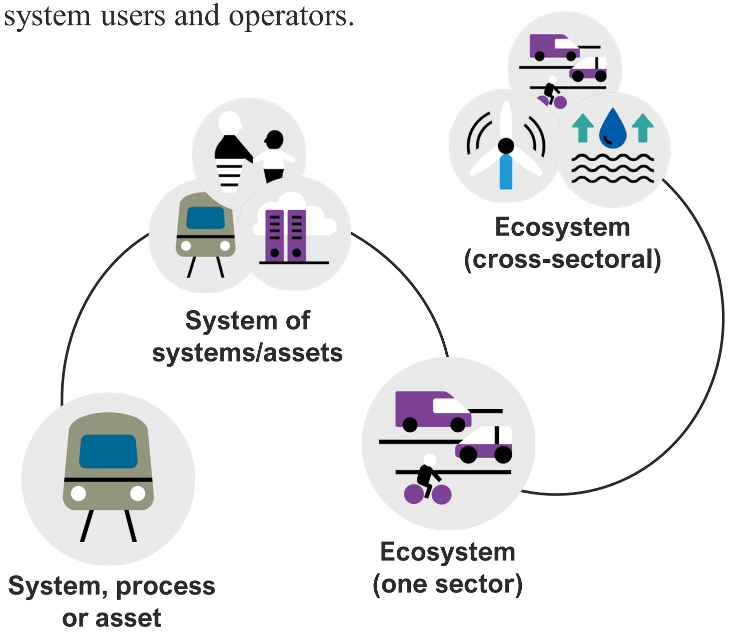

Figure 1: The journey of digital twin interconnectedness

Economic benefit analysis

Over the course of this study thorough stakeholder engagement, literary analysis, and use case identification was completed to inform an Economic Benefits Analysis (EBA) consistent with Transport Analysis Guidance (TAG) from a range of units, including Unit A1-3 "User and Provider Impacts" dated May 2022.

From the body of evidence investigated, a long list of potential IN-DT use cases were identified. A filtering activity was completed to select **five priority use cases** for quantitative analysis. The combined economic value from these five use cases amounts to approximately **£856m as a present value** across a 10-year appraisal period. Quantified benefits for each use case are provided below under core assumptions and as a range from sensitivity analysis.

The key sources of quantified benefits for each use case are as follows:

- *Network capacity management*: reduced congestion under business-as-usual conditions
- *Multimodal journey optimisation*: journey time savings from reducing interchange time between transport modes
- *Integrated incident and emergency management*: reduced congestion through better responding to incidents that occur on the transport network
- *Planned works and maintenance management*: saving journey time through improving the efficiency of temporary traffic control during roadworks
- *Freight management at ports*: reduced emissions by decreasing turnaround times for cargo ships

Network capacity management	£110.8m	(£60m-£230m)
Multimodal journey optimisation	£110.9m	(£55m-£160m)
Freight management at ports	£16.9m	(£10m-£35m)
Integrated incident and emergency management	£88.7m	(£40m-£190m)
Planned works and maintenance management	£528.3m	(£180m-£880m)

Figure 2: Monetised benefits of the five digital twin use cases analysed (in present value terms, 2010 prices)

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Glossary

BAU	Business as Usual
BCR	Benefit to Cost Ratio
CDBB	Centre for Digital Built Britain
DfT	Department for Transport
TRIB	Transport Research & Innovation Board
DSS	Decision Support System
DT	Digital Twin
EBA	Economic Benefits Analysis
EBR	Evidence Base Report
ICM	Integrated Corridor Management
IMS	Incident Management System
IN-DT	Integrated Transport Network Management Digital Twin
NDTP	National Digital Twin Programme
NUAR	National Underground Asset Register
RCM	Remote Condition Monitoring
RTCC	Regional Transport Coordination Centre
SITS	Surface Intelligent Transport System
SME	Subject Matter Expert
VMS	Variable Message Sign

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Introduction

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Introduction – Context and approach to the study

Better integrated transport network management

In 2023, the Department for Transport's (DfT) Transport Research Innovation Board (TRIB) created a clear vision and roadmap to facilitate the development of a national ecosystem of federated digital twins focused on improving the performance of integrated UK transport by 2035.

Responding to this vision, the TRIB Digital Twin Community of Practice (CoP) identified *network and operations management and crisis response* as the top priority use case for a digital twin of integrated transport. DfT commissioned this study to quantify the potential economic benefits of a transport digital twin dedicated to integrated network management. This has been delivered by a consortium led by Arup, including Connected Places Catapult and Digital Twin Hub, with specialist advice provided by the Chief Transport Analyst at TfL.

To quantify potential economic benefit, this study has adopted a process and deliverables set out in Figure 3. To achieve better integrated transport network management, any digital twin will be completing several nested functionalities (use cases) that coexist to achieve superior integrated transport network management. Hence this study has adopted a *use case approach* to bolster understanding of the potential functionalities of IN-DT, and work towards comprehending a possible future IN-DT architecture.

Evidence base, use cases and economic benefits

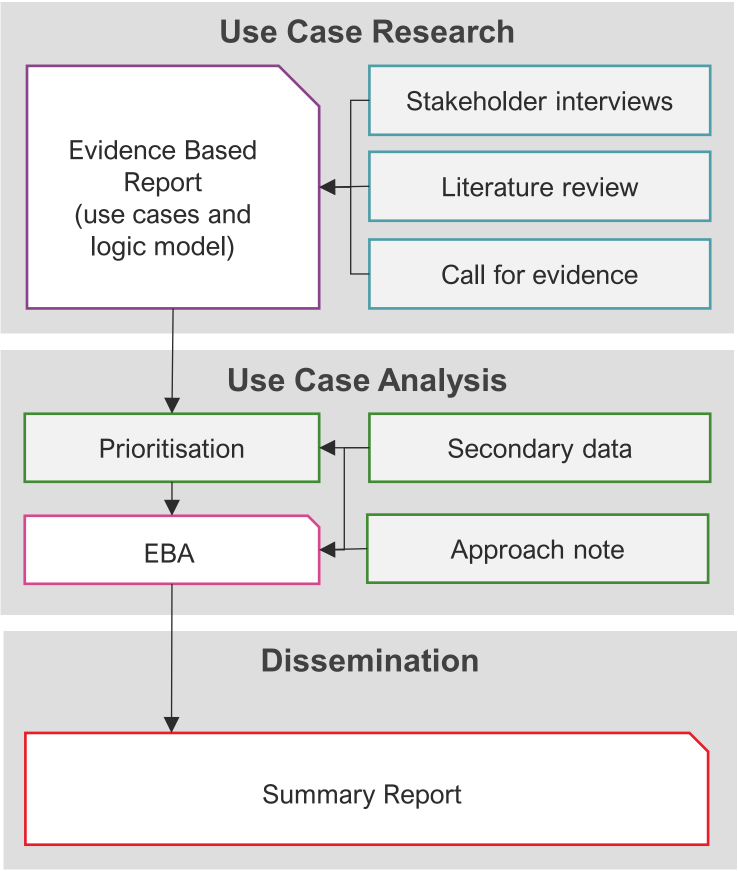
The identification and understanding of potential use cases during this study was completed via an Evidence Base Report (EBR) development process involving a thorough literature review, stakeholder engagement, and logic model conceptualisation procedure. The EBR was then used as a foundational document from which to explore each use case in more detail.

Within the constraints of this study, it was only possible to quantitatively analyse the economic benefits associated with five of 22 use cases. Through a scoring process outlined later in this document (Section 3), the most applicable use cases were selected for inclusion in the Transport Analysis Guidance (TAG) consistent Economic Benefit Analysis (EBA).

The EBA clearly sets out the approach and assumptions that have been used to estimate benefits, underpinned by a core set of assumptions, and sensitivity analysis. The quantified benefits are consistent with the TAG framework, with key benefits including journey time savings, journey quality and reliability.

This report is organised over three sections covering the evidence review, use case analysis, and economic benefits analysis.

Figure 3: Process and deliverables



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Evidence Review

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Evidence Review – Literature review

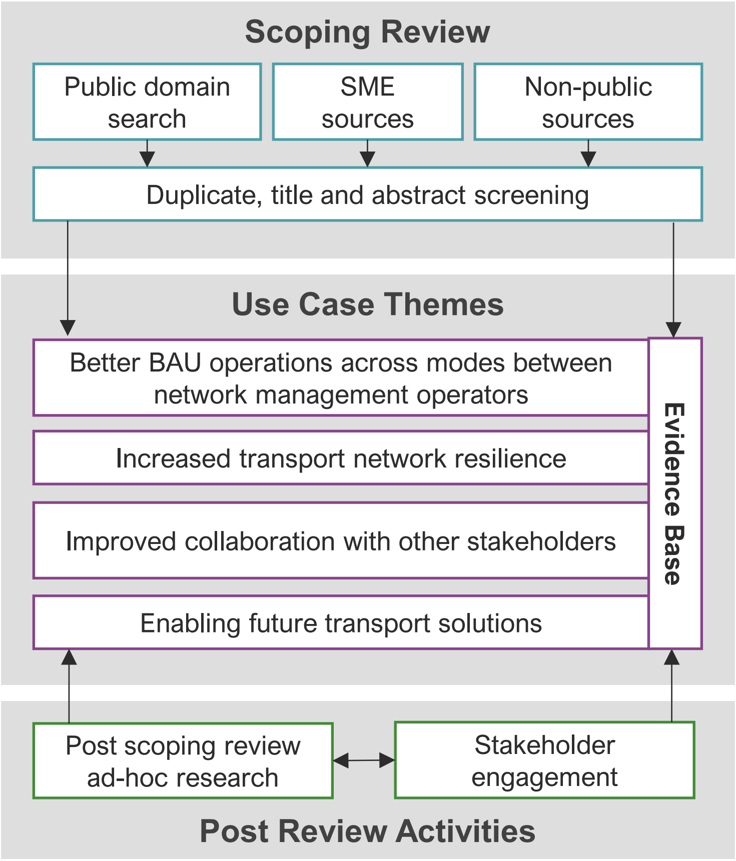
Outline

The aim of the literature review is to develop a foundation of evidence surrounding IN-DT. The methodology for the evidence review is set out in Figure 2.

Overall, for the scoping review, over 2,100 pieces of individual literature were considered. Sources targeted were specifically related to the application, federation, implementation, benefits, definitions, or review of digital twins in the context of the transport sector directly or indirectly, e.g. energy for transport. Some literature sources were identified from internal Arup or other stakeholders' documentation. Experts were asked where possible to bolster the literature review activities by directing Arup to or supplying key documentation.

Post scoping review, specific searches were conducted to address knowledge gaps, especially in conjunction with stakeholder engagement activities. The final output of the literature review was input into the Evidence Base Report (EBR), contributing to a list of thematically grouped potential use cases, key case studies, and associated benefits data where available. These have been reproduced in this summary report in the relevant sections that follow.

Figure 4: Literature Review Methodology



Challenges

The literature review revealed a number of challenges in relation to the future completion of an IN-DT TAG-consistent EBA.

Firstly, the domain of federated digital twins, and specifically the evidence associated with their application within integrated transport network management is relatively novel. Hence, there is a lack of published methodological approach to benefits quantification for this concept. We have therefore created a semi-bespoke methodology as outlined in Section 3 of this report, which has been checked to be consistent with TAG and Green Book guidance.

Secondly, there are a limited number of directly comparable case studies that have identified the benefits associated with this concept. Where examples do exist, these tend to focus on implementation, and general value statements, not quantified benefit. Thus, we have relied heavily on some key case studies e.g. TfL SITS operational surface transport digital twin. This also highlights the importance of accurate monitoring and evaluation of the benefits post implementation of a digital twin and its foundational building blocks (e.g. data exchange platforms).

Evidence Review – Stakeholder engagement

Purpose

Following the initial scoping review of the literature, over 20 organisations were engaged through formal interviews and a wider call for evidence process. The call for evidence was enabled by the Digital Twin Hub at the Connected Places Catapult and ITS UK.

The purpose of engaging stakeholders was to:

- Understand what individual stakeholders perceive transport network management to be in relation to digital twins.
- Confirm or refute use cases found within the literature review and, add new use cases which can be evidenced from stakeholder input/future ad-hoc searches.
- Aid the process of understanding what is of most importance to this study e.g., which thematic use case groupings matter most and what are the problems that stakeholders are trying to overcome in the context of integrated transport network management.
- Consider any barriers they may be facing in achieving their own digital twin initiatives.

Use cases

The case studies identified through the evidence review process are all examples of where digital twins are being used in slightly different ways, by different people, to solve different problems that they face in dynamically managing a transport network.

We use the term "use case" to encapsulate these kinds of dynamic. The important thing being that each use case ultimately generates real value to the transport users.

Figure 5: Stakeholder organisations engaged

Evidence Review

Key barriers expressed from stakeholder engagement

Standardisation and interoperability

There is a number of key outputs from the stakeholder engagement activities in relation to barriers that need to be overcome to expedite the development and success of an IN-DT implementation. These include but are not limited to:

The perceived lack of standardisation to support true interoperability across transport modes, geographies, and environments related to transport network management, which was perceived as a key barrier for a federated ecosystem of digital twins.

Absence of consideration by system actors to future data licensing and sharing arrangements to enable interoperability. For example, formalising data sharing requirements in contracts when awarding public transport franchises to operators.

Skills, incentives and funding

In certain scenarios a lack of trust between parties (public and private sector) and/or commercial incentive to share data or participate in an IN-DT initiative is a potential barrier to overcome.

Stakeholders perceive a need to increase and retain data and digital twin literacy, skills, and capacity to leverage the potential benefits of a digital twin approach. This includes senior leadership and the network management workforce.

Access to funding to support data and digital twin initiatives for resource constrained transport authorities was also raised by stakeholders as an issue.

Exploring accounting processes that recognise data as an asset was also recognised by some stakeholders as an opportunity to increase focus and investment in this area.

Many of the above points are aligned to DfT's Transport Data Strategy.

Security and infrastructure

Challenges around connectivity, privacy and security of sensitive information related to mobility will need to be addressed at a programme level.

Upgrades and expansion of connected infrastructures are inevitable to build digital twin capability. This is as much true for the digital infrastructure as it is for the physical infrastructure deployed onto transport networks to support the digital twin approach. This will present, cost, integration and architectural challenges, particularly for resourced constrained authorities, for whom this wider system approach and consideration will be both new and potentially considered an extra burden and complexity to deal with.

These challenges are also true at an individual digital twin level but are made more complex across modal and organisational boundaries due to differences (technology or otherwise) that exist.

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Evidence Review – Case Studies

The case studies were identified through desk-based research, interviews with digital twin experts, and through the delivery team's collective digital twin experience.

In addition to those highlighted here, examples from National Underground Asset Register (NUAR), the Climate and Resilience Demonstrator (CReDo), and the National Digital Twin Programme (NDTP) were reviewed in detail.

Regional control centre incident management

Transport for West Midlands (TfWM) has a multimodal dashboard within its Regional Transport Coordination Centre (RTCC) that works with an Incident Management System (IMS) to improve coordination between network managers, local authorities, transport operators, emergency services, and communication with transport users.

The systems are updated with real time events, and data insights have led to a full signal upgrade on the M5 Junction 1 which led to improvements to public transport journey times. National Express have reported a 10% improvement in route punctuality.

Transport for West Midlands

Integrated corridor management

Integrated corridor management (ICM) strategies have been developed for popular freight, tourist and commuter corridors in San Diego, Dallas and Minneapolis. ICM strategies aim to proactively coordinate these traffic corridors across modes to increase their performance.

Overall ICM was shown to increase reliability, reduce travel times, delays, fuel consumption and emissions. BCR's for ICM range between 10:1 and over 20:1. ICM is particularly useful under traffic incident scenarios where the corridor is unexpectedly constrained.

VDOT

RM3P

Travel Decisions Powered by Data

Surface intelligent transport system

Transport for London's (TfL's) Surface Intelligent Transport System (SITS) contains a digital twin interacting with an upgraded Real Time Optimiser traffic signal system, control room Decision Support System (DSS), the Transport for London (TfL) integration service, and a predictive capability in the future.

It is leading to improvements in situational awareness, incident management, congestion relief, air quality, road safety, and supporting the prioritisation of bus services and active travel across London.

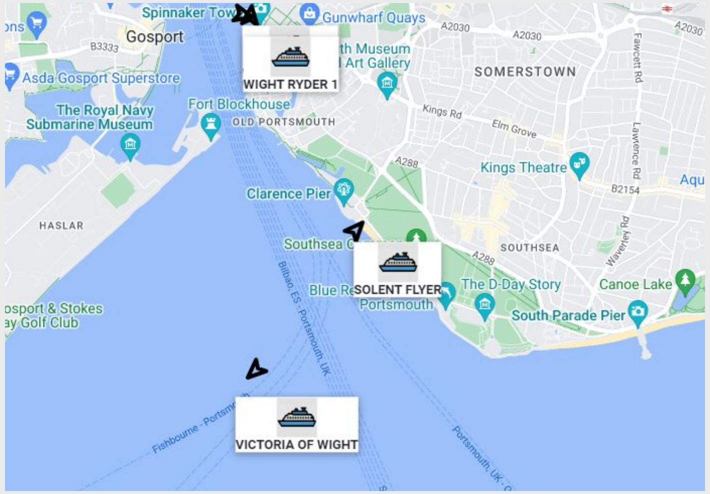
SITS has an approximate lifetime cost of £118m (£75m capital expenditure, £43m operational expenditure) and an original estimated Benefit Cost Ratio (BCR) of 7.3:1. A more recent analysis has suggested benefits of circa £1bn per annum from 2028.

Transport for London

Evidence Review – Case studies

Portsmouth maritime – road integration

The Portsmouth City Council (PCC) network management team utilise ferry tracking against timetable and anomaly detection to assess potential impact on approach roads, vehicle stacking, emergency services, and to inform customers on travel arrangements. The solution has improved situational awareness and helped overcome communication challenges between ferry operators and PCC.



Monitoring of Ferry locations versus timetable, anomaly detection. Image courtesy of PCC.

Network Rail ENRICH

Enhanced Network Rail Information interCHange (ENRICH) seeks to overcome data sharing barriers across the rail industry, mainly for Remote Condition Monitoring of vehicles or infrastructure assets e.g. wheels or overhead lines.

Whilst Network Rail has exchanged data sets with the industry for many years, interfaces have often been developed without an overarching data interchange framework, which creates inconsistencies and limits the ability to link data across the industry to innovate.

ENRICH has leveraged the Rail Delivery Group's (RDG's) Rail Data Marketplace (RDM) to agree suitable technical and commercial approaches for sharing of data.

NATS project Bluebird

The National Air Traffic Service's project Bluebird is a government-funded research project to deliver the world's first AI system, using digital twinning approaches, capable of controlling a section of airspace in live trials.

The digital twin has access to over 25 million flight data records and has three principal objectives:

1. To perform probabilistic modelling and risk-based analysis
2. To build and train 'agents' that can perform the role of air traffic controller to a suitable degree of competency
3. To harness the potential of Artificial Intelligence, whilst ensuring trustworthiness and traceability – of key importance to this operational setting.

Evidence Review – Identified use case themes

Use cases identified

Use cases have been identified through the evidence review that could be supported by an IN-DT. It should be noted that the use cases provided are not exhaustive and they reflect solely the evidenced examples captured by literature review and stakeholder engagement.

These applications could yield positive economic outcomes under both business as usual (BAU) and atypical transport network conditions. Due to the number of, and inherent connections between use cases, they have been grouped into four themes as shown.

Theme 1

Better business-as-usual operations across modes enabled from sharing operational information/data between transport system actors (e.g., multi-modal schedules) at local and/or national scales to enable more comprehensive network performance monitoring, design of timetables, and network capacity management for network management organisations.

Theme 2

Increased transport network resilience from network monitoring, coordination and dynamic response at a "whole system" level. This more holistic operational decision coordination between authorities, agencies, and modal operators could lead to faster and more efficient detection and response to planned and unplanned events across transport networks. It includes an understanding of implications to wider transport network elements and transport network users to minimise disruption.

Theme 3

Improved collaboration with other stakeholders, through the creation of a single way of interacting digitally. This includes cross-sectoral private sector organisations (e.g., road, rail, energy, weather, manufacturing, utilities etc.) leading to more effective network operations, more reliable journeys, improved processes, especially at hubs e.g., stations, depots, ports etc. Whilst not the focus for this analysis, this could include benefits to other sectors, such as those given as examples above.

Theme 4 – *emerging concept theme*

Enabling future transport solutions such as self-driving vehicles or drones through digital twin technologies. An Integrated Transport Network Digital Twin (IN-DT) could potentially support and de-risk deployment and enable a level of collaboration beyond what is currently possible.

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Evidence Review – Identified use cases

Theme 1: Better business-as-usual operations across modes between network management operators

- Network capacity management
- Multimodal journey planning
- Network capacity management around hubs
- Multimodal journey optimisation
- Network management at authority interface points
- Demand responsive transport

Theme 2: Increased transport network resilience

- Integrated incident and emergency management
- Crisis/disaster response planning and management
- Planned works and maintenance management
- Events planning and management
- Scenario analysis and forecasts
- Network management performance enquiries
- Intersection safety
- Freight abnormal loads

Theme 3: Improved collaboration with other stakeholders

- Strategic transport hub planning
- Public services planning
- Freight management at ports
- Operational resource planning
- Parking planning and management
- Energy-transport operational management

Theme 4: Enabling future transport solutions (emerging concept)

- Next generation transport enablement
- Operator training (Human and Artificial Intelligence)

Evidence Review – Identified use cases

Network capacity management

Network management decisions can be made to impact and improve capacity across a network and for specific modes. This could include prioritisation of buses or emergency services, and/or encouraging a shift in modal choice to balance load across a network e.g. from road to rail.

Theme 1 | Theme 2 | Theme 3 | Theme 4

Network capacity management around hubs

Network management decisions can be made in response to hub dynamics that may impact dependant networks. For example, if bad weather influences port or airport performance, incoming road/rail traffic may become congested, impacting public transport and services, local roads and facilities. In this case, information could be provided to travellers to influence demand, or specific management activities deployed e.g. regulation of public transport schedules into the hub.

Theme 1 | Theme 2 | Theme 3 | Theme 4

Multimodal journey planning

End-to-end, multimodal journey planning, timetabling and integration could be enhanced on a more granular, place-based level. Trips could be grounded on real time transport network performance, and this could positively impact journey time reliability and customer satisfaction. Furthermore, trips could be planned to reduce emissions etc.

Theme 1 | Theme 2 | Theme 3 | Theme 4

Multimodal journey optimisation

Improving the timeliness, accuracy, and richness of data associated with individual transport modes could enable the better linking up of modal interchanges. This more seamless interchange capability and potential reduction in interchange time will have direct benefits for customers e.g., through improved satisfaction, journey time savings and general ease of travel.

Theme 1 | Theme 2 | Theme 3 | Theme 4

Network management at authority interface points

Boundaries between transport authorities can be the subject of suboptimal performance e.g. local roads to local roads, SRN to local roads. These interface points could be improved through collaborative and integrated performance improvements supported by cross-boundary data exchange and action.

Theme 1 | Theme 2 | Theme 3 | Theme 4

Demand responsive transport

Demand Responsive Transport (DRT) is a form of public transport where routes and timings react according to demand. Schemes are already being developed and deployed e.g. DRT in rural Leicestershire, and MK Connect in Milton Keynes. Richer operational decision-making could be enabled by a digital twin, beyond customer input e.g., demand forecasting resulting from federated data shared between authorities and operators.

Theme 1 | Theme 2 | Theme 3 | Theme 4

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Evidence Review – Identified use cases

Integrated incident and emergency management

Improving the timeliness, accuracy, and richness of incident and emergency detection, including across transport modes, could directly impact the quality/coordination of response and communication with the most appropriate system actors. Over time, the learning should lead to improved response times and plans across the sector and potential predictive capabilities in the future. Refer to ISO 22361:2022 for definitions of incidents and emergencies.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Planned works and maintenance management

Better access to planned works and timely and reliable asset condition-related data across stakeholders could improve scheduling of asset maintenance that reduces impacts on network availability. For example, underground utilities works which typically result in costly temporary street or road works could be coordinated across stakeholders to improve scheduling. Note that this use case is complementary to NUAR, not duplicating it.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Scenario analysis and forecasts

Near-term, specific, operational planning could be supported through running scenario analyses and stress tests informed by an ecosystem of up-to-date integrated/multi-agency operational data. This could be useful to local stakeholders looking at niche network management initiatives, through to regional stakeholders in managing major corridors. E.g., BT are working with Network Rail to model major rail station disturbance scenarios, to help inform decisions about which train services to prioritise to minimise travel disruption.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Crisis/disaster response planning and management

Planning, monitoring, and responding to major events such as natural disasters through more accurate simulation and modelling of the transport system across modes e.g. city evacuation, pandemic social distancing etc. For instance, testing the potential impact of a crisis, or monitoring the impact of a disaster and decisions if it has occurred. Although similar to incident and emergency management, this use case involves distinct stakeholders and more coordination with central government.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Events planning and management

Developing and deploying responses to infrequent large-scale events, such as events that occur seasonally (sports games, concerts and marathons) or events with predictability (Olympics, Commonwealth Games, protests, strikes). Impacts to transport systems from these events may be derived largely by long distance transport demands not usually considered by a local / regional transport authority, such as international/inter-population centre trips.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Network management performance enquiries

Digital twins could aid in the transparency and traceability of, and responses to enquiries relating to transport network performance and/or management. For example, where queries are generated from the public to a transport authority, in response to an observation on the transport network. This functionality could also help stakeholders in fault finding or other analogous investigative exercises.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

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Evidence Review – Identified use cases

Intersection safety

Right time information could be used to form a comprehensive picture of an intersection's usage from multiple multimodal sources (e.g. surface transport - HGVs, buses, cyclists, pedestrians; or rail-road e.g. level crossings) to identify safety risks. Subsequent interventions (e.g., crossing or road layout, signal plan prioritisation) at these intersections can then be made to improve safety outcomes, with ongoing monitoring to ensure that they deliver the planned improvements.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Freight abnormal loads

Better matching of vehicle and cargo specifications to infrastructure features and availability could enable more accurate journey planning and reduce incidents that negatively affect journey time reliability or the wider transport network. Real time tracking and more accurate load information could also be useful to network managers across multiple network boundaries, and emergency services in responding to incidents involving freight vehicles.

Theme 1 | **Theme 2** | Theme 3 | Theme 4

Strategic transport hub planning

The strategic planning of where and when transport hubs should be built could benefit from integrated transport network data and specific traveller or freight journey information at an aggregated level. For example, data from an ecosystem of digital twins could help identify optimum locations for rail hubs for interchange from other modes.

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Freight management at ports

Port efficiency and performance are influenced by many factors centred around matching infrastructure (e.g., cranes, berths, parking, sidings) with inbound/outbound transport (e.g., vessels, HGV's, trains) and an appropriate supply of freight. More timely operational information shared between the many organisations involved will help improve port performance and freight operator efficiency and minimise/mitigate the impacts of operations on surrounding transport networks.

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Parking planning and management

The allocation of road space could be allocated dynamically and automatically, potentially through the combination of a digital twin and granular digital traffic regulation orders – (DTROs). Allocations could be based on transport system needs e.g., parking availability for last mile deliveries. This use case would be most effective when combined with high penetrations of self-driving vehicles.

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Operational resource planning

Improving understanding of activities and dynamics within hubs such as airports or stations could support resource planning for internal operations e.g., staffing of retail units, ticket booths, passport control. Different passenger demographics have differing needs impacting resource planning e.g., internal vs international vs connecting passengers. Suitable responses to these needs rely on the right-time exchange of information between the myriad of organisations operating within hubs.

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Evidence Review – Identified use cases

Public services planning

Digital Twins could be used to improve public services provision (e.g., public transport links to health or education facilities). Digital twins could enable more complex considerations to be factored into planning e.g., employment data informing the appraisal of new transport schemes versus other initiatives such as broadband upgrades. More dynamic delivery of public services could be enabled e.g. refuse collection routes being informed by live traffic conditions to reduce congestion at peak times.

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Energy-transport operational management

Richer right time data provision on the demand for electrical energy from transport systems could assist with the operation of electrical networks to best supply according to demand. Modelling and simulations run on historical data could be used to inform improvements e.g., substation enhancements, planning applications, vehicle charging infrastructure provision (private/commercial).

Theme 1 | Theme 2 | **Theme 3** | Theme 4

Next generation transport enablement

The next generation of transport such as connected self-driving vehicles or advanced air mobility could be de-risked by data supplied by integrated transport digital twins. For example, timely data on an entire transport system could help to achieve a more contextualised fleet coordination approach than is currently possible for these technologies.

Theme 1 | Theme 2 | Theme 3 | **Theme 4**

Operator training (Human and Artificial Intelligence)

Digital twins could be used to develop accurate virtual environments or training datasets for both human and artificial system operators. For example, the increasing automation and augmentation of air traffic control systems is enabled by comprehensive AI training data sets and subsequent training of human operators on these systems will involve simulators and virtual environments, aiming to reduce operator workloads.

Theme 1 | Theme 2 | Theme 3 | **Theme 4**

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Use Case Analysis

Use Case Prioritisation

Prioritisation process

This study quantitatively analysed the economic benefits associated with high-priority use cases across the themes (see right). The selection of these use cases was completed through a scoring exercise depicted in Figure 6 below. For detailed scoring see Appendix A.1.

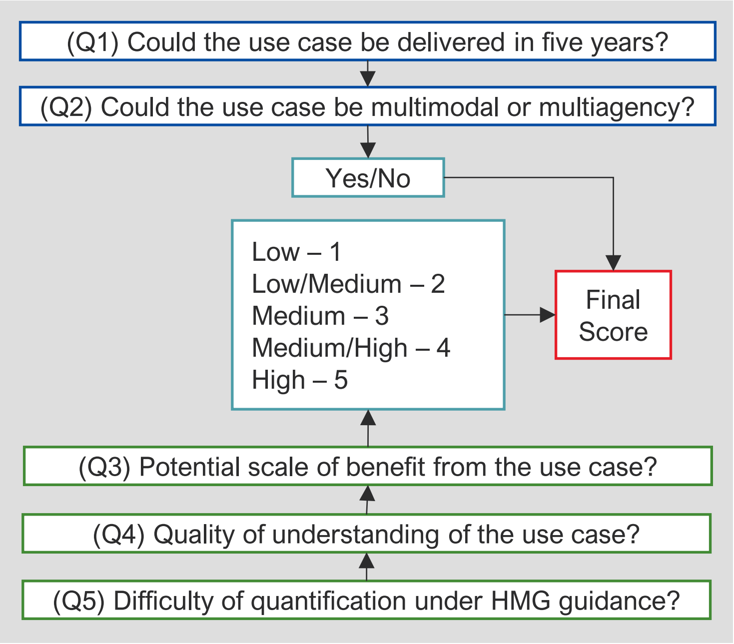
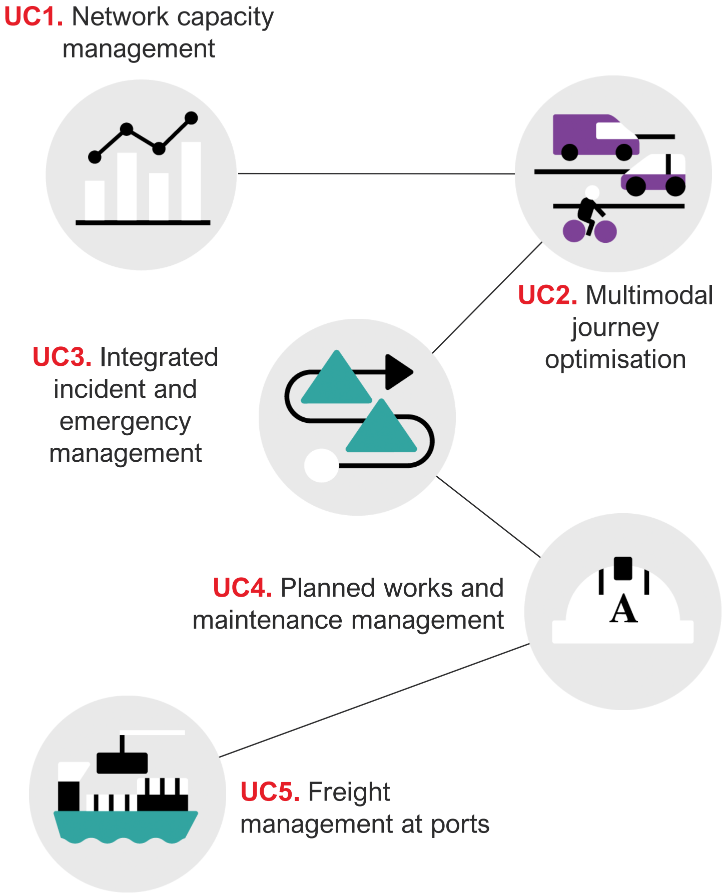


Figure 6: Use case scoring methodology

Figure 7: Five priority use cases for quantitative analysis



Assessment process

The five selected priority use cases had evidence to support their potential impact (Q3. scale of benefit). Arup has a good understanding of each use case's outcome (i.e. what success and improvement means for the use case) and the underlying functionality needed to achieve this (Q4). Quantification for each use case can be completed consistent with HMG guidance (TAG) (Q5) and it is likely that a digital twin providing such a use case is deliverable within the next five years (Q1).

Moreover, each of the priority use cases complete a multimodal or multiagency function (Q2). All five use cases involve road, rail, maritime and active travel modes; public and private sector collaboration; freight and passenger transport; and different transport system network management facets e.g., business as usual management, incident management, maintenance management, planning etc.

The following section describes each use case in detail to provide an understanding of the problem they are solving, supporting case studies, the digital twin functionality required to enable them including required data and stakeholders that need to be involved.

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UC1. Network capacity management

Problem Definition

Growth in network demand can make managing network capacity difficult. Capacity constraints can arise quickly, impact wider network components and be difficult to alleviate. A federated ecosystem of digital twins could enable various capacity management initiatives with an aim to improve the matching of network capacity with demand across the network.

This could include changing traffic signalling to prioritise buses or emergency vehicles, load balancing across the network, or mitigating disturbances at hubs that could impact capacity on nearby transport networks. For example, if inclement weather creates delays at an airport or port, incoming traffic may become congested as outflows are reduced. These impacts could ripple outwards from the hub onto the wider transport network.

The network capacity management use case proposes information is provided to inbound transport users to mitigate impacts on the neighbouring transport network. This use case is currently being considered by Portsmouth City Council, and explored by Virginia's Department of Transport (US) within its Integrated Corridor Management programme, RM3P.

Related Case Studies

Integrated corridor management (ICM) pilots that increase communication and improve collaboration for network operators to actively manage corridor capacity during or following incidents have demonstrated strong Benefit Cost Ratios between 10:1 and 20:1.

Portsmouth City Council use ferry tracking and timetabling data to detect anomalies, assessing impact on incoming traffic to the port. Information can be provided to port customers via Variable Message Signs (VMS) and wider network impacts can be mitigated.

Functionality Required and Enablement

Network capacity management is dependent on the availability of broad information related to network condition(s) and incidents across the network. This information can be made available from journey planning apps, sensor networks or vehicle status information. Development could be expedited through parallel coordination of initiatives e.g., connected traffic signal upgrades, in vehicle information schemes (Green Light Optimal Speed Advisory, next generation e-call initiatives etc.).

Potential Beneficial Outcomes

TAG Consistent – Reduction in network capacity constraints could reduce journey times, increase journey time reliability which also has second order effects including fuel savings, emission savings and localised air quality improvements.

Qualitative – Improved administrative efficiency, capacity constraint recovery/relief speed, infrastructure utilisation, explicit mode performance (e.g., ambulance vehicle response time), reduced rat running.

Stakeholders Involved

- Relevant transport authorities and operators across different modes (highway, rail, maritime, freight and passenger etc.)
- local, regional and national government
- emergency services
- map and journey planner app developers

Example Data Acquisitions / Flows

Traffic and incident information e.g., journey time (e.g. INRIX, National Highways NTIS), Google Maps congestion API, Waze. Live weather and forecast data, emergency services location and utilisation data.

UC2. Multimodal journey optimisation

Problem Definition

The efficiency of multimodal journeys is heavily reliant on independencies including interchange timings, customer facility provision, well designed wayfinding, weather conditions, and mitigating disruptive events such as vehicle breakdowns, delays, infrastructure failures (power, telecoms etc.).

Improving the timeliness, accuracy, and richness of data associated with transport networks could enable improved planning and operational resilience of multimodal interchanges. This could directly reduce interchange times, increase user satisfaction and the ease of travel.

Additionally, journeys could be planned more effectively in a dynamic, data driven fashion against certain objective functions e.g., speed, resilience, comfort, work, emissions (i.e., eco-routing) etc.

Furthermore, end-to-end integrated journey planning, timetabling/integration could be completed at a more granular place-based level i.e., based on right-time transport network performance, especially during periods of delay/change to positively impact journey time reliability and/or customer situational awareness.

Related Case Studies

VDoT Regional Multi-Modal Mobility Programme (RM3P) is a multi-agency, multi-mode programme leveraging the collaborative use of real-time data (e.g. transport demand, parking availability) by Virginia's public and private sectors to improve travel safety, reliability, and mobility.

Functionality Required and Enablement

Multimodal journey optimisation would benefit from operator decision making/journey planners, aided by a (potentially AI-based) decision support system. Tie in with other use cases such as incident/capacity management to ensure journey time reliability and/or alternative routings. Mechanisms to encourage certain modal patterns could include dynamic incentivisation. Interoperability and indications of data ownership/control restrictions to protect commercial sensitivities are key.

Example Data Acquisitions

Weather/climate, incident/capacity management data, parking data, multimodal movement data.

Potential Beneficial Outcomes

TAG Consistent – Increases in journey time reliability and safety. Reductions in transit times at interchanges. Reductions in emissions from eco-routing. Reduction in fuel use/wasted milage (i.e., costs) for freight consignments.

Qualitative – Journey quality/seamlessness. Increased efficacy of multimodal provision helps to meet the demands of diverse communities/populations.

Stakeholders Involved

- Relevant transport operators across freight and passenger transport (highway, rail, aviation, maritime etc.)
- local, regional and national authorities/operators
- journey planners/maps (Waze/Google/other DaaS)
- tolling stakeholders
- weather data providers
- OEM vehicle data brokers, for-hire vehicle data

UC3. Integrated incident and emergency management

Problem Definition

Unplanned incidents and emergencies occur regularly within transport networks and often impact multiple modes concurrently. These events can be unintentional (e.g., traffic crashes, poor weather related) and exacerbated by low network resilience (e.g., power faults, congestion, IT failures) however, they could be identified, analysed and responded to in a more effective way.

Improving the timeliness, accuracy, and richness of incident and emergency detection across transport modes could be facilitated directly by digitalisation and the use of digital twin technology. Centralised information provision via singular dashboards for transport network operators already influences the quality of their incident response e.g., coordinating with the most appropriate system actors.

Over time the analysis of archived incident and emergency reports (e.g. incident characterisation, contextualisation, and frequency) could also assist with the development of more effective response plans, especially mitigation through the utilisation of alternative modes, accurate information provision to operators/customers.

Related Case Studies

Transport for West Midlands (TfWM) have developed within their Regional Transport Coordination Centre (RTCC) a consolidated network dashboard that is fed right-time incident data federated across multiple sources. This data is used to improve workflows with an integrated Incident Management System (IMS).

Transport for London's (TfL's) Surface Intelligent Transport System (SITS) also provides a single view of the transport network with consolidated incident data and action plans through use of a digital twin.

Functionality Required and Enablement

Integrated incident and emergency management requires integration of incident data sources across relevant modes into shared view dashboards of the transport network. Predictive/automated response plan capability can be enabled by a digital twin using information from these sources. The twin can then augment administrative tasks including incident reporting, communication (e.g., to emergency services), ongoing monitoring, post incident evaluation/archiving, future analysis/factoring into future incident planning/suggested mitigation strategies.

Potential Beneficial Outcomes

TAG Consistent – Reduction impacts to transport network through reduction in incidents and incident severity. This improves journey time and journey time reliability which could yield subsequent economic and wider benefit.

Qualitative – Management/administrative efficiency gains lead to a decrease in calls, emails, wasted mileage, improved incident recovery plans (resilience), future mitigation strategies (resilience investment)

Stakeholders Involved

Relevant modal authorities (highway, rail, maritime etc.), local, regional and national authorities and resilience forums, emergency services and healthcare providers, journey planners (Waze/Google), works contractors, breakdown agencies, alternative transport service providers (e.g., rail replacement buses).

Example Data Acquisitions / Flows

Incident metrics, weather, journey planner data (e.g., Waze for Cities Data Prog.), hub statuses, emergency service info, CCTV etc.

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UC4. Planned works and maintenance management

Problem Definition

Across transport networks, the upkeep of infrastructure and assets is imperative to ensure reliable and efficient operation. The planning of maintenance works can occur across a multitude of actors including vehicle asset owners, highway/railway authorities, utility providers i.e., water, gas, electric etc.

Maintenance works typically result in disruptive transport conditions from temporary roadworks, partial station closures or capacity degradations etc. Furthermore, it is possible for some work to be duplicated (e.g., multiple excavations in the same location by separate utilities) or for works to not consider alternative transport modes (e.g., closing a highway when rail lines are also closed – leaving travellers with few/no alternative methods of travel).

Digital twins federating data, such as that provided by remote condition monitoring (RCM) and maintenance plans, could enable a deeper understanding, scheduling and control of maintenance works impacting transport. Functions could include combining maintenance tasks/improving scheduling to reduce maintenance work and minimise disruption or through improving the performance of roadworks.

Related Case Studies

Enhanced Network Rail Information interCHange (ENRICH) seeks to overcome data sharing barriers across the rail industry, mainly for RCM e.g., for wheels or overhead lines.

The National Underground Asset Register (NUAR) could deliver benefits of £490m/year from productivity gains, reduced asset strikes, public/business impacts.

SITS' single view of the transport network could help to mitigate roadwork congestion. GLA roadworks utility co-ordination platform could help reduce works.

Functionality Required and Enablement

Planned works and maintenance management will require incorporation of datasets e.g., NUAR, temporary traffic assets to understand works locations across sectors and avoid conflicts, whilst identifying coordination opportunities. Maintenance plans will be integrated to give right-time insight and alerts, and the digital twin will update plans to optimise accordingly. Temporary traffic signals could be remotely managed to network needs. Digital diversion routes, digitised temporary traffic regulation orders (TTROs) could be embedded to improve efficiency.

Potential Beneficial Outcomes

TAG Consistent – Reduced quantity of maintenance works from improved collaboration (could reduce overall congestion, emissions, or disruption).

Qualitative – Predictive maintenance/forecasting could help coordination, connected temporary traffic signals could reduce delays (UTC to SCOOT), workflow automation e.g., TTRO applications, could improve short term planning/response times when works are needed for acute incidents.

Stakeholders Involved

Relevant modal authorities (highway, rail, maritime etc.), local, regional and national authorities, industry stakeholders (contractors, planners, designers, engineers etc.), asset/infrastructure owners, financers, emergency services, journey planners/maps (Waze/Google), local transport system users/impacted businesses.

Example Data Acquisitions / Flows

RCM, TRO, diversion route, traffic flow, congestion, temporary traffic signals/infrastructure data, communication to users e.g. VMS, in-cabin display.

UC5. Freight management at ports

Problem Definition

Ports constitute a complex environment of actors providing varied services including but not limited to; cargo handling; container operations; vessel loading and unloading; storage and repair functions; outbound traffic loading/unloading; and the planning/timing of these activities so that they act symbiotically e.g., matching infrastructure (e.g., cranes, berths) with inbound vessels for processing, and/or HGV/rail arrivals with parking spaces, train sidings and a supply of outbound freight.

Holistic information provision via a digital twin could enable a more collaborative, integrated operational environment. Often, from the literature reviewed by this project, port digitalisation can be termed as the use of a port decision support system (DSS) or port management system. Such a system could be beneficial during normal operations or during periods of incident that require recovery e.g., advising a vessel of a new routing or arrival time (requiring a reduction in speed etc.).

Port operations have significant interdependencies with internal/inter-port stakeholders: border control/customs, maritime operations, global logistics firms, neighbouring communities/transport networks (coastal), supporting land transport operations (road/rail).

Related Case Studies

Port of Antwerp-Bruges (PoAB) has developed the APICA digital twin which aims to provide situational awareness and decision support through information provision related to traffic situations, bridge and lock statuses, infrastructure, and environmental sensor data.

Port of Rotterdam's use of a port management system and community system has resulted in 30 min vessel turnaround time saving (approx. €160m saving/year), 5-10% saving in dredging costs, €245m saving from reduced phone calls, email traffic, freight mileage.

Functionality Required and Enablement

Freight management use cases require federation of multimodal/agency data within a digital twin using existing/future resources (e.g., AIS, sensor networks, drones, GIS) to build a reliable, neutral source of port information that could augment functions such as administrative/financial processing, departure/arrival control, berth/cargo planning/handling, incident response etc. Any digital twins must be easy to integrate with and indicate data ownership/control restrictions to protect commercial sensitivities.

Potential Beneficial Outcomes

TAG Consistent – Reduction in dwell times for inbound/outbound traffic leading to fuel savings and time savings which could contribute to emissions savings and localised air quality improvements.

Qualitative – Management/administrative efficiency gains lead to a decrease in calls, emails, wasted mileage, improved incident recovery (resilience), infrastructure utilisation, journey reliability, and customs checks could be more effective.

Stakeholders Involved

Port owners (e.g., Associated British Ports), lessees (e.g., terminals, logistics facilities, industrial sites, real estate), carriers (e.g., road/rail/maritime operators), freight agencies, service providers (e.g., towing, bunkering, maintenance), NGOs (e.g., IMO), authorities (e.g., local, regional, national), other ports.

Example Data Acquisitions / Flows

Fleet information (timing, vehicle, consignment etc.), border updates, infrastructure utilisation, air quality, incidents/events e.g., nearby roads/rail corridor status.

Commonalities across prioritised use cases

Functionality

Data Sharing Architecture and Interoperability enabling various data sources such as sensor networks, vehicle or asset status information, incident data, response plans, and datasets like NUAR to exchange information. This integration is essential for providing comprehensive and accurate information for decision-making.

In addition to sharing, interoperability of this data (enabled by agreements on standards, data models, taxonomies etc. and in coordination with NDTP) between public and private entities are key requirements across multiple use cases. For example, future works and events plans being shared between contractors, local authorities, and transport network managers and operators.

Dashboards and Decision Support Systems (DSS) that make use of federated data sources allow stakeholders to access relevant data and information easily, can model alternative scenarios and their impacts facilitating incident management, maintenance planning, and coordination of works. Such systems can then output to communications systems to inform relevant stakeholders (e.g. transport users, or emergency services agencies).

Right-time Monitoring and Control for example, remotely managing road closures, monitoring port operations, and responding to incidents promptly.

Actors

Relevant Modal Authorities/Operators: Mentioned in all use cases, as different modes of transportation are involved in each scenario.

Local, Regional, and National Government: Also mentioned in all use cases, indicating their significant role in transportation management and governance.

Emergency Services: Common across all use cases, as they play a crucial role in incident management and response.

Journey Planners/Maps (Waze/Google): Found in multiple use cases, highlighting their importance in providing navigation and route planning services.

Maintenance Staff/Contractors: Mentioned in both UC3 and UC4, indicating their involvement in incident management, maintenance, and infrastructure development.

Data flows

Incident and emergency data: All use cases involve incident-related metrics, such as journey time, reliability, congestion data.

Environmental conditions data: Weather and climate data is important for understanding environmental conditions that may impact transportation operations, incidents and safety.

Journey Planner data: Data from journey planning applications provides real-time information about traffic conditions and alternative routes, which is valuable for journey optimization and incident management.

Traffic flow data: including congestion data, is essential for understanding traffic patterns. From sources like Google Maps API, road sensors, telematics and Waze inputs.

Utilisation data e.g., occupancy, freight loads.

Scheduling and demand information including timing, vehicle, and consignment details etc.

Interdependencies and links between prioritised use cases

Transport systems – especially in the multimodal context create high levels of interaction. Therefore, although Arup has made every effort to discretely classify several use cases for an IN-DT there is interaction between these use cases in the pursuit of improved network management. Figure 8 (right) highlights the key interactions between the five use cases chosen for the EBA, in summary:

- Improved incident management is a key component in unlocking network capacity more often and unlocked this capacity is likely to reduce incidents.
- Optimising multimodal journeys is dependent on having spare capacity with which to route journeys and better integrated journey planning can free up capacity (load balancing).
- Improved inter-hub management at ports is a factor in managing end-to-end multimodal journey.
- Maintenance management could directly impact a port environment and the requirements of the port will impact planned maintenance. Similarly, incidents, may be reduced by better planned works but also could impose maintenance e.g., post incident.

Due to these interactions, we propose there is no perfect way to categorise use cases, and that practitioners should be careful of double accounting of estimated/observed benefit(s).

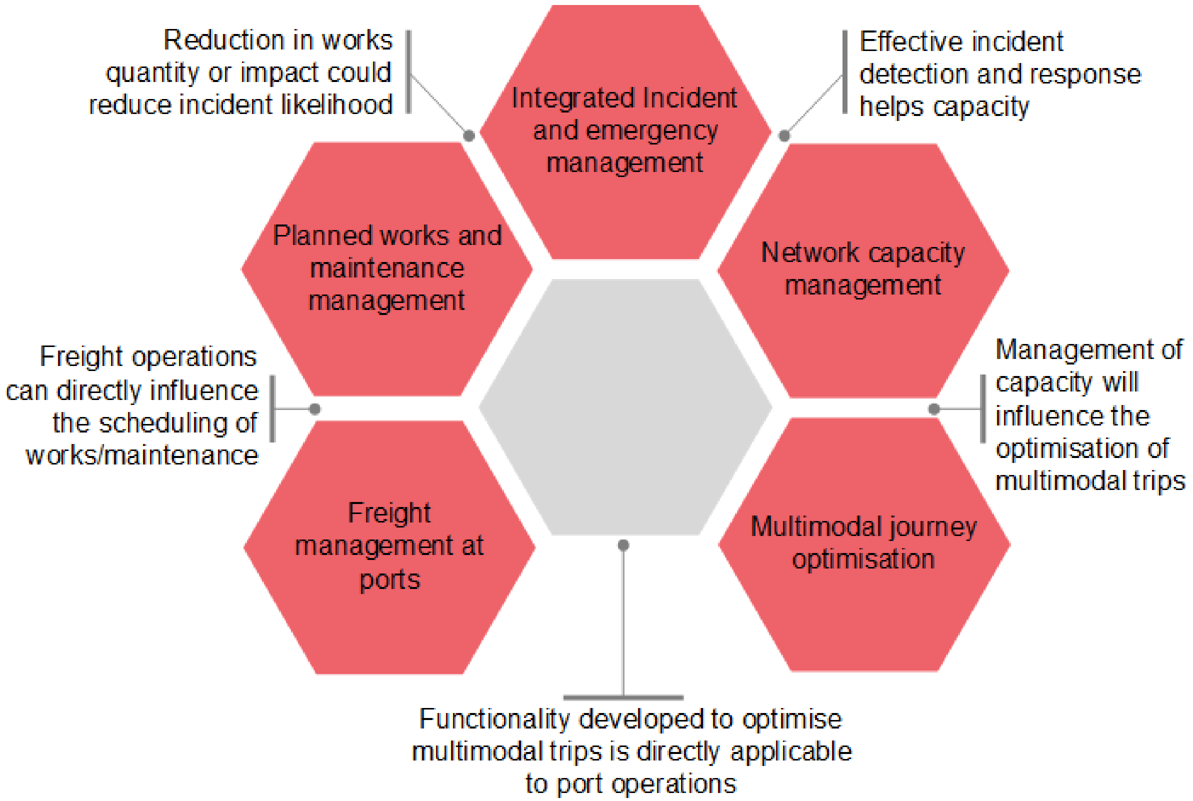

Figure 8: Examples of links between priority use cases

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Economic Benefits Analysis

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Economic Benefits Analysis – introduction

Background

The evidence review, set out in the previous section, sought to find evidence of quantifiable benefits of integrated network management and related digital twins which could be used to inform the EBA. Alongside this, use cases for digital twins in this area were identified and developed from the evidence gathered. A prioritisation process led to five use cases being shortlisted, as set out at the end of Section 3.

The intention of the EBA is to be consistent, where possible, with TAG (DfT Transport Analysis Guidance). This sets out a framework for assessing the economic benefits of a transport project. Schemes are assessed against four overarching impact categories in TAG, with additional sub-categories within each of these.

A logic model was developed, linking the inputs and activities that would be required to deliver an IN-DT with the outputs that would be produced, the outcomes that would follow from this, and the ultimate impacts that would be delivered. The impacts were designed to align with benefits that are assessed in TAG.

TAG Impact Categories

Economy – Benefits to businesses, business users, and private sector providers - in terms of generalised travel time or cost savings, improved reliability or wider economic impacts.

Environment – Impacts that transport may have on noise, local air quality and greenhouse gas emissions.

Social – Benefits to commuters and other transport users and non-users, including generalised time or cost savings, or improvements in safety, journey quality, physical activity or reliability.

Public Accounts – Impacts on public sector transport budgets or taxation.

Content

This section takes the use cases that have been identified in the earlier stages of the study forward to EBA and develops the correspondence between these use cases and quantified benefits.

The approach, underpinning assumptions and key data sources that have been used to estimate benefits.

The results (benefits that have been quantified) under a set of core assumptions; and sensitivity tests.

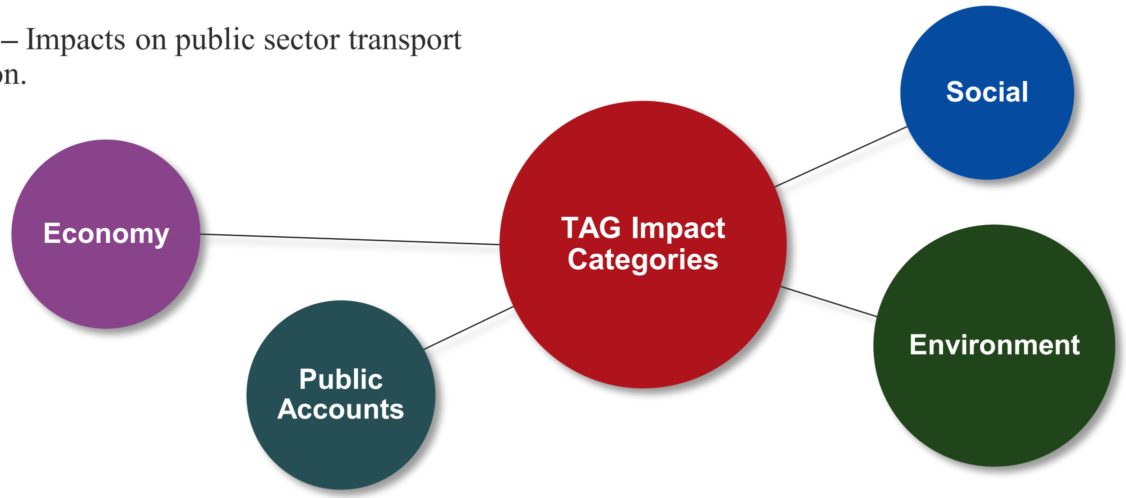

Figure 9: Transport Analysis Guidance (TAG) impact categories

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Economic Benefits Analysis – use cases

Benefits of the use cases

The next step was to understand which impacts would be likely to correspond with which use cases and would also be quantified in the EBA. This was based on an assessment of what the most significant quantified benefits were likely to be, which ones had evidence underpinning them that would enable quantification and hence would be most important to capture. Table 1 shows which benefits were selected for inclusion within the quantified analysis.

Table 1: Correspondence between use cases and quantified benefits

	Use Case				
Benefit	UC1 Network capacity management	UC2 Multimodal journey optimisation	UC3 Integrated incident and emergency management	UC4 Planned works & maintenance management	UC5 Freight management at ports
Journey time savings	✓	✓	✓	✓	
Reliability	✓		✓		
Journey quality		✓			
Vehicle operating costs	✓		✓	✓	
Mode shift benefits excluding environmental		✓			
Environmental benefits		✓			✓
Output change in imperfectly competitive markets	✓	✓	✓		

Economic Benefits Analysis – key data

Key data selection

A selection of key data sets underpinned the analysis. These are set out in the table opposite.

These data sources enabled a baseline to be established and an approach to be developed to quantify key impacts.

As an example, use cases 1 and 3 include journey time savings through congestion relief as a benefit. Data was obtained detailing the number of hours lost per driver across various UK cities. Evidence from previous work by TfL was then used to understand the breakdown of congestion by individual causes, and the extent to which the introduction of an IN-DT could reduce that.

Table 2: Key data sources

Data	Description	Which use case used for	Reference
INRIX congestion data	Hours lost per driver due to congestion in assorted UK cities.	UC1 and UC3	https://inrix.com/scorecard/
TfL – Surface Intelligent Transport System	Information about composition of congestion and what the scale of savings could be.	UC1 and UC3	Provided by TfL
National Travel Survey - interchanges	Number of interchanges between different modes of transport, by region.	UC2	Provided by DfT
Roadworks information	Number of roadworks per year in England, by organisation and region.	UC4	Provided by DfT (from Street Manager)
Port emissions and emissions factors	Fuel consumption and associated emissions of the UK shipping sector.	UC5	https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1712140936_ED61406_NAEI_shipping_report_12Dec2017.pdf

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Economic Benefits Analysis – approach

Assumptions

The table opposite sets out core assumptions that are common across all use cases. Benefits are assessed over a 10-year appraisal period, and a discount rate is applied so that benefits in each year are expressed as a present value.

A more detailed set of assumptions for individual use cases was also developed. This draws from published evidence as much as possible. A key source is the TAG Data Book, which sets out values for parameters used in the economic model including:

- Values of time, which are used to monetise time saving benefits;
- Journey purpose splits – i.e. what proportion of trips are for business, commute or other purposes – this is important because different trip types have a different value of time;
- Road-based traffic split – i.e. what proportion of traffic is car, light goods vehicle or heavy goods vehicle?
- Vehicle occupancy – which is used to understand how many people benefit from reducing congestion.

Table 3: Core assumptions

Assumption	Value	Source / comment
Starting year of benefits	2028	Reflects the rough timescale in which digital twins might be funded and delivered. Note, this should not be taken as a forecast or as representing an accurate timescale – for EBA purposes at this stage, it is considered unlikely that the results of a different 'starting year' would materially affect the scales of estimated impacts in relative terms.
Length of appraisal period	10 years	Aligns with other digital business cases such as SOBC for the delivery of the Digital Built Britain Programme*, and economic case for the National Underground Asset Register**.
Discount rate	3.5% per year	Green Book / TAG
Price base used to report benefits	2010	TAG
Base year used for discounting to present values	2010	TAG
Do Minimum scenario	Unless otherwise stated, the Do Minimum assumes a 'business as usual' scenario – that is, it assumes that there are no other investments during the appraisal period that would have a significant impact on transport network conditions that are relevant to the use cases.	

* EY, Strategic Outline Business Case[1] for the delivery of the Digital Built Britain Programme Level 3, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/810351/18.1139_141_SOBC_Digital_Built_Britain.pdf

**https://www.gov.uk/government/publications/national-underground-asset-register-unlocking-value-for-industry-and-the-wider-economy/national-underground-asset-register-nuar-economic-case-summary

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Economic Benefits Analysis – qualitative analysis

Additional impacts

Whilst the EBA has captured key quantifiable benefits, it should be recognised that non-monetised benefits are also an important consideration when determining the value of a project. Here, non-monetised is used to refer to benefits that either cannot be monetised due to the lack of an established method or evidence, or are excluded from the quantified analysis due to their likely scale relative to other quantified benefits.

The table here summarises some of the non-monetised benefits that are relevant within the TAG framework.

TAG category	TAG sub-category	Potential impacts
Economy	Business users & transport providers	In addition to the journey time savings and reliability impacts to business users that have been captured as monetised benefits, there could be cost savings to private firms that would be captured under this sub-category. For instance, for use case 5 (freight management at ports), a reduction to fuel usage and hence an increase in carbon benefits has been estimated. This would also represent a cost saving to freight companies.
	Wider impacts	Additional wider impacts not included in the quantified benefits could include: **Agglomeration**: this benefit reflects the uplift to productivity associated with increasing density. The use cases that include time savings could increase effective density – and hence output, as a result of agglomeration – through improving intra-city connectivity. The academic literature suggests that impacts such as agglomeration are typically in the range of 10-30% of the value of the conventional user benefits (such as time savings) that are estimated in economic appraisals. Agglomeration benefits for the use cases included in this study are considered to be likely to be at the lower end of this scale. **Increased labour force participation**: the use cases that reduce congestion lead to time savings for users of the transport network. Those time savings reduce the (non-monetary) costs of travelling to work, and therefore increase the returns that people get from working. This can induce increased labour supply at the margin. That in turn leads to an increase in output.

Table 4a: Additional TAG framework benefits (TAG impact category: Economy)

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Economic Benefits Analysis – qualitative analysis (continued)

TAG category	TAG sub-category	Potential impacts
Environmental	Greenhouse gases	A reduction to carbon has been monetised for use case 5, but could be applicable for other use cases too. To the extent that there is an increase in active travel or public transport usage (particularly in use case 2 which would improve interchange), there could be mode shift from highway which would bring about environmental benefits. In use case 4, optimising traffic signals would not only lead to less delay to vehicles, but also potentially reduce emissions as a result of less stationary vehicle time.
	Noise, air quality	As with greenhouse gases above, a mode shift from highway would lead to benefits against this sub-category.

Table 4b: Additional TAG framework benefits (TAG impact category: Environmental)

TAG category	TAG sub-category	Potential impacts
Social	Physical activity	In use case 2, it is possible that there would be increased usage of public transport due to improved interchange. This could lead to an increase in physical activity (people needing to access a station instead of travelling directly in a private vehicle) and hence improved health. Physical activity also plays a role in improving mental health. More generally, the positive improvement to transport users' experience of the network (e.g. reduced congestion) may reduce stress levels and improve mental health.
	Accidents	As with noise and air quality above, a mode shift from highway would lead to benefits against this sub-category by reducing highway accidents. As a general observation, this could be a very important impact to measure against for unplanned events and crisis management.
	Access to services	Through reducing congestion and improving the public transport offer (uses cases 1-4), journey times would be reduced for people accessing key services on the routes affected. This would also be significant in crisis situations if large barriers were caused to established routes.
Public accounts	Cost to broad transport budget	Costs to the public sector are not included as they are out of scope, but as well as the 'negative' impact of requiring an investment cost, an IN-DT could also bring about cost savings over time. For instance, in the business case for SITS, TfL identified benefits including: • reducing the costs of scheme planning and development ; and • increasing the economic benefit of future scheme investment due to improved decision making and design. These both represent efficiencies that could be captured by the use cases included in this EBA. Another example could relate to efficiencies around maintenance and renewal; any ways in which an IN-DT could help to extend the life of assets on the network would also represent a saving.

Table 4c: Additional TAG framework benefits (TAG impact categories: Social, Public Accounts)

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Economic Benefits Analysis – results

Quantified benefits

The table opposite shows the results of the quantified analysis. All benefits are expressed £millions as totals across a ten-year period (2028-37), expressed in 2010 prices. All impacts are shown as present values, discounted to 2010, in line with guidance in TAG.

A blank cell means that particular benefit has not been quantified for the use case in question, although those benefits have still been considered qualitatively.

The quantified analysis suggests that each use case would generate millions of pounds of benefit, with the fourth use case providing the highest level of quantified benefit, amounting to c.£530m as a present value. The total across all five use cases is approximately £1,850m in undiscounted terms, or c.£850m as a present value.

Benefit	UC1: Network capacity management	UC2: Multimodal customer journey optimisation	UC3: Integrated incident & emergency management	UC4: Planned works & maintenance management	UC5: Freight management at ports
Journey time savings (£m)	91.6	108.4	73.3	505.0	-
Reliability (£m)	13.7	-	11.0	-	-
Journey quality (£m)	-	2.1	-	-	-
Vehicle operating costs (£m)	2.5	-	1.9	23.2	-
Mode shift benefits excl environmental (£m)	-	0.04	-	-	-
Environmental benefits (£m)	-	0.03	-	-	16.9
Output change in imperfectly competitive markets (£m)	3.0	0.4	2.4	-	-
TOTAL (£m)	**110.8**	**110.9**	**88.7**	**528.3**	**16.9**

Table 5: Quantified economic benefits analysis results

Economic Benefits Analysis – sensitivity tests

Results of sensitivity tests

A range of sensitivity tests were undertaken in order to understand how the core results would change if particular key assumptions were adjusted.

This produced a range of results around the central estimates presented on the previous page. The table below summarises the ranges that result from the sensitivity tests for each use case.

There is uncertainty around the value of total benefits, reflected in the range that results from the sensitivity tests. In particular, UC4 has a wide range because the results are sensitive to the assumption about the proportion of delay that could be avoided due to the implementation of an IN-DT.

Use case	Results (total quantified benefits, £m, present value, 2010 prices and values)	
	Results using core assumptions	**Range from applying sensitivity tests**
UC1: Network capacity management	£110m	£60m-£230m
UC2: Multimodal journey optimisation	£110m	£55m-£160m
UC3: Integrated incident and emergency management	£90m	£40m-£190m
UC4: Planned works and maintenance management	£530m	£180m-£880m
UC5: Freight management at ports	£20m	£10m-£35m

Table 6: Quantified economic benefits analysis sensitivity tests

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Economic Benefits Analysis – conclusions

Conclusions

This chapter sets out the results of an economic benefits analysis for a set of use cases for an Integrated Transport Network Management Digital Twin. The use cases were developed as part of an evidence review at the outset of this study; a prioritisation process was undertaken in order to reduce an initial longlist down to five that were taken forward for EBA. These were selected on the basis of the whether there was sufficient evidence to undertake a quantification, and whether the benefits were likely to be at sufficient scale to justify doing so.

The analysis is based on underpinning evidence wherever possible. Where evidence for an assumption was more limited, a value was selected, and sensitivity tests undertaken to examine the impact of altering that assumption.

The quantified benefits are consistent with the TAG framework, with key benefits including journey time savings, journey quality and reliability. The results of the analysis suggest that quantified benefits for each use case could be in a range as shown in the Table 6 on the previous page. In total, the benefits across the five use cases using the core set of assumptions are approximately £1,850m in undiscounted terms, or c.£850m as a present value.

It is not always possible to capture all impacts of an investment in quantitative terms. Non-monetised benefits should also be considered in determining the value of a project and prioritising investments. For the use cases examined here, non-monetised impacts are likely to include:

- Cost savings to businesses
- Cost savings to the public sector
- Additional environmental benefits
- Health benefits due to increased levels of physical activity
- Improved access to services.

In summary, the results of the EBA suggest that there is value in further developing the case for investment in an IN-DT.

EBA results

£1.85bn

Undiscounted value, 2010 prices, 10-year appraisal period

£856m

TAG-consistent present value, 2010 prices, 10-year appraisal period

Appendices

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A.1

Use case scoring

Use case scoring

Theme 1 - Better business-as-usual operations across modes between network management operators

The following use cases were captured as a 'long list' from the evidence review (from literature review and stakeholder interviews). They were then scored according to an agreed criteria to help inform the 'short list' to be taken through into Economic Benefits Analysis. Subsequent development and rationalisation was completed, culminating in the 22 use cases shown in the 'Evidence Review' section of this report.

No.	Use case title	Use case description	Could the use case be delivered in five years? (Q1)	Could the use case be multimodal? (Q2a)	Could the use case be multiagency? (Q2b)	Potential scale of benefit from the use case (Q3)	Quality of understanding of the use case (Q4)	Ability to quantify under HMG guidance (Q5)	Rational for assessment	Score
1	Network capacity management	Make decisions to best allocate capacity to optimise demand e.g., optimise network to benefit public transport	Yes	Yes	Yes	High (5)	Med (3)	Low (1)	Would likely need transport modelling to quantify the impact. The impact could be high given estimates of the costs of congestion to the UK economy.	9
2	Network capacity management around hubs	Make decisions to best allocate capacity to optimise hub function and limit impact on neighbouring transport network	Yes	Yes	Yes	Med (3)	Med (3)	Med (3)	Evidence about benefits is generally anecdotal / qualitative rather than fully quantitative.	9
3	Multimodal journey optimisation	Better linking of different modes e.g., to reduce interchange time	Yes	Yes	Yes	High (5)	Low/ Med (2)	Low (1)	Quantification would likely need to rely on assumptions, although benefits could be significant given the wide level of applicability	8
4	Multimodal journey planning	Place-based, end-to-end timetable optimisation and journey plans that improve network performance and user experience	Yes	Yes	Yes	High (5)	Low/ Med (2)	Low (1)	Would likely need a significant transport modelling exercise (or lots of unfounded assumptions) to capture benefits	8
5	Network management at authority interface points	Detect suboptimal performance at boundaries/interfaces e.g., authority borders, change in road type (SRN/local), junctions etc.	Yes	Yes	Yes	Med (3)	Med (3)	Low (1)	Quantification would likely be assumption-heavy given lack of quantitative evidence from evidence review.	7
6	Passenger surge management from hubs	Priming local infrastructure to cope with surges in passengers existing hubs e.g., changing crossing signal timings outside rail stations.	Yes	Yes	Maybe	Low (1)	High (5)	Low (1)	Use case stemmed from engagement with TfL, though not much empirical evidence at present. Net benefits may be low given that there would likely be disbenefits to vehicles despite pedestrian benefits and not all traffic signals can be adjusted.	7
7	Network management performance enquiries	Respond to public queries e.g., verify and explain why traffic signals are working in a particular way	Yes	Maybe	Maybe	Low (1)	High (5)	Low (1)	Little or no data on the baseline and anticipated impacts. Relatively niche use case where benefits are not likely to match the scale of others.	7
8	Intersection safety	Using 'right time' multi-source data to analyse intersection usage (e.g. vehicle and pedestrian movements etc.) to inform traffic management (e.g. signal plans) to improve safety outcomes.	Maybe	Maybe	Maybe	Med (3)	Low (1)	Low (1)	Data is available on intersection safety incidents and there is some evidence of the possible impact from a DT (Hermes). However, following an investigation into methodology, it was not clear how a DT would improve safety outcomes.	5
9	Freight abnormal loads at tunnels	Better matching of vehicle and cargo specifications with infrastructure for journey planning	Yes	No	Maybe	Low (1)	Med (3)	Low (1)	Likely to be difficult to obtain data on freight usage at tunnels. Applicable to specific situations and hence likely lower benefits than for other use cases.	5

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Use case scoring

Theme 2 - Increased transport network resilience

The following use cases were captured as a ‘long list’ from the evidence review (from literature review and stakeholder interviews). They were then scored according to an agreed criteria to help inform the ‘short list’ to be taken through into Economic Benefits Analysis. Subsequent development and rationalisation was completed, culminating in the 22 use cases shown in the ‘Evidence Review’ section of this report.

No.	Use case title	Use case description	Could the use case be delivered in five years? (Q1)	Could the use case be multimodal? (Q2a)	Could the use case be multiagency? (Q2b)	Potential scale of benefit from the use case (Q3)	Quality of understanding of the use case (Q4)	Ability to quantify under HMG guidance (Q5)	Rational for assessment	Score
1	Integrated incident and emergency management	Combination of use cases that improve the timeliness, accuracy, and richness of incident detection; the quality of incident response with the most appropriate system actors; the methodology for and content of incident reports; better identify the characterisation, contextualisation, and frequency of incidents; provide the most appropriate mobilisation of emergency services for an incident.	Yes	Yes	Yes	High (5)	High (5)	High (5)	Strong evidence from TfL SITS which could be applied to other cities. Would likely use Inrix or TomTom data for baseline. Benefits likely to be significant given the SITS results.	15
2	Planned works and maintenance management	Using federated data, a digital twin could optimise temporary roadworks and minimise disruption across authorities and modes. This could include better road-rail maintenance plan sharing to improve scheduling (e.g. so as not to being doing major roadworks at the same time as weekend closures for rail or similar). Federated data sources could include remote condition monitoring initiatives to help to enable this use case.	Yes	Yes	Yes	Med (3)	Med (3)	Med/High (4)	Expecting to receive data from TfL that would support this, although would need to investigate the potential to carry it across to other cities (e.g. baseline data on temporary traffic lights)	10
3	Events planning and management	Planning for larger scale less frequent events (e.g. Olympics, Commonwealth Games) that could have a knock-on effect elsewhere	Yes	Yes	Yes	Med/High (4)	Med (3)	Low (1)	Would likely need to make assumptions to be able to quantify. Overall benefits probably low (i.e. average benefit per year) because of low frequency of applicability.	8
4	Crisis/disaster planning and management	Responses to major events such as natural disasters could be improved through being able to consider the response of transport system users more accurately and completely from right time data e.g. during an evacuation. This data could allow responses to be tested in advance, and for better responses to be developed. Holistic decision making could lead to more broadly successful outcomes (or more broad limitation of negative consequences).	No	Yes	Yes	High (5)	Low (1)	Low (1)	As outlined in the EBR, "These benefits would need to be counterfactually quantified which is difficult". Underpinning evidence is very limited. Frequency of applicability is low.	7
5	Scenario analysis and forecasts	Near-term operational planning through running scenarios / stress tests based on up-to-date data collected by a digital twin	Maybe	Yes	Yes	Med (3)	Med (3)	Low (1)	Would likely need to make assumptions about the scale of change that this use case would create.	7
6	Strategic freight hub planning	Using freight journey and composition data to better plan where freight can/should be transported by rail.	No	Yes	Yes	Med (3)	Low (1)	Low (1)	Potentially time-consuming exercise to understand where this could be implemented and what the scale would be, especially as understanding has been ranked 'low'.	5

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Use case scoring

Theme 3 - Improved collaboration with other stakeholders

The following use cases were captured as a 'long list' from the evidence review (from literature review and stakeholder interviews). They were then scored according to an agreed criteria to help inform the 'short list' to be taken through into Economic Benefits Analysis. Subsequent development and rationalisation was completed, culminating in the 22 use cases shown in the 'Evidence Review' section of this report.

No.	Use case title	Use case description	Could the use case be delivered in five years? (Q1)	Could the use case be multimodal? (Q2a)	Could the use case be multiagency? (Q2b)	Potential scale of benefit from the use case (Q3)	Quality of understanding of the use case (Q4)	Ability to quantify under HMG guidance (Q5)	Rational for assessment	Score
1	Freight management at ports	Improving the efficiency of hub operations at ports, particularly matching of supply/demand of inbound/outbound traffic in relation to hub facilities/capacity i.e., number of cranes, berths, parking, train sidings etc.	Yes	Yes	Yes	Med (3)	Med (3)	Med (3)	Would require assumptions to be made and baseline data collection could be time consuming.	9
2	Parking planning and management	Automating road space allocation (potentially through granular DTROs) based on transport system needs e.g., commuter cyclists and buses, last mile freight parking, could be particularly effective when paired with self-driving vehicles.	No	Maybe	Yes	Low/ Med (2)	Med (3)	Low/ Med (2)	Some evidence exists around scale of change to delay (Arup case study) although most evidence is heavily reliant on the mass adoption of new technologies e.g. self-driving vehicles.	7
3	Passenger management within hubs	Optimising intra-hub flows of passengers in relation to internal infrastructure to improve passenger flow, safety, and/or experience). Transport services arriving at a hub could be regulated (e.g., train arrival times) to prevent platform overcrowding, escalator overloading etc.	Yes	Yes	Maybe	Med (3)	Med (3)	Low (1)	Not much quantitative evidence from the EBR so would need to be assumption heavy. Could be difficult to quantify the benefit without modelling the scenario.	7
4	Operational resource planning	Improving operations particularly within large hubs (from the perspective of the operators) by better understanding passenger behaviour/needs (e.g. estimating required number of staff to cater for passengers within terminal such as public transport, retail, and cleaning staff.	Yes	Yes	Yes	Low (1)	Med (3)	Low/ Med (2)	Could probably collect some baseline data on number of rail passengers at airports but would still require heavy assumptions around the scale of benefit per operator.	6
5	Demand responsive transport	Richer decision making by DRT schemes, not just based on customer input but forecasts from federated data supplied to operators.	Yes	Yes	Yes	Low (1)	Med (3)	Low (1)	Evidence from EBR relatively limited	5
6	Public services planning	Improving the efficiency of public services provision (healthcare, education, utilities, refuse collection etc.) through a better understanding of transport network performance, connections between assets (e.g., doctors), ability for individuals to work from home (i.e., internet vs commute). Specific example was related to avoiding refuse vehicle being stuck in congestion.	Yes	Maybe	Yes	Low (1)	Med (3)	Low (1)	Limited evidence and benefits likely to be lower given focus on a small subset of total journeys	5
7	Energy-transport operational management	Better matching demand for electrical energy for transport and supply. Substation enhancements, vehicle charging availability (private/commercial), load profiles.	Yes	Maybe	Yes	Low (1)	Low (1)	Low (1)	Some limited evidence in the EBR of scale of change that can be achieved, but not specifically from a DT.	3

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Resilience

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The case for resilience

A potentially important use for a digital twin, but case making is more difficult than with other examples

Context

As part of the prioritisation process, use cases were identified that would represent a way of improving the resilience of the transport network, rather than affecting day to day operations or even unplanned incidents that occur with some degree of frequency.

As an example, the ‘Crisis/Disaster Planning’ use case is described as follows:

“*Better respond to major events such as extreme weather by being able to more accurately and completely model the response of transport system users from 'real' operational data captured on a continual basis. This fidelity of modelling allows a number of transport system management responses to be tested, and for better responses to be deployed, ultimately allowing decisions to be more holistically made, leading to more broadly successful outcomes (or more broad limitation of negative consequences). A digital twin could enable this scenario planning to be done on both a long term/long-range basis, or in a shorter term, approaching real-time to significantly improve the accuracy of the predictions being made by the twin.*”

Difficulties in making the case for resilience

From the perspective of an EBA, there are several issues with quantifying the potential benefits. These include:

Low probability but high impact events

Typically, transport economic appraisals estimate annual values of most or all the quantifiable benefits that are to be included, and then adds these up as a stream of benefits over time. For instance, several of the use cases included in the EBA within this study include a valuation of annual time savings.

This becomes more difficult with events that could be very rare but could deliver significant one-off benefits. The appraisal period for digital projects tends to be relatively low compared to physical transport infrastructure – we are using ten years for this study. The type of crisis/disaster that we are referring to in this use case might not happen at all within a given ten-year period.

A way of accounting for this would be to build in a probability adjustment to the calculations. Nonetheless, an incident that would cause £1bn of economic costs but only has a 0.1% likelihood of occurring in any given year, would ‘only’ generate an expected £1m of benefit per year, which might not be enough to justify investment depending on the costs involved.

Uncertainty around modelling scenarios

Even before getting to this issue, it would be necessary to have an estimate of the potential scale of benefit. This would need both a reference case and a ‘Do Something’ option to be modelled. This would not be straightforward, because it is difficult to understand how those scenarios would look – e.g., in the case of climate resilience, what other measures might be implemented prior to or in the absence of a digital twin? How might investing in a digital twin change that?

Difficulty in defining/obtaining the data needed

Related to the above, it may be difficult to define or obtain the data required for modelling impacts, because:

- Existing evidence is limited.
- The range of impacts is uncertain as a result – for instance, a report to the Climate Change Committee noted that “the biggest gap is the evidence on what physical impacts will occur from climate change”.
- It is unlikely that any individual existing model would capture the range of possible impacts from a multimodal perspective.

In summary, it is possible to articulate a case for resilience use cases qualitatively, but it is more difficult to quantify for the reasons outlined above.

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Planned Works & Maintenance Management – avoiding benefits claimed by others

The Use Case 4: Planned Works & Maintenance Management

An important use for a digital twin, but quantitative case making needs to be careful about avoiding benefits already claimed by other initiatives

Context

As part of the prioritisation process, use cases were identified that would represent a way of improving the management of the transport network at points where works or maintenance are planned. The 'Planned works & maintenance management' use case has been prioritised for quantitative economic benefits analysis, and is described as follows:

"Better access to planned works and asset condition data (e.g., from remote condition monitoring or reports) across stakeholders could enable a deeper understanding and scheduling of asset maintenance (i.e. temporary works) that impact the transport network. For example, underground utilities works which typically result in costly temporary roadworks could be coordinated across stakeholders to improve scheduling (e.g. avoiding roadworks during closures for rail)."

The benefits of a digital twin that has functionality to meet this use case are broadly in two areas:

- Reducing the total number of street and road works due to better coordination between stakeholders.
- Deploying better traffic management interventions (e.g. signal positions and timings) to reduce congestion to private vehicles and public transport.

National Underground Asset Register (NUAR) (2021)

The NUAR programme has been established following an economic case made by the Geospatial Commission for improvement to access to underground utilities asset data through a centralised platform. The economic analysis predicted a 30:1 Benefit to Cost Ratio (BCR).

Detailed analysis of the benefits claimed in this initiative's economic case shows that the focus for calculation of benefit is around reducing the number of so-called utility strikes (unforeseen strikes on other underground utilities when conducting maintenance or renewals work). The three benefits are:

1. Savings from reduced utility strikes
2. Reduced costs of sharing data
3. On-site efficiency improvements for projects

Since the case is made specifically around a purported 60,000 utilities strikes per year, which are a fraction of the estimated 4m street and road works each year, there is limited scope for double counting benefits here.

However, whilst the NUAR benefits claimed are large, there must be a reason why NUAR wasn't able to claim benefits across all street and road works events. We believe this is due to the economic case written for the DfT's 'Street Manager' initiative.

Street Manager (~2019)

DfT's Street Manager digital service replaces an incumbent system (Electronic Transfer of Notifications – EToN), and aims to transform the planning, management and communication of street and road works through open data and intelligent services. The economic case claimed annual benefits in the range of £3.5m - £10.5m due to a reduction in the quantity and duration of street and road works.

Detailed analysis of the benefits claimed shows that congestion costs were sourced from a 2004 Halcrow Report, which estimated that the cost of congestion per work per day of £355 for small works on rural roads, to £25,000 per day for large works on congested urban roads. These values were then used to calculate a value of congestion savings given three scenarios (0.05%, 0.1% and 0.15% reduction in duration).

Given that the calculations were made across all congestion cost (within England due to Street Works' initial rollout scope), we conclude that NUAR was unable to claim benefits across all street and road works events to avoid double counting benefits already claimed by Street Manager.

The implication for this IN-DT EBA is that benefits associated with reducing the amount of congestion-causing street and road works have already been claimed by others and should not be claimed again.

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