# Digital Twin Value Overview and Use Cases for Airport Operations

**A Digital Twin Consortium Whitepaper**

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## ABSTRACT

Modern airports rely on an intricate web of interrelated systems, fulfilling business and operational requirements. As complexity continues to increase, resources are being drained and costs are skyrocketing. Traditional methods of optimizing individual systems are no longer adequate. Digital twins have been introduced at airports to improve operational efficiency and reduce waste. Digital twins are driving business value across airport domains, including airport master planning, asset and workforce management, passenger experience, and emergency response.

This paper presents approaches to digital twin implementations based on a System of Systems (SoS) framework, which enhances the interconnectedness of airport systems, makes existing capabilities more accessible, and fosters new capabilities that create more value for airport operators and the broader airport ecosystem. The paper emphasizes the importance of system interoperability, supported by a common information model and data environment, and provides several case studies describing how a Digital Twin SoS can be implemented in airports. Finally, the paper provides actionable steps to minimize cost, risk, and time-to-value from digital twin implementations by aligning to business strategy, establishing proper governance, and incorporating an SoS framework.

# 1 PURPOSE AND INTENDED AUDIENCE

The purpose of this paper is to help airport owners, operators, and consultants understand the concept of digital twins and the potential stakeholder benefits by taking a System of Systems (SoS) approach to developing and implementing an airport digital twin. The approach is intended to be scalable to airports of all sizes and includes a methodology to minimize the risk, cost, and time-to-value from digital twin implementations.


Figure 1-1: Intended audience for this paper.
(*Source :Airports Council International.*)[1]

The intended audience for this paper is all service-providing stakeholders in an airport ecosystem that can realize value from implementing and connecting digital twins, including those identified in Figure 1-1 . The paper incorporates insights from an extensive survey of airport operators and consultants on the adoption and maturity of digital twins for airport operations. The survey was conducted jointly by the Digital Twin Consortium and buildingSMART USA.

# 2 INTRODUCTION

## 2.1 AIRPORT CHALLENGES

Airports, much like cities, are complex systems with numerous stakeholders. Both are hubs of activity and serve as gateways to economic and social interactions. They face similar challenges in infrastructure development, capacity management, revenue generation, and environmental sustainability.

For instance, airports must manage greenhouse gas emissions, energy consumption, water conservation, and waste management, akin to a city's public utilities. Moreover, both entities must consider the socioeconomic impacts of their operations and strive for resilience in the face of economic fluctuations and security threats.

[1] *https://www.slideshare.net/slideshow/aci-acris-semantic-model-an-introduction-v16/125331482*

An airport can act as a core of a larger urban development, magnifying the economic potential and connectivity of the broader region. However, achieving this requires overcoming significant challenges such as scaling sustainable aviation technologies, addressing noise and air pollution, and ensuring the health and safety of both travelers and residents.

### 2.1.1 Business Challenges

Despite the COVID-19 pandemic, air travel volume is increasing and is expected to almost double to 19.5 billion passengers by 2042[2], as shown in Figure 2-1. This growth presents challenges for the aviation industry, particularly related to airport infrastructure.

Airport operators must manage the surge in demand without compromising the passenger experience and strive for operational excellence. Most airports are nearing maximum capacity, and it's not feasible to construct new infrastructure in time to meet the growing demand. Therefore, operators must optimize operations and passenger flow using existing facilities and resources.

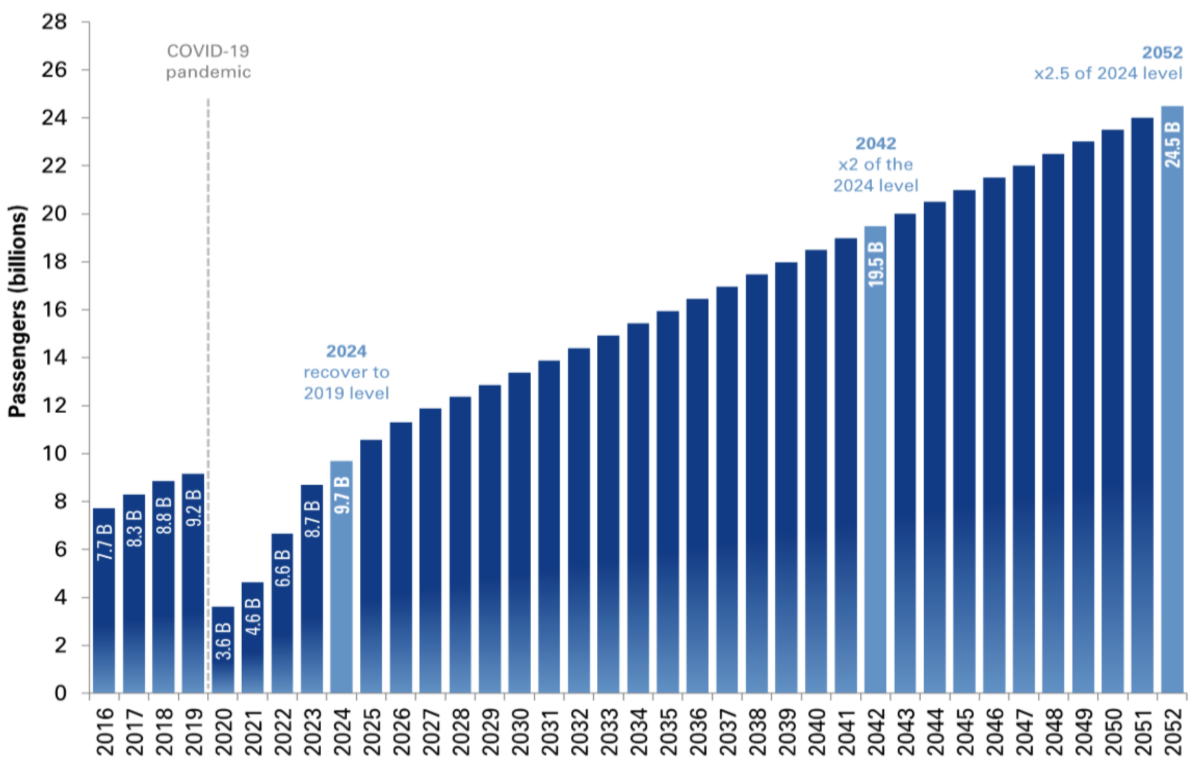


Figure 2-1: Long-term global passenger traffic forecast (2016-2052).
*(Source: Airports Council International.)*[3]

[2]*https://store.aci.aero/wp-content/uploads/2024/02/WATF-Executive-Summary.pdf*

[3] *https://store.aci.aero/wp-content/uploads/2024/02/WATF-Executive-Summary.pdf*

In addition, airports must ensure a consistent and predictable travel experience. With the rising number of passengers, operators need to provide safe, secure, and sustainable air transport to minimize the risk of transmission and potential future pandemics.

In the wake of the pandemic, airport operators are realizing the need for strong collaboration among all stakeholders and a transformation of operations to address unprecedented challenges. Sustainability, adaptability, and flexibility are crucial for an effective transformation.

The collaboration needed to effectively operate an airport is often constrained by inefficient communication between organizational units, information systems, projects, and individuals. These siloed operations hinder decision-making, which can have cascading effects on airport operations, leading to unnecessary disruptions for passengers. To overcome these challenges, airport operators must adopt a holistic view of their operations to facilitate cross-collaboration among stakeholders.

Furthermore, airport operators need to take a proactive approach. They should explore how new technologies can mitigate emerging threats and minimize their impact on business operations. They must then create the right conditions to implement and benefit from these new technologies, gaining greater agility to respond when disruptions occur. Operators will also need to assess the overall passenger experience and reevaluate operational models.

### 2.1.2 Technical Challenges

Airports are facing a myriad of technical challenges that can impact their efficiency and service quality.

System interoperability is crucial for seamless operations, yet many airports struggle with integrating disparate systems, which can lead to operational delays and reduced passenger satisfaction. People, digital systems, and infrastructures must operate in harmony for airports to deliver excellent passenger experiences. Despite the ongoing digital transformation of airports, the lack of seamless integration between different systems and IT infrastructure leads to work silos forming in landside, terminal, and airside operations, resulting in unnecessary delays, sub-optimal solutions, and costly advanced systems not being used to their full potential.

The lack of real-time data from these systems is another significant hurdle, as it hinders the ability to make informed decisions quickly, affecting everything from flight schedules to security measures. Decision-making support tools are essential for analyzing real-time traffic conditions and coordinating activities among stakeholders to respond quickly and effectively. For example, if a gate change is needed for an arriving plane, notifications must be sent to passengers, airport personnel, and airline personnel, and departing passengers must be redirected to a different security checkpoint to prevent delays.

Furthermore, data quality is paramount; inaccurate or incomplete data can lead to misinformed strategies and policies. The absence of common semantics in airport systems can significantly impact data quality by creating inconsistencies and misunderstandings. When data is not standardized, it becomes challenging to integrate and analyze information from different sources. Moreover, data quality underpins the entire digital twin framework; inaccurate or low-quality data can lead to misguided insights and decision-making.

When asked to identify challenges in implementing airport digital twins, the top survey responses were implementation cost and data readiness, as shown in Figure 2-2. Much of that cost is likely related to establishing proper governance to ensure quality data. The value of a digital twin is directly related to the value of the data it consumes.

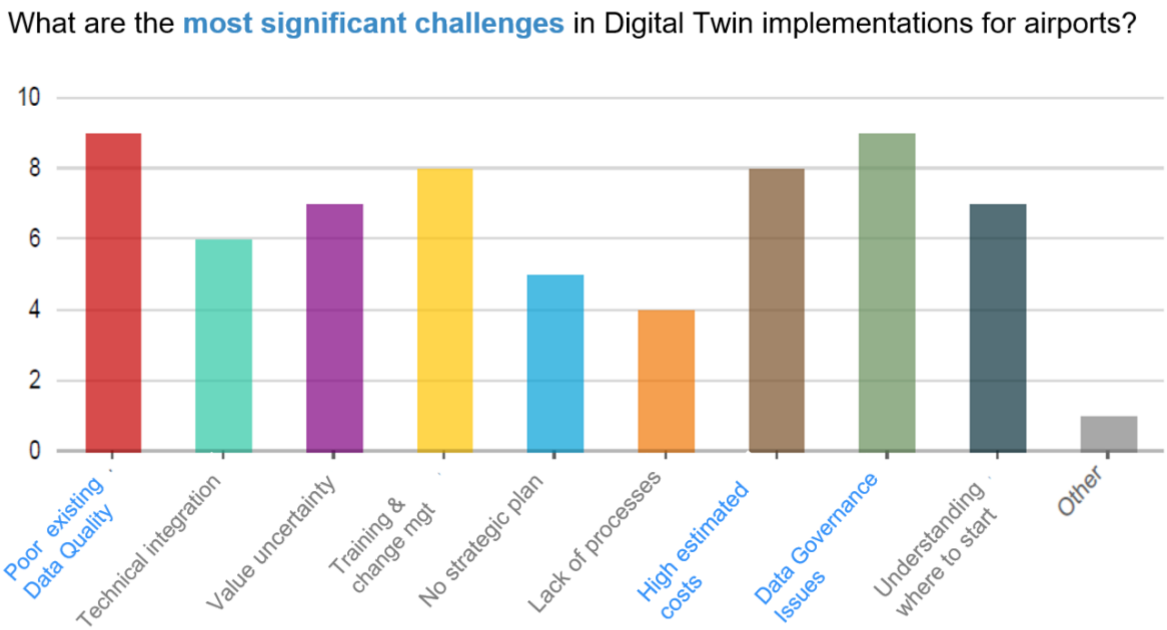


Figure 2-2: Airport survey results. (*Source: DTC and buildingSMART USA*.)

## 2.2 What is a Digital Twin?

The Digital Twin Consortium defines a digital twin[4] as an integrated data-driven virtual representation of real-world entities and processes, with synchronized interaction at a specified frequency and fidelity.

Within an airport, value can be realized from a digital twin representing a single elevator. However, the value can increase significantly when digital twins of all interconnected systems within the airport are gradually developed and connected. Rather than optimizing a single asset like an elevator, an aggregate digital twin can represent the entire airport as a business. It becomes an active knowledge base for contextual understanding, driving predictions of future states, which in turn, drives decisions and actions to optimize business outcomes. The digital twin

[4] *https://www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin/*

of the elevator, for example, can be leveraged when simulating and predicting people flow in the entire airport.

*"Digital twins can represent the entire airport ecosystem or smaller components. They can be spun up quickly by ingesting structural (relatively static) information to compose the environment and overlaid with actual or simulated events. These provide fast feedback on multiple scenarios to support short, medium, and longer-term decision making by humans and increasingly by machines."*

\- Airport Survey Respondent

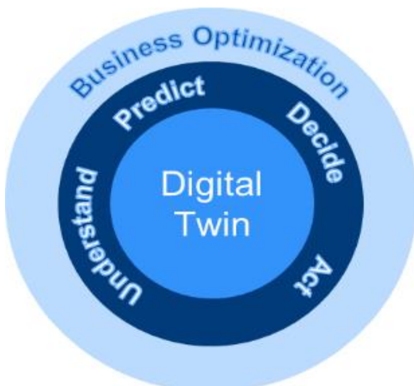


Figure 2-3: Business decision-making with a digital twin. (*Source: DTC Mobility & Transportation Working Group.*)

Decision-making in an airport can be a complex and time-consuming process that involves multiple stakeholders and significant resources. This can lead to unexpected negative impacts. However, with the help of digital twins, airports can create highly detailed virtual representations of their facilities and systems that are updated at the necessary frequency and fidelity.

These digital twins can be supported by artificial intelligence and reasoning to improve situational awareness and visualization of the complex airport environment.

## 2.3 WHAT IS A SYSTEM?

The International Council on Systems Engineering (INCOSE) defines a system as a construct or collection of different elements that together produce results not obtainable by the elements alone. The Object Management Group (OMG) defines a system as an assembly of interacting components organized to achieve specific goals and functions.

A digital twin can be implemented as a system.

### 2.3.1 SYSTEMS THINKING

In traditional design, it is common to focus too much on technical details and jump straight into creating a solution without fully considering the problem at hand. At times, we may also stay at a high management level without properly understanding how the product will be used. Much of our time is spent on integration and testing to ensure that the system functions correctly.

A system approach, on the other hand, takes a different approach. It prioritizes defining passenger needs and required functionalities early in the development cycle. This approach considers the required functionality in all phases of the airport's life, including design concept, detailed development, operation, maintenance, and decommissioning.

Systems consider both the business and technical needs of the airport to provide a quality product or service that meets the passenger needs. Risks are identified and mitigated early in the process due to the systematic and holistic approach of systems. Each change is simulated within the system as early as possible to ensure that all events or situations are addressed.

This approach leads to faster decision-making, lower risk, and a better service or product. It also enables rapid adaptation to new and potentially disruptive technologies. The airport's Master Plan is a great starting point for applying systems to ensure that designs and changes drive toward a common vision and airport goals.

### 2.3.2 AIRPORT SYSTEMS

The systems approach for airports involves viewing the airport as a complex system with various interconnected components that work together to achieve objectives within the airport infrastructure. A systems approach combines various capabilities such as passenger check-in, baggage handling, security screening, flight planning, air traffic control, and ground operations into a cohesive and interconnected platform.

This approach considers the interactions between different capabilities of the system such as technology, infrastructure, personnel, passengers, flight operations, regulations, and environmental factors to optimize airport operations and increase efficiency. Through a systems approach, airport operators can:

- Streamline processes,
- Improve communication and coordination between different departments,
- Increase efficiency,
- Minimize delays, and
- Ensure a smooth experience for passengers and airlines.

This system approach helps the airport operate more effectively as a unified entity rather than a siloed organization. It provides a holistic view of operations to ease the cross-collaboration between all stakeholders.

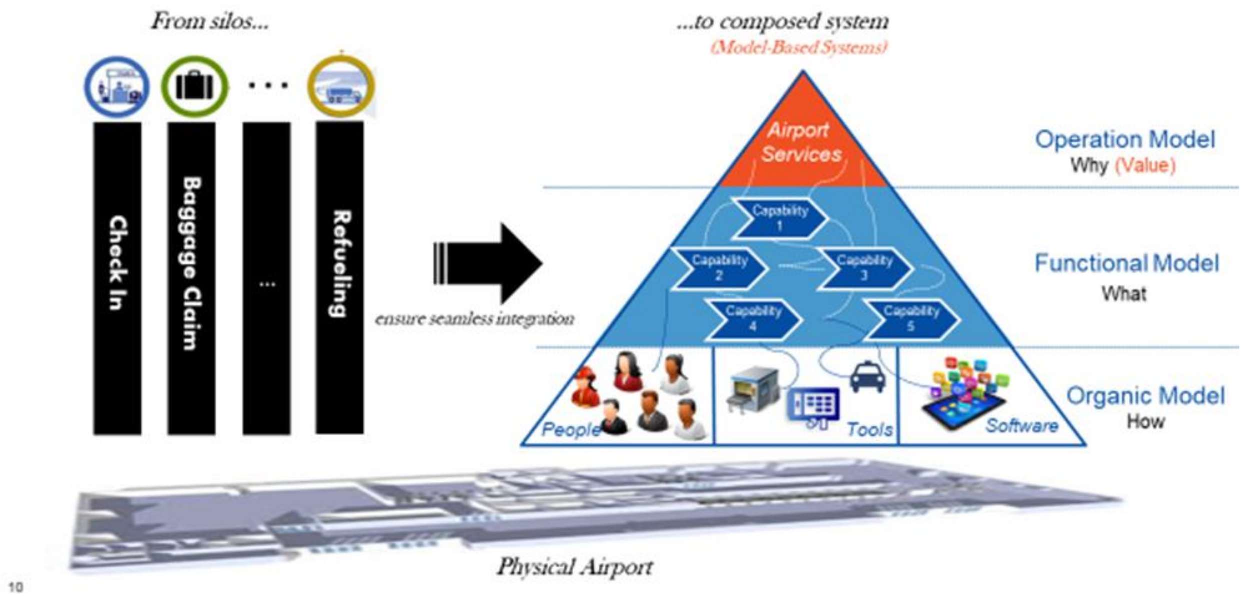


Figure 2-4: Transforming silos to an Airport-as-a-System.
(*Source: DTC Mobility & Transportation Working Group.)*

## 2.4 Aligning Digital Twin Investments with Business Value

As airports undertake digital transformation initiatives, it's increasingly important to connect technology investments directly to business value. In the most general sense, value is defined as usefulness, advantage, benefit, or desirability, rather than the relatively narrow accounting or financial perspective that defines value as being the material or monetary worth of something.

Non-monetary examples of value within an airport include delivering requested services, promptly resolving customer problems, and gaining access to actionable information for better business decisions. In each example, business value must be tied to reaching high-level goals: improving passenger experience, airport profitability, and sustainability.

By aligning digital twin initiatives with a digital transformation strategy to create value, airports can more effectively evaluate which enabling technologies truly support their strategic goals. Using digital twins, airports can model, measure, and virtually analyze how best to deliver stakeholder value. This strategy encourages a mindset shift among stakeholders, from engineers to executives, fostering a design philosophy that prioritizes tangible business benefits over technical specifications alone.

This shift requires a cultural change within organizations that emphasizes value creation rather than mere output. Stakeholders must embrace a new philosophy that values business impact over technical achievement. Training, development programs, and change management will be essential to equip teams with the skills and knowledge to think and operate in this new paradigm.

### 2.5 THE VALUE OF DIGITAL TWINS TO AN AIRPORT

Airports have successfully implemented digital twins to address specific challenges resulting in quantifiable value. Below is a representation of value potential within several use cases discussed in detail later in this paper.

- Managing increases in Passenger Volume
    - Increase execution efficiency through Digital Twin Master Plan
    - 15% increased passenger capacity through optimized space planning
    - Up to 30% decrease in design costs for expansion projects
- Increasing Operational Efficiency
    - Reduce equipment breakdowns by up to 75%
    - Cut maintenance costs by up to 25%
    - Increase uptime by up to 35%
- Maximizing Revenue Generation
    - Up to 30% reduction in passenger wait times
    - Targeted advertising
    - Increased concession spending
- Meeting Sustainability Goals
    - Less than 10% total water loss
    - 15-20% reduction in energy consumption
    - Net Zero/Carbon Neutral within 5-25 years

This paper will describe how these examples of value potential can be effectively realized using a System of Systems (SoS) approach to digital twin implementations. Although currently adopted by only a few forward-thinking airports, a SoS approach to value creation is poised to become a widespread practice in the near future.

## 3 CONSIDERATIONS FOR VALUE CREATION

Value creation is a multifaceted concept that lies at the heart of modern business strategies. Value creation involves turning valuable airport resources and relationships (inputs) into results (outputs) that create value for stakeholders including customers, employees, investors, and other relevant parties.

Airports create and distribute economic value in many ways, including generating revenue, jobs, and community investment. Collaborative efforts among all stakeholders in the aviation value chain are essential to enhance the overall value and ensure a robust, future-proof airport ecosystem.

By focusing on outcomes rather than technologies, airports can move beyond the novelty of digital twins and harness their full potential to drive passenger demand and sustainable profit. In practice, this requires a clear understanding of the key performance indicators (KPIs) that digital twins can impact, a robust framework for measuring success, and a commitment to continuous improvement based on the insights gleaned from the digital twins' data. Ultimately, the success of digital twins in value creation hinges on a strategic vision that places outcomes at the forefront of digital twin initiatives.

## 3.1 Quantifying Value

Quantifying business value often involves a combination of financial and non-financial measures. Each airport may prioritize different metrics based on its unique context and goals.

### 3.1.1 Financial Metrics

Financial metrics include Return on Investment (ROI), Net Present Value (NPV), and Payback Period. Based on digital twin case studies, a 12-18 month payback period is achievable.

### 3.1.2 Non-Financial Metrics

Non-financial metrics for quantifying value are listed in Table 3-1.

| | |
|---|---|
| Customer Satisfaction | Happy passengers are more likely to generate repeat business and referrals. |
| Airport Rankings | Exposure airports receive based on "best of" rankings list provides potential funding opportunities and more favorable passenger perspective. |
| Market Share | Indicates the company's position relative to competitors. |
| Employee Satisfaction and Retention | High employee satisfaction leads to better productivity and retention. |
| Quality Metrics | For software projects, this could be fewer defects or higher reliability. |
| Strategic Alignment | Consider how the project aligns with the company's strategic goals. Does it support growth, innovation, or competitive advantage? |
| Value Points (Agile) | Value points help quantify the value delivered by a project. They focus on what matters most to the business. |
| Sustainability Goals | Corporate stewardship and ESG initiatives are driving investments and federal funding into major projects at airports today. The focus can be significant with how federal dollars are allocated to new capital and operational projects. |

| | |
|---|---|
| Innovation and Brand | Airports leverage innovation in their competitive pursuit of new airline partners and expansions. Providing systems of systems ecosystems with avenues for airlines to benefit from operational efficiency, data-driven decisions, and intelligence can be an attractive offer. |

Table 3-1: Non-financial metrics for quantifying value.
*(Source: DTC Mobility & Transportation Working Group.)*

### 3.1.3 Key Performance Indicators

Key Performance Indicators (KPIs) are one of the most effective methods to measure and analyze airport performance.

Modeling KPIs into a digital twin can significantly enhance the monitoring and management of airport operations. For instance, an airport digital win may track passenger wait times and service revenue as KPIs, using these metrics to quantify improvements and calculate the ROI of the digital twin in tangible terms.

KPIs are used to evaluate performance based on a list of predefined criteria and use this data to improve operations. Here are some examples of airports KPIs:

Cost Avoidance/Savings:

- Reduce facility maintenance and equipment costs
- Reduce equipment, supplies and fuel costs
- Reduce electrical costs
- Reduce jet fuel burn
- Reduce workforce inefficiencies
- Reduce property damage from leaks
- Reduce asset early replacements

Risk Avoidance/Mitigation:

- Reduce claims and litigation
- Reduce time to address catastrophic failures
- Reduce airfield delays and closures
- Reduce taxi-in delays
- Reduce electrical and communication outages
- Reduce baggage downtime

## 3.2 Realizing Value from Digital Transformation

As airports continue to navigate the complexities of digital transformation, the strategic use of digital twins will be a key differentiator in achieving competitive advantage and long-term success. The synergy between digital transformation and digital twins lies in their ability to convert data into actionable insights, thereby driving smarter, more efficient business practices.

*"By centralizing data and establishing a streamlined workflow, teams can work together more effectively and efficiently; by creating a centralized hub for data exchange and collaboration, the digital twin platform empowers stakeholders to work together effectively."*

- Airport Survey Respondent

### 3.2.1 Aligning Business Strategy with Digital Twin Initiatives

Digital twins can bridge the gap between technical capabilities and strategic business objectives, marking a significant advancement in how airports leverage technology for growth and innovation.

When aligned with business strategy, digital twins can amplify the value of existing investments in data and technology within an airport. By capitalizing on existing business intelligence, rules, and AI models enabled through IT, a digital twin creates a synergistic relationship between business and technology. This strategic alignment not only streamlines operations but also fosters the development of new business models and strategies.

Using digital maturity models can help align business strategy and goals with digital twin initiatives. The Digital Transformation Maturity Model developed by the Digital Twin Consortium identifies the characteristics an organization needs to develop to successfully navigate a digital twin journey. The model acts as a framework that helps identify where to start and how to manage the changes that digital twins introduce to an airport.

| | **Level 1**<br>Passive | **Level 2**<br>Starter | **Level 3**<br>Progressive | **Level 4**<br>Mature | **Level 5**<br>Master |
|---|---|---|---|---|---|
| Strategy & Ops | No clear strategy | Limited strategy Unaligned with Ops | Limited strategy & Ops alignment | Strategy consistency & Ops alignment | Strategy continuously drives Ops decisions |
| Leadership | "Leaders" are misnomer | Traditional and limited leadership capabilities | Leadership skills recognized but not embedded in ways of working | Leadership enables cross-functional collaboration | Leadership promotes continuous change |
| Culture, Change & Capability | Active resistance to change and ideas | Change is the exception not the norm | Change not integrated at a strategic level | Digital Twins are recognized as effective drivers for change | Change is integral to culture supported by Digital Twin & Agile |
| Operating Model & Process Standardization | Siloed Ops, ad-hoc decisions, no data, no process | Limited process standardizations | Process standardization & basic automation | End to end process automation & Intelligence | Use of (DTO) and real time operational monitoring |
| Digital Twin Technology | **Descriptive**<br>• scattered, static data in systems<br>• no integration, communication or automation | **Diagnostic**<br>• operational & sensory data<br>• dashboard with operational insights | **Predictive**<br>• contextualized data<br>• machine learning<br>• some automation, connected data and systems | **Prescriptive**<br>• real time data from integrated systems<br>• situational awareness<br>• recommendations | **Autonomous**<br>• continuous decision intelligence<br>• adaptive and generative AI<br>• self-sufficient |

Figure 3-1: Digital transformation maturity model. (*Source: DTC Business Maturity Model Subgroup*.)

The model identifies five stages of maturity that can guide airports as they progress toward the full potential of digital twins. Five elements within each stage should be evaluated for all relevant use cases. These stages are points on a continuum and describe attributes of the organization that affect its openness to digital twin technology, mindsets, and work methods. At any given time, an airport organization is likely to be at different stages of maturity for different elements of the model. Understanding these complexities is crucial for successfully integrating digital twins into the organization. When implemented correctly, digital twins can aid in developing, executing, and continuously improving business strategies.

A supplemental Digital Twin Maturity Model provides a framework for assessing the development and implementation of the digital twin technology described in the Digital Transformation Maturity Model. This supplemental model includes multiple dimensions that reflect the various aspects of digital twin technology, including its integration with existing systems, the quality of data and analytics, and the technical capabilities to support its use.

Aligning these two maturity models is crucial for airports to ensure that their digital transformation efforts are in sync with the development of their digital twins. This alignment can lead to a more cohesive and integrated approach to digital innovation, where digital twins become a central component of the airport's digital ecosystem. By doing so, airports can leverage the full potential of digital twins to not only replicate and understand their physical assets but also to predict outcomes, optimize processes, and drive innovation.

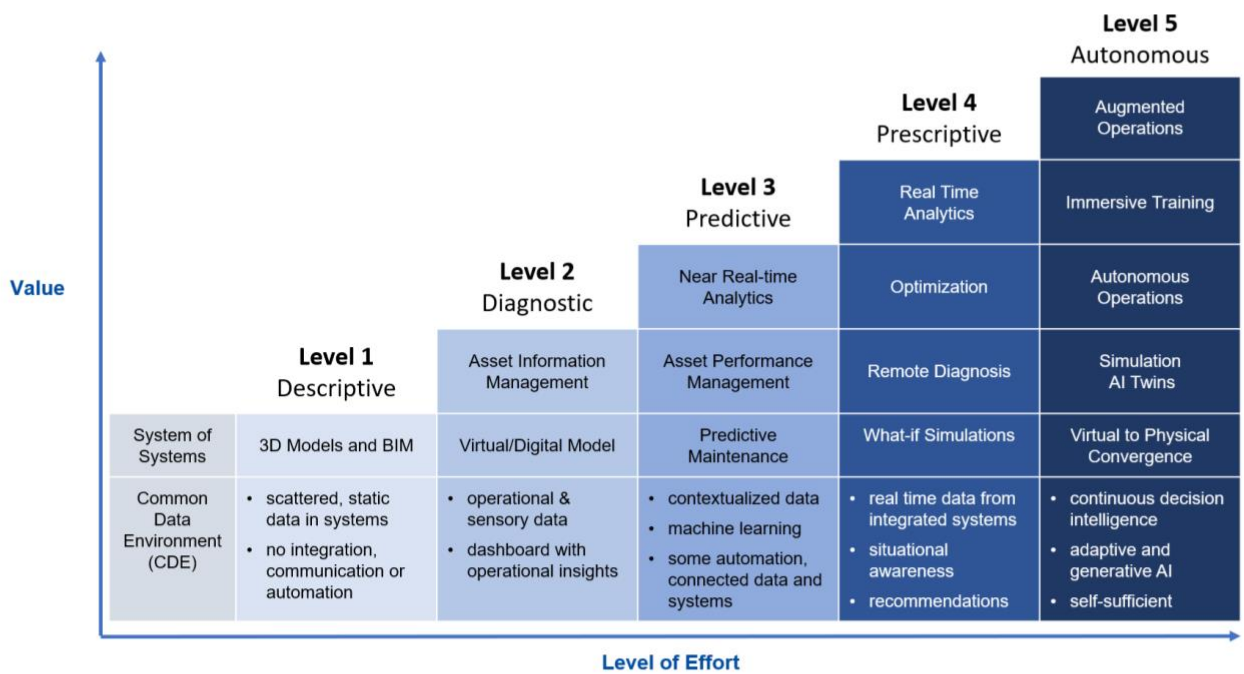


Figure 3-2: Airport Digital Twin Maturity Model (*Source: DTC Mobility & Transportation Working Group. Inspired by GW Consulting Analysis Maturity Model*.)

Foundational to this roadmap is a common data environment (CDE) that can minimize technical debt and support a system of systems approach to value creation. From there, more and more capabilities can be added to reach advanced stages of maturity.

The Digital Twin Maturity Model can help airports identify where they are on their digital twin journey and help develop a roadmap that creates incremental value from the effort expended to reach a level of maturity.

When asked to identify the maturity level of their digital twin initiatives, the majority of the airports surveyed indicated they are at the beginning stage, but a significant portion are also maturing.

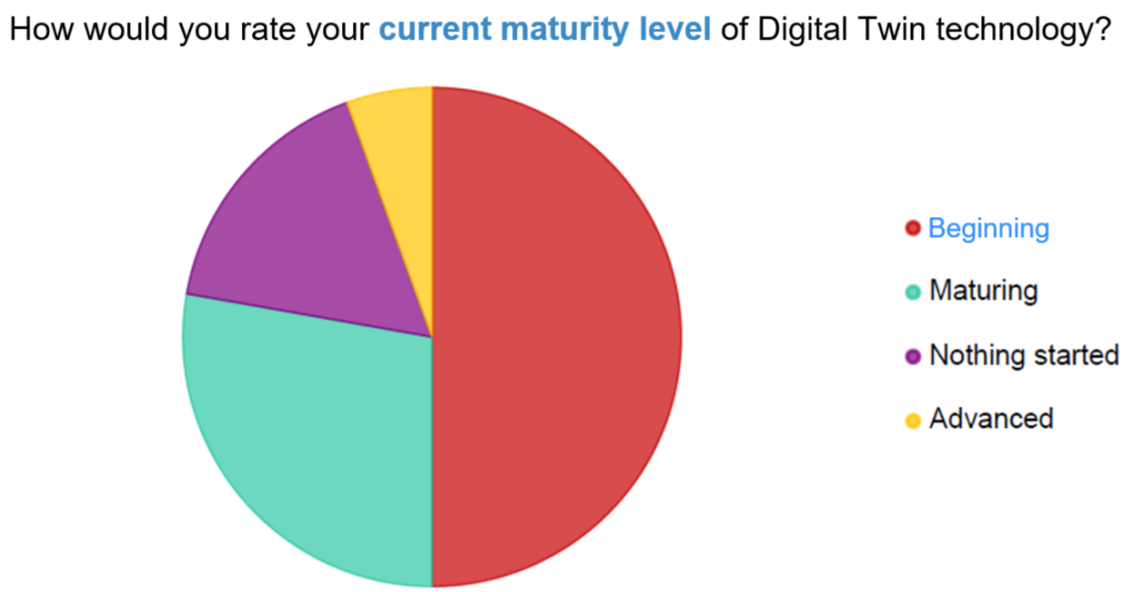


Figure 3-3: Airport survey results. (*Source: DTC and buildingSMART USA.*)

### 3.2.2 Using a Capability Value Matrix

The strategic implementation of digital twin capabilities is crucial for maximizing return on investment with minimal effort. The Capability Value Matrix developed by the Digital Twin Consortium serves as an invaluable tool for organizations embarking on a digital twin journey. This framework is designed to be architecture and technology-agnostic, focusing on the capability requirements of use cases rather than the features of technology solutions.

The matrix is a useful method to identify which capabilities to implement next that will provide the greatest return for the least amount of effort. By plotting capabilities based on their value and effort, an airport can create a holistic roadmap of how to most effectively leverage current investments and understand how interconnecting capabilities can support advanced capabilities. Every airport will have a different plotting based on their current maturity level and needs. An example is shown below.

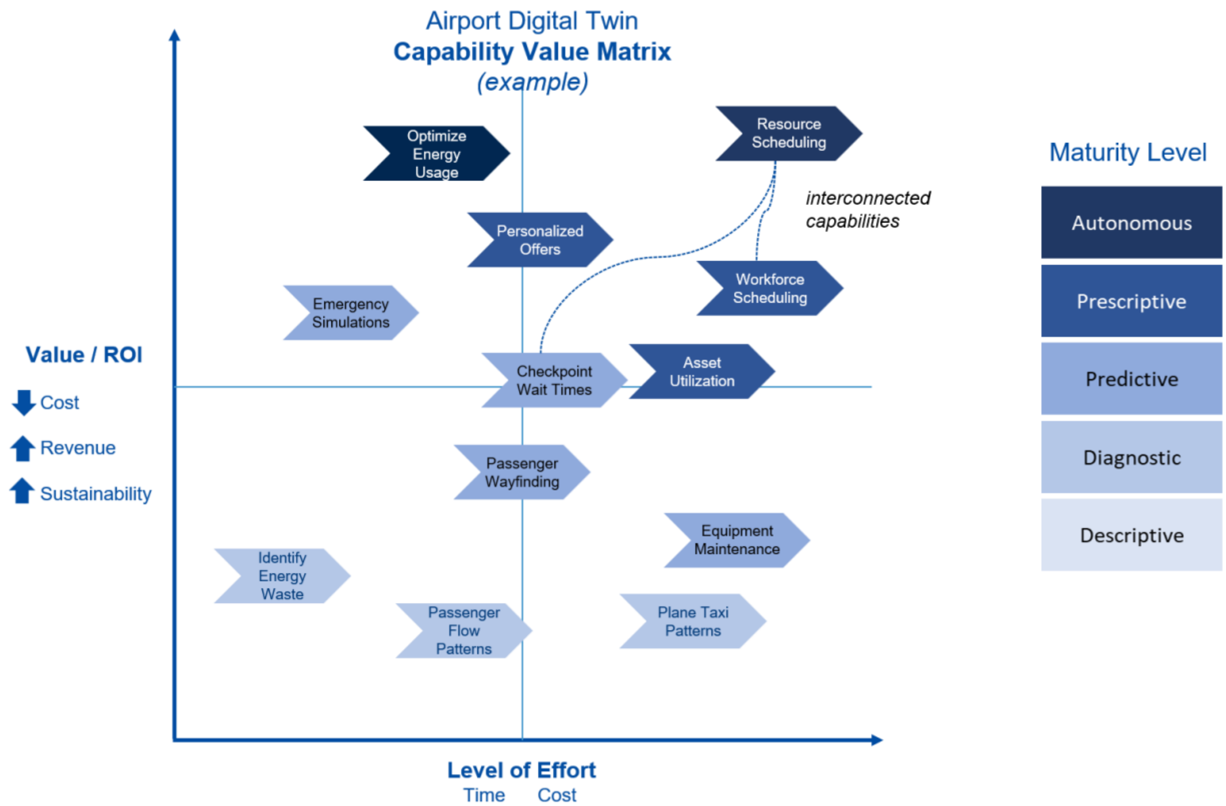


Figure 3-4: Capability value matrix. (*Source: DTC Mobility & Transportation Working Group*.)

By utilizing this matrix, airports can systematically evaluate and prioritize digital twin capabilities that align with their specific business objectives and operational needs. The matrix clusters capabilities around common characteristics, enabling a clear visualization of which areas will yield the most significant impact. For instance, capabilities that enhance real-time data analysis and predictive maintenance can be prioritized over those that are less critical to the core functions of the digital twin.

Moreover, the matrix aids in identifying synergies between different capabilities, revealing opportunities for integration that can further streamline processes and reduce effort. It also assists in pinpointing redundant or overlapping functionalities that can be consolidated, thereby saving time and resources.

When asked to identify capability milestones achieved, the most common responses from surveyed airports centered on BIM and GIS. These capabilities provide foundational building and geospatial information for digital twins to provide contextual understanding.

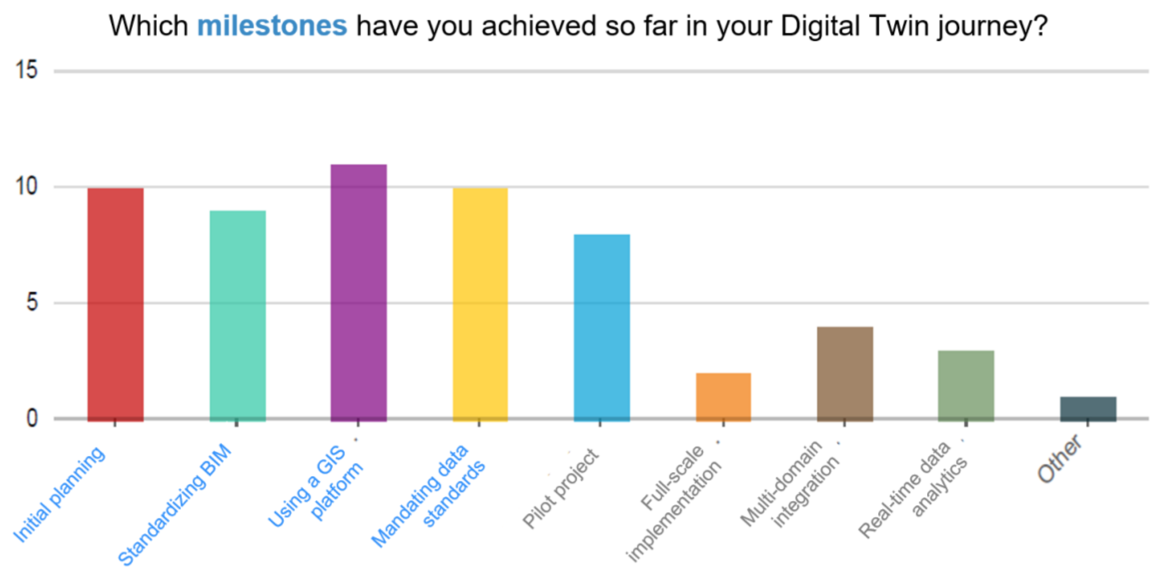


Figure 3-5: Airport survey results. (*Source: DTC and buildingSMART USA*.)

By combining detailed spatial information from GIS with the dynamic simulation capabilities of digital twin, airport authorities can achieve a comprehensive real-time visualization and analysis of their operations. For example, at Amsterdam Airport Schiphol, the CDE collects and processes data from BIM, GIS, and other systems to maintain a detailed and real-time digital representation of the airport.

### 3.2.3 Managing Innovation

Digital twins can play a pivotal role in innovation management, particularly within the framework of ISO 56002. This standard provides guidance for establishing, implementing, maintaining, and continually improving an innovation management system.

Digital twins serve as a critical tool in this process by enabling airports to simulate, predict, and optimize the performance of equipment and processes before they are physically realized, thereby reducing costs and time to value. They facilitate a deeper understanding of the innovation lifecycle, from the identification of opportunities to the deployment of solutions, aligning with the core components of ISO 56002 which emphasize the importance of managing innovation processes systematically to achieve sustainable success.

Furthermore, the integration of digital twins within innovation management systems allows for real-time data analysis and the ability to adapt to changes swiftly, ensuring that innovation initiatives are robust and resilient in the face of evolving market demands and technological advancements. By harnessing the power of digital twins, airports can foster a culture of continuous improvement and drive forward their innovation agendas with confidence and precision.

## 3.3 REALIZING VALUE FROM A COMMON INFORMATION MODEL

A common information model (CIM) serves as a blueprint for organizing and managing data to increase its value and utility across the airport ecosystem. It serves as the backbone for data integrity, interoperability, and scalability.

By adopting a CIM, airports can break down data silos, streamline data integration, and foster collaboration among different domains and stakeholders.

For example, Copenhagen Airport (CPH) has invested in sharing information with all significant entities within the airport ecosystem, resulting in enhanced overall efficiency.

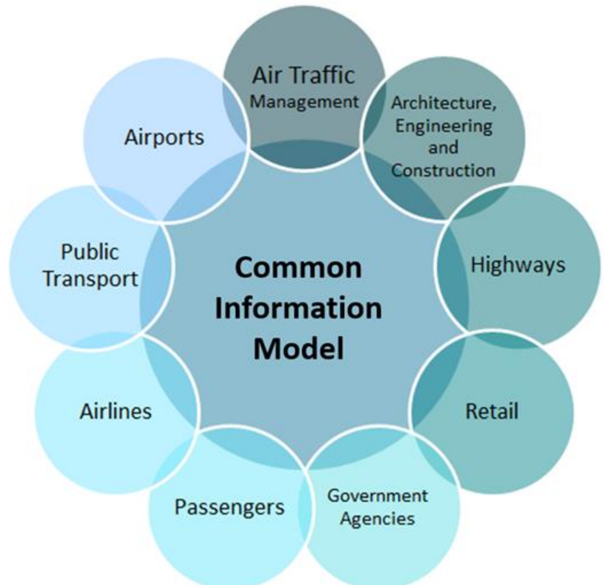


Figure 3-6: Common Information model. (*Source: Airports Council International*)[5]

A CIM is also pivotal in harnessing the full potential of digital twins, serving as a foundational framework that enables the seamless integration and synchronization of data across digital twin systems. A CIM promotes interoperability between digital twins, minimizing system integration costs and allowing for a more comprehensive and integrated view of complex systems. This is particularly beneficial where multiple digital twins interact within airport simulations.

The adoption of a CIM supports the scalability of digital twins. As airports grow and their operations become more complex, the need for a robust and adaptable information framework becomes increasingly apparent. A well-designed model can accommodate this expansion, enabling a digital twin to evolve alongside the business. Additionally, it supports the reuse of digital twin components, which can significantly reduce the time and effort required to develop new digital twins.

The strategic value of a CIM is further amplified when coupled with advanced technologies such as AI and machine learning. These technologies can leverage the structured data provided by the model to generate deeper insights and predict future states of airport systems. A CIM provides the framework for holistic knowledge across airport domains and ensures data is AI-ready for scalable and sustainable deployments.

[5] *https://www.slideshare.net/slideshow/aci-acris-semantic-model-an-introduction-v16/125331482*

#### 3.3.1 Extending the Value of BIM in a Common Data Environment

The CIM serves as the backbone for a common data environment (CDE), enabling a unified view of data that drives value across all phases of an airport lifecycle.

A CIM extends the value of building information modeling (BIM) within a CDE by fostering a more integrated and collaborative approach that caters to airport contexts. Unlike BIM, which primarily focuses on the physical and functional characteristics of a building, CIM encompasses a wider range of data that can be used across different stages of an airport's lifecycle.

By leveraging a CIM within a CDE, stakeholders can ensure that data is not siloed within the design phase but remains accessible and beneficial throughout the construction, operation, and renovation stages of an airport. A CIM facilitates the creation of a unified digital thread that connects all stages of the airport lifecycle.

This holistic approach not only enhances data quality and accessibility but also supports real-time decision-making with a complete audit trail and a single source of truth. It aims to amalgamate information systems related to airport design and planning, asset management, and operations management into a cohesive platform.

#### 3.3.2 Aligning Industry Information Models

Members of the Airports Council International, buildingSMART, Digital Twin Consortium, and TM Forum are collaborating to align open models and APIs to refine a Common Information Model supporting an airport ecosystem. The model is also being applied to smart city initiatives to solve interoperability challenges within highly distributed, heterogeneous information systems.

The ACRIS Semantic Model is an airport industry standard information model managed by Airports Council International. ACRIS comprises airport domain concepts represented by business terms and the relationships between these terms. The model enables semantic interoperability in the airport ecosystem by minimizing semantic heterogeneity. The model has been adopted by several international airports worldwide.

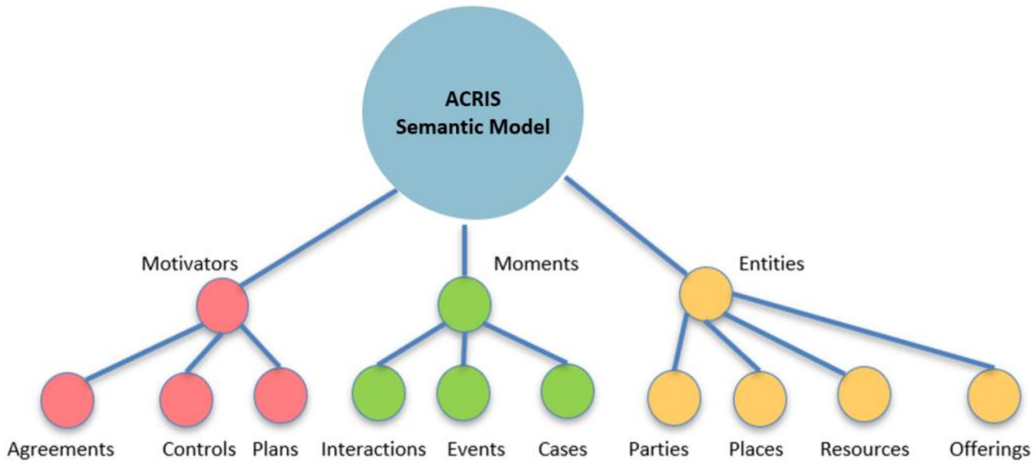


Figure 3-7: ACRIS semantic model vocabulary. (*Source: Airports Council International*.)

buildingSMART is an international organization that aims to improve the exchange of information between digital systems used in the construction industry. It has developed Industry Foundation Classes (IFCs) as a neutral and open specification for BIM. buildingSMART is engaging in this collaboration to align models for interoperability extending BIM to an operational digital twin.

# 4 SYSTEM OF SYSTEMS FRAMEWORK FOR VALUE CREATION

## 4.1 WHAT IS A SYSTEM OF SYSTEMS?

OMG defines a system of systems (SoS) as a complex assembly of multiple independently operable systems that collaborate to achieve a higher-order functionality that individual systems cannot achieve alone. In other words, an SoS is greater than the sum of its parts.

Connected digital wins can be represented as a system of systems.

### 4.1.1 AN AIRPORT SYSTEM OF SYSTEMS

The SoS approach for airports involves viewing the airport not just as a single complex system, but as a collection of interconnected systems that interact with each other and with external systems like a city system or vertiport system. The SoS approach addresses this complexity by focusing on the services necessary to improve the interactions among these systems. Using this approach, the airport is seen as part of a larger network.

By adopting a SoS approach, airports can better understand and manage the interactions and dependencies between these different subsystems or systems. It helps improve coordination, communication, and collaboration between various stakeholders to provide a seamless travel experience for passengers.

A practical example of the SoS approach can be seen at Amsterdam Schiphol[6].

By integrating the baggage control system with passenger check-in information, Amsterdam Airport Schiphol has streamlined the process for the airlines of baggage tracking and reconciling passengers with their bags. Linking into real-time flight information allows for quick off-loading of baggage when a passenger misses his flight and for redirection of bags on alternative flights when connections are missed. The integrated system also provides accurate, up-to-date information and metrics to monitor baggage handling performance, helping managers resolve issues quickly and identifying areas for improvement.

Approaches to architecting a SoS for airports include:

1. A top-down SoS approach involving a strategic, high-level perspective in managing and integrating the various subsystems within an airport. This approach starts with defining overarching goals and objectives and then decomposing these into specific systems and their interactions.
2. A network SoS approach emphasizing the interconnectedness and interdependence of various systems (e.g., between an airport system and a city system). This approach focuses on defining the services necessary to integrate these systems.

The architecture of a SoS serves as the technical framework for the systems within it. The architecture defines how these systems will be employed by users in an operational setting.

#### 4.1.2 Top-down Approach to Creating an Airport SoS

The top-down SoS approach allows airports to scale operations and adapt to new technologies through:

- Integration of diverse systems like airside and landside operations,
- Data integration and collaborative decision-making,
- Improved efficiency and performance (e.g., resource optimization, predictive maintenance),
- Ability to quickly adapt to unexpected changes or disruptions, such as flight delays or pandemics like COVID.

#### 4.1.3 Network-Based Approach to Creating an Airport SoS

Implementing a network-based SoS approach at airports involves:

- Integrating disparate systems,
- Sharing data and information across platforms,
- Coordinating decision-making processes, and
- Fostering collaboration among entities within and outside the airport ecosystem.

[6] *https://www.airport-technology.com/s?search=amsterdam*

For example, integrating airport systems with a city system creates a seamless and interconnected transportation network that enhances mobility and improves overall travel experiences. It helps to establish multimodal transport hubs where airports, vertiports, and city systems (e.g., buses, trains, metro) are closely connected. By taking a SoS approach, stakeholders can improve infrastructure design and services to enable easy and quick transfers between different modes of transportation. For example, passengers can move from a flight to an eVTOL service or city train without difficulty.

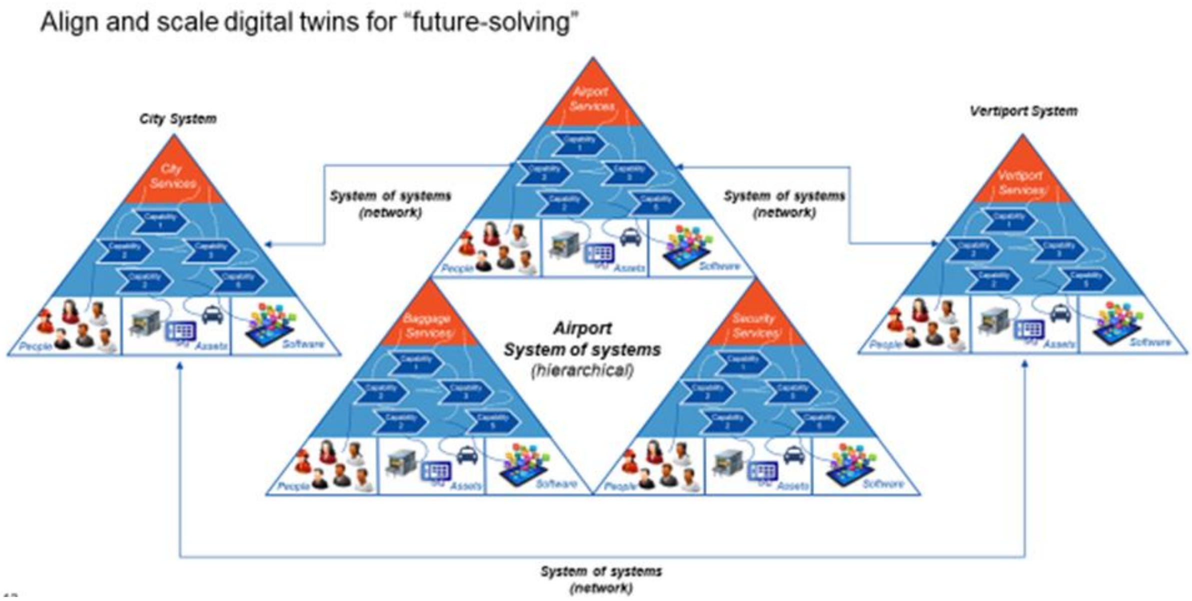


Figure 4-1: Composing an airport ecosystem as a System of Systems.
(*Source: DTC Mobility & Transportation Working Group.*)

## 4.2 A DIGITAL TWIN SYSTEM OF SYSTEMS

A Digital Twin SoS represents a cutting-edge approach to decision intelligence, where virtual models of complex systems are interconnected to reflect their real-world counterparts. These digital twins are not just static replicas; they are dynamic and updated at the necessary frequency and fidelity, harnessing data from sensors and other sources to simulate, analyze, and predict outcomes. This enables decision-makers to test scenarios, optimize operations, and make informed choices with a level of precision that was previously unattainable. Such systems can span across various domains, from transportation to retail, creating a cohesive and interoperable framework that enhances strategic and operational decisions.

As technology evolves, the integration of AI and machine learning further empowers these systems, providing deeper insights and automating complex decision-making processes.

## 4.3 THE VALUE OF A SYSTEM OF SYSTEMS FRAMEWORK

### 4.3.1 A HOLISTIC PERSPECTIVE

A SoS approach to value creation is a multifaceted strategy that recognizes the complexity and interconnectivity of an airport ecosystem. By viewing an airport as a composite of various interlinked systems, this approach seeks to optimize the creation of value across all levels. It involves a holistic understanding of how different components interact and contribute to the overall airport objectives.

The SoS approach provides a strategic framework that addresses the complexity of airport operations and their expansion. This approach considers the interconnectivity and interdependencies of various subsystems within an airport, such as air traffic control, security, passenger processing, and baggage handling. By analyzing these subsystems as part of a larger, integrated whole, airport authorities can identify bottlenecks, optimize resource allocation, and plan for future growth more holistically.

This method is particularly effective in identifying potential opportunities for innovation and growth, as it allows for a more comprehensive analysis of the factors that drive value. Moreover, it encourages a collaborative environment where the synergy between different systems can lead to greater efficiency and effectiveness in achieving business goals. The SoS approach can help balance the goal of maximizing profit with the goal of creating sustainable value that benefits all stakeholders, including customers, employees, and the broader community. It's a dynamic and adaptive strategy that aligns with the evolving demands of the global market and the need for responsible business practices.

A SoS approach decomposes the creation, capture, and delivery of value into discrete stages of value-producing activities, each enabled by the effective application of business and technical capabilities. This approach can minimize risk, cost, and time to value from digital twins.

A holistic perspective also recognizes the intricate web of interdependencies between an airport system and the broader city system of systems. In the context of a city, the SoS approach considers not just the physical infrastructure, such as buildings and roads, but also the dynamic interactions between various subsystems including transportation, utilities, communication networks, and the social fabric of the community.

The challenge lies in managing these systems in a way that is sustainable, resilient, and adaptable to change, ensuring that they serve their purpose while enhancing the quality of life for all stakeholders involved. A SoS approach allows for a more nuanced understanding of the cause-and-effect relationships that govern the operations and interactions within these vast, interconnected networks. City and airport planners and managers can better anticipate challenges, optimize operations, and innovate in response to the evolving needs of the population and the environment.

*"From the perspective of a public institution such as Orange County Public Works in California, responsible for managing critical public county, cross-city, and regional infrastructure, a system of systems framework has the potential to transform the way we deliver citizen and community benefits. More specifically, how we establish a resilient and robust organization of operations, management, and systems, how we improve and streamline visual intelligence and decision-making, and how we work with industry partners to embrace innovation and promote agile and cutting-edge technological digital transformation for our societies."*

- Kostas Alexandridis, Orange County Public Works

#### 4.3.2 Managing Complexity

Airports are one of the most complex public infrastructures to build and operate. Multiple stakeholders, including government agencies such as immigration authorities, operational entities such as airlines, ground handling companies, and security providers, as well as commercial players running retail concessions, must work together as a system of systems.

Each system within the airport has multiple components that operate independently and yet interdependently. For instance, efficient passenger processing within a terminal requires check-in, immigration, security, flight information, and baggage handling systems to work seamlessly.

These systems together act as the airport's intelligent nervous system. The foundation is built on a well-defined systems engineering methodology. This discipline is found in numerous industries and has proven to be effective.

In addition, integrating an airport's siloed systems through an SoS approach enables executives to ensure that their vision permeates the entire enterprise in a harmonious and agile manner.

As airports strive to be more business-like in their operations, it is key that decision-making is fundamentally aligned with customer needs. The complexity of an airport creates significant challenges when not approached from a systems perspective. Taking a top-down customer-centric systems engineering approach yields better, more deliberate results. Through systems thinking, innovation can be instilled cohesively throughout the organization.

Specifically, a SoS approach is inherently top-down starting from a clear and simplified, high-level view of an airport's mission, such as "Deliver a highly passenger-centric delightful traveling experience." This vision is then driven down into detailed sub-systems that must conform to the larger vision of a high-quality passenger experience. Decision-making must continually drive toward that vision at all levels.

#### 4.3.3 Situational Awareness

Situational awareness is critical in the complex and dynamic environment of an airport, where the safety and efficiency of ground operations and air traffic are at stake. It encompasses the collective perception of elements within the environment, understanding their significance, and anticipating their future status. This awareness extends to recognizing the position and intention of aircraft, vehicular and passenger movements on the ground, weather conditions, and the status of airport systems.

The holistic approach of an SoS framework can significantly enhance situational awareness in several ways:

| | |
|---|---|
| Aggregation of Information | The SoS can consolidate data from various constituent systems, providing a comprehensive view of the environment. |
| Coordination and Collaboration | The SoS enables better coordination and collaboration among systems, leading to improved awareness of events, threats, and opportunities. |
| Risk Assessment | By analyzing interactions between systems, the SoS can assess risks and vulnerabilities more effectively. |
| Adaptability | The SoS can dynamically adjust to changes, ensuring continuous awareness even in dynamic environments. |

Table 4-1: Holistic approach of an SoS framework.
*(Source: DTC Mobility & Transportation Working Group.)*

The SoS can integrate advanced technologies such as artificial intelligence, smart sensors, and computer vision into constituent systems to provide continuous decision intelligence. An SoS can combine real-time monitoring, predictive analytics, and visualization capabilities to improve overall operational awareness and data reliability while mitigating risks associated with human error.

Digital twin models can be developed and integrated within a SoS to predict future states based on current and historical information, enabling systems to anticipate and respond to potential emergencies swiftly.

A key goal in employing a SoS framework in airports is to create an environment where situational awareness is continuously updated and informed by the most accurate and timely information available, ensuring the highest levels of safety and efficiency in airport operations.

#### 4.3.4 Flexibility and Adaptability

Flexibility can be defined by the ability to change or respond quickly to minimize impact on passengers, costs, or performance. Flexibility is necessary for the airport as operations are constantly evolving.

Following the pandemic, airport operators are becoming more aware that they need to establish a strong collaboration between all stakeholders and transform operations to face unprecedented challenges. Adaptability and flexibility are some of the critical factors for an effective transformation.

The SoS helps improve airport flexibility and efficiency. It allows the integration of subsystem performance into the performance of the holistic airport system. Through "what-if" simulations it becomes possible to measure and monitor airport operation performances and explore improvements to increase airport flexibility and efficiency through a complex systemic approach in a measurable manner. SoS provides a holistic view on improving advanced airport operations and understanding how those adjustments will provide efficiency, effectiveness, and agility.

#### 4.3.5 INTERACTIVE SIMULATIONS

Leveraging a SoS framework, digital twins can transform simulations from static to dynamic tools that mirror the real world. This offers a deeper understanding of systems and their interactions, leading to more efficient and effective operations. Connected and interactive digital twins allow for the simulation of scenarios in a risk-free environment, providing valuable insights into potential outcomes without the need to physically test each variable.

Further, these interactive simulations can help improve airport planning, design and operations, as shown in Figure 4-2**Error! Reference source not found.**. For instance, passenger flow simulations are widely used in airport models to:

- Enhance capacity planning, resource planning, and flight scheduling,
- Increase non-aeronautical revenue,
- Improve passenger satisfaction,
- Improve hazard mitigation and evacuation, and
- Increase energy efficiency.


Figure 4-2: Airport simulation.[7] *(Source: DTC Mobility & Transportation Working Group.)*

[7]*https://www.icao.int/MID/Documents/2019/ASPIG1/WP%2013%20-%20AI%206%20-%20Airport%20Planning.pdf*

While a digital twin provides a real-time snapshot, active simulations can provide further value by predicting future states and potential outcomes of the system being modeled. This combination is especially powerful in airports, where it can lead to improved passenger flow, predictive maintenance, and optimized operations.  This value extends to optimizing the flow of everything that moves in an airport, including bags, aircraft, vehicles, and staff.

When combined with contextualized event data, digital twins can enable total process simulation of the airport system, allowing airport operators to visualize how individual parts of the complex systems work together. For planning and design, this proactive approach helps eliminate risks and costs before implementing physical systems. For operations, a holistic visual representation can help airports effectively manage day-to-day processes and envision future scenarios to optimize those processes.

Beyond 3D visualization, simulations significantly enhance the decision-making capabilities of digital twins. They provide decision-makers with the tools to make informed, complex decisions, improving the clarity, transparency, and reliability of outcomes. Simulations are thus indispensable for the effective deployment and utilization of digital twins in various applications, driving better design, operational performance, and optimization across different domains.

#### 4.3.6 Collaborative Systems

Siloed operations perpetuate inefficiencies. Slow decision-making leads to a domino effect on airport operations and causes unnecessary disruptions for passengers. To overcome challenges, airport operators must develop a holistic view of their operations to ease the cross-collaboration between all stakeholders.

A SoS collaborates to solve complex problems by leveraging the unique strengths of each component system, fostering inter-systemic communication and cooperation, and evolving through continuous learning and adaptation. This approach allows for a more holistic and robust response to challenges that are too intricate for any single system to handle. Each system within a SoS maintains its own operations and goals, yet when they synchronize their efforts, they create a dynamic network capable of adapting to and solving multifaceted problems.

Connected digital twins represent a SoS, where the interplay between different components can be analyzed and optimized. When these twins are connected, they form an ecosystem that can exchange data and insights, leading to a more holistic understanding of the issues at hand.

This interconnectedness is particularly crucial in tackling multifaceted challenges spanning multiple domains within an airport ecosystem.  A digital twin of an airport can interact with twins of city-wide transportation systems to simulate scenarios, predict outcomes, and inform decision-making processes.

The collaborative aspect of digital twins is not limited to machine-to-machine interaction. They also facilitate human collaboration by providing a shared platform for stakeholders to visualize, understand, and act upon data-driven insights. This collaborative environment is invaluable in complex projects, promoting a team-oriented approach to problem-solving and agile response to changes. Larger airports, including Dallas-Fort Worth, have Integrated Operations Centers that leverage collaborative systems and human decision-making.

Harnessing the power of collaborative systems can unlock new levels of efficiency, innovation, and sustainability, ultimately leading to better outcomes for the airport and its environment.

# 5 Digital Twin Use Cases in Airports

## 5.1 Managing Complexity in an Airport Master Plan

The airport is a complex system requiring planned improvements. Masterplans are crucial for shaping airports to become flexible, resilient, and sustainable. Before starting any capital project, masterplans must ensure that they enhance airport capabilities and services for an optimal passenger experience, meet safety and security requirements, and enhance overall airport services.

Adopting a SoS approach to planning enables the development of a comprehensive airport operations model for use case scenarios and "what if" simulations, leading to faster decision-making and reduced risk.

The SoS approach encourages collaboration to minimize disconnection with airport stakeholders. Developing the Master Plan System (MPS) is crucial for aligning infrastructure design, improving airport operations, and enhancing the passenger journey by focusing on real airport needs rather than design-driven processes. This provides airports with holistic capability-driven systems.

The adopted MPS should include new requirements and standards in the design criteria documents and verify their proper implementation to boost stakeholders' confidence during the design review process. This step is critical and requires focused attention to ensure the desired outcomes.

MPS increases design efficiency and decreases costs by up to 30% for expansion projects. It fosters innovation throughout the organization and is well-adopted in Advanced Air Mobility. Before building a vertiport, operators must ensure they meet all safety, security, robustness, and scalability requirements.

## 5.2 Interactive Simulation of Passenger Experiences

Passenger experience is paramount in an airport. There are many opportunities within the passenger journey for the experience to be positively or negatively impacted. There's an opportunity for value creation at every touch point throughout the departing passenger journey, from car parking, through check-in, bag drop, security checks, screening, concessions, facilities, and departure gates. This value extends to the arriving passenger journey, from immigration and customs through baggage claim and egress from the airport.

Interactive simulations that leverage a SoS provide a comprehensive approach to understanding and improving the passenger experience. This method integrates various subsystems, such as ticketing, security, and boarding processes, into a cohesive model that can simulate the complex interactions and behaviors of passengers in a controlled environment. By employing such a framework, stakeholders can analyze the effects of different variables on passenger flow and satisfaction.

Each subsystem can be represented by a digital twin that can be connected to form a virtual SoS. Through interactive simulations, the operations of all "constituent" digital twin systems are optimized for the goals of the entire airport SoS.


Figure 5-1: Simulating passenger journeys using a System of Systems framework. (*Source: TM Forum.*)[8]

Digital twins can interact by exchanging messages in a time-driven simulation that runs faster than in real-time, simulating the system's future behavior to predict the effects of what-if scenarios. The simulations can help airports develop new real-time decision intelligence that tracks passengers' progress from parking to boarding, responds to disruptions, and continuously optimizes routes to reduce stress and smooth operations.

8 *https://www.tmforum.org/catalysts/projects/M23.0.567/transforming-passenger-experiences-with-continuous-decision-intelligence*

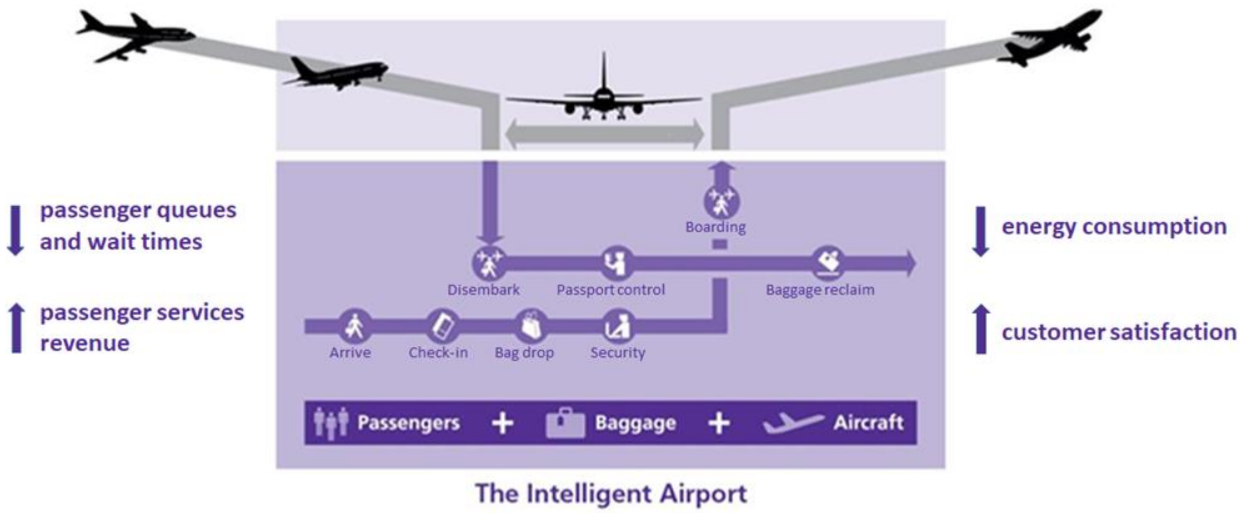


Figure 5-2: Transforming passenger experiences with continuous decision intelligence.
(*Source: TM Forum.)*[9]

Passenger flow models can include travelers' discretionary activities, such as shopping duty-free, to help identify non-aeronautical revenue opportunities. The average processing time of each service can be modeled, including passenger service equipment. Average queue length and wait times can be calculated by combining service times and passenger volumes interactively within the SoS.

Implementing and optimizing these models within a virtual SoS can:

- increase service throughput,
- reduce passenger queue time,
- increasing passenger free time,
- increase customer satisfaction, and
- increase non-aeronautical revenue.

## 5.3 A Holistic Perspective for Asset and Workforce Management

Airports aim to provide a service that meets and exceeds passenger expectations. To achieve this, airports must strive to minimize waiting times so that passengers can spend more time shopping rather than waiting in line. With air travel expected to increase tremendously in the coming years, there is an urgent need for industry players to ease bottlenecks and speed up processes.

To accomplish this, airports must ensure that the availability of resources, such as check-in counters, security checkpoints, baggage carousels, and boarding gates, aligns with passenger

[9] *https://www.tmforum.org/catalysts/projects/M23.0.567/transforming-passenger-experiences-with-continuous-decision-intelligence*

demand and the airport workforce. This synchronization is essential for creating a seamless passenger experience, optimizing resource utilization, and enhancing overall operational efficiency.

Adopting a holistic approach to synchronizing airport assets with passenger demand is crucial for many reasons. It ensures that all components of airport operations work in harmony to provide a seamless passenger experience, optimize resource utilization, and enhance overall operational efficiency. For example, when a boarding bridge is down, it directly impacts stand and gate planning as an aircraft cannot be parked at that gate anymore.

A holistic approach is needed to monitor airport operations against disturbances while taking swift action when needed. Speed and flexibility have become crucial factors in delivering high-quality service to airlines and passengers.

Through a systems approach, holistic planning can be achieved with real-time information on the necessary resources and service levels. This approach allows planners to monitor passenger flow in real-time, from check-in to boarding, and from deplaning to arrival.

Activities involved in adopting a holistic approach include:

- Resource planning,
- Data integration, and
- Asset management.

#### 5.3.1 Resource Planning

Providing a single resource planning solution that drives agile decision-making across the board, thus enabling companies to optimize their services, and meet business goals of higher efficiency and profitability.

To ensure that airports meet and even exceed passenger expectations, it is crucial to minimize waiting times, allowing passengers to spend more time shopping and less time standing in line.

For airport and ground handling, it is essential to have the right resources available at the right time, in the right place, and with the right skills. This requires striking a balance between accommodating employee preferences, ensuring seamless airport operations, and adhering to established rules and constraints.

By analyzing the impact of resource allocation on the passenger flow throughout the airport, operators can optimize the usage of important resources and enhance the overall passenger experience. This optimization could potentially increase passenger capacity by up to 15% through effective resource planning. This optimization must consider real-time events such as flight delays, allowing for real-time adjustments in resource and staff allocation to meet predicted demand. This ensures adequate resources and staffing during peak times and reduces them during off-peak times.

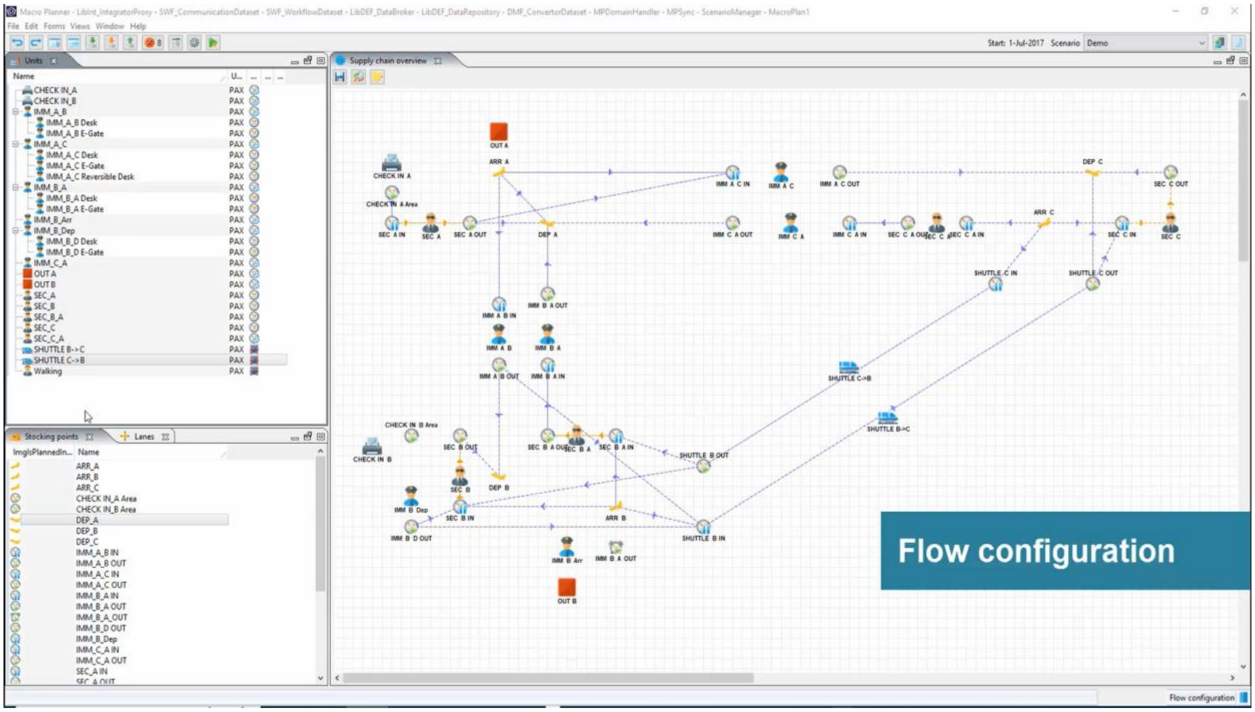


Figure 5-3: Airport resource optimization.
(*Source: Dassault Systèmes Airport Experience Industry Solution.*)

### 5.3.2 DATA INTEGRATION

Data integration is a critical component of a holistic approach to ensuring the synchronization of airport assets with passenger demand. Integrating data from various sources allows for comprehensive analysis and informed decision-making, aligning the availability of resources with passenger volumes. By integrating data systems, leveraging predictive analytics, and maintaining dynamic resource allocation and real-time monitoring, airports can effectively manage the complex interplay between passenger flow and resource availability, ensuring smooth and efficient operations.

### 5.3.3 ASSET MANAGEMENT

Asset management ensures that resources are efficiently utilized, costs are reduced, and passenger experience is enhanced. Effective asset management involves:

- Integrating data systems,
- Employing predictive maintenance,
- Dynamically allocating resources, and
- Continuously monitoring performance.

This strategic approach helps maintenance teams achieve over 25% in time reductions by optimizing the time spent on back-and-forth travel and searching for assets throughout the airport. More importantly, it can reduce breakdowns by 70-75%, downtime by 30-35%, and maintenance costs by 25-30%, offering a 10X savings when effectively implemented[10].

Predictive insights can be gained by incorporating real-time monitoring of sensors, setpoints, equipment schedules, sequence of operations, and condition-based monitoring. This is especially important for complex systems such as HVAC, passenger boarding bridges, and baggage systems. These insights enable maintenance teams to identify issues before they disrupt services or cause complaints, allowing airport management to schedule downtimes during periods of minimal disruption.

As a result, less burden is placed on call centers, providing a better experience, comfort, and trust to airport partners and stakeholders. Prevention and early mitigation of catastrophic failures become even more critical. An asset management system can reduce equipment breakdowns by up to 75%, cut maintenance costs by up to 25%, and increase uptime by up to 35%.

By aligning the availability of assets with passenger demand, airports can achieve operational efficiency, safety, and increased revenue, leading to a well-functioning and passenger-friendly environment.

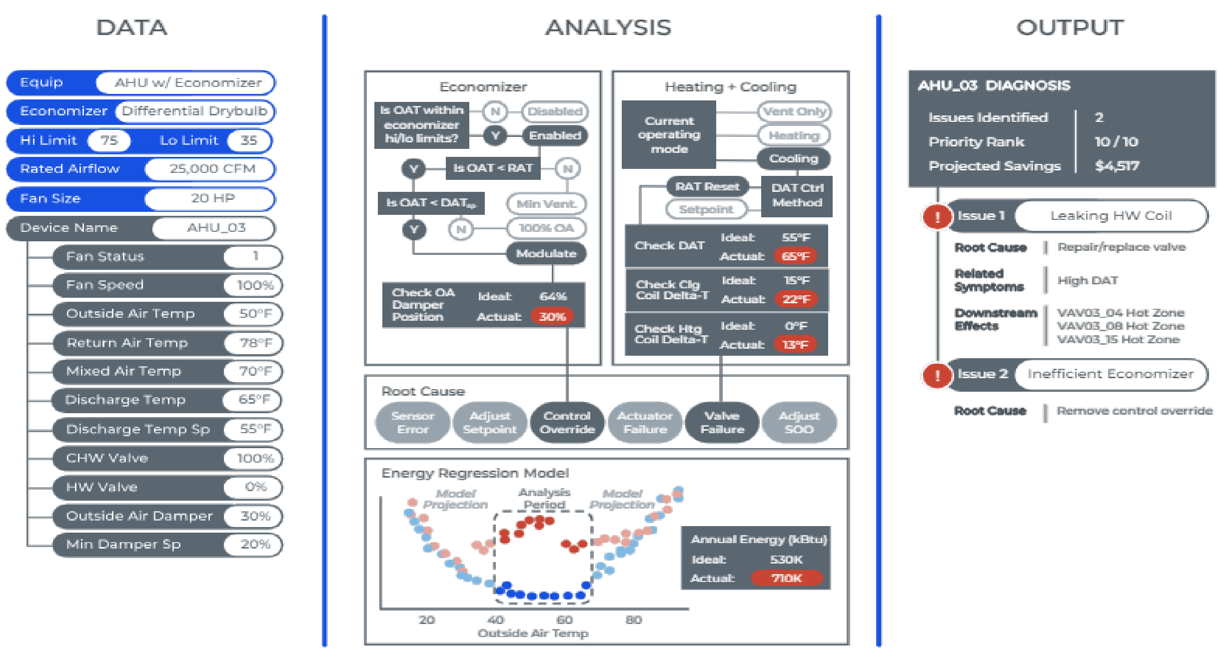


Figure 5-4: Fault detection and diagnostics. (*Source: Clockworks Analytics.)*

[10] *https://cw.clockworksanalytics.com/Home.aspx*

## 5.4 Situational Awareness for Emergency Management

Situational awareness is crucial in managing emergency situations at airports, where a rapid and coordinated response can save lives and minimize disruption. This involves understanding the current environment, anticipating potential challenges, and making informed decisions quickly.

Integrating digital twins into a SoS framework provides a comprehensive view of interconnected systems, enabling a coordinated response across various entities and infrastructure components. This approach not only enhances situational awareness, but also facilitates resource optimization and response strategies, potentially saving lives and reducing the impact of emergencies.

Moreover, the ability to simulate scenarios and predict outcomes aids in preparing for potential crises, ensuring that responders are better equipped to handle them effectively. In summary, a digital twin system of systems can provide enhanced preparedness, improved operational efficiency, and ultimately, a more resilient airport.

## 5.5 Collaborative Systems for a Sustainable Airport

To create a sustainable airport, collaboration among stakeholders is crucial. This includes airport authorities, airlines, passengers, and local communities. Sustainability involves energy usage, emissions reduction and waste management, and aims to enhance operational efficiency and the passenger experience.

To achieve sustainability goals, it's important to create a collaborative environment, involving stakeholders in planning, design, and optimization of operations. This involves engaging stakeholders such as airlines, airport staff, passengers, and local communities to ensure that sustainability goals align with the needs and expectations of all parties.

Having sustainable Operations and Maintenance:

- **Energy consumption**: Optimize the use of renewable energy such as solar, wind, and geothermal, move towards electrification, and decentralization of energy production through Microgrid and distributed energy resources. Explore new technology such as Hydrogen and SAF. Collaboration with energy providers is required to ensure a sustainable energy supply.
- **Emission reduction**: Improve airport operations such as the turnaround process to reduce $CO_2$ emissions, reduction of jet fuel burn, and other harmful emissions like methane. Indoor Air Quality (IAQ) is another metric important for airports aided by sensors and optimization of airflow, HVAC systems, and the influx of people and vehicles.
- **Water Management**: Smart use of water to reduce water consumption, provide continuous monitoring for leak detection, and rapid response to events such as extreme weather. But also implementing rainwater harvesting, water recycling, and efficient irrigation systems strategy.

### 5.5.1 Energy Management

Airport terminals consume more energy than average public buildings. The high energy demand and round-the-clock operation of airport terminals pose a significant challenge to the carbon neutrality policy. Integrating geospatial data and analytics into digital twin models allows for the development of spatial-temporal passenger distribution models to estimate energy consumption in different scenarios. Likewise, applying fault diagnostics to machine runtime and optimization can dramatically reduce energy costs while extending machine lifespan.

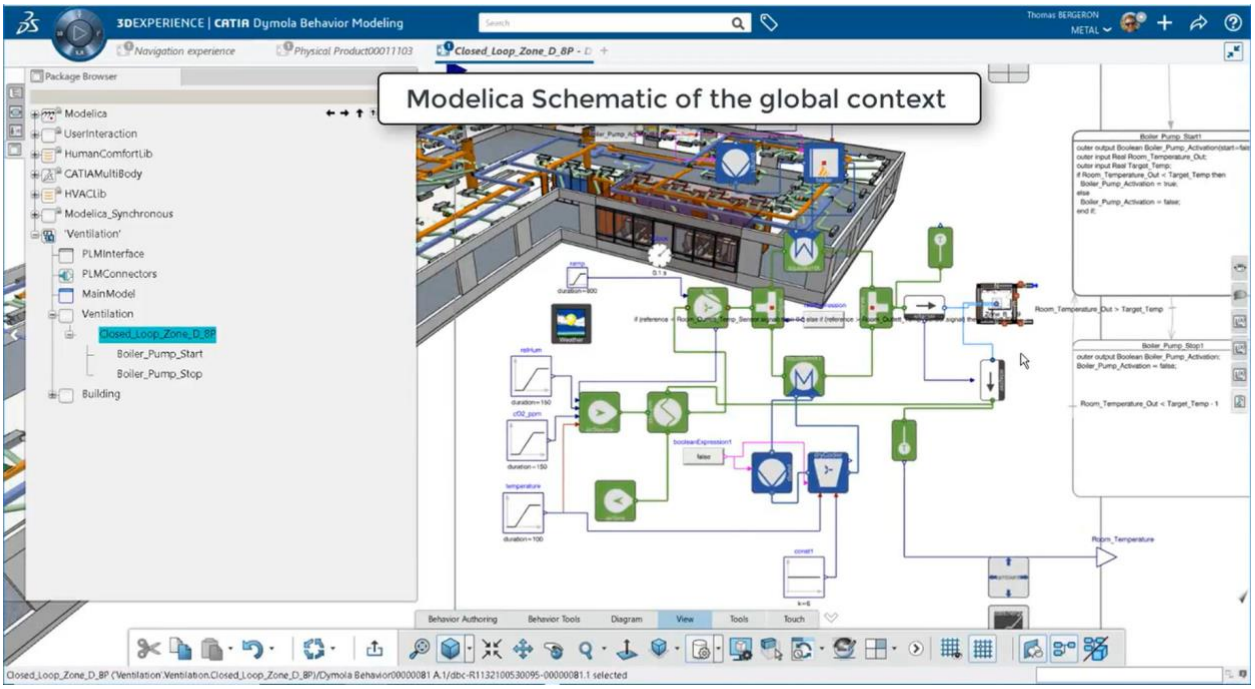


Figure 5-5: Electrical consumption simulation.
(*Source: Dassault Systèmes Airport Experience Industry Solution.*)

Passenger flow plays a vital role in the terminal's energy consumption and indoor environmental conditions. A prediction model of passenger flow confirms that optimizing operations and terminal layout design can address energy efficiency. Alternatively, energy consumption for each service level can be aggregated based on overall service use.

Investments in smart assets that perform during service demand and are left idle when not needed is a good example of how energy consumption can be dramatically reduced by minimizing asset runtimes. Good examples include escalators, elevators, and baggage systems that run on demand, rather than continuously; and by assigning smart schedules to runtime operations that consider passenger flow changes.

Season and daily weather changes are also critical here. As are rules-based automation for controls of our systems to minimize energy consumption.

Design optimization to meet all requirements and ensure that it's fully sustainable using M&S. The purpose is to simulate the building's energy consumption using the local weather conditions and thermal effect. Building a twin model of the building and its power systems (floor heating, heat pump, HVAC), to enable simulations over long periods. As a result, we obtained early insights into system interdependencies and consumption using model-based systems engineering (MBSE). This allows close integration of design and simulation activities, in particular by linking system simulation to physical simulation which can help reduce between 15-20% in energy consumption.

### 5.5.2 Energy Hub/Microgrid

With increasing passenger numbers in the upcoming years and the imminent arrival of electric aircraft and electric vehicles (EVs), airport energy is expected to increase significantly. Some are predicting that airports could increase electric power demand[11] by up to nearly five times the 2023 levels by 2050, according to a case study of the Denver and Minneapolis-St. Paul International Airports conducted by Enterprise Mobility, Xcel Energy, and Jacobs.

The concept of airports as energy hubs emerges from the ACI. It refers to the construction of an airport ecosystem allowing the production of renewable energy within its airport operations to decarbonize all airport-related activities but could also be distributed to airport surrounding communities.

The concept of airports as energy hubs refers to building a unique airport ecosystem that places renewable energy production at the center of its operations to decarbonize all airport-related activities and those in their vicinity.[12]

Airbus has launched the "Hydrogen Hub at Airports" concept to support future hydrogen-powered aircraft and decarbonize all airport operations using hydrogen.

OLGA, STARGATE, and TULIPS are three European Union (EU) projects funded under the H2020 Green Deal call. These three projects develop environmental innovations intended to put EU airports and the aviation sector on the path to a green transition.

Many airports are implementing green energy initiatives but it's not just about saving money or reducing emissions. It can also improve the resilience of the airport by providing energy in the event of an emergency to ensure the continuity of operations. This is especially important these days when weather conditions are becoming extreme with each passing day.

[11] *https://www.enterprisemobility.com/content/dam/enterpriseholdings/marketing/innovation-in-mobility/vehicle-innovation/airport-electrification-study-full-report-2024.pdf*

[12] *https://blog.aci.aero/airports-of-tomorrow-transforming-into-energy-hubs/*

For example, DFW Airport[13] has broken ground on a new Electrical Utility Plant to provide electrical demands for the future airport needs and meet sustainability goals. DFW plans to serve these new electric demands and mitigate risk to the Texas grid with an 86% calculated reduction of nitrogen oxide (NOx) emissions per year, a 15M kg reduction in CO2 emissions per year, and to contribute to regional air quality improvements.

The Micro-grid concept is critical with the ongoing demand increase from vehicle electrification, new charging stations, and storage needs from green energy production from wind, solar, and other power generation sources at the airport.

JFK is building New York's largest solar carport to meet the significant advances and goals of the Port Authority, seeking to reduce their agency's carbon footprint to NetZero while sharing the benefit of the investment with neighbors and local communities.

*"When complete, JFK will take its place as a world-class airport that is efficient, beautiful and sustainable"* - Governor Hochul Announces Groundbreaking for New York State's Largest Solar Carport and Battery Storage System at JFK Airport.[14]

Transforming an airport into an energy hub is a complex but feasible project. This can bring significant environmental and economic benefits. By leveraging advanced technologies like the systems approach, airports can understand what it takes to transform your airport into an Energy Hub, and help you plan this transformation.

#### 5.5.3 Emissions Reduction

The global economy has agreed on ambitions to reach Net Zero by 2050. With over 2500 airports worldwide serving 4 billion annual passengers and providing critical infrastructure such as terminal buildings, airfields, and ground service equipment. Aviation accounts for 2.5% of global greenhouse gas (GHG) emissions, excluding airport construction and operation. Airports only account for around 2% of aviation's total carbon emissions.

However, airport emissions, unlike those from aircraft, are fixed and are released at ground level with all the attendant consequences for local air quality and human health. These emissions arise from:

- Aircraft maneuvering on the airfield and aircraft engaged in the landing and take-off (LTO) cycle;
- Lighting, ventilating, and heating airport terminal buildings, airport offices, and business parks; and

[13] *https://www.dfwairport.com/business/about/investors/zerocarbonecup/*

[14] *https://www.nypa.gov/news/press-releases/2024/20240423-jfk*

- Constructing and maintaining landside and airside infrastructure, local road and rail transportation, and airport expansion activities.

Digital twin plays a role in decarbonizing airports, smart cities, and any built environment including energy, emission, water, waste, occupancy, air quality, and transportation as data can be tracked, traced, and monitored. Digital twins enable real-time analysis and optimization of climate-related data to support compliance with benchmarking and reporting frameworks, optimizing energy and operations, detecting anomalies, recommending corrective actions, and predicting faults before they occur, which can lead to reducing 50% of existing building greenhouse gas emissions.

- Visual Tracking of Emissions: Airports like Vancouver International Airport (YVR) use digital twins to calculate and visually track aircraft carbon emissions from landing to takeoff. YVR aims to become the world's greenest airport by leveraging its digital twin for sustainability.
- Baseline Measurement: YVR's digital twin establishes a baseline measurement for emissions, aiding in monitoring progress toward decarbonization goals.
- Comprehensive View and Decision-Making
- Airport Clusters: An airport digital twin clusters various digital twins representing different aspects (catering, traffic control, security lines, etc.). It provides a holistic view of airport processes and their global impact, enabling informed decisions.

This integration of digital twins in airport operations can incorporate environmental, social, and corporate governance (ESG) objectives within streamlined processes marking a significant stride towards sustainable and efficient airport management. It can help achieve Net Zero/Carbon neutrality within 5-25 years.

#### 5.5.4 Water Management

Ensuring the reliable delivery of clean potable water and effective management of reclaimed water and sewer systems is crucial for any smart city, including large airports. Disruptions caused by water leaks near critical airport assets—such as airfield runways, taxiways, adjacent highways, or large structures like terminals—can lead to catastrophic failures and costly downstream disruptions. Similarly, leaks from chilled water systems, glycol, and harmful chemicals used by airports can severely impact the environment and surrounding communities, which airports are responsible for protecting.

District metering has become a common method for enhancing water leak detection and improving water management strategies, augmented by real-time, or near real-time flow feedback. By measuring pressure and flow, district metering provides more accurate billing for revenue-generating water supply programs. Compliance is also a critical factor in managing water, impacting sustainability, costs, and adherence to audit and regulatory standards. Airports, like cities, must maintain compliance and are often faced with unique scenarios where risks can arise if not properly managed or detected.

Real-time monitoring of flow and pressure, along with district metering, can significantly improve response times, not only by measuring the severity of the loss but also by monitoring the precise location. Additionally, remote-actuated valves can isolate sections of the water system when a fault or leak is identified, further minimizing the impact.

In addition, large airports, like cities, need statistical water models for simulation. These models typically require topographical or geotechnical surveys to match the changing physical environment. Hydrologic modeling utilizes numerical and statistical tools to combine our understanding of hydrologic processes. Stormwater management (SWMM) supports planning, analysis, and design related to stormwater runoff, combined and sanitary sewers, and other drainage systems by simulating the quantity and quality of runoff generated from urban areas. Both are critical for severe weather contamination events, and during high-stress events.


Figure 5-6: Flood simulation. (*Source: Dassault Systèmes presentation on airport resiliency.)*

Building a digital twin of the airport water system can be greatly enhanced by having real-time data from sensors and digital simulation models.

# 6 CASE STUDIES

## 6.1 AMSTERDAM'S SCHIPHOL AIRPORT

Amsterdam Airport Schipol (AMS) has built a digital asset twin of the airport to take advantage of the numerous digital assets created for the capital improvement program. The airport's digital twin allows simulations to be run on potential operational failures throughout the entire complex, which saves time and money. The Common Data Environment (CDE) is a dynamic, digital twin of the airport premises that incorporates open standard Building Information Model (BIM) data through integration of geospatial information system (GIS) data with live data feeds for aircraft and ground vehicle locations.

The CDE organizes data from various sources, including BIM data, GIS data, and real-time data on project changes, incidents, financial information, documents, and project portfolios. The airport collects and processes data from remote sensors used for predictive maintenance within the 7,000-acre complex. It tracks and maintains more than 80,000 indoor and outdoor assets, including networks, runways, lighting systems, information booths, and fire extinguishers.

Schiphol's contractors provide construction data in Industry Foundation Classes (IFC) format, a platform-neutral, open file format used for standardizing data for BIM. BIM data is processed using an integrated spatial ETL (extract, transform, and load) toolset that runs within a geoprocessing framework. The BIM data is converted to Web scene layers via this processing, which are optimized for displaying large volumes of 3D data in a browser.

Automated passenger and freight systems at the airport, such as escalators, conveyor belts, and ticketing machines, are monitored by an asset control signaling and monitoring (ACSM) implementation within Schiphol's supervisory control and data acquisition (SCADA) system. These systems continually check the status of the multitude of servomotors, circuit boards, and mechanical devices that comprise these systems while maintaining their maintenance history and monitoring the systems' programmable logic controllers. Schiphol also uses an asset management system for asset registration and maintenance.

The ACSM lets the airport monitor and manage all the assets comprising these systems in real-time from a dashboard. If one of the components, such as a belt or motor, is not running correctly, the equipment can be turned off, automatically producing a work order, and assigning a maintenance crew to repair it immediately. Schiphol uses an indoor traffic monitoring system to detect a passenger's wireless device, and its unique ID is time-stamped and encrypted. As the device passes by multiple sensors, the system measures travel times and movement patterns. The system provides both real-time and historical information about queue times, occupancy numbers, and flow patterns to airport management, helping to maintain a safe and secure environment.

## 6.2 Dallas-Fort Worth Airport

Dallas-Fort Worth International Airport (DFW) has a rapidly evolving digital twin program leveraging BIM and GIS information and business system integrations through their digital twin platform and knowledge graph ontology.

DFW is preparing for digital twins at the planning, design, and construction stages to ensure data transfers seamlessly to operations. Critical steps include updates to design criteria manuals

(DCM), Digital Infrastructure (DFI) standards (to support the Common Data Environment), construction contracts, and standards around the acquisition of new technologies and sensors.

DFW has also forged strong partnerships with Autodesk and Bentley to implement these standards and hold governance with automation quality checks throughout the construction process. Project milestones include modeling and attribution at different stages and levels of detail and our digital twin partner is involved in the construction process to support our data handover requirements.

DFW has very aggressive sustainability goals to meet NetZero by 2030, including the construction of a new Electric Central Utility Plant and successful projects including ATHENA and Project Morpheus through their partnership with the Department of National Renewable Energy Laboratory.

Existing integrations include synchronized asset management platforms, building automation management and SCADA systems, and expanding access to airport-wide IoT data. DFW IoT data is constantly being analyzed for custom rule creation and implementation including fault detection, sustainability, and condition-based monitoring for predictive insights on system behavior and health monitoring.

Additional integrations include a gate management system, smart lighting, and smart glass, where improvements are being tested in a smaller environment before pushing out airport wide.

DFW has an operating 3D digital twin of their Terminal D infrastructure, Terminal D South Expansion and Parking Garage, Central Utility Plant, and Runway. Ongoing projects are bringing online 3D digital twins of additional Terminals and buildings in 2024-2025.

DFW's digital Twin roadmap includes the expansion of infrastructure monitoring of mechanical, electrical, plumbing, communications, water systems, conveyances, and passenger boarding bridges. Real-time data streaming utilizes data streaming pub/sub architecture where data is available for advanced analytics. DFW is also investing in improving and supporting infrastructure where gaps exist to support this digital journey.

## 6.3 Dubai International Airport

Dubai International Airport (DXB), the world's busiest airport by international passenger traffic, needed to optimize the use of its existing resources to meet increasing passenger numbers and deliver a world-class passenger experience. To address this challenge, DTP, a Dubai-based aviation solutions provider, developed and implemented an autonomous resource management solution using the DELMIA Quintiq software.

At the core of the solution are AI/system-based optimizers capable of taking into consideration a complex and comprehensive KPI profile as well as live updates from 25+ sources to produce the best operating plan for the next 45 hours. The solution auto-calculates continuously using these dynamic inputs, reducing the need for human interference while producing the optimal plan.

Furthermore, DTP's Type B and aviation message parser, tNexus Message Hub, which was implemented along with the DELMIA Quintiq resource planner, provides high-quality operations data for a more complete planning picture. These solutions ensure a holistic approach to resource planning that helps DXB provide an excellent passenger experience and meet its operational goals.

## 6.4 Orange County John Wayne Airport

Orange County John Wayne Airport (JWA) is implementing an asset-centric strategy to streamline operations, maintenance, and capital planning. Through the implementation of an Enterprise Asset Management System (EAMS), assets are systematically cataloged and integrated into the capital management plan to facilitate proactive planning for future capital investments.

The EAMS is integrated with a Computerized Maintenance Management System (CMMS), enabling efficient planning and monitoring of asset maintenance, repairs and replacements. Furthermore, Orange County is leveraging GIS and BIM systems to manage geospatial data, including utilities, leasing and space information. Future plans involve integrating the CMMS with these systems for enhanced functionality and coordination.

## 6.5 San Francisco International Airport

While the San Francisco Airport (SFO) does not have an official position on digital twin technology, it incorporates foundational concepts that can be applied to any business case and used to develop digital twins tailored to specific needs:

1. **Infrastructure data**: well-defined infrastructure data as its foundation.
2. **Dynamic data**: real-time or near real-time data streams combined with infrastructure data.
3. **Business rules and workflows**: triggers or actions that occur based on the data or a combination of data.

The airport is investing an Airport Integrated Operation Center (AIOC) where staff from various disciplines will collaborate to make data-driven decisions that provide the most optimal passenger experience at the airport. The goal is to automate actions and create efficient solutions for everyday issues. SFO plans to start implementing the AIOC in late 2024 and have it fully operational by 2025. The AIOC will have SFO-built systems that display real-time information and integrate data from various sources to facilitate operational decisions.

A significant part of the AIOC system consists of real-time dashboards that provide valuable insights about the dynamic operations at SFO, as well as comprehensive 2D and 3D maps with integrated data. The concept of an airport digital twin isn't just about spatial representation; underneath, it's powered by geographical data.

At SFO, efforts have been made to establish common semantics for naming conventions across different enterprise databases and systems, as well as design and construction standards for CAD and BIM modeling. Standardizing the naming of building spaces, doors, floor levels, and other infrastructure has been a major focus. SFO also employs industry and proprietary standards for GIS, CAD, and BIM, and looks to domain standards provided by the FAA and other aviation and infrastructure-related data models.

The GIS team aims to demonstrate the value of GIS at the airport. When beginning new projects or acquiring new datasets, the team considers the following:

- Is there value in this?
- What value does the request bring to the greater organization?
- Who is the audience for this?
- Is it just one person interested or are there 50 people who need to see this?

The GIS team at the airport plays a crucial role in creating operational efficiency to help drive safety, time savings, and overall cost reduction. Their web and mobile-accessible 3D models, virtual representation, and geospatial data provide insights into areas of the airport that are difficult to access or are otherwise inaccessible. Integrating GIS data into third-party systems has:

- Reduced the cost to maintain and operate software,
- Increased spatial awareness,
- Provided continuity of spatial data across enterprise business platforms,
- Helped bring a common operating language to users, and
- Improve efficiency and response times.

For instance, SFO outfitted scissor lifts and other mobile equipment with Wi-Fi tags to help the airport staff keep track of them. By using a Wi-Fi tracker and a web or mobile application built with GIS technology, the staff can quickly locate the last wireless access point that the lift connected to within the SFO terminal complex, where GPS signals may not reach. Thanks to the high-density Wi-Fi, the location of the lifts can be determined within a 20-foot range, making it easy for the staff to find where the assets were stored, even if it was by a different shift or team weeks earlier. This change has significantly reduced the time spent searching for these devices, potentially saving the staff many hours per week.

The GIS team has also mapped the geolocation of over 13,000 doors at the airport. This allows for efficient dispatch of personnel to respond to issues. Staff can easily locate specific doors using web-based or mobile map applications. This system results in substantial daily time savings for multiple team members and reduces the time needed to complete tasks that require a lift.

By utilizing airport GIS data, which includes indoor space information, the airport has been able to make informed decisions based on data. This infrastructure supports and adds value to various use cases and has enabled SFO to secure grants and issue more informed Requests for Proposals (RFPs).

SFO highly values its GIS and geospatial data as it serves as a primary component for various datasets. There has been a rapid increase in awareness and demand for using GIS and geospatial data throughout the entire airport.

The enterprise GIS data models were designed not only to provide the spatial locations of airport infrastructure and assets, but also to be used in conjunction with other airport data. This enables the spatial location for legacy non-spatial systems and databases, such as billing, facilities, operations, and security.

The SFO data models serve to map three airport domains: sub-surface utilities, exterior assets (including airside and landside infrastructure), and indoor mapping of terminals and other airport support buildings and structures. SFO's GIS team recommends having a predefined data structure for interiors in GIS, such as room and door numbers. The team uses the BOMA standard for space representation and has predefined usages for space types. Additionally, the team has established predefined floor numbering and naming conventions, as well as predefined structure numbering and naming conventions.

The SFO Infrastructure Information Management team, which consists of BIM Integration and Airport Geospatial teams, has incorporated BIM and GIS standards in the BIM build process, the design, and the AEC process. The team advises architects to accurately position their project's base point, use the correct scale and rotation, and adhere to the proper naming conventions for doors, levels, and spaces. The team only requests that architects include a few additional parameters in BIM to ensure compatibility with SFO's GIS and a smoother ETL transition without obstructing their creative process. The BIM Integration team also offers guidance for accurately defining latitude and longitude within BIM in the appropriate projection for a project's base point.

The team faces challenges with BIM models because project teams may use differing naming conventions and infrastructure definitions within the model. To address this issue, the team establishes standards early in the project and engages and collaborates with project teams at key points to ensure proper understanding and implementation of standards within the model. The team is also exploring automated methods for data validation in BIM, but they have found that validation is complex due to the unique characteristics of each model. Effective communication with the design team is essential throughout the stakeholder engagement process.

The team is dealing with challenges related to BIM models because project teams may use different naming conventions and infrastructure definitions within the model. To handle this issue, the team establishes standards early on and involves engaging and collaborating with project teams at key points to ensure proper understanding and implementation of the standards within the model. They are also exploring automated methods for data validation in BIM but have found that validation is complex due to the unique characteristics of each model. Effective communication with the design team is essential throughout the stakeholder engagement process.

The airport is also implementing new technologies such as the Maximo work order management system, 3D interior scanning, and real-time data streams using GIS.

The primary goal of SFO is to deliver the most efficient and seamless travel experience to every customer who passes through its doors. SFO believes it starts with measurable metrics and a knowledgeable and experienced staff. SFO wants to ensure its customers have a world-class experience every time they pass through, whether arriving or departing, regardless of their travel circumstances. A significant driver behind the creation of the AIOC is to ensure that this high-quality experience is consistently delivered.

# 7 Conclusion and Next Steps

For airports to meet increasing passenger volumes, while modernizing infrastructure investments, they must innovate while driving operational efficiency and leveraging data-driven intelligence.

As an executable virtual representation of the physical airport system, the digital twin system consumes learnings and experiences from real-world processes to update the digital twin model, intelligently connecting it to the airport in real-time.

To maximize business value and deliver excellent passenger experiences, people, digital systems, and infrastructures must operate in harmony. A unified airport ecosystem and digital twin system of systems framework can drive sustainability, operational efficiency, safety and security, new revenue streams, and optimized customer experience.

## 7.1 Shifting the Mindset

Realizing the full value potential of digital twins within an airport ecosystem necessitates a significant shift in mindset toward:

- Investment in digital data to enable data-driven decisions,
- Thinking and acting across functionally to enable cross-functional work, and
- Fostering a philosophy that embraces change.

It requires stakeholders, including top leadership, to embrace a holistic view that appreciates the interconnectedness and interdependence of airport systems.

This paradigm shift involves recognizing that digital twins are not just replicas of physical systems but are dynamic and evolving entities that can provide actionable insights and foresight into system performance, maintenance and operation.

By adopting a model-based approach and focusing on interoperability, airports can ensure that their digital twins are composable, connectable, and capable of providing high-fidelity data. This, in turn, enables more informed decision-making and fosters an environment where continuous improvement and innovation are possible, leading to enhanced value creation across the entire system of systems.

## 7.2 Establishing the Proper Governance

Airports must prioritize governance as they begin or expand their digital twin initiatives. Without a strong governance framework, the value of digital twins may not be fully realized, and the risks associated with their deployment may not be adequately mitigated.

Effective governance ensures that digital twin initiatives align with airport goals and strategies while addressing key challenges such as data quality, privacy and security.

### 7.2.1 Data Governance

Governance should ensure that data streams from all stakeholders are integrated and accessible for real-time analysis and decision-making. It involves setting standards for data management, defining roles and responsibilities, and establishing processes for continuous improvement.

A cross-domain common information model is a critical aspect of data governance, providing a standardized framework for describing and managing data within a complex airport environment. It ensures consistent data description and representation, which is essential for data quality, usability and protection.

Ensuring vendor compliance with a common information model is crucial in procurement to maintain actionable, quality data. Effective data governance, supported by a common information model, enables an airport to harness the power of its data, driving digital twins that create significant value.

### 7.2.2 Change Management

Implementing digital twins requires a robust change management strategy that considers the technological, process, and people aspects of change. For instance, the Prosci ADKAR Model can be applied to guide individuals through the change, ensuring they have the Awareness, Desire, Knowledge, Ability, and Reinforcement to adopt new technologies. Additionally, Kotter's 8-Step Change Model can provide a framework for leading organizational change, emphasizing the importance of creating a sense of urgency and building a guiding coalition. These methodologies, combined with agile project management principles, can facilitate iterative development and continuous improvement, which are crucial for the successful implementation of digital twins.

## 7.3 Building or Sharing a Digital Lab

Having access to a digital lab or “sandbox” can make the ideation process with stakeholders much smoother, it also provides a place to showcase the possibilities. In these spaces, stakeholders can meet and discuss the business benefits of creating a digital twin. Building intent/outcome-based system models will help you to identify the potential business benefits and the influence on the traditional business model. The ability to demonstrate ROI through a living type environment is powerful to airport owners.

## 7.4 Implementing a Digital Twin

It's challenging to shift from traditional digital transformation "projects" to a digital twin-centric, system of systems approach to value creation. This requires digital proficiency, new stakeholder collaborations, alignment with business goals, data governance, and system thinking. The majority of airports are only beginning this transition.

Many airports are unsure what they can do to make the most of a digital twin, finding themselves stuck in a state of analysis paralysis or pilot purgatory. As with any trend, it's easy to get caught up in the hype and jump in without a clear purpose.

From the start, airport owners/operators should determine the problems they are trying to solve and their ROI objectives. Once the key objectives are determined, they should be incorporated into the budgeting process to prevent funding cliffs when the program gains momentum and provides the expected ROI.

### 7.4.1 A Top-Down System of Systems Approach

Digital twin implementations must consider design, development, testing, and maintenance aspects of the system. It is essential to focus on how the system behaves in relation to other systems. Figure 7-1 shows a top-down SoS approach for developing digital twin systems for airports.

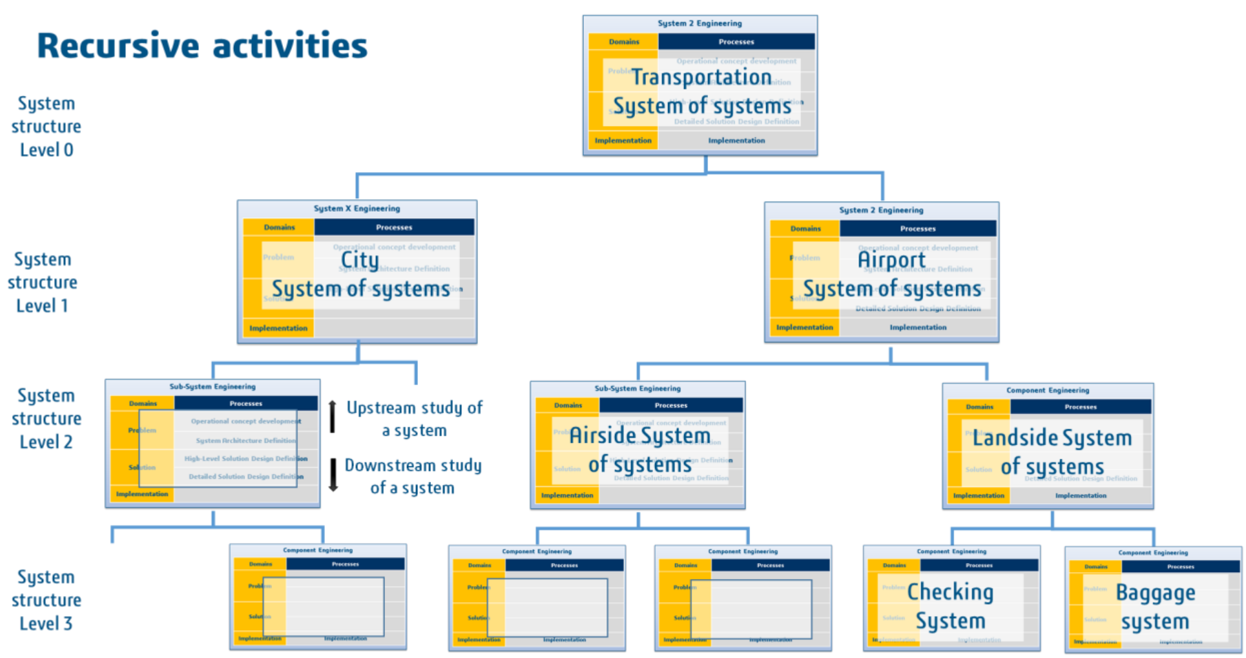


Figure 7-1: Defining an airport SoS within a transportation SoS.
(*Source: DTC Mobility & Transportation Working Group*.)

This approach starts by defining the top-level system (transportation system in Level 0). This system encompasses various subsystems (airport system in Level 1). Each system within an airport SoS (e.g., Airside System, Landslide System in Level 3) has specific services and capabilities, which collectively support the overall airport operations. This top-down, holistic approach to modeling and managing airport operations emphasizes the importance of interconnectedness and coordination among various subsystems.

### 7.4.2 A 7-Step System Development Approach

As we know that a Business Transformation is never easy, we are proposing in this paper a 7-step approach to developing, deploying and refining a digital twin system.

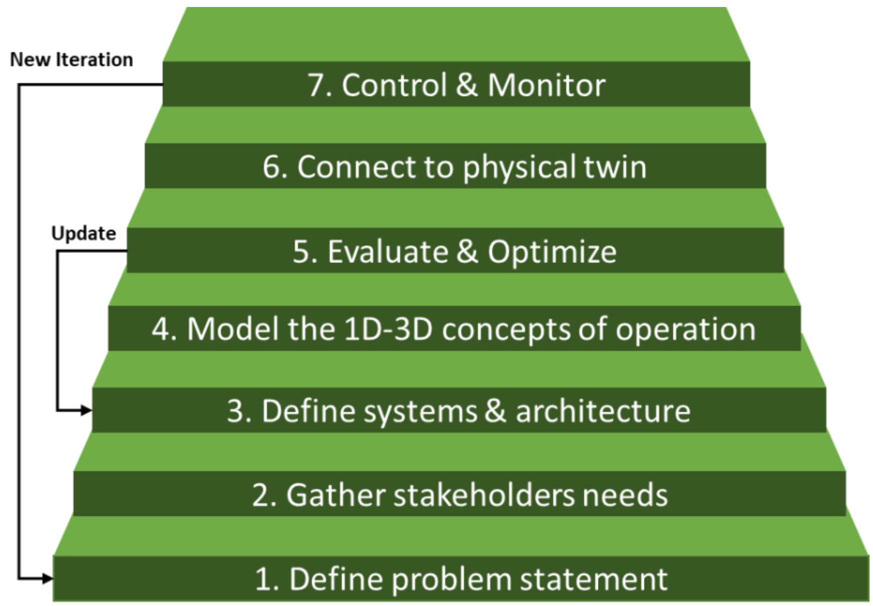


Figure 7-2: Seven steps to developing, deploying and refining a digital twin system.
(*Source: DTC Mobility & Transportation Working Group.*)

- **Steps 1 and 2:** preliminary business activities helping to define what the problem to solve is, what the objectives are, who will be involved, what kind of ROI is expected, assess the current and future Maturity states, etc. In step 1 you can determine the use cases based on Effort/Value (capability matrix) and leverage existing investments and capabilities. In step 2 you define the outcomes, quantify the value, and identify how, when, and why the problem is solved and needs to be updated based on all stakeholders' needs.
- **Step 3:** defines the system architecture by decomposing it into capabilities (e.g., must-have, nice-to-have) for all the stakeholders to ensure acceptable performance, safety, and security. It describes the systems and their components architecture and allocated in the system. Capabilities can be composed of multiple cross-functional disciplines that require defined, collectible, and measurable metrics (KPIs).

- **Step 4:** creates the System-of-Systems (SoS) from 1D to 3D. It can be extended to 4D (time) if required. This step is repeated for all Systems, Sub-systems, and components depending on the level of detail required to accurately model and simulate each specific use case.
- **Step 5:** simulation of use case scenarios and business studies based on the modeled systems to evaluate the results and compare them to the expected results (What-If scenarios). By looping with step 3, it provides a continuous system improvement (1D-3D), to optimize and automate all SoS components until the expected results are achieved.
- **Steps 6 and 7:** connect the digital twin system to data from the physical twin to monitor and reassess the SoS for continuous improvement. Knowing that the actors can change, it would therefore be necessary to return to step 1 to review the needs, and the objectives and to reassess them.

## 7.5 LEVERAGING THE DIGITAL TWIN CONSORTIUM

The Digital Twin Consortium plays a pivotal role in the advancement of digital twin technology, providing a comprehensive framework that unlocks business value and enables digital transformation at scale.

The Consortium's initiatives, such as the Capabilities Periodic Table and the Digital Twin Open-Source repository, provide valuable resources for airports looking to propel innovation. Moreover, research validates the systematic value creation with digital twins, emphasizing their importance in practical applications and the development of future priorities. As digital twins continue to provide new opportunities for value co-creation and decision-making, they bridge the gap between theoretical research and practical implementation, ensuring the successful value creation from digital twin initiatives.

Currently, there is a significant gap between implementing capabilities in a Systems-of-Systems approach and using tools like the DTC Capabilities Periodic Table and Platform Stack Architectural Framework - part of the Composability Framework.  One next step would be to apply a use case from this paper to connect the two and help airport operators realize end-to-end value.

> *"Today, smart airports are bringing innovative solutions to the world of transportation in operational efficiency, passenger services, and security. By leveraging new technologies and innovative approaches, including Generative AI-evolved digital twins, extended reality, and other enabling technologies, smart airports can offer improved airport operations, passenger accessibility, advanced security, and actionable insights into environmental impact.*
>
> *Digital Twin Consortium is at the forefront of these innovative solutions, developing and aligning frameworks, advanced technologies, and value-driven use cases through its member-lead working groups."*
>
> \- Dan Isaacs, Chief Technical Officer, Digital Twin Consortium

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## AUTHORS & LEGAL NOTICE



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