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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 191

A Primer to Prepare for the Connected Airport and the Internet of Things

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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FOREWORD

By Marci A. Greenberger
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ACRP Research Report 191: A Primer to Prepare for the Connected Airport and the Internet of Things introduces the concept of the Internet of Things (IoT) within the airport environment to leverage current and emerging technologies. IoT can be used to provide information and services to airport passengers with current and evolving technologies. Not only airports but airlines and other stakeholders can use these innovative technologies and the data collected from them to enhance the user experience and add value. Airport operators and their stakeholders can use this primer to understand the IoT environment and plan for implementation.

IoT is defined as the infrastructure that enables advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies. One airport application is providing indoor navigation whereby passengers are guided to points within the airport environment based on IoT devices.

These devices are proliferating within the airport environment and other such facilities. IoT devices can also be used to manage airport facilities for such functions as ambient temperature control, security, emergency response, and safety. As the airlines and other airport stakeholders use IoT, there are concerns about which entities have the data, what can or should be shared, privacy concerns, regulations, and the security of the data. The vast amount of data that is generated can benefit multiple stakeholders, but there remains a challenge to promote sharing and better use and control of IoT technologies.

IoT devices will continue to be connected in new and innovative ways to enhance airport operations and the passenger experience. Texas A&M Transportation Institute and Deloitte Consulting, LLP, were selected to conduct research to identify opportunities for IoT in the airport environment, the inherent challenges and barriers to implementation associated with them, data sharing methods, and standards that can benefit all airport stakeholders. This primer will be useful to airport staff and stakeholders interested in introducing or enhancing their use of IoT.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

A Primer to Prepare for the Connected Airport and the Internet of Things

What Is the Internet of Things?

The Internet of Things (IoT) is not a technology itself but rather a concept. IoT is a way of bringing together enabling technologies in a specific way to do something new. It is a way of looking at disparate systems and asking: what if those two machines could talk to each other?

IoT enables physical objects to see, hear, think, and perform jobs by having them share information and coordinate decisions. IoT transforms conventional physical objects into smart ones through various sensing devices and analytic functionalities (Figure 1). While the enabling technologies and functionalities in IoT are not new, the architecture that connects them and enables them to work together is new.

How Does IoT Bring Value to Airports?

Information Value Loop

An Information Value Loop describes how IoT creates value. For information to complete the loop and create value, it must pass through the loop's five stages:

1. A **sensor** creates digital information about the physical world.
2. The information is then communicated across a **network**.
3. **Standards**—technical, legal, regulatory, or social—allow that data to be aggregated with many other types of data.
4. **Intelligence** can analyze the aggregate data to find key insights.
5. The loop is completed when a **human or machine** uses those insights in a manner that leads to improved action.

With the completion of the loop, the improved decision or action is the **value** created by IoT.

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Example: Using IoT to Increase Airport Equipment Maintenance Frequency

Let's use a real-world example from an airport to illustrate how IoT creates value from information input into the Information Value Loop. First, there must be a business need or problem to be solved.

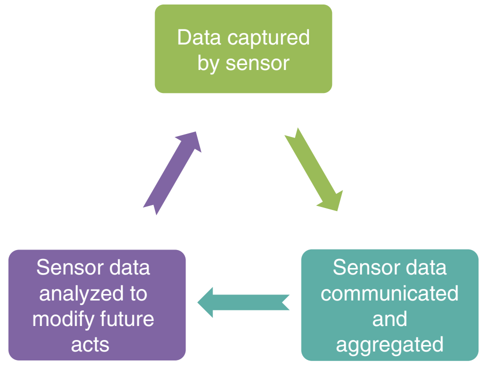


Figure 1. Basic IoT framework.

For example, an airport needs to locate its nonmotorized ground service equipment so that maintenance can be performed more often. Global positioning system (GPS) tags affixed to the equipment function as sensors, *creating* a thread of digital information about the equipment's specific location. That information is *communicated* via a network of radios back to a central server. At the server, one cart's location is *aggregated* with the location, type, and maintenance schedule for all other carts. All these data can then be *analyzed* to identify which carts need to be retrieved for maintenance. Finally, with that information in hand, workers can *act,* bringing in the right pieces of equipment for maintenance on time. With the completion of the loop, the digital information has created *value* in the real world—in this case, increasing the efficiency of equipment maintenance.

Defining IoT Value for Airports

The exact amount and type of value created by IoT are limited only by the business problem to which IoT is applied. Airports are complex spaces—not only in terms of aircraft and passenger movement, but also in terms of the large number of stakeholders necessary to make the airport work. The value of IoT is determined by the volume and quality of the information handled.

The more stakeholders an IoT application meaningfully connects, the more information there is for aggregation and analysis, and the more human or machine uses there can be that lead to improved decisions or actions. Various airport stakeholders (e.g., airlines, concessionaires, commercial tenants, vendors, and parking) each have different organizational structures, business models, profit motives, and goals. This means that each stakeholder will not only approach IoT differently but will accrue different benefits and face different challenges during implementation.

Where Are the Opportunities for Value at an Airport?

IoT can create value for an airport by supporting daily decisions or longer-term trends in operations. These typically cluster into one of two categories: *passenger experience* and *airport operations*.

The **passenger experience** includes 12 separate stages that describe a passenger's movements through an airport (the passenger experience journey map, described in Chapter 4). **Airport operations** also includes 12 stages, from arrival to ground and apron (the airport operations journey map and is described in Chapter 4 as well). Some IoT solutions track to one point in the journey map, while others track across virtually the entire airport experience. Some IoT solutions engage a widespread group of stakeholders in the airport environment, while others engage a more limited group.

To get the most from IoT, airport operators can review the case studies from other industries such as retail, commercial real estate (CRE), and transport and logistics. Lessons learned from these case studies show how IoT can improve efficiency, increase differentiation, or create entirely new sources of revenue. For example, an airport could use IoT to improve the efficiency of actions that support passenger experience by gathering data on the highest traffic areas in the airport and proactively direct cleaning staff to those areas. Or an airport could use IoT to distinguish itself from competitors by providing faster ramp servicing to aircraft, which saves money for airlines by allowing faster gate turns and making the facility a more attractive option.

How Should IoT Be Implemented at an Airport?

Regardless of the technology or application involved, IoT will have the biggest impact on airports when the technology is driven by the core business model. What business goals will an IoT solution support? The stakeholders and journey maps can determine all the possible IoT applications at an airport, as well as categorize known IoT applications currently under way. This offers airports that are investigating possible IoT projects a view of where proven solutions exist as well as where untapped value may lie. The next step, then, is to assess the current as-is capabilities of the airport and understand where they may fall short of the requirements for the potential IoT solution. This assessment of required and as-is capabilities should include at least the following criteria:

- The size and complexity of the data that the potential IoT solution will produce versus current capabilities to house and analyze data.
- The communications and other infrastructure required for the potential solution versus what already exists at the airport.
- The cost of the solution itself versus available funds.
- Stakeholder groups that can achieve benefits from the potential solution versus the security and privacy procedures that must be in place to secure their cooperation or use.

Assessing potential IoT solutions against these qualifiers can confirm (or disprove) the overall fit for the defined needs of the airport before moving toward implementation. More important, the gaps between required and as-is capabilities seen in each of these criteria offer guideposts to the first steps that must be taken in an implementation roadmap.

Implementation Checklist

- ☐ Select the IoT solution that supports your business goals.
- ☐ Determine the technical and organizational maturity needed to successfully implement the chosen solution.
- ☐ Assess your current technical and organizational maturity.
- ☐ Craft an implementation roadmap to address the gaps between current and needed maturity.

Using This Primer to Apply IoT at Airports

Implementing IoT must be a strategic process. The key is to remember that IoT solutions are tailored to the individual airport's specific business problem. Identifying upfront what an airport's IoT solution is meant to achieve is of paramount importance. (If you do not know where you are heading, how can you map the path to get there?)

This primer provides a resource for airport operators and their stakeholders to use in assessing the right IoT fit for their facility. It can be useful to airport staff at any level in their organizational hierarchy. Suggested focus areas for different kinds of personnel are noted as follows (with chapters in parentheses):

- **Leadership and management:**
  - How IoT creates value (Chapter 2).
  - Where IoT is likely to create value for airports (Chapter 3).
  - Strategies for successful IoT implementation (Chapter 4).
  - Barriers to IoT implementation (Chapter 4).
  - Importance of scalability (Chapter 5).
- **Marketing, operations, facilities, or information technology:**
  - IoT enabling technologies (Chapter 2).
  - Benefits of IoT applications (Chapter 2).
  - IoT in passenger and operations experiences (Chapter 4).
  - Strategies for successful IoT implementation (Chapter 4).
  - Implementation roadmap (Chapter 4).

CHAPTER 1

Introduction to the Primer

Purpose of This Research Report

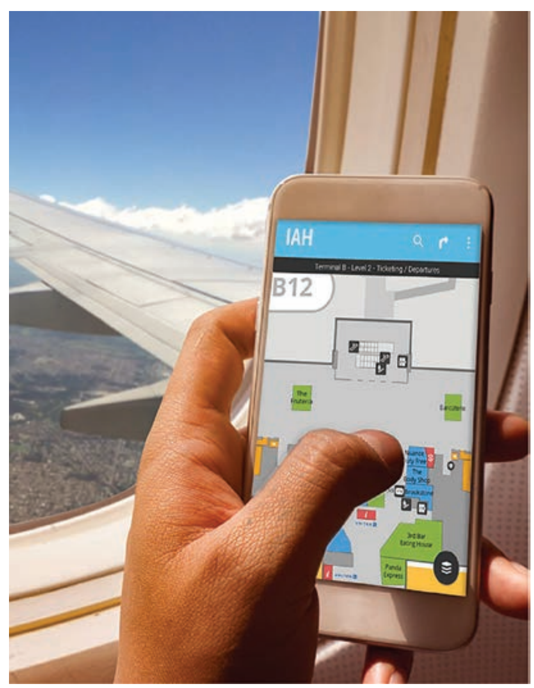
ACRP Research Report 191: A Primer to Prepare for the Connected Airport and the Internet of Things introduces IoT and its use in airports. IoT is a network of connected devices embedded with sensors. The sensors capture data, and the IoT system architecture enables these devices to communicate, aggregate, and analyze data.

IoT is becoming increasingly important because of its potential to generate new customer-serving and revenue-generating opportunities at airports. IoT also has the potential to optimize airport operations and achieve efficiencies that could impact various stakeholders. But what exactly is IoT, and what impact could it have on the airport industry? What new challenges will it bring?

This primer will help airport operators and their stakeholders understand and implement IoT. While in the early stages of application, IoT has the potential to be transformative for airports. Currently, there are no generally recognized practices for airports operators and their stakeholders to consider in determining how to best use IoT.

Definition

IoT is a network of connected devices that communicates, aggregates, and analyzes data. IoT can help airports better serve customers, generate more revenue, and achieve operational efficiencies.



Source: http://flytohouston.com.

Content of the Primer

This primer is an easy-to-use reference that describes the following:

- IoT concepts and underlying technologies.
- How other industries have implemented IoT.
- Opportunities for IoT in an airport environment.
- The current state of implementation and associated challenges.
- How airports should strategically consider specific application areas.

Benefits of the Primer

The benefits of the primer include the following:

- It provides a general context for IoT implementation in airports, including a description of enabling technologies.
- It helps airport operators and stakeholders understand current IoT activities in airports and emerging capabilities.
- It indicates how IoT may benefit the passenger experience and aviation operations.

- It describes the barriers and limitations to IoT implementation and strategies to overcome them.
- It provides an understanding of current best practices and lessons learned through informative case studies, including how other industries have implemented IoT.

Data Collection for the Primer

The information and guidance offered in this primer resulted from data collected through the following means:

- **A literature review.** The research team reviewed literature about IoT background and concepts, IoT as a technology architecture, IoT value propositions, and IoT applications outside an airport environment. The literature searches used commercial databases and resources available through the Texas A&M University System Libraries and other Internet resources. The team also reviewed more than 30 research reports published by Deloitte that investigate the impact of IoT on several industries.
- **Stakeholder interviews.** The team conducted 18 interviews with industry stakeholders representing IoT experts, airports, airlines, aviation industry associations, federal agencies, vendors, and intelligent transportation system/transportation providers in fall 2016. These qualitative interviews enhance the information uncovered in the literature search.
- **A stakeholder survey.** The team conducted an online survey of 103 industry stakeholders representing airports, airlines, airline vendors, aviation industry consultancies, IoT suppliers, and other consulting organizations in fall 2016. The survey gathered information from a broad group of respondents to determine the current extent of IoT applications in airports, perceptions of IoT, and attitudes toward possible future uses.
- **Case studies.** The research team conducted 11 case studies in spring and summer 2017. Eight studies were in an airport environment: Columbus John Glenn International Airport (CMH), Orlando International Airport (MCO), Delta Airlines, Singapore Changi Airport (SIN), Dallas Fort Worth International Airport (DFW), London Gatwick Airport (LGW), Toronto Pearson Airport (YYZ), and San Francisco International Airport (SFO). Three were in other industries: retail, CRE, and transport and logistics. The case studies examined potential implications for airports preparing to implement IoT. Studying specific IoT implementations in depth was a way to understand what is happening at the frontline of IoT activity, specifically with respect to applications that have moved from development to deployment—along with their enablers and barriers to adoption. These case studies are intended to prompt additional research and informal peer exchange among airport operators. Case study findings are interspersed throughout this primer, identified by the icon at the right.

Getting Started with IoT

This primer provides information about how airport stakeholders can get started with IoT. It is geared toward airport operators and their stakeholders at all airport sizes: general aviation, small hub, and large hub airports.

Intended Audience of the Primer

IoT is not a technology itself but rather a concept. IoT brings together technologies in a specific way to do something new. It looks at different systems and asks: What if those two machines could talk to each other? What could be learned by quickly analyzing digital data about the physical world?

While IoT is a big concept with lots of moving parts, developing a strategy to begin implementing IoT does not have to be complicated. This primer provides information about how to get started. It is geared toward airport operators and their stakeholders at all airport sizes: general aviation, small hub, and large hub airports.

Navigating the Primer

The primer is a resource for understanding and implementing IoT systems and applications. The content is organized in a hierarchical manner. Earlier chapters present foundational information, and later chapters present more advanced knowledge that builds on these underlying concepts.

The primer is organized into the sections described in Table 1.

Table 1. Sections in this primer.

Section	Description
Summary	Summarizes the most important points of this primer.
Chapter 1: Introduction to the Primer	Presents the purpose and potential benefits of the primer, the methodology used to develop the content, and how the primer is organized.
Chapter 2: Understanding IoT	Offers a simple description of IoT and its enabling technologies, describes other industrial applications, and examines generally how IoT creates value.
Chapter 3: Discovering the Impacts of IoT	Describes the current state of IoT awareness, opinions, and activities; provides insight specifically into how IoT can provide value in an airport environment.
Chapter 4: How to Use IoT	Presents current use cases, addressing both the passenger experience and aviation operations, and factors influencing IoT adoption, including both enablers and barriers.
Chapter 5: What's Next?	Provides a forward-looking assessment of promising IoT applications for airports and the importance of pilots and scalability to future opportunities.
Appendix A: Glossary	Presents definitions of terms and technologies that are specific to IoT.

CHAPTER 2

Understanding IoT

What Is IoT?

Source: Philip Pilosian/Shutterstock.com.

In IoT, different applications and devices must work together seamlessly across and within different sectors, enabling new capabilities and processes. This chapter introduces airport operators and their stakeholders to the definition, features, and enabling technologies of IoT, as well as ways in which IoT creates value.

Beginnings of IoT

In 1991, Mark Weiser of Xerox PARC first described how objects of all types could sense, communicate, analyze, and act or react to people and other machines autonomously—as easily as we turn on a light or open a water tap (Raynor and Cotteleer 2015). He developed a framework that became the basis for understanding how IoT works (Figure 1). The framework relies on three basic steps:

1. A sensor captures data about an action in the world.
2. The sensor communicates that data, and the system aggregates sensor data across time and space.
3. Analysis of the sensor data enables future acts to be modified.

From these basic beginnings, IoT has evolved to encompass different devices, technologies, and uses.

Evolving Definition

As IoT has evolved, so too has its definition. Finding one term to describe it can be challenging. It can be the Internet of Things, Internet of Everything, Industrial Internet, machine-to-machine communication, or even the fourth industrial revolution. The following are only some of the ways to describe IoT:

- From a general perspective, Deloitte defines IoT as "technology that connects objects (including people) to a network (such as the Internet) to provide access to information about that object's condition, position, or movement" (Eckenrode 2015).
- From a sensor and operating system perspective, Texas Instruments defines IoT as "Things, people, and cloud services getting connected via the Internet to enable new use cases and business models" (Texas Instruments 2018).

Definition: Internet of Things

IoT is a network of connected devices embedded with sensors. The sensors capture data, and the IoT system architecture enables these devices to communicate, aggregate, and analyze data to achieve results.

- One airport representative interviewed for this research report defined IoT as “the intelligent connectivity of smart devices by which objects can sense one another and communicate, thus changing how, where, and by whom decisions about our physical world are made.”

Components of IoT

A multitude of terms are also used to describe today’s smart technologies: IoT, wearables, connected devices, and ubiquitous computing, for example. As a result, it can be difficult to distinguish between them. However, several components are common to all these terms:

1. IoT requires *physical objects*.
2. Those objects need to be smart objects—physical objects that are *instrumented* to collect data about their location, state, or other activities.
3. If those data are to move from the objects to where they can be used, *connectivity* is required. Connectivity is the glue that binds all the sensors and devices in a system together, providing pathways to transfer and gather data for analysis.
4. *Analysis* provides information that leads to an appropriate conclusion or response (Figure 2).

While having representative technologies from each of these categories may be necessary to create IoT, they alone are not sufficient. All these technologies must work together to create a successful IoT solution.

Connected Airports

This primer aims to help airport operators and stakeholders understand the impacts of IoT technology and prepare for a connected airport environment. The connected airport brings together a variety of technologies through IoT, with the goal of improving the passenger experience and bringing monetary benefits to the host airport. Achieving this goal requires significant work behind the scenes in airport operations.

People interviewed for this research described the concept of the connected airport in the following ways:

- An IoT expert stated, “A connected airport would be one that has a fully digital interactive system that allows passengers to explore, travel, and be monetized. By be monetized, I mean being able to move passengers through the airport to learn what’s around them so that they can explore and buy stuff.”

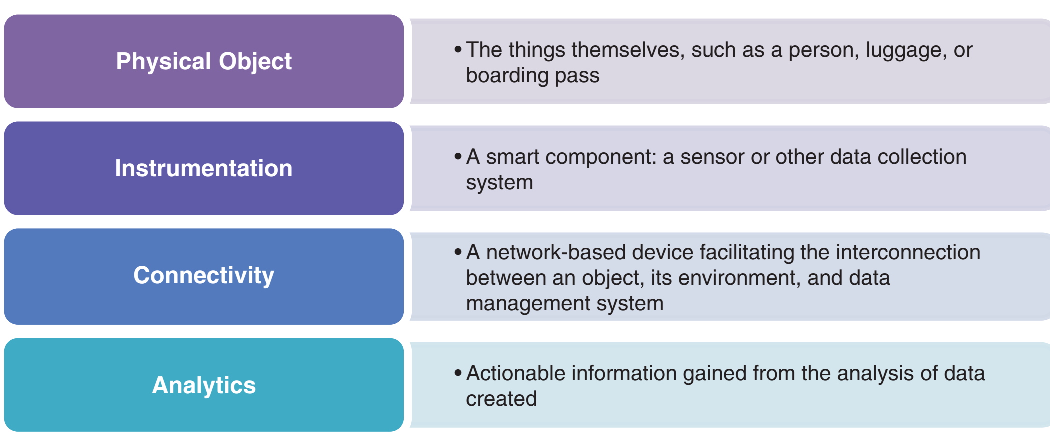


Figure 2. Fundamental components of IoT.

Definition: Connected Airport

The term *connected airport* refers to a wide variety of IoT technologies and applications deployed at airports.

- An airport representative offered an operations-oriented definition: a connected airport has "airport systems that are connected to the Internet, and capable of displaying the current operating state, in a manner that is both temporal and geospatial."
- A representative of an airline industry association described a connected airport as "connecting processes and data more centrally."
- An airport vendor also took a data perspective: "You've got connectivity into every aspect of the airport operation—security, baggage, passenger processing. You've got data at your fingertips."

IoT Enabling Technologies

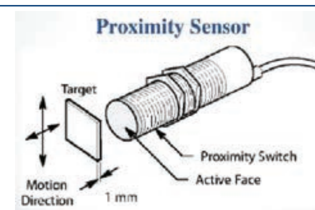
IoT enables physical objects to see, hear, think, and perform jobs by having them exchange information and coordinate decisions. IoT does this through two basic categories of technologies: sensors and communication protocols.

Sensors

At its core, IoT is about using digital information about the physical world to make better decisions and actions. This means that every IoT application, regardless of purpose or location, must begin with a physical object and a sensor measuring something about it. Figure 3 provides examples of common airport sensor systems.

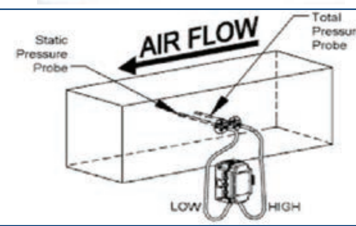
Proximity. Also known as tracking sensors, these sensors include radio frequency identification (RFID) tags, beacons, and Wi-Fi sensors. Sensors identify the presence or absence of an object within a defined distance limit. When the object is detected in the vicinity, a signal is sent to the controlling system to initiate an action once the data are received.

Typical uses in airports are in parking availability and lighting on/off systems, and radar and electromagnetic radiation systems that detect wildlife on airport grounds.



Pressure. These sensors detect the variation in the pressure against some standard range and send data to the controlling system when any change is found so that proactive, timely action can be taken.

Typical uses in airports are in heating, ventilation, and air conditioning (HVAC) systems and other liquid- and gas-oriented asset monitoring. For example, the airport operator may not need to employ an engineer to examine infrastructure on a regular basis for building maintenance when pressure sensors are embedded in the terminal.



Optical. These sensors measure the amount of light in the surrounding environment with electromagnetic energy monitoring and then convert it into a form that can be easily read by digital devices. Fiber optics, infrared, pyrometer, and photodetector are key types of optical sensors for IoT application.

Optical sensors are often deployed in digital cameras to determine biometrics, apply security settings, and even perform queue management and passenger flow analytics (Denman et al. 2015).

Motion sensors. These sensors detect the physical motion in an area and then send the information to the controlling device by transforming the motion into the signal.

These sensors are used in intrusion detection systems, smart cameras, automatic door controls, and boom barriers where they can detect a presence with passive infrared rays, ultrasonic waves, and microwaves. In airports, they include door sensors, beacons, and earthquake sensors (Hui 2008).

Figure 3. Examples of common sensors in airport IoT applications.

As noted in Figure 3, there are many varied types and uses of sensors in airports, but currently proximity sensors are most common in airports. The most common types of proximity sensors are as follows:

- RFID tags.
- Beacons.
- Wi-Fi access points as sensors.

Definition: Sensor

Sensors are mechanical or electrical devices that translate a physical phenomenon into useful signals—most often electrical impulses interpreted by computers.

RFID Tags

RFID tags use radio frequency signals to transmit data about the tag to RFID readers. RFID tags can be active or passive:

- An active RFID tag uses internal battery power to transmit directly to an RFID reader.
- A passive RFID tag reflects the energy that an RFID reader directs at the tag (Jovix 2018).

Active RFID systems are typically deployed in tracking an asset's location, movement about the airport, current functional status, and lifetime remaining, such as for wheel chairs, baggage carts, and flight displays (Figure 4) (Adelte 2016). Because active RFID tags have their own power source, they can contain a variety of sensors and have enough data storage capacity to transmit and communicate data and position.

Beacons

Beacons are sensors that report the location or presence of an object or person in a certain area. Among the most common beacons are those operating via Bluetooth®. Bluetooth low energy held a major beacon technology market share in 2016 and is expected to dominate the market in the future, according to Global Market Insights. It is a low-cost wireless technology alternative to Wi-Fi, near field communication, and GPS technologies for location-based services.

***Figure 4. Example of an RFID tag: a Delta baggage tag* (left) *and the RFID tag embedded in it* (right).**

Bluetooth beacons are small, low-cost, battery-operated devices that emit Bluetooth signal pings to other Bluetooth-enabled mobile devices, typically within a 70-m radius. The beacon senses these pings and estimates the relative proximity of nearby mobile devices to the beacon (Smartwhere 2015).

Beacons can be used as part of either one-way or two-way communication:

- In a one-way system, the beacon merely counts or tracks people or objects in an area.
- In a two-way system, the beacon can transfer information to an application on a device. The beacon can also ping an application to respond with information. For example, the application could show the user a relevant message based on how close the user is to the beacon (Figure 5). Users of the application agree to this transfer of information in a user agreement.

Wi-Fi Access Points as Sensors

Wi-Fi access points provide the Wi-Fi signal for passengers and airport stakeholders. While most people think of Wi-Fi as a resource, like a water fountain, even Wi-Fi access points can become sensors.

Wi-Fi-enabled devices continually transmit signals to detect available networks in the area (typically every 15 to 30 s) (Mattson 2016). Wi-Fi access points can collect and process these signals to count how many people moved through an area. By triangulating a user's location between multiple access points, the system can even provide navigation or other location-dependent services.

Airports are using this sensing capability of Wi-Fi access points to support functions such as optimization of staff allocations, queue management, directions and way finding, and real-time passenger flow analytics.

Figure 5. Example of a beacon: SITA lab technology.

Communication Protocols

Communication is a key element of IoT. Data are useless if they remain trapped on the physical object and cannot be sent where they can be used. A number of communication protocols are designed to transmit data over wired and wireless networks (Table 2).

The performance and cost of these protocols can vary depending on the use. Therefore, there is no single best communications network or protocol. As a result, airports can use any of the protocols listed in Table 2. Finding the right connectivity option involves comparing the cost, bandwidth, range, reliability, and other factors of each protocol to the requirements for the specific IoT application. A useful technical reference is *Internet of Things (IoT) Communication Protocols: Review* (Al-Sarawi et al. 2017).

For example, when LGW built its IoT infrastructure, it considered two types of low-power communication protocols:

- **Narrow-band IoT (NBIoT).** NBIoT is built on a licensed spectrum, meaning that it operates on a reserved slice of the electromagnetic spectrum. The result is less interference from outside sources, so connectivity can be more reliable, especially in a crowded radio-frequency environment like an airport. The downside is that because NBIoT relies on a licensed spectrum, airports need a contract with a telecommunications company, just like a monthly cell phone contract.
- **Low-power wide area network (LoRaWAN).** In an interview conducted on July 25, 2017, Abhilash Chacko, head of information technology (IT) commercial and innovation for LGW, LoRaWAN offers the inverse. It operates on an unlicensed spectrum, so no telecommunications company is needed. Once an airport sets up a network, it owns that network, so there are no recurring costs. The downside is the possibility of interference issues in certain areas.

LGW decided to use LoRaWAN in its IoT platform competition, but other options may be best for other airports.

Typically, these communications protocols bring data from sensors to a centralized repository where they can be combined with other data and analyzed. While some data can be processed and analyzed on the sensor itself, more complicated analysis for larger business problems usually requires aggregation of data.

The specifics of how aggregation and analysis are performed vary widely depending on the specific use. Data can be brought together and parsed for uses that require immediate responses,

Table 2. Broad network classes with sample communication protocols.

	Personal area network (PAN)	Local area network (LAN)	Wide area network (WAN)
Wired connections	USB	Ethernet	Not applicable
Wireless connections	Bluetooth, ZigBee, Near Field Communication, Wi-Fi	Wi-Fi, WiMAX	WiMAX, weightless, cellular technologies such as 2G, 3G, 4G (LTE)

Note: A few technologies can work in more than one network type depending on the range of the networking device used. For example, Wi-Fi can provide connection within a house (PAN) as well as within a building (LAN).

Source: Wenyuan Xu, *Introduction to computer networks*, Department of Computer Science and Engineering, University of South Carolina, www.cse.sc.edu/~wyxu/416Fall09/slides/Chapter1_Info.ppt, 2009, accessed March 12, 2015.

Graphic: Deloitte University Press | DUPress.com or data can be stored and analyzed over time. Some airports may host these systems in-house, while others outsource the handling of data to a cloud-service provider. Again, there is no single, best solution but many options from which to choose.

How IoT Creates Value

Improvements and advances made to IoT technologies have accelerated in the past few years. However, technological improvement alone is not at the core of what makes IoT so powerful and revolutionary. Interest in IoT did not increase until after all of these technologies were readily available (Figure 6). This is not because there was no need for IoT before or because interest was still building, but rather because industry was still determining exactly how the technologies should all be connected to work together. Those connections between the technologies, also called architecture, are the key to how IoT creates value.

Definition: Architecture

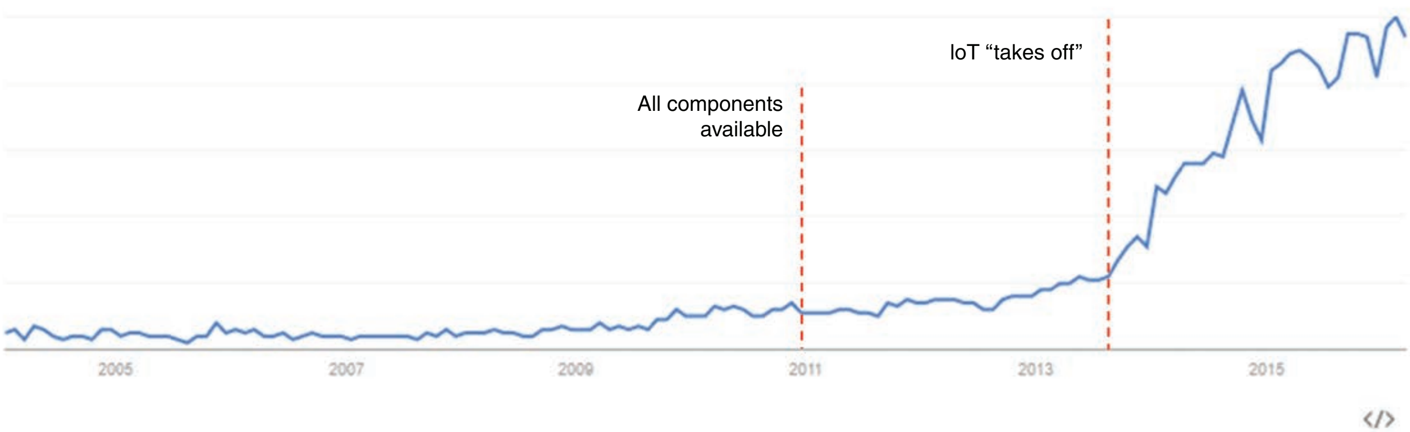
Architecture means the connections among IoT technologies.

IoT as a Technology Architecture

While new devices are easy to identify, technology alone cannot create significant value. New technologies can be useful but can also be easily copied by competitors. Only an architecture such as IoT can create sufficient value to give a business a strategic advantage over its competitors.

Enduring strategic advantage can only come from new architectures, that is, new ways of connecting technologies, people, and business processes. As a result, these architectures are essentially entirely new ways of thinking. While introducing an entirely new architecture is challenging because of the system reengineering that may be required, if done correctly, it can be incredibly difficult for competitors to copy or defeat.

For example, in the 1990s, Southwest Airlines created a revolutionary architecture. Other airlines could easily see the technology Southwest used—operating only one type of aircraft to keep maintenance costs low—but they could not see how that technology connected to other technologies. They could not see all the operating processes and strategies such as fuel hedges, employee culture, and so forth. In short, other companies could not see the architecture that



Source: Google (2016) (Google Trends using the search term *Internet of Things* from 2004 to 2016).

Figure 6. Relative search trends for Internet of Things.

allowed Southwest to be such a successful low-fare airline (Elliot 2002). The result was that when major airlines copied Southwest with in-house low-fare brands in the mid-1990s, every single one was out of business and folded back into the parent airline by 2003 (Kumar 2006). Architectures are hard to create but do make a difference.

Information Value Loop Concept

But how exactly do the enabling technologies come together to form an architecture? The architecture of IoT is explained by the Information Value Loop (Figure 7).

The loop begins when an action—the state or behavior of things in the real world—generates information, which then gets manipulated to inform future action. For information to complete the loop and create value, it passes through the loop's stages, each enabled by the following specific technologies:

1. **Sensors.** A sensor *creates* digital information about the physical world.
2. **Network.** The network *communicates* the digital information.
3. **Standards.** Standards—technical, legal, regulatory, or social—allow those data to be *aggregated* with many other types of data across time and space.
4. **Augmented intelligence.** Tools such as augmented or artificial intelligence *analyze* the data to find key insights.
5. **Augmented behavior.** The loop is completed when a human or machine uses those insights to *act* in a manner that leads to improved action.

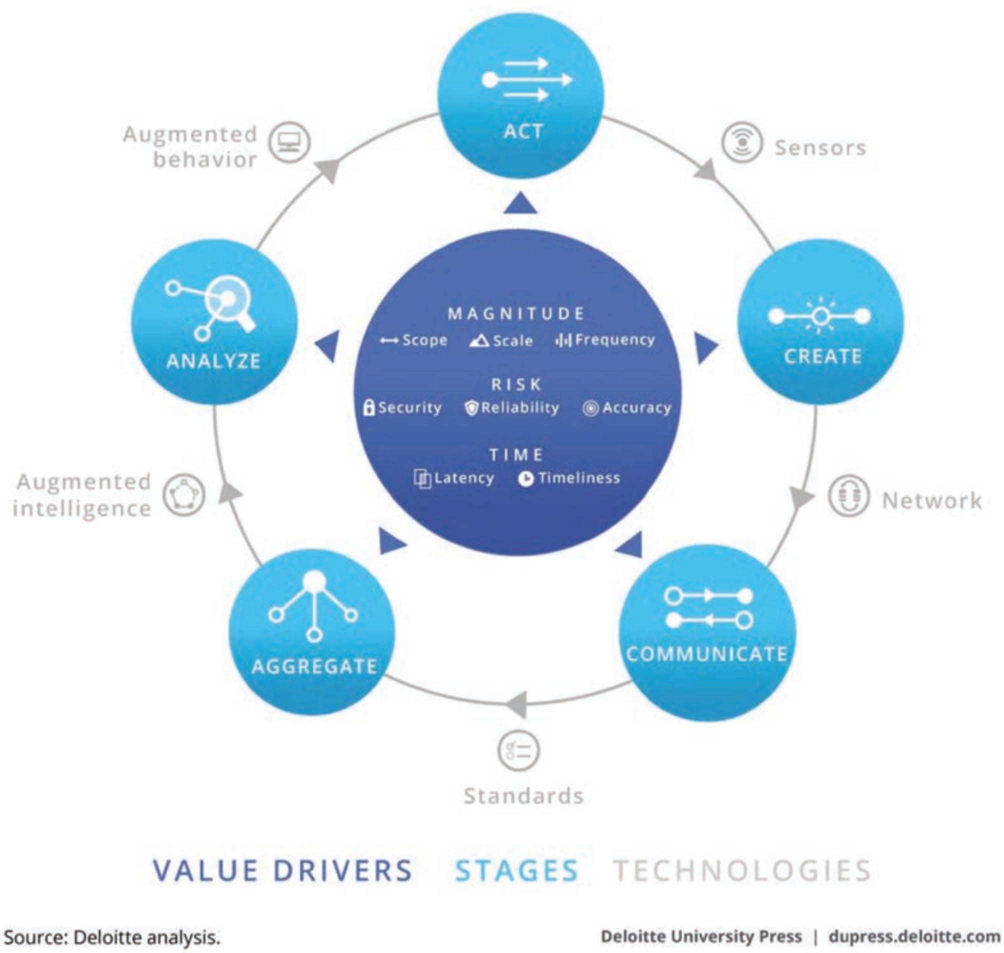


Figure 7. The Information Value Loop describing the architecture of IoT.

How Much Value Does IoT Create?

The amount of value IoT creates varies. In general, analyzing the value drivers (shown in the center of Figure 7) can determine the amount of value created from the information passing through the loop. The value drivers fall into three general categories:

- **Magnitude:** how much data are needed (scope, scale, and frequency).
- **Risk:** how reliable and accurate must those data be (security, reliability, and accuracy).
- **Time:** how quickly or how often the data are needed (latency and timeliness).

Making an improved decision or action is how IoT creates value. Information completes the loop and enables a new action—an impossibility without the combined efforts of all the technologies around the loop. Packages can be routed more efficiently, workers can be directed to where need is greatest, or maintenance can be conducted only when equipment requires it. All these actions save money or increase the value of a product or service because the enabling technologies of IoT have come together to process digital information about the physical world.

But most important, because IoT creates value from information, a mere change of the type of information it collects can significantly alter how it benefits a business. For example, the same architecture that gathers information about the location of luggage carts to improve efficiency can also locate passengers' baggage to create a better customer experience. The fundamentals of IoT remain the same; only the benefits a business realizes from IoT change.

Example of an Information Value Loop

The following example of an Information Value Loop from an airport illustrates how IoT creates value from information:

1. The airport needs to locate its nonmotorized ground service equipment so maintenance can be performed more regularly. GPS tags affixed to the equipment function as sensors, *creating* a thread of digital information about the location of a specific piece of equipment.
2. A network of radios *communicates* that information back to a central server.
3. The server *aggregates* the location of the one cart with the location, type, and maintenance schedule for all the other carts.
4. All these data are *analyzed* together to create a plan for which carts need to be retrieved and undergo maintenance.
5. With that information in hand, workers *act*, bringing in the right pieces of equipment for maintenance on time.

With the completion of the loop, the digital information has created value in the real world—in this case, proper maintenance and greater uptime for ground service equipment. The exact amount and type of value created by IoT are limited only by the business problem airports use IoT to solve.

Benefits of IoT Applications

The three principal classes of benefits from IoT are as follows:

- Operational efficiency.
- Strategic differentiation.
- New revenue.

IoT is already in use in airports in many different ways, especially traveler information systems, passenger traffic monitoring, baggage systems, and facilities management. Most of these uses focus on increasing efficiency. Other uses of IoT, such as improving security, often fit within either efficiency (maintaining throughput with fewer machines or staff) or differentiation (shorter and faster lines for a better traveler experience). As a result, these three categories are helpful guides to what IoT can achieve at an airport.

The following examples illustrate the ways in which diverse industries—aviation, finance, sanitation, surface transportation—are leveraging IoT-derived information to produce operational efficiencies, strategic differentiation, and new revenue.

Operational Efficiency

The majority of current airport uses of IoT focus on operational efficiency. For example, an airport representative shared that one airport has "a new online inspection system managed through a private contract with Siemens, which uses a tool provided to maintenance grounds crew and connected to the Internet with GPS functionality. The purpose of this tool is to digitally connect maintenance crew inspection findings to a map of the airport grounds."

Automatic teller machines. Other industries demonstrate the potential for gains in efficiency. Diebold, a leader in the automatic teller machine (ATM) industry, provides an example of increasing efficiency through connectivity. Diebold uses smart, connected products to conduct remote diagnostics and issue resolution procedures across its network of 5,000 ATMs. Results show a 17% increase in remote issue resolution, a 15% reduction in equipment downtime, and average downtime responses reduced to less than 30 min (PTC 2018).

Waste Management. In Barcelona, Spain, IoT is improving the efficiency of waste management. Sensors are embedded in garbage cans, and capacity—rather than fixed collection schedules—determines waste collection frequency. Barcelona is projected to save more than $4.1 billion in the next decade (Thomson 2014).

Transportation. IoT is currently being used in other transportation modes to improve operations (Figure 8). For example, container traffic at the Port of Hamburg was projected to grow from 9 million containers in 2013 to 25 million in 2025, while physical space at the port remained limited (Banker 2016). Hamburg addressed this problem by placing sensors on bridges, containers, trucks, and parking spaces. Then, a single data system connected all stakeholders in the port, including the port authority, ships, and shipping companies. Now, port managers collect and aggregate information about bridge closures, terminal congestion, and available truck parking. Information is then shared with other stakeholders so that trucks arrive

Source: Travel Mania/Shutterstock.com

Figure 8. IoT in port operations.

in the port when their assigned container is ready and then depart using the fastest route. To address companies' unease about sharing information with competitors, the system gathers all information in the port but shares only what is relevant to each stakeholder. With this system, the Port of Hamburg reduced wait times by 5 min per truck, saving more than 5,000 h per day and increasing throughput by 7% to 20%, depending on the port location (SAP 2018a).

Strategic Differentiation

While gains in efficiency can be significant, IoT can also provide a more differentiated product or better customer experience. Differentiation can be much broader, especially for airports where the greatest competition comes not from other airports but from other modes of travel. For example, limiting greenhouse emissions, reducing noise levels over neighboring areas, or even responsibly maintaining an airport's open space can all be differentiators that make the airport an integral part of the community and an attractive brand. In fact, smart products used as part of IoT can even gather information about customer preferences, providing a deeper understanding of what does and does not differentiate travel options.

Currently, very few applications of IoT in airports provide strategic differentiation. This trend is seen in other industries as well. A lack of investment capital, unease over technical complexity, and organizational concerns can play a role in an executive's decision to pursue efficiency over differentiation. One crucial factor is that, unlike operational efficiency deployments, differentiation requires changes that extend outside the organization and involve perceptions of, or transactions with, other stakeholders. In a multi-stakeholder landscape like the modern airport, involving external stakeholders in a rapidly changing technology implementation can be extremely challenging.

New Revenue

IoT can also create entirely new sources of revenue. This can come from creating new products or services to attract new customers or by using IoT to sell more to existing customers. While IoT solutions aimed at new revenue are often the largest and most complex, they can also build on existing solutions and generate efficiency gains. The following are some examples from rail and logistics industries.

Rail. European cargo rail consortium Deutsche Bahn AG used IoT to generate new revenue from previously untapped customers. Deutsche Bahn installed a network-wide track-monitoring system of over 1 billion *nodes*—collecting data on each segment of track, railcar, station, engine, switch, and signal—that span its global operating network (see Figure 9) (Optasense 2014). The system monitors the condition of all these physical objects in real time. Data flow back to a control tower that aggregates them every 5 s to provide near-real-time information across the entire fleet. Deutsche Bahn uses these data to improve operational efficiency by rerouting traffic around congested nodes to increase on-time arrivals. Deutsche Bahn then integrated the monitoring system with planned customer orders and billing information. This aggregation of diverse datasets enabled the company to create dynamic cost-to-serve pricing models. In contrast to traditional cost-plus pricing, Deutsche Bahn generates a price specific to a customer's needs by examining traffic patterns, network usage, freight type, destination, and a customer's desired timetable. In the past, many customers may have been quoted prices that seemed too high for their needs and moved their freight by road or other means. Now those customers see better value in rail, and Deutsche Bahn captures a larger portion of the market for moving passengers and freight (Bonsall et al. 2007).

Logistics. Companies can also use IoT to create entirely new products or services. Often a company may realize that data it is already gathering for the company's own internal efficiency

Source: Tupungato/Shutterstock.com

Figure 9. Deutsche Bahn AG train station.

can be used by another, external group that is willing to pay for it. For example, DHL gathers data across the world from its sensorized shipping fleet. DHL used that data to create an entirely new product to offer to customers. Airports may not have the global reach of data that a company like DHL has, but they can compile significant amounts of data about the passengers, aircraft, and cargo that move through them. These data could be significant to advertisers seeking to more accurately segment customers, to economists and traders seeking to predict economic trends, or even to academic researchers analyzing everything from climate to crowd dynamics. Airports should keep an open mind about finding other possible uses for their large volume of data gathered with IoT.

Introduction to the Case Studies

The fact that no particular device or piece of technology defines IoT makes it remarkably flexible. IoT has applications for consumer wearables and for in-home functions, in every industry and sector, both visible and behind the scenes. Because the architecture of IoT remains constant, airports can learn important lessons about how to harness IoT from other industries. Three case studies examined IoT's use in three industries with direct parallels to airports:

- Retail.
- CRE.
- Transport and logistics.

Case Study: IoT in Retail

CASE STUDY

Airports can take advantage of best practices and lessons learned from IoT in retail. Significant parallels can be drawn between the needs and challenges of airports and those of retail, including growing demands for improving the customer experience with e-commerce platforms. Airport operators can learn from the IoT proofs of concept executed by retailers as they define and develop their own IoT strategies to increase nonaeronautical revenue and improve security, efficiency, and overall operations.

While retailers have made tentative forays into IoT, most applications of IoT have focused on providing customer-facing applications as a way to gain new or retain existing customers. For example, some grocery retailers such as Sam's Club or Giant Food Stores offer a smartphone app that enables customers to scan item barcodes as these items are put in a cart and pay for them (with a pre-entered credit card) without ever going through a checkout line. This reduces the need for check-out personnel and provides time savings to customers. However, the true value of IoT comes from retailers combining both backroom and customer-facing applications. In this way, IoT is poised to transform the retail industry—helping retailers offer customized products for lower prices, find competitive advantages, and increase revenue by better understanding their customers and their preferences.

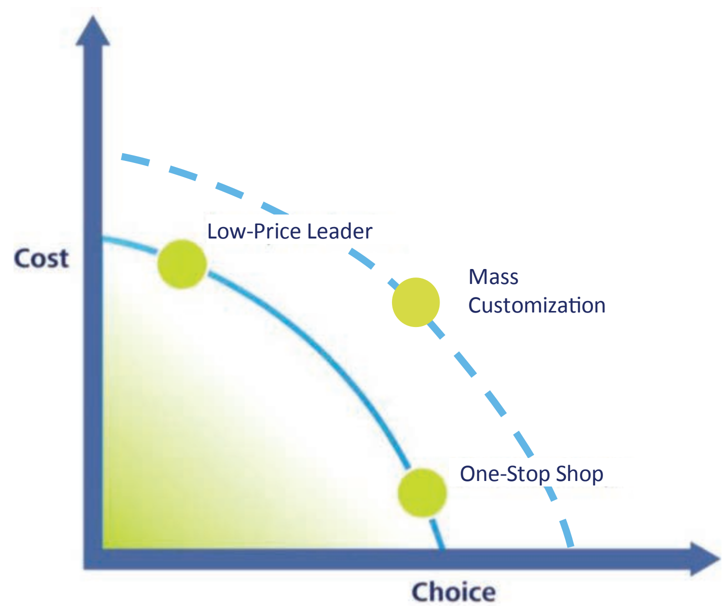
Defining the Business Need for IoT Applications in Retail

In general, retailers use one of two strategies to create value: high choice or low choice.

High-Choice Vendors. For most of retailing's history, customers made purchases by selecting from the goods available on store shelves or in on-site stockrooms. Because retailers had few ways to accurately gauge who would want what when, the only way to provide customers with what they wanted was to physically stock the goods in store. Providing this higher level of choice meant increased inventory-related costs associated with sourcing, moving, and holding a larger variety of products. As a result, retailers required higher margins (achieved through higher prices) to attain a level of profitability comparable with that of retailers who offered fewer choices. High-choice retailers charge higher prices on exclusive goods and the same price as competitors on goods offered by both.

Low-Choice Vendors. Alternatively, a retailer could provide fewer choices and enjoy lower overall inventory costs. It could then pass the savings on to consumers in the form of lower prices or keep the savings for itself with higher margins.

Comparison of High- and Low-Choice Strategies. A company's strategy is determined, in part, by how it chooses to address the costs and benefits of carrying inventory (Figure 10). One choice is not better or worse than the other, only different in its execution. The choices simply



Source: Deloitte analysis. Graphic: Deloitte University Press | DUPress.com

Figure 10. IoT can break the traditional trade-off of retail strategy, balancing cost versus choice.

represent different business strategies, each of which can be successful. In fact, the long-term performance of both low-price leaders and one-stop shop retailers is extremely close (Figure 10). Therefore, what is needed to be innovative is not a change from a low-price leader to a one-stop shop or vice versa, but to break the trade-off between them entirely.

Choice versus Cost

The declining costs for IoT-enabling devices can enable mass customization in retail.

IoT Option. Through IoT, technology may finally break that trade-off and create a third choice. The decreasing cost of sensors and computing power means that IoT is more widely deployed than ever. The result is that, if properly applied, IoT can drive the creation of business models that enable retailers to offer a wide array of goods, customized to a customer's unique needs, at a low price. The concept of mass customization shows how technology can help make this new business model a reality.

Sample Solution: Mass Customization of Athletic Shoes

Nike has used three-dimensional (3D) printing in its supply chain to shorten delivery times and reduce costs. Nike is now combining 3D printing with IoT to print shoes customized to individual customers (Burris 2014). Adidas is also pursuing this strategy and committed to make 5,000 3D-printed Futurecraft 4D shoes by the end of 2017, and an additional 100,000 by the end of 2018 (Yurieff 2017).

A smaller competitor, Feetz, is also applying IoT to use smartphones as the sensors for IoT. Customers create a 3D model of their feet from three different pictures taken using the company's app (Feetz 2017). Customers can then select from among the entire Feetz line of shoes and have a pair 3D-printed specifically to fit their feet. For the customer, this model offers a level of customization never before possible. For the manufacturer and retailer, the result is lower cost because only those shoes ordered are actually produced, lowering the inventory that must be kept on hand. IoT has made the mass customization business model feasible for the first time, and that model, in turn, has broken the age-old trade-off of retail: choice versus cost.

Enabling Factors

Mass customization requires both customers and the supply chain itself to have significant computing power at their disposal. When the size and cost of computing were both high, such distribution of technology was all but impossible. However, the declining cost—specifically of sensors and Internet communications—has enabled mass customization.

The cost and size reductions in computing are well documented, but even in recent years, improvements have been substantial. The cost of an accelerometer has fallen from $2.00 in 2006 to less than 40 cents in 2015 (Holdowsky et al. 2015). Similar trends have made other types of sensors small, inexpensive, and robust enough to place almost everywhere—from detecting fetal heartbeats via conductive fabric in the mother's clothing to sensing jet engine performance at 35,000 ft.

The cost to transmit that information over the Internet has also declined. In 2003, it cost $120.00 to transfer 1 Mbps in the United States. As of 2015, the cost has come down to 63 cents (Holdowsky et al. 2015). Together, these two trends mean digital information could be created anywhere anytime and transmitted to where it can be used efficiently and cost-effectively.

Barriers to Success

Technology adoption preferences. Many initial retail forays into IoT focused on creating a new channel to customers by using beacons to track customers in stores and push relevant notifications to them. Generally, these applications have been commercial failures

Mass Customization Barriers

The following are two significant barriers to successful implementation of mass customization via IoT:

- Technology adoption preferences.
- Resistance to internal organizational change.

(Grennan 2016). The problem is that customers do not see any benefit from them and find the push notifications annoying. Research from the marketing firm Kahuna indicates that, on average, 60% of users opt out of push notifications (Brian 2018). In retail, just over 10% of customers use that feature. This is a rate of use 3 to 4 times lower than in leading industries such as ride sharing and financial services. These industries succeed because they offer customers urgent, real-time information such as when a ride-share car has arrived or the gate for an airline flight has changed.

Resistance to internal organizational change. The challenge for retailers is that to create real-time information that customers care about, they must have real-time knowledge of their supply chain. A survey of United Kingdom customers indicated that 87% want retailers to provide real-time product availability (Friedlein 2016). Retailers need to know exactly where every product is at any time so they can answer customer questions; however, with the rate at which items are lost, broken, or stolen, obtaining a real-time inventory can be challenge (Smith 2016). Often, it requires not only technology upgrades but also significant organizational change within retailers. Successful IoT applications might require working in new teams and across traditional boundaries. In many retail organizations, marketing is focused on the consumer, while operations is focused on making existing processes more efficient. The two groups seldom cross paths. But in an IoT era, groups across the organization need to work together in new ways.

What's Next

The mass customization business model enabled by IoT has begun with small retailers and in pilot projects such as those at Nike and Adidas. The next step is the scaling of those efforts that prove successful. The most immediate form of scaling is in terms of the size of the applications. For example, Adidas plans to move from 5,000 3D-printed shoes to 100,000 within 1 year.

Similarly, scaling can also increase the scope of IoT applications. For example, Amazon's grocery store without checkout lines, Amazon Go, relies on the same ubiquity of sensors—both within the store and on its customers—to provide the basic data needed for its complex algorithms to determine what merchandise customers have selected and then bill them for it. That creation, analysis, and action on digital data about the real world is the core of IoT, and through mass customization and queueless stores, IoT is creating entirely new retail experiences.

From Retail to Airports: Using IoT to Improve the Customer's Shopping Experience

The automated collection, aggregation, and analysis of data provide a way for retailers to offer a customized experience for consumers while still drawing from a large pool of product options. For retailers in an airport, where space and inventory are often limited, this may mean that customers begin to demand greater choice at the same low costs. This would require IoT throughout the retail supply chain to achieve the visibility and flexibility needed to have what customers want, where they want it, and when they want it. For an airport, this can mean increased revenue from increased retail sales but it can also be applied to the airport itself—offering customized travel experiences to passengers.

What does this mean for the future of retail in airports? Mass customization could provide useful information, such as flight boarding status (as some restaurants already provide on monitors), to relieve stress and allow for more shopping time. Mass customization could also adapt to each traveler's particular travel type. For example, retailers next to a flight to Hawaii could help passengers plan a vacation experience by offering products attuned to that destination—leis, sunscreen, or novels. For an early morning business flight to New York City, retailers could offer coffee, toiletries, business books, and other amenities. Rapid shifts, complete inventory visibility, and knowledge of the customers and the world around them are the hallmarks of IoT-enabled retail.

Case Study: IoT in CRE

CASE STUDY

Use of IoT in CRE is now more than just sensors that turn lights on and off. New IoT enhancements create sustainable solutions that drive bottom-line cost-saving efficiencies, develop collaborative and productive work environments, and make buildings safer and more secure. As these advances improve the work experience of tenants, they also create new business opportunities for CRE companies. Airports can apply CRE successes to their own IoT implementations—in many ways, airports as structures share many commonalities with CRE.

Defining the Business Need for IoT Applications in CRE

As technology and the workplace evolve, CRE is looking at new technologies and applications to transform physical spaces, increase building efficiency, and enhance productivity of tenants. Using IoT solutions to create smart buildings enables personalized solutions for tenants, cost savings for building operators, and sustainability through resource reduction.

IoT solutions for physical real estate were simple at first, such as motion sensors to turn off unused lights and temperature sensors to more precisely control heating and cooling. These early efforts can be tied to cost and energy savings, and encouraged the creation of smart buildings, bringing the broad capabilities of IoT solutions to all aspects of real estate management. Emerging IoT applications in CRE now focus on both tenant-facing IoT solutions and operational IoT solutions.

Tenant-Facing IoT Solutions. These solutions can create healthy working environments through customizable time-of-day lighting, temperature, oxygen flow, and other attributes that make a working environment healthy and productive. CRE companies are also transforming workspace layouts that create new ways to collaborate.

Operational IoT Solutions. These solutions can improve building management. Data from the wearables of staff and Wi-Fi can help building management better understand workflow. Data from wearables and sensors that monitor building health can create a more secure environment for both building management and tenants. IoT can enable proactive maintenance that reduces breakdowns and other disruptive events. For example, sensors can measure when building parts are broken and need to be repaired. Some systems can even predict when equipment will need to be fixed by measuring usage and benchmarking wear and tear. This allows buildings to avoid downtime and decreases costs associated with systems such as HVAC.

IoT applications in smart buildings allow building owners to distinguish themselves from their peers through specialization such as eco-friendly efficiencies. This differentiation in the market keeps buildings competitive and allows owners to charge higher rents. However, rather than causing a race among real estate companies to have the latest gadget or technology, new IoT solutions may actually help companies keep costs down and productivity up, resulting in greater collaboration in the industry to achieve success.

Sample Solution: Creating a Smart Workplace at the Edge in Amsterdam

Located in Amsterdam's Zuidas business district, the Edge is the world's most sustainable office, with over 28,000 sensors working to inform and analyze building efficiency (see Figure 11). Sensors work to detect light, motion, temperature, humidity, and carbon dioxide levels. The building currently has the highest ever accreditation score from the Building Research Establishment and produces more electricity than it consumes from the solar panels installed on the roof (Deloitte 2018). The building has not only been used as an example of what is possible for smart buildings, but also as a recruitment tool for tenants to attract top talent.

Upon arrival at the Edge, workers can identify parking spaces available from the parking meter sensors. If workers choose to bike to work, they can identify a spot to store their bike in the 500-bike garage. The building helps workers with way finding based on their calendars and provides route options to get from meeting to meeting. The building also enables connectivity of personal wearables that track the health and fitness of staff in the building.

The Edge is a global leader and trendsetter in the application of IoT in CRE and was designed to ensure it is not only an exceptional place to work for tenants, but also easy and cost-effective to operate for building management.

Enabling Factors

The design of the Edge is crucial to its success. Constructed and managed by OVG Real Estate, the building was always intended as a showpiece for smart and environmentally friendly technology (Randall 2015). The Edge features more than 21 never-before-tried innovations in design and construction (Future of Construction 2017). One of these new techniques is two 129-m wells that allow storage of thermal energy deep underground for reuse later (PLP Architecture 2017). However, the true innovation was designing the building with technology in mind from the

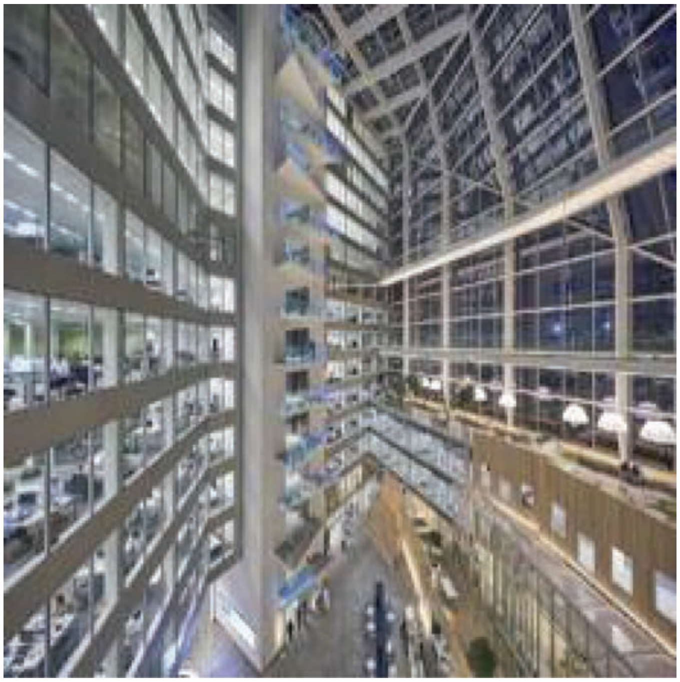


Figure 11. The Edge in Amsterdam, the Netherlands.

outset. Integration of technologies with each other was a prime consideration from the start. As a result, the connected parts and pieces in the building come together to create helpful ways for workers to better use its spaces and amenities.

At a technical level, this connectivity requires common data definitions and standards so that all equipment can cooperate effectively. The OASIS Open Building Information Exchange is one global industry-wide effort to define standard web protocols for communication between various building management systems (OASIS oBIX Technical Committee 2015). Buildings are designed to last for decades, if not centuries, while even the best technology can be obsolete in only a few years. Therefore, a smart building must be designed with a modular approach to technology so that components can be upgraded or new devices incorporated without the need to update or replace all other systems as well (Krawiec et al. 2015). Creating a smart building requires building for the future.

Barriers to Success

Magnitude of Data. Within any IoT solution, making unstructured data into structured data is a challenge. Roughly 10% of collected IoT data are structured and useful for analysis and application. The Edge and other CRE properties seeking to implement or expand their IoT capabilities must adapt and reevaluate their data strategy to make use of unstructured data and to protect employees' privacy when doing so.

Privacy Risk. Even seemingly innocuous data points can reveal very personal information about an individual when linked with other sources of data. While collecting one piece of data may not pose a challenge or threat, procedures for properly aggregating and storing every byte of data are key to avoiding privacy concerns, security breaches, and legal issues. Smart buildings must consider the workforce as well as the company. By helping to address the needs of users—and involving them in the design process to identify those needs—CRE companies can create truly novel IoT applications while avoiding privacy concerns.

Barriers to IoT in Buildings

The following are two significant barriers to successful implementation of IoT in physical buildings:

- The magnitude of data that IoT creates requires large capacities to store them.
- Privacy risk is inherent in monitoring individual movements of people.

What's Next

Smart buildings are becoming more prevalent as IoT capabilities evolve. Technology for buildings is moving beyond merely providing light and temperature sensors to creating work environments that are healthy for the tenants, eco-friendly, and less costly to operate. To prevent technological progress from becoming simply a race to provide tenants with the newest gadgets, CRE companies should articulate the core business case for the deployment of IoT. This can include saving costs, attracting higher-margin tenants, and creating entirely new sources of revenue or community engagement. The specific business case will be different for each business but should be clearly articulated.

Technical solutions are more integrated than ever before and will continue to grow with demand for better, smarter ways to manage CRE. This means that where initial applications of IoT in CRE were stand-alone efforts targeting lighting or HVAC, future efforts will increasingly integrate sensor-based knowledge of a building's systems into one building management system (BMS). Far from being simply another tool, a fully integrated BMS can create new opportunities, such as integrated storage and analysis of diverse information on common platforms, intelligent decision-making, full integration in enterprise

From Real Estate to Real Life: The Applicability of CRE Lessons to Airports

Lessons learned about traditional CRE apply directly to airports and airport operators, and lessons learned about interoperability apply to airport operators and airlines. Designing for users will help protect the privacy of passengers and airport staff in much the same way it does for tenants in traditional CRE.

resource planning (ERP) systems, deeper focus on tenant and end-client experience, and enhanced revenue by generating new services for tenants (e.g., infrastructure analysis).

For an airport, such a BMS can link actions in the real world, such as tenant sales or cab arrivals, directly to an ERP system to allow for event-based billing. A BMS can provide a rich source of data about how tenants use spaces so that building managers can design services to meet the needs tenants never even knew they had. In doing so, a fully integrated BMS can open up yet another potential benefit of IoT—the possibility of new revenue—and provide both a business case for IoT and a strong incentive for cooperation across real estate properties or airports.

Case Study: IoT in Transport and Logistics

To improve logistics, more information about the real-time location and status of goods and equipment is needed. In today's complex logistical environment, this means multiple stakeholders must share and aggregate data. While many have resisted such information sharing, IoT and its technologies make such data aggregation possible by providing value to every stakeholder. As they realize the value of this collaboration, public and private entities work internally and externally to implement solutions, scaled to meet other needs, and ultimately find new ways to create revenue.

Defining the Business Need for IoT Applications in Transport and Logistics

At their core, transport and logistics are the process of matching the demand of those with goods to move, with the supply of those who can move, store, and deliver those goods. Efficiently matching these needs is what defines the success and profitability of a logistical enterprise. Because logistics deals with the physical movement of tangible goods, having real-time, reliable information about the world is crucial to matching supply and demand.

Thus, IoT, with its ability to gather digital information about the physical world, can play a key role in improving transport and logistics operations. Specifically, IoT can supply logistics providers with information about when and where a specific product must move, where the assets are to move it, and the most efficient route to take—reducing scheduling time, cutting movement costs, and improving energy efficiency. Further, by aggregating information across many departments and stakeholders, IoT can create even greater value for those stakeholders and additional benefit for customers (via better security and traceability) and the environment (via reduced emissions).

Sample Solution: Data Efficiency at the Port of Hamburg

A prime example of IoT's impact is at the Port of Hamburg (Figure 12). Similar to airports, ports have a wide range of companies, stakeholders, and special interests that make operating efficiency a challenge. Hamburg is the third busiest port in Europe, handling 9 million containers and 10,000 ships per year in 2013. Given its proximity to the heart of Europe, the Hamburg Port Authority expects demand to increase to 25 million by 2025 (Banker 2016). However, this poses a significant business problem. The port is located near the heart of the city, which limits its ability to expand and grow. As a result, the Hamburg Port Authority needed to find a way to double the throughput of the port while using the same physical footprint. To solve problem, the authority turned to IoT.

To optimize space and increase capacity, the Hamburg Port Authority needed to aggregate data from all system stakeholders. The solution was the SmartPORT system, which captures logistics data from shippers and physical sensors spread throughout the port via SAP Hana, a single technology platform that enables aggregation of data from multiple sources. With this information, the Authority knows which containers are ready for offload from which ships, sees

Figure 12. Port of Hamburg.

the traffic conditions and parking availability near these ships, and adjusts the dispatch time and route for each truck sent to pick up each container. This allows the port to achieve increased efficiency in container loading and offloading, avoid traffic jams, and decrease pollution. Doing this, the Port of Hamburg reduced wait times for every trip of every truck by 5 min. This adds up to more than 5,000 truck h saved per day (SAP 2018a). Within just 6 months of going live, the port achieved a 12% increase in overall efficiency (SAP 2018b).

Enabling Factors

The Port of Hamburg's available technology and organizational structure enabled the success of IoT at the port. Technologically, the decreased cost of sensors and improved communications protocols made it feasible and cost-effective to add sensors to many aspects of the port's operations.

For example, every parking space features a combination of magnetic and infrared sensors to determine whether or not a truck is parked in that space. Gathering those data and communicating them from the lots back to the central port office are crucial to orchestrating the port's complex movement of containers and trucks.

The Port of Hamburg was able to accomplish this project because of its central operational approach. By serving as the sole owner and operator of the facility, the Hamburg Port Authority gained and maintained the trust of stakeholders. Strong leadership and emphasis on security enabled the Authority to overcome the barriers public transportation and logistics entities face when implementing cross-cutting solutions that require broad input.

Barriers to Success

The largest barrier to the success of IoT at the Port of Hamburg was the initial reluctance of stakeholders to share information. The port itself could create data on the traffic and parking conditions in the port, but without access to the demand information from the shipping lines that used the port, it could not efficiently orchestrate movements. While the shipping lines could benefit from the efficiency gains at the port, they were also worried about releasing potentially sensitive data about their operations to competitors that also operated at the port. To build and maintain the trust of stakeholder companies, the Hamburg Port Authority only provides information back to stakeholders that

Barrier to IoT in Transport and Logistics

A significant barrier to successful implementation of IoT in transport and logistics is the reluctance of stakeholders to share information.

have a valid reason to know. Thus, while the Authority is able to see a full picture of the port, each shipping line is only able to see information relevant to its operations. This allows companies to trust the system and have confidence in sharing information. After the initial project, efficiency increased significantly and, in turn, created faster turnaround and more profit for participating companies. Because of the positive results, these companies are now more willing to cooperate with additional updates and data requests to support ongoing enhancements.

Evolution of IoT

After IoT solutions are implemented, they can continue to grow and evolve to fit new needs and business objectives. While the majority of IoT solutions initially aim at efficiency, owners can—and should—look for ways IoT can create new business opportunities and even new sources of revenue.

One example of how this transition can take place is shown by the package delivery company DHL. Like other delivery companies, DHL was an early adopter of package tracking to help improve the efficiency of package sorting in its facilities. Later, DHL realized that the same tracking information used internally could also enhance how DHL served customers. As a result, DHL made tracking numbers publicly available so customers could see where their package was at any time, providing a source of differentiation over any competitors who did not do the same. Eventually, DHL realized that it was gathering enough data from the tracking of its packages, vehicles, and aircraft that it could create a system that visualizes traffic jams, construction, and other risks that impede on-time delivery. Such a system is invaluable to companies that operate large, multinational supply chains or use just-in-time delivery of parts and inventory. As a result, DHL is able to sell this information as a service through its Resilience360 supply chain risk management tool, providing DHL with a source of revenue based on information, not just package delivery.

As IoT evolves in transport and logistics, solutions will likely explore the means to create new business opportunities and revenue. Airports have an opportunity to leverage similar capabilities to consolidate the way they track not only the movement of aircraft through their airports, but also the people, goods, and tools required to support the entire end-to-end operation.

From Ports to Airports: The Applicability of Transport and Logistics Lessons to Airports

Like land and sea ports, airports feature a complex mix of stakeholders, each with its own particular goals. Like the Port Authority, airport operators are in a position to increase efficiency for all stakeholders by acting as trusted brokers of aggregated information. A prime example of this is airport collaborative decision-making. Much like the IoT application by the Port of Hamburg, airport collaborative decision-making gathers information from stakeholders and the physical world to improve the efficiency of surface movements at the airport. Therefore, the lessons from the Port of Hamburg about sharing and masking information are applicable to airports.

CHAPTER 3

Discovering the Impacts of IoT

Because IoT uses existing technologies, airport operators are often very familiar with the component technologies. They use some of these technologies, such as Wi-Fi or sensors, every day. However, airport operators often do not understand how these component technologies can combine to meet business needs.

This chapter describes (1) the current awareness, knowledge, and opinions airport stakeholders have about IoT; (2) the current state of IoT activities; and (3) where IoT is likely to create value for airports.

Source: Vasin Lee/Shutterstock.com.

IoT Awareness, Knowledge, and Opinions

Information about the current state of knowledge, attitudes, and experience with IoT comes from a data-gathering activity that involved representatives of airports; aviation industry and management consultancies; IoT suppliers; airlines and airline vendors; transportation planning and engineering firms; airport investors; and law firms. About half of the respondents were airport operators.

While awareness of IoT was high, knowledge of IoT's true capabilities and its potential helpfulness to an organization was much lower (Figure 13). Few airport representatives reported that their organizations were very prepared to benefit from IoT applications:

- 12% said their organizations were very prepared to benefit from IoT applications (i.e., doing this now).
- 36% said their organizations were moderately prepared (i.e., exploring opportunities).
- 42% said their organizations were somewhat prepared (i.e., building foundational knowledge).
- 10% said their organizations were not prepared at all (i.e., not exploring IoT yet).

Only a small percentage of airport employees responding to the online survey felt strongly (i.e., "totally true" in Table 3) that their organization has the capabilities and flexibility to currently benefit from IoT solutions.

Few airport stakeholders believed their organizations have clear leadership for IoT efforts and the processes needed to support IoT. On the other hand, most believed that control to begin IoT activities is within the airport's authority, so their organizations could start such activities. About half believed they relied on external stakeholders to begin IoT initiatives, which may slow progress. The bottom line is that the vast majority are only beginning to

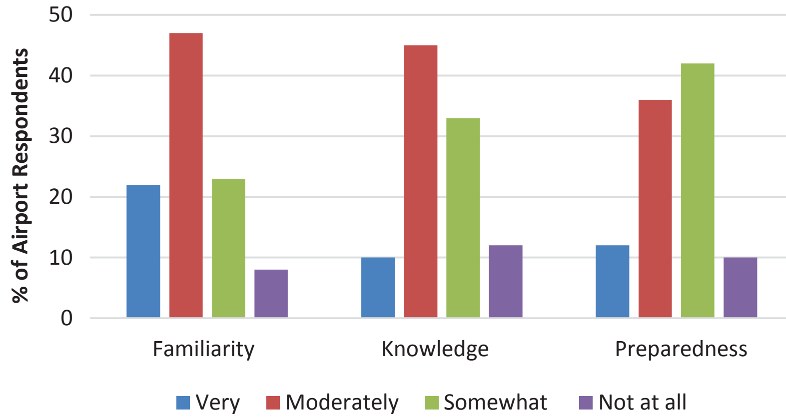


Figure 13. IoT familiarity, knowledge, and preparedness from the ACRP Project 01-33 online survey **(*N* = 103).**

think about and prepare for the connected airport, so progress toward implementation may be gradual. Yet most believed that the potential of IoT in an airport environment was "very significant" and that the ability to leverage IoT will be crucial for their organizations to achieve their strategic goals in the next 1 to 3 years.

The online survey pinpointed which application areas respondents thought were the most important in airports. Respondents thought the following IoT application areas would be "crucial" in an airport environment:

- 61% for emergency/security response.
- 55% for traveler information systems.
- 43% for baggage systems.
- 43% for facilities management.
- 40% for aircraft controls and alerts.

Leveraging IoT

The ability to leverage IoT will be crucial for airports to achieve their strategic goals in the next 1 to 3 y.

Important application areas were examined in more depth during the qualitative interviews. In the short term, interviewees identified the following areas that IoT could impact:

- Customer service.
- Asset management.
- Systems integration.

Examples include the following:

- Customizable ads for retailers targeting specific customers.
- The ability to order food and products from anywhere in the terminal.

Table 3. Airport sentiments on IoT from the ACRP Project 01-33 online survey (*N* = 103).

Statement about Airport	Totally True	Somewhat True
We have the organizational capabilities needed to support our work with IoT.	10%	51%
We have defined a clear leadership for our IoT efforts.	10%	42%
We are reliant on external stakeholders to begin IoT initiatives.	6%	40%
We lack the necessary control in an airport environment to begin IoT initiatives.	6%	34%
We have the processes needed to support our work with IoT.	2%	44%

Columbus John Glenn International Airport (CMH)

The initial motivation for the Aruba Airport Wireless System was to improve Airport Service Quality ratings for public Wi-Fi and cellular connectivity, which were consistently rated low quality.

CMH had significant recurring outages as a result of ad-hoc installation and patching of wired equipment. However, CMH has spent the past several years establishing a base layer of wired and wireless infrastructure that will support basic IoT solutions and deployments.

The total cost to install the Aruba Airport Wireless System was $1.5 million. The system ties together four user groups and their access needs:

- Airport customers.
- Concessionaires and tenants.
- Airlines.
- Employees.

- Advance information on security queues.
- Better resource management from RFID in employee identification badges (e.g., information about positioning and what the employee is doing and for how long).
- Improved baggage-handling technology to prevent theft and improve efficiency.
- Improved management of resources including oil, gas, and HVAC systems.

In the long term, the benefits of IoT could prove to be a game changer. More real-time data could enable increased passenger metrics and real-time boarding numbers, which could help in managing congestion at security and throughout the terminal. When all equipment has embedded sensors, failures can be predicted and avoided, maintenance costs reduced, and carry-ons monitored.

Orlando International Airport (MCO)

The single factor most contributing to the successful implementation of IoT is the airport's culture of innovation. The chief business goal of MCO management is to improve customer services. MCO staff are encouraged (and given resources) to try new ways to address issues through technology and contribute to a better experience for customers. Failure of a pilot project does not end an IoT initiative—staff are allowed to continue until a feasible and effective solution is found.

IoT remains an evolving technology, and the path to achieve a specific goal at a specific airport may not be immediately apparent, requiring several small pilot projects. A culture of innovation will facilitate the acceptance of and learning from the failure of any one project in the search for solutions.

Current State of IoT Activities

Some airport operators are currently involved in IoT activities (Table 4). Most are involved in more than one application area, indicating that while early adopters may be a small percentage of the overall airport population, they may drive a significant percentage of new technology uses.

The following are key classes of benefits from IoT implementation:

- **Operational effectiveness.** Operational effectiveness hinges on IoT allowing operators to (a) reduce costs, (b) achieve more with the same costs, and (c) drive continuous improvements that are sustainable.

Delta Air Lines

CASE STUDY

In 2016, Delta Air Lines became the first carrier to implement an RFID-based baggage tracking system on a global scale. This IoT investment not only allows Delta to track each RFID-tagged bag, it also enables the prevention of mis-loaded bags as well as the automatic redirecting of bags when passengers' routes are interrupted or changed. Initial results of RFID-tagged items show they are tracked at a 99.9% success rate. A key enabling factor was Delta's strategic $50 million investment in RFID technology including the following:

- 380 RFID bag tag printers.
- 4,600 scanners.
- RFID readers on 1,500 belt loaders (with green and red lights that flash for each scanned bag, indicating proper or incorrect routing, respectively).
- 500 pier and claim readers for hands-free scanning of baggage throughout the handling process.

Table 4. Number of survey respondents indicating involvement in a specific IoT application area from the ACRP Project 01-33 Online Survey (*N* = 103).

IoT Application Area	Number of Respondents
Passenger traffic monitoring	28
Traveler information systems	27
Baggage systems	23
Facilities management	21
Parking management controls	19
Retail-based advertising to passengers	16
Staff management/asset management	13
Emergency and security response	9
Knowledge management	7
Coordinated IoT systems	6
Off-system airport transportation integration or open data-sharing hub	5
Traveler security automation	4
Aircraft controls and alerts	1

- **Strategic differentiation.** Strategic differentiation can stem from an improvement in customer experience or a more differentiated product.
- **New revenue.** IoT can generate entirely new sources of revenue by creating new products or services to attract new customers or by using IoT to sell more to existing customers.

Operational Efficiency

Examples

Most current uses of IoT in airports focus on operational efficiency. For example, one airport representative said that the airport has "a new online inspection system managed through a private contract with Siemens, which uses a tool provided to maintenance grounds crew that is connected to the Internet with GPS functionality. The purpose of this tool is to digitally connect maintenance crew inspection findings to a map of the airport grounds."

According to an interviewee, another airport has enabled Bluetooth beacons and has developed an app that assists passengers in way finding (Figure 14). Airport management and operations also use passenger analytics from the app, coupled with beacons, to assist in maintenance-related activities. The airport tracks use of a given airport asset and the location of airport staff to optimize staff resources. Airlines have access to the app so they can link their own systems to show gate changes and flight status in the app. Vendors also have access to the app and beacon systems, but many do not use the technologies. Due to privacy concerns, the effectiveness of the app in directing passengers to vendors is not tracked.

According to another interviewee, an airport is planning a smart bathroom pilot test. The airport will install IoT sensors on various bathroom assets, including faucets, toilets, lighting, soap dispensers, air freshener sensors, toilet paper dispensers, and other equipment, in one of its busiest bathrooms. These sensors will transmit data to facilities management to alert it in real time of various shortages and breakdowns. As part of this pilot, the bathroom will have a people counter and a customer input button with a sensor to capture perceptions of bathroom cleanliness, which will enable facilities management to gauge perceptions of cleanliness against actual use.

The literature review also revealed some current IoT initiatives in airports. Japan Airlines is providing airport staff with an Apple Watch combined with Bluetooth beacons to monitor staff locations within the airport and to direct staff to areas where resources are needed (Babu 2016).

Source: Sorbis/Shutterstock.com.

Figure 14. Way-finding technology in the form of a terminal map.

When paired with other information, the real-time data on employees can also help improve core operational tasks. The data can be stored for trends analysis and visualization of queuing, and then used to solve bottlenecks based on time of day and flight departures. For example, Terminal 4 of John F. Kennedy International Airport (JFK) in New York uses iBeacon technology to collect passenger movements from Bluetooth signals and relay queue wait times to smartphone applications. In the event of a disruption, this allows arriving passengers to know in real time what the wait will be to clear the check-in and security process (Babu 2016). Questions remain about how to effectively share these new data between stakeholder groups such as airlines, transportation network companies such as Uber, onsite retail vendors, and roadway traffic navigation applications for travelers arriving at the airport. Terminal 4 at JFK is also exploring how to incorporate vendor-based proximity advertising into this iBeacon system (Samuely 2018). An example of how other industries have successfully overcome these barriers to information sharing and integration appears in the section "Sample Solution: Data Efficiency at the Port of Hamburg" in Chapter 2.

Long-Term Horizon

Efforts to integrate data from many different stakeholders to improve the efficiency of each can be the gateway to larger applications. The long-term horizon for IoT applications supporting efficiency at airports can include autonomous vehicles, tenders, and baggage carts. If integrated with other data sources such as schedules, push back times, and gate numbers, these data could come together in a fully automated tarmac where robots and autonomous vehicles deliver baggage, fuel planes, clear debris, and perform other tasks—all faster and to closer tolerances than human drivers. The result would be that airports could conduct surface operations more efficiently, fitting more planes onto the same physical ramps and taxiways. While something like the fully automated tarmac is still years away, the technology needed for such uses is already being proven on roadways today (Levin and Harris 2017).

IoT and Operational Efficiency

Most current uses of IoT in airports focus on achieving operational efficiency. For example, real-time data on staff locations can help improve core operational tasks.

Strategic Differentiation and New Revenue

Very few current applications of IoT in airports aim to provide strategic differentiation or new revenue. This same trend is seen in many other industries and is due to a variety of factors. Things such as lack of investment capital, unease over technical complexity, and organizational concerns can play a role in an executive's decision to pursue efficiency over differentiation or new revenue. Another key concern is the challenge of coordinating with multiple stakeholders.

While IoT applications aimed at differentiation are more challenging, they do offer the opportunity for greater return. So, while few airports are currently using IoT to create differentiation, interviews with subject matter experts indicate that airport stakeholders do see the value in such uses and may pursue them in the future. One example is the advertising of off-airport transit recommendations personalized to an individual passenger. Another example is partnerships with vendor management companies (VMCs). According to a VMC representative, these organizations focus on deploying IoT solely to tailor the service to meet customer needs at a time, place, and price that are right for customers. This can be an easy way to create location-based applications that improve customer experience—for example, the delivery of food directly to customers seated at a gate or, somewhat more advanced, the ability to find the nearest wheelchair or customer service agent who speaks a customer's native language.

IoT's Potential Value

Few IoT applications in airports aim to provide strategic differentiation or new revenue, but airport stakeholders see IoT's potential value to support their airport's brand through a variety of applications.

Singapore Changi Airport (SIN)

The newly built SIN Terminal 4 will support the International Air Transport Association's Fast and Seamless Travel initiative. The IoT applications will enable the design of self-service terminals and systems across the airport travel journey. The passenger will control check-in, bag drop, immigration, and departure gate check-in procedures. Common-use kiosks will enable passengers to use any part of the airport to conduct their check-in process and to conduct themselves along a path of their choosing up to and beyond the central security gate.

Differentiation is often a watchword for advertising or customer experience, but it can be much more. Differentiation is fundamentally about supporting the brand of an airport. IoT applications that support differentiation can come in various forms—aimed at passenger satisfaction or even environmental causes. For example, Heathrow Airport (LHR) set the goal of reducing nitrogen dioxide emissions to help improve local air quality. The airport realized that a major—and avoidable—source of ground-level nitrogen dioxide emissions is aircraft using auxiliary power units (APUs) while parked at the gate rather than plugging into the power grid. LHR deployed an IoT solution to help improve air quality. Microphones positioned around the apron pick up the telltale sound of APUs running. These data are cross-referenced with schedules and other data to determine whether an aircraft is running its APU instead of being plugged into the power grid. The airport can then share these data with airlines and remind aircraft to plug in and switch off the APU—not just saving money for the airline but also improving local air quality for all.

Moreover, just because an airport makes one IoT choice now does not mean it is locked into that specific IoT composition or configuration forever. In fact, even simple IoT solutions grow and evolve over time. Quite often, a solution designed only for efficiency can to support differentiation or even generate new revenue as it gains capabilities. One example is IoT-enabled boarding. Instead of having passengers standing, lined up by number or boarding zone, passengers could stay seated or continue to enjoy a final beverage in the lounge or airport restaurant until receiving their personalized notification telling them it is time to board (Steffen and Hotchkiss 2012; Nyquist and McFadden 2008). This individualized boarding time is calculated based not only on seat location, but also on carry-on bag, premium status, fare class, load factor, and so forth. While such an application of IoT may initially be aimed at improving passenger experience by eliminating standing around the gate, it could soon do more. Speeding up boarding allows an airline to generate faster gate turns, increase aircraft utilization, and therefore improve the return on assets for the airline.

Where IoT Is Likely to Create Value for Airports

As described in Chapter 2, IoT creates value by creating, communicating, analyzing, and aggregating digital information about the physical world to support a new business decision or action. Therefore, IoT can create value by supporting a business's numerous daily decisions or operational actions. For an airport, these typically cluster into one of two categories (1) passenger experience or (2) airport operations.

In each of these categories, airport operators can import lessons learned from other business sectors. By examining how IoT developed and created value in industries such as retail, CRE,

Dallas Fort Worth International Airport (DFW)

In 2011, DFW developed an overarching strategy, the Terminal Renewal and Improvement Program (TRIP), to remodel the airport's terminals. In 2012, DFW launched free Wi-Fi service, in partnership with AT&T, as part of the TRIP strategy. The service is multi-use, providing Wi-Fi to customers, data for the airport, and infrastructure for operations.

The primary motivator was to provide free Wi-Fi to customers. The secondary motivation was the need for Wi-Fi access over the entirety of the airport operational field. While free Wi-Fi does not directly produce revenue from passengers who use the service, it is an important enabler of IoT. Reliable, ubiquitous Wi-Fi can serve as the backbone of numerous IoT applications, which can later generate efficiencies or new revenue.

and transport and logistics (Chapter 2), airport operators can use IoT to generate different types of business value. An airport could use IoT to improve the efficiency of actions that support passenger experience. For example, by gathering data on the highest traffic areas, the airport could proactively direct cleaning staff to those areas to maintain the highest state of cleanliness, even with the same staff. Similarly, an airline could use IoT to differentiate itself from competitors by providing faster ramp servicing to aircraft, saving money for the airline by enabling faster gate turns and making the airport a more attractive option.

Trends in IoT Adoption

Industries generally have a typical development progression with IoT. The expected benefit of an IoT application varies with the scope, and therefore complexity, of the project. As a result, most industries begin by pursuing small-scope IoT projects aimed at efficiency because these can often be managed entirely within the control of an organization. Differentiation requires expanding that scope to interact with other stakeholders, and new revenue requires expanding the scope further to include consumers/customers. Therefore, in most industries, IoT applications aimed at efficiency are the most common, followed by differentiation and then new revenue.

In one recent survey, 34% of companies—the top response—said they anticipated gains in efficiency from IoT technology (Groopman and Jeambon 2016). On the other hand, only 6%—the lowest response—anticipated realizing new revenue as a result of IoT technology.

Pathways to IoT

Most industries begin by pursuing small-scope IoT projects aimed at efficiency. However, unique forces in the aviation industry also open other pathways (e.g., improving passenger experience) to IoT adoption.

Another survey of companies already using IoT found similar results when comparing internal uses of IoT aimed at efficiency (52%) versus customer-facing IoT that combined IoT applications aimed at differentiation and new revenue (40%) (Gartner 2016).

Overall, airports follow these trends in IoT adoption as well. In this survey, 76% of respondents using IoT indicated they used it for efficiency/optimization, compared with 58% for customer experience/differentiation, and 35% for new revenue.

However, while many airports may follow the typical IoT development trends (moving from efficiency to differentiation to new revenue), unique forces in the aviation industry also open other pathways to IoT adoption. The aviation industry maintains high standards for passenger experience. Although IoT applications that improve passenger experience at an airport are more challenging than those dealing only with internal efficiency, airports may find it easier to begin with differentiation and move to internal efficiency. As Jack Loop of indoor mapping company Locus Labs puts it: "Very often [airports] begin with the consumer-facing side. Consumer-facing projects need to meet a higher bar of usability, so it is actually easier to take a slick consumer-facing project and use it internally, than it is to take a purely functional internal tool and bring it up to consumer-facing standard."

These sentiments were echoed by other interviewees from airlines and airports, who indicated that future IoT plans were largely focused on improving customer experience.

Cultivating an Ecosystem of Partners

As airports pursue more complicated IoT applications aimed at differentiation or new revenue, they will increasingly be forced to work with other stakeholders both on and off the airport. Therefore, cultivating and cooperating with different partners are crucial to the success of IoT.

The diverse nature of technologies needed to make IoT work means that even the largest organizations typically do not have all the technical expertise required at every stage of the Information Value Loop. Some may have expertise in analytics in their internal IT department but lack needed experience with physical sensors. Others, such as maintenance organizations, may have great experience with sensors and machinery but lack the expertise to aggregate the collected data to gain relevant insights. As a result, nearly every IoT project will feature some level of technical collaboration. The exact mix of technology manufacturers, software creators, and technology integrators will be determined by the needs of the specific airport involved and its IoT needs.

As airports continue to develop IoT and seek differentiation and new revenue, these partnerships will expand beyond mere technology enablers and begin to involve other airport stakeholders. The greater the goal of IoT becomes, the more information that is required to support the ultimate decision or action. For example, the data needed to move custodial staff to high-traffic areas are

London Gatwick Airport (LGW)

CASE STUDY

LGW aims to become more attractive to passengers and, at the same time, improve operational efficiency. To achieve these goals, the airport is experimenting with a competitive procurement between three companies. The objective is to establish a cloud-based IoT platform the airport can offer to stakeholders as a service.

The envisioned platform would support many different IoT applications, each serving a different task around the airport and used by a different stakeholder. For example, current test applications include sensors measuring the fill level in trash cans, tracking water flows through pipes from pump stations, and monitoring seat occupancy in the check-in area. The goal is to provide the infrastructure needed for airport stakeholders to use in developing new applications that align with their (or their customers') needs.

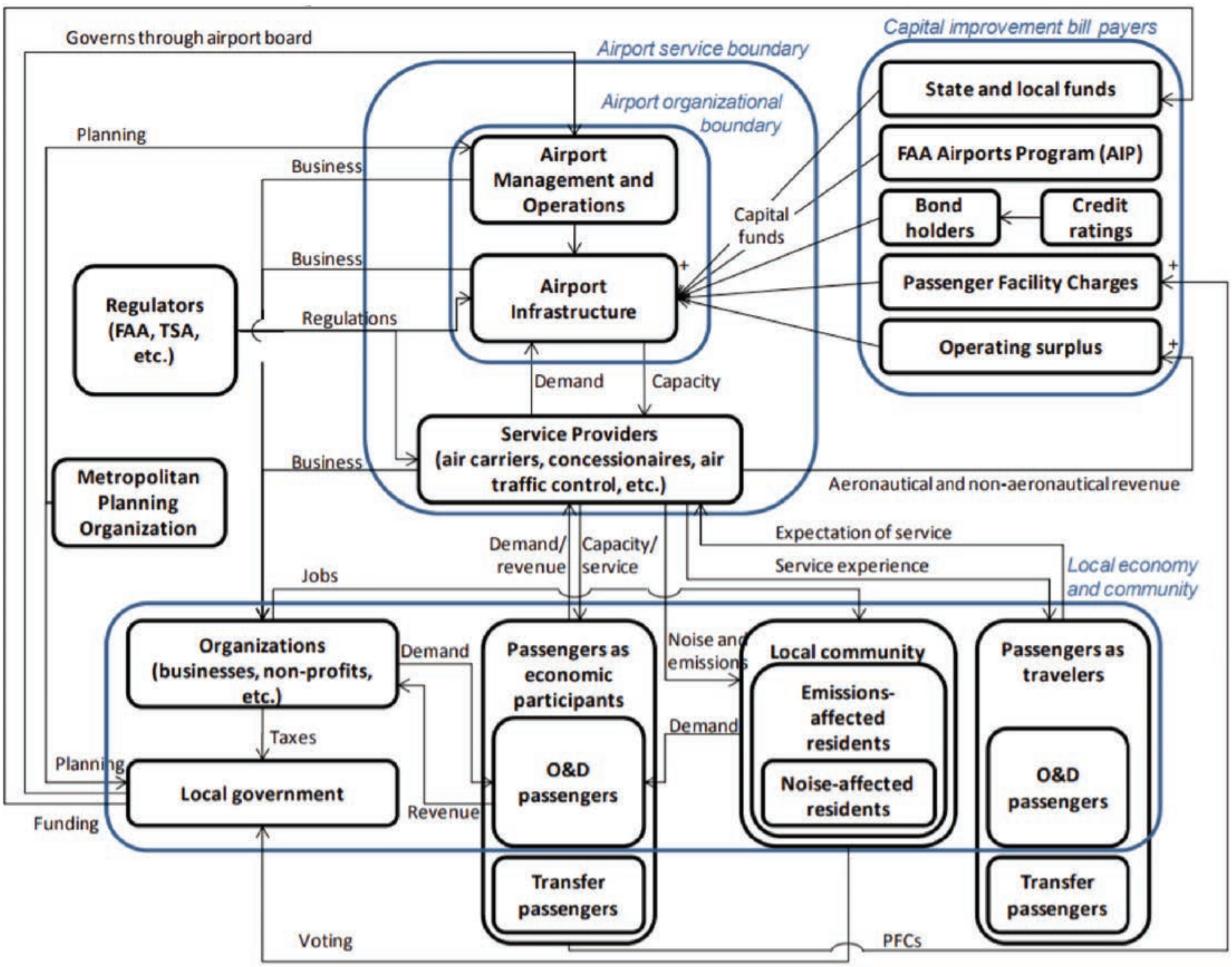
At the end of the procurement competition, the best platform will be selected and the managed service provider retained on an ongoing contract.

Collaboration Crucial for IoT

The greater the IoT goal, the more information required to support the ultimate decision or action. Since most IoT projects feature some level of collaboration with other airport stakeholders, cultivating relationships and cooperating with different partners are crucial to successful IoT implementation.

relatively simple and can be collected and managed by the airport operator alone. However, a larger goal such as providing real-time flight status information to passengers requires much more data—some owned by the airport and some owned by airlines, air traffic control, and other organizations. This means that data from (or cooperation with) other stakeholders are essential for IoT applications to create the most value.

Given the complex and often competing interactions between airport stakeholders (Figure 15), gathering data from them can be challenging. For example, an airline may be unwilling to provide data on aircraft arrival times to an airport operator in the belief that such information could give away competitive secrets to other, competing airlines.



Source: Schaar and Sherry (2010)

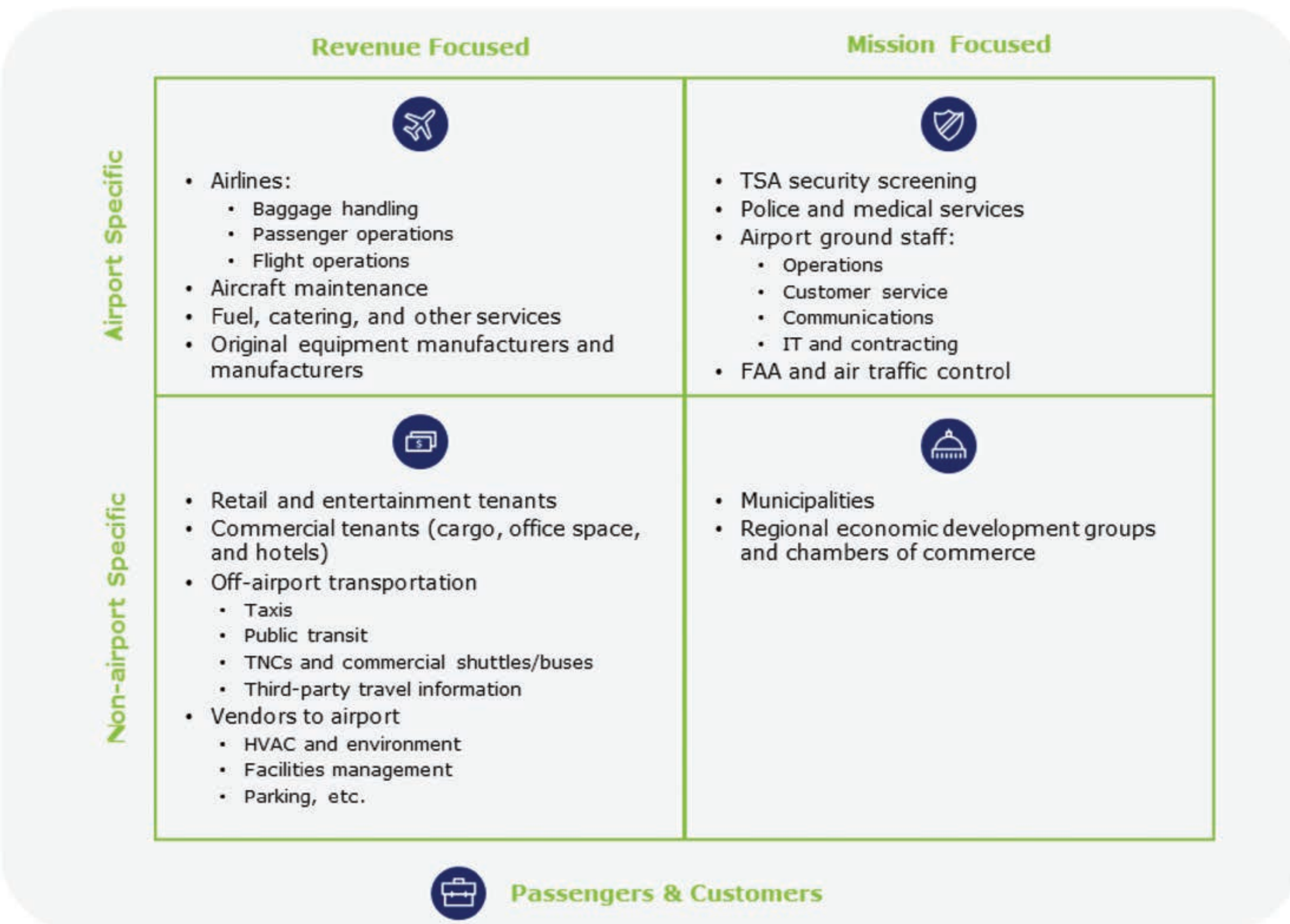
Figure 15. Complex and overlapping relationships among airport stakeholders.

However, a few common factors determine how different stakeholders approach IoT, for example:

- Some stakeholders operate in the airport in essentially the same way they would operate in another non-airport location. Retail tenants, for example, run their stores at airports in the same manner as stores in shopping malls or elsewhere. Other stakeholders are so tied to aviation that they operate solely at airports, or their operations at airports differ unique from those at other locations.
- Some stakeholders may be motivated by revenue, while others are governmental or non-profit organizations motivated by accomplishment of an assigned mission.

Research from other industries has shown these factors have a great impact on how an organization pursues IoT. Figure 16 shows a simplified framework for IoT based on the airport/non-airport orientation and the stakeholder's mission to help in IoT planning.

Since the greatest value from IoT comes from the aggregation of data from multiple stakeholders, this framework can be helpful for designing the most valuable future IoT applications.



Note: TSA = Transportation Security Administration, FAA = Federal Aviation Administration, TNC = transportation network company.

Figure 16. Airport stakeholder framework for IoT.

Research from other industries suggests that the greatest value is likely to be created when stakeholders from different categories work together toward a common goal. This framework can help airport operators understand the various motivations and incentives of stakeholders. Creating an IoT implementation that meets the business need of both the airport and the stakeholders contributing data or expertise is essential to the long-term success of any IoT initiative.

Challenges and Benefits of Cooperation

Sharing Data

For large IoT projects to succeed, airport operators need to find ways to encourage stakeholders to cooperate—creating an environment where stakeholders can share enough data to allow IoT to succeed but doing so in a manner that does not reveal any of their business secrets.

The airport industry is not the first or only one to confront this challenge. The Port of Hamburg faced it when determining how to more efficiently route trucks and containers through the port. The Hamburg Port Authority needed data about shipments from the shipping lines, but the shipping lines could not reveal that information to other lines without losing competitive advantage. The solution was a system that displayed only the information needed to each user. So, drivers for one shipping line saw only data related to their next pickup and could not access information from other shipping lines.

Airports are already working on designing similar systems in the form of airport collaborative decision-making (ACDM) tools. Such tools combine information from the airport, airlines, air traffic control, and other sources to support more efficient surface movement and other operational needs. For example, YYZ is investigating ACDM to help speed operations and reduce environmental impact. Proactive and predictive scheduling methods reduce taxi time and allow aircraft to take off without waiting in line at the runway (Gupta et al. 2012).

Data Definitions

Defining data terms is a key barrier to implementation. For example, the term as *arrival time* can mean something different to each stakeholder:

- To air traffic control, it may mean the time when the wheels touch the ground.
- To an airline, it may mean the time when the aircraft is chocked at the gate and the boarding door is open.

Before progress in sharing data can be made, common data definitions must be in place so that when one user shares an arrival time, other users know exactly what that means. A collaborative process involving all stakeholders is required to reach standard definitions for every term. Successful implementation does not end with a good project design. Rather, stakeholder engagement must continue to ensure that all stakeholders are properly using the system and having their goals and needs met.

Stakeholder Engagement

Stakeholder engagement is not solely the province of large airports that need complex ACDM systems to support operations. Engagement is crucial even at small airports. In fact, in an industry where relationships with airlines and vendors are key to generating revenue, small airports with less staff may benefit most from formal stakeholder engagement programs (Elliot et al. 2015). For IoT specifically, these programs can help identify which stakeholders have the information an airport needs for a particular IoT project.

Stakeholder engagement programs can also help in understanding the needs and equities of stakeholders so the right incentives can be found to motivate a project to completion. Keeping

Toronto Pearson Airport (YYZ)

YYZ is implementing an ACDM program to more effectively assign gates and departure windows to create the most efficient, flexible schedule possible. The program begins with data from NavCanada, the air traffic control authority; the FAA System Wide Information Management program; and other sources. Data on the major milestones of a flight are automatically generated from various sources, including airlines, ground handlers, and air traffic control. The data can then be transmitted to other stakeholders so that, for example, fueling tractors can react quickly to a gate change for a departure or customs agents can adjust schedules for a large delayed international arrival.

After the first phase goes live in 2017, a dashboard will provide stakeholders with the ability to share important information and to view information needed for stakeholders' own operations. To allow data to be available to any stakeholder that may need it without overwhelming them with nonapplicable information, the ACDM solution uses a publish/subscribe pattern with a central message broker.

lines of communication open throughout the development process is key to successful IoT adoption, and stakeholder engagement helps keep parties talking.

For more specifics about how to create or run a stakeholder engagement program, see *ACRP Synthesis 65: Practices to Develop Effective Stakeholder Relationships at Smaller Airports.*

Stakeholder engagement programs may also begin to uncover deeper industry trends. Perceived or assumed competition may not actually be competition but rather a potential ally in IoT or other data-sharing projects. For example, airport operators may assume the competitor from which they must differentiate themselves is the closest airport of similar size.

However, in many cases, the largest competitor to an airport is not another airport at all but a different mode of travel. The decision of which airport to use is typically based on the price of travel for passengers and the price of operations for cargo (Loo 2008; Gardiner 2006). While airports do have some control over final ticket and transit prices in the form of landing fees, these fees are a small percentage of passenger travel cost (Plush 2016). The majority of a ticket price is determined by the operational cost of the airline (International Civil Aviation Organization 2017). As a result, airports may have little direct leverage on travel choices. This means that the most direct competition facing an airport may not come from a neighboring airport but rather from other forms of transport or even other forms of leisure spending.

Airports may often be better served by collaborating with other airports to present a differentiated picture of air travel (i.e., its benefits compared with other travel modes such as rail) than by competing to differentiate themselves from other airports. From an IoT perspective, assuming that another airport is a competitor may cause airport leaders to overlook that other airport as a source of data or a potential partner for an IoT project that may help the first airport improve its own customers' travel experience. A seamless door-to-door experience—regardless of the airport used—may promote air travel instead of other travel options such as train or personal vehicle, thereby helping ensure air travel as the mode of choice by consumers.

In summary, IoT is not just about connecting things. It is also about the connections that it creates between organizations, customers, vendors, and competitors. Benefiting from IoT applications is strongly associated with sharing data with other organizations. The following examples are data-sharing models from different industries. What these models have in common is the aggregation of data in data-sharing (often cloud-based) platforms that are typically under the stewardship of third-party aggregators. Data stewards ensure consistent formats as well as de-identification and confidentiality.

Best Practices for Data Sharing

The following examples from the transportation, public health, agriculture, and energy sectors describe best practices for data sharing.

Data Sharing in the Transportation Sector. The Metropolitan Area Transportation Operations Coordination (MATOC) program is a partnership between transportation agencies in the District of Columbia, Maryland, and Virginia. Their aim is to improve safety and mobility in the region through information sharing, planning, and coordination. Clearing a road quickly requires responders to work together efficiently. The MATOC program accomplishes its data-sharing mission primarily through the Regional Integrated Transportation Information System (RITIS)—an automated operations data-sharing platform. RITIS software collects, standardizes, and disseminates data to thousands of operations personnel throughout the region. (More information is available from Pack, M., and N. Ivanov. *NCHRP Synthesis 460: Sharing Operations Data among Agencies*. Transportation Research Board of the National Academies, Washington, DC, 2014, pp. 27–29.)

The Washington State GPS Freight Performance Measures project uses data from commercial fleet management GPS devices in trucks to develop a statewide freight performance measure program. Private commercial fleet management GPS vendors, who were initially reluctant to share their clients' data with the public sector, agreed to discuss data sharing after the state trucking associations stated that the data would support improved freight infrastructure decisions. The DOT assured the vendors that the GPS data would be used for freight performance measurement only and not for regulatory or enforcement purposes. This assurance addressed the concerns about an individual company's business-sensitive information, but the vendors still required privacy protection in the form of a nondisclosure agreement. (More information is available from Cambridge Systematics, Inc., North River Consulting Group, and University of Washington. *NCFRP Report 25: Freight Data Sharing Guidebook*. Transportation Research Board of the National Academies, Washington, DC, 2013, pp. 48–49.)

Data Sharing in the Public Health Sector. DataSphere, an initiative of the CEO Roundtable on Cancer, was designed as an ideal data-sharing system—simple, systematic, publicly accessible, and respectful of privacy issues. The CEO Roundtable on Cancer consists of chief executive officers (CEOs) of companies involved in cancer research and treatment who seek to accomplish what no single company can do alone. DataSphere relies on CEOs, together with support from patients and advocacy groups, to secure and provide data. De-identification is standardized, and DataSphere works with third-party data aggregators to pool the data in meaningful ways—a significant challenge when hundreds of cancer drugs are being developed at any given time and thousands of studies are registered in ClinicalTrials.gov. (More information is available from Olson, S., and A. S. Downey. "The DataSphere Project." *Sharing Clinical Research Data Workshop Summary,* Institute of Medicine of the National Academies, Washington, DC, 2013, pp. 31–32. https://www.nap.edu/read/18267/chapter/5#31. Accessed January 30, 2018.).

Data Sharing in the Agricultural Sector. Data sharing in the agricultural sector helps farmers evaluate their management practices. Monitors on combines accurately measure and report crop yields. Farmers then share data with farmers' networks to improve crop production practices, which increases profitability. The creation of standardized protocols, especially for confidentiality and sharing of data, enabled many networks to combine their results into one secure database. A combined database facilitates analyses across space and time that provide much more useful and robust answers to many applied questions about crop production practices. The results are increased profitability and decreased environmental pollution caused by food production. (More information is available from Research Data Alliance. "On-Farm Data Sharing (OFDS) WG." https://www.rd-alliance.org/groups/farm-data-sharing-ofds-wg. Accessed January 30, 2018.)

Data Sharing in the Energy Sector. The U.S. Electric System Operating Data Tool, sponsored by the U.S. Energy Information Administration (EIA), provides hourly electricity operating data, including actual and forecast demand, net generation, and the power flowing between electric systems. The tool features nearly real-time demand data, plus analysis and visualizations of hourly, daily, and weekly electricity supply and demand. The data are provided on a national and regional level for the 66 electric system balancing authorities that make up the U.S. electric grid. Although electric system balancing authorities have released public, nearly real-time information on grid operations since the late 1990s, EIA's tool expands the availability of data to the entire contiguous 48 states and makes it available in a consistent format from a single source. (More information is available from the U.S. Government. "Hourly Information on U.S. Electricity Supply, Demand, and Flows Now Available from the U.S. Energy Information Administration." https://www.data.gov/energy/. Accessed January 30, 2018.)

CHAPTER 4

How to Use IoT

This chapter describes IoT solutions categorized according to the passenger or operations experience. It also describes strategies for—and barriers to—successful IoT implementation.

IoT in Passenger and Airport Operations Experiences

Source: MNBB Studio/Shutterstock.com.

Understanding the full potential of IoT and preparing for the opportunities and risks it brings require considering the airport process from two perspectives:

- Passenger experience.
- Airport operations experience.

Case study findings illustrate touch points for interactions between key stakeholders and IoT-based solutions. Table 5 lists common IoT technologies and solution sets found among the respective case study sites.

These 10 IoT solutions rely on some combination of IoT technologies to transmit data from sensors across communication networks to central processing systems. However, the way in which the airports approached these solutions often varied:

- Some airports relied on third-party development of solutions and infrastructure. This was the case in the open cloud-based platform under development at LGW.
- Some airports focused on developing these solutions in-house. This was the case with the application programming interface (API) and application-based ground transportation and concessionaire services under development at SFO.

Given this variability, comparing different IoT solutions at different airports can be challenging. To provide a full picture of the IoT solutions found in the case studies, this section examines the most common tasks at an airport using the two perspectives of passenger and airport operations experiences.

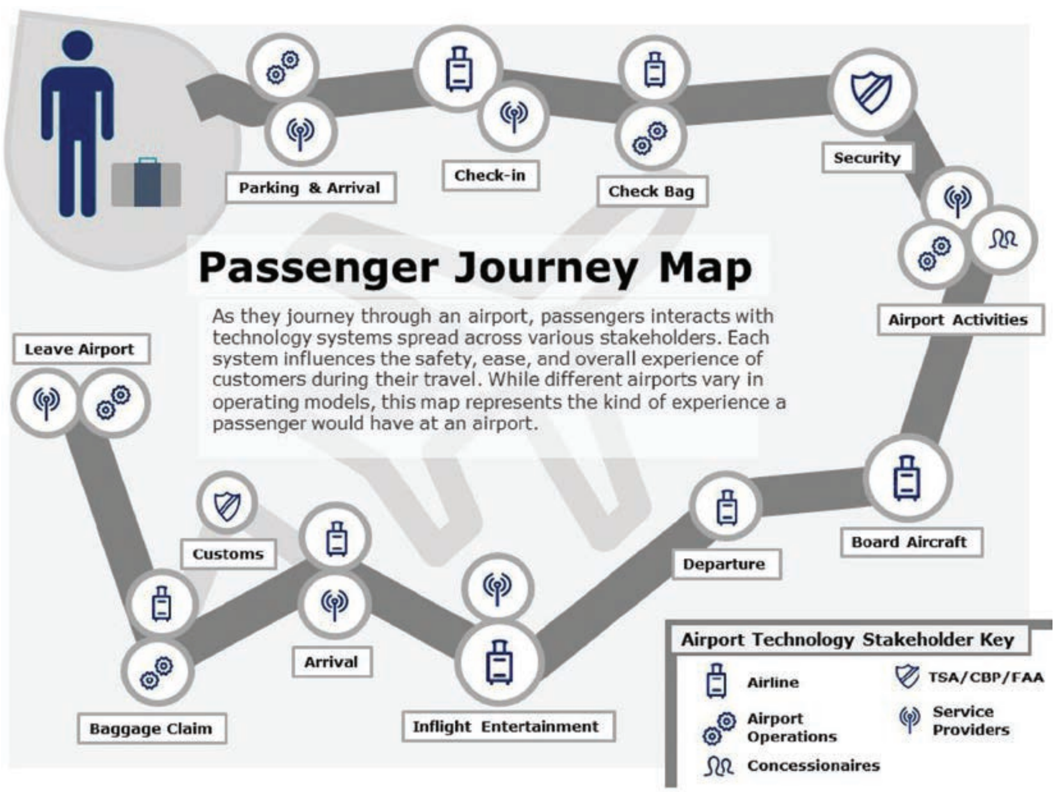
Passenger Experience

The passenger experience is divided into 12 stages that describe a passenger's journey through an airport (Figure 17). Opportunities for implementing IoT solutions arise at all stages. For example, IoT way-finding applications could be relevant at the parking and arrival stage and the check-in stage. Table 6 maps each IoT solution to the stakeholders involved for each stage.

Table 5. IoT-based airport solutions from case studies.

IoT Solution with Description	Case Study Site (Airport Code)
Wi-Fi-based tracking via access points and proximity sensors	CMH, MCO
Smartphone application way finder synched with Wi-Fi-based proximity sensors, Bluetooth sensors, and traveler information systems	MCO
Bluetooth beacon sensor-based queue analyzer	MCO
Passive RFID baggage checking and routing	ATL
Sensor-embedded assets for tracking	DFW, SFO
Cloud-based API and application services with data exchange to offsite ground transport and onsite concessions stakeholders	SFO
Open cloud-based IoT platform and infrastructure	LGW
Airport collaborative decision-making and integrated information systems	YYZ, SFO
Biometric control system (BCS)-based check-in, security, and departure automation	SIN
Sensor-driven building management and asset maintenance systems	SFO

Note: ATL = Hartsfield–Jackson Atlanta International Airport (Delta Airlines case study).



Note: CBP = Customs and Border Protection

Figure 17. Passenger journey map with IoT.

Table 6. Passenger journey stages, IoT solutions, and stakeholders.

Steps of Passenger Journey

<table>
<tr><th></th><th></th><th>Arrival/ Parking</th><th>Check-In</th><th>Check Bag</th><th>Security</th><th>Airport Activities</th><th>Board Aircraft</th><th>Departure</th><th>Arrival</th><th>Customs</th><th>Baggage Claim</th><th>Departure/ Parking</th></tr>
<tr><td rowspan="10">Stakeholder</td><td rowspan="2">Airlines</td><td></td><td colspan="2">Bag Tracking</td><td></td><td></td><td></td><td></td><td colspan="3">Bag Tracking</td><td></td></tr>
<tr><td colspan="5">MCO Indoor Navigation Apps</td><td></td><td></td><td></td><td colspan="3">MCO Indoor Navigation Apps</td></tr>
<tr><td>Concessionaires</td><td></td><td></td><td></td><td></td><td>In-Store Beacons</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other Commercial Tenants</td><td>MCO App</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>MCO App</td></tr>
<tr><td>Off-Airport Transportation</td><td>Geo-fencing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Geo-fencing</td></tr>
<tr><td>Vendors to Airport</td><td colspan="11">Asset Tracking</td></tr>
<tr><td rowspan="2">Security, Customs, & Aviation Authorities</td><td></td><td></td><td></td><td>Queue Analyzer</td><td></td><td></td><td></td><td></td><td>Queue Analyzer</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Biometric Screen</td><td></td><td></td></tr>
<tr><td rowspan="2">Airport Ground Staff</td><td></td><td colspan="4">Wi-Fi Passenger Tracking</td><td></td><td></td><td></td><td colspan="2">Wi-Fi Tracking</td><td></td></tr>
<tr><td colspan="11">Building Management System</td></tr>
</table>

Some IoT solutions apply to one point in the passenger journey map, while others apply across virtually the entire passenger journey map. Some IoT solutions engage a wide range of stakeholders, while others engage only a few. Airport ground staff involved in custodial, customer service, communications, IT, and operations factor heavily into many of the IoT solutions. Consequently, this group displayed more robust engagement and impact in the various IoT solutions across the passenger journey.

The airport case studies provide examples of how IoT applications interact in practice across the passenger journey.

MCO Case Study

CASE STUDY

The MCO Airport App, a smartphone way-finding application, provides a seamless customer experience by integrating across multiple passenger and aircraft journey points. As a result, it draws on multiple stakeholders in the airport to provide input at each point. For example, airport parking facilities populate the map with location and cost information for the parking point in the journey. Vendors in charge of the queue analyzer populate the application with security wait times. Gate information and delay updates from airlines feed into the application across check-in and boarding gates.

The MCO app also uses multiple IoT technologies to deliver information across the passenger journey points. The app uses Bluetooth beacons managed by Wi-Fi access points to assist with navigation and calculate wait times.

This IoT solution faces the following barriers:

- Relying on passengers to download the application.
- Ensuring that all data collected from multiple stakeholders are accurate and up to date.

SFO Case Study

CASE STUDY

SFO uses an API integrated information system. It coordinates ground transportation service and revenue collection for TNCs like Uber and Lyft. Each time a driver leaves the TNC holding lot and heads to the terminal, the agency that manages the airport collects an access fee. Multiplied over the course of a day, a month, and a year, the fee adds up to increased revenue. GPS sensors on smartphones alert SFO when a TNC passenger crosses a geo-fence around the airport for departure drop-off, or when a person arrives outside baggage claim for TNC pickup. SFO is also exploring integration with existing Bluetooth beacons to help TNCs guide passengers and TNC drivers at earlier stages of the passenger journey. For example, the TNC app could guide passengers from their arrival gate to the correct door outside baggage claim where the TNC driver is waiting.

SFO's API-driven approach does not rely on an airport-based application but allows TNCs to use their own applications to exchange data with airport ground transportation managers. These managers monitor the TNC lot capacity, reduce TNC-based traffic congestion, and document permit-based access fees. For example, when the TNC lot is approaching full capacity, the managers close the lot to new TNC drivers and reopen it as open spaces become available. Future approaches include opening an API for use by concessionaires to support the *airport activities*' passenger journey point. This will allow SFO IT to provide location and store information through a digitized map to any other interested parties such as airlines for use within their own applications. Where MCO focuses on integrating this information into a single airport application, SFO focuses on providing APIs as informationexchanges, enabling multiple stakeholders to use the data to improve how they deliver services at airports.

One barrier to this solution is the assumption that other stakeholders beyond legally bound TNCs will be willing to connect their APIs to an SFO database to exchange information.

Airport Operations Experience

The airport operations experience is also divided into 12 stages that describe the airport operations journey through an airport (Figure 18). As with the passenger journey, opportunities for implementing IoT solutions arise at all stages. Table 7 maps each IoT solution to the stakeholders involved for each stage.

The airport case studies identified a more limited set of IoT solutions that impact aircraft operations than those that impact passengers. These include the following:

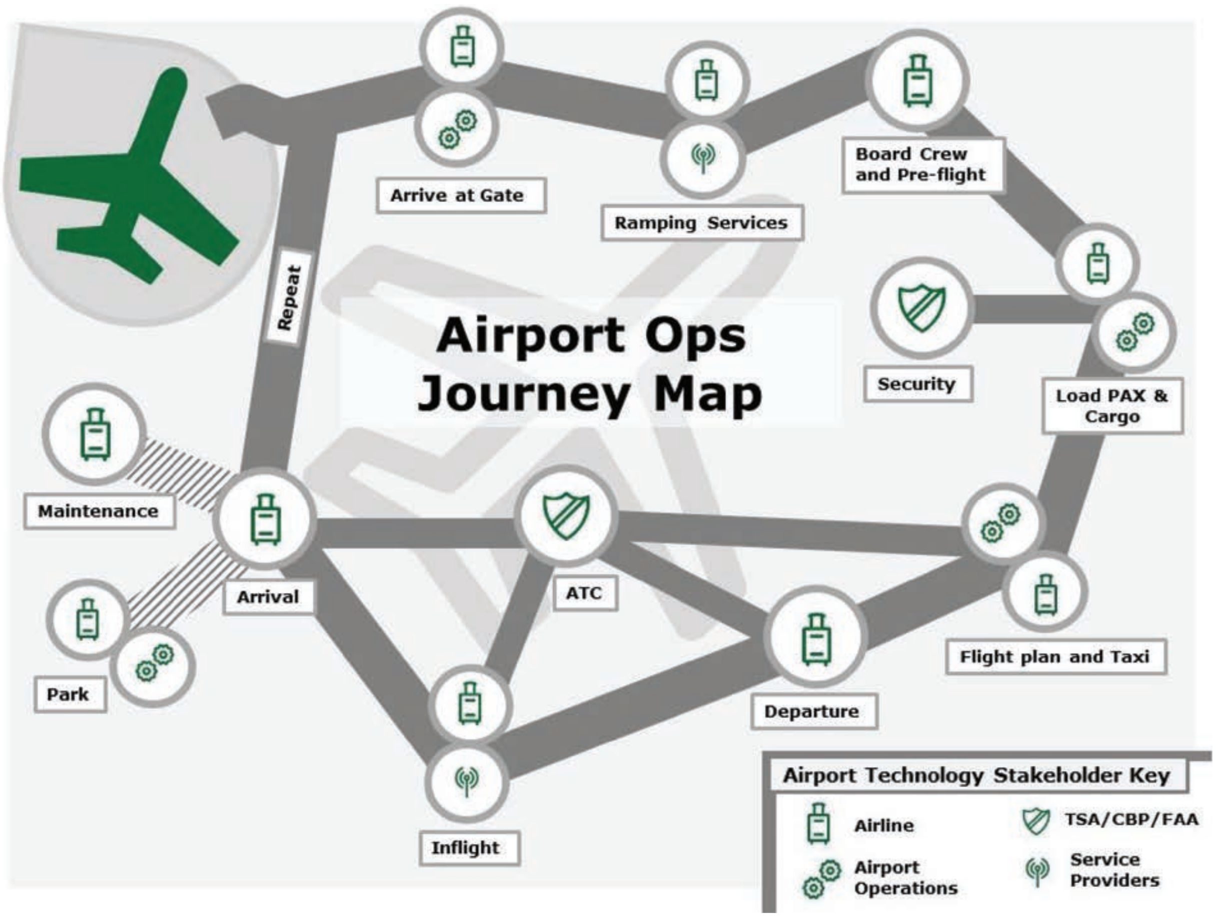
- ACDM.
- Passive RFID baggage tracking systems.
- Open cloud-based IoT platforms.
- Sensor-enabled asset and maintenance systems.

BCSs, such as facial recognition and iris or fingerprint scanners, improve processing times in the passenger experience. These improved processing times also impact flights and departures, and thus airport operations.

DFW Case Study

CASE STUDY

Case studies provide examples of how these elements interact in practice. For example, DFW uses Bluetooth sensors to track janitor carts around the airport in order to better direct cleaning staff to high-traffic bathrooms and communal terminal areas. DFW also uses historical data to plan for high volumes of passengers.



Note: PAX = passengers

Figure 18. Airport operations journey map with IoT.

Table 7. Aviation operations journey stages, IoT solutions, and stakeholders.

<table>
<tr><th colspan="2"></th><th colspan="10">Steps of Aviation Operations Journey →</th></tr>
<tr><th colspan="2"></th><th>Land</th><th>Arrive at Gate</th><th>Ramping Service</th><th>Board Crew & Pre-flight</th><th>Security Screening</th><th>Load PAX and Cargo</th><th>Flight Plan & Taxi</th><th>Departure</th><th>ATC Control In-Flight</th><th>Maintenance</th></tr>
<tr><td rowspan="5">Stakeholder</td><td>Airlines</td><td colspan="3">ACDM</td><td></td><td colspan="2">Bag Tracking</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other Commercial Tenants</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Vendors to Airport</td><td></td><td></td><td>ACDM</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Security, Customs, & Aviation Authorities</td><td colspan="2">ACDM</td><td></td><td colspan="3">Biometric Screening</td><td colspan="3">ACDM</td><td></td></tr>
<tr><td>Airport Ground Staff</td><td></td><td></td><td></td><td></td><td colspan="2">Bag Tracking</td><td></td><td></td><td></td><td></td></tr>
</table>

DFW currently uses wireless sensors to monitor ambient light within a building and feed that information to a BMS. When sunlight is high, artificial light is lessened, saving energy. By determining whether humans are present in a room, the same process can be used to control temperature.

DFW was granted a patent for an "apparatus, system, and method supporting compliance with customs/border requirements" in 2016. This system wirelessly transmits traveler information to process passengers faster while filtering passengers who need additional screening.

SIN Case Study

CASE STUDY

SIN uses a facial recognition and BCS to enable automated passenger processing at self-bag drops, integrated border clearance, and self-boarding departure gates. The BCS allows centralized monitoring of various process points. Real-time closed-circuit television streams video from the gates to a central monitoring location, which enables real-time searches for persons on security watch lists. In this way, the system integrates biometrics and identity confirmation data with passenger processing and airport operations. SIN innovation was in part a response to the International Air Transport Association (IATA) Fast Travel program, which encourages self-service options in six areas of the passenger journey:

- Check-in.
- Baggage tagging and acceptance.
- Travel documentation checks.
- Flight re-booking.
- Self-boarding.
- Baggage recovery.

(More information is available from Best, H. *IATA Program Strategy: Fast Travel Program.* International Air Transport Association, 2015.)

Strategies for Successful IoT Implementation

Airport operators seeking to implement IoT should do so only after developing a strategic implementation roadmap—not only to guide their implementation strategy but also to confirm the right set of implementation choices. While airports may achieve incremental gains by implementing one-off IoT solutions, they can only achieve true near-term success and long-term transformation by taking a holistic approach. This approach includes developing an IoT strategy that aligns with the greater airport and stakeholder goals. Tying IoT objectives to airport goals produces the following:

- Enables airport operators to make a business case for investment in IoT infrastructure and technologies.
- Promotes continued long-term investment in IoT and strategic development of an architecture that can accelerate IoT adoption.

Development of the implementation roadmap is aided and accelerated by the *IoT capability model framework.* The framework allows an airport operator not only to self-assess the airport's capability maturity that enables (and, in some cases, may accelerate) IoT implementation, but also to determine how and where IoT can help accomplish these

Definition: Implementation Roadmap

A strategic IoT implementation roadmap provides potential IoT solutions to specific business needs and a view of the infrastructure and capability requirements for those solutions.

Definition: IoT Capability Model Framework

The framework allows an airport operator to self-assess the airport's capability maturity that enables (and, in some cases, may accelerate) IoT implementation, and to determine how and where IoT can help the airport achieve these goals.

goals. The framework also considers the maturity of an airport's network infrastructure and architecture—crucial to supporting implementation and growth of an airport IoT ecosystem.

The IoT capability model framework is then used in developing the following three precursors to the implementation roadmap, which provide the information needed to develop the roadmap itself:

- Stakeholder framework.
- Journey maps.
- Capability gap assessment.

This section describes the following:

- The IoT capability model framework.
- The precursors of an implementation roadmap.
- The implementation roadmap.

IoT Planning Process

A Top-Down Approach to IoT Selection

In planning for their desired IoT solution, airport operators may consider using a capability model that helps them select the right set of IoT capabilities based on the goals in their strategic plan. These goals become the primary motivator for choosing a specific IoT solution. Motivators such as new revenue result in a more complex IoT solution than those aimed at efficiency. As a result, an airport's strategic plan drives the selection of a primary motivator, which in turn drives the infrastructure requirements needed for a successful IoT implementation.

Airport operators can also use this model to identify future infrastructure needs to support their desired final system and can craft their investment business case accordingly. This assessment process can give airport operators a clear view of what they need to meet their goals with IoT. Then, in turn, airport operators can create a detailed implementation roadmap to guide the step-by-step actions to bring the project to life. For example, the implementation roadmap will help airports identify the gap between what the airport currently has in place and what the airport needs. The steps taken to address this gap become the crucial first tasks on the journey to a successful IoT implementation.

CASE STUDY

Delta Air Lines is pursuing IoT initiatives to improve its technological excellence to manage costs and drive revenue. Baggage handling is one of these initiatives. Delta invested $50 million in RFID technology in 2016.

DFW developed a 5-year strategic plan in 2016 to guide IoT initiatives in business development, employee engagement, operational excellence, and community engagement.

The airport also needs enabling technologies in place (i.e., infrastructure maturity) before it can expect to achieve differentiation or new revenue via IoT. For example, an airport may need robust passenger Wi-Fi capability before it can monitor and measure passenger queueing in real time.

Table 8 shows how airports should consider their own IoT readiness and select appropriate solutions. After completing this table, an airport will have the ability to do the following:

- Consider the IoT capabilities that will help it achieve its strategic goals.
- Develop a customized IoT capability model—based on an individual airport's situation and strategic goals—that describes its IoT capability strengths and limitations.
- Use the customized IoT capability model when creating an implementation roadmap, establishing an implementable path to IoT maturity while also considering the required infrastructure maturity.

The details of how an airport can assess its infrastructure maturity and create an implementation roadmap can be found in the section "Implementation Roadmap."

Table 8. Top-down IoT planning model.

Infrastructure Maturity Requirements	Primary Motivator: Safety/ Security	Efficiency	Differentiation	New Revenue
Low				
Moderate				
High				

Note that devices that achieve differentiation or new revenue goals require at least some level of infrastructure maturity to achieve measurable gains.

A Bottom-Up Approach to IoT Selection

Airport operators can also identify promising opportunities for IoT by examining the existing IoT solutions operating in their airport. This can help identify gaps where IoT may help operations and also show where other stakeholders may have data an airport requires—saving the airport time and money. Given the breadth and depth of IoT applications, the steps are as follows:

1. Use the information in this primer to consider the full spectrum of what IoT can do at an airport, regardless of whether IoT is currently being used in that way today.
2. Determine where the various stakeholders around the airport are currently deploying IoT solutions.

With all existing IoT applications in view, an airport operator can determine the gaps that a potential IoT solution could fill. Each potential solution has infrastructure maturity requirements associated with it, based on the number of stakeholders involved, level of technology needed, and so on. In evaluating the suitability of a potential IoT solution, an airport should consider the following:

- The actual cost of the device itself.
- The complexity and robustness of the data produced by the device.
- The accuracy, reliability, and timeliness required of these data.
- The network bandwidth and connectivity capabilities required.
- The primary motivator (efficiency, differentiation, or new revenue) that the solution helps to achieve.

As in the top-down approach, this assessment of the infrastructure requirements for an IoT solution can help the airport gauge the feasibility of a project. However, the map created by the bottom-up approach has an additional benefit: it can identify other stakeholders who may be able to provide some of the capabilities needed. Capabilities that are a priority for a specific stakeholder—but not at the top of the airport's list—may move up the airport's priority list when considered in the context of a holistic IoT strategy.

CASE STUDY

SFO acts as an information broker and wholesaler of information-based services. SFO's IT department uses an API development strategy to help improve the services provided by all stakeholders—whether internal, external, mission, or revenue oriented. All available data that stakeholders are willing to provide are put into a common data lake. These data can then be reassembled to create new service products that improve business performance in terms of the passenger experience and optimized operations and maintenance.

Precursors to the Implementation Roadmap

Three precursors provide information necessary to develop an implementation roadmap:

- Stakeholder framework.
- Journey maps.
- Capability gap assessment.

Stakeholder Framework

Definition: Stakeholder Framework

A stakeholder framework identifies a holistic picture of the various stakeholders involved in day-to-day operations at airports who may implement, use, or manage an IoT solution. This framework also identifies stakeholder motivations for using IoT.

The value of IoT is determined by the volume and quality of information it handles. Typically, the more stakeholders that an IoT application meaningfully connects—the more information for aggregation, analytics, and useful applications—the greater the value of that application to the airport. Therefore, it is important to understand the range of airport stakeholders.

The stakeholder framework in Figure 16 details a holistic picture of the various stakeholders involved in day-to-day operations at airports that may implement, use, or manage an IoT solution. This framework also identifies stakeholder motivations for using IoT: revenue or mission focused, and airport or non-airport specific. For example, does the stakeholder (e.g., a retail tenant) use IoT to make money, or is the stakeholder (e.g., a public safety officer) interested solely in accomplishing an assigned mission? Can a stakeholder directly import an IoT solution from a non-airport use (e.g., HVAC in office buildings), or are the tasks of that stakeholder particular to airports and aviation? By answering these questions, the stakeholder framework offers not only a group of possible participants for any IoT project, but also crucial information about the needs of those stakeholders for IoT.

Journey Maps

Definition: Journey Map

A journey map is a simplified and summarized process that identifies the common activities or locations within an airport where IoT can offer something new.

After the stakeholder framework provides a list of who can undertake IoT at an airport, the next questions are where and how they can implement IoT. That is, what are the common activities or locations within an airport where IoT can offer something new? With the many and frequent moving parts of airport operations, these processes can be simplified and summarized in two journey maps: one for passengers and (Figure 17) and one for operations (Figure 18). These maps can help airport operators think about where IoT exists, where it can be applied, and which stakeholders can apply it.

Airports must examine the both journey maps as follows:

- Consider the passenger journey from arrival to departure. Define how the journey can be enhanced and how components can be connected.
- Consider the journey of airport operations, which includes the movement of aircraft through the airport. Define how the journey can be enhanced and how components can be connected. These operational steps lie at the heart of any airport, but since they are often not passenger facing, they may be overlooked in discussions of new technologies.

Capability Gap Assessment

A customized airport capability gap assessment (Table 9) can also be created that includes the steps in the aviation operations journey and the existing and possible IoT solutions for each stakeholder. The assessment can help airport operators identify potential opportunities for new IoT solutions and which stakeholders may be viable partners for those solutions. The assessment also allows airport operators to take a holistic approach to their IoT strategy and more quickly identify capability gaps or misalignment of their devices with their current or planned infrastructure. For example, this assessment can help airport operators review IoT options with a group of stakeholders who may be considering co-investment to address a mutual pain point or set of pain points. Displaying this information in an easy-to-understand format can accelerate solution selection and adoption.

Table 9. Example capability gap assessment.

Steps of Aviation Operations Journey →

Stakeholders		Arrive at Gate	Ramping Service	Board Crew and Pre-flight	Load PAX and Cargo	Etc.
	Airport Operator	**Existing Solution:** *Automatic runway warning lights* **Objective Achieved:** *Safety/security*		**Possible Solution:** *Biometric security access for crew* **Objective Achieved:** *Differentiation* **Infrastructure Maturity:** *High* (red)		
	Airline	**Existing Solution:** *Sensorized wheelchairs to meet aircraft at gate* **Objective Achieved:** *Efficiency*	**Existing Solution:** *Sensor to determine food or beverage levels on plane* **Objective Achieved:** *Efficiency*		**Possible Solution:** *Individualized boarding of passengers not by groups/zones* **Objective Achieved:** *Efficiency* **Infrastructure Maturity:** *Low* (green)	
	Etc.					

Infrastructure Maturity Required

Low (green) Moderate (yellow) High (red)

> **Definition: Capability Gap Assessment**
>
> A capability gap assessment is a matrix that highlights the stage and stakeholders involved in a potential IoT solution, and then assesses an airport's readiness to implement such solutions.

> **Definition: Digital Maturity**
>
> Digital maturity is the dual objective of meeting demands in the long run and making digital improvements a core business strategy. Digital maturity is a progression through early, developing, and maturing stages. For airports, this maturity can mean different things for each stage depending on the size and goals of an airport. For example, a general aviation airport has a different scale of digital maturity than an international hub.

Implementation Roadmap

Assessing the Airport's Capabilities

Whether using the top-down or bottom-up approach, airport operators arrive at a potential IoT solution and a view of the infrastructure and capability requirements for that solution. The next step is to assess the current capabilities of the airport and understand where they may fall short of the requirements for the potential IoT solution. In this way, airport operators can begin to understand the technical and organizational changes required for their projects to succeed. In short, airport operators assess their overall digital maturity versus the desired end state of a successful IoT implementation.

This assessment should include at least the following criteria:

- The size and complexity of the data that the potential IoT solution will produce versus the current capabilities to house and analyze data.
- The communications and other infrastructure required for the potential solution versus what already exists at the airport.
- The cost of the solution versus the available funds.
- Stakeholder groups that can achieve benefits from the potential solution versus the security and privacy procedures that must be in place to secure their cooperation or use.

Assessing potential IoT solutions against these qualifiers can confirm (or disprove) the overall fit of that device for the defined needs of the airport before moving to implementation. More important, the gaps between required and current capabilities in each of these criteria can guide the first steps to be taken when developing an implementation roadmap.

As technologies and connectivity expand and grow, stakeholders must keep pace to be able to operate and respond to new demands in the market. The implementation roadmap takes into account not only the desired end-state capabilities, but the processes, technologies, and stakeholders required to achieve this end state. Simply put, it offers tactical steps to accomplish the IoT vision.

Working with Stakeholders

Developing the implementation roadmap requires coordination and collaboration with key stakeholders who may either own IoT applications or receive data from applications once implemented, as well as those stakeholders who may achieve secondary benefits from these applications. Functional and technical resources are key for roadmap development:

- Functional resources pertain to the strategic management processes of an airport's IT organization, such as budgeting and investment strategies, as well as the general state of current and planned infrastructure required to support IoT applications.
- Technical resources pertain to the current and planned technological (e.g., device and communication) infrastructure to ensure that selected IoT devices can be supported now and in the future.

Stakeholder objectives and desired outcomes should be carefully considered—and incorporated if they align with overall priorities and strategy—during the development of the implementation roadmap and accompanying IoT strategy.

A targeted and robust requirements-gathering effort among all stakeholders can accelerate roadmap development following these steps:

1. One-on-one and group meetings with an airport's executive leadership team can help establish the overall vision.
2. Then, internal and external stakeholders can present their requirements through facilitated sessions, electronic surveys, and one-on-one interviews to maximize participation.
3. Upon aggregation of these requirements, airports can identify duplicative requirements, which can motivate co-investment by ecosystem stakeholders.
4. Last, an airport (or other IoT business owner) can prioritize functional capability requirements, align them with the most appropriate technology, and set the implementation strategy. This creates a roadmap that airport operators and stakeholders alike can accept.

This collective buy-in is crucial to success and may continue to motivate airport stakeholders to co-invest in the IoT ecosystem.

Barriers to IoT Implementation

Even with all the right tools and information, implementing IoT solutions can be a significant undertaking filled with new challenges for even the most mature organizations. These challenges can be broadly grouped as follows:

- **Technological challenges.** Technological challenges go beyond choosing the right hardware and software. These challenges concern safety, security, and privacy. While these challenges demand uncompromising solutions, many of the technological elements of these solutions already exist.
- **Organizational challenges.** Organizational challenges—such as finding the right business case, financing, or talent—are less hard and fast and require every organization to find its own solutions.

This section describes both technological and organizational challenges as they apply to the following:

- Safety, security, and privacy.
- Technology and infrastructure.
- Talent.
- A compelling business case.
- Financing.

Barriers to implement IoT solutions can seem overwhelming. However, with the right team, a thoughtful plan, and supportive buy-in, airports can implement IoT solutions to create a better, more profitable operation.

Safety, Security, and Privacy

In the aviation industry, safety is an inviolate standard. No new technology, no matter how efficient or cost saving, can be introduced if it compromises safety. That standard clearly applies to anything that goes on, in, or around aircraft. But in the modern world where digital information and physical devices are linked, safety can begin to have an even larger scope. When physical objects are connected digitally, the compromise of digital data can have real-world, physical consequences. Researchers have reported the ability to take control of the steering and acceleration of cars via wireless hacking and even access crucial systems on airplanes from in-flight entertainment systems (Greenberg 2015; McGoogan 2016). Therefore, as IoT is adopted, safety, cybersecurity, and data privacy are all increasingly linked.

There are many known solutions to these issues. The same approach that has given aviation such an impressive safety record over the years can help secure IoT. Just as no technology is allowed to compromise the physical safety of an aircraft, no IoT adoption should be allowed to outstrip the ability of airports, airlines, and others to protect data. Using known, trusted technology vendors and designing IoT solutions with security and privacy in mind from the start are key to robust security.

CASE STUDY

CMH is beginning to encounter privacy issues related to existing employer-employee and customer relationships as it deploys sensors capable of monitoring and tracking airport operations. While the airport is fully compliant with federal and state regulations pertaining to data privacy, there is a corporate cultural factor to the introduction and use of any new technology. For example, the airport is able to track data associated with specific devices. If employees are using large amounts of data per day, the airport can suspend their access. But the airport is hesitant to act because this could raise issues for employee morale and labor relations, with negative implications for airport management.

While such safeguards in design are a step in the right direction, airport operators will need to be conscious of staying up to date with the latest privacy standards and being resilient in the face of inevitable disruptions. No technology solution is immune to failures or downtime, so being able to continue operations and protect sensitive data of stakeholders and customers alike during such periods will aid long-term adoption of IoT. Airports will need to complete routine security screenings and privacy impact assessments and check regularly for updates to National Institute of Standards and Technology security guidelines and technology patches.

Technology and Infrastructure

The solutions to such significant problems as ensuring the safety, security, and privacy of IoT often fall on technology and appropriate infrastructure. However, even with a solid plan, the technology that supports IoT solutions can be extensive. Large IoT implementations involve numerous, disparate systems and devices, which all need to connect and operate together. Very few out-of-the-box IoT solutions for airports are currently on the market. This can make it challenging to determine what is needed to support an IoT ecosystem.

There is no single IoT solution to serve the diverse needs of all airports. Airport operators need to procure different technologies to link together and create the IoT solution specific to their unique business needs. Some of the technologies may be new and customized. However, some elements will be legacy systems or networks. This linkage between new and legacy devices, business intelligence tools, networks, and so forth, may create compatibility challenges. In some cases, airports may find that opting for an all-in-one IoT platform may be the best option. These solutions are often offered by vendors or integrators and provide a common place for all IoT-produced data to be stored and analyzed.

IoT can range from relatively light platforms run in the cloud to infrastructure-intensive, custom-built, on-premises solutions meant to serve as the entire digital backbone for an airport. However, in other cases, even the lightest platforms may not be necessary. Some airports, especially those with simpler IoT needs, may be able to integrate different types of hardware and software as needed. This method requires open-source compliant hardware and choosing the right APIs so data of all types can be used by other programs.

In all cases, to ensure interoperability, airport operators should consider not only the technical and protocol solutions that may allow devices to communicate, but also the data structure and integrity. Given that disparate data sets must somehow connect to support meaningful analysis, data need to be consistent for useable insights.

A similar challenge may be found in the walls and wires of airport buildings themselves. Airports in the United States often feature aging infrastructure designed in previous decades that does not support today's digital technologies. For example, thick concrete walls and sharp angles in terminal designs are not conducive to good Wi-Fi signal propagation. Similarly, laying new cables or other technology upgrades in older facilities can be time consuming and require innovative solutions to avoid major disruptions to operations. Airport operators can look at other industries for ideas on how to work around crowded spaces or layouts that do not support connected networks. Designing IoT solutions with modular architectures can also ensure that upgrades can be made more easily and that such major infrastructure barriers do not occur in the future.

Implementing New Technologies

Each airport is technologically unique and relies on a combination of legacy and new systems. When implementing new technologies, older airports might present greater challenges than newer ones in terms of supporting digital technologies.

Talent

As IoT gains wider adoption, it can bring digital technology to new areas within the airport. As a result, the roles and responsibilities of airport employees may also change as they have more interaction with technology. To keep up with this trend, airports must hire and train employees strategically as jobs of all types require increased use of digital technology. To support IoT applications, airports must address talent and skill gaps as a high priority. To do so, airports should account for talent in their strategic plan as follows:

- Implement training programs for existing employees.
- Expand hiring for new technical roles.
- Change the way leaders manage and organize work groups.

Training Programs

The single most valuable asset most airports possess is their workforce. As measured by annual expenditure, workforce costs are typically the largest single category of expenditure for airports, according to Airports Council North America. Therefore, training current employees in the new skills that IoT requires may be the most important action an airport can take to ensure IoT adoption. Given the speed with which technology can change, training programs should not be one-off events but rather a long-term program aimed at enabling workers to keep pace with the technical skills they need. Training is a large investment, and retaining trained workers is key to receiving a return on that investment. Data suggest that training programs themselves may aid in retention because employees value developing themselves and their careers (Kane et al. 2017).

Additional Hiring for New Technical Roles

Effective IoT implementations require teams that understand the power of IoT applications and the ramifications of adopting new technologies. Whether implementing a large or small IoT solution, airports will require a team of experts who bring the most value from the IoT solution, protect the airport from new risks, and manage the solutions over their lifetime. These objectives may require entirely new skills and roles that have traditionally not been a part of an airport operations team. To address this, airports need to hire specialists equipped to work on such projects. These positions can include the following:

- Data scientists.
- Cybersecurity experts.
- Data architects.
- System engineers.
- Developers.
- IT managers.

For example, YYZ hired data experts to understand and strategize applications of data captured daily.

Some of these positions are new to airport IT teams but essential to the success of IoT solutions. The solutions are only as powerful as how well the application understands the data and protects the data from attacks.

IoT and New Hires

As airports come to rely on technology innovations, strategically hiring new employees with technical skills (and training legacy employees) becomes a crucial component to getting the most value out of the IoT solutions implemented.

CASE STUDY

SFO supports a data science intern program, in association with the City of San Francisco's intern program that engages with undergraduate and graduate programs from colleges and universities in the region. Skill sets include data science, software development, and business analysis. When interns come to the SFO IT department, they work on developing real solutions that are applied in the field. For example, the security group needed to be able to authenticate certain people that were given certain functions at the airport. Previously, it would have taken 1.5 years to develop a solution. Interns were able to develop one in 2 weeks.

Leadership

As the role of technology increases, the ability to lead technology innovation within airport departments becomes more crucial. Airport leaders must have the technology literacy and experience with technology solutions necessary to make informed decisions about IoT projects. Like other public-sector entities, airports need to use innovative best practices to inform problem solving. Creating successful, resilient IoT solutions in a complex ecosystem like an airport requires leaders that understand technology applications, the hiring strategies that can create those applications, and ways to bring these core components together to produce effective solutions.

As roles begin to shift, the smart technology within IoT can begin to take on some tasks previously done solely by human workers. This creates a valuable opportunity for airport operators to shift talent to fill new, value-added roles interacting with customers rather than doing basic tasks such as filling out forms. One example of technology replacing labor in the modern world is the introduction of ATMs. With ATMs, bank branches were able to operate with an average of 13 tellers rather than the typical 20, enabling management to redeploy the freed-up tellers to expand geographically (Bessen 2015). For their part, bank tellers also shifted the nature of their roles. Tellers could move on to higher-value, relationship-driven tasks such as opening new accounts or issuing credit cards, while the machines handled the high-volume but lower-value tasks of dispensing cash and depositing checks. As a result, the number of bank tellers in the United States has increased over the past four decades, from 250,000 to about 500,000 (O'Marah 2016). IoT will likely have similar impacts at airports, taking on repetitive tasks and freeing up human workers to focus on activities that create value. In the case of airports, those value-added activities are likely to focus on customers: enhancing passenger experience by providing in-person custom care or working directly with cargo customers to ensure the right facilities and equipment are available at the right time.

To take advantage of these shifts, airports need to create an agile workforce as roles begin to shift. If workers spend less time on repetitive tasks and move to more customer-oriented activities, they will need to have an end-to-end understanding of all the airport's operations. If a customer has a question about baggage, an airport worker should be able to respond with the appropriate information rather than state, for example, "I work in scheduling." This means the future IoT-enabled workforce cannot be siloed by function but rather will need significant cross-functional experience. So, in addition to the technical competence airport leaders must have for IoT, they must also manage work groups differently to take full advantage of IoT.

A Compelling Business Case

Return on Investment

In every industry, concerns about return on investment (ROI) are among the top barriers to implementing IoT. Both upfront and continuing costs can vary widely, depending on the specific IoT application. Some IoT applications require significant capital investment in infrastructure, while others may use existing technology and cost only a change in business process. In addition, because IoT has few test cases, the ROI for any IoT investment has not been fully ascertained. The result of this uncertainty is that cost can quickly become a barrier to IoT implementation. However, this does not mean that airport leaders should avoid IoT or even only pursue those applications that have been proven elsewhere. Rather, careful consideration of the factors that drive costs and ROI in IoT can help leaders narrow down options and structure their decision-making.

Strategic Goals of the Airport

To begin building a business case for IoT, an airport operator should look at the bigger picture: how IoT solutions and data fit into the broader strategy. IoT is often deployed in ad-hoc solutions throughout airport operations, fragmented across different departments and with limited centralized oversight. When deployed in this manner, IoT can certainly create benefits but is unlikely to have the desired transformative impact. On the other hand, as other industries have learned, when deployed as part of a centralized, strategic plan, IoT can support long-term goals and reshape the very core of how airports operate and engage with customers.

Business Goal of the IoT Application

Another important consideration is the business goal the airport wishes to accomplish with IoT. The answer to that question determines what technology is needed to gather, analyze, and act upon the data collected. The larger the business goal, the larger the scope and complexity

Business Strategies and IoT

Understanding how IoT solutions fit into the overall business strategy is key for airports to ensure these solutions contribute to their big-picture success. By tying an IoT project to a business goal, an airport can use data to generate dollars.

> **The Toronto Pearson Airport (YYZ)** has begun quantifying aspects of its business to support IoT applications aimed at reducing wait times at check-in, security, and customs. Using concessionary data and wait time data, the airport staff manually calculates the monetary loss of passengers spending time in security rather than inside the terminal. From this information, the airport obtains a definitive dollar amount for every minute a passenger no longer spends in a line—a clear ROI for the IoT application that can create such time savings. Measuring baseline airport processes can clearly define the ROI of an IoT solution and help turn solutions from optional to necessary.

of an IoT application. An IoT application with a larger scope will by definition feature a larger number of stakeholders and a wider variety of technological components. Understanding the business goal will provide at least a rough idea of the upfront and life-cycle costs.

Ultimately, tying an IoT project to a business goal is about using data to generate dollars. Whether IoT saves money by increasing efficiency or creates new revenue sources, the business case for IoT must rest on solid financials. However, it can be challenging to quantify the exact bottom-line impact of a specific change that improves efficiency. As a result, creating a compelling business case for IoT may also call for quantifying previously unmeasured aspects of airport operations and passenger experience.

Financing

Even with a solid business case that promises clear ROI, airports can struggle to find the upfront funding needed to begin a project. Given the thin margins of the aviation industry, finding extra dollars to finance an IoT project can induce fear in any airport executive. With new technologies such as IoT, fear can be as big a barrier as any technical hurdle (Sniderman et al. 2016). Reducing uncertainty is a key method to encourage adoption of IoT and other novel technologies (Schmidt 2016).

Questions to Consider for Financing

Business Goal. The first question is: what is the business goal?

Timeline. Financing is not just about the total amount of money involved. It is also about the time over which that money must be made or paid. As a result, another business question that must be considered before implementing IoT is: what is the required timeline to recoup investment?

Stakeholders Needed. Since almost no company has all the technical components and expertise needed for IoT in house, even relatively simple IoT projects require a number of stakeholders. A third question is: how many stakeholders are involved? Having a clear idea of the number of stakeholders involved in the IoT project will help in estimating the cost of the IoT project.

A Framework for Financing Decisions

Information about the business goal, timeline, and number of stakeholders, in the context of ROI, can narrow the set of suitable financing options available to an airport. Figure 19 provides a framework of considerations that can help take the uncertainty out of financing IoT. The framework can help airports evaluate the needs of their IoT project and understand what financing options may be suitable for such a project.

For example, an airport that seeks to improve the efficiency of waste collection can achieve that goal via internal methods. The airport employs or controls the collection of waste and so can easily implement a suitable IoT solution and change its business process based on its results to achieve the desired efficiency. Similarly, the technical solution needed will likely not be very complex—possibly just a few sensors on wastebaskets and minimal software, which could be

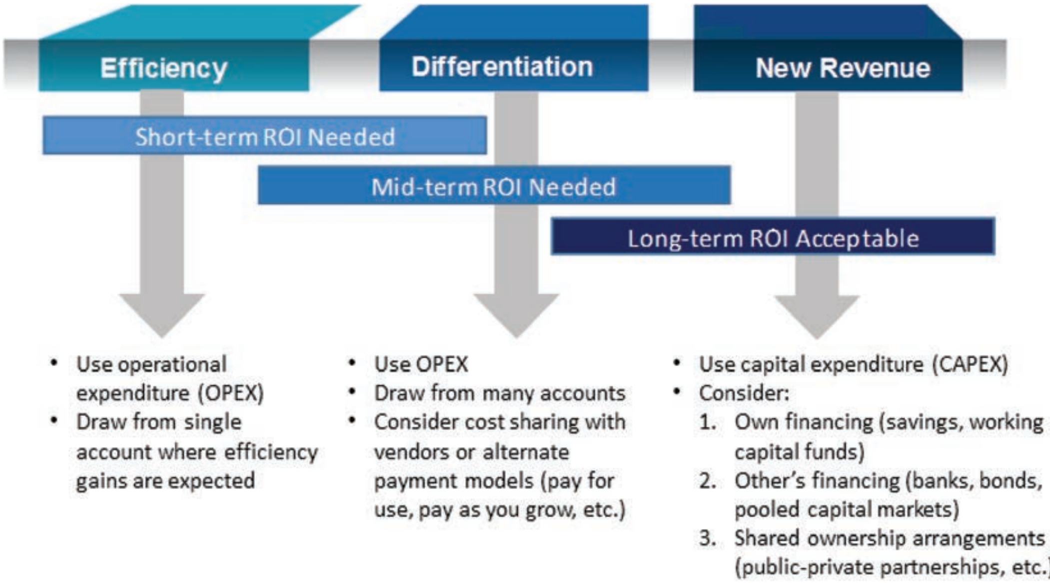


Figure 19. A Framework for structuring IoT financing options.

purchased or implemented for relatively little cost. The following are the answers to the three questions:

- What is the business goal? *Efficiency.*
- What is the required timeline to recoup investment? *Short term needed.*
- How many stakeholders are involved? *Just the airport and potentially an IT service provider.*

With this information, the airport can determine that capital expenditure is not required for such an implementation, and that the project could be funded from operational funds. With this in mind, it would make the most sense to draw the funding entirely from the account where the efficiencies are expected to be recognized. This will ease payment; streamline governance and oversight; and make final tabulation of ROI for the project easier.

Naturally, the considerations and recommendations are different for more complex IoT applications. As the scope of the application increases, airports can consider splitting an operational expenditure across multiple accounts or investigating alternate payment models with technology and service vendors, such as pay as you go, pay as you upgrade, or payment based on measured outcomes. However, if a project has a large enough scope or sufficient technical complexity that it requires significant upfront investment, airports may need to use capital expenditures. Even here, options vary widely depending on the amount of funding needed and the timeline in which it is needed, for example:

- Small amounts of funding may be most easily pulled from internal sources such as savings or working capital funds.
- As the amount grows, airports may wish to investigate capital markets via traditional lending, bond offerings, or even more novel methods such as pooled capital markets.
- For the largest and most significant capital needs, perhaps where IoT is a component of larger projects such as terminal building or integration with new mass transit, airports may wish to look into shared ownership arrangements such as public-private partnerships.

While the array of these options can be widespread, by structuring them around the core questions about an IoT project, airport operators can limit the number of options. The result is a more manageable decision and one more likely to be taken with confidence.

Focus IoT Solutions

Focusing IoT solutions around specific, core strategic goals can make decisions regarding how best to plan, fund, and implement them easier.

As with any financial decision, the specifics of any individual case can vary. As a result, every airport operator should consult with the airport's financial advisors before making any financing decisions. The recommendations of this framework are merely intended to serve as a decision-making aid to ensure that the set of options is manageable and that no suitable options are overlooked. This framework is a starting point from which to begin detailed analyses of what is right for a specific airport at a specific time. As an emerging technology, IoT changes quickly. So, building flexibility and agility into any IoT project is important. This extends not just to technology but to financing as well if the business is to grow and evolve along with the technology.

CHAPTER 5

What's Next?

Future IoT Activities

Airport executives see a clear need for IoT to increase efficiency and differentiation in the future. In fact, the online survey, qualitative interviews, and literature review all revealed burgeoning use of IoT in airports. While most of today's applications of IoT seek to improve operational efficiencies in areas such as facilities management, asset management, and baggage handling, the online survey revealed a very different picture for the future of IoT at airports.

Source: ssguy/Shutterstock.com and phipatbig/Shutterstock.com, adapted by TTI.

Survey respondents identified IoT solutions capable of enhancing the customer experience or strategic differentiation more often among their future plan than solutions focused on operational efficiency. This suggests that survey respondents (primarily from airports) may be approaching IoT with an unspoken maturity model in mind, beginning with easy wins with operational efficiency and then progressing to the more complex, high-reward uses of IoT, which require information flows across a broad set of airport stakeholders. The introduction of new products or services was not mentioned frequently, so it appears that the envisioned IoT solutions will build on services or products already in place. Also, the percentages responding "definitely yes" for the different types of IoT solutions varied, while the percentages responding "probably yes" did not vary significantly (Table 10). This indicates optimism about future implementation even though current plans may not exist.

Within these categories of solutions, a wide range of specific IoT projects are planned, according to responses from the online survey and qualitative interviews. In the online survey, respondents were asked to briefly describe the IoT solutions that their organization will most likely implement. Answers were diverse and covered a range of airport operations as follows:

- Self-check-in and bag drop apps.
- The ability to push notification of shopping opportunities to travelers.
- Asset tracking.
- RFID-enabled baggage tags and labels.
- Extension of passenger flow and queue monitoring.
- Security queue wait time monitoring.
- Lighting and HVAC integration.
- Parking technology.
- Indoor positioning, way finding, analytics, and tracking.

Going Beyond Operational Efficiencies

While most of today's airport IoT applications focus on improving operational efficiencies, survey respondents were more interested in IoT solutions that enhance the customer experience or facilitate strategic differentiation.

Table 10. Response to the question: within the next 5 years, will your organization implement an IoT solution capable of the following activities? [from ACRP Project 01-33 (*N* = 103)].

IoT Solution	Definitely Yes	Probably Yes	Total Yes
Customer experience/differentiation: allows for the personalization of the user experience	37%	48%	85%
Monitoring: enables comprehensive monitoring of conditions, systems use, and external environments	27%	49%	76%
Efficiency/optimization: helps optimize operations and enhance performance	24%	51%	75%
New products/revenue: enables offering new products and services	19%	53%	73%
Autonomy: IoT combined with monitoring, control, and optimization enables autonomous operation	11%	46%	57%

Scale: Definitely yes, probably yes, probably no, definitely no.

Systems and Data Integration

Responses received during the qualitative interviews provided insight into future IoT activities and perceived challenges. The future activities were similar to the IoT solutions identified in the case studies. For example, the need to secure the underlying Wi-Fi network that supports IoT remains a fundamental future implementation for some airports. Airports are expanding Wi-Fi from terminal or passenger-focused application to include coverage for use in operations. This includes covering certain areas outside the terminal and 100 ft beyond the tail of the airplanes parked at the gate. The widespread implementation of a wider Wi-Fi coverage area is a requirement to connect to systems, objects, hardware, and other devices.

Interviewees emphasized IoT solutions that enable system and data integration—either processual or technological, for example:

- Future plans at a large airport, being driven by executive leadership, were to develop standards to make it easier to integrate various airline- and airport-operated terminals, systems, and approaches into an overarching IoT airport operations system. A wider net operating system approach was considered a requirement to ensure all key stakeholders are involved in the process.
- A smaller airport focused on implementing an airport management operational software database that connects different systems (i.e., operations department reporting and HVAC information) and provides a dashboard of those systems. The airport has many different systems on separate virtual local area networks with no overarching one to bring them together. The airport determined the overarching system would be needed before it could proceed with IoT in any efficient way.

Responses received during the qualitative interviews noted that the airport budget was typically a major constraint. Most of the focus is generally on terminal and runway infrastructure. Avoiding solutions that come with rigid and costly service, licensing, and maintenance contracts is also an issue.

IoT in the Core Business Model

Regardless of the technology or application involved, IoT will have the biggest impact on airports when the technology is driven into the core business model. For example, one of the areas where IoT can have a large impact but in which there are still few applications is traffic management of the roadway system on approach to the airport. Many airports have traffic problems around the airport, and it is often challenging to figure out how the airport can contribute to resolving this traffic congestion. IoT can be used to monitor traffic or determine parking capacity, but more significant impact can come when that IoT-generated data are used in the business model itself as San Francisco has done with its street parking. While many areas use sensors to gauge how full parking lots or garages are, San Francisco has used those data to change the core business model of how it generates revenue from parking. Rather than simply charging a flat or time-based rate, San Francisco is now using sensors to determine where demand is highest and adjusting parking rates accordingly (Cohen 2017). This can help encourage faster turnover in highly congested areas, generate more parking revenue for the city, and disperse parking to underused areas.

IoT's Influence

Successful IoT applications can even influence implementers to change their core business model to a more profitable one, as happened in San Francisco.

The long-term future of IoT at airports lies in the ability of airport operators to do the same—not just use IoT data but drive IoT into the very core of the business model. Cutting-edge changes could include biometric check-in, variable services or prices based on wait times, or any number of other opportunities that IoT can create.

Importance of Scalability

There is no one IoT solution. Rather, every solution must be customized to the specific business problem an airport is trying to solve. Finding the right technologies, vendors, and processes all rely on beginning with a clear vision of what IoT is meant to achieve. The details of this planning process are described in Chapter 4 and can help airport operators begin IoT implementation confident in achieving a positive result.

Adapting IoT

In a competitive marketplace, survival equals adaptability. An agile organization examines the outcomes of IoT pilot projects to determine whether and how they were successful—and has feedback mechanisms to improve and expand successful uses.

However, that first IoT project or solution is just the beginning. To achieve the full benefits of IoT, it is important to scale pilot projects and expand the scope of successful IoT efforts. Scaling IoT projects involves more than merely deploying more devices. Rather, expanding IoT projects to new departments or teams will bring significant organizational change as business processes change and individual workers acquire new tools and skills. Managing this change requires that the whole organization remain agile. An agile organization can change with changing technology and consider using lightweight prototypes and rapid experimentation. But most important, an agile organization examines the outcomes of IoT pilot projects to determine whether and how they were successful—and has feedback mechanisms to improve and expand successful uses. This means that leadership must encourage change and be available to listen to the workforce about what is working and what is not. The ultimate success of IoT rests not only on the technology used but also on the people involved.

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Acronyms and Abbreviations

3D	Three-dimensional
ACDM	Airport collaborative decision-making
API	Application programming interface
APU	Auxiliary power unit
ATL	Hartsfield–Jackson Atlanta International Airport
ATM	Automatic teller machine
BCS	Biometric control system
BMS	Building management system
CBP	Customs and Border Protection
CEO	Chief executive officer
CMH	Columbus John Glenn International Airport
CRE	Commercial real estate
DFW	Dallas Fort Worth International Airport
EIA	U.S. Energy Information Administration
ERP	Enterprise resource planning
FAA	Federal Aviation Administration
GPS	Global positioning system
HVAC	Heating, ventilation, and air conditioning
IATA	International Air Transport Association
IoT	Internet of Things
IT	Information technology
JFK	John F. Kennedy International Airport
LGW	London Gatwick Airport
LoRaWAN	Low-power wide area network
MATOC	Metropolitan Area Transportation Operations Coordination
MCO	Orlando International Airport
NBIoT	Narrow-band IoT
PAX	Passengers
RFID	Radio frequency identification
RITIS	Regional Integrated Transportation Information System
ROI	Return on investment
SFO	San Francisco International Airport
SIN	Singapore Changi Airport
TNC	Transportation network company
TRIP	Terminal Renewal and Improvement Program
TSA	Transportation Security Administration
VMC	Vendor management company
YYZ	Toronto Pearson Airport

APPENDIX A

Glossary

- **3D printing:** the action or process of making a physical object from a three-dimensional (3D) digital model, typically by laying down many thin layers of a material in succession.
- **Actuator:** a device that complements a sensor in a sensing system. An actuator converts an electrical signal into action, often by converting the signal to nonelectrical energy, such as motion. A simple example of an actuator is an electric motor that converts electric energy into mechanical energy.
- **Airport collaborative decision-making (ACDM) tool:** a tool that combines information from the airport, airlines, air traffic control, and other sources to support more efficient surface movement and other operational needs.
- **Airport Service Quality rating:** a global benchmarking program of the Airports Council International to measure passenger satisfaction while traveling through an airport.
- **Analytics:** the systematic analysis of confusing and conflicting data in search of insight that may inform better decisions.
- **Application program interface (API):** a set of software commands, functions, and protocols that programmers can use to develop software that can run on a certain operating system or website. APIs make it easier for programmers to develop software and ensure that users experience the same user interface when using various software built on the same API.
- **Artificial intelligence:** the theory and development of computer systems able to perform tasks that normally require human intelligence. The field of artificial intelligence has produced a number of cognitive technologies such as computer vision, natural-language processing, and speech recognition.
- **Automated passport control:** a program for border control that uses self-service kiosks to allow travelers to verify information through an automated process.
- **Automated teller machine (ATM):** an electronic banking device that enables customers of financial institutions to perform financial transactions, such as cash withdrawals, deposits, or acquisition of account information, at any time and without the need for direct interaction with bank staff.
- **Auxiliary power unit (APU):** a device on a vehicle, such as a plane, that provides energy for functions other than propulsion.
- **Batch processing:** the execution of a series of computer programs without the need for human intervention. Traditional analytics software generally works on batch-oriented processing in which data are aggregated in batches and then processed. This approach, however, does not deliver the low latency required for near-real-time analysis applications.
- **Beacon:** a class of sensors that can help report the location or presence of an object or person in a certain area. Among the most common beacons are those that operate via the Bluetooth communication protocol.
- **Big data:** a term popularly used to describe large data sets that cannot be handled efficiently by traditional data management systems. The concept of big data also refers to the variety of

data sets—structured and unstructured—as well as the velocity or rate at which the data are incoming.

- **Bluetooth:** a standard for the short-range wireless interconnection of mobile phones, computers, and other electronic devices.
- **Bluetooth low-energy beacon:** a class of wireless devices that transmit their identifier to nearby portable electronic devices.
- **Building management system (BMS):** a computer-based system that controls and monitors a building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems.
- **Cloud computing:** an infrastructure of shared resources (e.g., servers; networks; and software applications and services) that allows users to scale up their data management and processing abilities while keeping costs low. A cloud vendor invests in and maintains the cloud infrastructure; a user pays for only the resources and applications he or she wishes to use.
- **Cognitive technologies:** a set of technologies able to perform tasks that only humans used to be able to perform. Examples of cognitive technologies include computer vision, natural-language processing, and speech recognition.
- **Communication protocol:** a set of rules that provide a common language for devices to communicate. Different communication protocols are used for device-to-device communication; broadly, they vary in the format in which data packets are transferred. One example is Hypertext Transfer Protocol (HTTP).
- **Complex event processing (CEP):** an analytics tool that enables processing and analysis of data on a real-time or a near-real-time basis, driving timely decision-making and action. CEP is relevant for IoT in its ability to recognize patterns in massive data sets at low latency rates. A CEP tool identifies patterns by using a variety of techniques such as filtering, aggregation, and correlation to trigger an automated action or to flag the need for human intervention.
- **Computer vision:** a type of cognitive technology that refers to the ability of computers to identify objects, scenes, and activities in images. Computer-vision technology uses sequences of imaging-processing operations and other techniques to decompose the task of analyzing images into manageable pieces. Certain techniques, for example, allow for detecting the edges and textures of objects in an image. Classification models may be used to determine if the features identified in an image are likely to represent a kind of object already known to the system.
- **Data rate:** the speed at which data are transferred by a network. Sometimes termed bandwidth, data rates are typically measured in bits transferred per second. Network technologies that are currently available can deliver data rates of up to 1 gigabyte per second.
- **Descriptive analytics:** a type of analytics that provides insights into past business events and performance. In a fundamental sense, descriptive analytics helps answer the question "What has happened?" Descriptive analytics tools augment human intelligence by allowing users to work effectively with much larger or more complex data sets than they would ordinarily be able to without such tools.
- **Fast and Seamless Travel initiative:** a program of the International Air Transport Association to improve operations at airports.
- **Gateway:** a combination of hardware and software components that connects one network to another.
- **Heating, ventilation, and air conditioning (HVAC):** the system of technologies used to provide heating and cooling services in buildings and vehicles.
- **In-memory processing:** the process of storing data in random access memory instead of hard disks; this enables quicker data querying, retrieval, and visualizations.
- **Information technology (IT):** the study or use of systems (especially computers and telecommunications) for storing, retrieving, and sending information.
- **International Air Transport Association (IATA):** a trade organization of airlines that supports aviation with global standards for airline safety, security, efficiency, and sustainability.

- **Internet Protocol (IP):** an open network protocol that provides unique addresses to various devices connected to the Internet. The two versions of IP are IP version 4 (IPv4) and IP version 6 (IPv6).
- **Internet transit price:** the price charged by an Internet service provider (ISP) to transfer data on a network. Since no single ISP can cover the worldwide network, ISPs rely on each other to transfer data using network interconnections through gateways.
- **IP version 4 (IPv4):** an older version of the Internet Protocol; IPv6 is a most recent version. IPv4 offers an addressing space of about 6 billion addresses, out of which 4 billion addresses have been used already. IPv4 allows a group of co-located sensors to be identified geographically but not individually, thus restricting the value that can be generated through the scope of data collected from individual devices that are co-located.
- **IP version 6 (IPv6):** a recent version of the Internet Protocol that succeeds IPv4. IPv6 has superior scalability and identifiability features compared with IPv4: the IPv6 address space supports approximately 3.4×10^{38} unique addresses compared with 6 billion addresses under IPv4.
- **Latency:** the time delay in the transfer of data from one point in a network to another. Low-latency networks allow for near-real-time data communications.
- **Local area network (LAN):** a network that extends to a geographic range of at least 100 m, such as within a house or office. Devices can connect to wired or wireless LAN technologies. Examples of wired LAN technologies include Ethernet and fiber optics. Wi-Fi is an example of a wireless LAN technology.
- **Low-power wide area network (LoRaWAN):** a type of wireless telecommunication WAN designed to allow long-range communications at a low bit rate among connected objects, such as sensors operated on a battery.
- **Machine learning:** the ability of computer systems to improve their performance by exposure to data, without the need to follow explicitly programmed instructions. At its core, machine learning is the process of automatically discovering patterns in data. Once discovered, the pattern can be used to make predictions. For instance, presented with a database of information about credit-card transactions—such as date, time, merchant, merchant location, price, and whether the transaction was legitimate or fraudulent—a machine-learning system recognizes patterns that are predictive of fraud. The more transaction data the system processes, the better its predictions are expected to be.
- **Machine-to-human (M2H) interface:** a set of technologies that enable machines to interact with human beings. Some common examples of M2H interfaces include wearables, home automation devices, and autonomous vehicles. Based on the data collected and algorithmic calculations, machines have the potential to convey suggestive actions to individuals who then exercise their discretion to take or not to take the recommended action.
- **Machine-to-machine (M2M) interface:** a set of technologies that enable machines to communicate with other machines and drive action. In common vernacular, M2M is often used interchangeably with IoT. For the team's purposes, though, IoT is a broader concept that includes M2M and M2H interfaces, as well as support systems that facilitate the management of information in a way that creates value.
- **Metadata:** the data that describe other data. For example, metadata for a document would typically include the author's name, size of the document, last created or modified date, and so forth.
- **Narrow-band IoT (NBIoT):** a type of low-power WAN designed to enable a range of devices and services to connect using cellular telecommunications bands.
- **National Institute of Standards and Technology:** a measurement standards laboratory and a nonregulatory agency of the U.S. Department of Commerce.
- **Network:** an infrastructure of hardware components and software protocols that allows devices to share data with each other. Networks can be wired (e.g., Ethernet) or wireless (e.g., Wi-Fi).

- **Network protocol:** a set of rules that define how computers identify each other on a network. One example of a network protocol is the Internet Protocol, which offers unique addresses to machines connected to the Internet.
- **Nitrogen dioxide:** one of a group of gases called nitrogen oxides that primarily come from the burning of fuel and are of concern for their potential effects on human health and air quality.
- **Parallel processing:** the concurrent processing of data on clusters of computers in which each computer offers local aggregation and storage.
- **Personal area network (PAN):** a network that extends to a small geographic range of at least 10 m, such as inside a room. Devices can connect to wireless PAN technologies such as Bluetooth and ZigBee, as well as wired PAN technologies such as Universal Serial Bus (USB).
- **Predictive analytics:** the computational tools that aim to answer questions related to "What might be happening or could happen, given historical trends?" Predictive analytics exploits the large quantity and the increasing variety of data to build useful models that correlate sometimes seemingly unrelated variables. Predictive models are expected to produce more accurate results through machine learning, a process that refers to computer systems' ability to improve their performance by exposure to data without the need to follow explicitly programmed instructions.
- **Prescriptive analytics:** the computational tools that endeavor to answer questions related to "What should one do to achieve a desired outcome?" based on data related to what has happened and what could happen. Prescriptive analytics includes optimization techniques that are based on large data sets, business rules (information on constraints), and mathematical models. Prescriptive algorithms can continuously include new data and improve prescriptive accuracy in decision optimizations.
- **Radio frequency identification (RFID) tag:** a tag that uses radio frequency signals to transmit data about the tag to RFID readers.
- **Real-time processing:** the processing of data instantaneously upon receiving the data and/or instruction. There is often the question of "What data can be considered truly real?" Ideally, data are valid the second they are generated; however, because of practical issues related to latency, the meaning of *real time* varies from application to application.
- **Relational database:** a type of database that organizes data by establishing relationships based on a unique identifier. Structured data stored in relational databases can be queried using structured query language (SQL).
- **Return on investment (ROI):** A performance measure used to evaluate the efficiency of an investment as a ratio of the benefit (or return) of an investment divided by the cost of the investment.
- **Sensor:** a device that is used to sense a physical condition or event. A sensor works by converting a nonelectrical input into an electrical signal that can be sent to an electronic circuit. A sensor does not function by itself—it is a part of a larger system made up of microprocessors, modem chips, power sources, and other related devices.
- **Smart building:** a real estate project that integrates IoT technologies and applications to transform physical spaces, increase building efficiency, and enhance productivity of tenants.
- **Speech recognition:** a type of cognitive technology that focuses on accurately transcribing human speech. The technology has to accommodate challenges such as diverse accents, background noise, homophones (e.g., *principle* and *principal*), speed of speaking, and so forth. Speech-recognition systems use some of the same techniques as natural-language processing systems, as well as others such as acoustic models that describe sounds and their probability of occurring in a certain sequence in a given language.
- **Structured data:** the data stored in predefined formats, such as rows and columns in spreadsheets. Structured data are generally stored in relational databases and can be queried using SQL.

- **Transportation network company (TNC):** an organization that uses digital technology to connect passengers to drivers via mobile applications or a website to arrange taxi-like services.
- **Unstructured data:** data that do not fit into predefined formats. Common sources of unstructured data include images, videos, webpages, emails, blog entries, and Microsoft® Word documents.
- **Wi-Fi:** a technology that allows computers, smartphones, or other devices to connect to the Internet or communicate with one another wirelessly within a particular area.
- **Wide area network (WAN):** a network that spreads to a large area, such as beyond buildings and cities. WAN is an internetwork that is set up by connecting a number of local area networks through routers. The Internet is an example of a WAN.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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