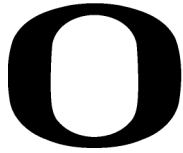


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Best Practices in IoT Implementations at Small Commercial Service Airports

CAPSTONE REPORT

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Abstract

The Internet of Things (IoT) is transforming the passenger experience and operational efficiencies at commercial service airports. Strategies and tactics employed to implement IoT infrastructure have direct impacts on successful decision-making processes and risk mitigation, especially at small hub airports. This paper identifies best practices in IoT in the aviation industry over the past five years. Airport executives and IT managers can benefit from this work to create business value within their organization.

Keywords: Internet of Things, IoT, passenger experience, operational efficiencies, airport, small airport, small hub airport, regional airport, smart airport

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Introduction to the Annotated Bibliography

Over the past decade airports, already leaders in innovation, have been early adopters of new technologies connected to the emergence of the Internet of Things (IoT) (Zmud et al, 2018). For the purposes of this research, the Internet of Things is defined as “a system of physical objects that can be discovered, monitored, controlled or interacted with by electronic devices which communicate over various networking interfaces, and eventually can be connected to the wider Internet” (Guinard & Trifa, 2016, p. 5). Numerous proprietary and costly new technologies have been adopted by airports, first in Europe, and more slowly in the United States (Molina, Olivares, Palau, & Esteve, 2018). Many times the implementation of IoT technologies has taken the form of limited trials or pilot programs in an effort to test these new technologies in an active airport operation, but also as a way to ferret out the system hardware and software that are the easiest to implement “without placing undue strain on IT budgets” (Vogel, 2016, p. 33).

How to best select and implement the emerging IoT platforms integrated with the architecture of the Web of Things (WoT) is an industry-wide challenge at airports of all sizes (Zmud et al., 2018). For the purposes of this research, the Web of Things is defined as architecture which enables information technology (IT) professionals to “reuse and leverage readily available and widely popular Web protocols, standards and blueprints to make data and services offered by objects more accessible to a larger pool of (Web) developers” (Guinard & Trifa, 2016, p. 6). Stakeholder engagement is crucial in implementing IoT at small airports (Zmud et al., 2018). “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” for IT projects (Elliot, Chapman, & Kelly, 2015). Understanding the technology, knowing how to evaluate platform interfaces, and making smart decisions about where to invest limited IT funds are paramount to successfully leveraging IoT to support an

airport's and associated stakeholder's strategic goals (Zmud et al., 2018). Especially for small airports, "intelligent investment is crucial to seeing ROI from digital initiatives" (Lamb, 2018).

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 (Zmud et al, 2018, p. 60).

Despite constrained budgets, airports will have to adapt to the changing technological landscape, as noted in a study produced in a partnership between University of Cambridge researcher Karen Lamb and the Centre for Digital Built Britain (2012). The study cites a previously published report by Amadeus, an aviation research consultancy firm, which provides a vision of a technology and service ecosystem.

The long-term challenge is to evolve sustainable ecosystem models where airlines, airports, ground handlers, concessionaires and other key stakeholders work together, bearing an equitable share of the costs and receiving fair returns (as cited in Lamb, 2012, p. 13).

A Massachusetts Institute of Technology (MIT) Sloan Management Review study on how IoT is influencing management practices found that "deriving business value from the Internet of Things is as much about managing relationships as it is about device management" (Jernigan, Ransbotham, & Kiron, 2016). Some of the key findings of this report include:

- The Internet of Things is not just about connecting things, but is also about the connections that it creates between an organization and its customers, suppliers, and competitors;
- Creating business value from the Internet of Things is strongly associated with sharing data with other organizations; and

- Unlike many IT projects, increasing the size of IoT projects can lead to diseconomies of scale (Jernigan et al., 2016, p. 4).

Thus, unlike traditional software-focused IT projects that scale up for relatively low cost, “each additional [IoT] device may bring considerable ongoing maintenance costs” (Jernigan et al., 2016, p. 9). Jernigan et al. (2016) also note that stakeholder engagement may involve just as much challenge as maintaining the expanding IT infrastructure. The report concludes with the advice that “managers should consider developing the following three key factors at an early stage of their [IoT] projects: a strong analytics capability; sharing data; and preparing customers for an ongoing business relationship with their IoT devices” (Jernigan et al., 2016, p. 13).

This research paper attempts to gather relevant articles to answer the question of what best practices in implementing IoT at regional airports offer the most efficient and cost-effective outcomes to achieve the major objectives of enhancing the passenger experience, improving operational efficiencies, and creating business value.

Problem Description

IoT is noted by some as a disruptive technology and by others as transformative, but adapting to and harnessing this emerging technology is critical to the success of businesses and other organizations, including airports (Vogel, 2016). Those who do not adapt to and harness IoT run the risk of losing competitive advantage and becoming *uberized* (Vogel, 2016), defined as “to change the market for a service by introducing a different way of buying or using it, especially using mobile technology” (Uberize, 2018). Businesses that do not leverage the opportunities afforded by IoT run the risk of losing the ability to compete in markets that have been transformed by their competition’s use of IoT (Vogel, 2016).

Airports that do not keep up with expected technology enhancements run greater risks of not achieving strategic differentiation and potentially inducing increased passenger leakage; this

point is especially true for small hub airports in proximity to large hub airports (Zmud et al., 2018). For the purposes of this study strategic differentiation is defined as “an improvement in customer experience or a more differentiated product” (Zmud et al., 2018) and passenger leakage is defined as an air traveler who utilizes an out-of-region, large hub airport rather than the local small hub airport, typically by driving (Ryerson & Kim, 2017).

Air transportation has long been the dominant mode for transcontinental and intercontinental travel and “is becoming more competitive for shorter trips in many regional markets” (Bowen & Rodrique, 2017, para. 10). In tandem with this growth has come innovation (Bouyakoub, Belkhir, Guebli, & Bouyakoub, 2017). “The use of technological solutions in Airports aims to cope with the increasing growth in passenger numbers, but also to improve the passenger experience” (Bouyakoub et al., 2017, para. 2). The issue of what hardware and software airports should choose is not so much about proving the added value of these new technologies, but rather trying to accurately predict which tools and platforms will ultimately prevail in a vast marketplace (Molina et al., 2018). Leveraging current and emerging technologies and the application of IoT is even more challenging for small, regional airports (Zmud et al, 2018).

One example of the challenges airports face when leveraging current and emerging technologies and applying IoT is in trying to determine which system to install for geolocation services inside a terminal building, which encompasses providing a platform for applications; offering cloud-enabled digital maps; and enabling wayfinding and push notifications from the airport, airlines, or vendors directly to passengers’ smart devices (Molina et al., 2018). Platform choices include beacons that receive location data from nearby Bluetooth-enabled devices or Apple’s developing Geolocation application program interface (API), which integrates the Global Positioning System (GPS) latitude and longitude coordinates data on mobile devices with

wireless (Wi-Fi) networks in designated indoor locations (Molina et al., 2018). There are numerous factors to consider with both types of systems, including connectivity challenges, dead zones, bandwidth requirements, the maintenance logistics of software and hardware updates, and security considerations (Molina et al., 2018).

Success or failure in leveraging IoT to meet strategic objectives will ultimately be determined by which IoT platforms elevate to become the predominant choice in the marketplace (Molina et al., 2018). For small airports that have limited IT budgets and are likely not attracting pilot program partnerships with vendors to test new technologies, making the right choices in investments is critical to the economic feasibility and successful implementation of IoT in a *smart airport ecosystem*, defined as the synergy between advances in travel technology and key aspects of the airport management structure (Reinventing the Airport Ecosystem, 2012, p. 5).

Purpose Statement

The purpose of this research is to identify best practices in the implementation of integrated IoT systems to enhance the air transportation passenger experience at small hub airports. A small hub airport is defined as an airport that has least 0.05%, but less than 0.25% of annual passenger boardings of flights in the United States (FAA Airport Categories, 2016). This study will assist small airport directors, airport services managers, and technology managers in identifying and evaluating IoT technologies, including integrated GPS, Wi-Fi, and beacon infrastructure and systems to enhance the passenger experience. The method of inquiry will be an analysis of selected peer-reviewed journal articles, recognized conference proceedings, government sponsored research reports and synthesis of practice, and white papers from reputable professional organizations. The objective of identifying IoT implementation best practices is to identify strategies for small hub airport operators and other stakeholders to

leverage current and emerging IoT technologies within the airport environment (Zmud et al, 2018).

Research Questions

Main question. What best practices have been identified in the implementation of integrated IoT systems to enhance the passenger experience and operational efficiency at commercial service airports?

Sub-questions. What strategies have been successfully utilized in developing decision-making processes to guide the implementation of these IoT technologies? What tactics have been identified to mitigate risk in IoT implementations within the common budget constraints of small hub airports?

Audience

Disruptive innovations are forcing the hand of the aviation industry to respond to and leverage developing technologies like machine learning, defined as “the ability of computer systems to improve their performance by exposure to data, without the need to follow explicitly programmed instructions” (Zmud et al., 2018, p. 72); artificial intelligence (AI), defined as “the theory and development of computer systems able to perform tasks that normally require human intelligence” (Zmud et al., 2018, p. 70); and IoT (Alghadeir & Sakran, 2016). As noted in an article published in the International Journal of Geo-Information, personalization is of key importance in the field of tourism by “adapting products according to users’ values, motivations, lifestyle, beliefs, behavior, attitudes, or needs” (Manrique-Sancho, Avelar, Iturrioz-Aguirre, & Manso-Callejo, 2018, p. 3).

This study addresses this transformation and is intended for use by several segments of the aviation industry, including small hub airport operators, concessionaires, and airline partners. Most small airport operators do not have a dedicated IT staff person and instead rely on the

airport sponsor organization for basic information services support (Zmud et al., 2018). An airport sponsor is defined as a “public agency or tax-supported organization such as an airport authority, that is authorized to own and operate the airport, to obtain property interests, to obtain funds, and to be able to meet all applicable requirements of current laws and regulations both legally and financially” (FAA Airport Compliance Manual, 2009). The championing of new technologies is most often lead by those members of an airport management team who want to address specific passenger processing and customer service challenges and have a passion for innovation (Zmud et al., 2018). This research topic is of interest to all airport management professionals who are decision makers in the realm of airport IT, including small airport directors, airport services managers, and technology managers. This study will serve as a resource to industry colleagues who are researching IoT technologies for their airports and may use the results of the study to review best practices, establish decision-making processes, and streamline implementation of IoT technologies at their airports.

Search Report

Search strategy. My search strategy for this study started with an extensive search utilizing Google Scholar for academic articles using the keywords *Internet of Things*, *IoT* and *airport*. From the results I gleaned additional keywords from each article and added *Web of Things*, *passenger experience*, *smart airport*, *small airport*, and *regional airport*. I used these keywords to perform searches utilizing UO Libraries Research Guides and Databases, accessing the most recent articles first, and focusing on keywords in articles. I determined from initial search results that the most timely and relevant articles were included in the narrow date range of 2014 to 2018. Narrowing my search further, I selected filters to include only peer-reviewed and full-text articles.

Libraries, databases, and search engines. I utilized the following UO Libraries research guides and databases for the majority of my searches:

- Computer & Information Science Research Guide,
- Association for Computing Machinery (ACM) Digital Library,
- Institute of Electrical and Electronics Engineers (IEEE) Xplore,
- Academic Search Primer,
- CiteSeer,
- Web of Science,
- MathSciNet, and
- WorldCat.

I utilized the following search engines during my search for sources:

- UO Libraries Quick Search (LibrarySearch),
- Google Scholar, and
- Airport Cooperative Research Program database.

Key Terms. I used narrowly focused search terms, quotation marks, the Boolean word *and*, and keywords and combinations of words to search for sources. The list of key terms I used in my search includes:

- Internet of Things,
- Web of Things,
- Airport,
- Passenger experience,
- Smart airport,
- Small airport, and

- Regional airport.

Documentation Strategy. I utilized the online Zotero collection tool in reference collection, including the Digital Object Identifier (DOI) reference metadata when available, then exported and reformatted the reference for use in the Annotated Bibliography and Reference sections. I downloaded full text articles in portable document format (PDF) and stored them in categorized folders. I utilized a Microsoft Excel file to log entries for each article including the information needed for references as prescribed by the Publication Manual of the American Psychological Association (APA) (2010), abstracts, keywords, and source information for accessing articles.

Reference Evaluation Criteria. This report includes a systematic review of studies that are related, but not similar in research design, providing diversity in the evidence base. The evaluation criteria are guided by the University of Florida's Center for Public Issues Education *Evaluating Information Sources* (2014) guide, including five characteristics to consider: authority, timeliness, quality, relevancy, and lack of bias.

- **Authority.** I determined authority for only those sources obtained from peer-reviewed journals, current books, recognized conference proceedings, and reputable professional organizations.
- **Timeliness.** I included publications between 2014 and 2018 for review, but gave additional weight to more recent sources. Articles published before 2014 were too dated to include as relevant in addressing the emerging technologies of IoT.
- **Quality.** I considered writing standards that demonstrate accuracy in grammar, spelling, punctuation, and organization in reviewing the quality of each document.
- **Relevancy.** For the purpose of this study, I determined the relevancy of sources by requiring that each article included in this paper presented the narrow topics of

IoT at airports as the main focus. My evaluation criteria also included a review each article's contribution to the focus of my topic and whether each idea, quote, case study, or concluding statement contributed in a significant way to my report.

- **(Lack of) bias.** I reviewed each author's or organization's credentials to affirm non-biased presentation of the material in each book, article, conference proceeding, or white paper. White papers from recognized industry research firms, whose authority has been established by esteemed academic institutes such as the University of Cambridge or peer-reviewed journals, have also been accepted for utilization in this study on a limited basis.

Annotated Bibliography

Introduction to the Annotated Bibliography

This Annotated Bibliography includes 15 peer-reviewed articles that defined research into best practices in the implementation of integrated IoT systems at commercial service airports. These references were compiled as the most relevant and timely examples to provide airport directors, airport services managers, and technology managers with strategies in developing decision-making processes and tactics to mitigate risk in the implementation of IoT technologies. These references are arranged into three categories: (a) background and supporting references for IoT and the passenger experience, (b) background and supporting references for operational efficiencies to be gained with IoT, and (c) supporting references for creating business value through the use of IoT.

Each reference contains the following features: (a) an APA citation, (b) an abstract, and (c) a summary. While many of the articles selected are highly technical, the focus of the summaries is based on a high-level understanding of IoT at airports. This focus provides accessibility of the information to airport managers while noting where additional technical information can be found for technology managers. All of the abstracts are presented as published by the authors. The summaries are the work of the author of this research paper; however, the content presented in the summaries is based upon the work of the authors of the selected articles.

Background and Supporting References for IoT and the Passenger Experience

Alghadeir, A., & Al-Sakran, H. (2016). Smart airport architecture using internet of things.

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(IJRCST), 4(5), 148-155. Innovative Research Publications. Retrieved from

http://www.ijrcst.org/DOC/6_IRP5163f09b717-c1df-42c0-ada9-a38fa1f3bfe0.pdf

Abstract. The future vision of internet is to connect everything, such as connecting things like transportation networks, communication networks, etc. Each of the entities will be connected through a network framework that will let all channels interconnect and communicate with each other in an easy mode. This will further turn into a good source of motivation for integrating a more efficient transport system. By employing the proposed architecture in this research paper, the airports can be transformed into smart airports with the integration of Radio Frequency Identification (RFID) technology and Internet of Things (IoT) which will allow all concerned an immediate access to relevant information about various operations required by the travelers and employees and make use of the smart airport facilities. It will ensure better efficiency and effectiveness of all the operations of smart Airport services. As a result, departures, arrivals, luggage delivery and welcoming visitors - everything will be handled in a smart way with the help of proposed architecture. Smart airport technology will lead to many innovations in the aviation sector, which in turn will increase the efficiency and productivity of the entire airport management system. This architecture will provide personalized services and content to different travelers at the airport and makes sure that each and every traveler who enters the airport will get the ultimate customer experience and satisfaction.

Summary. This research paper proposes a system architecture that integrates radio-frequency identification (RFID) and IoT to transform airports into smart facilities. RFID is used to transmit signals wirelessly, without the need for physical gadgets, to track movable object. The authors assert that RFID and IoT technologies can transform airports into smart facilities using the proposed architecture, which features a passenger with a smart device, a mobile application, and kiosks. The kiosk enables passengers to

change preferences and print boarding passes and luggage tags, an RFID reader system is used to track bags linked to each passenger, the mobile application is used to verify payment, and Google Maps is used to track passenger location.

A literature review section provides an overview of other IoT implementations currently in use at airports, including sensors embedded in runway pavement and logistics technologies in airport parking lots. The authors state that the proposed smart airport architecture holds promise in improving services by creating the ability to provide personalized services for individual passengers; realizing greater efficiencies, as the demand for air transportation increases due to global population growth, in the form of optimized processes and improved passenger flow; and ensuring that the top investment priorities of passengers, operations, and baggage handling are executed successfully.

The authors recognize challenges in integrating different applications and operating systems, including several new technologies not yet vetted as viable IoT-integrated technologies, like RFID. However, through the proposed *smart airport architecture* the authors assert that these challenges can be overcome. The IoT architecture layers include the physical layer of IoT utilizing Ethernet, Wi-Fi, mobile devices, and fiber; the network layer providing the connection between devices; and the application layer of IoT utilized by system applications and mobile applications. The authors conclude that the use of RFID technology with IoT will enable new form of communications to carry out various operations with ease of use. This study was developed outside of the United States, but the solutions and technology in the article are not country-specific, and it is specific to the focus of my research into IoT and airports. This article is relevant in my research by identifying successful strategies in the deployment of passenger tracking technologies at airports.

Hussein, D., Han, S.N., Lee, G.M, Crespi, N., & Bertin, E. (2016). Towards a dynamic discovery of smart services in social internet of things. *Computers and Electrical Engineering*, 58 (2017), 429-443. <https://doi.org/10.1016%2Fj.compeleceng.2016.12.008>

Abstract. The paradigm of the Social Internet of Things (SIoT) boosts a new trend wherein the connectivity and user friendliness benefits of Social Network Services (SNS) are exhibited within the network of connected objects, i.e. the Internet of Things (IoT). The SIoT exceeds the more traditional paradigm of IoT with an enhanced intelligence and context-awareness. In this paper, a novel service framework based on a cognitive reasoning approach for dynamic SIoT services discovery in smart spaces is proposed. That is, reasoning about users' situational needs, preferences, and other social aspects along with users' surrounding environment is proposed for generating a list of situation-aware services which matches users' needs. This reasoning approach is then implemented as a proof-of-concept prototype, namely Airport Dynamic Social, within a smart airport. Finally, an empirical study to evaluate the reasoning approach's efficiency shows improved services adaptability to situational needs compared to common approaches proposed in literature.

Summary. This research study proposes a new service discovery framework utilizing the social internet of things (SIoT); the new framework is named by the authors as the *dynamic social structure of things* (DSSoT). In developing the new framework, the authors note that the biggest current challenges in IoT are the management of large numbers of disparate devices, communication protocols, and deployment goals. Their new framework is made up of two kinds of contextual data types, objective and subjective, and the authors apply this combination to achieve situational awareness in smart environments. The authors define situational awareness as a decision-making approach

that combines the objective context, or the physical environment, with the subjective context, or the social aspects of relationships and preferences (Hussein, Park, Han, & Crespi, 2015). Combining situational awareness in smart environments allows for dynamic services discovery in smart spaces “in which smart objects become exposed to the Web, allowing command and control-based interactions with people and other objects” (Hussein et al., 2015, p. 12).

The authors developed a proof-of-concept prototype application for this study, called the Airport Dynamic Social, which was meant to realize DDSOT in a smart airport environment through sensors at check-in counters and boarding gates, on flights, and in smart vending machines. In applying the Airport Dynamic Social service examples in their experiments, the authors came to several conclusions. First, SIoT exceeded the paradigm of the more traditional model of IoT, with improved intelligence and context-awareness. User-friendliness and connectivity were also determined to be more effective under the SIoT model. The new service discovery framework in this empirical study, DSSOT, provided improved levels of service adaptability that were achieved by the proposed cognitive approach compared to lower levels of service adaptability provided by the location-based reasoning approach found in previous literature.

This study is relevant for my research because the authors identify a new and successful strategy to implement location-based IoT applications in an airport environment, with an enhancement utilizing the social internet of things, to bolster the resulting improved passenger experience.

Jeon, K.E., She, J., Soonsawad, P., & Ng, P.C. (2018). BLE beacons for internet of things applications: Surveys, challenges, and opportunities. *IEEE Internet of Things Journal*, 5(2), 811-828. <https://doi-org.libproxy.uoregon.edu/10.1109/JIOT.2017.2788449>

Abstract. While the Internet of Things (IoT) is driving a transformation of current society toward a smarter one, new challenges and opportunities have arisen to accommodate the demands of IoT development. Low power wireless devices are, undoubtedly, the most viable solution for diverse IoT use cases. Among such devices, Bluetooth low energy (BLE) beacons have emerged as one of the most promising due to the ubiquity of Bluetooth-compatible devices, such as iPhones and Android smartphones. However, for BLE beacons to continue penetrating the IoT ecosystem in a holistic manner, interdisciplinary research is needed to ensure seamless integration. This paper consolidates the information on the state-of-the-art BLE beacon, from its application and deployment cases, hardware requirements, and casing design to its software and protocol design, and it delivers a timely review of the related research challenges. In particular, the BLE beacon's cutting-edge applications, the interoperability between packet profiles, the reliability of its signal detection and distance estimation methods, the sustainability of its low energy, and its deployment constraints are discussed to identify research opportunities and directions.

Summary. This article is a survey of the development of Bluetooth low energy (BLE) and its influence on emerging IoT technologies and applications. BLE beacons have been utilized in several IoT innovations aimed at improving the customer or user experience, including indoor localization, and tracking. Indoor localization is defined by the authors as similar to outdoor localization utilizing the global positioning system (GPS), which has been found to be ineffective in indoor environments and on high building density city streets due to signal fading. The authors focused their paper on detailing different applications and features of beacons, including protocol design, Bluetooth signal characteristics, hardware components, casing designs, and software

development, with a goal of identifying an interoperable, easy-to-deploy and scalable IoT solution.

The BLE beacon applications section focuses on localization, including a note that a BLE signal may suffer attenuation in crowded areas like airports. The authors cite Gatwick International Airport's system as one example of the use of BLE beacon applications, which combines augmented reality (AR) technology with a BLE beacon-based localization system to enhance the passenger experience. AR is defined as an extension of virtual reality (VR); where VR seeks to replace the real world, AR adds information to the reality by adding computer generated images to the viewing of real scenes (Chiu & Lee, 2018). Other topics addressed in the BLE beacon applications section include proximity detection and interaction, activity sensing, and future applications. The BLE protocol and radio frequency (RF) signal characteristics, BLE beacon hardware, and software and system for BLE beacon sections are highly technical, but contain relevant information for technology managers.

The authors note several challenges and opportunities in the study, including the interoperability between the two major BLE beacon protocols: iBeacon by Apple and Eddystone by Google. Another challenge of the hardware the authors identified is the limited power source and short battery life of BLE beacons. Challenges of the software and system include the need for battery monitoring, difficulties in achieving accurate distance estimates due to unstable BLE signals, system scalability issues regarding network request data capacity, and security issues regarding the possibility of a beacon device being removed, relocated, or cloned. The authors conclude that even with these challenges, the affordability and flexibility to potentially host numerous types of IoT applications makes further investigation of BLE beacons worthwhile. This study is

relevant in my research because the authors identify successful strategies in the implementation of BLE beacons at airports.

Lin, Y., & Lin, C. (2018). An interactive real-time locating system based on Bluetooth low-energy beacon network. *Sensors*, *18*(5). MDPI. <https://doi.org/10.3390/s18051637>

Abstract. The ubiquity of Bluetooth-enabled smartphones and peripherals has brought tremendous convenience to our daily life. In recent years, Bluetooth beacons have also been gaining popularity in implementing a variety of innovative location-based services such as self-guided systems in exhibition centers. However, the broadcast-based beacon technology can only provide unidirectional communication. In case smartphone users would like to respond to the beacon messages, they have to rely on their own mobile Internet connections to send the information back to the backend system. Nevertheless, mobile Internet services may not be always available or too costly. In this work, we develop a real-time locating system based only on the Bluetooth low energy (BLE) technology to support interactive communications by combining the broadcast and mesh topology options to extend the applicability of beacon solutions. Specifically, we turn the smartphone into a beacon device and augment the beacon devices with the capability of forming a mesh network. The implementation result shows that our beacon devices can detect the presence of specific users at specific locations, and then the presence state can be sent to the application server via the relay of beacon devices. Moreover, the application server can send personalized location-based messages to the users, again via the relay of beacon devices. With the capability of relaying messages between the beacon devices, it would be convenient for developers to implement a variety of interactive applications such as tracking VIP customers at the airport, or tracking an elder with Alzheimer's disease in the neighborhood.

Summary. This research study focused on integrating BLE-enabled smartphones and IoT infrastructure by designing an interactive real-time locating system using beacons. The authors note several low-power wireless communication protocols that have been standardized for IoT including BLE, ZigBee, Wi-Fi HaLow, and LoRa. These protocols differ in short-range or long-range communication, but share a common purpose of having the lowest possible battery draw to extend the lifetime of these IoT devices. Connectivity however is not equal, with BLE being the only protocol universally supported by nearly all smartphones. The authors therefore focused their experiments utilizing the BLE protocol. The authors provided a use case as a framework for the study that employees the traversing of a passenger through an airport, from the parking area to the airline gate, utilizing geolocation, push notifications, and real-time communication.

A related work section provides a review of literature in the field of BLE-based locating systems and applications and existing implementations of Bluetooth mesh networks. For the purpose of this study, a Bluetooth mesh network is described as combining the broadcast and mesh topologies in the BLE network to serve as an infrastructure for interactive applications such as a real-time locating system. The system design section is highly technical, but may be useful to technology managers to better understand the system architecture, the principle of operation, and the design of messages in the beacon network.

The authors present several key findings and challenges in the implementation of and experiments with utilizing the BLE mesh prototype system. Limitations were noted in the communication range of Bluetooth beacons. The authors determined that in deployments in large buildings like airports Bluetooth devices with stronger output power or external antennas should be chosen to increase the radio coverage; these devices, along

with proper line-of-site placement, improve transmission quality. Problems resulting from interference from Wi-Fi may be alleviated when commercial Bluetooth 5.0 chips are utilized in beacons. Dividing larger spaces with multiple mesh routers alleviates long response times between smartphone and server. With these fine tunings of the prototype system, the authors believe their interactive locating system has the potential to provide an improved passenger experience. This study is relevant in my research by identifying successful strategies in the implementation of interactive, real-time locating systems in airports.

Molina, B., Olivares, E., Palau, C.E., & Esteve, M. (2018). A multimodal fingerprint-based indoor positioning system for airports. *IEEE Access* 6 (2018): 10092–106.

<https://doi.org/10.1109/ACCESS.2018.2798918>

Abstract. Indoor localization techniques are becoming popular in order to provide a seamless indoor positioning system enhancing the traditional GPS service that is only suitable for outdoor environments. Though there are proprietary and costly approaches targeting high accuracy positioning, Wi-Fi and BLE networks are widely deployed in many public and private buildings (e.g. shopping malls, airports, universities, etc.). These networks are accessible through mobile phones resulting in an effective commercial off-the-self basic infrastructure for an indoor service. The obtained positioning accuracy is still being improved and there is ongoing research on algorithms adapted for Wi-Fi and BLE and also for the particularities of indoor environments. This paper focuses not only on indoor positioning techniques, but also on a multimodal approach. Traditional proposals employ only one network technology whereas this paper integrates two different technologies in order to provide improved accuracy. It also sets the basis for combining (merging) additional technologies, if available. The initial results

show that the positioning service performs better with a multimodal approach compared to individual (monomodal) approaches and even compared with Google's geolocation service in public spaces such as airports.

Summary. This article presents the results of a study to determine whether using both Bluetooth Low Energy (BLE) and Wi-Fi networks utilizing fingerprinting provides significant improvement in indoor positioning systems for large public spaces, including airports. Fingerprinting is a data processing technique that uses a location calibration grid, or radio map, coupled with the location of a user estimated by comparing real-time data with the radio map. The authors assert that multimodality, or combining different types of indoor positioning technologies, is gaining acceptance as the best approach to increase the accuracy and reliability of indoor positioning systems. While indoor accuracy of multimodal networks is assessed as good in controlled environments, in large busy spaces like airports, a more robust indoor positioning system is needed to perform well.

The authors provide a synopsis of related work focused on radio-frequency (RF) based techniques, including the Global Positioning System (GPS), wireless local area networks including Wi-Fi and BLE, and radio-frequency identification (RFID) localization. They also provide a system architecture, including detailed information on maps service, points of interest (POIs), and indoor location positioning. Their performance evaluation section revealed success in testing at two international airports, with the BLE and Wi-Fi fingerprinting indoor service outperforming Google's geolocation plugin. The authors identified a shortcoming in the study as Wi-Fi signal variability, which provided inconsistent results.

The authors conclude with several key findings: Wi-Fi is not accurate enough for indoor location when used as a singular technology, combining multiple technologies increases accuracy and reduces the effects of signal variability, using both 2.4 GHz and 5 GHz Wi-Fi bands helps to mitigate signal strength variability and improve accuracy, and high passenger density areas require more BLE beacons to provide a tighter fingerprinting grid. This article is relevant in my research by identifying successful strategies in the deployment of passenger tracking technologies at airports.

Wang, W., Cole, S.T., & Chen, J.S. (2017). Tourist innovation in air travel. *Journal of Travel Research*, 57(2), 164-177. SAGE. <https://doi.org/10.1177/0047287516686724>

Abstract. This essay explores the recent phenomenon associated with tourists' adaptability to new services driven by technologies and proposes the concept of tourist innovation as the theoretical underpinnings describing tourists' adaptability to novel services. To glean the underlying concept of tourist innovation, a series of in-depth personal interviews are deployed. An online survey containing 40 indicators representing the innovation dimensions is distributed that gathers 524 useable responses from air travelers. In the data analysis, a parsimonious model derived from a confirmatory factor analysis validates a four-dimensional solution: (1) novelty seeking, (2) vigilance, (3) hedonic experience seeking, and (4) social distinctiveness. This scale is explained by 10-item tourist innovation measurement, wherein the validity of the resultant scale is achieved.

Summary. The authors perform a research study to examine tourist adaptability to technology-driven services, or *tourist innovation*, with an aim to explore tourists' adaptability to new services driven by technology. An innovative tourist is defined for this study as one who demonstrated a high propensity to use progressive information

technology to learn about a destination and manage services at or in relation to tourism settings. The authors assert this study is the first of its kind to conceptualize tourist innovation, unveiling underlying dimensions of tourist innovation, which may in turn allow marketers to better understand the mindset of innovative travelers and anticipate their needs accordingly.

A literature review provides an overview of previous work in the conceptualization of consumer innovation, measurements of consumer innovation, and the conceptual model of tourist innovation. The study was conducted in an air service setting, using an airport navigation application that included information on more than 1,000 airports worldwide and featured information on gate locations, flight changes, weather, and luggage status. The research method included qualitative interviews, conducted via on-site personal interviews and focus groups, to collect opinions from local hospitality managers, residents, and college students at a large Midwestern university. A discussion in the findings section provides an overview of the survey instrument and sample selection, scale validation, model, and hypotheses testing and predictive validity. A limitation of the study is identified in the research design and data collection process as the utilization of online surveys as the primary data collection method, which may result in a low response rate.

The authors provide several key findings in this study. Three of four dimensions tested were found to be valid descriptors of why travelers may be more influenced by tourist innovation: (a) hedonic experience seeking, or those for whom acquiring new products makes them happier, or using new products gives them a sense of personal enjoyment; (b) novelty seeking, or those who are eager to try new products, are curious about trying products they have never used, or enjoy trying unusual products; and (c)

social distinctiveness, or those who enjoy using new products that make them a visionary leader, to stand out among friends, or that distinguish them from others. Another key finding is predicting the causal relationship between tourist innovation and behavioral intention, with several factors at play: relative advantage, compatibility, and complicity.

The authors note several practical implications that could be applied in marketing new tourism products and services, including: (a) striving for new designs and promotions that highlight the best features in travel products, (b) incorporating excitement, fantasy, and happy moods in hedonic-based travel product marketing, and (c) using this study's measurements to segment consumer markets by using tourist innovation to predict behavior intentions. Finally, the authors detail service innovations as operationalized in a new airport navigation application, that provides airlines with information about the flights they operate and the airports and cities they serve. This research paper is relevant in my study because it identifies strategies to address tourists' adaptability to new services driven by technology.

Background and Supporting References for Operational Efficiencies Gained with IoT

Bouyakoub, S., Belkhir, A., Guebli, W., & Bouyakoub, F.M. (2017). *Smart airport: An IoT-based airport management system*. Proceedings of the International Conference on Future Networks and Distributed Systems (ICFNDS '17), Article No. 45. Cambridge, United Kingdom. ACM: New York, NY. <https://doi.org/10.1145/3102304.3105572>

Abstract. The IoT vision enhances connectivity from “any-time, anyplace” for “any-one” into “any-time, any-place” for “any-thing”. Once these things are plugged into the network, more and more smart processes and services are possible which can support our economies, environment and health. On the other hand, Air transport has become one of the essential elements of globalization. Its development has been exponential for

decades, following the technological advances of aviation on one side, and the propensity of men to move on the other. With rapidly increasing traffic, the current logistics and infrastructure models of airports must inevitably evolve in order to adapt quickly and sustainably. To make the passenger journey more fluid, airports are increasingly using new technologies. In this paper, we propose an airport management system based on the IoT paradigm, where passengers, baggage, plane or the departure lounge are considered as “things”. Our smart airport management system aims to automate passengers processing and flight management steps, in order to improve services, facilitate airport agents’ tasks and offer passengers a pleasant and safe journey.

Summary. The authors of this paper propose a *smart airport management system* based on IoT with a goal of fully automating passenger processing and flight management systems to provide an improved passenger experience. The researchers performed a simulated test to determine whether the objectives set forth in the *smart airport management system* were achieved. The objectives were to show how common operational problems at airports, including lost baggage and slow passenger processing, can be addressed by automating those processes using IoT technologies. The article includes a review of related works, including the current use of biometrics to confirm the identity of those accessing the secure areas of airports, which has improved the security, efficiency, and facilitation of worker movement through the terminal.

The authors propose the creation of the smart airport by creating a management system that utilizes IoT. Each element of the airport operation, including the airline operations room, check-in desk, departure lounge, passengers, luggage, aircraft, and crew, is treated as an autonomous *thing* which can interact with other things within the system. The system architecture features three layers: the abstract layer, which defines

how each thing interacts and communicates with other things; the temporal layer, which describes the synchronization and the constraints of objects within the system; and the physical layer, which connects the things to the physical world. When these three layers are integrated through IoT, the authors conclude their objectives were met, resulting in economic and operating efficiencies by reducing the number of security personnel needed and increased safety controls by providing full control of passengers in each stage of transit. This article is relevant to my research by identifying means of obtaining operational efficiencies and increased safety controls at airports through the use of IoT.

Mayer, C., Felkel, R., & Peterson, K. (2014). Best practice on automated passenger flow measurement solutions. *Journal of Airport Management*, 9(2), 144-153. Retrieved from <https://www.henrystewartpublications.com/jam>

Abstract. The authors introduce a best practice paper recently published by the ACI World Airport IT Standing Committee on Automated Passenger Flow Measurement Solutions. The paper shows how this supplier-independent best practice paper is structured and what benefit it can provide to those who want to implement and use such solutions in terminal buildings. Therefore, some general characteristics of the solutions are given, as well as the typical influencing factors from technology, terminal layout and passenger behaviour. The paper is available on the ACI World website at www.aci.aero.

Summary. The scope of this paper is to determine best practices in passenger flow measurements, using technical solutions that do not require an opt-in mechanism, to aid in the selection of an automated passenger flow measurement solution. These solutions typically use data from existing passenger processes such as boarding pass scans, with terminal Wi-Fi infrastructure and mobile device connectivity. They measure flow without awareness by the passenger, but do not breach data privacy as they monitor

passenger movement through anonymized data. The authors of this study sought out best practices in the area of passenger flow measurement by using a framework that included several factors leading to a performance indicator (PI). For the purpose of their study, the authors defined a performance indicator as aggregated information in the context of passenger flow derived from raw data (RD) measured by a sensor. Raw data is defined as basic information measured by a sensor solution, which may include data collected through bar coded boarding pass scans, timestamps of Bluetooth and Wi-Fi signal strength peaks, or passenger counting devices utilizing thermal, infrared, or camera sensors.

The authors note that automated passenger flow movement solutions can be of value in improving efficiency and enhancing the passenger experience, but care must be taken when selecting the technical solution to achieve the best results for business value. The authors identify limitations of this study as typical error rates in the RD and the related effect on PIs and potential errors in the accuracy of sensors in the terminal environment; the authors advocate acknowledging these limitations to users of the PIs in order to manage expectations and achieve buy-in.

The study is broken into several sections including performance indicators, use cases, and influencing factors. The authors recommend giving consideration to several areas when implementing an automated passenger flow technology: (a) the solution architecture and the technology used, both sensor and software, including percentage of effective coverage in each space and whether the number of passengers in a defined area influences PI; (b) careful positioning of sensors, which can influence the quality of the measurement, by avoiding a mixture of different passenger streams in one observed area, ensuring that sensors are not blocked or compromised by doors or walls, and lighting

considerations are taken into account for visual sensors; and (c) passenger behavior and flow characteristics to account for anomalies, including high passenger flows, individual passengers entering or leaving the queuing area in the wrong direction, and movement of people in groups.

The authors conclude that automated passenger flow measurement solutions can be used to optimize airport processes and decision-making for stakeholders and at the same time improve the passenger experience through more personalized service. The result can be substantial financial and reputational gains for airport operators. This article is relevant to my research by identifying best practices in obtaining operational efficiencies through automated passenger flow measurement solutions.

Medhurwar, S., & Mishra, R. (2018). Emerging synergies between internet of things and social technologies. *Journal of Global Information Technology Management*, 21(2), 75-80.

<https://doi.org/10.1080/1097198X.2018.1462918>

Abstract. This essay discusses the phenomena of amalgamation of two prominent technologies: Internet of Things (IoT) and Social technologies. IoT devices are primarily used for connectivity between physical objects while Social technologies are responsible for collaboration and social interaction. The domain of Social Internet of Things (SIOts) points toward social interactions of IoT devices. This phenomenon will further enhance the collaboration capabilities of IoTs to deliver huge amounts of human–computer interactions with very limited interventions from humans. Thus, high degrees of human–computer interfaces can be created among physical objects by enabling them with human-like capabilities and social interactions. In this context, we discuss relevant research developments, contextually analyze the drivers and challenges of SIOts, and

describe some interesting business use cases along with suitable recommendations going forward.

Summary. This scholarly essay explores the drivers of growing synergies between IoT and social technologies including an analysis of state-of-the-art developments, the potential of these developing technologies, and implementation challenges, and a proposal for a way forward. The authors provide an historical background of IoT, WoT, and the social internet of things (SIoT), defined in their research as bridging the gap between real and virtual worlds through the integration-potential of IoT and social networks. The authors assert that the integration potential has been realized as the market penetration of mobile smart devices reaches the saturation point, driven by the social media generation, which demonstrates the emerging proximity of IoT and social technologies. The authors give as an example public spaces like airports where there is growing interest in coupling IoT devices with social analytics to personalize the passenger experience. The authors note that operational efficiencies can be realized by utilizing IoT devices like cameras coupled with video analytics to track passenger movement, provide trigger notifications of needed facility maintenance to airport staff smart devices, and inform passengers of security screening wait times and baggage status based on individual preferences, leading to optimal service delivery.

Challenges noted by the authors include the need for universal adoption of standards to provide seamless system interfaces; the authors note that currently the integration of IoT still relies on vendor or application specific methods. Another challenge is security concerns with the “everything connected to everything” vision and the need to protect passenger privacy. The authors raise the question of whether unabated investments in research into futuristic technologies are likely to continue, given fluid

economics and uncertainty in technology cycles. Specific to SIoT, the authors state that business use cases and more detailed research may be required to define tangible outcomes for future investments.

The essay concludes with consideration of the global implications of social and IoT technology convergence: facilitating communication, collaboration, and learning with initiatives that will spark further information technology research and lead to the pursuit of future digital business strategies. To achieve these benefits, the authors note that current practices in data management, analytics, and testing methods will need to be augmented to bring about coalescence of diverse technologies. This article is relevant to my research by identifying operational efficiencies that can be gained through SIoT and challenges that must be overcome to recognize these efficiencies.

Supporting References for Creating Business Value Through the Use of IoT

Curry, E., Derguech, W., Hasan, S., & Kourourpetroglou, C. (2018). A real-time linked dataspace for the internet of things: enabling “pay-as-you-go” data management in smart environments. *Science Direct*. Elsevier B.V. <https://doi.org/10.1016/j.future.2018.07.019>

Abstract. As smart environments move from a research vision to concrete manifestations in real-world enabled by the Internet of Things, they are encountering a number of very practical challenges in data management in terms of the flexibility needed to bring together contextual and real-time data, the interface between new digital infrastructures and existing information systems, and how to easily share data between stakeholders in the environment. Therefore, data management approaches for smart environments need to support flexibility, dynamicity, incremental change, while keeping costs to a minimum. A Dataspace is an emerging approach to data management that has

proved fruitful for personal information and scientific data management. However, their use within smart environments and for real-time data remains largely unexplored.

This paper introduces a Real-time Linked Dataspace (RLD) as an enabling platform for data management within smart environments. This paper identifies common data management requirements for smart energy and water environments, details the RLD architecture and the key support services and their tiered support levels, and a principled approach to “Pay-As-You-Go” data management. The paper presents a dataspace query service for real-time data streams and entities to enable unified entity-centric queries across live and historical stream data. The RLD was validated in 5 real-world pilot smart environments following the OODA (Observe, Orient, Decide, and Act) Loop to build real-time analytics, decisions support, and smart apps for energy and water management. The pilots demonstrate that the RLD enables incremental pay-as-you-go data management with support services that simplify the development of applications and analytics for smart environments. Finally, the paper discusses experiences, lessons learnt, and future directions.

Summary. This research paper introduces a new enabling platform for data management within smart environments called real-time linked dataspace (RLD). At a high level, RLD combines “pay-as-you-go” data management with dataspace services, linking data with entity-centric [IoT] real-time query capabilities. A dataspace is defined by the authors as an emerging data management architecture, a distinct approach in which data is integrated on an as-needed basis, reducing the initial effort to set up data integration by using matching and mapping generation techniques. The authors assert that real-world smart environments are fraught with challenges, including interoperability of legacy systems, meeting stakeholder expectations, and limited IT infrastructure budgets.

Dataspaces have shown promise for personal information and scientific data management, but use within smart environments and for real-time data remained largely unexplored until this study.

A related work section provides a synopsis of existing approaches to data sharing and management within smart environments. The scope of the author's report examines the data management requirements of smart energy and water management systems as a study of the practical data requirements of smart environments. The case studies were developed through five pilot projects, including a project at the Linate airport in Milan, Italy. The researchers performed a systems analysis focusing on the challenges and technical requirements of: (a) integrating multiple data formats and semantics by facilitating integration and sharing, ideally with open standards and non-proprietary approaches, (b) discoverability and access by allowing the organization access to datasets and metadata through a single location, and (c) data re-use and sharing in a low-cost, incremental manner, by enabling a low barrier to entry and establishing a low-cost "pay-as-you-go" structure in developing smart applications for the pilot programs.

The RLD architecture expands beyond the traditional dataspace approach by extending the dataspace support platform with real-time processing and querying capabilities. The result is a tiered approach to data management that can be expanded incrementally or on an as-needed basis, which in turn reduces implementation barriers and initial costs, creating business value. Key lessons from this study include: (a) an identified need for developer education in utilizing this dataspace data management approach; (b) incremental data management can support agile software development; (c) the importance of articulating the business case for RLD to justify investment in data infrastructure; and (d) integration with legacy data sources is a significant cost in smart

environments. Additional findings include: (a) significant cost savings can be achieved by avoiding unnecessary integration costs under the “pay-as-you-go” structure; (b) demonstrating the secure query service was essential for stakeholder buy-in; (c) physical access to secured areas of the airport posed additional challenges in maintaining IT infrastructure by making physical access to reboot or update systems difficult; and (d) engineering and operational challenges were identified in maintaining the different processing pipelines, which required a simultaneous effort to diagnose problems and faults on the system.

This article is relevant for my research because it provides an airport case study example of a new data management platform which may streamline implementation, foster cost-savings, and provide business value for investments in IoT technologies at airports.

Howell, C. (2016). Case studies in airport management: Big Data: Does it add to the bottom line? *Journal of Airport Management: an international journal*, 10(4), 326-333. Henry Stewart Publications. Retrieved from <https://www.henrystewartpublications.com/jam>

Abstract. In recent years technological advances have made large-scale data mining, analytics and forecasting solutions ('Big Data') less costly and more readily available to smaller institutions such as airports. This paper considers how Big Data can be utilised to enhance service and operations within an airport environment and whether using Big Data does in fact add to the bottom line, referencing case studies from Gatwick Airport. The paper suggests that, with the right combination of data analysis/data science capabilities in the organisation and the necessary alignment between operational, commercial and technology functions, Big Data does add to the bottom line, directly and indirectly, through automating decisions, embedding analysis in all functions for

decision-making support and enabling wider information flow and collaboration in many areas, one of which is the machine learning required to derive bottom-line value from the Internet of Things.

Summary. The author analyzes case studies from Gatwick Airport in determining how Big Data and IoT, when applied to small airports, enhance the flow of information and support for decision-making to improve passenger service, operations, and the bottom line. The author asserts that airports have the potential to capture data from multiple sources, including control systems for electricity, water, lighting, baggage belts, jet bridges, Wi-Fi, proximity card readers, and point-of-sale (POS) systems. These varied data sources, with the ability to gather real-time information, represent Big Data in airports.

The case studies analyzed included the development of an *airport collaborative decision making (A-CDM) programme* and the implementation of MyGatwick and GatwickConnects IoT passenger interface tools. The findings show improved sustainability efforts through more efficient use of utilities, efficiencies in passenger movement by facilitating a zero queue from curb to gate, and operational efficiencies through improved gate utilization. Other key lessons noted by the author include realizing the value of collaboration with stakeholders in leveraging Big Data and adding to the bottom line through improved operational efficiencies. This article contributes to my research by identifying business value created through the use of IoT at an airport.

Jernigan, S., Ransbotham, S., & Kiron, D. (2016). Data sharing and analytics drive success with IoT. *MIT Sloan Management Review*. Retrieved from <https://sloanreview.mit.edu/projects/data-sharing-and-analytics-drive-success-with-internet-of-things/>

Abstract. We found that obtaining business value using the connections the IoT creates between an organization and its customers, suppliers, and competitors depends on companies' willingness to share data with other organizations.

Summary. This research report discusses the findings from a global executive study focused on understanding the challenges and opportunities associated with IoT. The study involved a survey of business executives, managers, and IT professionals. In addition to analyzing the survey results, the authors conducted interviews with subject matter experts across several industries and drew upon several case studies to illustrate how organizations are using IoT. A key assertion by the authors from the survey results is that creating business value from IoT is as much about managing relationships with a wide range of stakeholders as it is about device management.

Other main findings from the research include: (a) IoT is not just about connecting things, but also about the connections that it creates between an organization and its customers, suppliers, and competitors; (b) creating business value from IoT is strongly associated with sharing data with other organizations; (c) companies with strong analytics capabilities are three times more likely to get value from IoT than are those with weaker analytics capabilities; (d) unlike many IT projects, increasing the size of IoT projects can lead to diseconomies of scale; and (e) general managers seem to underappreciate security issues that accompany device network growth.

The body of the report includes an analysis of several aspects of IoT related to expanding the value chain. The sections of the report most relevant to this annotated bibliography address *taking IoT projects to the next level* and *creating business value with IoT*. In the section on taking IoT projects to the next level, the concept of economies of scale are discussed. The authors assert that unlike traditional IT projects, where

variable costs are extremely low, each additional IoT device may bring considerable ongoing maintenance costs, potentially leading to a diseconomy of scale. The authors go on to state that when IoT evolves from a one-time transaction to a relationship with end users, that relationship requires management that defies seamless economies of scale. The section on creating business value with IoT includes a discussion on the intrinsic complexity of IoT and the increased analytics capabilities needed to be well-positioned as this technology evolves. The authors assert that gaining business value from IoT alone is not enough to stand out; extracting competitive advantage from IoT will require a combination of value, rarity, difficulty of imitation, and lack of substitutes for organizations to achieve differentiation in the marketplace. The survey and research in this report also indicate that relationship management is an important key to success with IoT.

This research paper is relevant for my research because it provides a business-value focus for the implementation of IoT across many industries, to include airports.

Lamb, K. (2018). Challenges of digitalization in the aerospace and aviation sectors. *Centre for Digital Built Britain*. (CDBB_REP_002). Cambridge, England: University of Cambridge. <https://doi.org/10.17863/CAM.26276>

Abstract. This report describes digital transformation in aerospace and aviation, and identifies some challenges that are likely to have parallels with the architecture, engineering and construction (AEC) sector. It begins with a discussion of drivers and innovation in these sectors, focusing on digital twin technology and Internet-of-Things (IoT). Several challenges have been identified that may provide some forewarning to the AEC sector as it moves into digital operation and integration. Data challenges, such as interoperability in systems-of-systems, pose the biggest technical challenge to both

sectors, followed by the security of those systems, where the risks posed by a breach are severe. The human factors discussed in the previous report are now separated into human factors in enterprises such as recruitment and change management, and social outcomes such as customer engagement. Finally, the role of regulation in digitalisation and the investment challenges facing these sectors are considered. The report concludes with an overview of the literature, including a bibliometric review.

Summary. This research report describes the digital transformation in the aviation industry, identifying challenges and opportunities in leveraging data to transform the passenger experience and boost return on investment (ROI) from digital initiatives. The author asserts that the aviation industry is highly competitive, but is generally more innovative in integrating data. The aviation sector already relies heavily on data sharing partnerships to facilitate a seamless journey, while ensuring a safe travel experience for passengers and safe handling of their data. A key challenge noted by the author is the need for the aviation sector to create intelligent platforms to anticipate customer needs that are not invasive or insecure. The report gives the example of London City Airport using sensors and networked data to enhance the customer experience, a multi-million dollar investment in an IoT framework focused on managing increasing passenger volume. An overview of the literature section provides a review of academic literature utilized in this report.

The body of the report addresses challenges and solutions in several broad categories including data challenges, security, human factors in enterprises, social outcomes, the role of regulation, and investment, with suggestions drawn from each area of focus listed at the end of each section. The sections chosen for review in this annotated bibliography include the sections on social outcomes and investment, as they are most

relevant to this study. The social outcomes section addresses how best to leverage a data-rich environment for customer engagement and wellbeing without being intrusive. Areas of consideration include: (a) customer engagement, with an example given of five dimensions of customer experience at airports including engagement, empowerment, being heard, being delighted, and being understood; (b) accessibility, including the implementation of assistive technologies that can be used by everyone, for example virtual reality wayfinding; and (c) trust, by empowering customers in how and where to share their data. Possible solutions the author offers include: (a) prioritizing human experience and trust from design and implementation to iteration; (b) sourcing data from a more representative range or population demographics to avoid biased algorithms; (c) informing customers of how you will use their data at the point of capture to foster a culture of transparency; and (d) capturing, analyzing and valuing qualitative data that tell individual stories about how technology is or is not making people's lives better.

The investment section addresses the increasing, yet necessary, cost of IT solutions and how intelligent investment is crucial to achieving ROI from digital initiatives. Possible solutions offered in this section include: (a) centering digital projects around empowered digital leaders and flexible teams that will focus on producing minimal viable products; (b) engaging in systems thinking; (c) setting targets for cost savings, operational efficiency, revenue growth and innovation, and then monitoring the results; (d) investing ahead of the business case; (e) being strategic about when to develop digital technology and when to go with ready-made, taking advantage of strategic partnerships; and (f) focusing on a small number of high-value digital initiatives. This report is relevant for my research because it provides recommendations for

improvements in passenger experience and creating business value through the use of IoT in airports.

Robinson, J. (2017). Passenger terminal development in the digital age. *Journal of Airport Management*, 11(4), pp. 355-368. Henry Stewart Publications.

Retrieved from <https://www.henrystewartpublications.com/jam>

Abstract. It is undeniable that we are in the midst of a digital revolution that holds the promise to reinvent the entire air travel experience. The 21st century is being defined by pervasive digitisation and is characterised by disruptive and transformative processes that are underway in virtually every industry. Digital trends such as (1) social media, (2) the sharing economy, (3) hyper-personalised connectivity and (4) the Internet of Things are already transforming travel. In addition, it is forecast that air travel demand will double in the next 15 years. This new digital age presents the opportunity to not only reinvent the travel experience, but also to develop solutions that result in cost-effective capital expenditure and optimise existing infrastructure. Unfortunately, there is a general lack of a coordinated mindset that puts the passenger first. The air transport sector needs to move away from the legacy of organisations that exhibit entrenched ‘tribalism’ and self-interest. Airports, airlines and government agencies need to collaboratively begin to identify and utilise the technological opportunities that are now becoming available. To achieve this will require a level of trust and sharing of data to even begin the process of innovation. Though digital solutions are being developed at an airport-by-airport level, to achieve any meaningful change in the global air travel system will require global solutions involving truly collaborative initiatives. This paper explores the opportunities and challenges faced by airport operators in redefining the passenger terminal aligned to the 21st century digital age.

Summary. This paper explores challenges and opportunities airport managers face in passenger terminal development in the digital age. The author asserts that digital disruption has impacted many industries, and the air travel sector is no exception. Coupled with the emergence of disruptive technologies, the continued rate of growth in the air travel industry will force changes in how airport operators plan for increasing demand. With construction of new passenger terminals at the scale needed becoming cost-prohibitive, the author lays out an argument for digital technologies that promise to improve the passenger experience while optimizing capital expenditures.

The author provides a review of digital technologies driving the reinvention of the passenger terminal, and emerging technologies in other industries that are anticipated to migrate into the aviation sector and transform the industry. Big Data, once it is fully leveraged by airport operators, is expected to help deliver an enhanced passenger experience while providing new opportunities for revenue enhancement. The author introduces the concept of the aviation digital ecosystem, which he asserts will be championed by early adopter airports and airlines, based on the principles of open source collaboration, which led by *hyper-personalisation* will change how the passenger terminal will operate. The key to this change is the establishment of a level of trust and sharing of data among sometimes adversarial entities: airports, airlines, and governmental agencies. It will require a shift in thinking from the consumer as a passive participant, to the passenger dictating needed innovation.

The author identifies impediments to this change including regulatory roadblocks in the form of inflexible procurement processes, the need to shore up privacy issues and bolster cybersecurity, the need for resiliency and redundancy in deploying innovative technologies, and required changes in corporate culture for both airports and airlines. The

author is focused on building business value from the application of new technologies and makes several recommendations, including ensuring the airport master planning process targets enabling technology solutions to optimize operational efficiency, using futuristic planning scenarios, and honing in on customer experience and revenue enhancement through digital means. Other recommendations include developing small pilot programs to manage risk while gaining an understanding of potential benefits of an innovation solution before making a major investment, striving for a few scalable solutions instead of many disconnected applications, and managing and analyzing data to drive the entire airport's business agenda.

This article is relevant for my research because it provides a look into the future *experience travel platform* that will drive the development of new services and products, leading to increased business value in the aviation industry.

Zmud, J., Miller, M., Moran, M., Tooley, M., Borowiec, J., Brydia, B.,...Gunnels, A. (2018). A primer to prepare for the connected airport and internet of things. *Airport Cooperative Research Program, Report 191*. National Research Council (U.S.), Transportation Research Board. The National Academies of Sciences. <https://doi.org/10.17226/25299>

Abstract. *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.

Summary. The purpose of this report is to provide guidance to airport operators and their stakeholders in understanding and implementing IoT at airports of all sizes. Drawing from a project panel made up of academic, aviation industry, and IT subject matter experts, the authors collected data for the primer from a literature review, stakeholder interviews, a stakeholder survey, and case studies. The authors assert that successful application of IoT at airports means tailoring solutions to individual airport's

specific business problems and that it is critical to identify up front what an IoT solution is meant to achieve. The authors note that IoT implementations are in the early stages of development at most airports, but have the potential to be transformative. Before this report there were no generally recognized practices for airport operators and their stakeholders to consider in determining how to best use IoT in an airport environment.

The body of the report includes a comprehensive study of several key areas of IoT relevant to this annotated bibliography. A high-level summary of each section follows, but airport directors, airport services managers, and IT managers at airports would benefit from reading the full report. The section on understanding IoT provides an overview of the history of IoT and a description of enabling technologies, including sensors, RFID tags, beacons, and Wi-Fi access points. Some sub-sections of the primer are highly technical, but would be beneficial for IT managers to review. The authors assert that improvements and advances in IoT technologies have accelerated in the past few years, but it is the connections between the technologies, referred to as the architecture, are key to how IoT creates business value. Three principal classes of benefits from IoT are recognized by the authors as operational efficiency, strategic differentiation, and new revenue. The research found that the majority of current airport uses of IoT focus on operational efficiency, while very few applications of IoT in airports provide strategic differentiation. New revenue opportunities represent the largest and most complex IoT solutions, but can build on existing solutions and also generate efficiency gains.

The section on discovering the impacts of IoT provides airport industry survey results and details the current state of IoT activities through several examples and case studies. The section on how to use IoT describes solutions categorized according to the passenger or operations experience and strategies for successful implementation of IoT,

including tying IoT objectives to airport goals to enable the business case for investment in IoT infrastructure and technologies and promote continued long-term investment in IoT. The authors define an extensive planning process, including stakeholder framework, journey maps, and a capability gap assessment. The authors caution that IoT is still an emerging technology that changes quickly, so building flexibility and agility into IoT projects is critical to successful implementation. An implementation checklist offers a path forward including: (a) selecting the IoT solution that supports your business goals, (b) determining the technical and organizational maturity needed to successfully implement the chosen solution, (c) assessing your current technical and organizational maturity, and (d) crafting an implementation roadmap to address the gaps between current and needed maturity. The report wraps up with a *what's next* section, anticipating the ways in which IoT will soon go beyond operational efficiencies and expand into solutions that enhance the customer experience or facilitate strategic differentiation at airports. The report is relevant for my research because it provides a comprehensive review of IoT in airports to improve the passenger experience, create operational efficiency, and create business value.

Conclusion

As airline passenger volumes continue to increase at a brisk pace, a trend that is anticipated to continue into the foreseeable future, airports of all sizes will need to find ways to accommodate this growth through efficiency in a cost-effective way (Bouyakoub et al., 2017; Lamb, 2018; Robinson, 2017). Building more concourses and terminals alone will not solve the problem (Robinson, 2017). Small airports especially will need to find smart ways to adapt, and the implementation of IoT will play a major role in accomplishing this necessity, despite budget constraints (Bouyakoub et al., 2017; Lamb, 2018). The articles selected for review in this annotated bibliography provide key findings, concluding recommendations, and identified best practices to guide small airport directors and IT managers in choosing the best options, and unanimous encouragement to invest now in IoT, in acknowledgement of future demands on the aviation industry.

IoT and the Passenger Experience

Using IoT to improve the passenger experience starts with system architecture that integrates multiple IoT components (Alghadeir & Al-Sakran, 2016; Bouyakoub et al., 2017; Molina et al., 2018). Over the past five years there have been increasing theoretical studies, case studies, and pilot programs to determine which components of IoT integrate to provide the best interoperability (Curry et al., 2018; Robinson, 2017; Zmud et al., 2018). The integration technologies evaluated in these studies range from RFID (Alghadeir & Al-Sakran, 2016; Molina et al., 2018; Zmud et al., 2018); BLE beacon sensors (Jeon et al., 2018; Lin & Lin, 2018; Molina et al., 2018; Zmud et al., 2018); Wi-Fi (Alghadeir & Al-Sakran, 2016; Howell, 2016; Mayer et al., 2014; Molina et al., 2018; Zmud et al., 2018); and passenger counting devices utilizing thermal, infrared, or camera sensors (Mayer et al., 2014; Medhurwar & Mishra, 2018). Fine-tuning of the BLE beacon technology is identified in several studies as providing additional

accuracy when integrating multiple components, including the BLE beacon mesh prototype system (Lin & Lin, 2018) and BLE with Wi-Fi fingerprinting (Molina et al., 2018). The enhanced BLE beacon architectures provide more precise location tracking of passenger devices and faster real-time communications, resulting in faster response times to address passenger needs (Jeon et al., 2018; Lin & Lin, 2018; Molina et al., 2018).

Determining which architecture to implement should be driven by specific goals to improve the passenger experience (Bouyakoub et al., 2017; Lamb, 2018; Mayer et al., 2014; Zmud et al., 2018). If the goal is to improve passenger throughput, a smart airport management system (Bouyakoub et al., 2017) can be implemented, integrating passenger counting devices to monitor and alert airport staff when congestion occurs (Mayer et al., 2014) to facilitate real-time mitigation of the issue (Curry et al., 2018; Molina et al., 2018). Baggage handling systems can be improved by using RFID technology to track bags linked to each passenger (Alghadeir & Al-Sakran, 2016; Bouyakoub et al., 2017; Medhurwar & Mishra, 2018). Allowing passengers to choose how and when they share their data notifications creates trust of and buy-in for airport IoT systems (Lamb, 2018; Zmud et al., 2018), which paves the way for an IoT system architecture interface with mobile devices that allows for passengers to set preferences to allow for push notification communications (Alghadeir & Al-Sakran, 2016; Hussein et al., 2016; Medhurwar & Mishra, 2018; Wang et al., 2017). These communications encompass notifications to passengers about flight delays, gate changes, and promotions from concessionaires (Alghadeir & Al-Sakran, 2016; Hussein et al., 2016; Medhurwar & Mishra, 2018; Wang et al., 2017). Wi-Fi ties all of these technologies together by providing connectivity to passenger and staff devices, and in some cases to the system architectures (Alghadeir & Al-Sakran, 2016; Howell, 2016; Mayer et al., 2014; Molina et al., 2018; Zmud et al., 2018).

Operational Efficiencies to be Gained With IoT

Learning from and expanding upon successful IoT applications to improve operational efficiencies are likely the best place to start when looking for additional opportunities to leverage smart airport system architecture (Alghadeir & Al-Sakran, 2016; Bouyakoub et al., 2017). The operational goals and deficiencies of an individual airport should be defined clearly before IoT implementations are attempted to better ensure success (Zmud et al., 2018), although small pilot programs may be warranted as an investment in future potential (Curry et al., 2018; Robinson, 2017). Applied properly, IoT systems can improve operating efficiencies to enable reductions in security staffing while maintaining or improving safety controls by tracking passengers through each stage of their journey (Alghadeir & Al-Sakran, 2016; Bouyakoub et al., 2017; Molina et al., 2018). Other gains in the optimization of airport processes through IoT include providing data to airport planners and other stakeholders that is critical to decision-making for improvements and expansion of terminal buildings, and to provide financial and reputational gains for airport operators (Curry et al., 2018; Howell, 2016; Mayer et al., 2014). Interoperability continues to be a challenge in applications targeting operational efficiency improvements, with several authors noting the need for universal adoption of IoT standards (Curry et al., 2018; Lin & Lin, 2018; Medhurwar & Mishra, 2018; Zmud et al., 2018).

Even with the asserted need for a universal standard, several of the articles in this annotated bibliography provide recommendations for fine-tuning IoT configurations in airports. When using beacons in large buildings like airports, sensor signal strength can be improved by using stronger output power or external antennas, utilizing multiple mesh routers, and implementing Bluetooth 5.0 chips (Lin & Lin, 2018). Combining BLE and Wi-Fi fingerprinting, using both 2.4 GHz and 5 GHz Wi-Fi bands, and installing more sensors in high density areas increases accuracy and reduces signal variability (Molina et al., 2018).

System architecture and sensor choice are important, and in the selection process decision-makers should discuss typical error rates in the raw data and the associated effect on performance indicators with the solution provider (Mayer et al., 2014). Careful positioning of sensors and estimates of the real, achievable accuracy in the terminal environment when the sensors are placed should also be discussed with the solution provider prior to selection (Mayer et al., 2014). It is also important for decision-makers to understand anomalies in the data due to passenger spontaneity in order to manage expectations and achieve acceptable user acceptance rates (Mayer et al., 2014). In addition, fundamental information management practices need to be in place for successful IoT implementations, including educating developers in the chosen data management approach, being able to articulate the business case for investment in data infrastructure, and acknowledging the significant cost of integrating legacy data sources (Curry et al., 2018).

Creating Business Value Through the Use of IoT

Adding to the bottom line through improved operational efficiencies and creating new sources of revenue from personalizing the passenger experience are goals that can be realized through implementation of IoT at airports (Howell, 2016). The key is choosing the right application to support business goals (Lamb, 2018; Zmud et al., 2018), which can ultimately lead to strategic differentiation in the airport sector (Zmud et al., 2018). Business value may be easily found by enhancing IoT systems that are already focused on operational efficiency and expanding into more complex IoT solutions to pursue new revenue (Alghadeir & Al-Sakran, 2016; Bouyakoub et al., 2017; Zmud et al., 2018).

While there are untapped revenue innovation options related to the use of IoT in airports, it is important to acknowledge that IoT implementations scale much differently than traditional IT projects, with incremental costs typically trending up with each added device (Jernigan et al.,

2016). The achievement of ROI may be elusive in the short-run as IoT technologies develop, but focusing on one or two targeted initiatives is an investment in the future of the digital transformation in the aviation sector (Lamb, 2018; Zmud et al., 2018).

When considering investments in IoT, airports must consider where to start (Jernigan et al., 2016; Zmud et al., 2018). One innovative concept combines pay-as-you-go data management with dataspace services, which links data with entity-centric real-time data queries and postpones labor-intensive data integration activities until they are needed (Curry et al., 2018). One prototype example of this system architecture is the Real-time Linked Dataspace (RLD), which is an enabling platform providing tiered levels of support for data management and retrieval. While more experimentation and development is needed to fully vet this hybrid technology for use with IoT and real-time data, dataspaces have been used in applications for personal information and scientific data (Curry et al., 2018). Utilizing this technology could reduce initial costs in developing smart applications for pilot programs (Curry et al., 2018). Multiple authors included in this annotated bibliography recommend pilot programs to manage risk while testing innovation solutions (Curry et al., 2018; Robinson, 2017). Despite the constrained budgets of a small airport, finding the funding for emerging technology projects, with proper alignment to business goals, may be the best way to facilitate strategic differentiation (Zmud et al., 2018).

Concluding Remarks

Stakeholder involvement and data sharing among those stakeholders is noted by many authors as an important component to any IoT implementation at airports (Curry et al., 2018; Howell, 2016; Jernigan et al., 2016; Lamb, 2018; Zmud et al., 2018). While airports, airlines, and governmental agencies have sometimes had adversarial relationships, establishing a level of trust will be imperative to removing barriers to change (Lamb, 2018; Robinson, 2017). Airport

management teams and other stakeholders will need to embrace change to enhance the passenger experience, improve operational efficiency, and create business value (Curry et al., 2018; Jernigan et al., 2016; Lamb, 2018; Robinson, 2017; Zmud et al., 2018). Moving toward a smart airport ecosystem, leveraging data sharing among multiple stakeholders, and choosing IoT projects wisely has the potential to transform the aviation industry (Curry et al., 2018; Howell, 2016; Jeon, 2018; Jernigan et al., 2016; Lamb, 2018; Robinson, 2017; Zmud et al., 2018).

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