Future Trends in Airport due to impact of innovation and Technology.

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1. Abstract

The outlook of air travel is expected to undergo rapid transformation in the coming decades as new technologies emerge. Airports will be at the core of these changes and they themselves undergo transformed in the process. Airports have been playing vital role at both local and global levels. Their role will only grow as the aviation industry expands. The global commercial aviation fleet is expected to increase to more than 36,000 aircraft by 2033 (Oliver Wyman analysis). Meanwhile, Airports Council International (ACI) World predicts an average annual growth of 5.8% in passenger traffic up to 2040. By 2040, more than 19 billion passengers are expected to pass through world airports each year. Growth of this proportion can only be met with innovative practices, paradigm shift in thinking process, and exploitation of technologies. This article explores these aspects and projects the likely scenario during the years 2030, 2040, and 2050.

2. Key words

Technological Innovation, Passenger Experience Revolution Carbon Net Zero, Intermodal Connectivity, Changing Workforce,

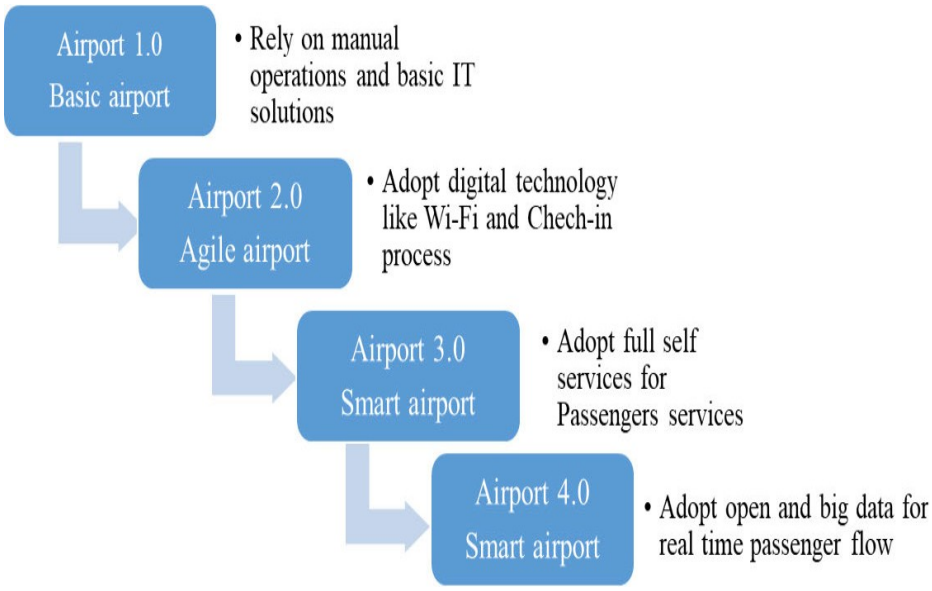
3. Introduction

For over a decade, the subjects of Innovation and sustainability have constituted a primary emphasis within management strategy and scholarly inquiry. Despite significance of this subject, a very few studies address this important inquiry regarding the evolution of Airport infrastructure over recent past, culminating in its current state and the preparedness to overcome impending challenges. This article tries to bridge this gap to some extent and contribute to the existing fund of knowledge.

Classification of Airports:

Airports provide fundamental infrastructure that enables aerial operations for the transportation of passengers, their baggage, and freight. Historically, airports were categorized based on their type of construction as either Brick & Mortar or Glass & Steel. The facilities within airports were primarily segmented into land side and air side, designated for the use of passengers and aircraft, respectively.

However, in the year 2000, a novel classification system was introduced. According to this classification, airports are categorized as illustrated below (Nau & Benoit, 2017):



According to the above, the traditional airports which have manual processes and basic Information Technology (IT) solutions are classified as Airport 1.0.

Airport 2.0 classification includes Airports that are early adaptors of digital technology into airport operations and partial self- service facilities such as Wi-Fi technology & check-in process.

Airport 3.0 classification includes the Airports that are equipped with all levels of passenger facilities to provide full self-services.

Airport 4.0 classification includes airports where operational controls are automated whilst predictive and mobility solutions are heavily used in passenger Terminal as well as in the airside.

Contemporary Classification

The aviation sector has been experiencing substantial advancements in innovation and technology, alongside their increased accessibility and acceptance. Concurrently, various challenges have also been encountered by humanity at large, and the aviation industry specifically. The imperative to integrate technology at an unparalleled magnitude became evident promptly. This realization catalysed a significant transformation in the cognitive frameworks of leaders within the airport sector, encompassing the Airport Council International (ACI) and the Sustainable Tourism Global Center (STGC).

The categorization of airports according to their functional roles and strategic outlook has arisen in response to the necessity for airports to incorporate sustainability and innovation while adapting to the amazing expansion of aviation. Consequently, a novel classification has been delineated as follows (Oliver Wyman, ACI World, and the Sustainable Tourism Global Canter):

a. The City Airport: an airport situated within a central urban locality, predominantly catering to business travellers and short-haul commuters.
b. The Global Hub Connector: an airport primarily accommodating transit passengers engaged in global travel, as well as servicing the local catchment area.
c. The Cargo Champion: an airport that serves as a pivotal facilitator for the transportation of goods and commodities.
d. The Leisure Gateway: an airport that functions as a prominent tourist attraction

3. Objectives

i). To identify the blueprint of futuristic technologies and their applicability and implication on the airport ecosystem

ii).To outline likely scenario in the ensuing decades viz 2030, 2040, and 2050.

4. **Methodology**

i.). Exploratory study using secondary data gathered from various studies, articles related to Aviation and reported interview of heads of various progressive Airports across the world.

ii). Articles referred to are Evolution of Airports – A flightpath to 2050, SMART AIRPORT-HOW TECHNOLOGY IS SHAPING THE FUTURE OF AIRPORTS.

iii)..Blogs related to Airports from Oliver Wyman Forum

iv). Excepts of interview of heads of various Airports such as

a. André Schneider, CEO, Geneva Airport
b. Paul Griffiths. CEO, Dubai Airports
c. Steve Brockman, CEO of Memphis International Airport
d. Diego Arrosa. CEO of Aeropuertos Uruguay
e. Stefan Schulte. CEO of Fraport AG

The Airport CEOs prioritise the requirement the following features

Net zero achievement,
Technological innovation,
Intermodal connectivity,
Workforce transformation, and
Passengers' experience revolution

as major required initiatives for the aviation industry's future.

Limitations.

In this article the Focus of discussion will be limited to

I. Technological Innovation,
ii. Passenger experience and
iii. Work force transformation.

Discussion.

Technological Innovation

The advancements in biometrics, automation, three-dimensional printing, artificial intelligence (AI), and machine learning (ML) are beginning to revolutionize the conventional operational frameworks of airports, thereby enhancing the passenger experience and boost productivity levels. A growing demographic of travellers is increasingly accepting digitalization, indicating willingness to replacing the traditional paper tickets with digital identities. The existing human workforce will be tasked with managing and personalizing exceptions, while artificial intelligence and complementary technologies will be utilized to automate routine operations. In order to facilitate this transition, future airports must be comprehensively integrated to get the benefit of innovation and digitalization in both cargo and passenger operations.

The current internal architecture and design of airports must be re-evaluated in light of technological deployment, as it enables "on-the-move" processing of passengers with minimal stoppage points. Collaboration among stakeholders and regulatory agencies regarding data sharing will be of vital importance otherwise, the vast potential of technology will remain untapped. To fully utilise the capabilities of emerging technologies, airports, governing bodies, and other stake holders within the travel industry must strategically plan and execute their operations utilizing an open architecture that promotes seamless data interchange among multiple stakeholders and simultaneously maintaining stringent security and safety protocols.

Airlines, airports, and governmental entities persist in allocating resources toward biometrics and digital identity management solutions, given their capacity to foster a more secure, uninterrupted, and contactless end-to-end passenger journey. By the year 2030, a broader implementation of biometrics is anticipated to replace traditional paper tickets, boarding passes, and other travel documentation, including visas. In 2015, Aruba Airport unveiled its Happy Flow system, which employs facial recognition technology to capture a biometric image of passengers, linking it to their passports so that individuals need only position themselves in front of a camera at nearly every passenger interaction point, excluding security screenings. Initially restricted to residents and citizens, the biometric initiative at Dubai International Airport was expanded in 2023 to encompass international travellers. A pre-existing biometric database now allows passengers to navigate through check-in, lounges, boarding, and immigration processes, with artificial intelligence correlating their unique facial characteristics to their passports for quick verification. The exchange of data, coupled with data security and integrity, is hallmark for successful implementation of biometric technologies. It is anticipated that by 2030, these technological innovations will have reached a stage of maturity.

Passengers are increasingly preferring efficiency and seamlessness, and willing to share their biometric data to enhance airport procedures. By the year 2030, a more integrated methodology for baggage management is anticipated to emerge, characterized by customizable, contactless, and diverse solutions. Available alternatives will include collection from and delivery to both origin and destination utilizing third-party logistics services. as well as designated bag-drop points throughout the aviation ecosystem. By 2030, traditional paper baggage tags are expected to be systematically replaced by electronic luggage tags that can be modified with a passenger's travel information and monitored via a smartphone application.

Recent amendments to the International Civil Aviation Organization's (ICAO) regulations now permit the utilization of electronic bag tags for checked baggage. The transition from paper tags to reusable electronic tags will not only expedite the check-in process for passengers at airports but will also contribute positively to environmental sustainability. The adoption of 3D printing technologies will render maintenance operations more cost-effective and time-efficient, thereby equipping the airports with a competitive advantage,

By 2030, the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies will constitute a fundamental aspect of airport operations. The employment of this digital twins of airports is expected to facilitate quick and high-quality decision-making through the visualization, simulation, and forecasting of speculative scenarios and resultant changes. The swiftness of technological advancement is invariably linked to the emergence of cybersecurity threats. However, the increase of self-controlled vehicles, biometric systems, and an expanding digital environment shall contribute to the increased exposure to cyberattacks. The aviation sector operates within a broader geopolitical context encompassing intergovernmental policies, security apprehensions, national interests, economic factors, and societal considerations. In relation to transportation within and surrounding the airport, the deployment of autonomous electric vehicles and equipment has the potential to revolutionize the entire turnaround process involving fuelling, catering, cleaning, and pushback, thereby yielding substantial improvements in operations and reduced emissions. Airports can re design car parking facilities by reallocating current capacity or reducing the available space. Further autonomous delivery robots are becoming increasingly popular at airports.

Unmanned aerial vehicles are expected to be largely implemented by the year 2040, facilitating runway evaluations and perimeter surveillance across vast regions with greater efficiency and safety by capturing high-definition imagery and video content. Additionally, drones possess further utility in applications such as topographical mapping and wildlife hazard prevention. As a word of caution in the light of the rigid security procedures at airports, there is a growing apprehension regarding the management of drones and other unmanned systems that can pose possible risks to scheduled flights.

For air travellers, touchless digital identification cards are expected to replace conventional paper tickets by 2040, serving as a singular repository that verifies the passenger's identity, health information, passport details, historical and current travel records, as well as visa information. The integration of this digital identification with biometric technologies implies that passenger processing, including security checks, could evolve into a completely seamless and touchless experience conducted at a leisurely pace. Indeed, numerous security protocols are likely to be consolidated with different modes of transport—allowing for the verification of a passenger's information while they transit from the city to the gate, for example. Collectively, the travel infrastructure envisioned for 2040 will prioritize open-airport design, enabling both physical and software architectures to interface, thereby facilitating touchless security and check-in processes. Authorities contend that such advancements will promote data sharing and enhance security and collaboration between airport administrators and regulatory agencies. According to the Chief Executive Officer of Los Angeles International Airport, much of this technology has already been implemented at the facility, and the focus now lies on integration and achieving greater standardization globally to avoid reliance on multiple technological solutions depending on the specific airport or airline.

By the year 2050, a multitude of operational processes within airports are projected to be fully automated, thereby enhancing the speed and quality of various activities—from security procedures to immigration and boarding operations. These efficiencies are expected to further support cargo management activities. The concept of huge departure and baggage handling areas may become obsolete; such space-efficient processes will be particularly advantageous for City Airports, where land resources are limited. The passenger processing experience could resemble a leisurely stroll in a park, which will be particularly significant for Global Hub Connectors handling substantial daily passenger volumes.

Currently, Changi Airport's Terminal 4 exemplifies an early instance of a fully autonomous terminal, characterized by automated processes for check-in, baggage-drop, immigration clearance, and boarding, facilitated by facial recognition technology. Numerous other terminals and airports are anticipated to adopt and expand upon this operational model by 2050.

Through collaborative initiatives by governmental and regulatory entities, there exists a promising prospect for the establishment of an internationally recognized digital identity for all passengers by 2050.

. **The Transformation of Passenger Experience**

The passenger experience is expected to be re organised to facilitate free of physical contact, diligently personalised, and instantly readily accessible upon request. The digitization of airports is expected to facilitate personalized end-to-end travel experiences throughout the airport environment, thereby creating new opportunities for commercial and retail transactions. Airlines and airports are projected to offer individualized solutions for baggage drop-off and collection, reliving the necessity for travellers to transport their luggage to the airport. It is likely that prior to departure, luggage will be collected and checked from the travellers' residence or accommodation and conveyed to the airport. From getting reservations at dining establishments to buying duty-free items, travellers have the capability to manage every aspect of their journey and overall experience utilizing personal devices in conjunction with integrated travel applications. Airports will extend services and personalised marketing strategies to customers at each phase of their journey. To realize this vision, fostering open communication and ensuring data accessibility are crucial to delight consumer experiences. In addition to advancements in digital technology, the physical infrastructure of airports will require comprehensive redesign and improvements to align with passenger expectations. For instance, the demand for airport lounges is increasing, alert airlines to request for the modernisation of facilities to adopt innovative features such as cinema lounges, swimming pools, and virtual reality gaming areas. As airports progressively evolve into "aerotropolises" or airport-centric urban environments, they will offer a diverse array of interconnected activities that can be engaged in either nearby or on-site. The internal architecture of airport terminals will undergo substantial modifications as a direct consequence of the evolution of passenger processing. In the foreseeable future, the demarcation between airside and landside operations is expected to to undergo sea change from its present design. The reduction of check-in counters and security screening queues will result in an expanded allocation of space within terminals for commercial retail establishments and relaxation zones.

Given that the airport serves as both the initial and final point of contact for travellers, the airport experience holds considerable significance in shaping visitors' perceptions of a destination. Consequently, it is imperative to ensure that the passenger experience is both seamless and pleasurable. Amenities such as comfortable lounges, a variety of food and beverage options, and free access to Wi-Fi are regarded as essential by consumers. With a heightened emphasis on customer experience, airports will need to capitalize on and systematically evaluate opportunities for collecting feedback to guarantee that passengers' needs are adequately met.

By the year 2030, it is expected that the adopting of emerging technologies will empower airports to offer passengers personalized, on-demand services that enhance their overall airport experience. One illustrative example of this is the implementation of virtual queuing instead of joining a physical line. Seattle-Tacoma International Airport (SEA) and Los Angeles International Airport (LAX) are among the first airports in North America to have trialled the system, while some airlines, such as Delta, have used a similar tool to notify passengers when their seat is boarding.

The airport experience expected for the year 2040 is to show as a service-centric model, having quick parking solutions, coordinated journey planning, streamlined security processes, and personalised wayfinding assistance.

Many chief executive officers believe that airports go beyond the primary functionalities of runways and terminals.

According to he chief executive officer of Brisbane Airport Corporation they "will further promote sparkling urban campuses encompassing office spaces, hospitality establishments, retail amenities, as well as entertainment venues and different modes of transportation to the airport."

Substantial investment will be channelled towards the establishment of expansive networks of interrelated enterprises and activities aimed at the creation of airport cities or "aerotropolises." These urban regions are strategically cantered around an airport in terms of economic activities and infrastructural development, capitalizing on land that is unsuitable for residential use. The designated land uses include shopping centres, entertainment facilities, event arenas, health and wellness establishments, hotels, e-commerce infrastructures, and educational institutions. At the moment, Asia is at the forefront of this initiative, with China integrating these principles into over one hundred airports. Singapore's Changi Airport has already introduced "Jewel," a dome-shaped attraction that features a vibrant amalgamation of retail, leisure, garden, and hotel amenities, along with operational functions of the airport. Concurrently, the Middle East is progressing in this regard, as Riyadh Airport is set to undergo an expansion to evolve into an aerotropolis that includes airport support facilities, residential and recreational amenities, and retail establishments, with a projected capacity to serve 185 million passengers by the year 2050.

This aerotropolis framework is fundamentally about reimagining the airport as a destination in its own right rather than merely a transit point for air travel; it also seeks to separate airport revenues from air transport operations and enhance commercial resilience.

By the year 2050, zero-queue terminals are going to become a noticeable reality, with personalised and pre-arranged processes facilitating an uninterrupted journey from the point of origin to the planned destination and vice versa. Passengers will equip their personal devices or travel and airport applications to manage every facet of their journey and overall experience. Innovative remote processing and integrated processing pods, which may be accessible during transit to the airport, will streamline boarding and security protocols. This advancement will be essential for both City Airports—where time and space are at a premium—and Leisure Gateway airports, where tourists increasingly opt for shorter yet more frequent vacations and anticipate enhanced service while minimizing their airport dwell time for smoother connections. Certain chief executive officers propose that a disaggregated model comprising smaller terminals is necessary to facilitate a more efficient flow of passengers, as opposed to directing them through a centralized processing hub.

The Changing Workforce

The aviation industry is struggling with labour shortages which started as a result of the COVID-19 pandemic, hindering its capacity to cater to the increasing demand for air travel. In future the functions of the Aviation workforce is expected to change as artificial intelligence and other technological advancements transform airport procedures. Personnel engaged in customer interactions will require an improvement in their customer service expertise, while Personnel engaged in airport operations will require new skill sets to encompass Technical, Digital, Cybersecurity, and Information Technology.

Airports must give importance to attract and retain Generation Z employees, who are equipped with multitasking abilities, possessing the requisite skills to uphold their competitive edge. To achieve this collaboration with academic institutions will be essential to facilitate the identification of a sufficient labour pool to meet future demands and ensure sustainability.

Labor shortages are pervasive across the entire value chain, encompassing pilots, mechanics, and baggage handlers, thereby posing a threat to the industry's capacity to cater the increasing demand for air travel.

Specifically, the shortage of pilots represents a persistent trend that is projected to continue influencing travel supply over the next decade, with a requirement for an estimated additional 60,000 pilots globally by the year 2032, which includes 17,000 in North America and 17,500 in the Middle East. For the first instance recorded in history, four distinct generations coexist within the workplace, each characterized by unique values, beliefs, behaviors, and varying levels of commitment to their respective employers.

The expectations of the future workforce impose a great challenge on airports where onsite presence is mandated: 85% of Generation Z express a preference for hybrid or remote work scenarios. Within the transportation sector, work-life balance emerges as a important motivator for Generation Z, with remuneration ranking as a secondary importance this requires that airports devise more delicate and customised strategies to attract, manage, motivate, and retain this blooming workforce. Singapore's Changi Airport, which was recognized as Singapore's Most Attractive Employer in various sphere such as career advancement, financial stability, attractive job content, work environment, and aggressive integration of innovative technologies. In addition to attraction and retention, upskilling of employees will play a more important role. Needless to say, there exists a increased demand for employees equipped with digital or technical skill sets, together with individuals possessing soft skills to effectively to deal with core customer-facing roles.

By the year 2040, technological advancements would have largely transformed the airport workforce. Technology will enlarge and streamline airport roles, enabling personnel to concentrate on customer engagement. Novel technology-centric positions that are integral to operations will emerge, particularly in the realms of data science and artificial intelligence. Technology will also support and replace certain traditional roles, such as baggage handling, while passenger service and delivery robots will assist with other functions within the airport of 2040. Notwithstanding the rise of automation, customer-centric positions at airports will continue focusing on tasks that are less predictable. However, it will be necessary for these employees to possess updated skill sets. Such positions may include serving as an ushering to greet visitors entering a country, as well as providing assistance to customers regarding mobility or directions. Concurrently, robust upskilling in areas such as engineering, information technology, maintenance, and digitization will be essential to sustain and maintain systems including electric aircraft, hydrogen technologies, and drones.

Conclusions.

Although the projected timeline of 2050 may appear distant, it is evident that the airports of the future will be fundamentally influenced by the methodologies adopted in addressing contemporary challenges.

The integration of biometrics, big data, and other interrelated technologies is poised to enhance the passenger experience and simultaneously enabling effective airport facility management, which will result in mutual benefit to all stake holders. However, due to nonflexible existing infrastructures, certain airports need additional time to adopt new functionalities into their existing frameworks. Concurrently, The adoption of emerging technologies such as electric Vertical Take-Off and Landing (eVTOL) vehicles, electric transport, and automation will influence airport design, affecting various aspects from parking facilities to runway safety protocols to a great extent. Such transformations will redefine the role of airports within the urban mobility model, converting them into intermodal transportation hubs.

The demand for air travel is projected to persist in its upward trajectory, leading to the expansion of large aerotropolises which will redefine the spatial limits of airports. Simultaneously, advancements in technology are expected to facilitate remote processing of passengers and baggage, as well as the utilization of smaller runways made possible by vertical

take-off and landing capabilities. Indeed, this may result in the emergence of two distinct categories of airports: those that are significantly larger than the current average airport size, and those that are considerably smaller, similar to the City Airports situated near urban centres. Aligning the increasing demand for travel with workforce limitations poses another medium-term challenge that will necessitate substantial industry investment; however, by 2050, it is anticipated that many process-driven roles will be automated. Nevertheless, human resources will continue to be essential in managing and personalizing exceptional circumstances.

For pioneering airports, strategic vision, active co-operation between public-private sector , and pro-active community involvement will be crucial differentiators. The CEOs' observations and the supporting data reveal a recurring trend that motivates airport managers every day to guarantee a smooth, safe, hassle free, pleasurable, and ecologically sustainable travel experience. Future travellers have a lot to look forward to.

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