AIRPORT INSIGHTS REVIEW : **AIRPORT R&D**

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Incheon Airport

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TOPIC
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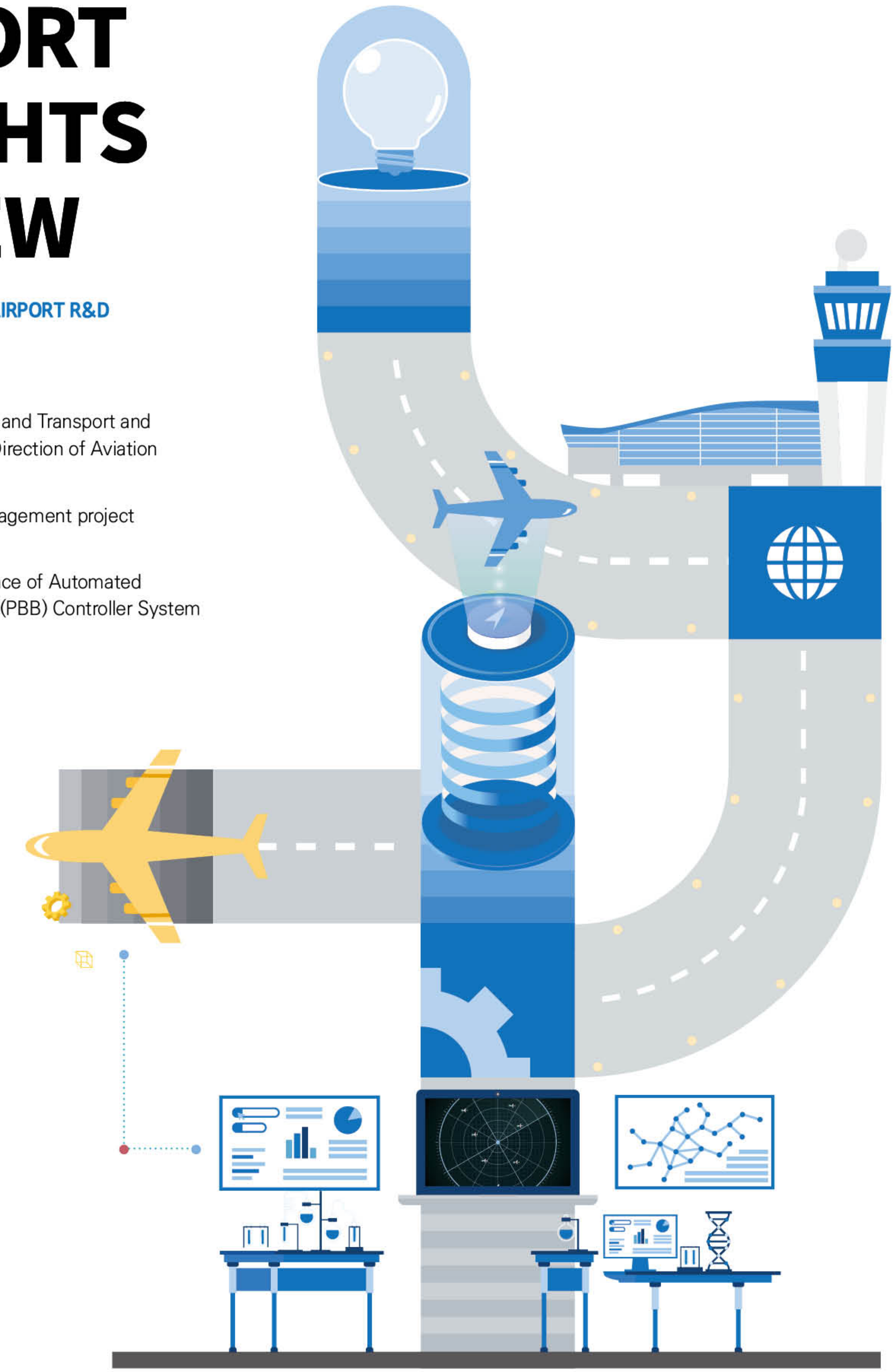
R&D
Data-Driven Air Traffic Management project

AITRI FOCUS
Development and Significance of Automated Passenger Boarding Bridge (PBB) Controller System



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Here, we will share insights
from **industry experts**.

TOPIC

Incheon International Airport Corporation (IIAC) conducts extensive research and development in infrastructure.
In this context, we strive to communicate the current status of aviation R&D and
chart a course for its future trajectory with readers.

R&D in Land, Infrastructure and Transport and Current Status and Future Direction of Aviation

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Scope and Characteristics of R&D in Land, Infrastructure and Transport

Research and development (R&D) is defined as "systematic and innovative efforts aimed at the accumulation and advancement of diverse knowledge domains for human understanding, cultural insights, and societal dimensions" (Kim Byeong-mok, Lim Yun-cheol, 1989). According to the OECD, R&D means "purposeful creative activities undertaken systematically to expand the reservoir of knowledge that pertains to human life, culture, and society, with a view to enhancing its practical utility through novel applications." Regardless of these definitions, the core determinant distinguishing R&D activities from non-R&D activities is the infusion of originality and innovative elements.

R&D in land, infrastructure and transport (LIT), including construction (SOC), urban development, architecture, spatial planning, road transportation, rail networks, air travel, and logistics (Table 1), are promoted to provide innovative public services, notably aimed at enhancing public safety and convenience. Consequently, LIT R&D hold the attributes of a public good, primarily driven by governmental bodies or public institutions, functioning both as technology providers and consumers. Furthermore, since LIT R&D focuses on giant systems, sensors, AI, and other various elements are organically integrated with various technology, granting system R&D nature that operates on a single system (Table 2).

Table 1 Definition and Scope of LIT R&D Activities (STSI, 2023)

Category	Field	R&D Definition and Range
Land	Con-struc-tion (SOC)	▪ Fundamental technologies to maintain the performance, such as design, construction, and maintenance of societal infrastructure such as bridges, tunnels, and slopes.
	City/ Resi-dence	▪ Technologies for smart city, urban planning, enhancements in residential quality of life, and the resolution of urban challenges
	Archi-tecture	▪ Technologies concerning the design, construction, and enhancement of buildings to ensure the secure and efficient accommodation of individuals, goods, and facilities
	Plants	▪ Technologies essential for the design, building, operation, and maintenance of production facilities dedicated to power generation, resource development, new and renewable energy, and environmental preservation
	Spatial Infor-mation	▪ Technologies for acquiring, managing, and leveraging diverse digital territory-related information spanning the entire national land
Transport	Road	▪ Automobiles, road transportation infrastructure, and management systems that facilitate the movement of passengers and freight via roads
	Rail	▪ Technology catering to the bulk movement of passengers and cargo via rail, including rail vehicles, railroad infrastructure, and related management
	Air	▪ Technologies concerning the constituent elements of air transportation systems, such as aircraft, the development, and administration of air transportation infrastructure
	Logis-tics	▪ Technologies pivotal for the optimization of transportation systems and uninterrupted logistics operations, including transportation, logistics infrastructure, and management

Table 2 Characteristics of LIT R&D (Kim Byeong-su, 2018)

Category	Ministry of Land, Infrastructure and Transport (MOLIT)	Ministry of Trade, Industry and Energy (MOTIE)	Ministry of Science and ICT (MSIT)
Purpose	Improving infrastructure safety & convenience Reducing construction & operation costs	Supporting companies that secured industrial competitiveness	Enhancing research capabilities and securing original technologies
Demand	Government, public institutions, public	Enterprises	Academia & institutes
Charac teristics	System R&D	Product development R&D	Knowledge creation R&D
Implemen tation	Public institutions	Enterprises	Universities/ research institutes

Investment Progress and Achievement in LIT R&D

Over the past decade, the R&D budget allocated to land, infrastructure and transport has been on a continuous growth trajectory, with an average annual increase of 5.7%, culminating at KRW 614.9 billion in 2023. Nonetheless, this figure marks a 2.9% decline from the preceding year, constituting a mere 2.0% of the government's extensive R&D funding of approximately KRW 30.7 trillion. Even though LIT presents a substantial impact on the nation's economy and citizens' daily lives, accounting for 15.6% of the GDP in 2017 (Kim Byeong-su1, 2022), the government investment in the fields is absolutely and proportionally insufficient. Considering the pivotal role of LIT R&D, it demonstrates the dire necessity for larger government investment for the expansion and development of the fields.

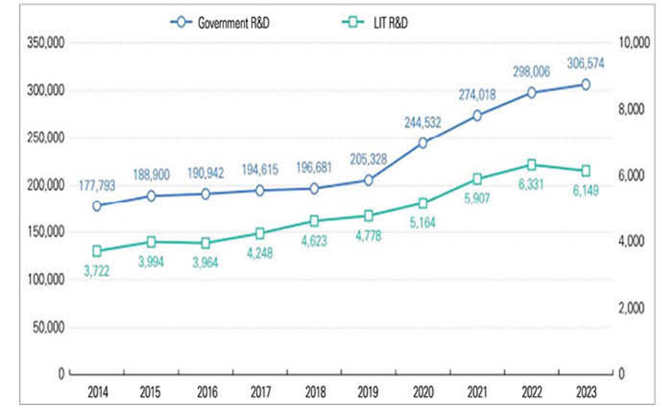


Figure 1 Annual Investments by Government and in LIT R&D (MOLIT, 2022)

Despite this challenging backdrop, the continuous investments in LIT R&D have borne fruit in various quantifiable achievements. These include a surge in the publication of SCI(E) papers (471 in 2019 → 509 in 2020 → 542 in 2021), a rise in patent registrations (654 in 2019 → 679 in 2020 → 724 in 2021), and the successful establishment of pioneering technologies like ultra-long cable-stayed bridges, notably contributing to qualitative advancement as well, such as catalyzing the emergence of innovative markets like K-Smart City, enhancing technological competitiveness through the development of small aircraft, and fortifying national stability through initiatives like the pandemic contact trace system (MOLIT, 2023).

Figure 2 Best Practices of LIT R&D (MOLIT, 2023)

○ World's first and best

Ultra-long cable-stayed bridge	Super concrete	Autonomous Driving Experimental City (K-City)
		
The cable-stayed temporary construction method for suspension bridges (Canakkale Bridge in Turkey (2,023 m))	Engineered super concrete with an unparalleled lifespan of 200 years	Constructed the world's first 5G network applied autonomous test bed

○ Market creation

Double-decker electric buses	Power-distributed high-speed trains	Low-floor trams
		
Development of localized technology for double-decker electric buses and distribution to local governments	Commercialized 120 units of KTX EMU-260 and 16 units of EMU-320	Signed a contract to export low-floor trams to Warsaw, Poland

○ Enhancement of technological competitive power

High-rise building design and construction	Zero-energy housing	Hydrogen city
		
Applied double-deck elevators, active complex vibration control device (Lotte Tower)	Attained the German PHI certification, the highest green building accreditation (2017)	Legislated construction standards for hydrogen fuel cell houses and complexes (2021)

○ Enhancing public safety and convenience

Epidemiological investigation support system	Showcase of autonomous city buses	Wheelchair-accessible express bus
		
Developed COVID-19 epidemiological investigation system of the smart city, shortening the time to trace contacts of a confirmed case (24 hr→10 min)	Lv3 autonomous driving buses are applied in the city of Sejong, providing precise stop at bus stops and booking services to get on/off	The wheelchair-accessible express bus traveling to Busan, Gangneung, Jeonju, and Dangjin

Future Policy Direction for LIT R&D

In a landscape where the forces of Industry 4.0, including AI, IoT and the metaverse, are converging with the traditional LIT sector, and where eco-friendly mobility ventures beyond roads to encompass the seas, skies, and even outer space, Korea stands at a crossroads demanding profound transformations and breakthroughs in all areas. In response, the MOLIT's R&D has charted a strategic course guided by three pivotal principles. First, "Digital Transformation" aims to foster new, high-value-added industries by virtualizing the nation's land, converging construction and mobility with cutting-edge technologies. Second, "Climate Crisis Response" pledges to build and operate a transportation system powered by renewable energy, bolstering the mass production, distribution, and utilization of eco-friendly fuels. Lastly, "Enhancement of National Safety and Convenience" envisions a user-centric, secure, and convenient transportation network, alongside well-prepared residential spaces that assure safety and convenience for all (MOLIT, 2023).

Pioneering this vision for the future of LIT, and tackling existing challenges while bolstering innovation, the MOLIT's R&D focuses on five development strategies. "Hyperconnected National Urban Space Innovation" links natural and artificial environments in the national urban space through virtual realms; "Future Mobility System Transformation" enables seamless mobility connections, ensuring fluid interaction; "Advancement of Sustainable LIT" prioritizes long-lasting, secure infrastructure; "Creation of Creative Living Spaces Through Public Participation" crafts healthier, happier living environments; "Creation of Foundation for Industrial Innovation Foundation Through R&D" establishes a robust groundwork for industrial evolution (MOLIT, 2023).

Aligned with these policy directions and five development strategies for LIT R&D, we are propelling the 12 Strategic Technologies and Advanced Research (STAR) initiatives. These initiatives are geared to produce world-class brand technologies (G3) capable of fundamentally reshaping entire industries, including the global fifth level (G5) and strategic national sectors. Through these endeavors, we strive to realize the vision of LIT R&D–a "paradigm shift in space and movement through technological innovation" (see Figure 3).

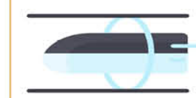
Figure 3 Vision and Strategies for LIT R&D (2023-2027) (MOLIT, 2023)

Vision	Transforming the paradigm of space and movement through technological innovation

Promotional strategies and tasks to prepare for the future of LIT, addressing existing issues, and reinforcing the capacity for innovation

Strategies \ Direction	Digital Transformation	Climate Change Response	Public Safety & Convenience
Strategy① Hyperconnected Land Urban Space Innovation	Tech Task① Open Digital Land Space	Tech Task② Hyper Connectivity ·Green Smart City	Tech Task③ Disaster and Social Safety Service
Strategy② Transformation of Future Mobility System	Tech Task④ Advanced Intelligent Mobility	Tech Task⑤ Carbon Neutral Mobility	Tech Task⑥ Inclusive and Safe Mobility
Strategy③ Advancing Sustainable LIT	Tech Task⑦ Smart Digital Construction	Tech Task⑧ Green Plants & New Spaces	Tech Task⑨ SOC Safety and Rapid Recovery
Strategy④ Creative Living Space Through Public Participation	Tech Task⑩ Urban Convergence Industry & Community Hub(self-sustaining local development)	Tech Task⑪ Net Zero Smart Architecture (private sector-led)	Tech Task⑫ Safe Wellbeing Housing (public participation)
Strategy⑤ Foundation for Industrial Innovation Through R&D	Policy Task① Improving research planning and management system to propel toward mission-driven, audacious, and innovative R&D Policy Task② Nurturing private-sector-led innovation for corporate growth and engineering a system tailors performance to the unique needs of end users Policy Task③ Building a platform and knowledge-sharing library to activate the data ecosystem Policy Task④ Laying strong research foundations, including nurturing the convergence of talents and building advanced experimental infrastructure Policy Task⑤ Promoting balanced national development through research and development and amplifying global engagement based on technology		

〈 Main Brand Task: 12 STAR Initiatives Program 〉

		
Automatic cooperative driving	UAM	Superspeed hypertube
		
User-centered mobility	Digital logistics	Carbon neutral city
		
Net zero architecture	Liquid hydrogen infrastructure	Digital twin spatial info
		
Hyper-connected smart city	Smart construction	Smart buildings

Current Status and Future Direction of Aviation in LIT R&D

Scope and Characteristics of Aviation R&D

In the narrow sense of the word, aviation technology means aircraft serving as a conduit for transporting individuals and cargo across the skies. An aircraft itself is a comprehensive system of systems (SoS) technology and constitutes intricate subsystems such as propulsion, body, and electronics.

In other words, aircraft is a means of transportation undertaken along an aerial route. Unlike a car traversing painted lanes on a road, an aircraft navigates its course along invisible trajectories. Aircraft should take the responsibility of safely ferrying passengers and goods to their intended destination from a departure airport to an arrival airport. Air Traffic System Technology is a combination of various systems to facilitate safe and smooth flying along the aerial route and is a system encompassing all procedures spanning flight planning, departure, takeoff, ascent, cruising, descent, landing, and eventual arrival (Figure 4). ICAO under U.N as well as all other countries has set and applied strict technical standards for diverse systems, including aircraft, airport facilities, safety protocols, control and communication systems, security frameworks, and information networks. Aviation technology is a transportation system for aircraft, international and transboundary aircraft certification, and movement of people and commodities (economic activities) and is a comprehensive system of systems (SoS) that encompasses infrastructure and economic air traffic management system and the entirety of the aviation industry and economy (Kim Byeong-soo2, 2022).

Hence, in the wide sense, Aviation technology is more than just aircraft; it encompasses an intricate system of systems (SoS) that includes not only the planes themselves but also the entire infrastructure, various systems, and technologies essential for ensuring the safe and efficient execution of the entire aviation process-from flight planning to landing. In light of this comprehensive scope, R&D efforts in both land, infrastructure, transport, and aviation are directed towards advancing aviation technology in its broadest sense.

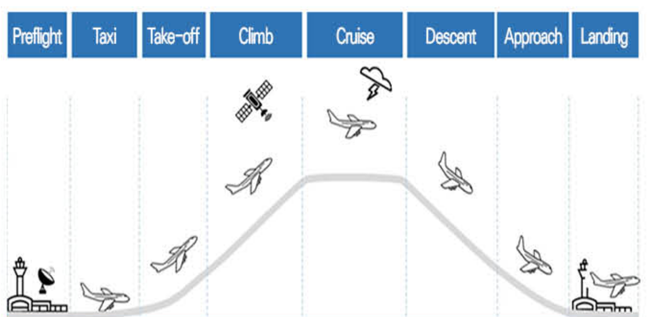


Figure 4 Conceptual Scope of Aviation in LIT R&D Targets (MOLIT, 2019)

Strategic Significance of Aviation Technology

Aviation technology stands at the crossroads of diverse technological domains, blending middle-tech machinery, high-tech semiconductors, new materials, batteries, and the groundbreaking realms of Industry 4.0, including AI and data. In the context of a technology-driven modern society where progress hinges on technological advancement, the competitiveness of the aviation industry often considers the nation's prowess. Notably, advanced countries like the United States proactively cultivate and develop aviation technology as a core national strategy. Moreover, advanced aviation nations establish legal barriers, preventing the entry of less-developed countries like Korea, by enforcing mutual compliance with safety standards, test protocols, technical benchmarks, and certification methodologies as dictated by international bodies like ICAO.

According to UN Comtrade data from 2018, the narrower scope of aviation industry trade (exports + imports) accounted for approximately $987.1 billion, equating to roughly 2.7% of total manufacturing trade. This positions aviation as the fourth most significant sector following automobiles (9.7%), semiconductors (5.9%), and pharmaceuticals (4.5%) (Kim Byeong-su, 2023). In the broader context of air transportation, the aviation industry assumes a colossal worth of about $3.5 trillion, a scale similar to the automobile sector. Despite a recent contraction due to the global recession induced by the COVID-19 pandemic and a subsequent decline in air travel demand, the industry is projected to exhibit an average annual growth rate surpassing 7.3% in the medium to long term. Regrettably, Korea's share in the aviation industry hovers below 1.0%, a mere third of the automobile sector's standing. To ascend as a pivotal force in the national economy and stake its claim as a burgeoning major industry, a comprehensive and strategic approach is imperative.

Aviation R&D Investment Rate and Issues

The MOLIT has been actively investing in aviation as part of its LIT R&D, committing approximately KRW 846.2 billion since 2007 through initiatives such as the Aviation Advancement Project (2007-2023), supported by governmental funding. For the year 2023, the allocated budget for aviation R&D stands at KRW 110.9 billion, marking a notable increase of around 15.7% compared to the preceding year, accounting for 16.6% of the total LIT R&D funding. Over the past five years (2019-2023), the aviation R&D budget has exhibited an impressive average annual growth rate of approximately 18.5%. This rate significantly outpaces the growth rate of the LIT R&D budget at a three times faster pace.

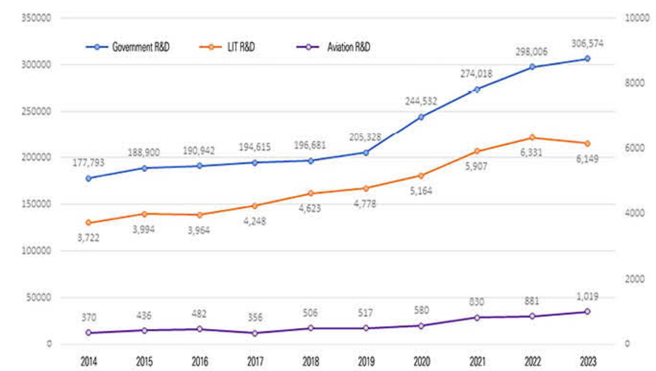


Figure 5 Government's Investment of Aviation in LIT R&D (Kim Byeong-su, 2023)

In the last half-decade (2019-2023), R&D in aviation have predominantly revolved around two main axes: firstly, expanding the current technological and institutional groundwork, such as air traffic efficiency, safety, security, and certification standards, and enhancing aviation capability with around 70.0% of investment; secondly, building new industries such as UAM and drones, with around 30.0% of investment. Particularly noteworthy is the swift and continuous expansion of the budget allocated for future-oriented endeavors. In fact, research on unmanned aerial vehicles including UAMs and drones began in 2015 and were fully executed since 2019.

Table 3 Status of Investments in Aviation by R&D Purpose

Purpose		Year					Average
		2019	2020	2021	2022	2023	
Expanding technological and institutional groundwork and enhancing aviation capability	Transportation & Efficiency	49.8	16.4	33.9	40.4	52.5	39.7
	Safety & Security	7.1	15.0	21.2	13.7	7.5	13.1
	Certification Standards	17.3	21.0	20.3	16.7	12.9	17.2
Future New Business Building	Future Aviation	25.8	47.6	24.6	29.3	27.1	30.0
Total		100.0	100.0	100.0	100.1.0	100.0	100.0

Based on such R&D investments, South Korea has attained a certain level of technological prowess (approx. 70%) across domains like aviation safety, traffic management, airport infrastructure, security, aircraft manufacturing, and maintenance. Its technological capacity stands at approximately 73.3%, trailing the most advanced country (United States) by a gap of around 6.7 years. In terms of research competitiveness, Korea holds a rating of 76.3% compared to the United States, as of 2019. The nation has made continued strides in both quantitative and qualitative technological advancement, particularly evident in the field of unmanned aerial vehicles, such as UAMs and drones, encompassing their safe navigation, operation, and control sector. However, the patent competitiveness rate of 31.2% indicates that the nation is highly insecure in exclusive collaborations with advanced aviation nations, entering into the competitive arena and securing industrial competitiveness.

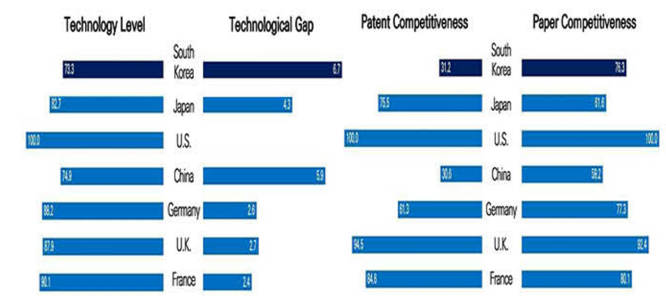


Figure 6 Aviation Technological Competitiveness (Korea Agency for Infrastructure Technology Advancement, 2019)

Despite the fact that aviation R&D investment has experienced an annual growth rate averaging about 18.5% in the past five years. It's worth noting that the share of aviation R&D in government budgets has averaged around 0.29% during this period, this situation arises because the investment scale only allows us to maintain the status quo. This is in stark contrast to the allotments for other sectors, such as 19.2% for biotechnology, 16.4% for ICT (including software), 8.5% for materials and nanotechnology, and 8.0% for machinery and manufacturing. Given the aviation sector's vital role in the global economy and its strategic significance, there is a pressing need for an appropriate level of investment.

Table 4 Aviation R&D weight (%) against to 2019-2023 government R&D budget (Kim Byeong-su, 2023).

Category	2019	2020	2021	2022	2023	합계
Gov-ernment R&D (A)	205,328	244,532	274,018	298,006	300,574	1,322,458
Aviation R&D (B)	517	580	830	900	1,019	3,846
Weight (B/A,%)	0.25	0.24	0.30	0.30	0.34	0.29

* Weight compared to government R&D (2019): Life & Health 19.2%; ICT & SW 16.4%; Materials & Nano 8.5%; Machinery & Manufacturing 8.0%

Future Direction of Aviation R&D

The future of aviation is set to be deeply intertwined with the advancement of eco-friendly aviation technologies. This shift is propelled by a global impetus towards environmental sustainability and carbon neutrality, echoing the increasing importance of curbing greenhouse gas emissions, pollutants, and noise. Notably, the ICAO, along with the United States and the European Union, has proactively established international certification standards aimed at curbing aircraft emissions and hazardous substances, with implementation scheduled to commence in 2023. In response to this international push for greener aviation practices, diverse R&D endeavors are already in motion, aimed at pioneering environmentally conscious aviation technologies. A noteworthy area of exploration is the deployment of advanced composites and novel materials to reduce aircraft weight and enhance fuel efficiency. The progress in this domain has reached a substantial milestone. Concurrently, researchers to develop high-performance aircraft engines that effectively curtail carbon dioxide emissions and transition aircraft propulsion systems from conventional fossil fuels to hydrogen fuel and biofuel, ultimately striving for emission-free flight. The promise of sustainable hydrogen fuel and biofuels holds the potential to completely offset aviation's carbon impact over the long term.

The acceleration in the popularity of unmanned aerial vehicles (UAVs) is a trend well underway, and it is not a distant future. Drones, which were formerly confined to military applications, are making swift expansion into various domains such as facility management, logistics, and agriculture. Particularly, big data, AI, IoT, advanced materials and optionally piloted personal/passenger air vehicles (OPPAVs) are becoming commercialized at a rapid pace, the dawn of urban air mobility (UAM), wherein urban centers emerge as pivotal nodes for aerial traffic, will come soon. Such technological innovations promise an aviation landscape harmoniously embedded in urban living, marking a pivotal step towards a more sustainable and integrated future.

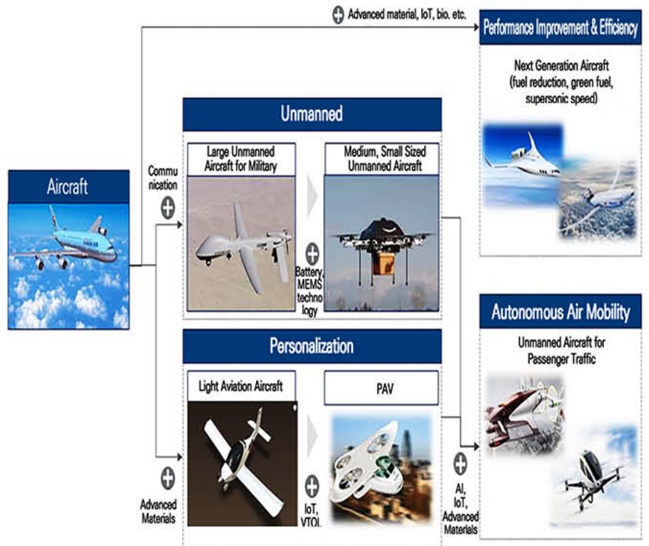


Figure 7 Future Development Direction of Aircrafts (Kim Byeong-su2, 2022; Kim Byeong-su, 2023)

The smooth and secure experience of flying hinges on a complex network of systems both on the ground and in the air, even extending to outer space. These systems encompass planning flights and monitoring the airport environment, handling immigration procedures, overseeing sky conditions and air routes, keeping tabs on weather patterns, and managing and providing air traffic information for navigation and airport conditions of other countries. These systems have been developed for various purposes and implemented in different ways, but they are standardized and function effectively all over the world. However, it's worth noting that despite some connections, these systems have operated relatively independently and in a decentralized manner.

Industry 4.0 technologies, encompassing big data, AI and IoT, are anticipated to organizationally connect or combine all air traffic-related systems into a unified one. The assortment of data gathered, analyzed, and shared by each system will be linked, merged, and broadly understood. This could even lead to predicting possible upcoming issues based on current system data and offering the best ways to prevent them. This new phase is termed the era of "smart skies." It envisions a scenario where all aspects of aviation infrastructure, spanning planes, airports, and airspace, aren't just connected but smartly interconnected.

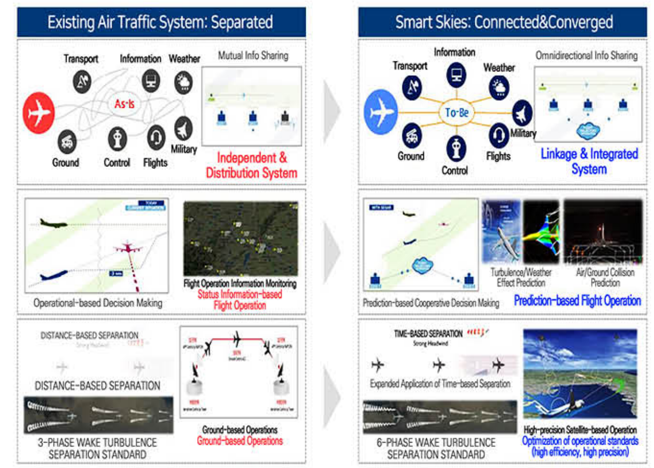


Figure 8 Future Development Direction of Air Traffic System Technology (Kim Byeong-su2, 2022; Kim Byeong-su, 2023)

Furthermore, the influence of space technologies, including satellites, is poised to dramatically broaden aviation's boundaries, extending from the terrestrial and aerial realms into space. This expansion is already underway. Fueled by the involvement of major private players like Blue Origin, SpaceX, and Virgin Galactic, this foray into space will propel the era of space traffic and astronautics beyond the realm of air traffic and aeronautics, potentially marking the onset of a new era of exploration.

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The IIAC Airport Industry Technology Research Institute is at the forefront of active engagement in **national R&D projects**, contributing to the realization of a safe and efficient national air traffic system.

The IIAC Airport Industry Technology Research Institute is involved in the **"Data-Driven Air Traffic Management" R&D project** (Apr. 2021–Dec. 2025) as a managing R&D institution, developing the **"ATM Performance Evaluation and Target Management Technology"** and **"ATM Decision Support System."** Through this, we will reinforce the research capability of the corporation in the field of air traffic and contribute to developing a safe and efficient national air traffic system.

ATM Performance Evaluation and Target Management Technology R&D Process and Achievements

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1. Introduction

How can we effectively meet the rising demand for air transport? As airport operators, the response might think of expanding physical facilities to enhance capacity and introducing cutting-edge technologies to expedite passenger processing. While expanding infrastructure and optimizing operations by utilizing cutting-edge technologies are indeed crucial steps, the development of air traffic management (ATM) technologies is equally essential.

The International Civil Aviation Organization (ICAO) has been in torment over this problem since the 1980s. This effort led to the establishment of the Global ATM Operational Concept (GATMOC)[1], a set of shared objectives for optimizing the operation of airports and airspace-resources that are inherently constrained, as demonstrated in Table 1 and the publication of the Global Air Navigation Plan (GANP)[2], a comprehensive framework encompassing strategies and technology pathways to realize this vision.

ICAO Vision Statement To achieve an interoperable global air traffic management system, for all users during all phases of flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements.
Vision of the ICAO's ATM Implementing an ATM system that ensures safe, efficient, sustainable, and seamless global interoperability throughout all stages of aircraft operations

Table 1 Vision of the ICAO's ATM (Doc 9854)

1) ICAO Doc 9750 Global Air Navigation Plan (GANP): In 1998, initially published GANP had been renewed every three years. However, due to rapid technology development and timely application of the requirements by ATM users, it has been transferred to online (web portal) to allow access anytime starting with 6th edition in 2019

2) ICAO Doc 9854 Global ATM Operational Concept (GATMOC)

To realize this ATM vision, ICAO suggests the Basic Building Block (BBB) and Aviation System Block Upgrade (ASBU) frameworks, outlining the organizational structure and requisite functions each contracting state must establish within the GANP. The ultimate aim is to achieve trajectory-based operations (TBO), wherein optimal flight paths are pre-designed by forecasting an aircraft's 4D trajectory (latitude, longitude, altitude, and time).

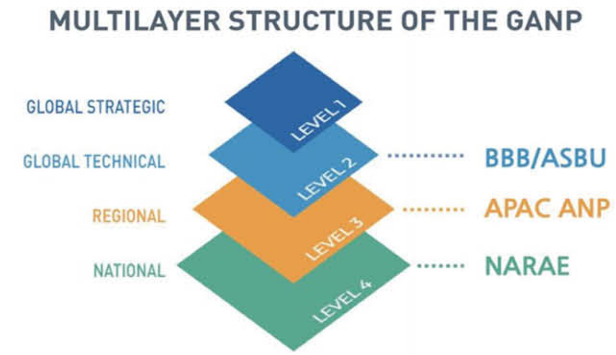


Figure 1 Structure of the ICAO's GANP

2. Data-Driven ATM R&D

Aligned with ICAO's guidance, Korea has established the National ATM Reformation And Enhancement (NARAE) Plan in 2021, comprising 5 core strategies and 14 pivotal tasks to ensure continuous, secure, and optimal flights through effective utilization of data and robust system support. Notably, the Ministry of Land, Infrastructure and Transport (MOLIT) is establishing an integrated air traffic data system, referred to as the "ATM Data Center" that can integrate, collect and process scattered air traffic data in a unified matter to realize "Data-Driven Air Traffic Management (Information)" along with the five core strategies (until 2024). In parallel, the "Data-Driven Air Traffic Management Technology Development Project" (hereinafter referred to as "R&D") is in the process by MOLIT to build an ATM decision support system utilizing this data (until 2025).

Initiated in 2021, the R&D is aimed at developing three pivotal core technologies essential for effective ATM, crucial for the implementation of the ICAO's GANP. This comprehensive endeavor engages eight entities spanning various sectors, including industry, academia, and research institutes, and the target technologies are elaborated in Table 2.

Table 2 Major R&D Technologies Categorized by Configuration Technology

Category	R&D Target Technology (system)
Configuration Technology 1	ATM performance evaluation and operation effect analysis technology (Air Traffic Performance Management System, ATPMS)
Configuration Technology 2	Air traffic capacity prediction technology (Integrated System for Airport and Airspace Capacity, ISAAC)
Configuration Technology 3	4D trajectory-based air traffic flow management technology (Collaborative Tactical Flow Management System, CTFMS)

Firstly, "ATM Performance Evaluation and Operational Effect Analysis (Configuration Technology 1)" endeavors to develop a technology that continually assesses Korea's ATM performance in accordance with ICAO-endorsed methods, identifies areas of deficiency, and assess (via simulation) proactive policies to improve them. For instance, this technology can predict how the introduction of a new system to reduce aircraft ground handling time might impact the overall air traffic system, including capacity and delays.

"Air traffic capacity prediction technology," being developed under Configuration Technology 2, dynamically assesses the aircraft capacity of airports and airspace, considering various constraints such as weather events and air traffic control (ATC) directives. Since aircraft delays escalate exponentially over time when demand surpasses capacity, it is imperative to accurately predict capacity to keep the balance between demand and capacity.

Lastly, Configuration Technology 3, "4D Trajectory-based Air Traffic Flow Management," is to advance air traffic flow management (ATFM) technology to effectively manage air traffic within capacity limits. For instance, Ground Delay Programs (GDP), issuing calculated take-off times (CTOT) to flights, prevent unnecessary holdings and delays when weather conditions are expected to reduce the airport's capacity for arrival.

This document introduces the research and accomplishments within the "ATM Performance Evaluation and Target Management System (ATPMS)," a core technology under Configuration Technology 1 within the aforementioned three focus areas. We will first look at the air traffic performance management techniques, key performance areas (KPAs), and key performance indicators (KPIs) as proposed by the ICAO. Additionally, we will provide a concise overview of the development progress of the ATPMS starting product (prototype).

3. Performance-Based Approach (PBA)

The ICAO places significant emphasis[3] on the systematic application of the performance-based approach (PBA) as a pivotal decision-making process to realize the vision of a "safe and efficient air traffic system," as outlined in the GATMOC. The ICAO's recommendation extends to all stakeholders in the ATM domain, encompassing governments, airport authorities, and airlines. They are encouraged to engage in air traffic performance management through the following six-step PBA process.

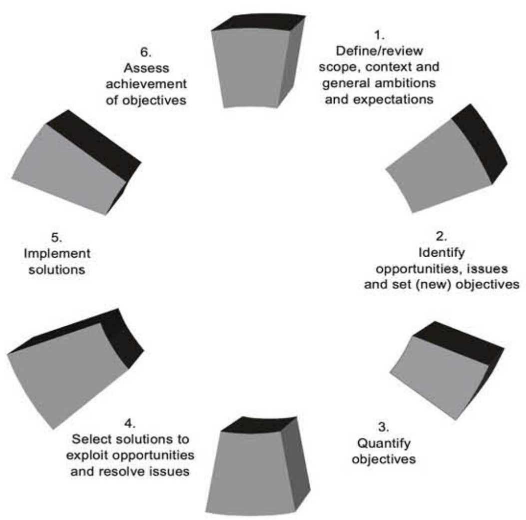


Figure 2 ICAO's PBA (ICAO Doc 9883)

Figure 2 explains an overview of the PBA process as delineated by the ICAO. The first step is to identify the overall context and scope of the tasks and set the goal and expectation in a strategic perspective. During this step, the ICAO integrates the direction and user expectation of the global ATM system development through the GATMOC, GANP, and the Manual on Global Performance of the Air Navigation System to define as eleven KPAs, stated in Table 3.

Table 3 KPAs of the ICAO's ATM (Reorganization of the GANP)

Key Performance Areas (KPAs)	Major contents and goals
Access and equity	Eliminating disparities by advancing technology to ensure equitable availability of air transportation resources for all
Capacity and Resilience	Expanding capacity to accommodate growing flight demands and establishing resilience to flexibly respond to unforeseen circumstances
Cost-effectiveness	Striving for optimal results with minimal expenditure, directing investments appropriately and timely
Efficiency	Achieving optimum operational efficiency by tailoring trajectories to users' preferences
Environment	Enhancing operational efficiency to reduce fuel consumption and emissions
Flexibility	Establishing a CDM system for operations aligned with user-preferred trajectories
Global interoperability	Securing the global interoperability amid the trend of automation and enhancement of navigation and information processing systems to ensuring seamless navigation
Participation by the ATM community	Encouraging participation and contributions across the aviation value chain to optimize limited navigation resources utilization
Predictability	Enhancing predictability through consistent navigation service operations and resource management to curtail unnecessary expenses
Safety	Eliminating navigation-related accidents and reducing near-miss incidents by 50%
Security	Developing a trust network to mitigate cyber threats stemming from system automation, digitization, and increased connectivity and accessibility

The 2nd and 3rd step of PBA is to identify problems and set goals. During these steps, performance objectives are established through methods like SWOT analysis, taking into account the system's strengths, weaknesses, and characteristics. The 4th and 5th step is to seek solutions based on the analysis outcomes and implement them afterward. The final 6th step is to assess the plan's proper execution. Subsequently, we circle back to the step 1 and carry out continuous performance management.

3) ICAO Doc 9883 Manual on Global Performance of the Air Navigation System

4. ATM Key Performance Indicators (KPIs)

Among the KPAs, the ICAO has developed 23 KPIs across the domains of efficiency, capacity, predictability, and safety (see Table 4). These KPIs facilitate the assessment of effectiveness of the GANP of each country.

First, efficiency aims for streamlined operations through optimal flight trajectories. This entails nine KPIs, including metrics like unnecessary waiting time on the ground (KPI 02, 13), optimal flight path taking (KPI 04, 05), and avoidance of unnecessary delays in taking off/landing (KPI 08, 17, 19). Through such indicators, ineffectiveness is measured at the gate-to-gate phase before the operation to calculate fuel consumptions to be saved (KPI 18) or carbon emission.

Capacity aims for managing surging peak demands and encompasses nine KPIs, including metrics like hourly aircraft capacity at airport and airspace (KPI 06, 09), delays incurred due to flow management (KPI 07, 12), and efficient handling compared to its capacity (KPI 10, 11).

Predictability aims for consistent and dependable air traffic services and encompasses six KPIs that compare actual performance against plans, including on-time arrivals and departures (KPI 01, 14) and flight time consistency (KPI 15). The evaluation outcome of predictability is used as essential information to establish flight schedules of airlines, ANSP airspace operation strategies, airport operation plans for airport administrator, etc.

Lastly, Safety aims for managing elements that hinders the safety of air traffic, including aircraft accidents (KPI 20), runway incursions and departures (KPI 21, 22), and in-flight hazards (KPI 23). Until today, the ICAO has managed aviation safety related issues through distinct frameworks like the Global Aviation Safety Plan[4](GASP). Yet, recognizing the imperative of harmonizing "efficiency and safety" in advancing the air traffic system, a more integrated approach has come to the fore. Consequently, since the 41st ICAO Assembly in 2022, a notable inclusion of four new safety-centric KPIs has been seamlessly integrated within the GANP framework.

4) ICAO Doc 10004 Global Aviation Safety Plan (GASP)

Table 4 KPIs of the ICAO's GANP

KPI	Content and Purpose	KPA
KPI 01 Departure Punctuality	Confirm aircraft departure(non-osculation) punctuality	Predictability
KPI 02 Excess Departure Ground Time	Minimize avoidable ground time for departing aircraft	Efficiency Predictability
KPI 03 Compliance with ATFM Slot	Enhance compliance with CTOT (Calculated Take-Off Time) for streamlined air traffic flow management (ATFM)	Predictability
KPI 04 Extension from Planned Flight Route	Check the efficiency of route at flight planning phase	Efficiency Capacity
KPI 05 Actual Route Extension	Check the efficiency of actual flight route	Efficiency Capacity Predictability
KPI 06 Airspace Route Capacity	Manage maximum capacity of designated airspace	Capacity
KPI 07 Route ATFM Delays	Measure the delayed time resulting from flow management actions due to route-related cause	Capacity
KPI 08 Additional Time in Terminal Airspace	Minimize unnecessary delays within the approach control zone	Efficiency
KPI 09 Airport Peak Capacity	Manage maximum capacity of designated airport	Capacity
KPI 10 Airport Peak Throughput	Measure the throughput of an actual aircraft in a specific airport	Capacity
KPI 11 Efficiency of Airport Throughput	Measure aircraft processing efficiency in relation to capacity	Capacity

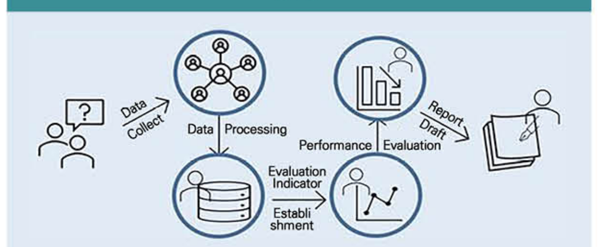
KPI	Content and Purpose	KPA
KPI 12 Airport/Terminal ATFM	Measure the delayed time resulting from flow management actions due to airport or access control zone-related cause	Capacity
KPI 13 Excess Arrival Ground Time	Minimize avoidable ground time for landing aircraft	Efficiency
KPI 14 Arrival Punctuality	Confirm aircraft arrival(osculation) punctuality	Predictability
KPI 15 Flight Time Consis-tency	Realize flight schedules by measuring route-based time deviation	Predictability
KPI 16 Excess Fuel Con-sumption	Measure additional fuel con-sumption and carbon emissions incurred due to avoidable stops and delay	Efficiency
KPI 17 Level Flight During Climbing Phase	Minimize maintaining level flight (altitude consistency) during the climbing phase after taking off	Efficiency
KPI 18 Altitude Limitations during Cruise	Minimize operational inefficien-cies stemming from altitude restrictions during cruising	Efficiency Capacity
KPI 19 Level Flight During Descent Phase	Minimize maintaining level flight (altitude consistency) during the descent phase for landing	Efficiency
KPI 20 Number of Aircraft Accidents	Enhanced air traffic safety through accident prevention	Safety
KPI 21 Number of Runway Intrusions	Enhanced safety of runway operation	Safety
KPI 22 Number of Runway Deviations		Safety
KPI 23 Instances of Close Encounters, TCAS Alerts, Separation Failures, and Mid-air Collisions	Enhanced operational safety during flight	Safety

5. ATM Performance Assessment and Target Management System (ATPMS)

Currently, various Korean organizations establish and oversee air traffic performance indicators. However, a comprehensive performance management system is insufficient, characterized by limited data availability and sporadic analysis of specific KPIs tailored to individual organization needs. To effectively enhance the national air traffic system's performance, a consistent and ongoing pan-national analysis is imperative.

The Air Traffic Performance Management System (ATPMS), a focal point of this R&D project, conducts real-time performance evaluation for over 20 air traffic performance KPIs, supporting data-based comprehensive decision making. Particularly, AT-PMS will be mounted in an "ATM Data Center" described earlier and ensures accurate and consistent performance evaluations through the utilization of high-quality data. Moreover, it provides goal management function for all ATM stakeholders to progress toward shared goals by sharing the performance information.

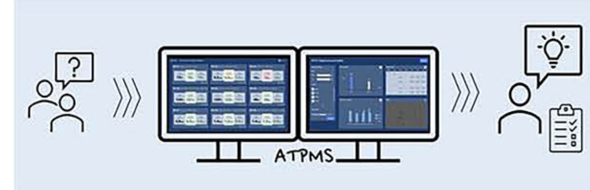
As-is



- Conduct on-demand ATM performance evaluations

- **Define** and analyze **essential indicators** for each organizational unit and responsible party → heavy workload/lack consistency
- **Directly collect** and process **data** from diverse entities → heavy workload/**limited accuracy**
- Use foreign-made system → **limited scalability**/excessive maintenance cost
- Impossible to manage performance target goal → difficult to identify **achievement**

To-be



- Execute data-based ATM performance evaluations and goal management

- Facilitate KPI-driven **performance monitoring and management** → streamlined operations/**securing consistency**
- Utilize the data from **ATM data centers** (2023) → streamlined operations/**enhanced accuracy**
- Develop domestic system → easy to apply the requirements and scale up /securing core technology

Figure 3 Current Status and Future of Korea's Air Traffic Performance Management

ATPMS provides the Dashboard, as depicted in Figure 4, offering a quick overview of performance evaluation outcome for each KPI of the ICAO introduced earlier. Additionally, it allows for a direct comparison between current performance levels and targeted values. Furthermore, it enables detailed analysis of performance evaluation outcomes through advanced analysis function. For instance, when KPI 01 "Departure Punctuality" is analyzed to have an annual average of 88%, users can specify detailed analysis parameters such as specific airports, airlines, and years. Notably, it provides detailed information, including flight plans and operational performance for each flight, offering a range of tools to identify causes of non-compliance.

With the complete development of ATPMS in 2025, Korea will possess a performance evaluation system for KPAs and KPIs aligned with international standards. This system will enable an objective assessment of airport and national air traffic system performance, pinpoint areas for improvement, and facilitate comprehensive policy establishment. Moreover, it is expected that this put Korea in position among the leading countries of aviation on the global stage, similar to Eurocontrol collaborating in performance management with the FAA[5], Brazil[6], etc.

Figure 4 ATPMS Dashboard (left) / Detailed Analysis (right)

5) EUROCONTROL and FAA (2019), Comparison of Air Traffic Management-related Operational Performance:

6) EUROCONTROL (2021), Brazil/Europe Comparison of Operational ANS Performance

Introduction to Core Technology Development for Capacity Forecasting

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1. Introduction

In a market economy, a product's price is determined by the balance between its supply and demand. If demand surpasses supply, the product's price will rise. Air traffic management (ATM) systems bear a resemblance to market economies. If an airport experiences more flight requests than it can accommodate, delays occur. In other words, the capacity of an airport is supply in a market economy, while the number of flights requesting to use an airport is demand in a market economy.

Major global airports, including those in Korea, limit the hourly demand– the number of taking-offs and landings–to avert delays arising from demand surpassing capacity. The moderate number of flights per hour is referred to as "slot." Airport administrators usually determine and allocate these slots to airlines to ensure the airport's seamless operation. For instance, Jeju Airport permits 35 aircraft taking offs or landings (slots) per hour. Adhering to allocated slots by airlines prevents delays.

As long as the airline operates business according to the number of allocated slots, no delay occurs. Nevertheless, various real-world factors can disrupt normal flight operations. Inclement weather and airport conditions are major exemplary cases[1]. The following Figure 1 illustrates the weather forecast for Jeju Island on May 27, 2019, before the outbreak of COVID-19. On that day, both a heavy rainfall watch and a strong wind watch were in effect simultaneously. Wind speeds at Jeju Airport reached 27 knots (approx. 50 km/h).

Figure 1 May 27, 2019 Jeju weather forecast (source: KBS Jeju)

A total of 504 flights (= 253 departures + 251 arrivals) were scheduled for operation at Jeju Airport on the specified day. However, due to adverse weather conditions, a total of 42 flights were canceled. Consequently, the day saw a total of 462 flights (= 231 departures and 231 arrivals) taking place. Among these, 184 flights (= 116 departures + 68 arrivals) experienced delays exceeding 30 minutes from their scheduled times[2].

Flight path data may allow you to check a comprehensive insight into the flight operation at Jeju Airport. The following Figure 2 illustrates the flight path data landed at Jeju Airport on May 27, 2019[3] at 3-hour intervals. Several observations can be made from the flight plan detailed in Figure 2 are as follows: Firstly, it is evident that arriving aircraft circled extensively within the airspace surrounding Jeju Airport, leading to a considerable elongation of airspace distance, particularly from 9 AM to 12 AM (as indicated in the second figure from the top left). Another notable aspect is the change in aircraft landing direction from 6 PM to 9 PM (as depicted in the third figure from the right.[4] The change in runway direction is a natural response to shifts in wind direction, doubling the workload of air traffic controllers and serving as an attribute to flight delays.

1) Other factors influencing standard flight operations include temporary airport facility closures for maintenance and navigation facility downgrades due to maintenance. However, such maintenance events are typically pre-planned. (in contrast to rapidly changing weather conditions) It implies that maintenance events offer a longer preparation window compared to weather-related occurrences.

2) Source: FOIS (Flight Operation Information System) Seoul Regional Office of Aviation

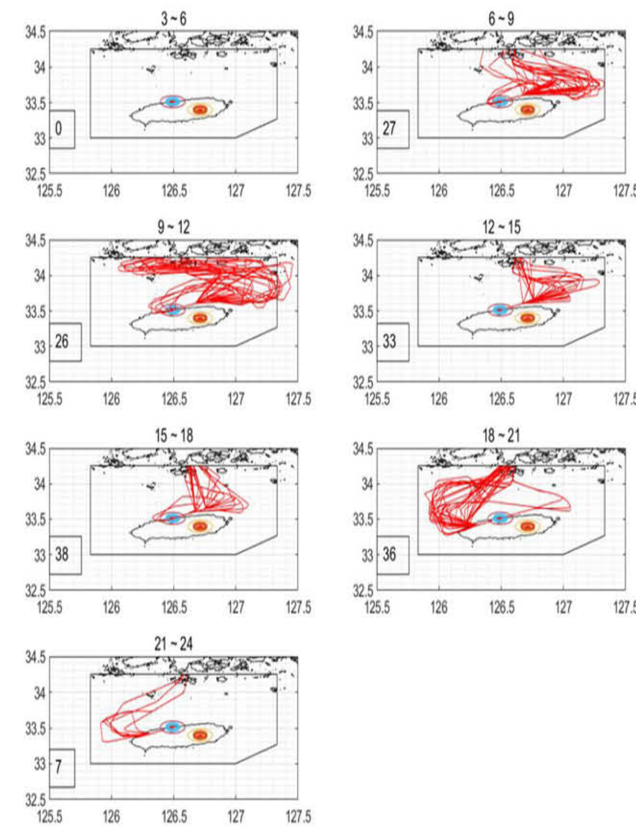

Figure 2 Trajectory of flights arriving at Jeju on May 27, 2019 (Source: FlightRadar24)

3) Routes to Jeju Airport are predominantly categorized into two main pathways: Gimpo-Jeju and Gimhae-Jeju routes. [Figure 2] illustrates the trajectory of an aircraft following the Gimpo□Jeju route within the Jeju Airport approach control airspace.

4) Jeju Airport features runways oriented towards headings 07 and 25. On May 27, 2019, most aircraft utilized runway 25 until 6 PM, at which point the runway direction changed to 07.

[Figure 3] describes the flight times of the aircraft in Figure 2 in a box plot format. As evident from the figures, aircraft entering the airspace encompassing Jeju (specifically the Jeju Approach Control Area), between 3 PM and 6 PM completed landings within an average duration of less than 15 minutes (as indicated by the red line within the third box from the right). Conversely, aircraft entering the airspace between 9 AM and 12 PM flied over an average of 30 minutes (as indicated by the red line within the second box from the left), consuming nearly twice the duration of aircraft entering the airspace between 3 PM to 6 PM.

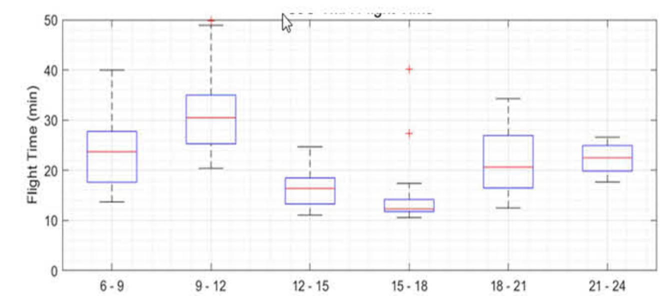

Figure 3 Flight time of aircrafts in Jeju Airport airspace on May 27, 2019 (Source: FlightRadar24)

At this point, we inevitably wonder "Can flight delays caused by adverse weather conditions be predicted and mitigated in advance?" More specifically, can we devise a system that harnesses a specific airport's flight plan, localized weather insights, airport control regulations, and historical operational data to autonomously anticipate impending flight delays? Such a system holds the potential to substantially curtail flight disruptions stemming from inclement weather–a frequent occurrence at Jeju Airport. This fundamental query, coupled with the necessity in real time, triggered to begin this research.

2. Body

What data can be used to predict future weather conditions at Jeju Airport?

To begin with, airlines have to report flight plan data to the air traffic control before taking off. This data encompasses intimate detail of the flight, including departure and arrival airport, aircraft type, flight number, and anticipated arrival and departure time for each flight to Jeju Airport.

The Korea Aviation Meteorological Office systematically discloses airport-oriented weather data relevant to aviation activities. An illustrative example is the terminal aerodrome forecast (TAF), which is a leading meteorological resource employed by airlines. TAF forecasts information on wind, the height of the cloud ceiling, visibility, and precipitation levels within an 8-km radius of the airport four times a day (2 AM, 8 AM, 2 PM, and 8 PM) at least six hours in advance (extending up to 30 hours). The Korea Meteorological Administration provides the Local Data Assimilation and Prediction System (LDAPS) and Korea Local Analysis and Prediction System (KLAPS), which segment the nation into a grid structure, providing comprehensive weather-related data, including wind direction, wind velocity, and visibility. Figure 4 is a localized forecast at Jeju Airport on May 27, 2019, 3 AM, forecasting robust southwesterly winds at noon.

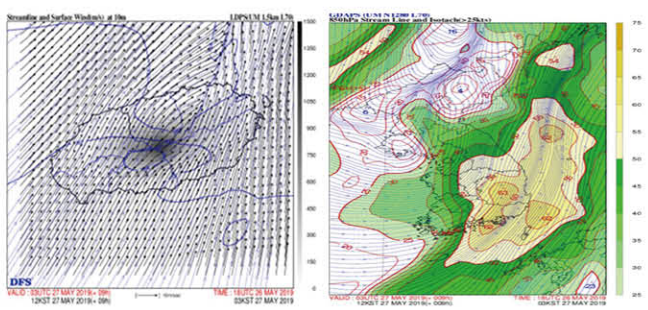

Figure 4 Example of localized forecast (left: wind field 10 m above ground; right: wind field at altitude of 1,500 m)

The objective of this research project is to develop core technology applicable to capacity forecasting by pivotal control organization (airport, access control, and local control) essential for proficient air traffic flow management by utilizing past aircraft and meteorological data. In this report, we will introduce one of the core technologies currently under development: Jeju Airport Capacity Prediction Model.[5]

To develop the Jeju Airport Capacity Prediction Model, aircraft and meteorological inputs. between 2018 and 2021 are collected. Typically, meteorological data are provided in graphical form (as indicated in Figure 4), we collected them in a numerical format and transformed them into a format, suitably primed for the purpose of analysis. We excerpted pivotal information, such as flight time, flight range, and runways employed by each aircraft. Table 1 is the summary of the variables used in the prediction model refined over multiple stages of experimentation.

Table 1 Consideration Variables of Airport Capacity Prediction Model

Category	Variable
Weather around the runway	Wind direction on the runway 10 m above ground (deg)
	Wind speed on the runway 10 m above ground (kt)
	Wind direction on the runway at the altitude of 1,500 m (deg)
	Wind speed on the runway at the altitude of 1,500 m (kt)
	Visibility at runway point (m)
Airport forecast	Airport predicted wind direction (deg)
	Airport predicted wind speed (kt)
Weather at the specific spot in the airport	YUMIN (IAF) wind speed at the altitude of 1,500 m (kt)
	DUKAL (IAF) wind speed at the altitude of 1,500 m (kt)
Flights	Employed runway
	Number of aircraft arrivals per hour (flight)
	Flight time in airspace around Jeju (min)

5) The term "airport capacity" refers to the hourly capacity that the runway can manage, which is subject to change depending on weather conditions. Put succinctly, when the weather condition is worsen, aircraft capacity decrease, diminishing its capacity.

Flight time in airspace around Jeju (min)

As described in Figure 5, the airport capacity prediction model is developed by going through three steps: 1) predicting the direction of the runway to be employed, 2) TMA delay prediction, and 3) predicting throughput. In each step, a distinct AI model[6] was applied. Figure 5 illustrates the input data, data source, and output data for each development stage within the prediction model.

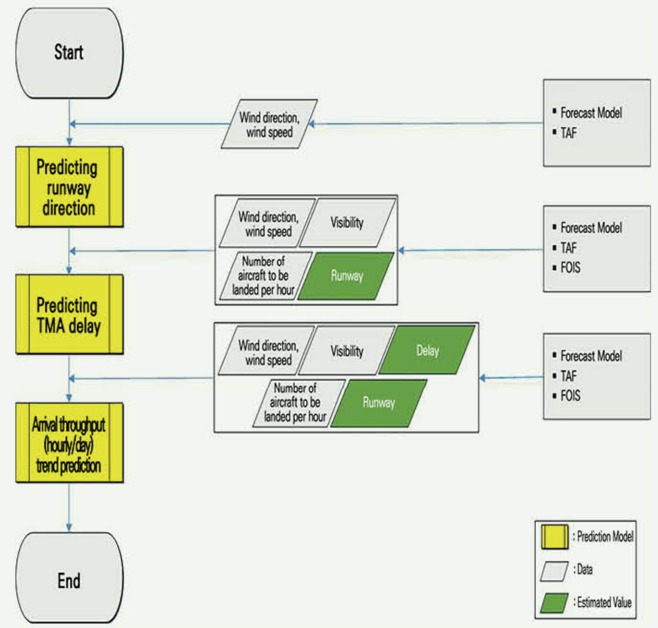

Figure 5 Airport Capacity Prediction Model Building Process (3-Steps)

Table 2 compares the estimated runway and employed runway based on the meteorological data released on May 27, 2019, 3 AM. As indicated in the table, runway prediction AI model, developed in step 1, accurately forecasts actual runway utilized across all time periods except for 8 PM.

Table 2 Runway Prediction Results

Time	Actual runway	Estimated runway	R25 probability	R07 probability
2019-05-27 7:00	25	25	0.95	0.05
2019-05-27 8:00	25	25	0.99	0.01
2019-05-27 9:00	25	25	1.00	0.00
2019-05-27 10:00	25	25	1.00	0.00
2019-05-27 11:00	25	25	1.00	0.00
2019-05-27 12:00	25	25	1.00	0.00
2019-05-27 13:00	25	25	1.00	0.00
2019-05-27 14:00	25	25	1.00	0.00
2019-05-27 15:00	25	25	0.99	0.01
2019-05-27 16:00	25	25	0.99	0.01
2019-05-27 17:00	25	25	1.00	0.00
2019-05-27 18:00	07	07	0.19	0.81
2019-05-27 19:00	07	07	0.32	0.68
2019-05-27 20:00	07	25	0.57	0.43
2019-05-27 21:00	07	07	0.46	0.54
2019-05-27 22:00	07	07	0.37	0.68

Figure 6 compares the estimated arrival flight throughput and actual flight throughput (i.e. number of incoming) at Jeju Airport based on the flight plan data and meteorological data released on May 27, 2019, 3 AM. As the figure depicts, the actual arrival flight to Jeju Airport (blue line) rapidly reduces due to worsening weather conditions from 9 AM to 12 PM, demonstrating that the AI model accurately predicts the actual throughput)[7].

6) Applied AI models are runway prediction and TMA for model development, random forest and light GBM model for delay prediction, and prophet model for arrival throughput prediction.

7) Root mean square error (RMSE) of the prediction outcome is 1.97.

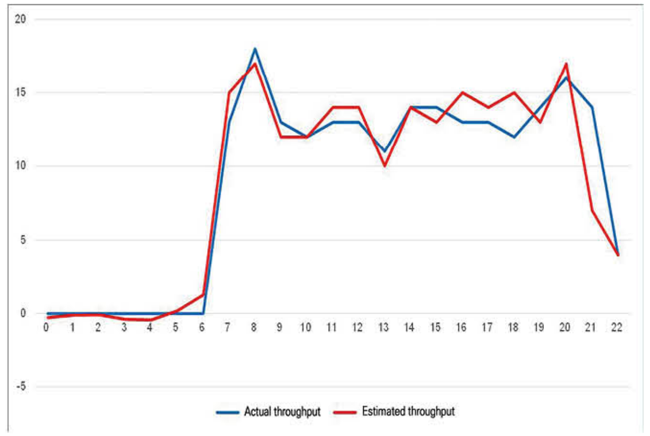

Figure 6 **Comparison between actual and estimated aircraft throughput that arrived at Jeju on May 27, 2019 (X-axis: time slot, y-axis: hourly arrival throughput)**

It seems necessary to quote the price determination by demand and supply in a market economy explained in the introduction. In this context, an airport's throughput corresponds to the supply facet in a market economy. If the airport's throughput dwindles to a point unable to meet the demand for flights due to unfavorable weather conditions, delays become an inevitability. Capacity prediction results can be utilized as input data for air traffic flow management (ATFM). If delays are anticipated as a result of comparing the estimated capacity and flight demand, a process known as "demand-capacity balancing" can be initiated to harmonize the airline demand, fostering seamless flow management.

So far, we explained the capacity prediction core technology development, centered on the Jeju Airport capacity projection model. However, this study concurrently embarks on designing a system that can predict capacity not solely for airports, but also for approach control airspace and flight routes-sectors. (The capacity prediction system devised in this study is named Integrated Airport and Airspace Capacity (ISAAC).)

3. Conclusion and Future Plans

This paper has introduced a segment of the ongoing research into the development of core technology for capacity prediction. Forecasting the capacity of air transportation infrastructure is a vital and intricate undertaking pursued across several nations, including the United States.

A prototype of the ISAAC system is expected to complete its development by the end of 2023. In the subsequent stage, spanning from 2024 over a span of two years, the ISAAC system developed in the initial stage will be installed and tested at the MOLIT Air Traffic Management Office's Air Traffic Command Center (ATCC) in Daegu, with the thrust of capacity prediction technology development poised to continue.

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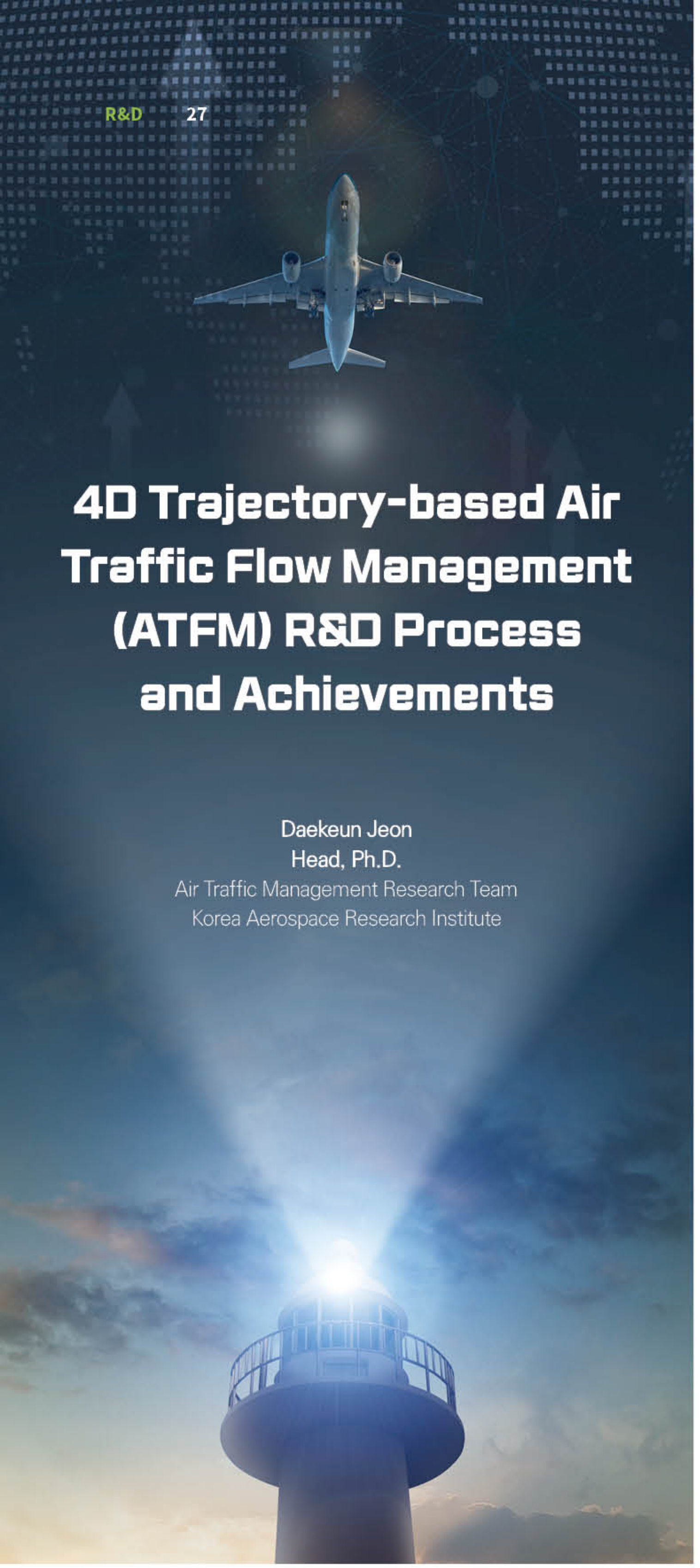

4D Trajectory-based Air Traffic Flow Management (ATFM) R&D Process and Achievements

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1. Introduction

The International Civil Organization (ICAO) has put forth trajectory-based operation (TBO) as the foundational principle for realizing the global air traffic management operational concept (GATMOC).[1] TBO shares accurate trajectory information among stakeholders, managing trajectories through collaborative decision-making (CDM), and universally employing trajectories as a comprehensive flight plan, aiming to enhance efficiency, predictability, capacity, flexibility, and interoperability.[1, 2] In this regard, the Korea Aerospace Research Institute (KARI) is spearheading the development of core 4D trajectory-based air traffic flow management (ATFM) technologies as part of its data-based ATFM technology development project and developing the collaborative traffic flow management system (CTFMS). CTFMS, a pivotal component of TBO with a demand capacity balancing (DCB) perspective within GATMOC, aims to facilitate the secure, efficient, and cooperative management of traffic flows across airspace and airports, leveraging precise 4D trajectories.[1] CTFMS is expected to develop through two phases(first phase: Apr. 2021-Dec. 2023, second phase: Jan. 2024-Dec. 2025), and the first phase is currently in progress.

This paper introduces an in-depth exploration of the research journey and outcomes encompassing the analysis of Korea's air traffic environment, recognition of existing system limitations, formulation of CTFMS requirements to address these challenges, and the system design, core algorithms, and initial product prototypes.

2. Analysis of the Korean Air Traffic Environment and System Constraints

ATFM initially sought to control air traffic demand not to exceed air traffic control (ATC) capacity. Over time, ATFM evolved beyond its foundational role, progressing towards optimizing ATC capacity utilization while ensuring the coherence of traffic demand with available ATC capacity for smooth, safe, and fast air traffic flow.[3]

Figure 1 Traffic Demand and Capacity Balance (DCB)

In Korea, the MOLIT Air Traffic Management Office's Air Traffic Command Center (ATCC) takes the role of ATFM, targeting all aircraft departing from, arriving at, or transiting through the Incheon flight information region (FIR). The Incheon FIR exhibits, as indicated in Figure 2, has smaller air space compare to its neighboring countries like China and Japan, and has a rigid structure due to its large portion of airspace for military purposes. Moreover, international flight takes a larger portion of all flights and is predominantly centered around Incheon Airport, it is difficult to employ conventional ATFM, which is employed in countries like the United States and Australia for domestic flights, to be effective. Considering that unpredictable and complex ATFM restrictions from neighboring countries take place often and adjusting take-off time is highly significant due to the short distance between the Incheon Airport and Incheon FIR (see Figure 2), a more tactical level of integrated airspace/airport scheduling using precise 4 trajectory information is required. Furthermore, establishing linkages between proposed initiatives like the Northeast Asia Regional ATFM Harmonization Group (NARAHG) and the Asia-Pacific Cross-Border Multi-Nodal ATFM Collaboration (AMNAC). However, existing ATFM systems used in domestic operations exhibit limitations concerning four-dimensional trajectory prediction, intricate scheduling based on ATFM restrictions, integrated airspace/airport scheduling, and regional ATFM linkage.[1]

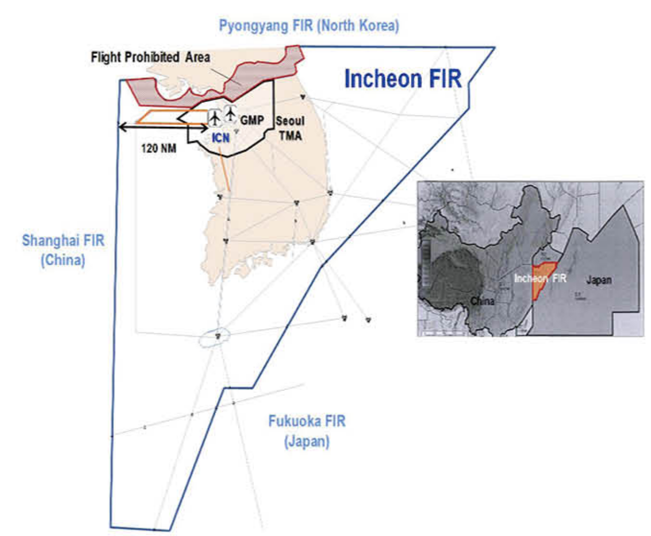

Figure 2 Korean Air Traffic Landscape

3. Definition of CTFMS Requirements

CTFMS was proposed to establish a system that fosters a higher level of collaborative and tactical ATFM within the context of the Korean air traffic environment outlined in Chapter 2.

Table 1 outlines the principal requisites of the CTFMS. These requirements encompass established slot-based traffic management initiatives (TMIs) applicable to both airspace and airports, including Airspace Flow Programs (AFP) and Ground Delay Programs (GDP). Additionally, the CTFMS extends support to TMIs requisite for decision-making by flow managers. Meanwhile, to ascertain the necessity for TMIs concerning flow management and modeling, forecasting the demand for airspace and airports is a crucial step. This demand calculation necessitates the input of various variables, including flight plans, navigation data, and meteorological information, to predict the four-dimensional trajectory. Furthermore, diverse displaces are indispensable for effective flow management, such as visual aids like demand graphs, flight lists, and maps.

Table 1 Major Requirements of CTFMS

Category	Requirement	Summary
Linkage	Input external materials	Input flight plans, navigation data, and weather conditions data
Modeling	4D trajectory prediction	Predicts aircraft trajectories in four dimensions based on flight plans, navigation data, and weather conditions.
	Airspace demand prediction	Predicts the demand for flow constrained areas (FCA) utilizing 4D trajectories
	Airport demand prediction	Predicts the demand for specific airport demand from utilizing 4D trajectories
	AFP	Calculates CTOT to balance demand and capacity in the FCA
	GDP-A	Calculates CTOT to balance demand and capacity for arrival airports
	GDP-D	Calculates CTOT to balance demand and capacity at departure airports
	GS	Calculates CTOT to match demand and capacity (capacity=0) at arrival airports

Cate-gory	Requirement	Summary
Mod-eling	DS(FCA GS)	Calculates CTOT to balance demand and capacity (capacity=0) in the FCA
	Level capping	Calculates change in demand when aircrafts are subjected to level capping
	Re-routing	Calculation of change in demand when aircraft flight path is modified
	Multi-TMI processing	Generates TMIs considering multiple FCAs or airports concurrently
	AMNAC/NARAHG linkage	Inputs and issues CTOT and CTO, the concept of AMNAC and NARAHG
	Integrated airspace-airport scheduling	Seamlessly links scheduling inputs and outputs between A-CDM (or DMAN) and CTFMS
	Manual slot adjustment	Selects CTOT target, manual adjustment, and slot exchange between aircrafts
	Automated flight path generation	Automatically generates missing flight paths within the schedule based on statistical data
	CTOP	Calculates path allocation and time delay considering the Trajectory Option Set (TOS)
Dis-play	Flow management status board	Displays the summary of the traffic status for major stations and airports subject to flow management
	Demand graph	Depicts demand graph for airports/FCAs (if necessary, display with the demand)
	Flight list	Displays airport/FCA flight list and filtering
	Map	Displays AIP, FCA, airport, real-time navigation, 4D trajectories, etc.
	FCA/airport and TMI setting	Generates, modifies and deletes FCA/airport parameters and configures TMI

AFP: Airspace Flow Program
GDP-A: Ground Delay Program - Arrival
GDP-D: Ground Delay Program - Departure
GS: Ground Stop
DS: Departure Stop
TMI: Traffic Management Initiative
CTOP: Collaborative Trajectory Options Program
FCA: Flow Constrained Area
CTOT: Calculated Take-Off Time
A-CDM: Airport - Collaborative Decision Making
DMAN: Departure Manager
AIP: Aeronautical Information Publication

Among the various requirements described in Table 1, the shaded items are distinct from CTFMS when compared to existing operational systems. These requirements are added to respond to the unique traffic environment of Korea and support future TBOs. Among these, multi-TMI processing, which considers the flow management of multiple airspace and airport, regional ATFM support including AMANC/NARAHG, ATFM, and arrival management linked scheduling, airlines-control organization trajectory information sharing-based Collaborative Trajectory Options Program (CTOP) are included.

4. CTFMS Design

With reference to the identified system requisites, the system's components and data flows have been systematically organized, as depicted in Figure 3. One of CTFMS's vital elements is the flow management server (FMS), encompassing the flight correlator, responsible for integrating flight plans and establishing connections between navigation and flight plans; the Trajectory Predictor, which anticipates the four-dimensional trajectory of each aircraft employing flight plan and navigation data; and the flow manager, tasked with predicting demand based on trajectory data and generating ATFM measures by comparing demand and capacity. Besides FMS, CTFMS includes the flow management terminal (FMT), designed for user interface functions, and the external interface system (EIF) as subsystems to process raw external data.[1]

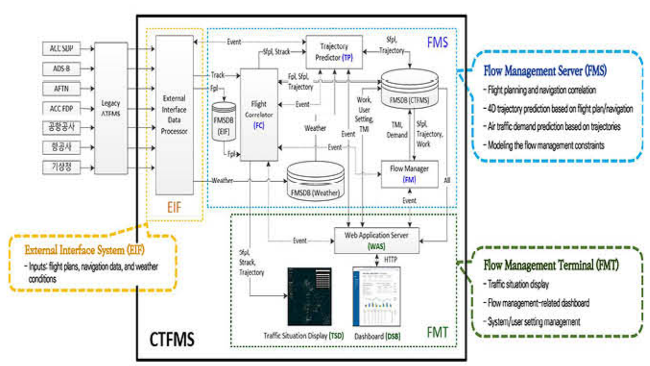

Figure 3 CTFMS System Design

5. CTFMS Core Algorithm Development

The fundamental algorithms of CTFMS can be summarized as aircraft 4D trajectory prediction, traffic demand estimation, and TMI modeling. Aircraft 4D trajectory pertains to an aircraft's flight trajectory in four dimensions (3D coordinates by time), and the predicted 4D trajectory data constitutes the foundational information for estimating traffic demand. As depicted in Figure 4, Aircraft 4D trajectory prediction involves synthesizing flight plans, navigation data, and meteorological information. Eurocontrol's Base of Aircraft Data (BADA) is employed as the performance data for different aircraft types.

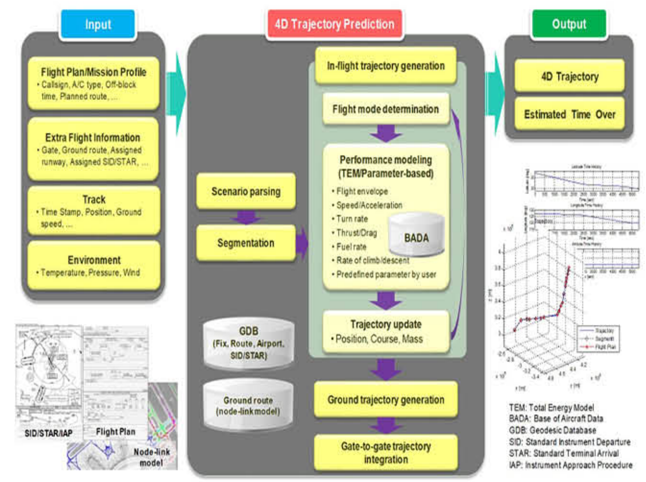

Figure 4 4D Trajectory Prediction

Air traffic demand has to be calculated for each airport and airspace. For airports, the calculation of demand of a certain time range involves extracting takeoff and landing times from the anticipated 4D trajectories. For airspace, it necessitates the forecasting of traffic demand in diverse domains (including altitude upper/lower limits), encompassing control sectors, flight paths, and fixes. This is achieved by determining the entry time of aircraft into three-dimensional zones, presented as polygons, circles, columns, or the instances when aircraft cross lines or points.

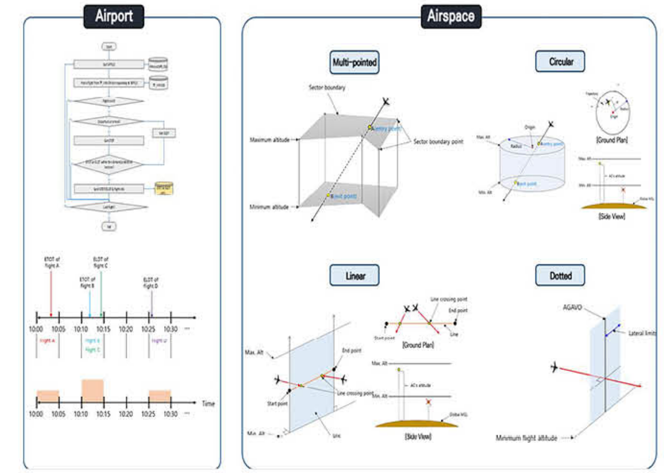

Figure 5 Air Traffic Demand Calculation

Flow management interventions encompass measures like AFP, GDP-A, GDP-D, etc., as outlined in Table 1 and Figure 6. Grounded in the modeling of these flow management strategies, calculated take-off time (CTOT) is computed and issued to adjust aircraft departure schedules, resulting in lower congestion at both airports and in the airspace.

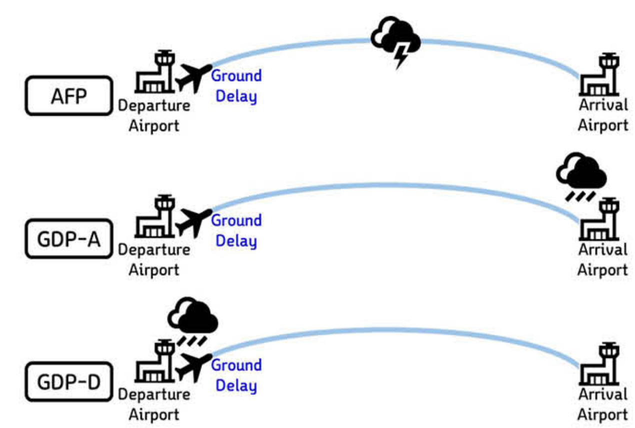

Figure 6 Slot-Based Flow Management

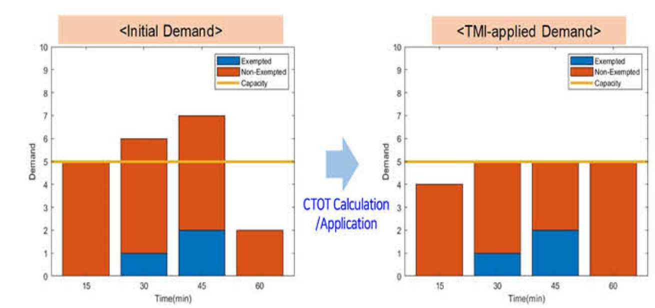

Figure 7 CTOT Calculation and Application

The study entails the development of optimization-based and heuristic-based algorithms for CTOT computation. In the initial phase, heuristic-based algorithms are applied due to their computational expediency and calculation stability to the prototype. Beyond slot-based TMIs, TMI, which is responsible for supporting decision-making for methods like level capping and re-routing, and TBO-based CTOPs are subject to TMI modeling. These will be integrated into the system during the second phase.

6. CTFMS Prototype Development

Before full-scale system development, a prototype was promoted to gather specific user feedback. Figure 8-12 is an example of 4D trajectory, demand, and flow management modeling exhibited via the FMT.

Figure 8 provides a comprehensive view of the flow management status, vividly illustrating the demand within all managed airports and airspace against their capacities. Furthermore, in the case where GDP-A, AFP, and other TMI modeling are being executed or TMI is issued, these are marked with distinct colors (blue and red, respectively) to enhance the visibility of flow management progress.

Figure 8 Comprehensive Flow Management Status Display

Figures 9 and 10 present detailed representations of airspace and airport traffic demands, respectively. These visuals show the map-based location of target points, historical data regarding flight waypoints, and demand distribution.

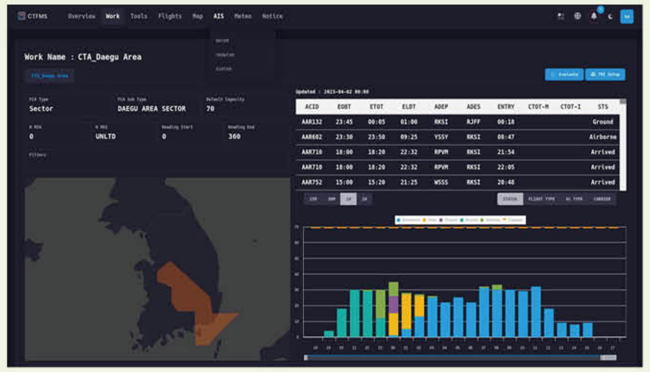

Figure 9 Example of Airspace Traffic Demand (Daegu Sector)

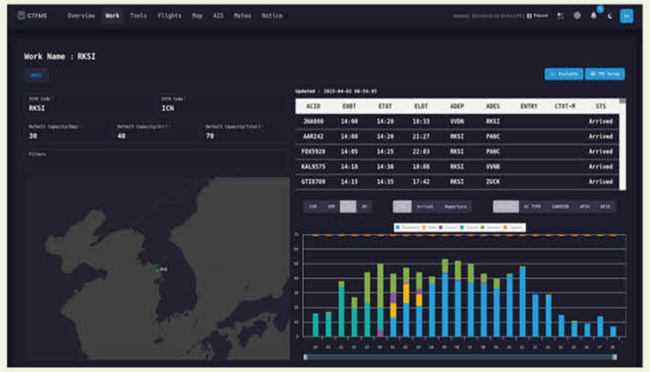

Figure 10 Example of Airport Traffic Demand (Incheon Airport)

Figures 11 and 12 exemplify the results of modeling AFP and GDP-A to attain demand-capacity equilibrium in airspace and airports. In Figure 11, Program rate shows the applied capacity limit to flight passing AGAVO Fix. It can input the corresponding value by categorizing time slots. The bar graph placed on the bottom right shows the distribution of demand before and after modeling, while CTOT modeling results (CTOT-M) is in the flight list in the upper right.

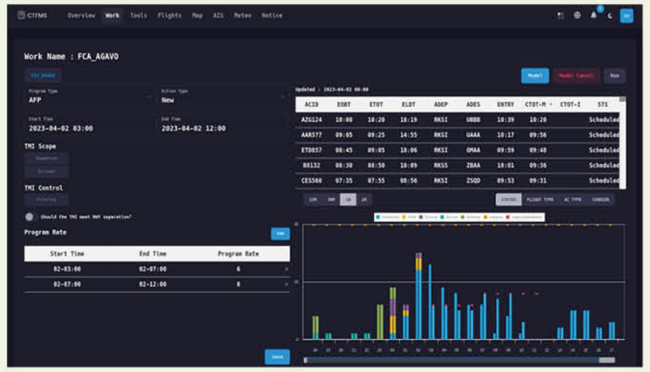

Figure 11 Example of AFP Modeling Result (AGAVO Fix)

Figure 12 is the GDP-A modeled result according to the Demand Program Rate of Jeju Airport, demonstrating that the demand is adjusted to not exceed the capacity at the set time and calculated ground delay results (CTOT-M) in the flight list.

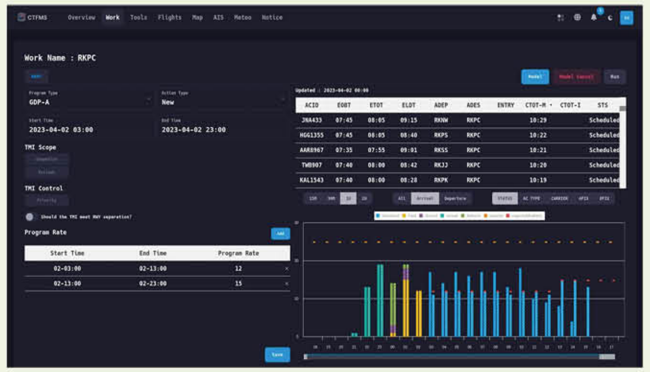

Figure 12 Example of GDP-A Modeling Result (Jeju Airport)

7. Conclusion and Future Plans

This paper encapsulates the inception, requirements definition, system design result, core algorithm and prototype development of CTFMS.

Currently, CTFMS is in the midst of phase 1 prototype development, expected to conclude by the close of 2023. In phase 2, which is expected to begin in 2024 and end in 2025, the MOLIT Air Traffic Management Office's Air Traffic Command Center (ATCC) will deploy and test the phase 1 prototype and then test the phase 2 system. AIR

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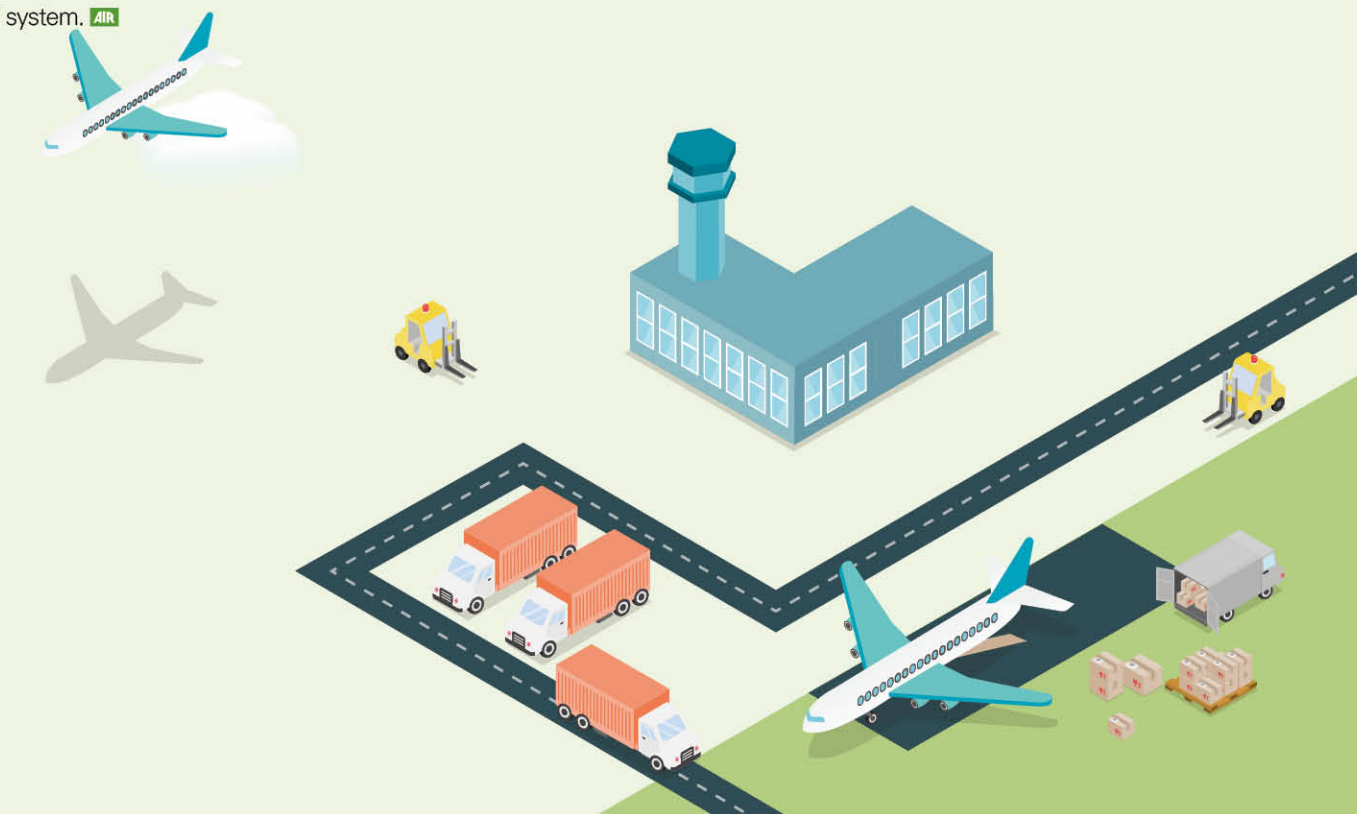

With our sights set on the **global aviation sector**,
we aspire to propel the IIAC Airport Industry Technology Research Institute into a specialized research institution.

As part of its independent R&D activities, **we developed a passenger boarding bridge smart controller system.**
With automated facilities developed by
IIAC, we will take the lead in securing efficiency in airport operations and operating smart airports.

Development and Significance of Automated Passenger Boarding Bridge (PBB) Controller System

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The passenger boarding bridge (PBB) is an essential infrastructure to operate airports and requires relatively high dependency on human labor. Recently, due to the COVID-19 pandemic and strikes, there have been issues in operating core facilities of the airport. Against this backdrop, our research project focuses on the automated PBBs, encompassing the development of route planning, following control technology, and aircraft recognition capabilities to mark a crucial step toward improving airport operations and resilience.

Figure 1 Incheon International Airport PBBs and Apron

Introduction

The rapid advancement of autonomous driving and artificial intelligence technologies has led to increased applications in various industrial sectors. This progress has also elevated the maturity level of core technologies related to these fields.[1] Globally, there is a growing adoption of robots for automating routine tasks within industrial settings, particularly for activities like facility cleaning, physical operation system management, and monitoring.[2]

This trend is mirrored within domestic industrial contexts, with a rising number of applications and development instances.

Notably, large-scale public facilities such as logistics centers, hospitals, terminals, and airports – crucial national infrastructures heavily reliant on human labor – are increasingly embracing these technologies.[3]

In light of these developments, this research project focuses on autonomy of the osculating for PBBs, a prominent feature of airports. The primary objective is to enhance operational efficiency and align with the future vision of smart airport initiatives. To achieve this goal, we have undertaken comprehensive research and development in route planning, follow-up control technology, and aircraft recognition.[4] Developed technologies are currently undergoing operational validation through a pilot installation at Incheon Airport's aprons at the concourse.

Background and Necessity of Research Development

(Development Imperative) Changing societal dynamics, such as the escalating cost associated with labor-intensive facility management and operations, alongside the emergence of non-face-to-face work environments driven by infectious disease considerations, underscore the mounting need for facility automation. This imperative is particularly pronounced in the context of airport terminals. The continuous surge in traveler and cargo demand necessitates the expansion of terminal infrastructure, compelling the need to optimize airport operations and achieve peak efficiency through comprehensive integrated systems.

(Market Trend) Since 2019, starting in Japan, Australia, and European countries have actively pursued direct development or introduction of automation technology for PBB operations. Particularly, Shin Meiwa, a major PBB manufacturer in Japan, co-developed with Panasonic, a front-runner in deep learning and PLCs, to collaboratively engineer this technology. Completed in 2020, pilot testing is underway at Changi Airport in Singapore and various airports across Japan.

Figure 2 Automated PBB systems by Shin Meiwa (up), by Australia (down)

China has embarked on the establishment of guidelines for the application of autonomous driving facilities. A strategic blueprint aims to deploy smart PBB technology in over 10 international airports within China by 2025, leveraging standardized automation protocols.

Figure 3 Concept Map of China's Smart PBB

(Competitiveness of Aviation Industry) PBBs are pivotal components akin to navigation facilities within airport operations. In Korea, these facilities are integral not only to Incheon Airport but also to Gimpo Airport, Jeju Airport, and Gimhae Airport, with more than 300 units operational. Given their lifespan of 10 to 15 years, these assets necessitate periodic replacement. The global landscape showcases a consistent pattern of constructing and renovating international airports, steadily increasing in the demand for PBBs.

Consequently, this technology emerges as a formidable force, not only as a fundamental for PBBs, but also as a linchpin for facility integration through automation.

Development Details

There are three phases to developing the configuration of an automated PBB system: construction of an automated PBB simulation system and scenario verification technology; automated PBB controller system development technology; and deep learning-based aircraft door and engine recognition technology.

1) The construction of an automated PBB simulation system and scenario verification technology focus on designing integrated

scenarios for automated PBB operation. This includes the construction of designed scenarios within a virtual environment, facilitating the identification of potential operational risks associated with the PBB in advance.

The simulation environment is a meticulously modeled realm encompassing aircraft depots, PBBs, operational vehicles, and personnel. Incorporating realism in shape, it factors in parameters (wind direction, wind speed, and friction coefficients), simulating varying weather conditions' influence on PBB operations in advance.

This simulation covers an array of aircraft types, featuring three representative models. And it is designed to accommodate 3 aircraft in a single apron to adjust the number of PBBs according to a scenario.

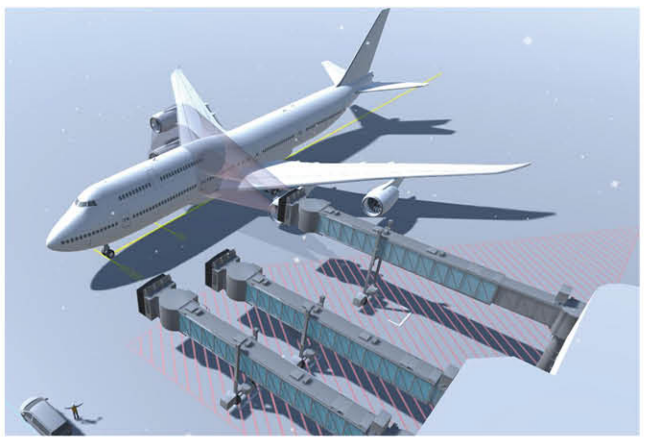

Figure 4 Virtual Simulation Screen of Automated PBB Operation

2) Automated PBB controller system development technology is designed and developed to be applicable to new as well as existing PBBs, facilitating seamless interlocking between diverse control systems. The transition from the conventional analog control, managed by joysticks and contact buttons, involves a systematic conversion of data into a digital format to establish a controller system that can both transmit and receive data by integrating the operation of the automated PBB system.

Moreover, a distinct message format was devised to enable data linkage with the controller, following an established PLC method. This format was developed to efficiently link the automatic integrated processor and the existing controller. The further enhanced system is inserted and interlocked with logic capable of tracking and contacting the position of the PBB and facilitating vibration reduction. In this process, it was developed to have identical human driving procedures.

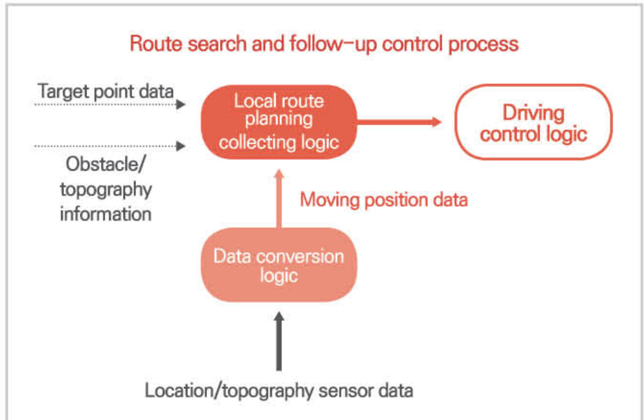

Figure 5 Block Diagram of Automated PBB Controller

3) Deep learning-based aircraft door and engine recognition technology is a groundbreaking innovation aimed at precisely identifying the tangent position of PBBs. Developed by harnessing advanced deep learning techniques and sensor convergence technology, this technology was utilized in many technological developments. To ensure seamless real-time processing of data captured by cameras and lidar deployed at the PBB site, we implemented a user-friendly interface program operation technology to facilitate smooth monitoring. For the implementation of aircraft recognition technology, we adopted a strategic approach by deploying multiple sensors to mitigate the impact of data errors arising from varying daytime and nighttime conditions as well as weather fluctuations.

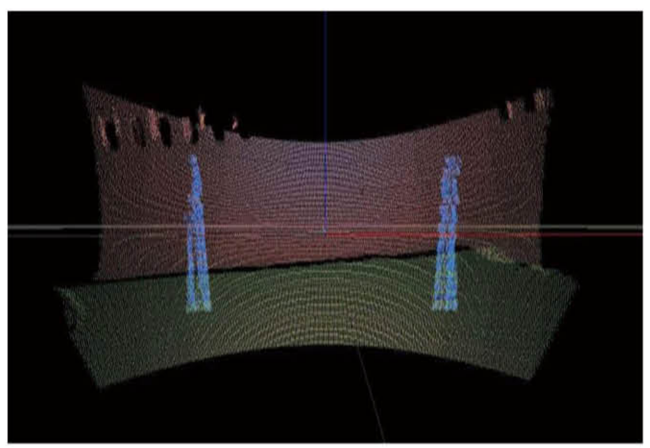

Figure 6 3D Lidar Sensor Aircraft Body Data

To amass a dataset for aircraft images encompassing diverse weather conditions-daytime, nighttime, and everything in between to apply deep learning techniques, we collected over 10,000 aircraft images and we embarked on an extensive research endeavor to master the nuances of deep learning through a labeling process.

Furthermore, by fusing and harmonizing data from multiple sensor types, we succeeded in generating unified three-dimensional aircraft door position data.

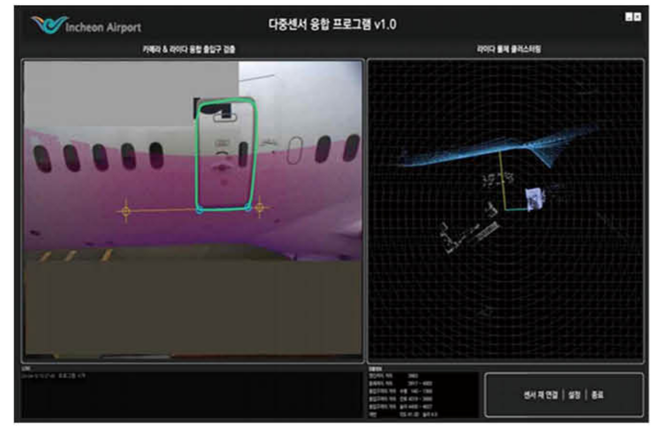

Figure 7 Aircraft Door and Engine Recognition System

Development Results and On-site Evaluation

The PBB smart controller system, developed as a result of this research, underwent rigorous testing on real aircraft, specifically E-class aircraft A330 and B777. Consequently, the identification accuracy of aircraft doors and engine unit identification rate surpassed an impressive 99%. The time taken for approach and contact to the PBB, which is the standard under the operation manual, clocked in at under 2 minutes. Moreover, the proximity between the fuselage and the PBB during the approach, amounting to a mere 45 cm, demonstrated close alignment with the full approach.

In the forthcoming stages, our focus will center on enhancing the technology through exhaustive experimental validation across diverse conditions and environments. We are committed to further simplifying the established system and developing a modular automated PBB system that is not categorized by manufacturer.

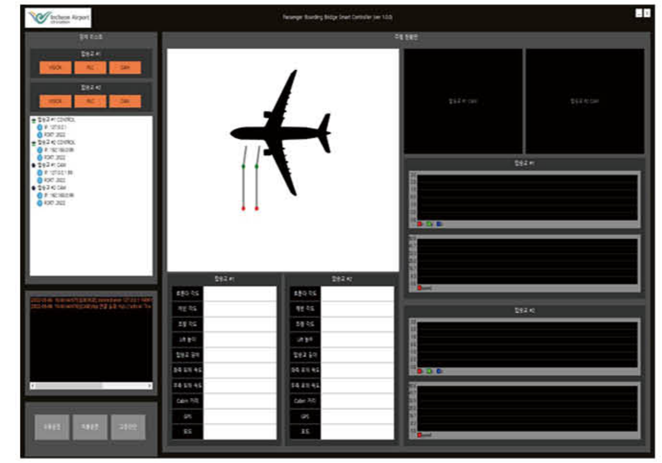

Figure 8 Configuration of Integrated Automated PBB System

Conclusion and Closing

So far, we took a glimpse into the remarkable achievement by the Incheon International Airport Corporation (IIAC) Airport Industry Technology Research Institute in developing its exclusive PBB smart controller system. This is not only a platform development project by the IIAC, but also development projects for the automation of critical aviation/airport industry facilities. This innovation holds the potential to reverberate globally, revolutionizing the airport industry across different regions. AIR

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