KAA kenya Airports Authority

Master Plan for Jomo Kenyatta International Airport (JKIA)

KE25032-0100D February 2026

Volume I : Final Master Plan Report

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LIST OF ABBREVIATIONS:

S/N	ACRONYM	DESCRIPTION
1	KAA	Kenya Airports Authority
2	JKIA	Jomo Kenyatta International Airport
3	WAP	Wilson Airport
4	IATA	International Air Transport Association
5	ICAO	International Civil Aviation Organization
6	FAA	Federal Aviation Administration
7	CAT	Category
8	KQ	Kenya Airways
9	RFFS	Rescue and Firefighting Services
10	MW	Megawatt
11	KV	Kilovolt
12	GA	General Aviation
13	KCAA	Kenya Civil Aviation Authority
14	GSE	Ground Support Equipment
15	FBO	Fixed Base Operator
16	GDP	Gross Domestic Product
17	O&D	Origin and Destination
18	DDFS	Design Day Flight Schedule
19	ATCT	Air Traffic Control Towers
20	OLS	Obstacle Limitation Surface
21	ADRM	Airport Development Reference Manual
22	SWM	Solid Waste Management
23	MSW	Municipal Solid Waste
24	MP	Master Plan
25	NEP	Noise Exposure Projection
26	NEF	Noise Exposure Forecast
27	EPNL	Effective Perceived Noise Levels
28	dBa	A-Weighted Decibel
29	CAPM	Capital Asset Pricing Model
30	AGL	Airfield Ground Lighting
31	WACC	Weighted Average Cost of Capital
32	NPV	Net Present Value
33	IRR	Initial Rate of Return
34	MS	Microsoft
35	CAD	Computer Aided Design
36	GIS	Geographic Information System
37	PSZ	Public Safety Zone
38	CAPEX	Capital Expenditure
39	EAC	East African Community
40	AIP	Aeronautical Information Publication
41	ATM	Aircraft Movement
42	CAGR	Compound Annual Growth Rate
43	ANPR	Automatic Number Plate Recognition
44	ARINC	Aeronautical Radio Incorporated
45	AV	Audio Visual
46	AVSEC	Aviation Security
47	BHS	Baggage Handling System
48	BIDS	Baggage Information Display System

S/N	ACRONYM	DESCRIPTION
49	BS	British Standards
50	CCTV	Close Circuit Television
51	CUTE/CUPPS	Common Use Terminal Equipment/ Common Use Passenger Processing System
52	DAS	Distributed Antenna System
53	DB	Distribution Backbone
54	DB	Distribution Board
55	DCI	Directorate of Criminal Investigation
56	DCS	Departure Control Systems
57	ELV	Extra Low Voltage
58	EMI	Electromagnetic Interference
59	EOL	End Of Life
60	ESD	Emergency Shutdown
61	FAS	Fire Alarm System
62	FIDS	Flight Information Display System
63	FO	Fibre Optic
64	FOC	Fibre Optic Cable
65	GEA	Government Enterprise Architecture
66	HMS	Hydrant Monitoring System
67	HQ	Headquarters
68	HVAC	Heating, Ventilation and Air Conditioning
69	IATA	International Air Transport Association
70	ICAO	International Civil Aviation Organization
71	ICT	Information Communication Technology
72	IEC	International Electro-Technical Commission
73	IEEE	Institute of Electrical and Electronics Engineers
74	IP	Internet Protocol
75	IPTV	Internet Protocol Television
76	ISMS	Information Security Management System
77	ISO	International Organization for Standardization
78	ISP	Internet Service Provider
79	IT	Information Technology
80	JKIA	Jomo Kenyatta International Airport
81	JTL	Jamii Telecommunications Ltd
82	KAA	Kenya Airports Authority
83	KATO	Kenya Association of Tour Operators
84	KCAA	Kenya Civil Aviation Authority
85	KMD	Kenya Meteorological Department
86	KNBS	Kenya National Bureau of Statistics
87	KPC	Kenya Pipeline Company
88	KQ	Kenya Airways
89	KRA	Kenya Revenue Authority
90	KRC	Kenya Railways Corporation
91	KURA	Kenya Urban Roads Authority
92	LAN	Local Area Network
93	MCS	Master Clock System
94	MER	Main Equipment Room
95	MOD	Ministry of Defence
96	MOI	Ministry of Interior
97	NEC	National Electrical Code

S/N	ACRONYM	DESCRIPTION
98	NFPA	National Fire Protection Association
99	NTP	Network Time Protocol
100	OSP	Outside Plant
101	PA/VA	Public Address Voice Alarm
102	PAS	Public Address System
103	PBX	Private Branch Exchange
104	PCK	Postal Corporation of Kenya
105	PDC	Primary Data Centre
106	PIDS	Perimeter Intrusion Detection System
107	PMR	Private Mobile Radio
108	POE	Power Over Ethernet
109	PTB	Passenger Terminal Building
110	SACS	Security Access Control System
111	SAN	Storage Area Network
112	SER	Small Equipment Room
113	SFC	Safaricom
114	SITA	SITA Airport Management
115	SS	Substation
116	T1A	Terminal 1A
117	TDMM	Telecommunications Distribution Methods Manual
118	TETRA	Terrestrial Trunked Radio
119	TIA/EIA	Telecommunications Industry Association/ Electronic Industries Alliance
120	UL	Underwriters Laboratories
121	UPS	Uninterruptible Power Supply
122	UVSS	Under Vehicle Surveillance System
123	VIP	Very Important Person
124	VLAN	Virtual Local Area Network
125	VSS	Video Surveillance System
126	WAN	Wide Area Network
127	WLAN	Wireless Local Area Network

EXECUTIVE SUMMARY

The Final Report for Jomo Kenyatta International Airport (JKIA) sets forth a visionary roadmap to transform Kenya's primary international gateway into a world-class aviation hub by 2045. This plan is anchored in Kenya Vision 2030 and ICAO standards, addressing the dual challenge of meeting surging demand while enhancing operational efficiency and passenger experience. JKIA currently handles 8.6 million passengers annually, with projections indicating growth to over 23 million by 2045. To accommodate this trajectory, the master plan adopts a phased development approach, ensuring flexibility and cost efficiency while safeguarding future expansion.

Current Challenges and Strategic Imperatives

JKIA operates a single 4,117-meter runway under ICAO Code 4E standards, supported by limited rapid exit taxiways and constrained apron capacity. While the airport has robust cargo throughput and installed power capacity, operational bottlenecks—such as high runway occupancy times, limited parking, and aging terminal infrastructure—pose risks to service quality and competitiveness. Regional rivals like Addis Ababa and Kigali are aggressively expanding, making timely intervention critical for JKIA to maintain its hub status.

Traffic forecasts underpinning the plan predict a compound annual growth rate of 4.1% in aircraft movements, driven by larger aircraft and liberalized air service agreements under SAATM. Domestic traffic will more than double, while international flows will dominate, supported by Kenya Airways' fleet expansion and strategic partnerships.

Phased Development Plan

Phase 1: Improvement Projects (2025–2029)

Phase 1 focuses on optimizing existing infrastructure to sustain operations through 2029. Key interventions include:

- **Airfield Enhancements:**
  - Construction of two **Rapid Exit Taxiways (RETs)** at 2,000 m and 2,450 m from the runway threshold, angled at 30° to reduce runway occupancy time from 66 to 60.1 seconds.
  - Extension of partial parallel taxiways and apron reconfiguration to improve aircraft flow and reduce delays.
  - These upgrades will increase arrival capacity from 25 to 31 ATMs per hour.
- **Terminal Upgrades:**
  - Expansion and modernization of existing terminals to handle up to 10 million annual passengers (MAP).
  - Landside improvements, utility upgrades, and support facilities to enhance passenger experience without major new construction.
  - Detailed Existing Infrastructure assessment study is recommended in order to access the structural conditions and assess the existing capacity and estimating the capacity expansion limits.

Phase 2: Expansion Projects (2030–2045)

Phase 2 introduces transformative projects to meet long-term demand and position JKIA as East Africa's premier hub:

- **Second Independent Runway:**
  - A new runway, separated by 1,525 meters from the existing one, enabling fully independent operations.

  - Equipped with multiple RETs (at 1,775 m, 2,325 m, and 2,850 m) and dual parallel taxiways for segregated arrivals and departures.
  - Capacity boost to 61 arrivals and 80 departures per hour.

- **New Passenger Terminal Building (PTB):**
  - **Phase 2a:** A 10 MAP terminal operational by 2040, integrating smart technologies for seamless passenger processing.
  - **Phase 2b:** An additional 5 MAP expansion to handle 22.3 MAP by 2045.
  - Existing terminals, including T1E, will be decommissioned post-Phase 2a completion.

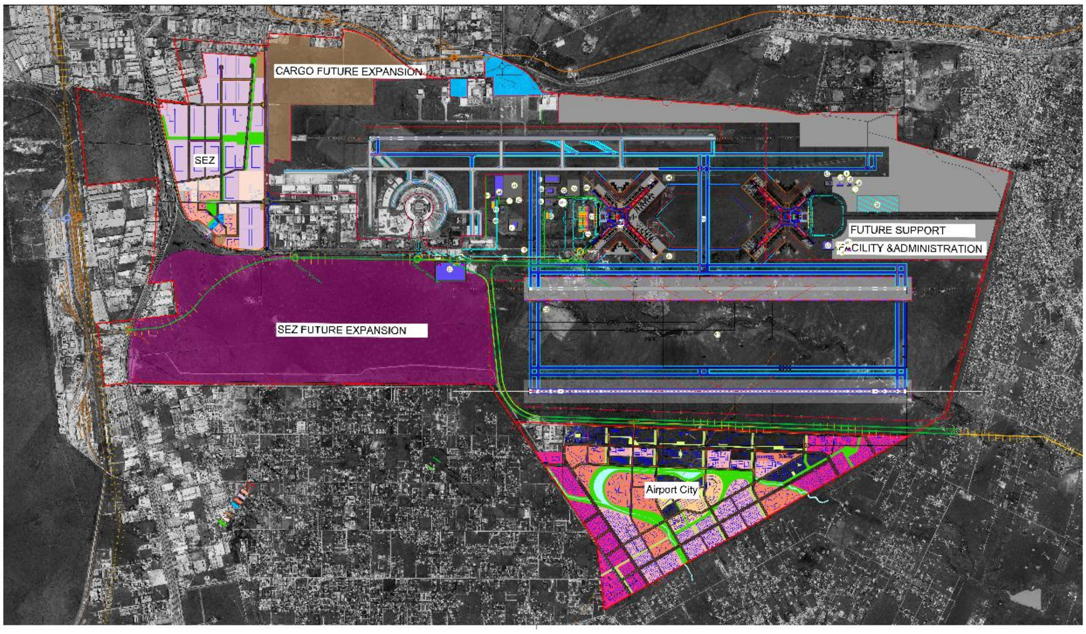
- **Support Infrastructure:**
  - New substations, SCADA-enabled power distribution, and emergency systems to meet rising electrical demand (26 MVA to 36 MVA).
  - Advanced baggage handling, biometric-enabled check-in, and AI-driven queue management.

Future-Proofing Beyond 2045

The plan safeguards land for a **third runway**, additional terminals, and an airport city development to accommodate evolving aviation trends and economic growth. Integration of SMART Airport principles—digital twins, IoT-based predictive maintenance, and AI-powered security—will ensure JKIA remains agile and sustainable.

Summary

The JKIA Master Plan is more than an infrastructure blueprint; it is a holistic strategy combining technology, sustainability, and economic foresight. By implementing phased improvements and major expansions, JKIA will deliver operational excellence, superior passenger experience, and secure its role as East Africa's aviation leader. This forward-thinking approach ensures adaptability to market dynamics while reinforcing Kenya's position in global air transport.



1 BACKGROUND

Airports play a critical role in national and regional economic development by facilitating air travel, cargo movement, and international connectivity. As aviation demand continues to rise, the need for well-planned, efficient, and environmentally sustainable airport infrastructure becomes imperative. Strategic planning is essential to ensure that airports can meet current and future demands while maintaining operational efficiency, safety, and environmental sustainability.

Kenya Airports Authority (KAA), a public authority responsible for operating and maintaining the entire airport infrastructure in Kenya, recognizes the importance of aviation in the country's economic growth and connectivity. One of its primary objectives is to develop the necessary infrastructure to meet the increasing air traffic demand.

Jomo Kenyatta International Airport (JKIA) and Wilson Airport are key aviation hubs in Kenya, serving both international and domestic air traffic. JKIA, as the primary international gateway, handles significant passenger and cargo volumes, whereas Wilson Airport caters to domestic and regional flights, including charter and general aviation operations. The effective management and future development of these airports require a comprehensive and integrated approach, addressing aspects such as capacity planning, environmental considerations, and regulatory compliance.

Jomo Kenyatta International Airport (JKIA) in Nairobi, Kenya, features a layout designed to efficiently manage both international and domestic air traffic. The airport comprises two main terminals: Terminal 1 and Terminal 2.

Terminal 1 is organized in a semi-circular configuration and is subdivided into five sections:

- Terminal 1A,1B,1C,1D and 1E.
- Terminal 2 caters mainly to low-cost carriers, accommodating both international and domestic flights. This prefabricated terminal, opened in April 2015, has a capacity of 2.5 million passengers annually. It includes check-in desks and boarding gates, with lounges such as the Mara Lounge and Mount Kenya Lounge available for passengers.

2 EXISTING CONDITIONS

Jomo Kenyatta International Airport (JKIA) is located in Nairobi, Embakasi Area, covering an area of 11,000 acres at an elevation of 5327 feet. The airport is classified with IATA and ICAO codes NBO and HKJK, respectively.

JKIA is categorized as a Category A Aerodrome under ICAO and Category 2 under FAA regulations. The airport began operations in May 1958 and operates 24 hours a day.

The airport serves a total of 70 destinations, with 8 local and 62 international destinations. JKIA employs a total of 1,057 staff members in 2016.

Facilities

JKIA Runway 06/24, classified as code 4E, the approach type for this runway is precision with a CAT I approach capability, allowing for high-performance aircraft operations under various weather conditions.with a length of 4117 meters and a width of 45 meters.

Figure 2.1: Overview of Jomo Kenyatta International Airport

Terminal 1 (70,000 m2, capacity of 5 Mpax), which is mainly operated by Kenya Airways and Skyteam airlines. The terminal is divided in five terminals including T1A (International Arrivals and Departures), T1B and T1C (International Departures), T1D (Domestic Arrivals), and T1E (International Arrivals)

For cargo, JKIA has several existing cargo terminals: Kenya Airways Cargo (KAHL, KQ Cargo Centre), Swissport Cargo, Africa Freight Services, and Siginon Cargo Centre. The airport's total annual cargo capacity is 1,032,362,000 kg, with an actual throughput of 339,828,475 kg in 2015/2016.

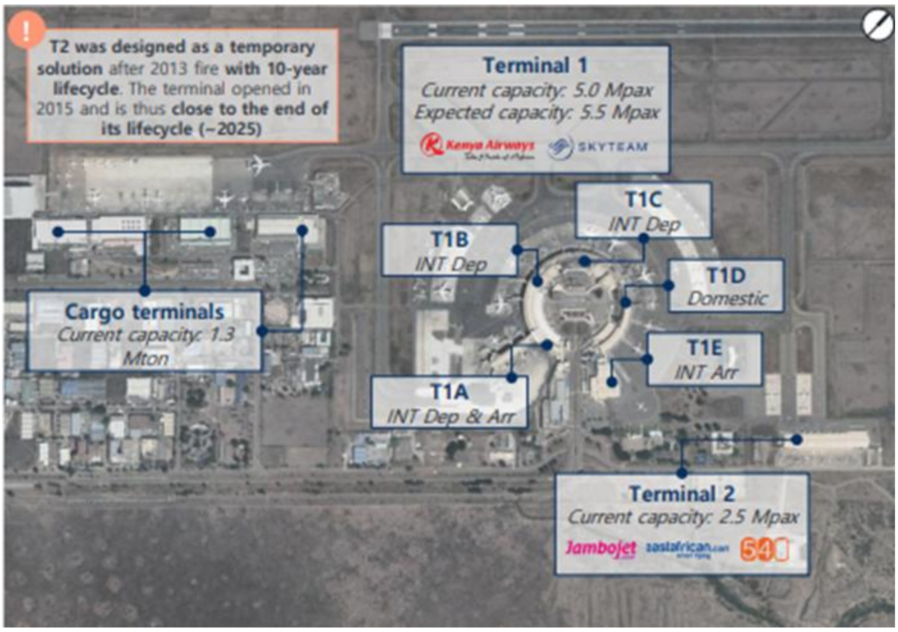


Figure 2.2: Passenger and Cargo terminal at JKIA

Fire Station

JKIA's Fire Station is classified as Category 9, with a minimum of three crash tenders and a total water capacity of 24,300 liters. Currently, the fire station operates two fire vehicles, one of which is fully serviceable. Other equipment includes one ambulance, one command vehicle, and disabled aircraft recovery equipment. Additionally, there is one aerial firefighting vehicle for building fires.

The JKIA RFFS has an approved establishment of 143 personnel, although only 73 personnel are currently in service, working in four shifts. Four personnel are assigned to the fire prevention unit located at T2.

Figure 2.3: JKIA Fire station location

Power Station

JKIA has an installed power capacity of 10 MW, with current consumption at 5.6 MW. The power supply comes from 2 x 66kV and 1 x 11kV supply lines. The airport operates 17 power substations, all supplied at 11kV.

Car Parks

The airport features 2,700 parking spaces, with different categories: 250 for cargo, 600 in Parking 3-8, 750 in Parking P9-12, and 1,100 in the parking garage.

Apron

There are three aprons (commercial, cargo, and GA/long stay) at JKIA providing a total of 68 stands able to accommodate up to Code E aircraft. The estimated capacity is distributed as follows:

- 49 commercial stands (16 code E, 4 code D, and 29 code C).
- 9 cargo stands (7 code E and 2 code D).
- 10 stands for General Aviation and long-stay aircraft

Figure 2.4: Existing Apron at Jomo Kenyatta International Airport

JKIA currently has 110 fuel hydrants and a water storage capacity of 6.7 million litres.

The current condition and conservation status of JKIA have been assessed using data provided by KAA, along with observations and data collected by the consultant team during a site visit that covered the majority of the airside and landside facilities.

The following is a general layout that outlines the primary facilities and equipment inventory at JKIA. This layout will be reviewed, updated, and modified as necessary throughout the course of the project to reflect any changes or new developments. Adjustments will be made based on ongoing assessments, emerging needs, and evolving project requirements.

ID	Facility	Area (m2)	ID	Facility	Area (m2)	ID	Facility	Area (m2)	ID	Facility	Area (m2)
1	RWY	185,265	9	Apron - commercial T1 (flexible)	294,265	17	Apron - other	51,111	25	Surface car park - GA/long stay	36,556
2	RWY shoulders	61,755	10	Apron - commercial T1 (rigid)	123,521	18	Service roads	23,226	26	Perimeter road	37,178
3	RWY stopways	5,490	11	Apron - commercial T1A (rigid)	20,634	19	Main road	238,948	27	Perimeter fence (m)	16,363
4	TWY - parallel & RWY exits	235,833	12	Apron - commercial T2 (flexible)	29,402	20	Secondary road	82,762	1	Terminal 1	70,000
5	TWY - commerical apron T2	56,931	13	Apron - commercial T2(rigid)	10,502	21	Surface car park - T1	30,040	1	PBBs (unit)	11
6	TWY - commerical apron T1	48,540	14	Apron - cargo (flexible)	76,723	22	Surface car park - T1	10,618	2	PBBs - T1A (unit)	7
7	TWY - cargo apron	9,178	15	Apron - cargo (rigid)	64,308	23	Surface car park - T2	12,094	2	Terminal 2	10,000
8	TWY - long stay/GA apron	73.010	16	Apron - GA/long-stay (flexible)	134.340	24	Surface car park - cargo	13.489	3	MSCP	36.846

Figure 2.5: JKIA Main Facilities

3 TRAFFIC FORECAST

3.1 SCOPE AND APPROACH

This traffic forecast is prepared for Kenya Airports Authority (KAA) and is part of the overall project to develop a masterplan for Jomo Kenyatta International Airport (JKIA) and Wilson Airport, both in Nairobi, Kenya.

The traffic forecast is an integral part of the masterplan and provides vital input for the planning of the facilities in line with the expected demand of users.

This SECTION therefore aims to set out the market study performed to analyse the potential development of traffic, the assumptions and methodology taken to forecast the future passengers, Air Transport Movements (ATMs) and Cargo, and finally show the results of the same.

A previous forecast was prepared for JKIA as part of a wider study for air traffic development in the whole of Kenya. This forecast was prepared in 2022 and dealt with recovery from the pandemic. This updated forecast uses the latest information and statistics available including the full calendar year 2024. With these latest statistics, this 2022 forecast is reviewed in chapter 2 the resulting outcome compared to the updated forecast results in chapter 8.

The scope of the forecast includes annual passenger, ATMs and Cargo volume forecasts from 2025 to 2045. The annual forecast is thereafter converted into design peak hours to serve as input for the planning of the facilities.

The work performed in this task will furthermore develop forecasts of future passengers by domestic, international, O&D, and transfer segments.

Extensive stakeholder meetings are performed to obtain data, insights and strategic inputs. Strategic input from Kenya Airways was received on i.e. future fleet and passenger development, route expansion and the role of Jambojet. These inputs have been carefully implemented in the forecast to ensure that the development of Kenya Airways can be facilitated at JKIA.

The forecast is prepared on an unconstrained basis. This means that no capacity limitations are considered. This is to assure the true demand is estimated, and subsequently an infrastructure development strategy can be prepared based on this demand.

Similarly, no excessive stimulation of demand is considered in the base case. i.e. by significantly capacity provision and government support for Kenya Airways to expand beyond reasonably considered hub operations.

The forecasts furthermore assume a status quo in the political and safety situation. The situation is stable at the moment and considered a prudent baseline for the forecast. Any significant changes would be considered alternative scenarios which are not typically included in a base case forecast.

The traffic forecast for Jomo Kenyatta International Airport (JKIA) combines both top-down and bottom-up approaches to provide a comprehensive and robust view of future passenger demand. These complementary methods ensure that the forecast captures both macroeconomic trends and market-specific operational dynamics. The methodology also incorporates scenario planning to address uncertainty and concludes with the estimation of air traffic movements (ATMs), which is essential for infrastructure and capacity planning.

Top-Down Approach

The top-down element begins with the analysis of macroeconomic drivers, primarily Gross Domestic Product (GDP), as a proxy for demand. Passenger traffic is segmented into domestic and international, and statistical regression models are developed for each segment to quantify their relationship with economic growth.

These models are validated against historical traffic data to ensure reliability, and then used in conjunction with GDP forecasts to derive long-term organic growth rates. This provides a strategic view of demand growth under normal economic conditions.

Bottom-Up Approach

In parallel, the bottom-up approach builds the forecast from the ground up, starting with route-level and airline-level data. It assesses:

- Current airline capacity and load factors
- Route frequencies and new service announcements
- Market trends such as tourism flows, policies and aviation development in Africa
- Infrastructure constraints and expansion plans

The two forecasts are compared and reconciled to ensure consistency. Once total passenger volumes are forecasted, air traffic movements (ATMs) are calculated by applying:

- Assumed load factors (passengers per aircraft)
- Aircraft mix and average seats per movement

3.2 BACKGROUND ON PREVIOUS FORECAST

In 2022 a forecast was prepared by ALG as part of the study for the National Aviation Policy. The forecast included all KAA airports in Kenya and JKIA was part of this forecast results with a forecast of total, domestic, international and transfer passengers, as well as ATMs and peak hour volumes.

An extensive study of the Keny aviation market was included, as well as an analysis of all macroeconomic drivers for potential growth.

This forecast used 2021 as the last reference year. The Pandemic recovery was ongoing and much of the analysis, especially regarding bottom-up forecasts, focused on this step.

With additional information of 2022-2024 this forecast can be reviewed, and the base of the forecast can be updated to the latest actual volume in 2024.

The forecast in 2022 was relatively close in 2022 and 2023, however, it continued a strong trend to recover to 13% above the 2019 level for 2024, which did not materialize. Mainly international traffic has remained below the estimation.

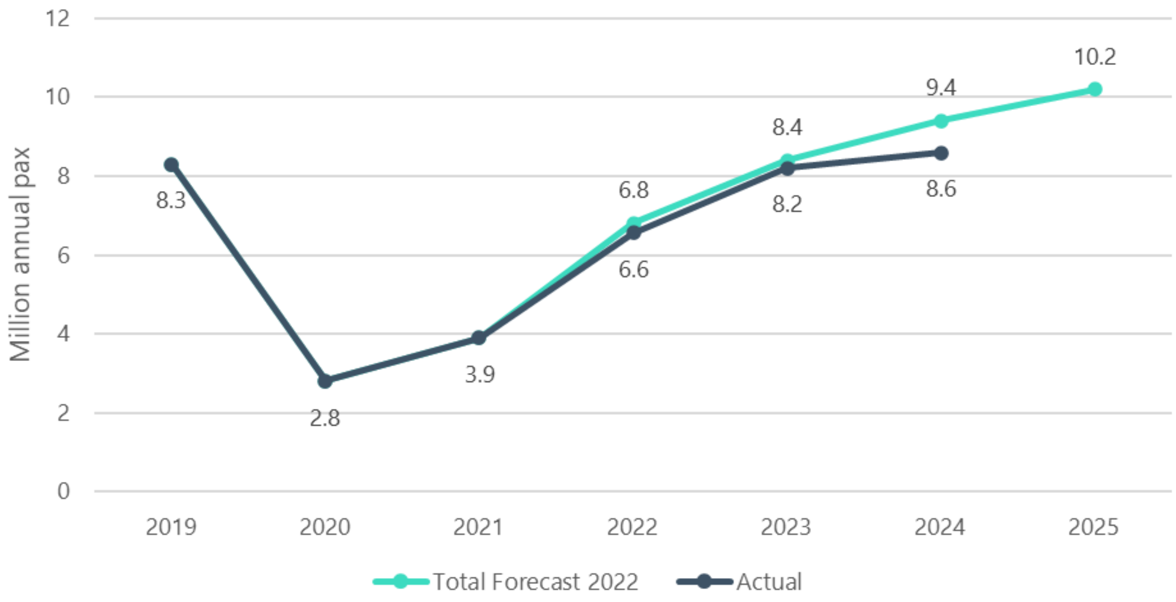


Figure 3.1: Previous forecast comparison vs actual traffic

The forecast as prepared by ALG for their National Aviation Policy for Kenya study in 2022 has been reviewed and the following is noted:

- The forecasts applied a standard top-down and bottom-up methodology, which is considered adequate.
- The forecast was prepared in 2022, with 2021 as the last reference year. As this was during the Pandemic recovery, 2022 and 2023 traffic development should be carefully reviewed and updated.
- JKIA international traffic is forecast to grow from 6.6 million passengers in 2019 to 7.4 million passengers in 2024. Traffic then grows at a 4.8% CAGR to 24.9 million passengers in 2050.
- It is considered that this is a very strong growth rate to maintain over a long period of time.
- The reason for this is that the consultant did not apply any maturity to the growth rate in the long term.
- This might well be adequate for the Kenyan market due to the macro-economic outlook, however it should be verified in an independent analysis.
- Domestic O&D traffic is forecast to grow from 1.6 million passengers in 2019 to 2.0Mpax in 2024 and 4.3Mpax by 2050, at a CAGR of 3.3%. This is considered more conservative, however with the population growth and potential increase of low cost carriers over time could actually be outperformed. This should be verified.
- Additionally, the bottom-up element focused on the recovery from the Pandemic and less on the development of airlines and routes. This is also a factor that should be further verified.
- It is noted that the forecast grows transfer passengers to 7.6 million, while the actual 2024 is only 0.8 million, well below the forecast for the short term. It is likely that a new trend has emerged after the Pandemic, with more O&D demand, and less transfer focus.
- The previous forecast splits the passengers by Domestic, International and Transfer. However, it is important for the more detailed planning of the forecast to break the numbers further down by airline or airline type. This is to estimate the passengers for each facility, as Skyteam airlines will likely used specific areas, LCCs use other areas, etc. This applies to both the annual as the peak hour forecasts.

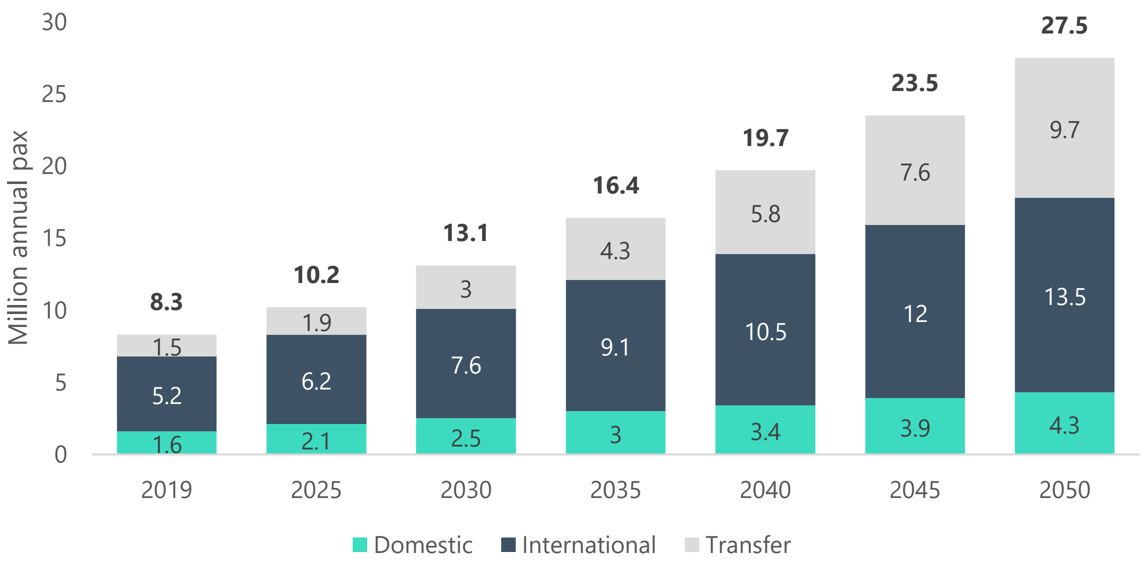


Figure 3.2: 2022 Forecast for JKIA

3.3 HISTORICAL TRAFFIC TRENDS ANALYSIS

3.3.1 KENYA AIR TRAFFIC CONTEXT

Kenya's air traffic has experienced remarkable growth over the past two decades, driven by expanding infrastructure, increased passenger and cargo demand, and a thriving tourism industry. The country serves as a major aviation hub in East Africa, connecting international and regional flights through its key airports, including Jomo Kenyatta International Airport (Nairobi), Moi International Airport (Mombasa), and Eldoret International Airport.

In the capital Nairobi, there are two airports, JKIA is the hub airport of Kenya and the base for Kenya airways. There is a smaller airport (Wilson) in the city which handles mainly flights to national parks.

JKIA handled just under 9 million passengers in 2024 while Wilson airport handles around 0.9 million passengers.

The national carrier, Kenya Airways, remains the dominant airline, operating an extensive network across Africa, Europe, Asia, and North America. Other key players include Jambojet (a low-cost subsidiary of Kenya Airways), Fly540, and regional airlines such as Safarilink and AirKenya that cater to domestic and safari destinations.

Figure 3.3: Key Airports in Kenya

Recent years have seen significant developments, including the modernization of Jomo Kenyatta International Airport to handle increasing passenger traffic, Kenya Airways' strategic partnerships to enhance connectivity, and government initiatives aimed at improving air transport efficiency. However, challenges such as financial struggles at Kenya Airways and the impact of global economic shifts have influenced the sector's trajectory.

Looking back 20 years, Kenya's aviation industry has transformed from a largely regional network to an increasingly globalized hub. Investments in infrastructure, policy improvements, and growing airline competition have positioned Kenya as a crucial player in Africa's aviation landscape.

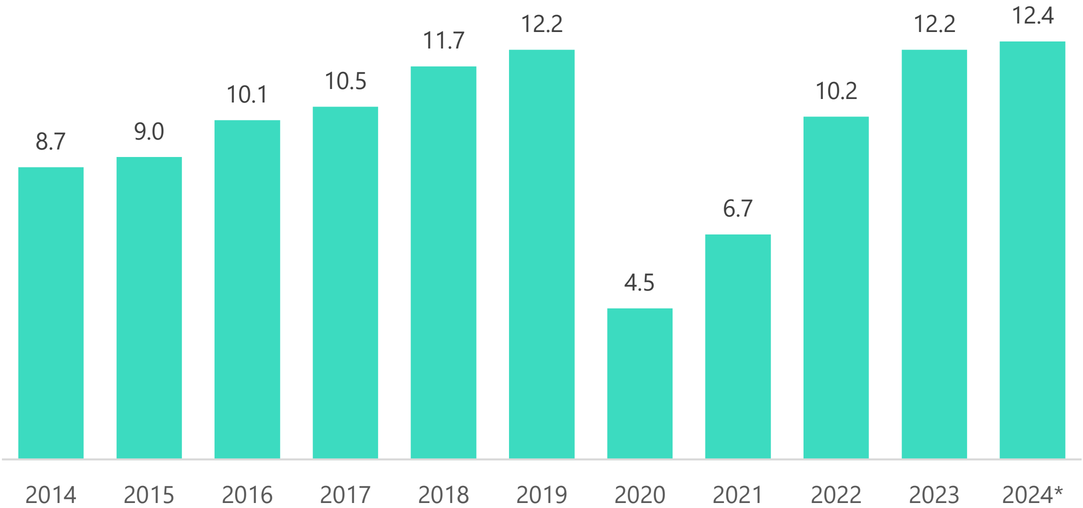


Figure 3.4: Total Passengers in Kenya per year (Million total passengers)

Kenya has a large number of airports, 18 of these airports are managed by Kenya Airports Authority (KAA), the rest by Kenya Wildlife Services, the Military and the State Department of Interior. The busiest airports in the country (i.e., Jomo Kenyatta International Airport, Mombasa/Moi International Airport, Wilson Airport, and Kisumu International Airports) are operated by KAA.

JKIA is by far the main airport in the country. Other airports mainly serve connections to the capital

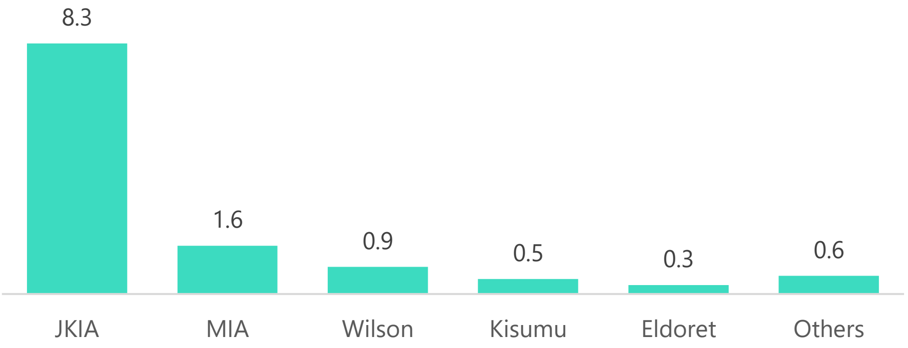


Figure 3.5: Airport traffic distribution (2019)

There are four main Kenyan scheduled commercial airlines operational as of 2025:

Kenya Airways – The Pride of Africa

- Main airline with some 50% of domestic market share and nearly all international by Kenyan airlines.
- In the process of restructuring as it has been dealing with high debts.

Jambojet.com

- Low cost subsidiary of KQ, operating 6 Dash-8 aircraft in the domestic market.

SKYWARD EXPRESS

- privately-owned Kenyan airline headquartered at Nairobi's Wilson Airport.
- Established in 2013, it offers scheduled passenger flights and cargo services across Kenya
- Fleet of 10 aircraft, including Fokker 50s and Dash 8-Q300s

AIRKENYA – The best way to fly

- AirKenya is a regional airline based at Wilson Airport in Nairobi, Kenya.
- It operates scheduled and charter flights to safari destinations across Kenya and Tanzania. The airline is known for serving the Maasai Mara, Amboseli, and Serengeti with small turboprop aircraft.
- From JKIA it has flights to Mombasa and Mogadishu on Fokker 70 and Fokker 100 aircraft.

540 – Your Quality Airline

- Private low cost airline operating two Dash-8 aircraft.
- Not operational as of 2025. Ceased operations in November 2022 following regulatory action by the Competition Authority of Kenya (CAK). The CAK issued a cease-and-desist order due to multiple violations.

3.3.2 JKIA ANNUAL TRAFFIC

In the second half of the last decade traffic grew rapidly, despite a struggling home carrier and continued political unrest, showing a resilient demand based on its economic development and strong tourism offer.

JKIA reached 8.3 Mpax in 2019 (including connections), accounting for almost 70% of total passenger traffic in the country. This represents an average growth rate (CAGR) of 5.3%, which is relatively high, and similar to the GDP development in the same period. In 2024 this record was broken, reaching 8.6 million passengers.

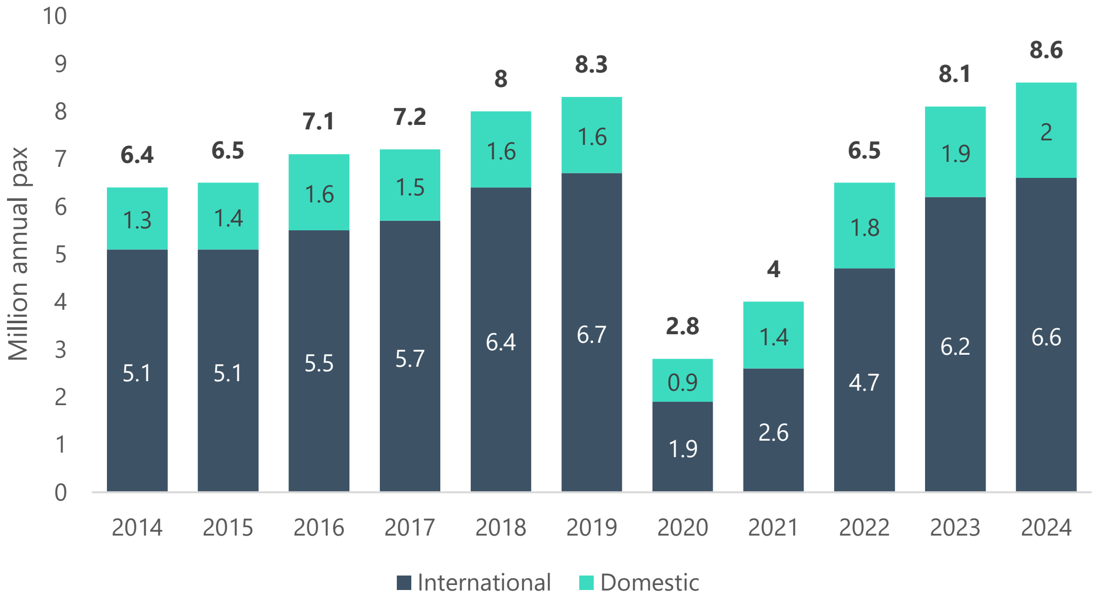


Figure 3.6: Domestic and International passengers JKIA (2014-2024)

In 2024, JKIA handled 2 million domestic passengers (23% and 6.8 million international passengers (77%).

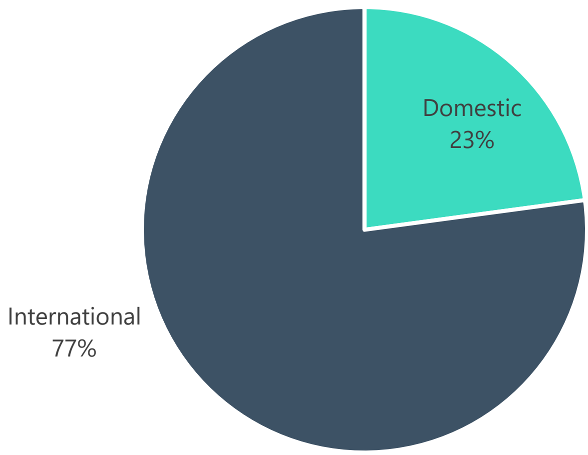


Figure 3.7: JKIA Domestic vs International share (2024)

Between 2019 and 2024, mainly domestic and international O&D passengers have grown, while transfer traffic has significantly decreased. This is a result of the tourism focus of the government and relaxation of the visa policy.

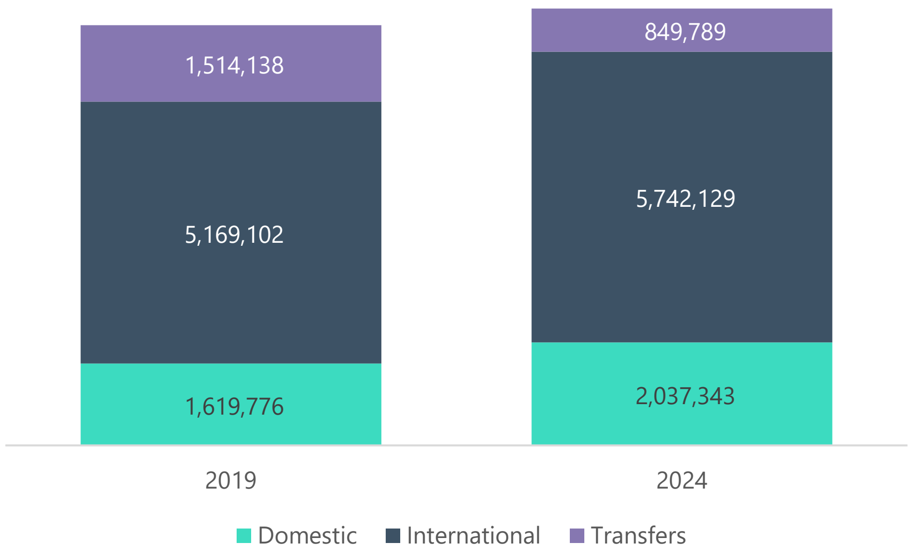


Figure 3.8: 2024 traffic breakdown vs 2019

3.3.3 ROUTES AND REGIONS JKIA

3.3.3.1 INTERNATIONAL OPERATIONS

The largest share of passengers fly to and from the UAE, followed by Tanzania, Qatar and South Africa. The Middel Eastern destinations are key transfer hubs and serve connections to the wider network of Emirates and Qatar Airways. In Tanzania the tourism destinations of Dar es Salaam and Zanzibar are frequently served by Kenya Airways as well as Precision Air.

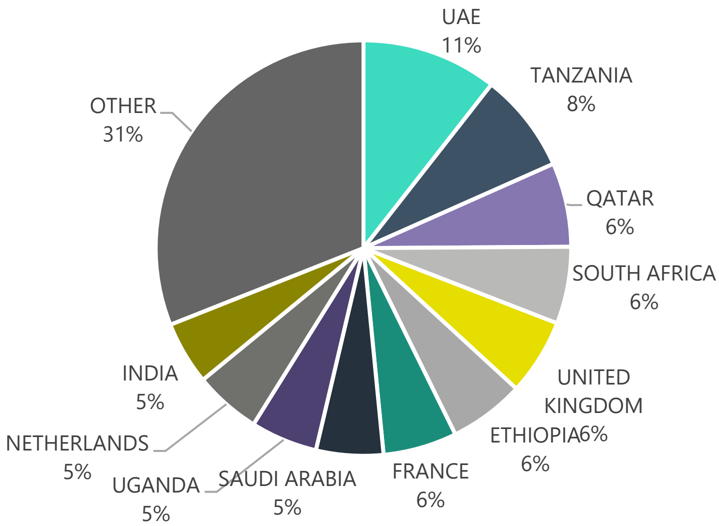


Figure 3.9: International share of passengers per country

The top ten routes reflect the country distribution with the Middle East hubs Dubai and Qatar serving the most passengers in 2024. This is complemented by regional hubs Addis Ababa, Johannesburg and Entebbe, as well as European capitals London, Paris and Amsterdam.

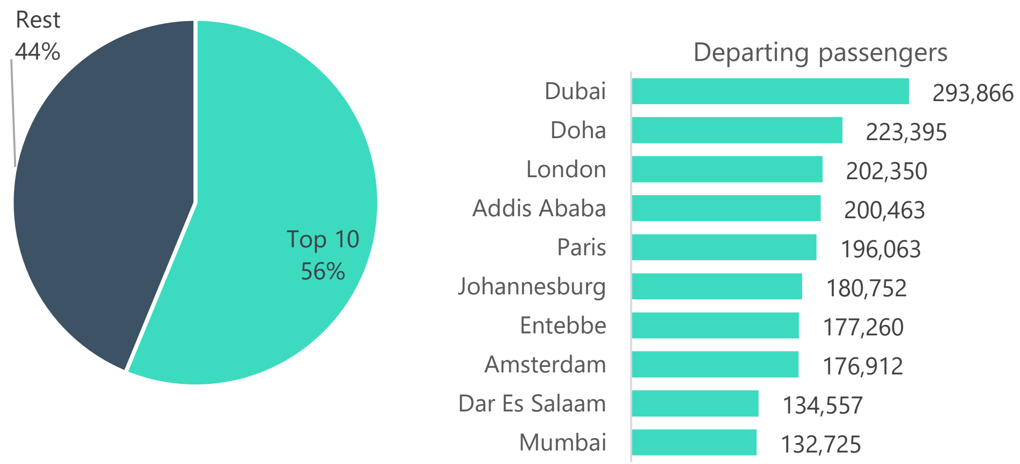


Figure 3.10: Top 10 routes by weekly departures

3.3.3.2 DOMESTIC OPERATIONS

The domestic operations are operated almost exclusively by Jambojet and Kenya Airways. Since Jambojet and Kenya airways belong to the same group, this is a monopoly. Jambojet acts as the low cost subsidiary of Kenya Aiways.

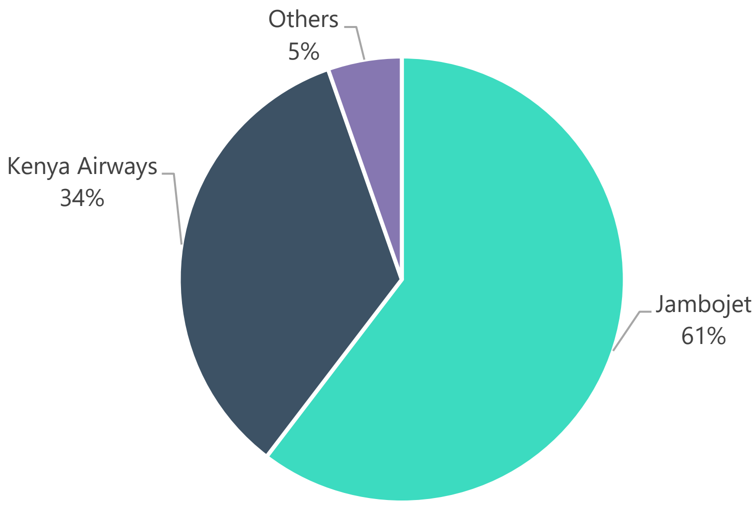


Figure 3.11: Domestic traffic by airline shares

The main domestic route is to Mombasa, followed by Kisumu and Eldoret. The other routes are relatively small. The domestic network is therefore not extensively developed from JKIA. This is in part due to the neighbouring airport Wilson which handles a large share of the domestic passengers for Nairobi.

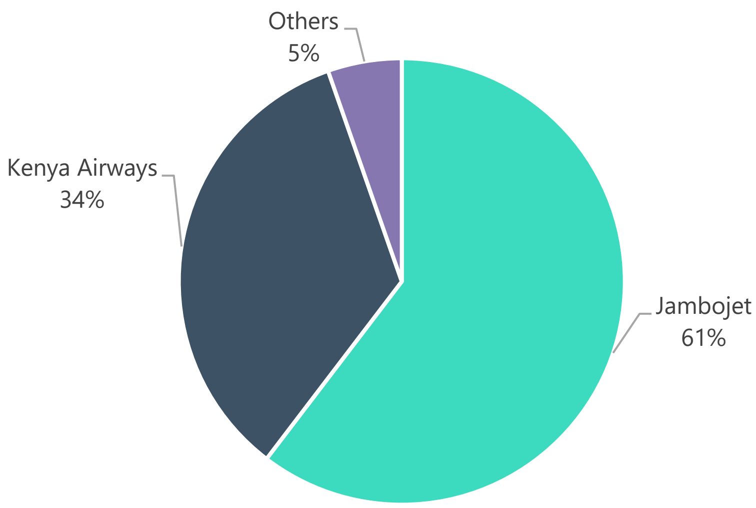


Figure 3.12: Key Domestic routes

3.3.4 AIRLINES

3.3.4.1 INTERNATIONAL OPERATIONS

Kenya Airways performs 43% of the international flights at JKIA. This is followed by Precision Air. RwandAir and Uganda Airlines as neighboring countries also offer multiple daily flights.

Thereafter, a number of large hub airlines offer double daily flights, such as Emirates, Qatar Airways and Ethiopian.

The majority of European hub airlines have a daily connection, i.e. KLM, British Airways, Lufthansa and Turkish Airlines.

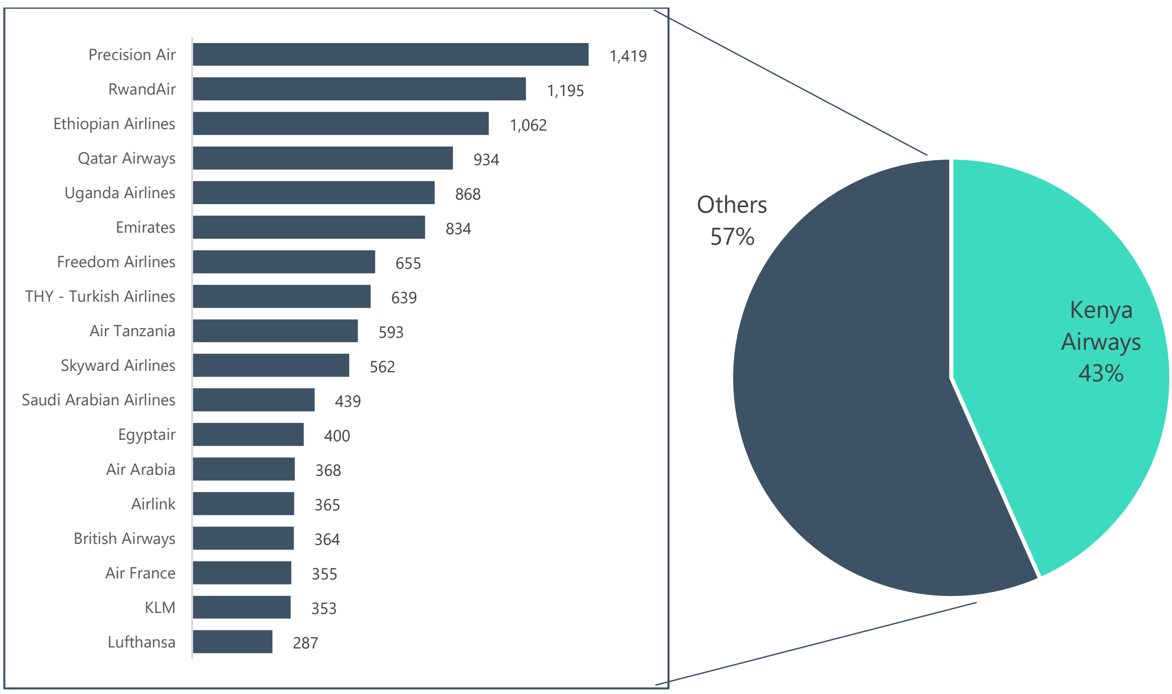


Figure 3.13: 2024 International departures from JKIA per airline

Kenya Airways operates an international network in the region and some destinations outside Africa such as Mumbai, London, Dubai, Paris, Amsterdam, Bangkok and New York.

For the top destinations, typically another hub airline from the destination base serves the route. However, in the majority of smaller routes, KQ is the only airline operating without competition, including for example Accra, Lagos and Antananarivo.

Mogadishu is the 12th largest route in terms of passengers, but there are a large number of flights from a range of airlines, carrying on average little passengers per flight.

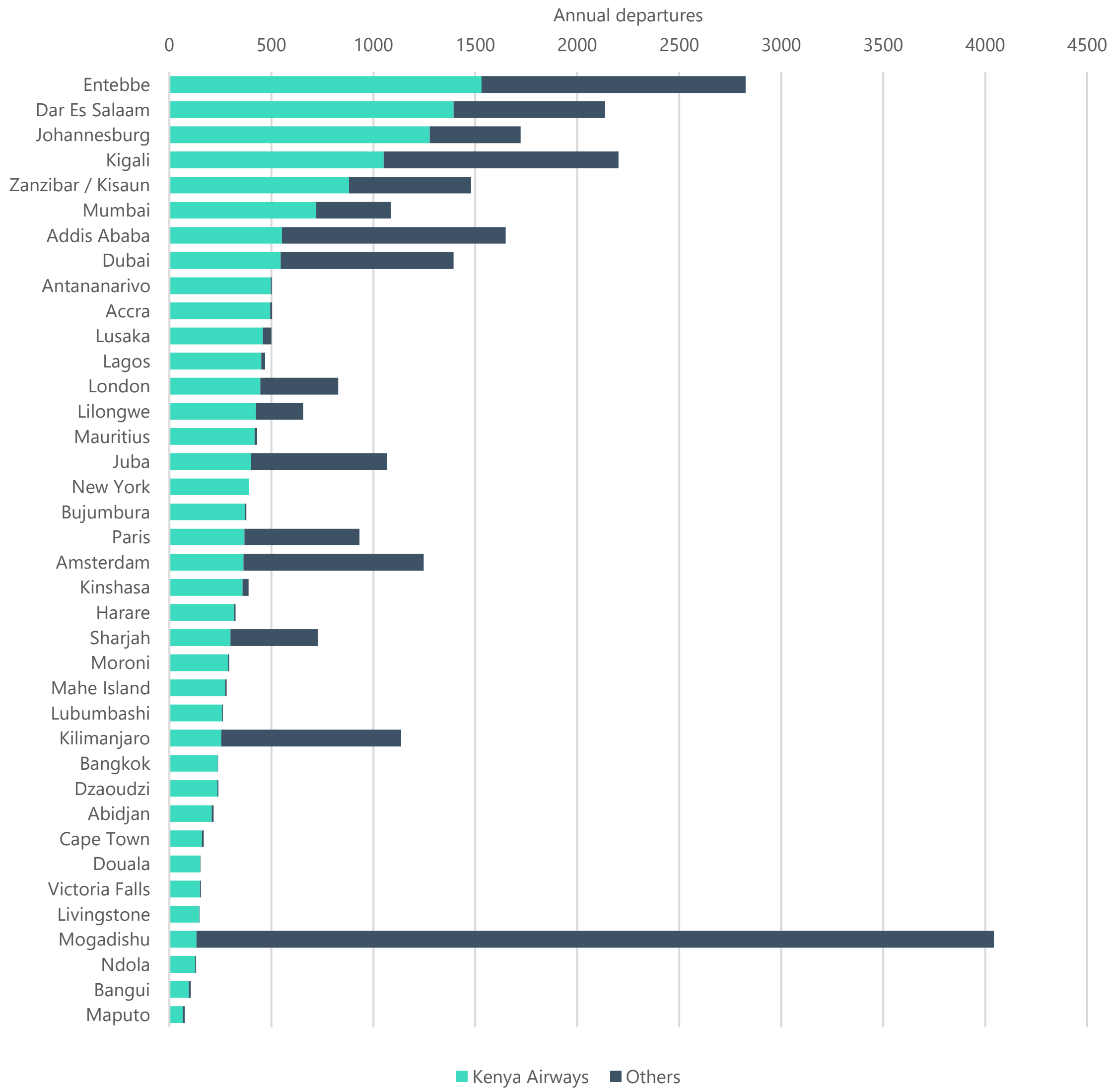


Figure 3.14: Annual departures per route by KQ and other airlines (2024)

3.3.4.2 DOMESTIC OPERATIONS

In the domestic market, nearly all traffic from JKIA is operated by Kenya Airways and its low-cost subsidiary Jambojet, with a small share by Skyward Airlines.

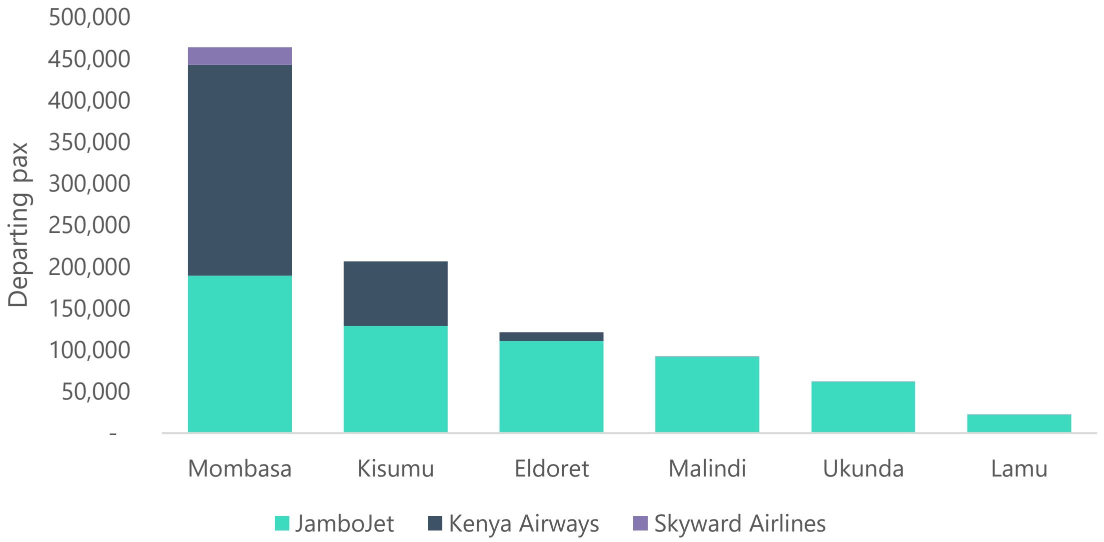


Figure 3.15: Domestic routes by airline

3.3.5 ATMS AND TYPES

In 2024, 112,708 movements took place at JKIA airport. The most common aircraft type is the Embraer E90, which is the main short haul aircraft for Kenya Airways. This analysis contains all movements, including Cargo freighters, General Aviation, positioning flights etc.

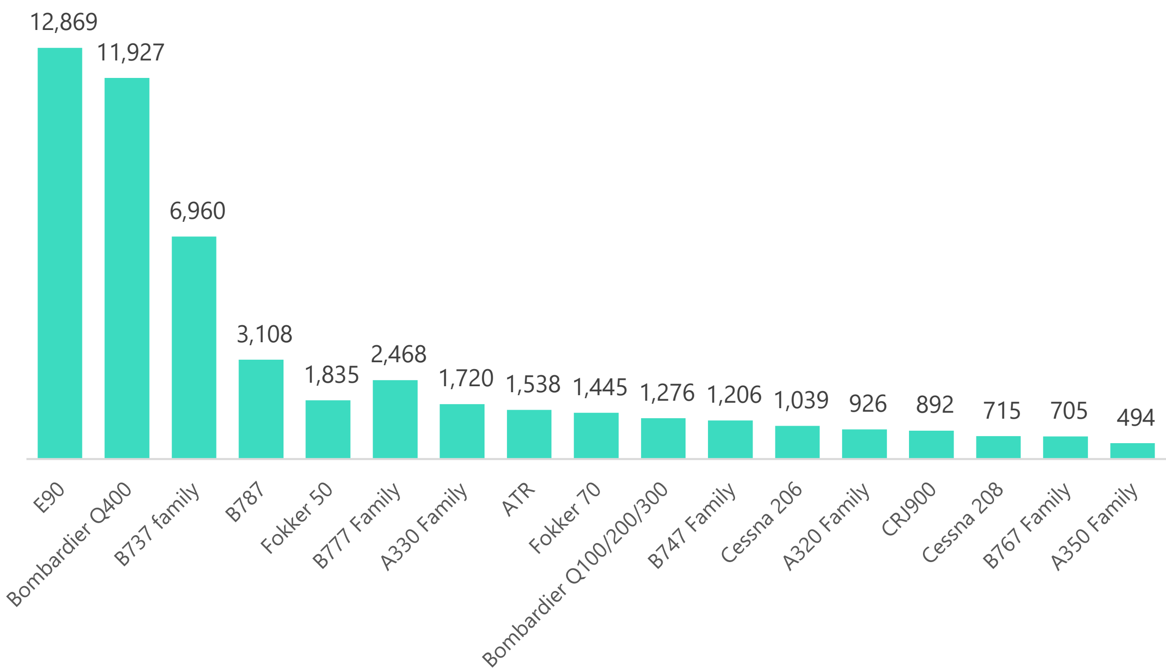


Figure 3.16: ATMs by aircraft types

The majority, with 77%, of operations were Code C aircraft.

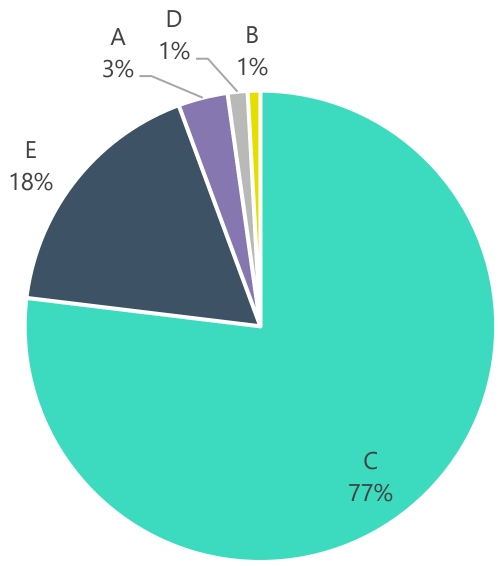


Figure 3.17: Share of ATMs by aircraft code

Kenya Airways operates a fleet of Embrear E190 aircraft and B737 aircraft for its narrow body fleet. Their wide body fleet consists of B787 and A330 aircraft.

Jambojet only operates Bombardier Dash-8 aircraft.

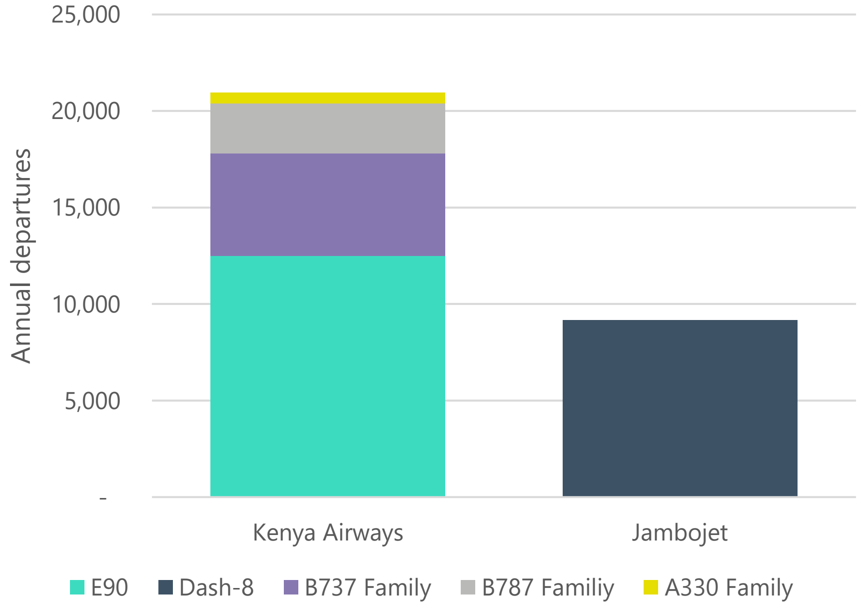


Figure 3.18: ATMs by aircraft type Kenya Airways and Jambojet

On the other hand, Precision air operates an ATR turboprop only fleet. RwandAir also uses mainly turboprops, the Bombardier Dash-8. The middle Eastern hub airlines typically use the Boeing 777.

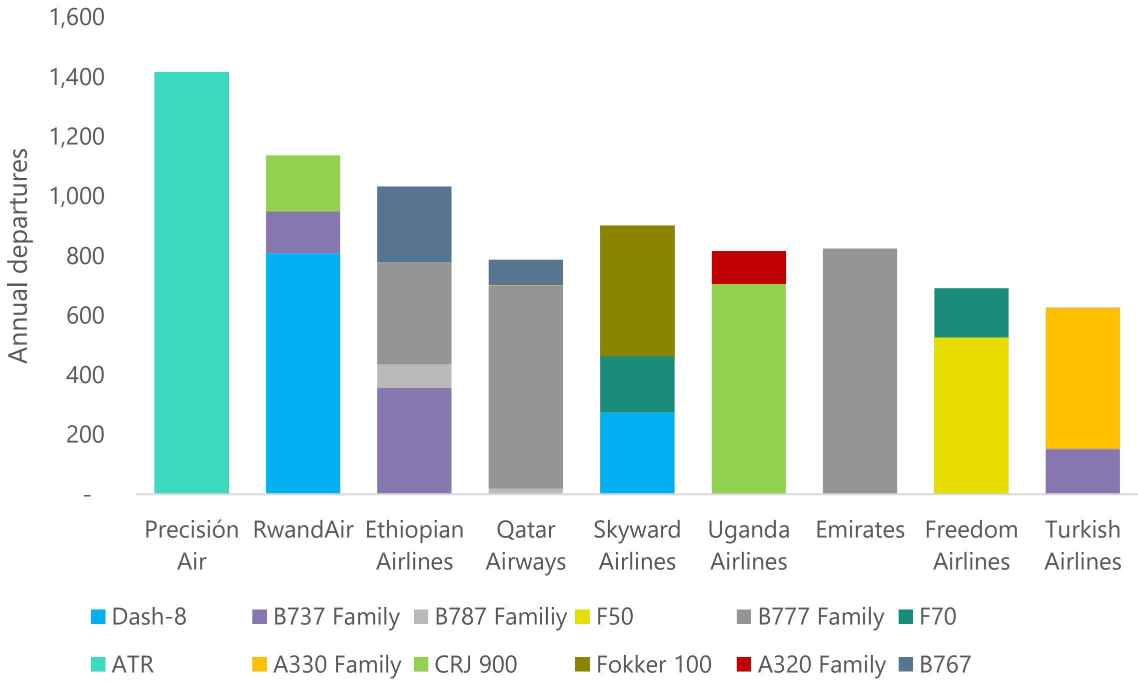


Figure 3.19: ATMs by airline and aircraft type

3.3.6 SEASONALITY

The traffic pattern throughout the year is relatively equal, with a slight peak in July and August, as well as December.

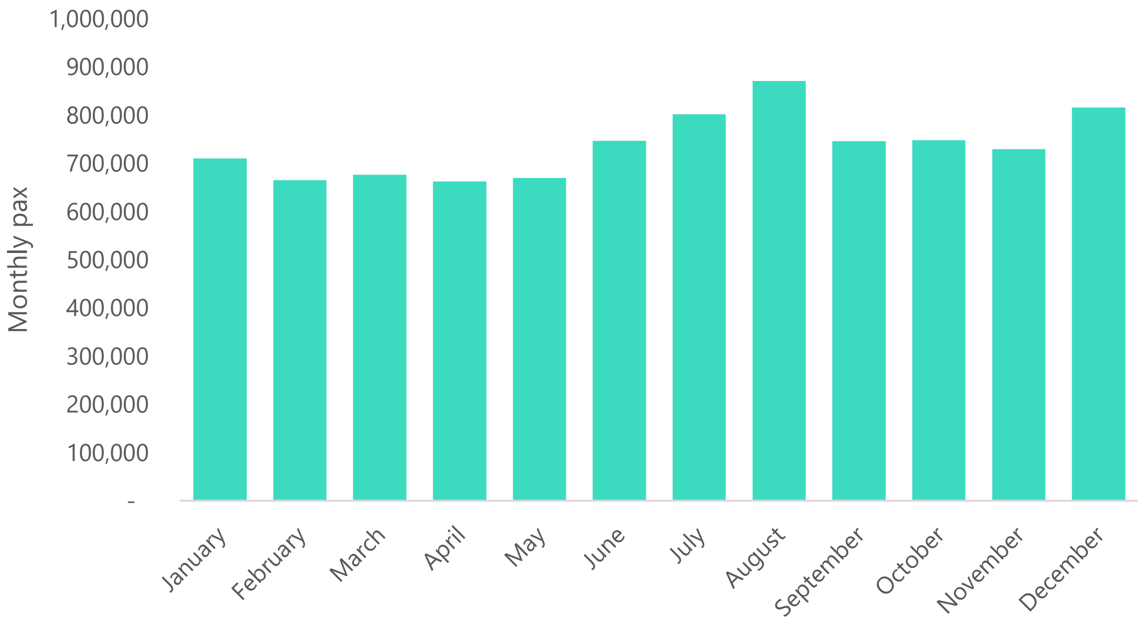


Figure 3.20: Passengers per Month

The pattern is similar for both international and domestic operations.

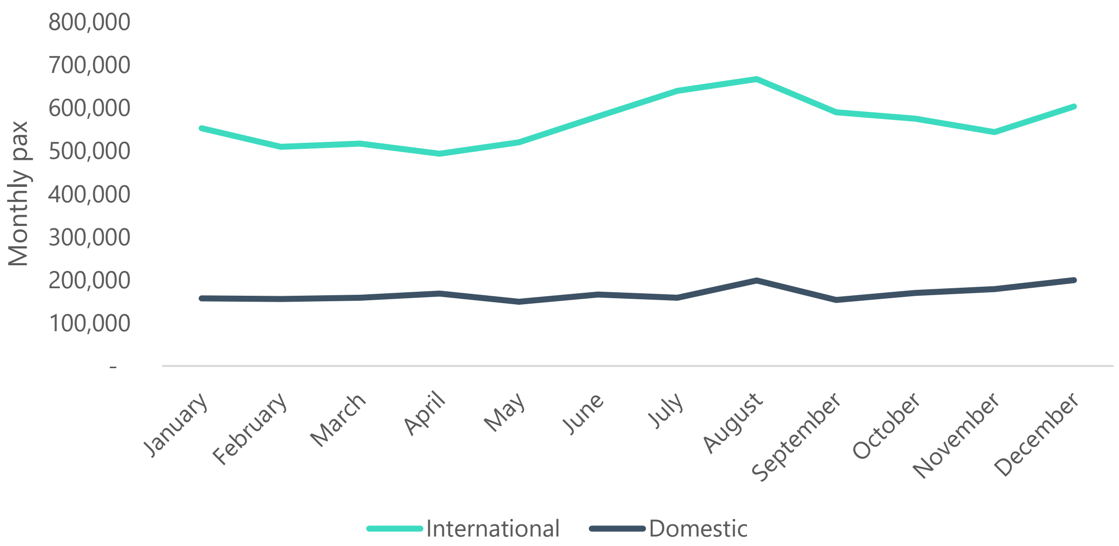


Figure 3.21: Monthly passengers Domestic vs International

3.4 SOCIO-ECONOMIC ANALYSIS

3.4.1 KENYA ECONOMY

Kenya has one of the largest and most diversified economies in Africa, serving as a regional hub for trade, finance, technology, and tourism in East Africa. The country's GDP is primarily driven by agriculture, services, manufacturing, tourism, and infrastructure development. Agriculture remains the backbone of the economy, contributing about 20-30% of GDP and employing a significant portion of the workforce, with key exports including tea, coffee, horticultural products, and livestock. The services sector, especially financial services, telecommunications, and tourism, plays a crucial role. Manufacturing, though still developing, includes food processing, textiles, and cement production. Infrastructure investments in roads, railways, and energy projects have also been a key focus in recent years.

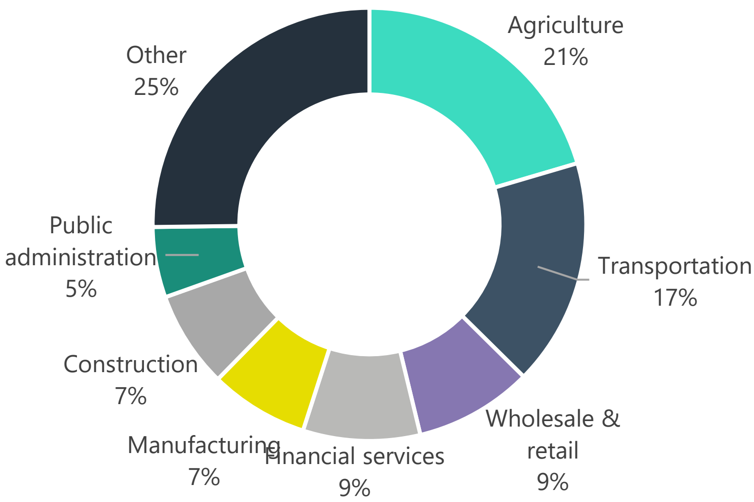


Figure 3.22: Kenya GDP composition Q3 2024

Tourism is a vital industry, contributing significantly to foreign exchange earnings and employment. Kenya is renowned for its diverse wildlife, including the Maasai Mara's Great Migration, its coastal destinations like Mombasa and Diani

Beach, and cultural heritage sites. The sector was heavily impacted by the COVID-19 pandemic but has since rebounded, with increased investments in eco-tourism, hospitality, and travel infrastructure.

Recent trends in Kenya's economy highlight rapid urbanization, a shift towards digital transformation, and increasing foreign direct investment (FDI) in technology, renewable energy, and tourism. The fintech industry, driven by mobile money and digital lending, continues to expand, enhancing financial inclusion. The country is also experiencing a surge in real estate and construction due to growing urban populations. Additionally, Kenya is positioning itself as a hub for green energy, with significant investments in geothermal, wind, and solar power, making it a leader in renewable energy in Africa. The tourism industry is also diversifying, with a focus on sustainable and experiential travel, including community-based tourism and conservation efforts.

Nairobi city is responsible for more than a quarter of the total country´s GDP. Meru is a key contributor to agricultural production. Mombasa, Machakos and Kiambu also have relatively high contributions in the manufacturing sector, being neighbouring regions to Nairobi.

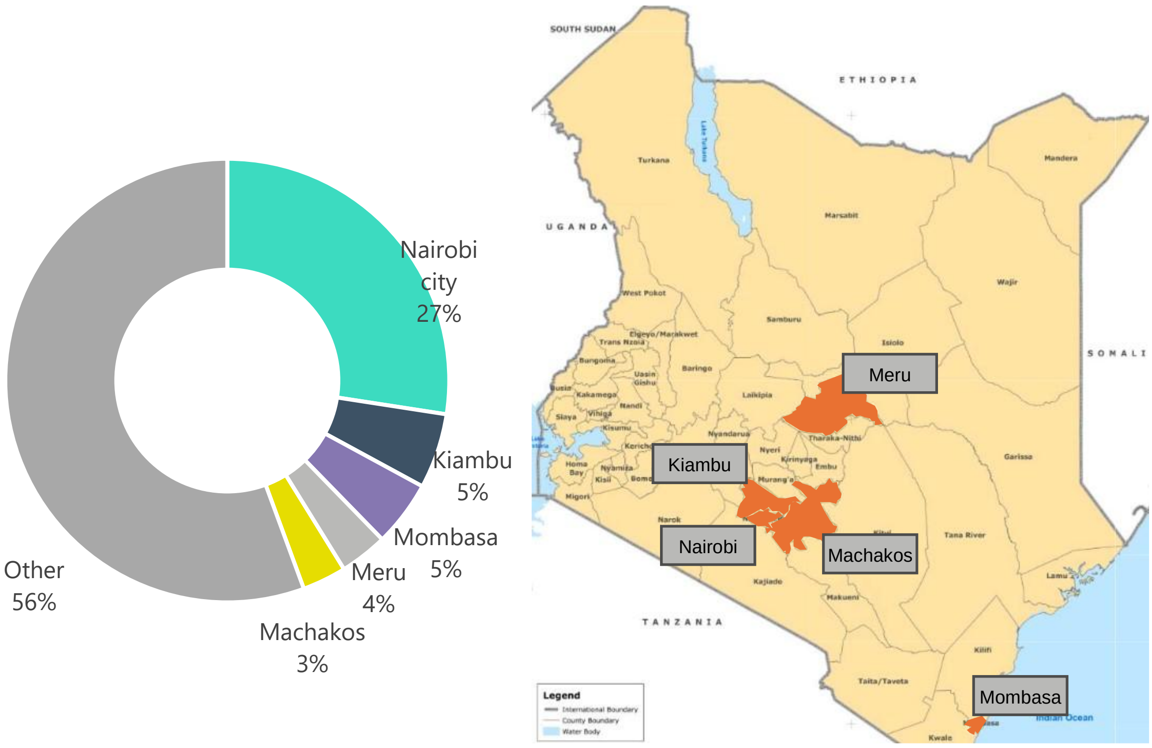


Figure 3.23: Regional GDP contribution in Kenya

Kenya's economic growth is fuelled by several key factors. The expansion of digital technology, particularly mobile banking and e-commerce, has boosted financial inclusion and entrepreneurship. Infrastructure investments, including roads, railways, ports, and energy projects, continue to support economic activity and regional trade. Agriculture modernization, through irrigation projects and value-added processing, is helping to enhance productivity. Additionally, Kenya's strategic location and membership in regional trade blocs like the East African Community (EAC) and the African Continental Free Trade Area (AfCFTA) offer opportunities for expanding exports and attracting investment. Tourism remains a strong driver of growth, with the government and private sector focusing on diversification, marketing, and sustainability to attract international visitors.

Despite its economic potential, Kenya faces several challenges. High public debt, which has exceeded 60% of GDP, poses a risk to economic development and investment potential from the government. Inflation, currency depreciation, and the rising cost of living have also put pressure on households and businesses. Unemployment, particularly among youth, remains relatively high, while political uncertainties and governance challenges can impact investor confidence. Climate change is another growing threat, affecting agricultural productivity and water availability.

Despite challenges, Kenya's economy remains resilient, with strong prospects for growth, particularly in the digital economy, green energy, tourism, and regional trade.

Vision 2030

In 2007, the Government of Kenya pronounced "Vision 2030" as its long term plan for attaining middle income status as a nation by 2030. To ensure implementation of the Vision 2030, the government prepares successive medium-term plans ("MTPs") that outline the policies, programmes and projects that the government intends to implement over a five-year period.

Kenya's Fourth Medium Term Plan (MTP IV) for 2023-2027 outlines a comprehensive strategy to drive economic transformation and inclusive growth, aligning with the nation's Vision 2030 objectives. Fourth MTP focuses on five core pillars:

1. **Agriculture** – Boosting productivity through value chains, irrigation expansion, agro-processing, and climate-smart farming.
2. **MSMEs** – Strengthening small businesses with affordable credit (Hustler Fund), industrial parks, and market linkages.
3. **Housing** – Constructing 200,000 affordable housing units per year and supporting the Jua Kali sector for construction materials.
4. **Healthcare** – Expanding social health insurance, digitizing healthcare, and recruiting 20,000 health workers.
5. **Digital & Creative Economy** – Laying 100,000 km of fiber-optic cable, digitizing government services, and supporting innovation.

MTP IV also emphasizes the importance of public-private partnerships, infrastructure development, and leveraging technology to optimize operations and create efficiencies across sectors.

3.4.2 GDP PERFORMANCE

GDP has been strongly increasing over a long period of time, the CAGR from 2005-2024 was 4.7%. it is expected to accelerate in the next 10 years to a CAGR of 5.5% in real terms.

From 2005 to 2010, the economy grew steadily at an average rate of around 5-7%, driven by infrastructure investments, agricultural expansion, and a growing services sector, particularly in telecommunications and finance. However, the 2007–2008 post-election violence disrupted growth, causing GDP expansion to slow significantly in 2008. The early 2010s saw a recovery, with growth rates stabilizing around 5-6%, supported by major infrastructure projects such as the Standard Gauge Railway (SGR), a booming real estate sector, and financial inclusion through mobile banking innovations like M-Pesa. Despite these gains, Kenya faced challenges such as high public debt and fiscal deficits. The COVID-19 pandemic in 2020 led to a sharp contraction, with GDP growth declining to around 0.3% due to lockdowns and reduced economic activity. However, the economy rebounded in 2021 and beyond, supported by a resurgence in tourism, agriculture, and digital transformation. By 2024, Kenya's economic growth remains resilient but faces headwinds from global inflation, currency depreciation, and debt servicing pressures.

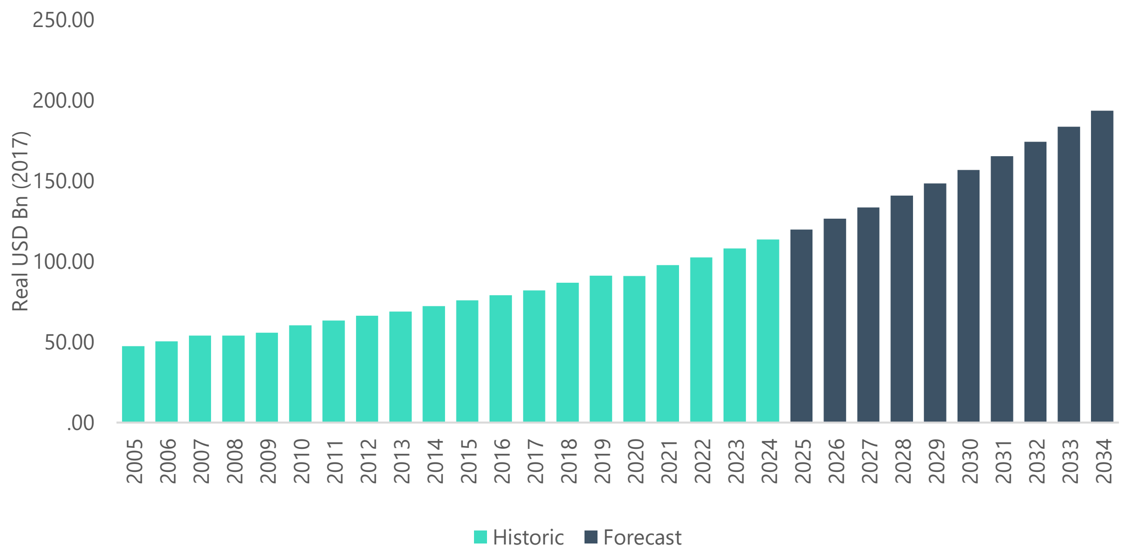


Figure 3.24: Kenya Real GDP (in 2017 USD) historically and forecast

Kenya's GDP growth has generally outpaced the average growth rate of Africa over the past two decades, but it has also been subject to similar economic shocks. Between 2005 and 2019, Kenya's economy expanded at an average rate of 5-6%, compared to Africa's overall growth, which hovered around 3-5%, with resource-rich countries like Nigeria and South Africa experiencing more volatility due to commodity price fluctuations. Kenya's economic resilience stemmed from its diversified economy, particularly its strong services sector (including mobile banking and ICT), infrastructure investments, and agricultural output.

During the COVID-19 pandemic in 2020, Africa's economy contracted by approximately -1.9%, while Kenya's GDP growth slowed to about 0.3%, showing relative resilience. Post-pandemic, both Kenya and Africa experienced economic rebounds, with Kenya growing at around 5% in 2021-2023, compared to Africa's overall recovery of 3-4%. However, in recent years, Kenya has faced challenges like rising public debt and inflation

The forecast for Kenya is above the performance of Africa overall.

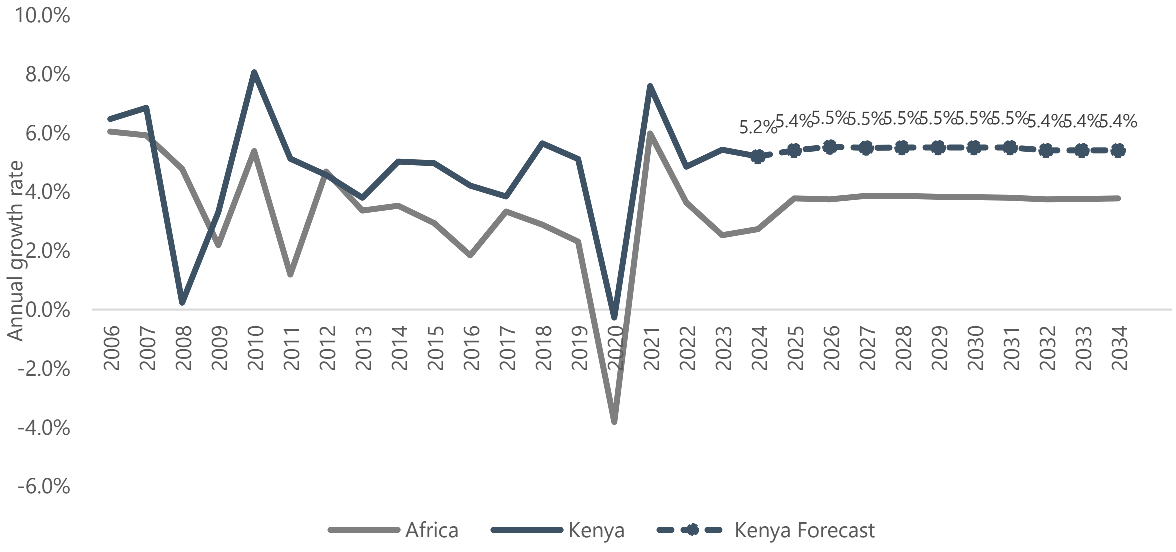


Figure 3.25: Kenya annual GDP growth vs Africa

3.4.3 GDP PER CAPITA

Between 2010 and 2024, Kenya's GDP per capita experienced notable growth, rising at a CAGR of 2.2%, while Africa as a whole only grew at a rate of 0.1%.

Several factors have contributed to Kenya's robust GDP per capita growth:

1. Economic Diversification: Kenya has successfully diversified its economy beyond traditional agriculture, with significant growth in sectors such as services, manufacturing, and technology. The services sector, in particular, has become a major contributor, accounting for 56% of the country's economic output by 2019.
2. Technological Advancements: The adoption of innovative technologies, especially in financial services, has spurred economic activity. The widespread use of mobile banking platforms like M-Pesa has increased financial inclusion and facilitated business operations.
3. Infrastructure Development: Investments in infrastructure, including transportation networks and energy projects, have improved connectivity and efficiency, attracting both domestic and foreign investments.
4. Political and Economic Reforms: Government initiatives aimed at improving the business environment, such as regulatory reforms and anti-corruption measures, have enhanced investor confidence and economic stability.

Figure 3.26: GDP/Capita development and forecast Kenya vs Africa

3.4.4 TOURISM

Tourism is a vital pillar of Kenya's economy, contributing significantly to GDP, employment, and foreign exchange earnings. Kenya boasts a wide range of world-class tourist attractions, drawing visitors for its wildlife, landscapes, and cultural experiences. Most of the tourist attractions are located in the southern part of the country, at relatively short distance to Nairobi.

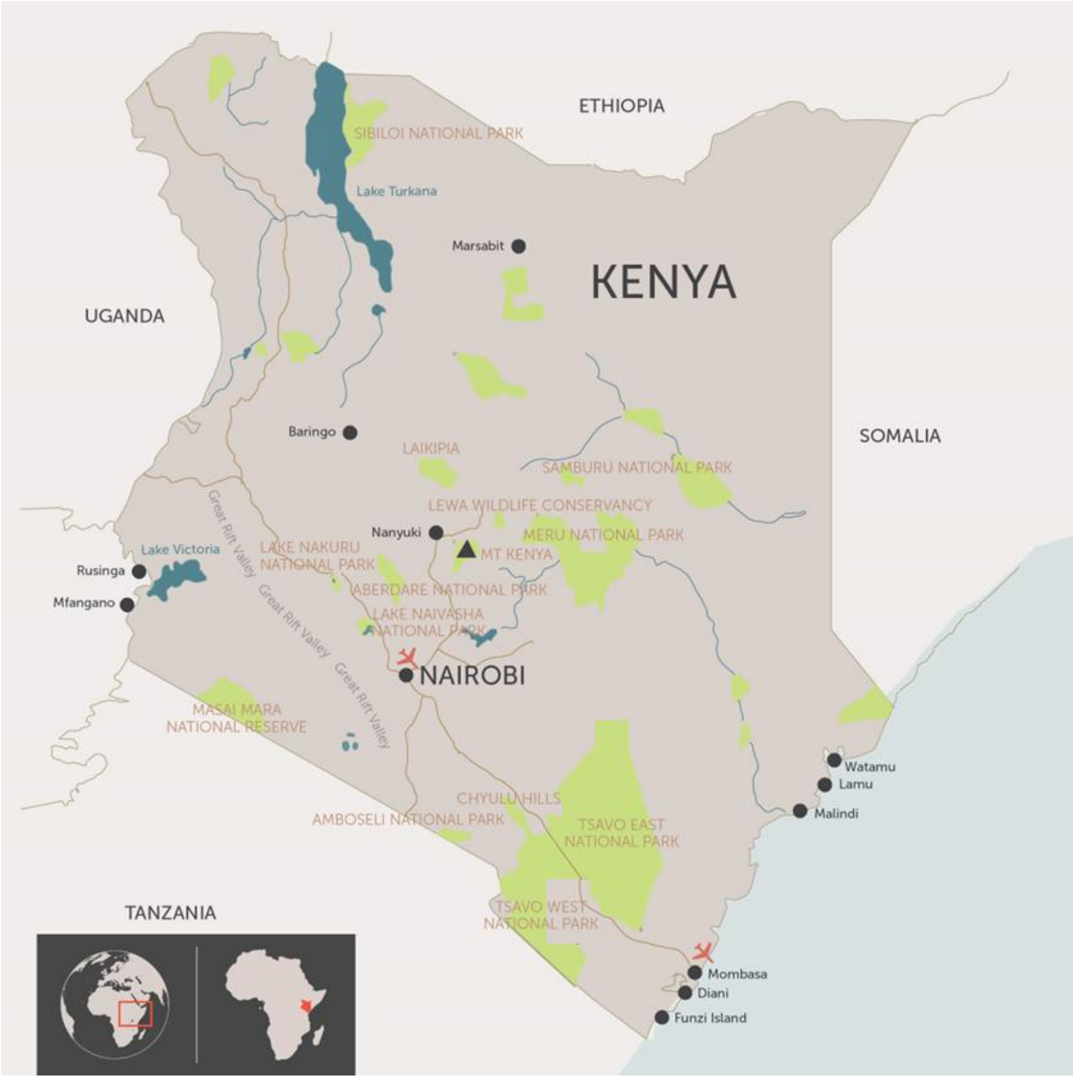


Figure 3.27: Kenya key tourism regions

Table 3.1: Kenya Tourism Offer

Wildlife & Safari	Coastal & Marine	Natural & Scenic	Adventure & Eco-Tourism
Maasai Mara National Reserve – Famous for the Great Migration, **Amboseli National Park –** Known for elephants and Kilimanjaro views, **Tsavo National Parks** – One of Kenya's largest wildlife reserves**,** **Lake Nakuru National Park** – Home to flamingos and rhinos, **Samburu National Reserve –** Features rare species like Grevy's zebra.	**Diani Beach** – White sandy beaches and water sports, **Mombasa & Fort Jesus** – A historic coastal city with Swahili culture, **Lamu Island** – A UNESCO World Heritage site with unique architecture, **Watamu & Malindi Marine Parks** – Great for snorkeling, diving, and marine life.	**Mount Kenya** – Africa's second-highest peak, great for trekking, **Great Rift Valley** – Stunning escarpments and lakes, **Hell's Gate National Park** – Unique rock formations and geothermal activity, **Aberdare Ranges** – A cool highland area with waterfalls and forests.	**Lake Turkana** – A remote desert lake with unique fossils and tribes, **Chalbi Desert** – Offers camel safaris and breathtaking landscapes, **Aberdare Ranges** – High-altitude forests and waterfalls, **Mount Kenya** – Ideal for rock climbing and hiking.

In line with this Kenya attracts many international tourists annually. However some security issues have tampered the development. Between 2011 and 2015 there were various attacks by the militant organization Al-Shabaab, which caused tourism numbers to decline in this period.

A growing trend was seen until the Covid-19 pandemic limited international travel in 2020. The country recovered from that strongly with 2023 recording the highest ever international tourism count. This was even further exceeded in 2024 when a 15% growth in international tourism arrivals was recorded.

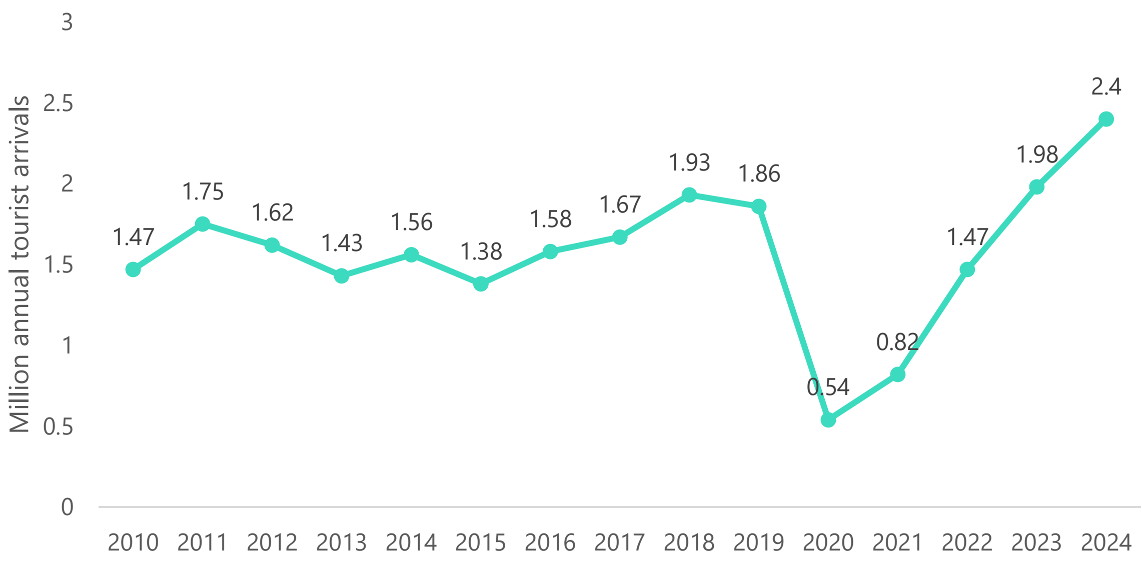


Figure 3.28: Annual Tourist Arrivals in Kenya (Millions)

Of these arrivals, over two thirds arrives at JKIA, with 8% at Mombasa Airport and the 23% other arrival points include other airports as well as ports and land crossings. JKIA therefore directly benefits from a strongly growing tourism sector.

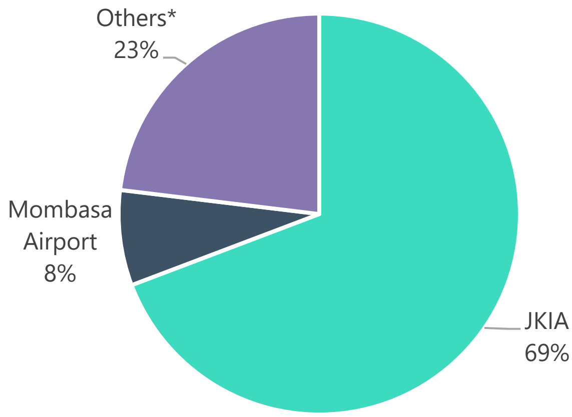


Figure 3.29: Point of entry international tourists (2023)

The most tourists are coming from the United states, 14% in 2023, followed by neighbouring countries, a number of European countries, and India and China. Economic performance in those countries is important for the generation of tourism, in addition to the stability of Kenya and continued improvements in the tourism infrastructure.

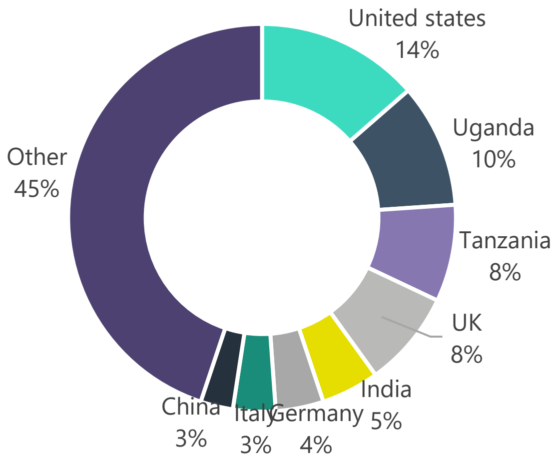


Figure 3.30: Tourists per origin country

The national parks recorded 3 million visitors in 2023, up from 2.3 million in 2019. Some 75% of visitors are Kenya residents, and 25% are foreign tourists.

The strong growth is the result of the Kenyan government revitalizing tourism post-pandemic through strategic initiatives. The Kenya Tourism Board (KTB) launched aggressive marketing campaigns, leveraging digital platforms, trade fairs, and collaborations with influencers to attract international visitors. To enhance accessibility, the government introduced visa-free entry for all visitors starting in 2024, eliminating bureaucratic barriers. Significant investments in infrastructure, including airport upgrades, improved road networks, and expanded air travel routes, made key tourist destinations more accessible. Additionally, the Tourism Recovery Fund provided financial support to struggling businesses, ensuring the industry's stability and enabling a faster recovery. These efforts positioned Kenya as a prime travel destination, driving strong post-pandemic growth.

With a continued focus on the abovementioned points, the current projections from the Ministry of Tourism and Wildlife expect growing international tourism arrivals from 2.4 million in 2024 to 5.7 million in 2028, an increase of 138%.

This will directly benefit JKIA as it handles the majority of tourism arrivals, as well as Wilson, as it distributes international tourists further to national parks in the country.

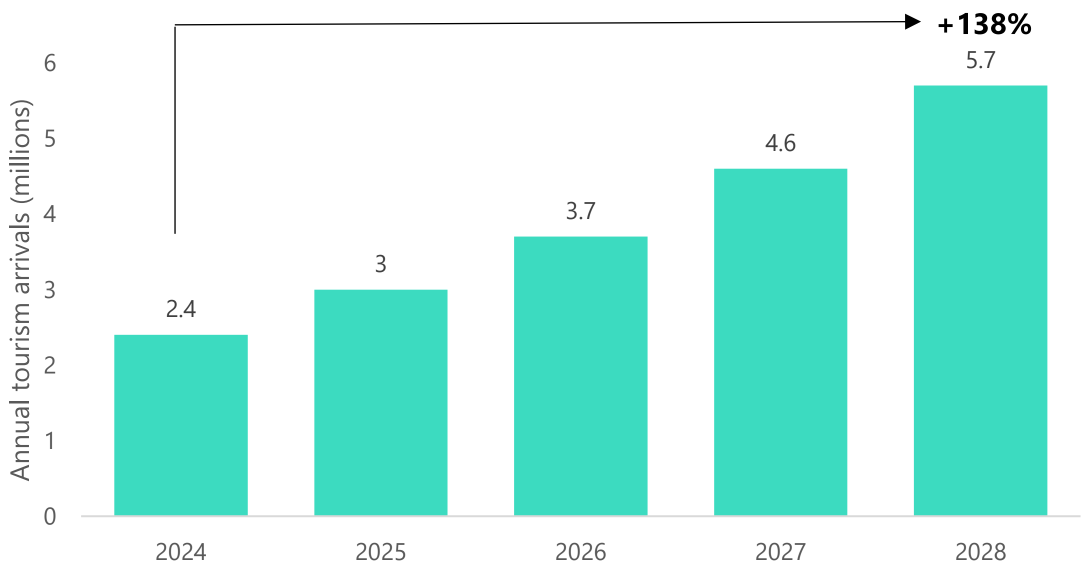


Figure 3.31: Annual tourism arrivals forecast (Ministry of Tourism)

3.4.5 POPULATION DEVELOPMENT

As of 2024, the population of Kenya counted over 52 million inhabitants. In 2023 the country recorded a poverty ratio of 39.8% for individuals, meaning that nearly 20 million people could not meet their basic food and non-food needs. In Nairobi city this ratio stood at 16.5%.

This is an important aspect as the people in lower income classes typically do not form part of the potential market for flights. As seen in section 4.3, the GDP per capita in Kenya was historically below the Africa average, confirming that the majority of the population did not have the means for air travel. This is however forecast to change significantly, with a strong growth of GDP/capita and subsequently a strong growth of the middle class, who will be able to afford air travel. This means that the potential market for air travel becomes much larger in the future, driving demand up.

As can be seen in the chart below, compared to its neighbours, Kenya has a more developed aviation demand, due to the relatively well performing economy and national airline with a wide range of routes and frequencies. However, it is still very low compared to top performing African countries with a larger middle class, and in the global context. Therefore, the population in Kenya can generate much more demand when the internal domestic network improves, infrastructure improves, and the wealth of the population improves.

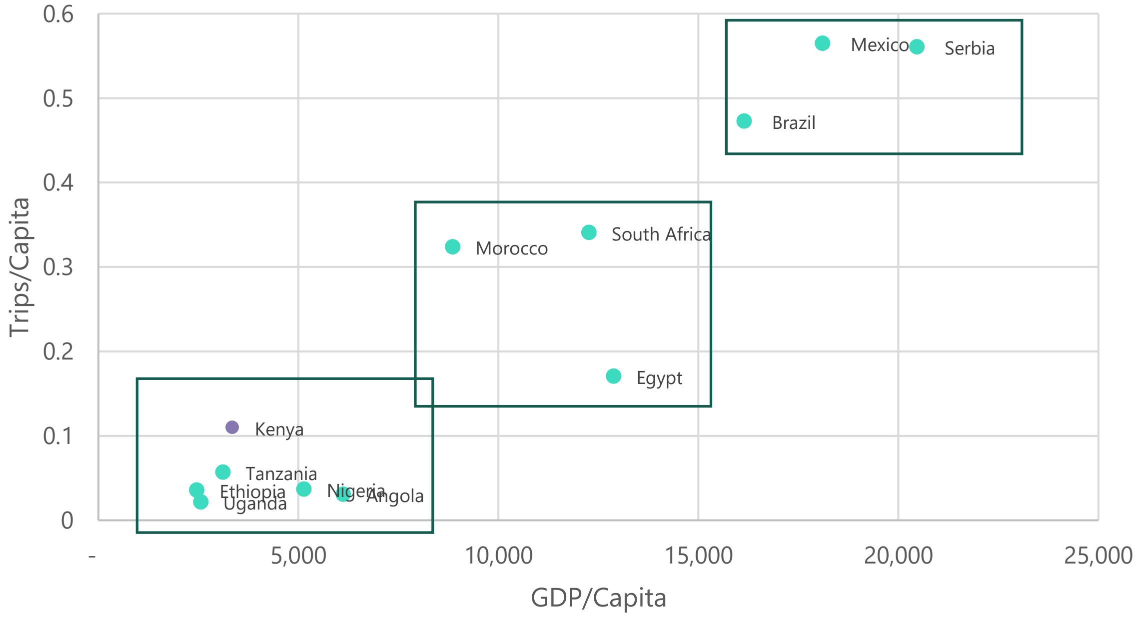


Figure 3.32: Trips per capita benchmark (2025 forecast as per Airbus GMF)

In terms of size, the population has grown at a rate of 2.2% in the last decade, it is forecast to grow at a medium rate of 1.5% until 2050. In addition to the growing middle class, the overall population will therefore also grow significantly, counting more than 50% more people in the country by the end of the forecast period.

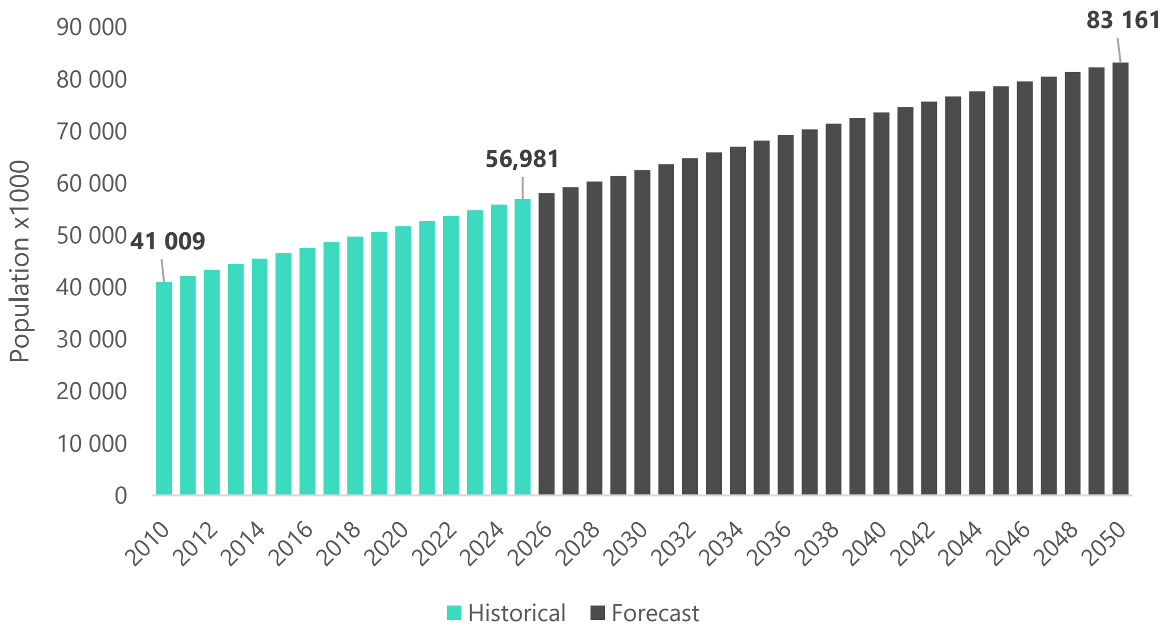


Figure 3.33: Population development of Kenya

The expected growth rate is below the rate forecast for Africa total, although it will still generate significantly larger population by 2050.

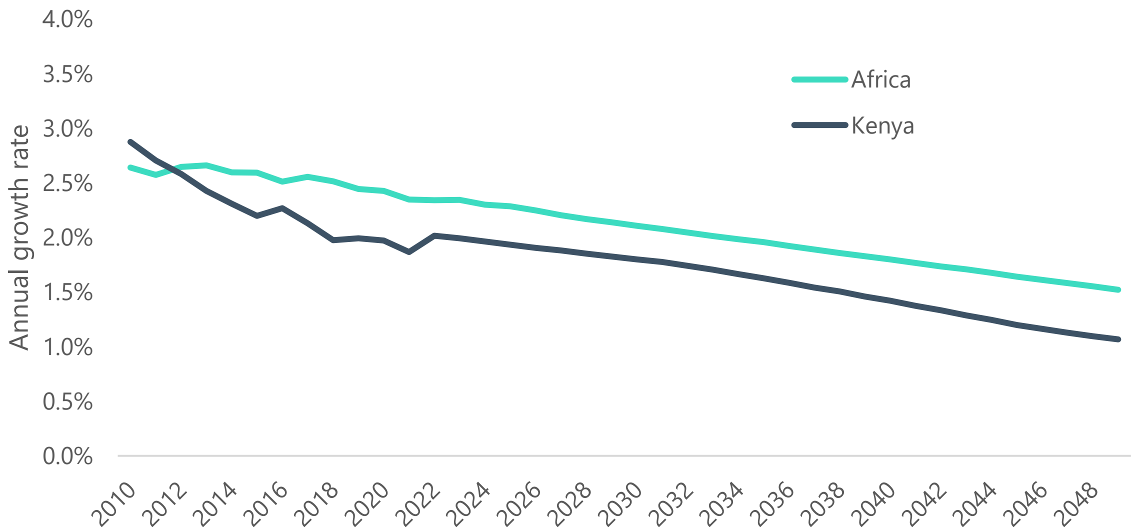


Figure 3.34: Population growth rates Kenya compared to Africa

The population is distributed along the capital Nairobi, lake Victoria in the west and the coastline along Mombasa. That is also where the main other airports are located. The remainder of the country remains sparsely populated and would generate little demand for domestic air travel.

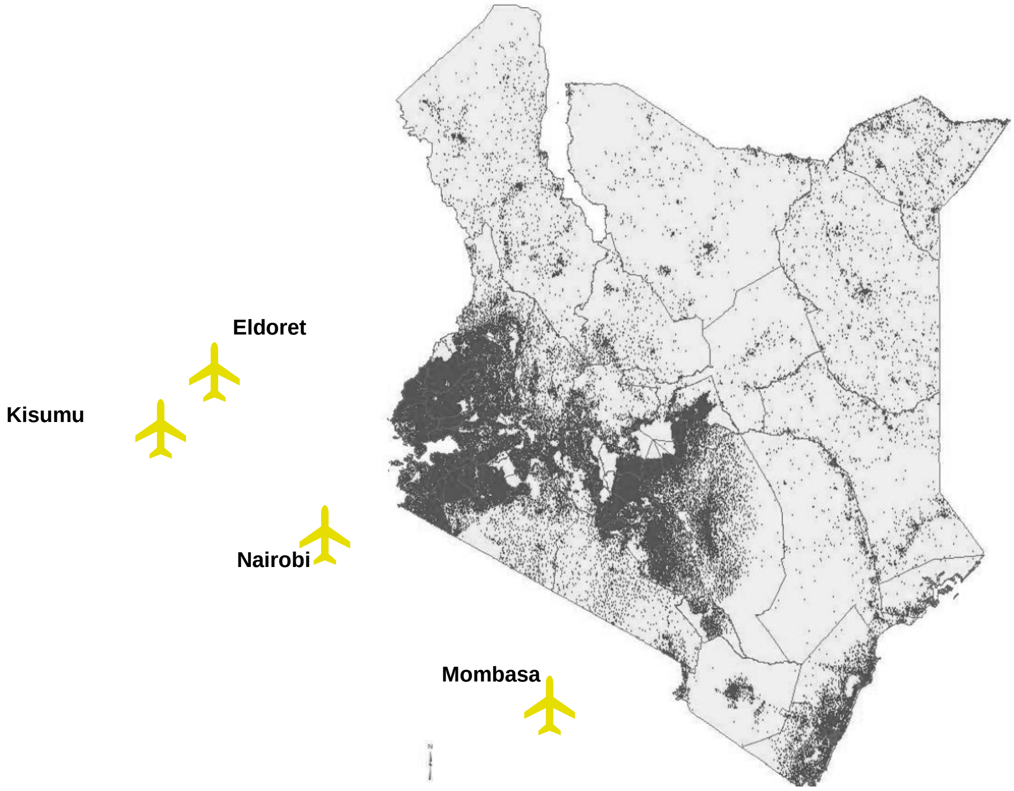


Figure 3.35: Kenya Population distribution

3.4.6 ECONOMIC OUTLOOK

Kenya's economic outlook reflects cautious optimism. The high population growth and the relative young population means that the labour force will grow strongly. The African Development Bank (AfDB) emphasizes the need for Kenya to achieve an average growth rate of 5.8% annually to absorb the increasing labour market entrants. This is in line with the various industry GDP forecasts as shown in the Figure 3.36 below.

Key reasons for the strong economic growth forecast in Kenya are:

- Kenya's population is projected to continue growing, with significant urbanization expected.
- At the same time, the middle-class population is expected to grow significantly, these are people which can afford air travel.
- The government's Vision 2030 plan aims to transform Kenya into an industrializing, middle-income country. This includes investments in infrastructure, manufacturing, and services to drive economic growth.
- Kenya's tourism sector is on a promising trajectory, bolstered by strategic initiatives, infrastructure enhancements, and favorable policies. This is expected to continue in the future.

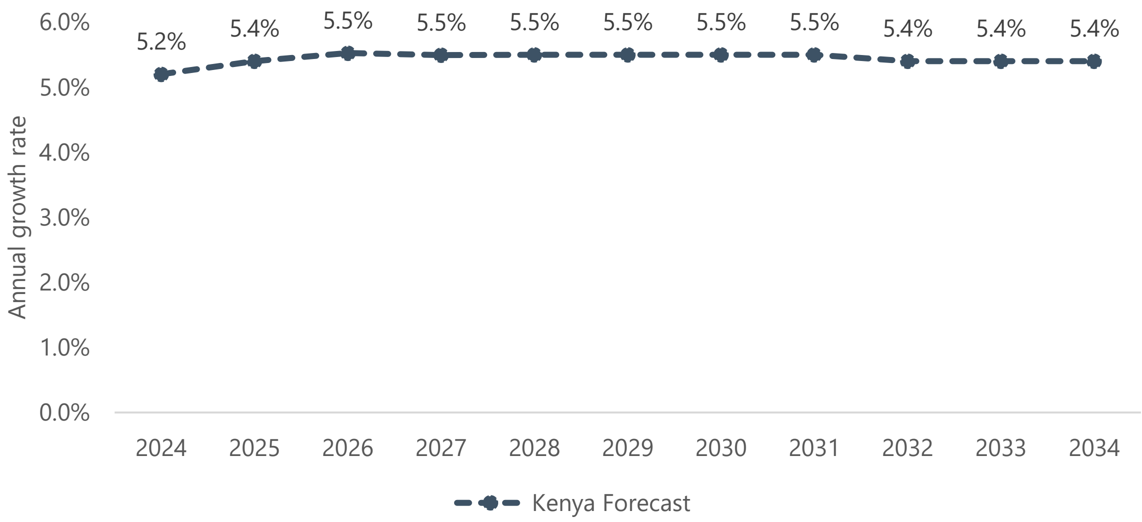


Figure 3.36: Kenya GDP Forecast

3.5 KEY GROWTH DRIVERS

3.5.1 GROWTH DRIVERS

For this forecast, the analysis in the previous two sections leads to a number of growth drivers for air traffic demand at JKIA. These drivers will be used in the subsequent calculation of the future growth for each traffic segment at JKIA, in both the top-down and bottom-up methodologies.

The key drivers are:

Table 3.2: Key growth drivers

Driver	Specification	Traffic Segment affected
Kenya Population growth	Leading to a larger potential market of air passengers	Domestic traffic and outbound travel from Kenyans for leisure purposes.
Kenya middle class growth, measured through GDP and GDP/capita.	The increased population will also be more affluent and able to afford air travel	Domestic traffic and outbound travel from Kenyans for leisure purposes.
Kenya Economic growth, measured through GDP	More industrial and commercial activity in the country, as well as more employment and higher disposable incomes of inhabitants.	Leading to more business travel both domestically and internationally, from Kenya residents and foreigners.
Kenya Tourism growth	Strong post-pandemic growth expected to continue in short term due to development projects and government policies	Inbound international tourism from all regions.
Development of infrastructure at domestic airports	KAA development plans of other airports	Allowing for increased domestic traffic and connectivity within the country to the capital.
Kenya Airways	Ambitious fleet growth and subsequent passenger volumes	Kenya airways international traffic and transfers
Jambojet	Part of Kenya Airways, expected to receive part of the forecast fleet growth	Jambojet domestic traffic

3.6 TOP-DOWN FORECAST

3.6.1 APPROACH

This study employs a top-down regression analysis approach to forecast long-term organic traffic growth at JKIA, with traffic segmented into domestic and international components. The methodology involves identifying appropriate economic drivers, testing various statistical models, and validating the model using historical data before projecting future growth rates.

1. Traffic Segmentation

The total passenger traffic at JKIA is first disaggregated into two primary components:

- Domestic Traffic: Passengers traveling within Kenya.
- International Traffic: Passengers traveling between JKIA and other countries.
- Transfer Traffic: passengers traveling between other countries via JKIA

This segmentation allows for a more targeted analysis, recognizing that different macroeconomic and structural factors influence each category.

2. Driver Identification

For each traffic segment, potential macroeconomic drivers are evaluated. The key candidate driver considered is Gross Domestic Product (GDP), based on its established correlation with air traffic demand.

- Domestic Traffic: Correlated with Kenya's national GDP.
- International Traffic: Evaluated against both Kenyan GDP and a composite GDP index of key passenger flows.

3. Regression Model Specification and Testing

For each segment, multiple regression models are tested to capture the relationship between traffic and the selected driver(s). The following models are evaluated:

- Linear regression (traffic vs. GDP)
- Log-linear regression (log(traffic) vs. log(GDP))
- Various time frames to capture the right period suitable to forecast long term organic growth.

Model performance is assessed using the following statistical metrics:

- R-squared and Adjusted R-squared
- P-value and significance F within statistical limits
- Residual analysis

4. Model Validation

The historical regression model results are plotted against actual recorded passenger traffic to visually and statistically validate the model's fit. This comparison ensures that the model captures the trend and turning points of past traffic evolution.

5. Forecasting and Traffic Growth Rate Estimation

Once validated, the selected models are used to project future traffic volumes based on independent forecasts of GDP. Long-term organic growth rates are derived from these projections, reflecting baseline demand absent structural shocks or exogenous interventions (e.g., airline strategy, major policy changes, infrastructure developments).

3.6.2 REGRESSION ANALYSIS

3.6.2.1 DOMESTIC TRAFFIC

Firstly the domestic passenger development is compared against the GDP of Kenya. As seen Figure 3.37 below, while the traffic development is more erratic due to external shocks (i.e. political conflicts), the general trend is similar.

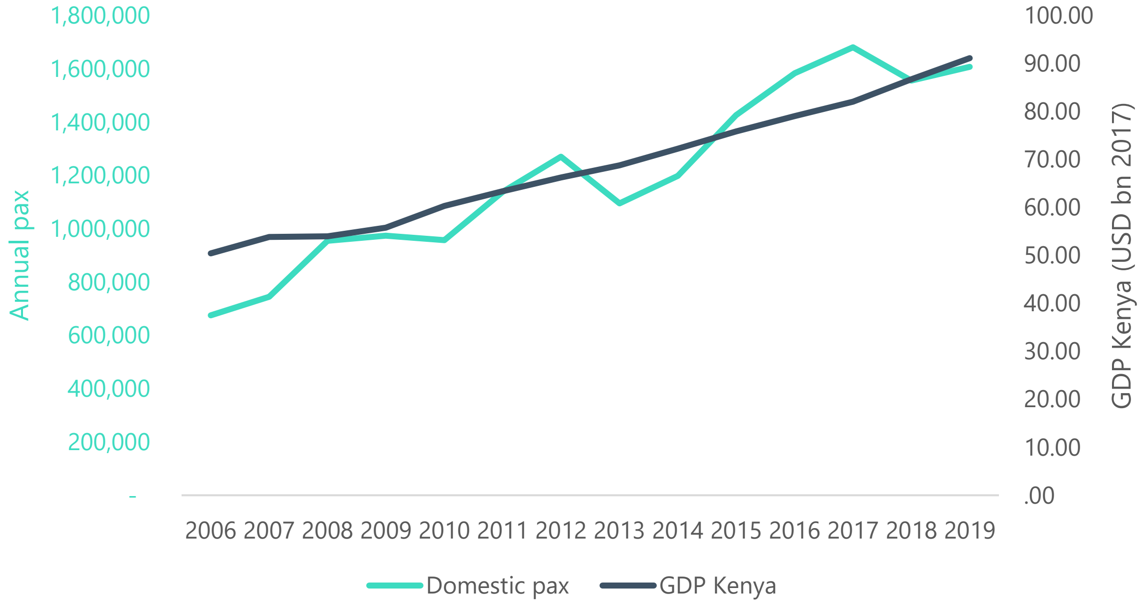
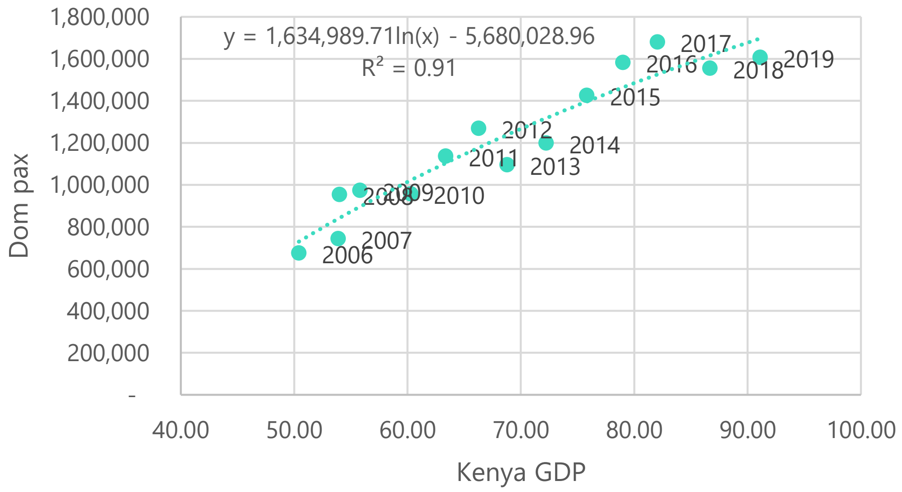


Figure 3.37: Domestic passengers vs Kenya GDP

Subsequently, a linear and logarithmic regression is performed to find the best model fit. The logarithmic model includes a declining curve, and thereby natural market saturation. In developing markets such as Kenya it is expected that after high growth initially, the rates reduce (mature) and elasticity between GDP and traffic growth reduces. As it furthermore has the highest R2 and therefore correlation, this model is selected.

Logarithmic regression	**Selected**



Variable input:

GDP Kenya (in real 2017 USD bn)

R2

91%

Formula:

*Passengers (y) = 1,634,989 * LN(GDP bn) - 5,680,028*

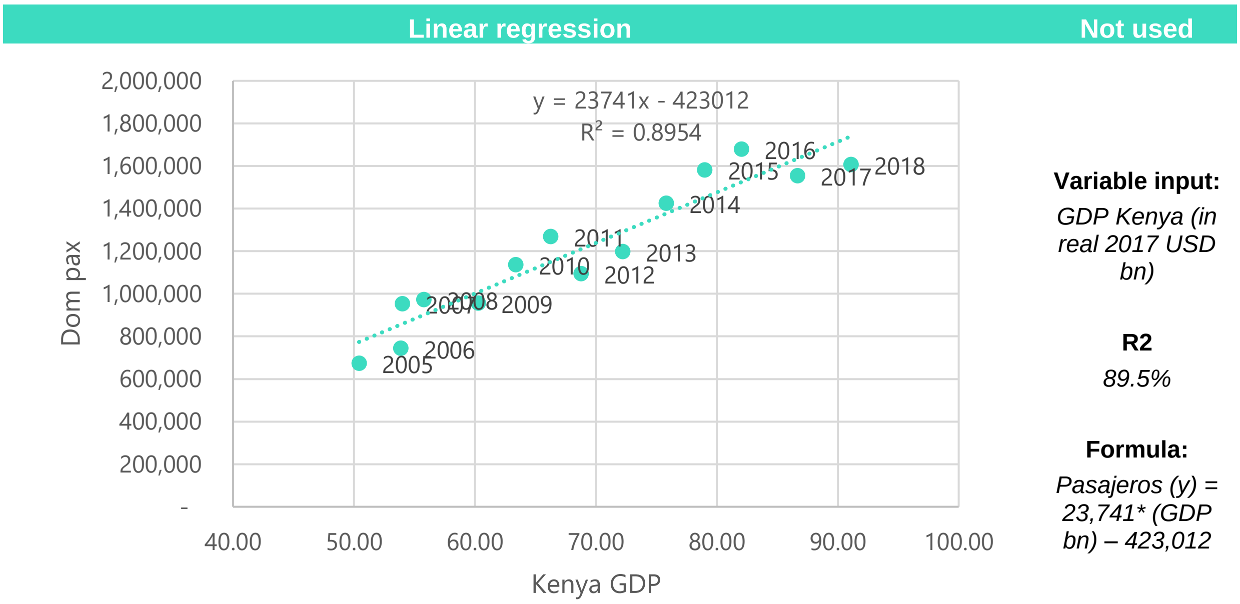


Figure 3.38: Regression models

To verify the selected model, a ´backcast´ is performed, plotting the model results against the actual traffic numbers.

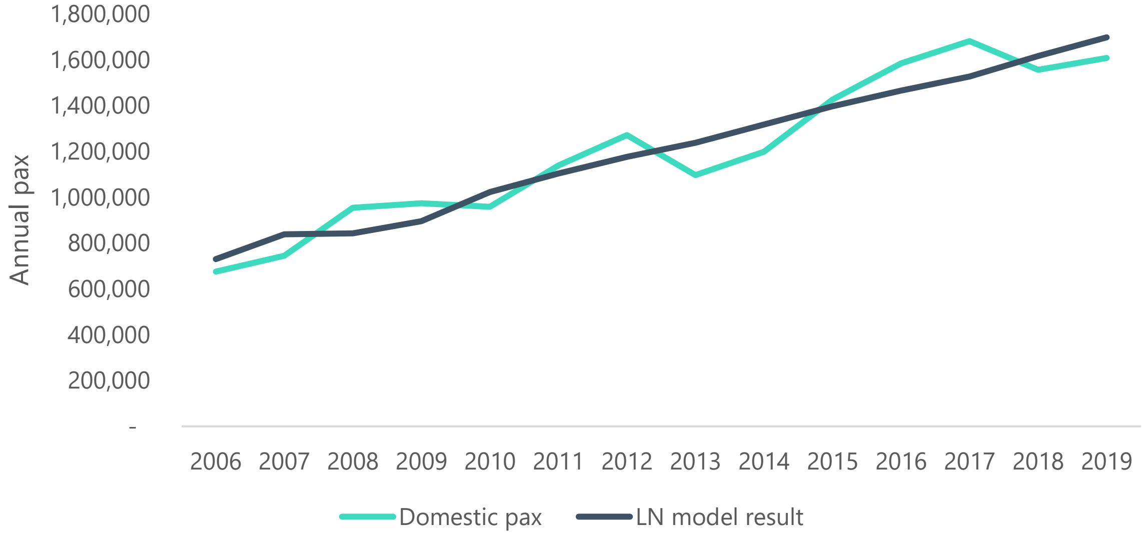


Figure 3.39: Model results vs actuals

As can be seen, the model accurately predicts the trend of the traffic development. It is therefore used to forecast the organic growth of domestic passengers from JKIA airport.

3.6.2.2 INTERNATIONAL TRAFFIC

Analyzing 2024 international traffic, the flows are divided into four main geographic areas:

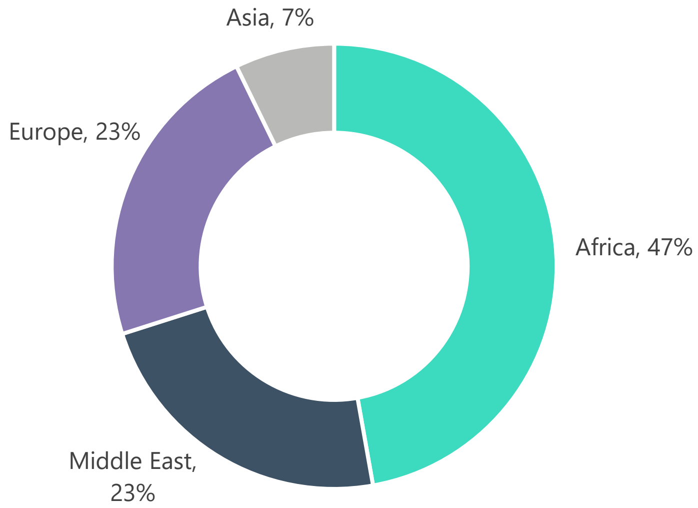


Figure 3.40: International passenger shares per geography

It is further assumed that 50% of international passenger traffic is Kenyan, or dependent on Kenyan GDP. The GDP mix used in the model is therefore as follows:

Table 3.3: GDP mix used

Geography	% GDP Weight
Kenya	50%
Africa	23.6%
Europe	11.3%
Middle East	11.4%
Asia	3.6%

Furthermore, the organic growth forecast only includes the O&D passengers, as transfer passengers are dependant on other factors not related to macro economic drivers. Mainly the airline strategy of Keny Airways and the capacity deployed in the market is a leading driver for transfer passengers. Therefore, this flow is forecast as part of the bottom-up analysis.

The international O&D flow against the mixed GDP is showing a similar trend, albeit affected by the political conflict in 2013-2014.

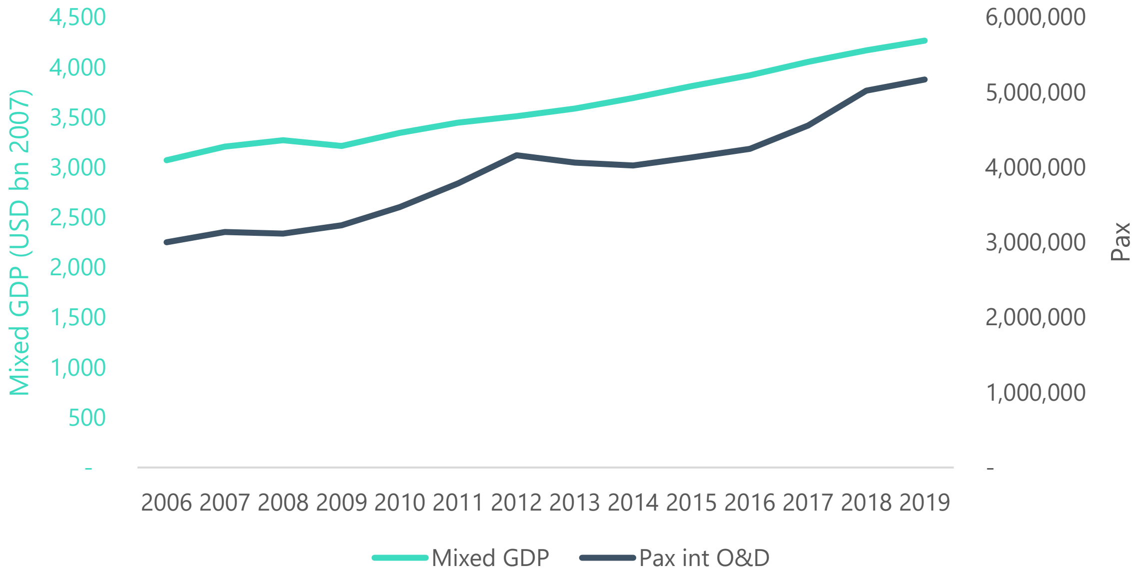
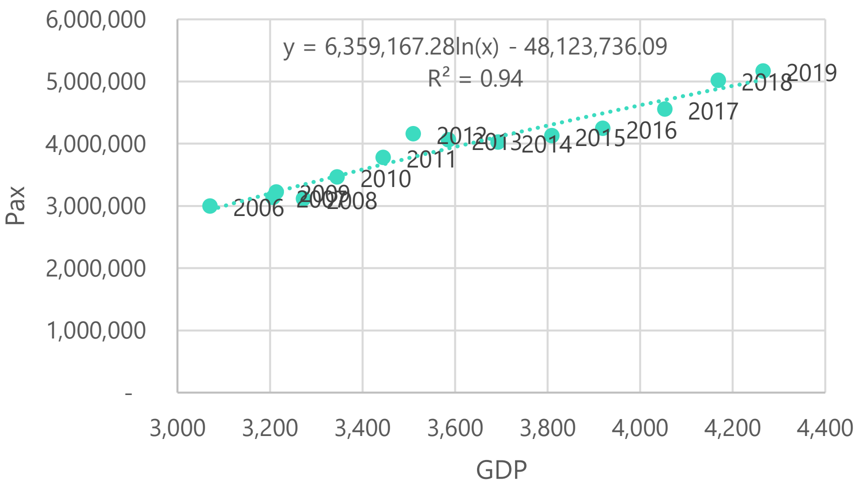


Figure 3.41: International passengers vs mixed GDP

Similar to the domestic analysis, both a linear and a logarithmic model are tested. Both models show high correlation of 94%. The linear model is selected as both models show similar correlation and it is expected that the African international market is still far from mature. The grow trend over the next 20 years will therefore remain strong.

Logarithmic regression	**Not used**



Variable input:

GDP mix (in real 2017 USD bn)

R2

94%

Formula:

Passengers (y) = 6,359,167 LN(GDP bn) – 48,123,736*

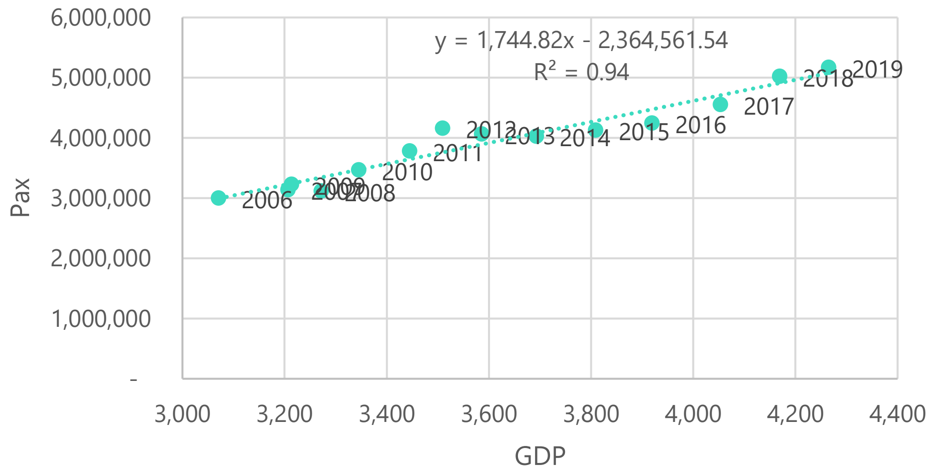
Linear regression	Selected
	**Variable input:** *GDP mix (in real 2017 USD bn)* **R2** *94%* **Formula:** *Pasajeros (y) = 1,744* (GDP bn) – 2,364,561*

Figure 3.42: International regression models

To verify the selected model, a ´backcast´ is performed, plotting the model results against the actual traffic numbers.

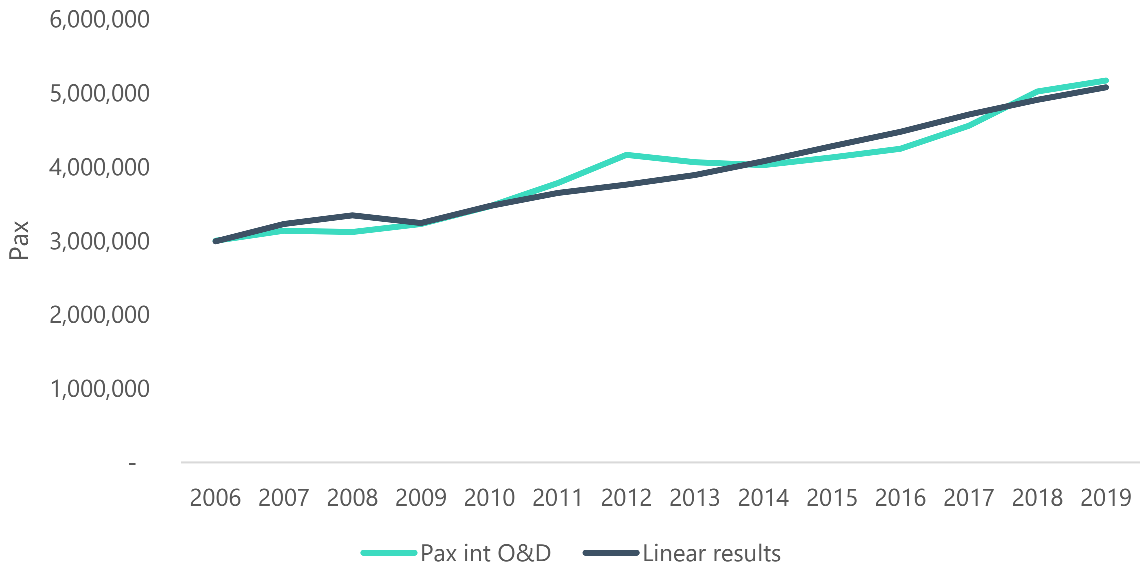


Figure 3.43: Model results vs actual international traffic

As can be seen, the model accurately predicts the trend of the traffic development. It is therefore used to forecast the organic growth of international passengers from JKIA airport.

3.6.3 FORECAST DRIVERS

GDP is the driver used to forecast organic growth of passengers at JKIA. The forecasts are a mix of respected sources such as Oxford Economics and EIU, until 2034. From 2034 to 2045, a similar trend is followed as in the previous decade, showing a steady reduction in annual growth rates.

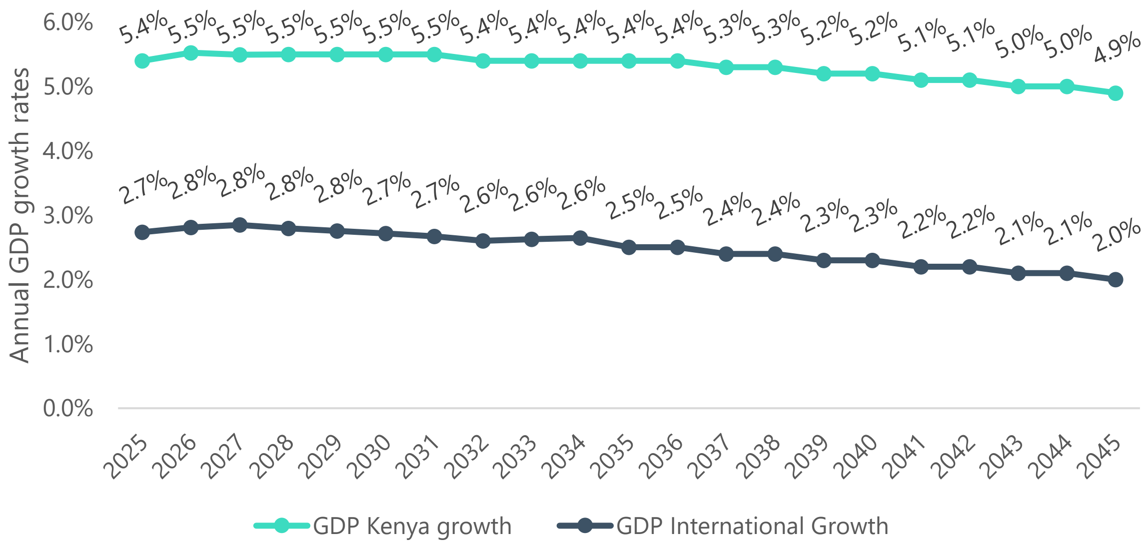


Figure 3.44: GDP forecasts used

3.7 BOTTOM-UP FORECAST

3.7.1 APPROACH

The bottom-up methodology builds the traffic forecast for Jomo Kenyatta International Airport (JKIA) by aggregating detailed traffic components and operational factors from the ground up. This approach focuses on route-level, airline-level, and market-specific drivers, capturing granular dynamics that are often not reflected in macroeconomic indicators alone.

The key factors considered in this element are:

- Airline network strategies and capacity plans (especially Kenya Airways/Jambojet, as this is the hub airline)
- Tourism development
- Regulatory and geopolitical factors

3.7.2 KENYA AIRWAYS & JAMBOJET DEVELOPMENT

This airline group, comprising Kenya Airways and Jambojet, carried 59% of all passengers at the airport in 2024 and is therefore the main factor to consider in terms of strategy and future expansion. The planning of the future airport facilities should accommodate for the plans this airline group envisages.

In the domestic market, these airlines transport 95% of passengers, Jambojet is the largest in the domestic market, with market share of 60%.

In the international market, Kenya Airways carried 48% of all passengers.

Kenya Airways currently has a fleet comprising 34 aircraft, of which 30 are for passenger use. In addition, Jambojet has a fleet of 9 Dash 8 aircraft. The total fleet for passenger transportation therefore consists of 43 aircraft, of which 39 are for passenger transport.

Table 3.4: Kenya Airways and Jambojet fleets

Airline	Aircraft Type	Quantity	Role	Typical Use
KQ	Boeing 787-8	9	Wide-body Passenger	Long-haul international routes
KQ	Boeing 737-800	8	Narrow-body Passenger	Short to medium-haul regional routes
KQ	Embraer E190	13	Regional Passenger	Domestic and regional African routes
KQ	Boeing 737-300SF	2	Freighter	Dedicated cargo operations
KQ	Boeing 737-800SF	2	Freighter	Dedicated cargo operations
JM	De Havilland Canada DHC-8-400	9	Turboprop Passenger	Domestic and short regional routes

Project Kifaru 2 is Kenya Airways' comprehensive strategic recovery and growth plan, initiated to transform the airline into a financially sustainable and operationally efficient carrier. Building upon the initial phase, which focused on stabilizing operations post-COVID-19, Project Kifaru 2 aims to modernize the fleet, enhance customer experience, and achieve long-term profitability. The last phase of the programme is now ongoing and is the growth phase.

Under its strategic plan, Kenya Airways aims to double its passenger numbers and revenues by 2030. By 2035 the airline group aims for 12.5 million annual passengers and 70 passenger aircraft. In 2024 5.2 million passengers were handled.

It is envisaged that the Kenya Airways fleet grows to 45 aircraft and the Jambojet fleet to 25 aircraft. Jambojet is also envisaged to expand into regional Eastern African routes. In the long term, post 2035 the growth of the fleet should then continue to some 100 aircraft. It is however noted that no firm orders have been placed at the time of preparing this forecast in 2025.

While O&D passengers are expected to grow strongly due to tourism growth and economic growth, enhanced by growth of the middle class and population growth, the airline also aims to increase its transfer share. In 2024 20% transfer share was recorded (on international traffic).

Kenya Airways is launching direct flights between Nairobi and London Gatwick Airport, commencing on July 2, 2025. This new route will operate three times a week, supplementing existing services to London Heathrow and increasing total weekly flights between Nairobi and London to ten. It is however mentioned that the overall 2025 growth is limited due to limited fleet availability.

While no firm orders have been placed, the consultant has used the Kenya Airways strategic outlook as a base and made assumptions on the potential incorporation timeline of the total fleet growth by 2035. The fleet growth incorporated in the forecast, is therefore as estimated as shown Figure 3.45 below. The additional passengers that each aircraft can carry over a year is added to the organic growth of all other airlines. It is assumed that all Kenya Airways fleet expansion will be used for international routes, and Jambojet will take the majority of the domestic growth while 6 of its new aircraft are destined to develop an international network in the region.

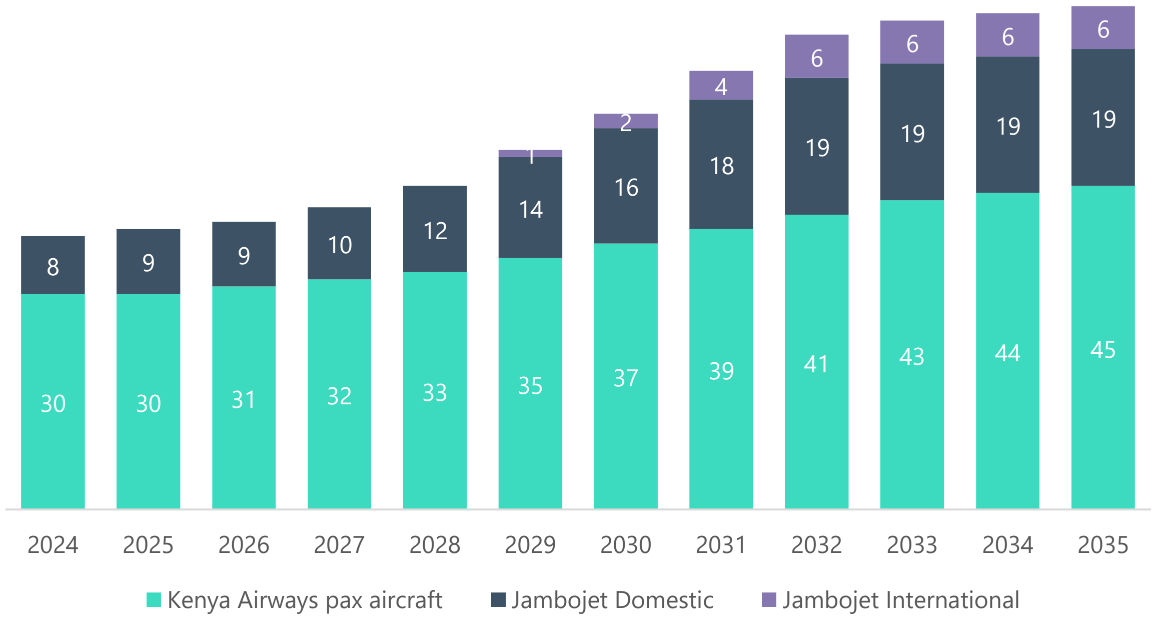


Figure 3.45: Assumed fleet growth in base case

3.7.3 OTHER DRIVERS

3.7.3.1 TOURISM GROWTH

Tourism is a key driver for growth, as 69% of tourists arrive at JKIA. As seen before, tourism has grown from 1.9 million in 2019 to 2.4 million in 2024. This is partly due to fact that Kenya has recently made moves to ease visa restrictions for many nationalities, including the implementation of an electronic travel authorization (ETA) system. It is expect that this policy will continue to drive tourism demand. The Ministry of Tourism estimates continued growth to 5.7 million by 2028, more than double the current level. This is also in line with Kenya Airways´ ambition to double their passenger numbers.

As shown in the Figure 3.46 below, 5.7 million tourists will lead to 7.4 million passengers at JKIA (a tourist counts for 2 passengers, arriving and departing). This means an additional 4 million passengers for JKIA.

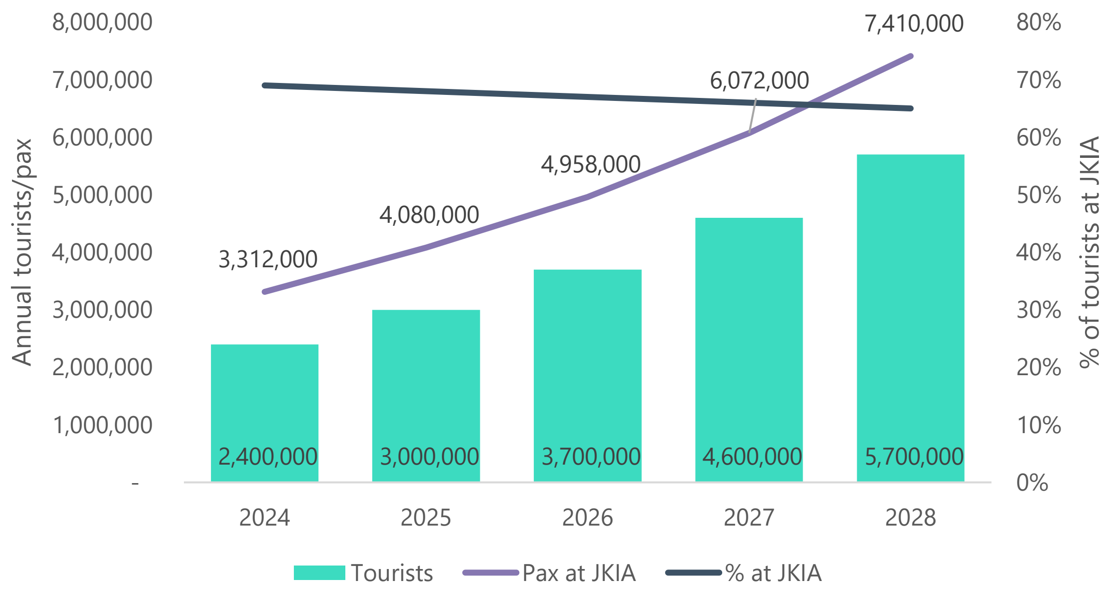


Figure 3.46: Forecast tourists and resulting pax at JKIA

It should be noted that this is a target set by the government and although the initial trend suggests this is feasible, it is used as guidance and support for the strong growth expected in the first years of the forecast. The resulting additional passengers are not fully implemented in the base case, however serve as an upside case later detailed.

3.7.3.2 REGULATORY AND GEOPOLITICAL FACTORS

Air traffic at Jomo Kenyatta International Airport (JKIA) is also shaped by regulatory policies and geopolitical developments. These factors can either constrain or stimulate traffic flows depending on how they evolve and are implemented. The Table 3.5 below outlines key regulatory and geopolitical influences relevant to JKIA and discusses their potential future impact.

Table 3.5: Other traffic drivers

Factor	Future outlook
Security situation in the Horn of Africa, particularly: • Armed conflict and instability in Somalia, including operations involving Al-Shabaab, periodically impact Nairobi-Mogadishu air services and traveler sentiment. • Spillover effects from conflict in Sudan and tensions in the Democratic Republic of Congo (DRC) can also affect regional travel patterns, especially connecting traffic via Nairobi.	Improved stability and peace-building efforts in Somalia and neighboring countries could unlock significant regional demand, particularly for business and diaspora travel. Conversely, persistent or escalating conflicts may depress demand or necessitate rerouting and higher insurance costs for airlines.
Single African Air Transport Market (SAATM) SAATM is a flagship African Union initiative aiming to liberalize air services across Africa by allowing airlines from member states to operate freely within the continent. implementation remains uneven, with only partial liberalization in practice due to protectionist policies in some countries.	Full or broader adoption of SAATM could boost intra-African connectivity from JKIA, leading to increased frequencies, new city-pairs, and passenger volumes. Conversely, slow implementation would limit JKIA's potential as a continental hub.

These two factors have a significant impact on the forecast but are highly uncertain. Therefore, assumptions regarding the future development will be incorporated into the scenarios, in order to indicate the impact either way.

The base case assumes a status quo, meaning that unrest remains in the region, but not directly in Kenya. The SAATM remains at its current level, prohibiting for example the entry of a large African Low Cost Carrier, and limiting more direct route developments.

3.7.4 TRANSFER PASSENGER FORECAST

Historically, transfer passengers have hovered between 1 and 1.2 million at the airport (2008-2017). The last two years before the pandemic this grew to 1.5 million, some 18% of total traffic. However, transfer passengers have not recovered to prepandemic volumes, while international and domestic O&D passengers have exceeded 2019 performance. It is expected that this is due to the increased tourism demand as a result of the Government's policies and general economic growth in Kenya. More space in the cabins has therefore been taken on by O&D passengers, leaving less capacity for transfers.

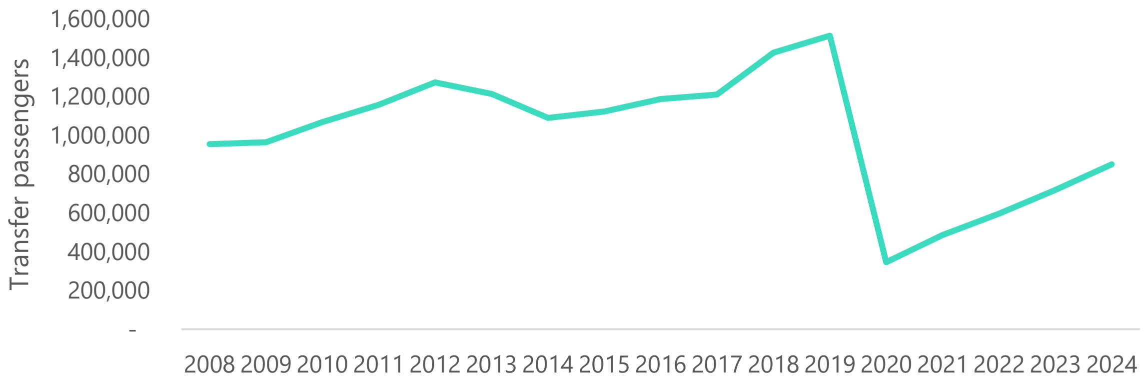


Figure 3.47: Historic transfer passengers at JKIA

Due to the continued improved tourism situation with a more open visa policy, and the continued focus of the government to improve this sector, it is expected that this trend will continue. Therefore the transfer forecast will be based on the 2024 actual volumes and market shares.

It is expected however, that due to the large extra capacity projected by Kenya Airways, and its focus on being a hub airline, that transfer passengers will grow to a share higher than before the pandemic. To estimate this flow, firstly the transfer passengers by airline are separated. It is known that Kenya Airways transports 76% of transfer passengers. The other 24% is equally distributed along the Skyteam partners.

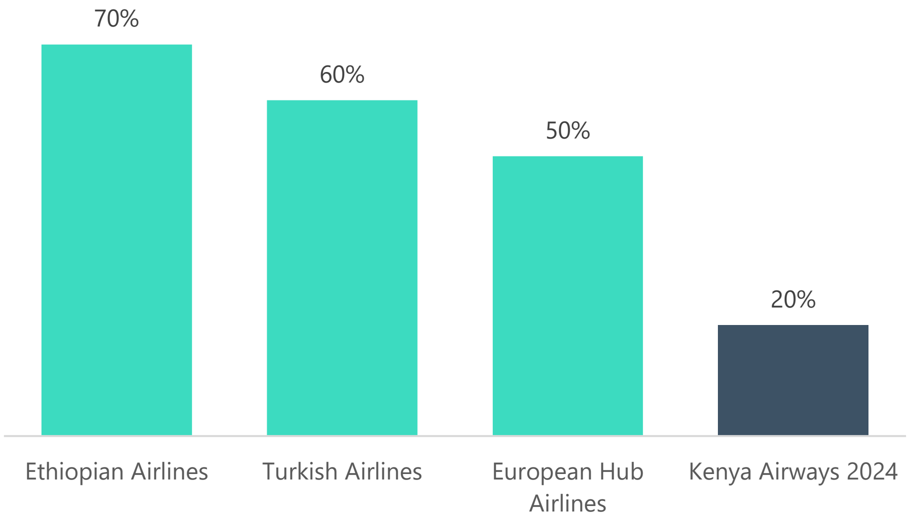
Table 3.6: 2024 transfer passengers per airline

Airline	Transfer pax 2024
Kenya Airways	645,840
KLM	67,983
Air France	67,983
Saudi Arabian	67,983

For Kenya Airways, the capacity available grows and the connections improve with the new fleet available. In 2024, 20% of the airline´s international passengers were transfers. This ratio is increased to 40% by 2040, resulting in a boost in transfer passengers.

Typical long standing hub airlines can reach transfer passenger shares of 50% - 60%. In the case of Ethiopian Airlines this is 70%. However, with the current lower starting point and the strong expected growth of O&D passengers, the transfer share for Kenya Airways is expected to grow from 20% to 40% in the base case.

Table 3.7: Typical transfer shares of hub airlines



The other airlines´ transfer passengers grow in line with their overall growth, to maintain the ratio of transfers at the same level as 2024.

3.8 FORECAST RESULTS

3.8.1 OVERALL RESULTS

The consolidated base case forecast, which takes into account the assumptions set out in the previous chapters results in a strongly growing traffic demand to 22.3 million passengers by 2045 with an overall growth rate of 4.6%.

This forecast takes into account the strong fleet growth and ambition expected by Kenya Airways and Jambojet, banking on the increased tourism trend and positive economic outlook. Passengers grow therefore from 8.6 million in 2024 to an expected 13 million in 2030.

Domestic and international O&D passengers will see the strongest volume growth, while transfer passengers grow from 9.9% in 2019 to some 21% of total passengers. These are mainly carried by Kenya Airways and Jambojet.

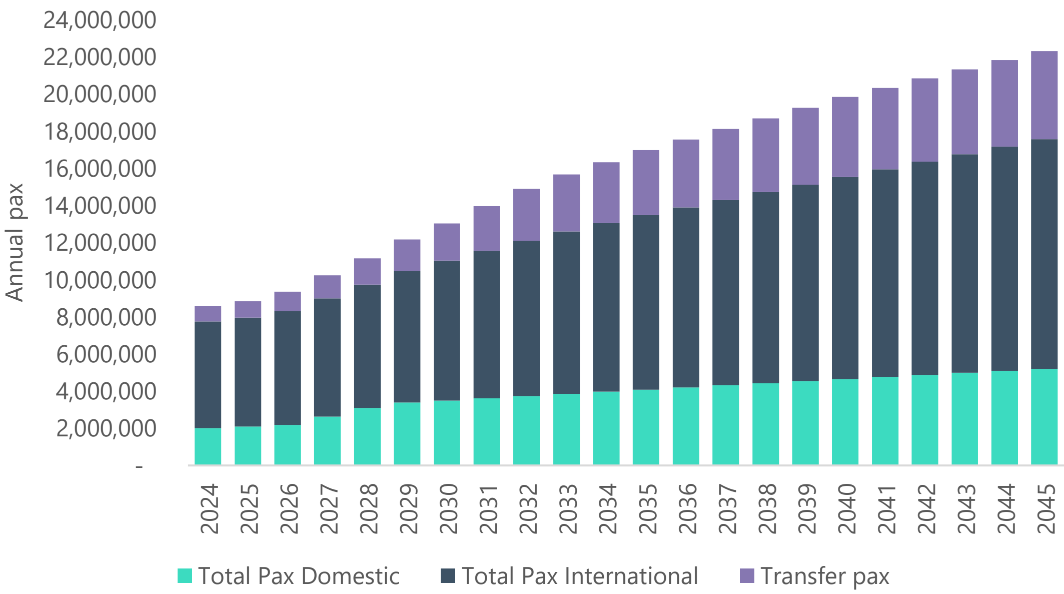


Figure 3.48: Passenger forecast results

	2024	2030	3025	2040	2045	CAGR 2024-45
Total Pax Domestic	2,009,000	3,503,000	4,088,000	4,658,000	5,201,000	4.6%
Total Pax International	5,742,000	7,529,000	9,387,000	10,879,000	12,367,000	3.7%
Transfer pax	850,000	2,009,000	3,499,000	4,305,000	4,743,000	8.5%
Total Pax	**8,601,000**	**13,041,000**	**16,974,000**	**19,843,000**	**22,311,000**	**4.6%**

3.8.2 INTERNATIONAL FORECAST

The international forecast is driven by general economic growth in Kenya, Africa and the other markets. Kenya Airways/Jambojet is the main airline driving this growth, due to their fleet expansion and opportunity to capitalize on the overall demand growth. Their market share therefore grows to 60%, from 49% in 2024.

The forecast below includes both O&D and transfer passengers. The rate of transfer passengers increases compared to the 2024 rate.

The other main airlines, which are Qatar Airways, Emirates and Ethiopian, are expected to continue growing steadily at the airport in accordance with the market growth. These airlines all transport passengers to their respective hubs, for onward connections.

Qatar Airways is expected to double in the long term and grow from around 450.000 passengers in 2024 to 850.000 in 2045.

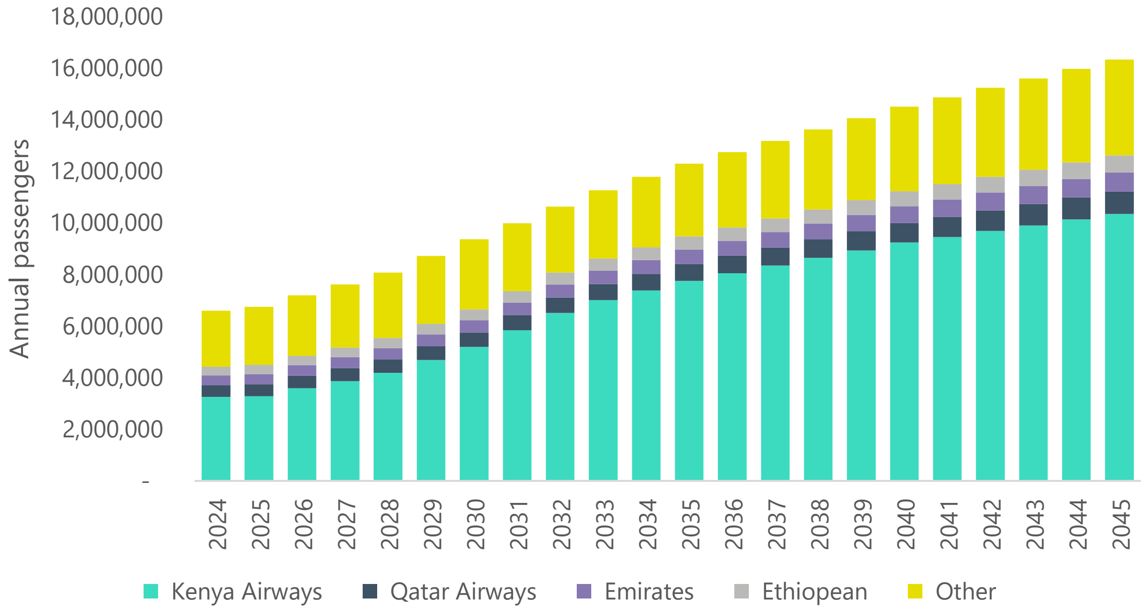


Figure 3.49: International forecast passengers by airline

3.8.3 DOMESTIC FORECAST

The domestic market is expected to grow at the strongest rate. It is considered that there is high demand for the highly populated areas around Kisumu and Eldoret to expand frequencies, in addition to continued expansion to Mombasa.

It is expected that Kenya Airways will focus on international growth and Jambojet on the domestic market. Jambojet with their significantly expanded fleet will therefore drive the growth in the next 5 years.

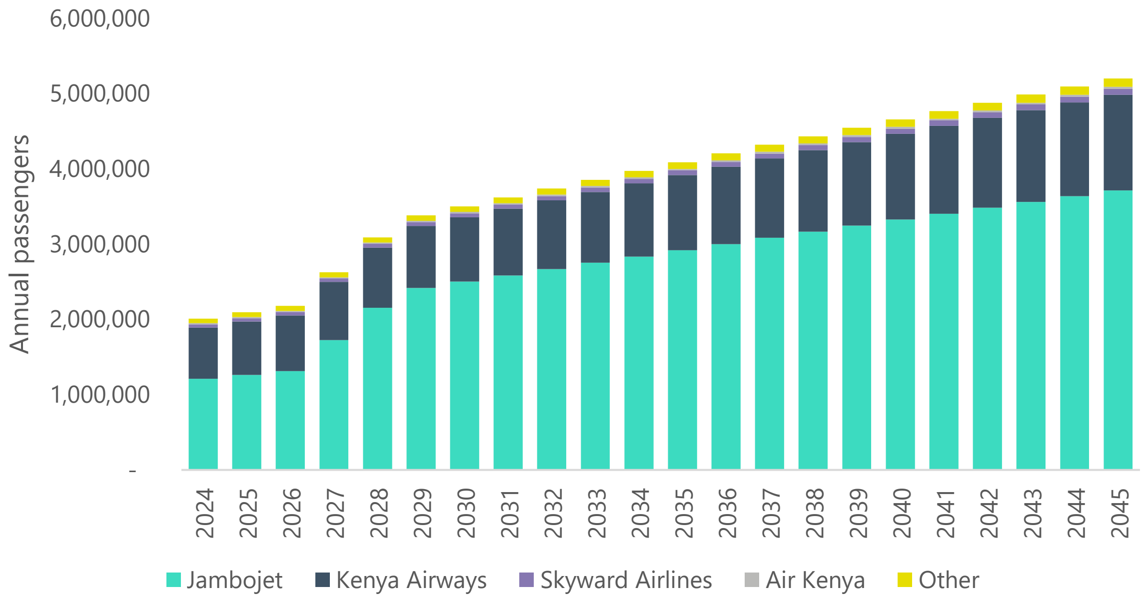


Figure 3.50: Domestic passengers forecast by Airline

3.8.4 COMPARISON WITH 2022 FORECAST

The 2022 forecast was prepared during the pandemic with 2021 as latest data point. The main difference is the transfer passengers have not recovered and are still some 40% below 2019 levels while domestic and international O&D passengers have well exceeded 2019 levels.

It is unknown why the previous forecast includes such a high growth in transfer passengers to 7.6 million by 2045. Based on the latest statistics and knowledge growth is coming from O&D passengers, which result higher than the 2022 forecast. Overall transfer passengers remain at the same percentage as 2024, some 11% of total traffic. Resulting in 2.3 million passengers by 2045, while the 2022 forecast reached a significantly higher level. Due to this difference, the new forecast results slightly lower than the previous forecast.

It should be noted that that in this forecast Kenya Airways has not yet provided inputs. A strategic change in relation to transfer passengers could change the future view.

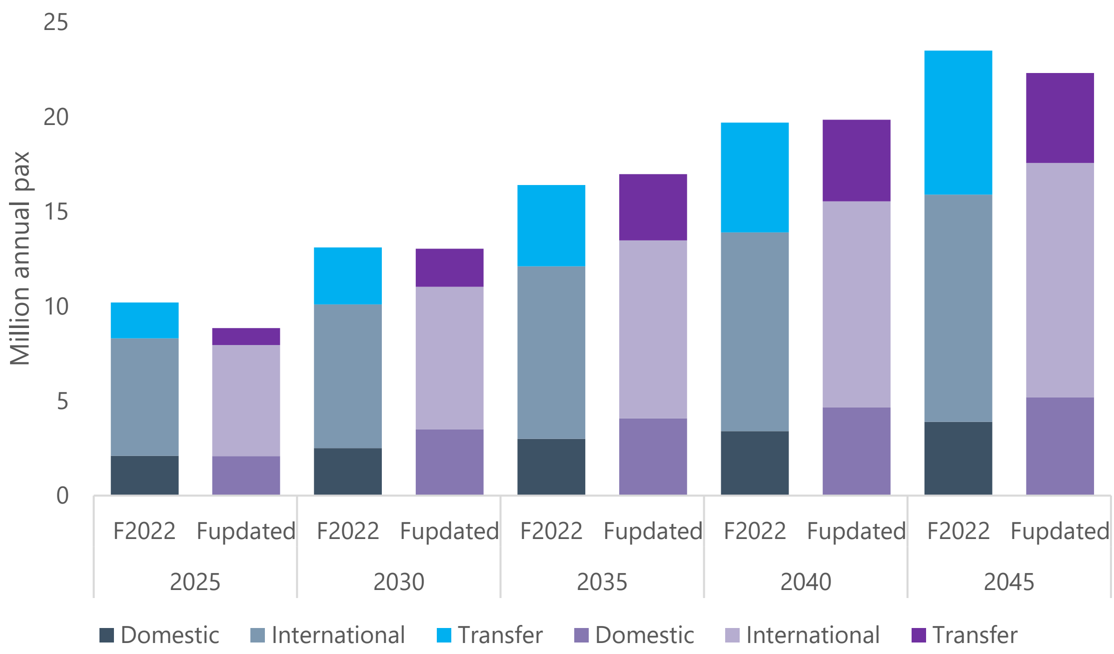


Figure 3.51: Forecast results comparison with 2022 forecast

3.8.5 AIR TRANSPORT MOVEMENTS

The ATMs are calculated for the following categories:

- Domestic flights
- International flights
- Cargo Flights
- GA & Other flights

The following start values are derived from the 2024 schedule and historical statistics.

Table 3.8: 2024 ATMs per category

Category	2024 ATMs
Domestic passengers ATMs	29,108
International passenger ATMs	57,047
Cargo ATMs (all international)	18,243
GA & other ATMs (mix international and domestic)	11,330
Total ATMs	**115,728**

Cargo flights are not specifically identified in the schedule but assumed to be flights without passengers.

GA & other flights are not specifically identified in the schedule but are assumed to be the flights with between 1-10 passengers.

For domestic and international passenger flights, the 2024 ratio of passenger per aircraft has been established. This ratio is then grown slightly over time to reflect increased load factors and larger aircraft (KQ focusing on international routes).

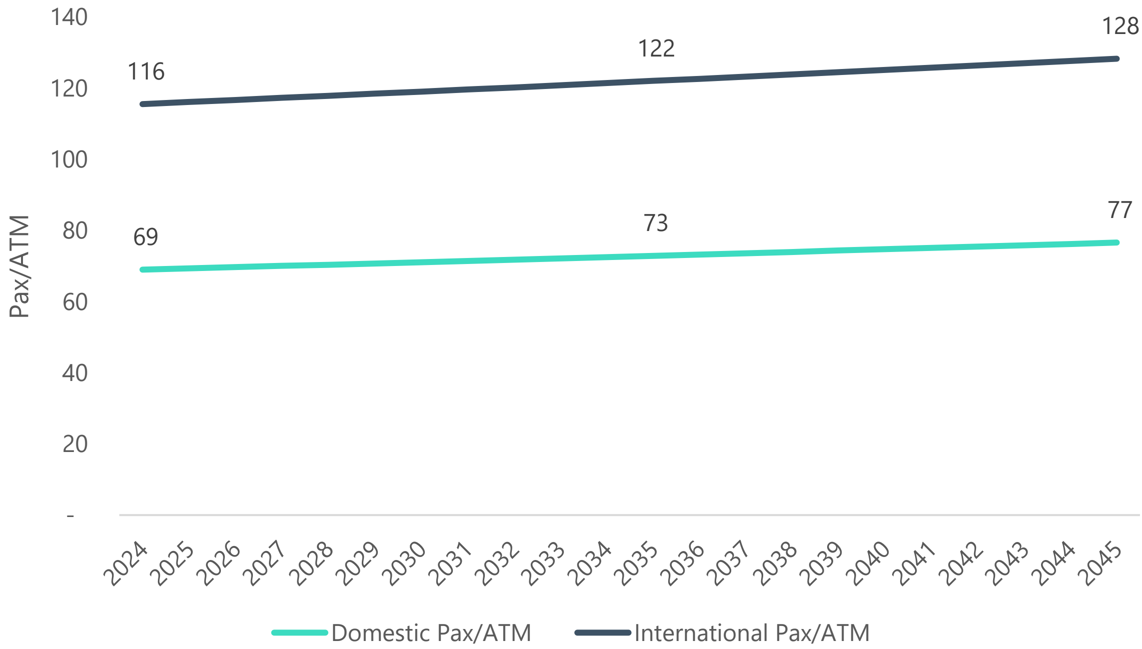


Figure 3.52: Forecast Pax/ATM

This results in some 73 thousand domestic ATMs and 121.000 international ATMs.

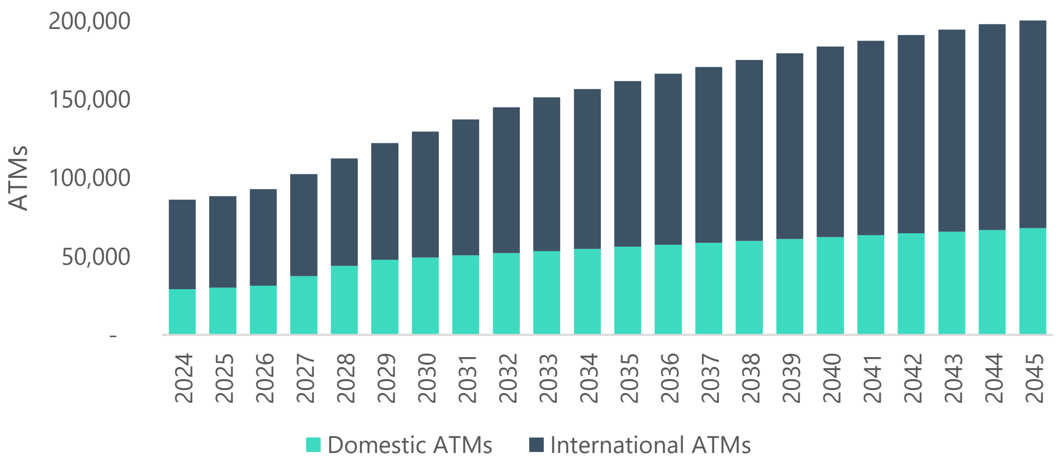


Figure 3.53: ATMs forecast

	2024	2030	2035	2040	2045	CAGR 24-45
Domestic ATMs	29,108	49,256	56,069	62,320	67,871	4.1%
International ATMs	57,047	80,110	105,562	121,329	133,347	4.1%

General Aviation and Other movements are calculated in accordance with the organic growth rate of the international passengers. Thereby it considers the economic development of Kenya and partner regions. The movements in this category result in a growth from some 11.000 movements to 22.000 by 2045, at a 3.2% average growth rate.

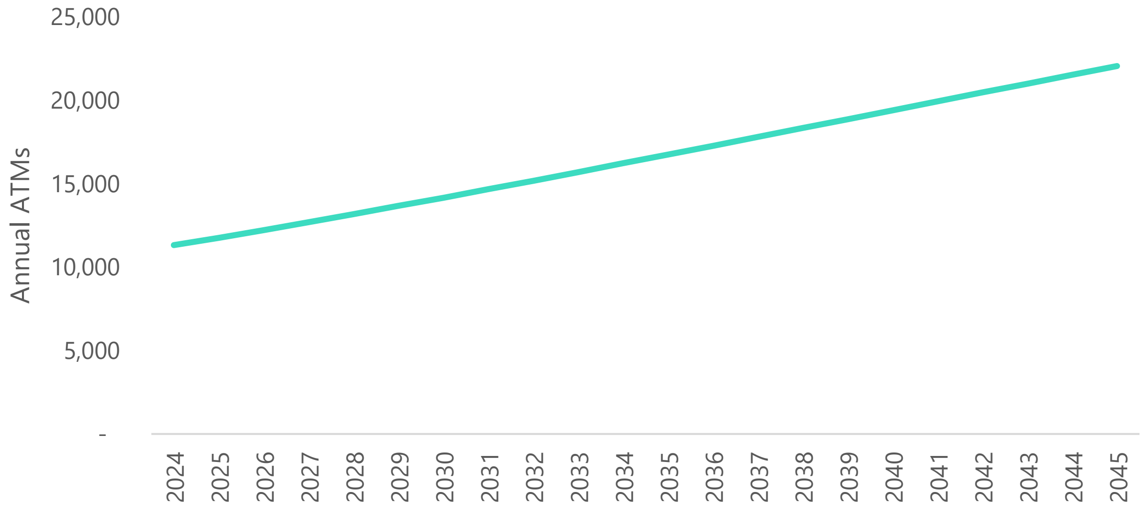


Figure 3.54: GA and other ATMs forecast

Cargo ATMs are calculated in accordance with the cargo forecast. In 2024 it is estimated that some 18,000 international cargo ATMs took place.

It is assumed that the cargo ATMs grow in line with the overall cargo volume forecast, this means that the split between cargo handled in passenger bellyholds and full freighters remains stable. The cargo growth forecast is further specified in chapter 10, and the resulting annual ATMs are shown in Figure 3.55 below.

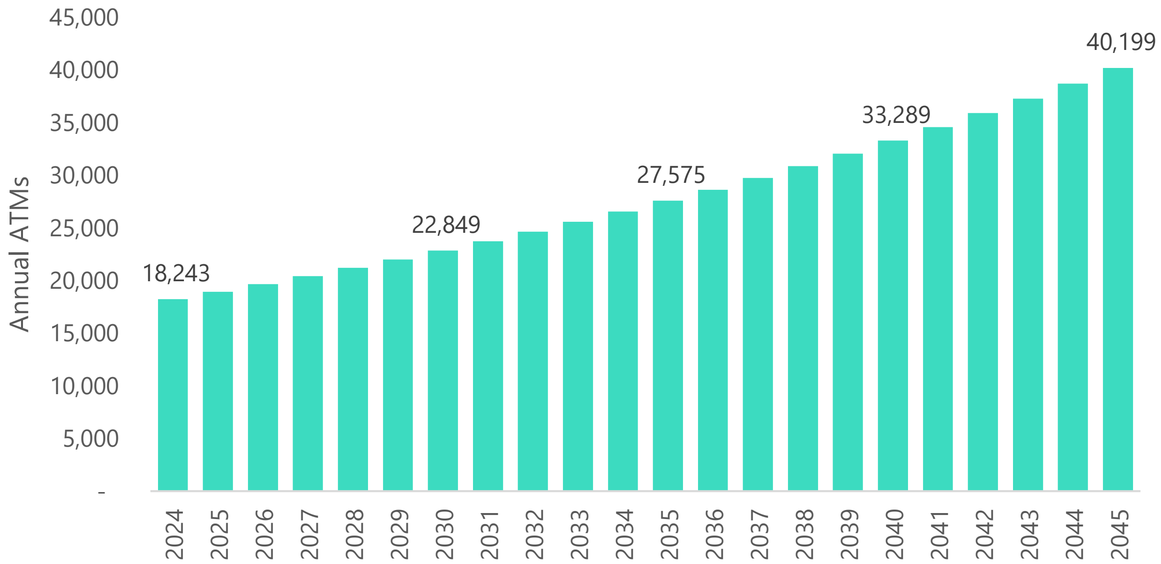


Figure 3.55: Cargo ATMs forecast

3.9 FORECAST VALIDATION

3.9.1 STATISTICAL VALIDATION

Firstly, the statistical models are validated to ensure that these are statistically valid and a food fit for the forecast.

3.9.1.1 Domestic Model Validation

A logarithmic model as seen in Figure 3.56 below is developed.

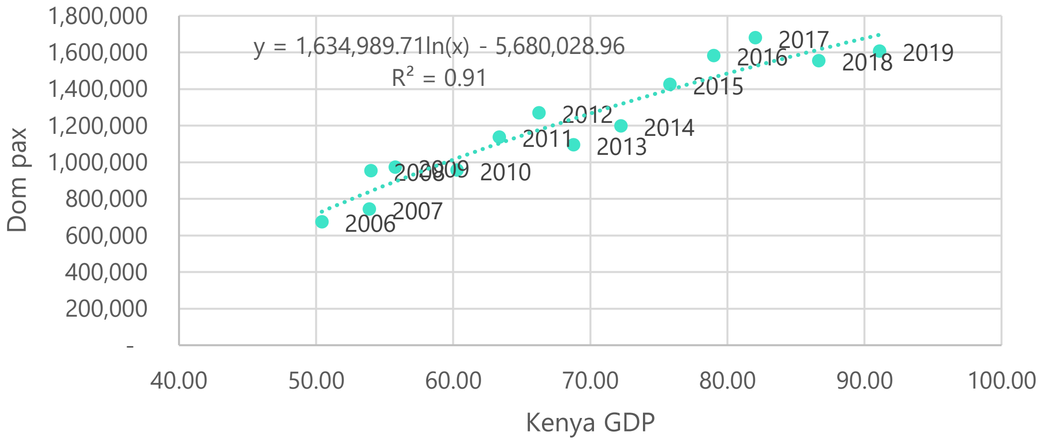


Figure 3.56: Domestic Regression Model

The analysis of the model parameters suggests it is a good fit. The R square suggests a good correlation between the driver (Kenya GDP) and the passenger development. The P-value is within limits. The **Root Mean Square Error shows a 96 thousand passenger error**, which is less than 5% of the total passengers in 2024.

Table 3.9: Domestic Regression results

Metric	Result
Intercept	- 5,680,029
X Variable Kenya GDP	1,634,990
R Square	90.7%
Adjusted R Square	89.9%
P-value	1.50281E-07
RMSE	96,133

Plotting the errors also indicates that the model values are within acceptable range of the true values.

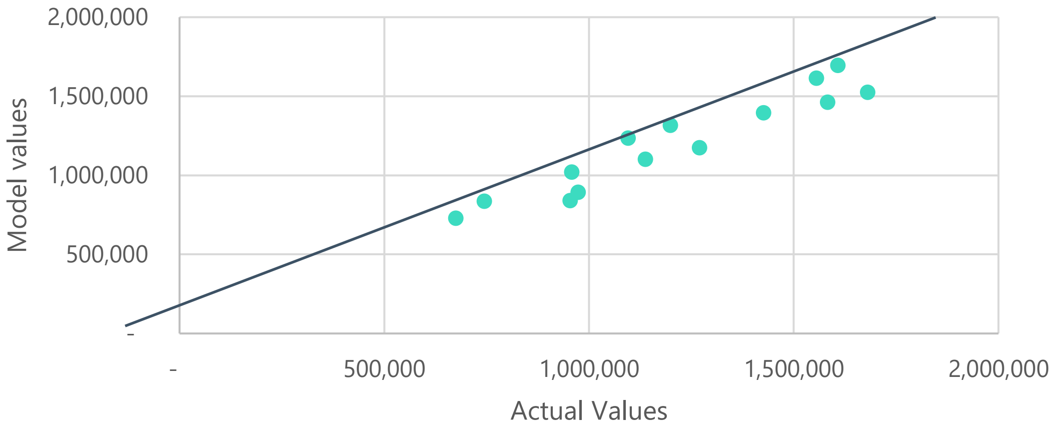


Figure 3.57: Error analysis Domestic Regression

3.9.1.2 International Model Validation

A Linear model as seen below is developed.

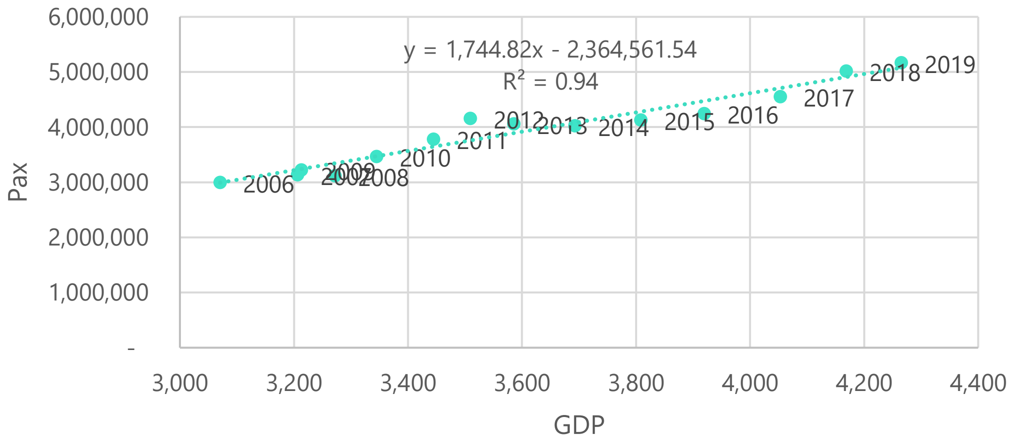


Figure 3.58: International Regression Model

The analysis of the model parameters suggests it is a good fit. The R square suggests a good correlation between the driver (Kenya GDP) and the passenger development. The P-value is within limits. The **Root Mean Square Error shows a 167 thousand passenger error**, which is less than 3% of the total passengers in 2024.

Table 3.10: Domestic Regression results

Metric	Result
Intercept	-2,364,562
X Variable Kenya GDP	1,745
R Square	93.7%
Adjusted R Square	93.2%
P-value	1.443E-08
RMSE	167,216

Plotting the errors also indicates that the model values are within acceptable range of the true values.

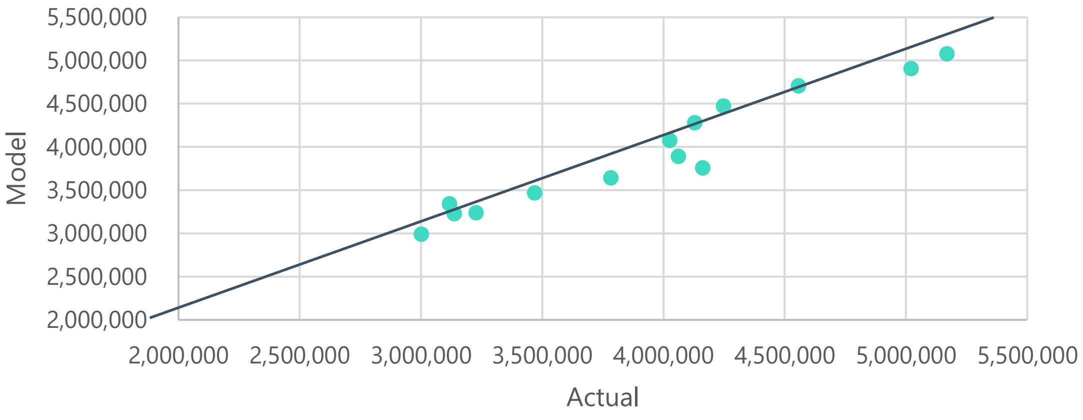


Figure 3.59: Error analysis Domestic Regression

3.9.2 REGIONAL CONTEXT

East Africa is experiencing major airport expansion, with **Addis Ababa, Kigali, and Entebbe** investing heavily in new terminals and infrastructure to position themselves as key aviation hubs.

Figure 3.60: Hub airports in East Africa

New mega projects:

- **Addis Ababa**: New Abusera/Bishoftu airport aims for 100+ million passenger capacity.
- **Kigali**: Bugesera airport under construction with capacity up to 14 million.
- **Entebbe**: Upgrading terminals to handle up to 6 million passengers by 2033.

Regional governments are investing in national carriers (e.g., Ethiopian Airlines, RwandAir, Uganda Airlines), often tied to airport expansion strategies.

Key Airport Expansions:

Table 3.11: East Africa Hub Airport Expansions

Airport	Development Plans	Current Annual Passengers	Future Potential / Capacity
Addis Ababa (Bole + new Abusera/Bishoftu airport)	• Developing a new mega-airport near Bishoftu/Abusera (~40 km SE of current airport). • Backed by Ethiopian Airlines and AfDB. • Phase 1 opens ~2029, includes two runways expanding existing capacity and constructing an "airport city"	• Current Bole handles ~17 million/year (capacity ~25 M; expanded terminal supports ~25 M) .	• Phase 1 (by 2029): capacity ~**60 million**/year . • Full build-out: **100–110 million/year** (4 runways, 270 aircraft stands)
Kigali (Current + Bugesera new)	• Building new Bugesera International ~40 km SE of Kigali. • Construction ongoing • Operational by 2027–28 .	• Kigali International recorded ~710,000 in 2023 (report shows 600k in 2022, 710k in 2023) .	• Bugesera Phase 1: ~1.7–1.8 million/year capacity . • Full new airport build-out: **~8 million/year initially, expandable to 14 million+**
Entebbe (Uganda)	• Expansion of terminal (20,000 m² added; arrivals/departure upgrades, new terminal wing to open in 2025). • Runway/cargo facility enhancements. • **Long-term plan to reach ~6 M passengers/year by 2033** .	• ~1.93 M in 2023 (pre-COVID), ~3.5 M by mid-2024 projection;.	• Short-term (2024–25): ~3.5 million/year . • Long-term (by 2033): ~6 million/year

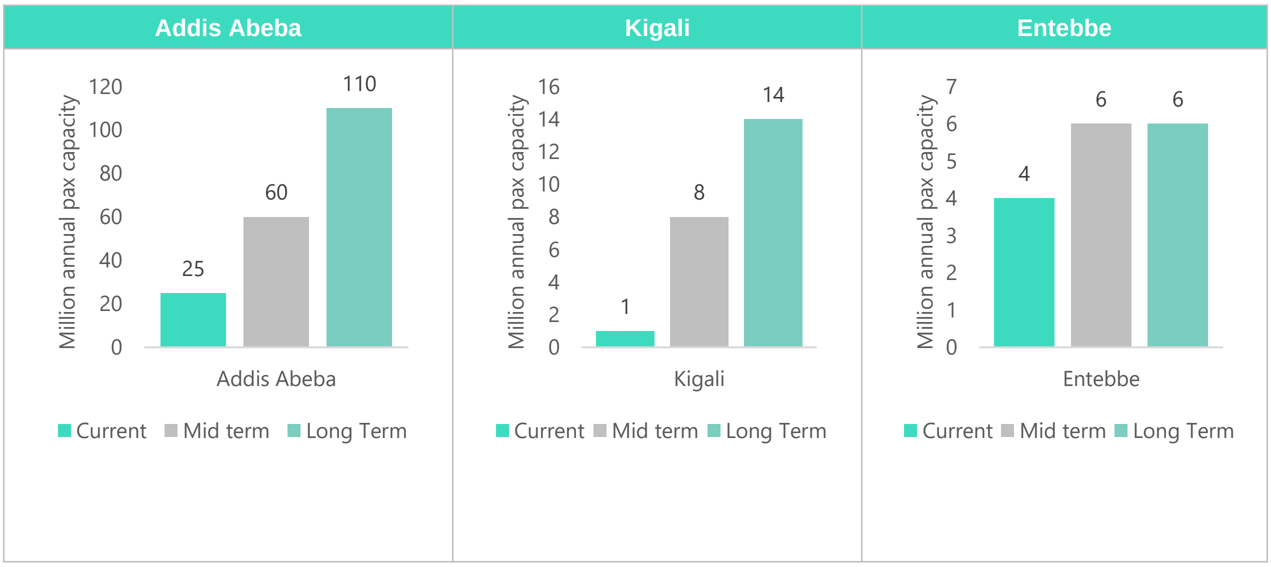


Figure 3.61: Capacity addition in East Africa Hubs

Airline development plans in the region are as follows:

Table 3.12: East Africa Hub Airline Expansions

Airline	Current Fleet Size	Future Fleet (yr 5–10)	Future Ambitions & Strategy
Ethiopian Airlines	• ~150 passenger + ~17 cargo aircraft (total ~167) as of early 2025	• On order: 65 aircraft (incl. A350s, B787-9, B777-9X, 33×737 MAX); • Planning an additional ~20 regional jets (A220/E2/737 MAX 7). Total fleet projected to nearly double from ~145 to ~271 by 2035	• Growth under "Vision 2035": expand to 207 destinations, ~65 M pax/year, triple cargo volume. Focusing on regional connectivity and modernising fleet; pioneering 777-9X in Africa
RwandAir	• 14–15 aircraft	• Plans to double fleet in upcoming years (~28–30 aircraft); • Aiming to add ~13 more by 2029 (both narrow- and widebodies).	• Strategic ambition to standardize fleet (737s & A330s), expand across Eastern & Southern Africa; improve efficiency and passenger experience. Qatar Airways likely to take ~49% stake, boosting access and accelerating growth
Uganda Airlines	• 6 aircraft	• Intends to double fleet to ~12–13 over 5 years: adding 2×A320neo (dry lease June 2025), +4 more A320s, 2×787-9 long-haul by 2029–30, plus cargo freighters (737-800BCF, 777F)	• Aiming for network expansion beyond current 17 routes (e.g. London, Mumbai, Abuja, Riyadh, Cape Town), boosted long-haul capacity, regional cargo operations, and fleet modernization

Contrasting the planned additional capacity against the regional traffic outlooks suggest that the capacity developments are in line with potential volume. Therefore, JKIA should invest in the modernizing the facilities to maintain its strategic position in the region and facilitate growth of Kenya Airways.

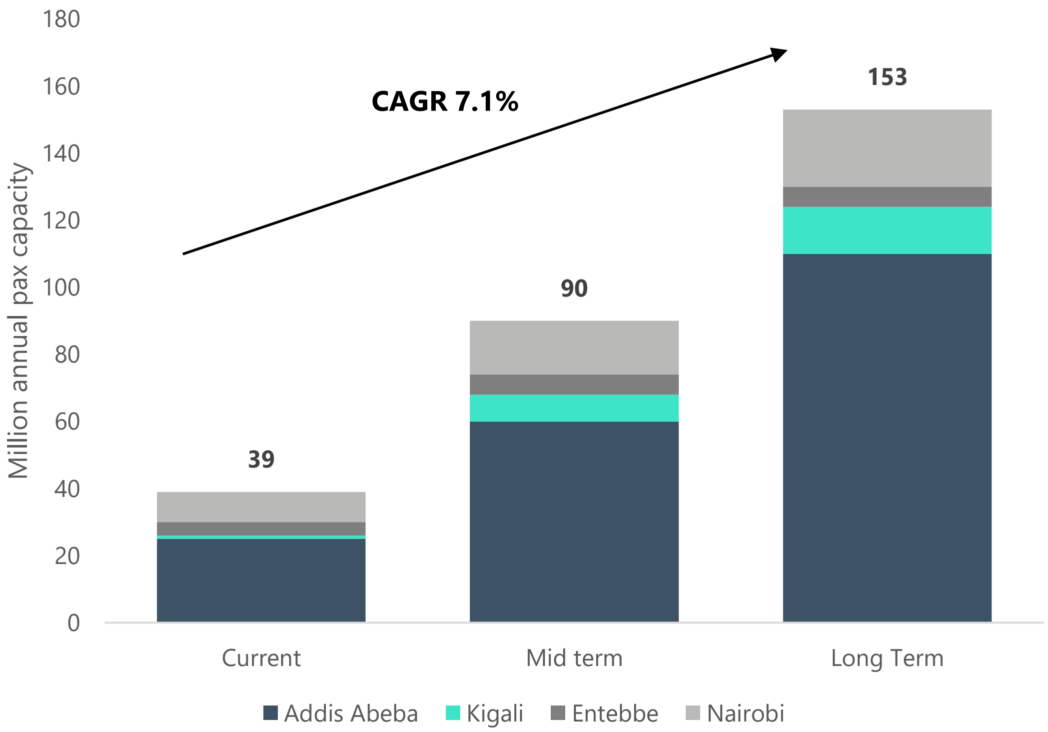


Figure 3.62: Growth of hub capacity in East Africa

Industry forecasts are prepared by Boeing and Airbus, for specific regions and traffic flows. Below is a visualization of their forecasts for Africa. As can be seen especially intra-Africa is expected grow strongly.

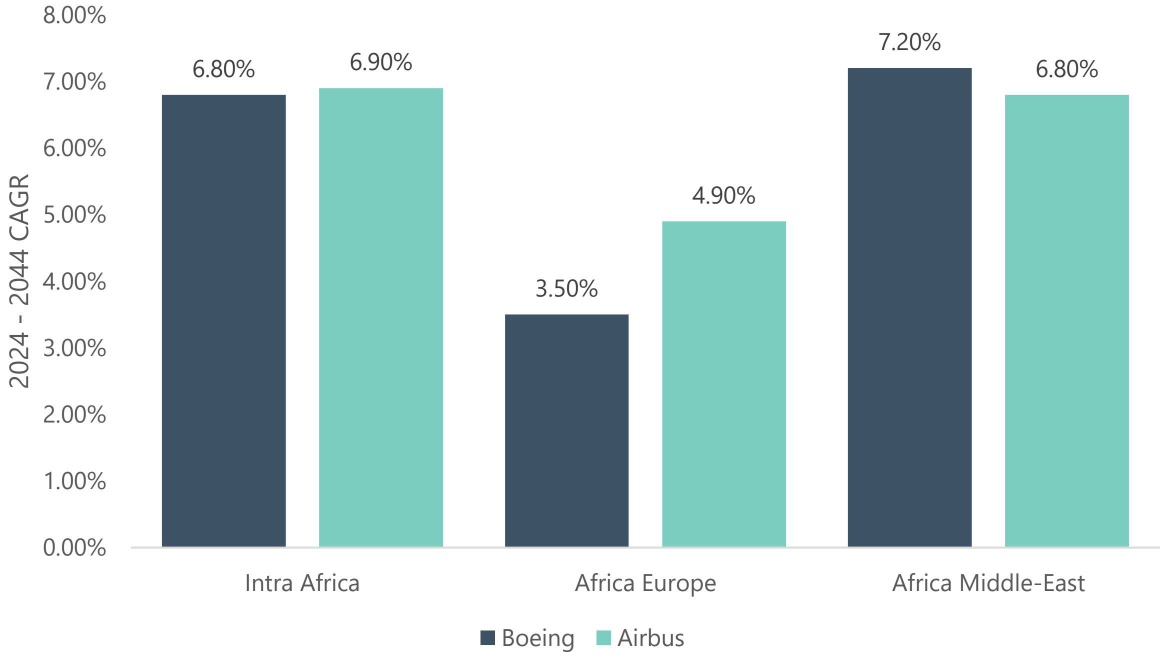


Figure 3.63: Industry Africa Traffic Forecasts

3.9.3 DOMESTIC PASSENGERS

The domestic passenger volume is compared to the Mombassa forecast, as there are limited routes possible and Mombassa is the main route from JKIA domestically.

As can be seen in Figure 3.64 below, ALG forecast for Mombassa reaches 2.8 Mpax by 2045. In 2024, 83% of domestic traffic was on the Nairobi route, some 1 million passengers.

Assuming the same Split continued to 2045, this leads to 2.3 Mpax on the JKIA route by 2045 according to the previous forecast.

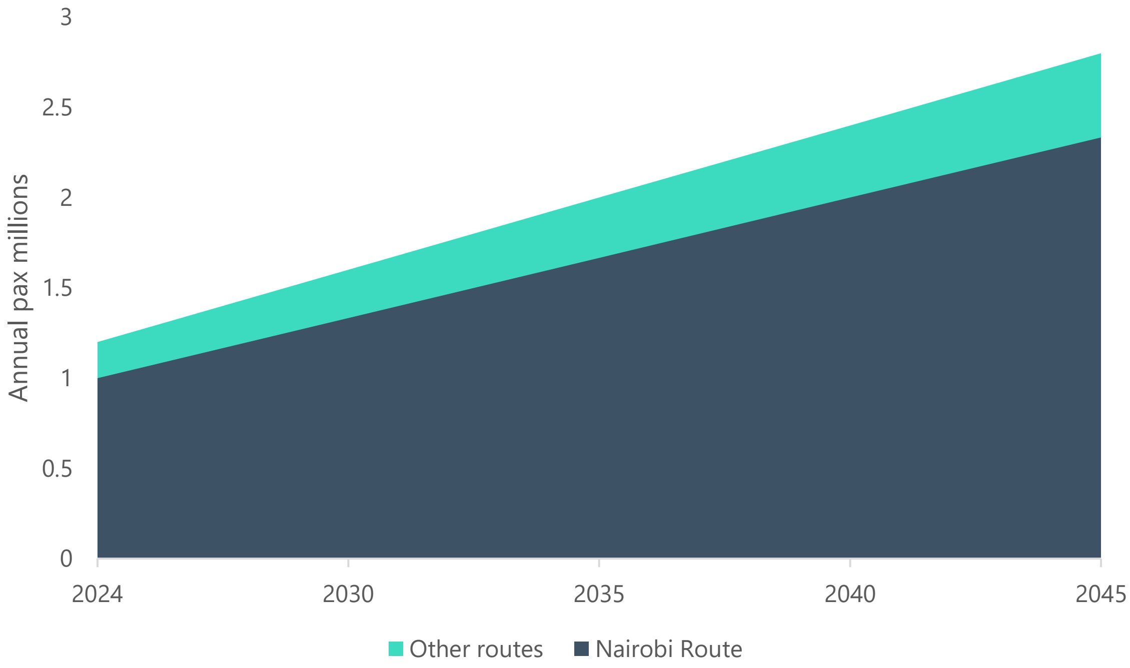


Figure 3.64: Mombassa Domestic passenger forecast

Regarding JKIA, domestic forecast passengers reach 5.2 Mpax by 2045. In 2024 50% of domestic passengers were on the Mombassa route.

Assuming the same Split, this leads to 2.6 Mpax on the JKIA-Mombassa route by 2045. This is in line with the higher expected O&D growth in the updated forecast.

This compares to around 4.7 million passengers on the Cape Town – Johannesburg route currently. As the population is about 2x the size of Nairobi and Mombassa, it is considered appropriate volume for the Nairobi – Mombassa route.

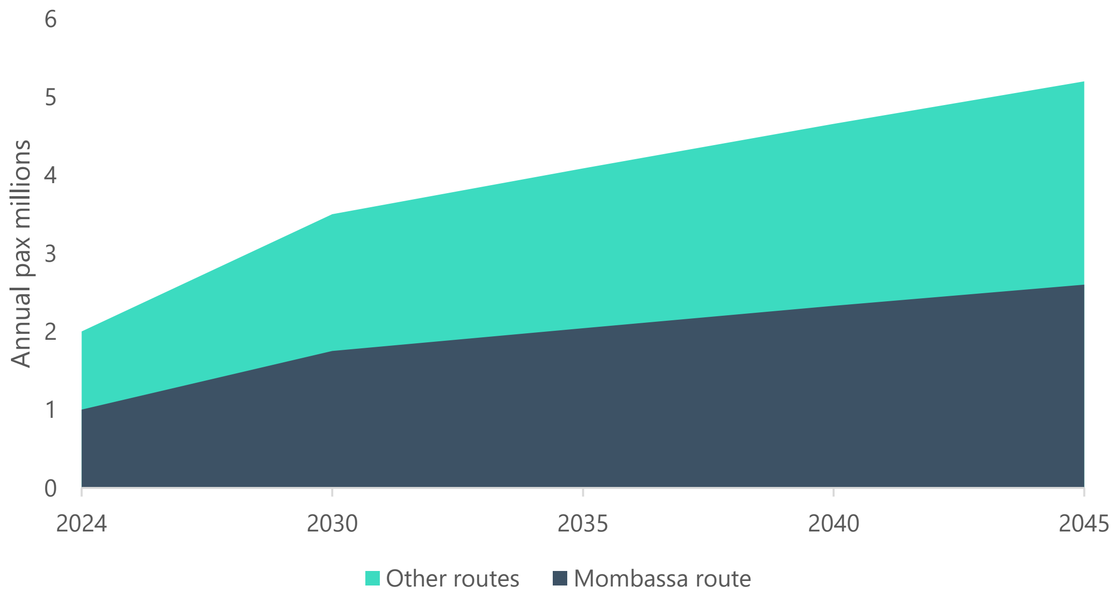


Figure 3.65: JKIA Domestic Forecast

3.9.4 BILATERAL AGREEMENTS

As of 2025, Kenya maintains a network of over **80 BASAs**, including highly liberalized arrangements with key partners such as **Qatar, India, South Africa, the United Arab Emirates (UAE),** and **Tanzania**. Recent expansions—including new agreements with **Somalia** and updates with **Czech Republic, Cyprus, and Chile**—reflect a strategic shift toward **deepening market access and increasing operational flexibility** for Kenyan carriers.

Many of Kenya's agreements feature **open skies elements**—such as unlimited frequencies, double designation, and unrestricted aircraft size—which position the country to attract more international carriers while allowing local airlines to expand into underserved markets. The **Kenya–UAE** and **Kenya–Qatar** BASAs, for example, permit unrestricted cargo and passenger movements, offering vast growth potential in long-haul and transshipment traffic. At the same time, updated African BASAs (e.g., with Angola and Somalia) support regional integration under the **Single African Air Transport Market (SAATM)**.

Kenyan officials participated in the most recent ICAN session (held in Kuala Lumpur, Oct 21–25, 2024), where numerous countries—including European, Asian, and Middle Eastern partners—entered into discussions over both new BASAs and updates to existing agreements. **ICAN Participation** signals Kenya's active role in negotiating multiple bilateral agreements simultaneously.

Kenya Airways' CEO met with Mexico's partners to explore expanding the 2011 air services framework to allow **direct passenger, cargo, and mail flights**—indicating formal movement toward a refreshed BASA.

These efforts reflect Kenya's strategic pursuit of a more liberal and diverse air services network, vital for expanding its aviation growth and global connectivity this supports the forecast with a strongly expanded network and frequencies.

3.9.5 ROAD NETWORK IMPROVEMENTS

As part of the national Vision 2030 strategy, the Government of Kenya has prioritized the development of an extensive, modern road network to support the country's transformation into a **middle-income economy**. Recognizing transport infrastructure as a key enabler of economic growth, regional integration, and equitable development, the road expansion programme seeks to **enhance mobility, reduce transport costs, and improve connectivity across urban and rural areas**.

Flagship initiatives include:

- **Expansion of the Northern Corridor** linking the Port of Mombasa to Nairobi, western Kenya, Uganda, and Rwanda. This project has already been delivered in 2023.
- **Mombasa–Nairobi Expressway**. 4-lane toll expressway to shorten travel time from 10.5 to 4.5 hours, completed under PPP. Expected construction start by 2026.
- **Construction of bypasses** (e.g., Kisumu, Eldoret, and Mau Summit) to ease urban congestion and facilitate freight movement.
- **Improvement of low-volume sealed roads** in rural counties to open up agricultural and tourism regions, enhancing domestic market access.

Especially the Mombasa – Nairobi expressway reducing travel time by car significantly can impact air travel demand on that route.

Looking at routes with a similar road travel time however, it can be seen that demand for air travel persists:

Route	Road Time	Air Time	Million annual passengers on route
São Paulo – Rio de Janeiro	~4h 45m	~1h	4
Barcelona - Madrid	4h	1h	3.6
Milan – Rome	~4h 30m (train)	~1h 10m	3
Los Angeles – Las Vegas	~4h 30m	~1h	3
Madrid – Lisbon	~5h (road), no HSR	~1h 10m	2

Air travel demand on the Nairobi–Mombasa route is likely to remain strong due to several factors.

- Air travel continues to offer significant time savings, with a one-hour flight plus minimal transfer time proving more efficient than even a 4.5-hour road journey.
- Low-cost carriers such as Jambojet and Fly540 keep fares competitive with road alternatives,
- Many travelers prioritize the comfort, safety, and reliability of flying—especially for tight schedules or premium service expectations.
- Additionally, the route is heavily used as a domestic leg for international itineraries arriving via Nairobi's JKIA.

3.10 SCENARIOS

Recognizing uncertainty in the aviation sector, three scenarios are developed:

- **Base Case**: Continuation of current trends, including forecast GDP growth, stable airline operations, Kenya Airways expansion as per their currently shared strategic vision, continued tourism growth, and a similar political and security situation as present.
- **High Growth Case**: Accelerated economic growth, aggressive airline route development, further stimulation of the hub operations by Kenya Airways, growing more towards competitor Ethiopian Airlines.
- **Low Growth Case**: No progress in intra-Africa cooperation in terms of aviation, open skies and route development, no significant fleet expansion from Kenya Airways.

Each scenario includes different assumptions regarding the key drivers of traffic in Kenya. This allows stakeholders to understand the **range of potential outcomes** of the forecast.

3.10.1 UPSIDE SCENARIO

As set out above, the upside scenario considers an increased hub activity of Kenya Airways. The environment for this is optimal as in this scenario increased economic performance of Africa is assumed, as well as increased African cooperation for the aviation sector. This all in all leads to more connections and Kenya Airways further fleet growth.

In this scenario, additional fleet deliveries are expected for Kenya Airways and Jambojet. In addition, the transfer share will grow to 50% instead of 40% in the base case.

In the long term, the transfer share at the airport will grow from 9.9% in 2024 to 27% by 2045.

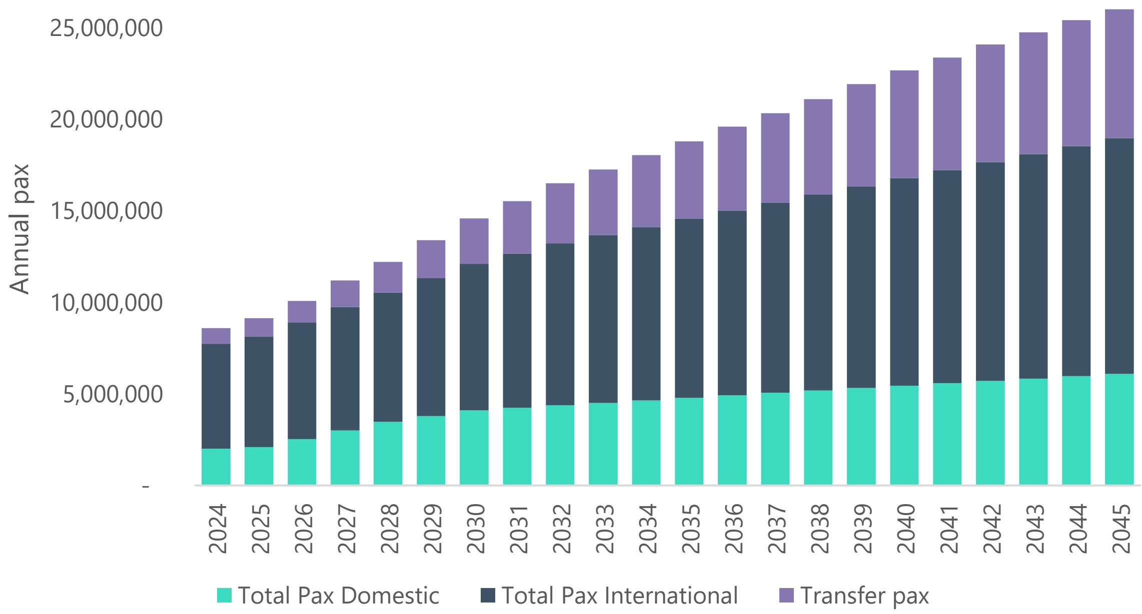


Figure 3.66: Upside case forecast results

	2024	2030	3025	2040	2045	CAGR 2024-45
Total Pax Domestic	2,009,000	4,105,000	4,790,000	5,459,000	6,095,000	5.4%
Total Pax International	5,742,000	8,016,000	9,780,000	11,335,000	12,885,000	3.9%
Transfer pax	850,000	2,472,000	4,243,000	5,890,000	7,048,000	10.6%
Total Pax	**8,601,000**	**14,593,000**	**18,814,000**	**22,684,000**	**26,028,000**	**5.4%**

3.10.2 DOWNSIDE SCENARIO

The downside scenario explores how traffic would develop when cooperation between African countries and airlines no develops, inefficiencies and high ticket prices remain, and Kenya Airways only manages a moderate fleet expansion in coming years. The airlines remains operating transfer shares as currently recorded.

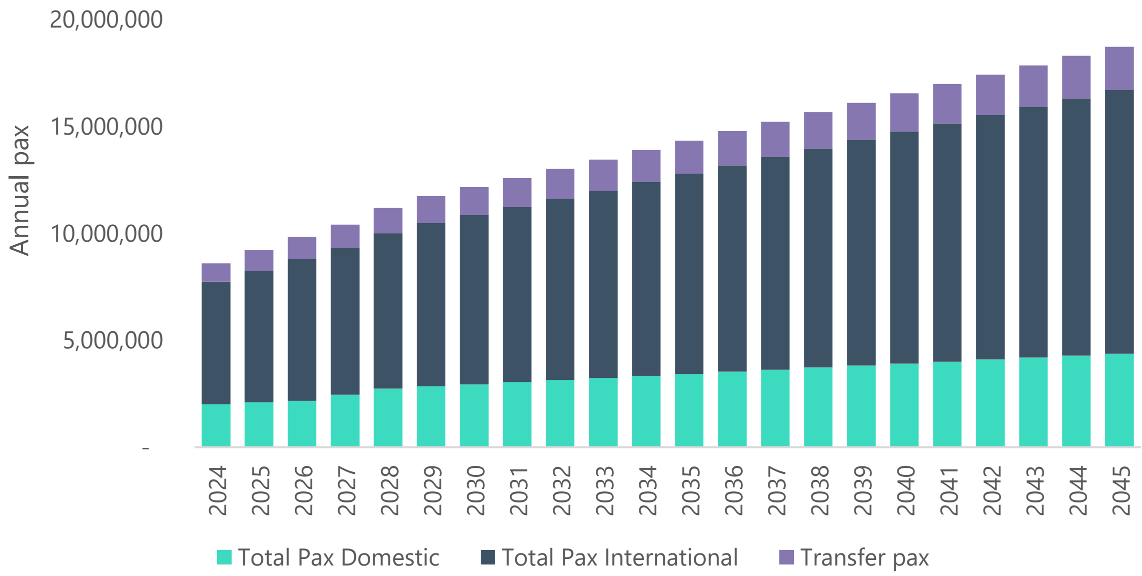


Figure 3.67: Downside case forecast results

	2024	2030	3025	2040	2045	CAGR 2024-45
Total Pax Domestic	2,008,816	2,942,104	3,433,622	3,912,763	4,368,878	3.8%
Total Pax International	5,742,129	7,919,640	9,360,283	10,848,285	12,331,414	3.7%
Transfer pax	849,789	1,304,960	1,542,342	1,787,528	2,031,911	4.2%
Total Pax	**8,600,734**	**12,166,704**	**14,336,247**	**16,548,576**	**18,732,204**	**3.8%**

3.10.3 SCENARIOS COMPARISON

The upside and downside scenarios represent the range of the potential development with a high degree of certainty. The high case, with more transfer traffic and Kenya Airways development ends up 16.7% higher than the base case. The low case, assuming less connectivity and cooperation in Africa ends 16% below the base case.

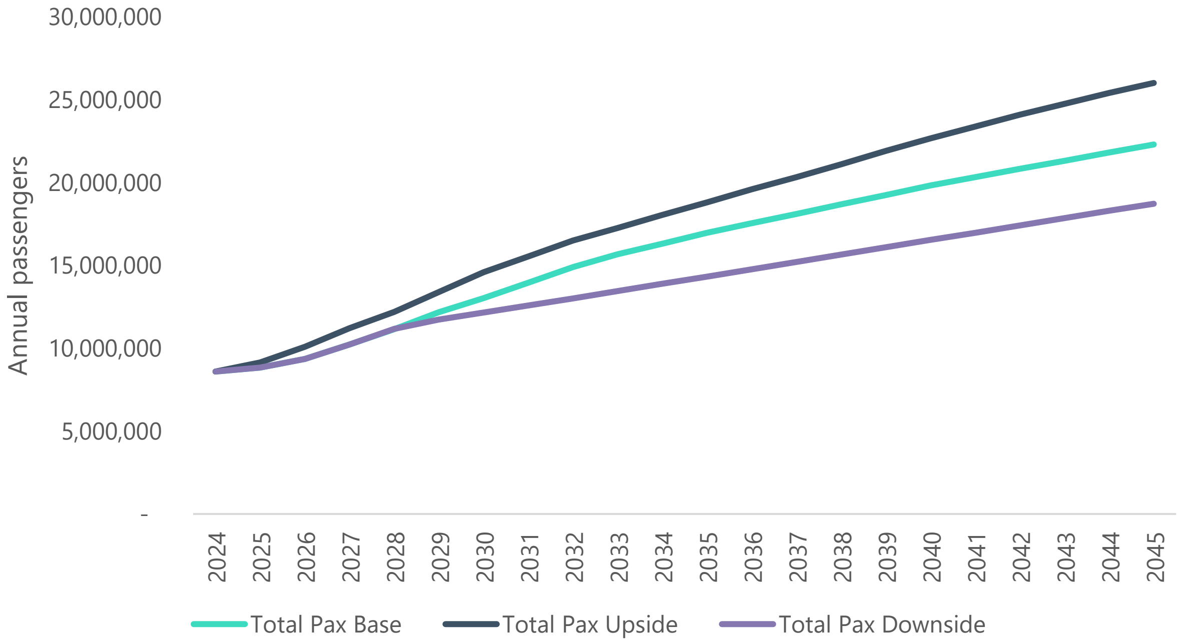


Figure 3.68: Scenarios Comparison

3.11 CARGO FORECAST

3.11.1 HISTORICAL CARGO ANALYSIS

Cargo has been very erratic historically, as can be seen, after a growing trend until 2007, the development was static until 2017. Between 2017 and 2024 cargo has grown strongly, especially the export. As production of fresh goods like flowers, fruit and vegetables is a major economic activity in Kenya this has driven the export, which comprises some 80% of total cargo carried. Only a minor share of less than 1% is domestic, all other cargo is international.

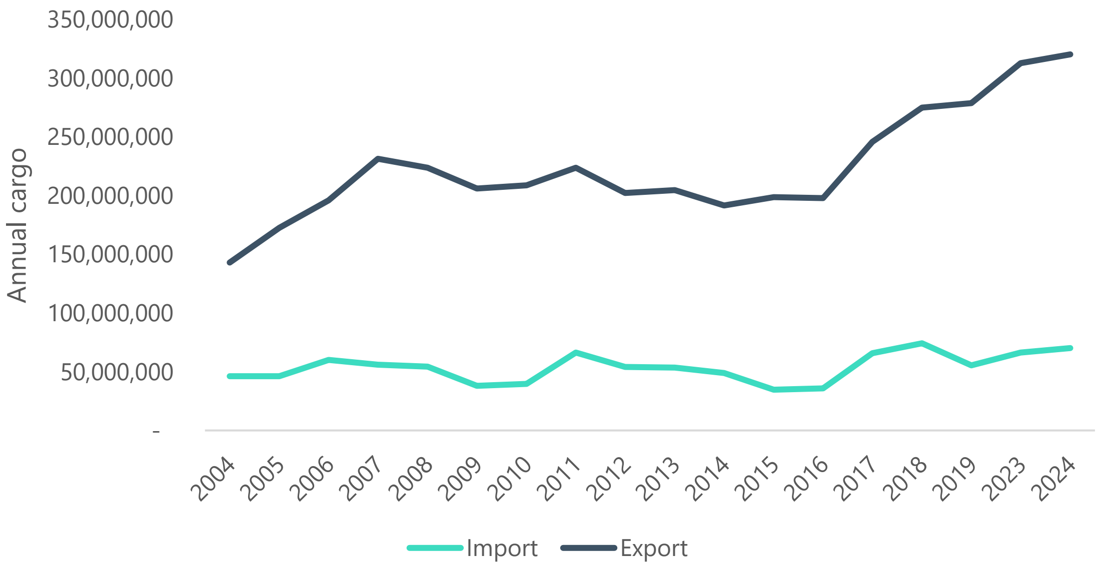


Figure 3.69: Historic Cargo development

Export comprises mainly flowers, which is nearly 50% of all export. Fresh fruit and vegetables is the next main export market with 30%.

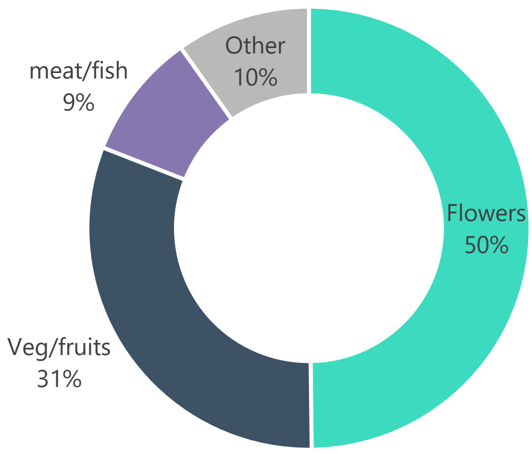


Figure 3.70: Cargo export breakdown

3.11.2 APPROACH

Typically, air cargo is highly correlated to GDP growth (national GDP for import, and GDP of destination countries for export). However, it appears that in this case, there is very little correlation, as shown in Figure 3.71 and Figure 3.72 below.

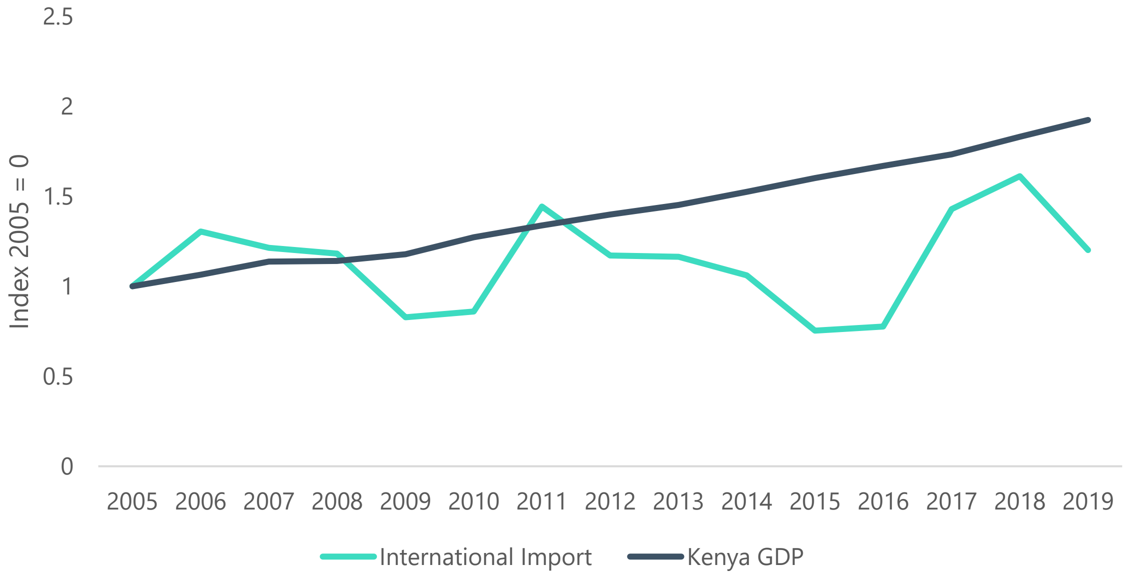


Figure 3.71: Cargo import growth index vs Kenya GDP

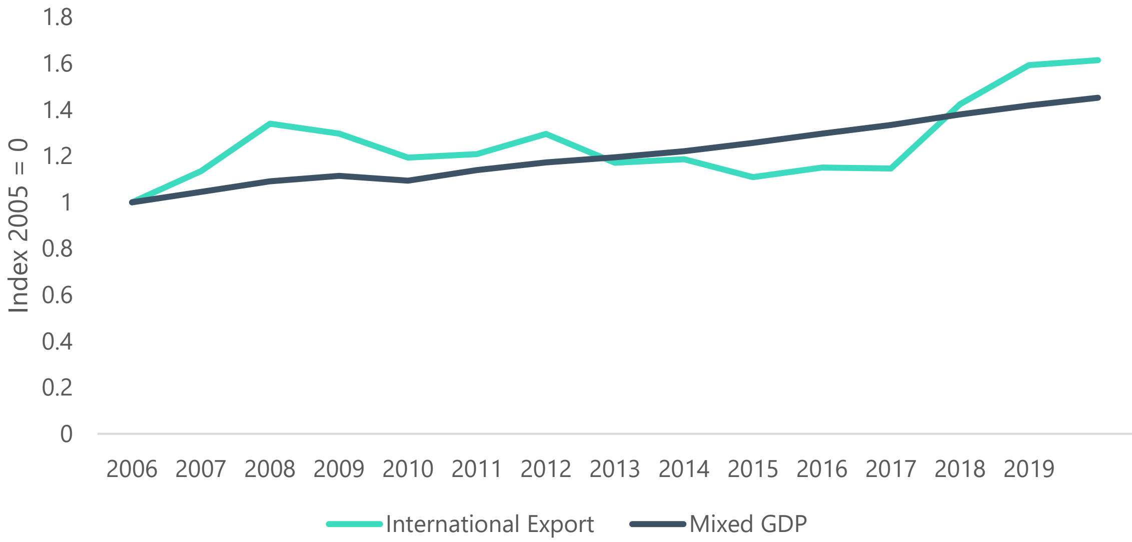


Figure 3.72: Cargo export growth index vs mixed international GDP

As a result, plotting GDP and export does not result in a statistically valid relationship (R squared at just 46%, indicating little correlation), a different methodology therefore has to be sought, not taking GDP as a driver.

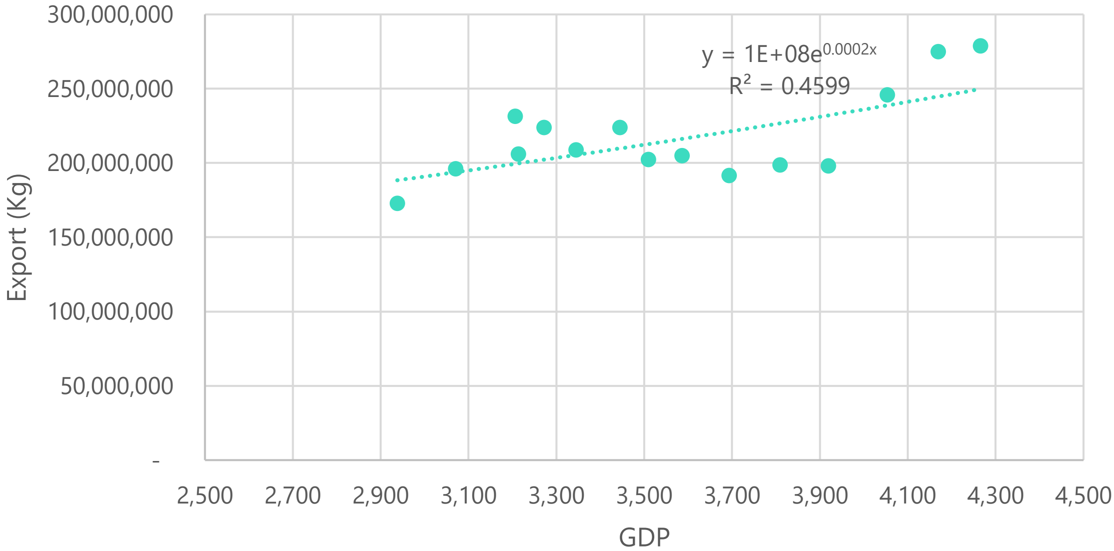


Figure 3.73: Export vs GDP model results

In order to estimate the potential future development of air cargo in JKIA firstly various industry forecasts are consulted. Boeing produces the World Air Cargo Forecast with projections per flow per key region. Africa as a whole is included in the forecasts. The latest update was from 2023 and shows expected growth to Asia reaching 5.7% until 2043. To/from Europe is expected to show average annual growth rates between 2.3% for export and 4.8% for import.

Airbus Forecasts 6.2% annual growth from 2027-2043 on average for intra Africa cargo. Between Africa and other regions this average expected annual growth lies around 4%.

This is also compared to historical growth at JKIA itself in the very long term. Analyzing the average growth rates from 2004 to 2024 should indicate the very long-term trends. It is seen that in this period export grew with 3.3% on average while import grew at a 2.2% rate.

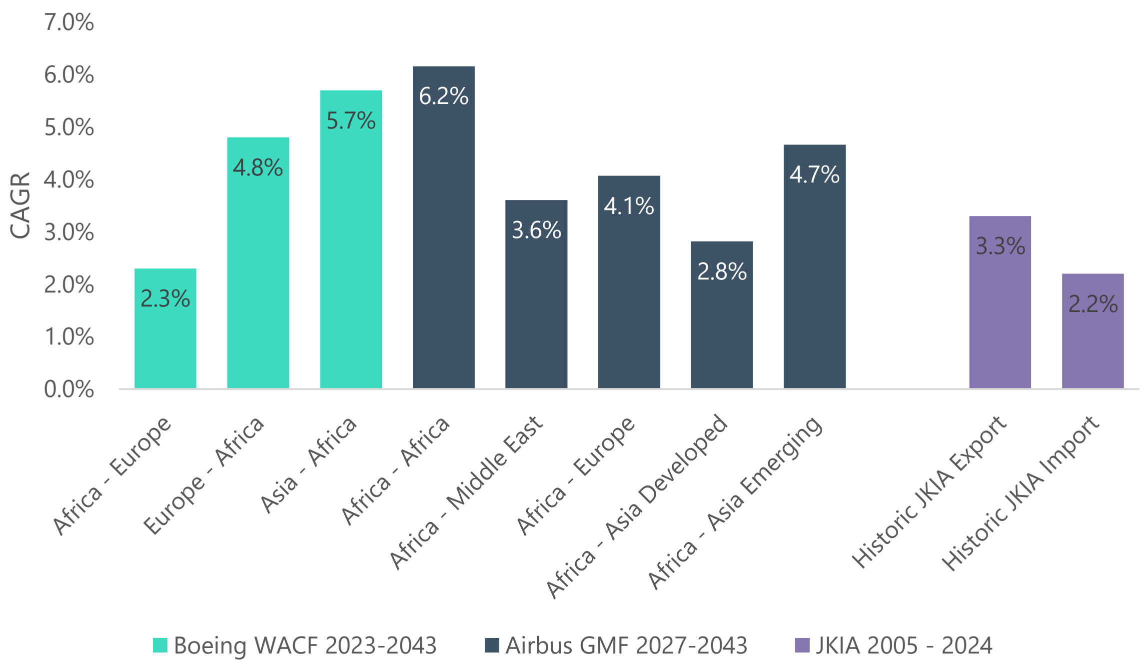


Figure 3.74: Cargo forecast outlook Boeing and Airbus vs JKIA historical

In addition, Kenya Airways´ plans for their cargo growth should be taken into account. In 2024 the airline carried some 70.000 tons of cargo, with a fleet of 3 Boeing 737 cargo aircraft and on their bellyhold flights.

Their ambition is to grow their cargo volume by 200% by 2035 and operate a fleet of 15 full freighter aircraft, including wide bodies.

Combining the historical performance at JKIA with future potential market development and the plans of Kenya Airways, the expected growth rates are set. It is noted that the entire Africa market is expected to grow strongly. With JKIA being a key hub in Africa it is expected that the airport will develop more in line with the overall market. This assumption also takes note of the strong economic development expected, the population growth forecast, and expected growing middle class.

Taking this into account, future growth rates are set as follows:

Table 3.13: Cargo CAGRs forecast

Cargo Flow	Growth rate 2024-2045
Export	4.0%
Import	3.0%
Domestic	3.0%

3.11.3 FORECAST

With the assumptions set out before, air cargo at JKIA is expected to grow from 390 thousand tons in 2024 to 777 thousand tons in 2045, doubling the volume over the forecast period.

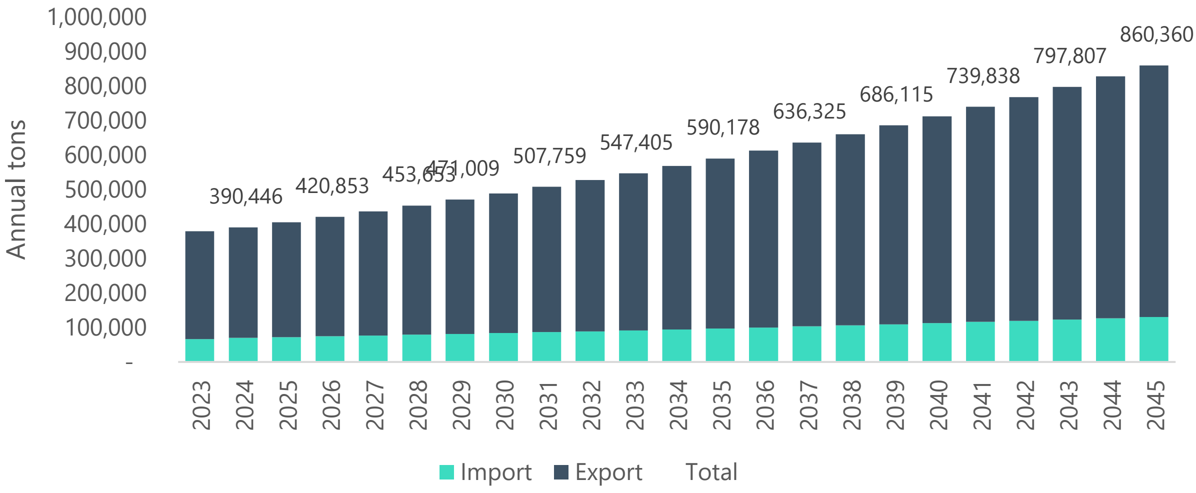


Figure 3.75: Cargo Volume forecast

Based on analysis of the schedule of 2025, and maintaining this level, it is expected that 71% is carried on full freighters and the remaining in the bellyhold of passenger aircraft.

3.12 DESIGN PARAMETERS

3.12.1 APPROACH

Design hour parameters are essential in planning airport terminal and airside facilities. These parameters, such as Peak Hour Passengers and Aircraft Movements, are derived from forecast annual traffic and reflect the highest demand periods expected under normal operational conditions.

The 12th Edition of the IATA ADRM provides updated guidelines for deriving these parameters, emphasizing data-driven, scenario-based forecasting that balances capacity, service level, and cost-efficiency.

Firstly, the base year design hours are established from the 2024 flight log facilitated by KAA. The following peak hour segments are established:

- Domestic O&D passengers Arrivals
- Domestic O&D passengers Departures
- Domestic O&D passengers two-way
- International O&D passengers Arrivals
- International O&D passengers Departures
- International O&D passengers two-way
- Combined O&D passengers Arrivals
- Combined O&D passengers Departures
- Combined O&D passengers two-way
- Transfer passengers
  - Domestic – Domestic
  - Domestic – International
  - International Domestic
  - International - International

The same is calculated for the ATMs (less transfers)

In accordance with IATA 12th Edition, the 97th - 99th percentile hour for each segment is defined for each category. Thereafter these are related to a peak to annual ratio, and forecast in line with the annual passenger volumes.

In the IATA Airport Development Reference Manual (ADRM), 12th Edition, the selection of the design hour percentile—97th, 98th, or 99th—is guided by the desired balance between infrastructure capacity, cost-efficiency, and service quality. These percentiles represent the hourly passenger demand levels that are exceeded only 3%, 2%, or 1% of the time annually, respectively.

Percentile	Use
97th Percentile	for airports aiming for high facility utilization with some tolerance for congestion during peak times. This percentile is often chosen when budget constraints are significant, and occasional crowding is acceptable.
98th Percentile	Represents a balanced approach, providing a compromise between infrastructure investment and passenger comfort. It is commonly used for airports seeking to maintain a consistent level of service without overbuilding.
99th Percentile	Ideal for airports prioritizing exceptional service quality, ensuring facilities can handle nearly all peak demand scenarios with minimal congestion. This choice often leads to higher capital expenditures but enhances passenger experience.

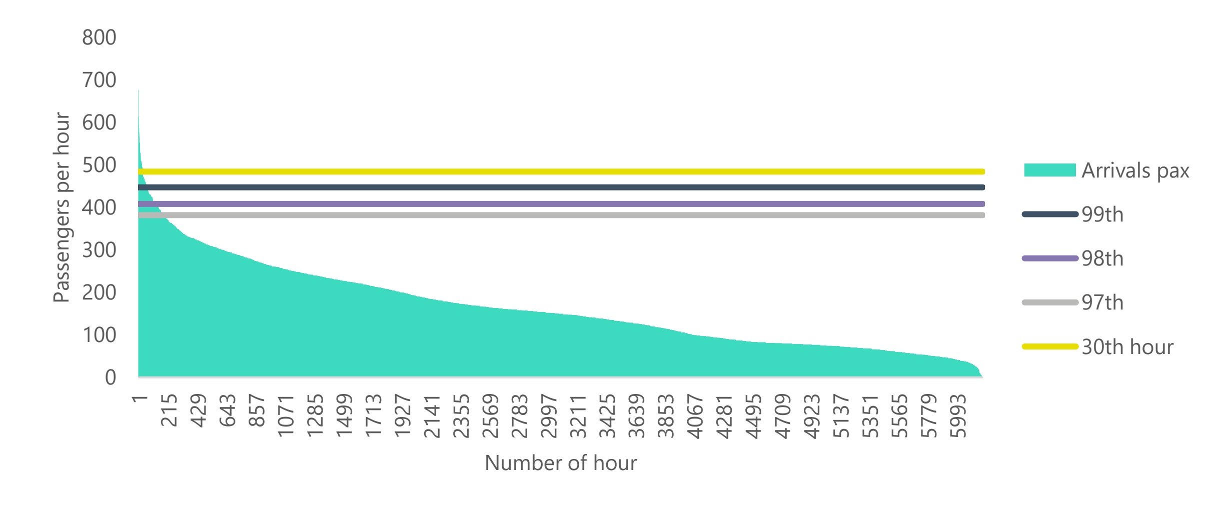
In addition, these percentiles are compared with the 30th busiest hour of the year, which is the traditional way to plan airport facilities. This means that in only 29 hours a year the design hour is exceeded. This is generally higher than the 99th percentile and gives a higher service quality.

3.12.2 2024 PEAK VOLUMES

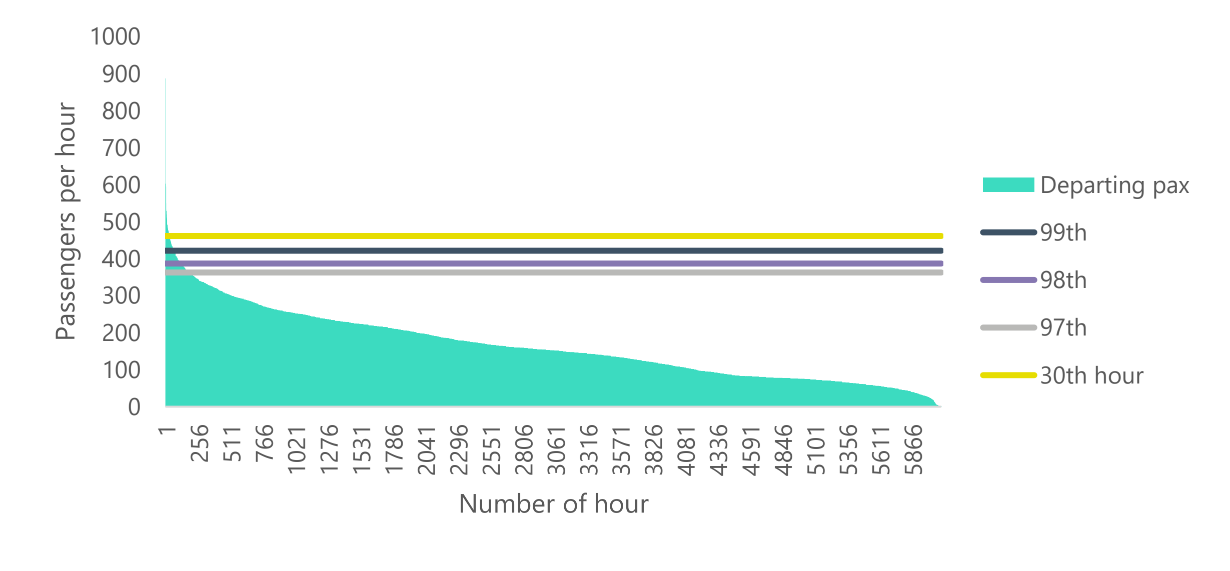
3.12.2.1 Domestic Hourly Analysis

The full year 2024 is analyzed to obtain the start values of the Domestic design parameters. Domestic passengers for arrivals, departures and totals are organized per hour to obtain a ranking of the busiest hours of the year.

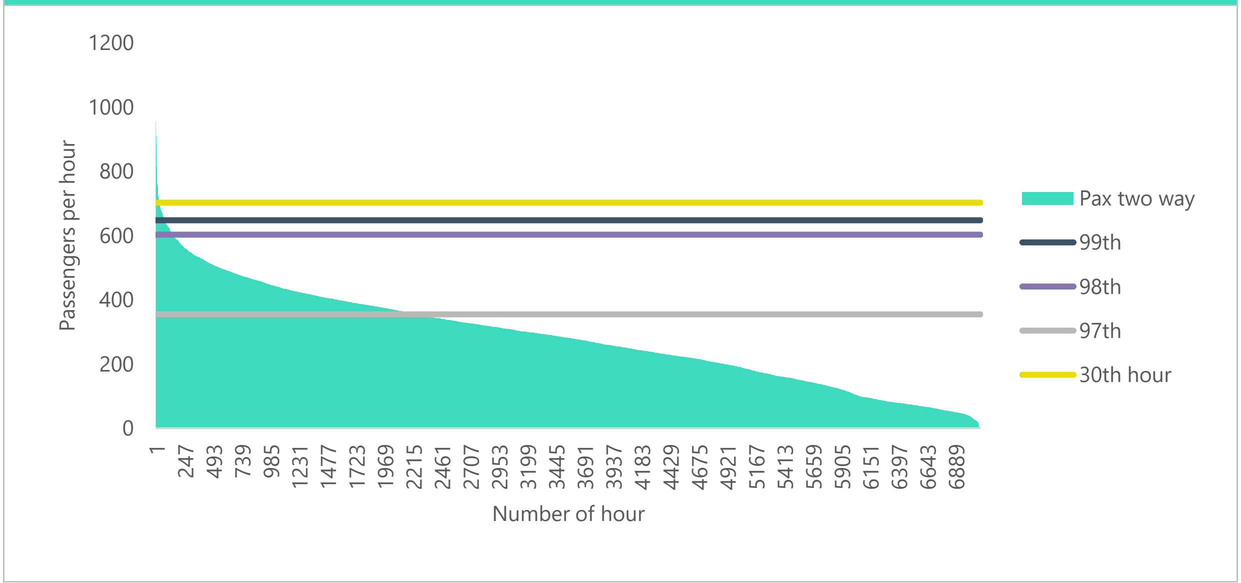
Domestic Arrivals



Domestic Departures



Domestic two-way

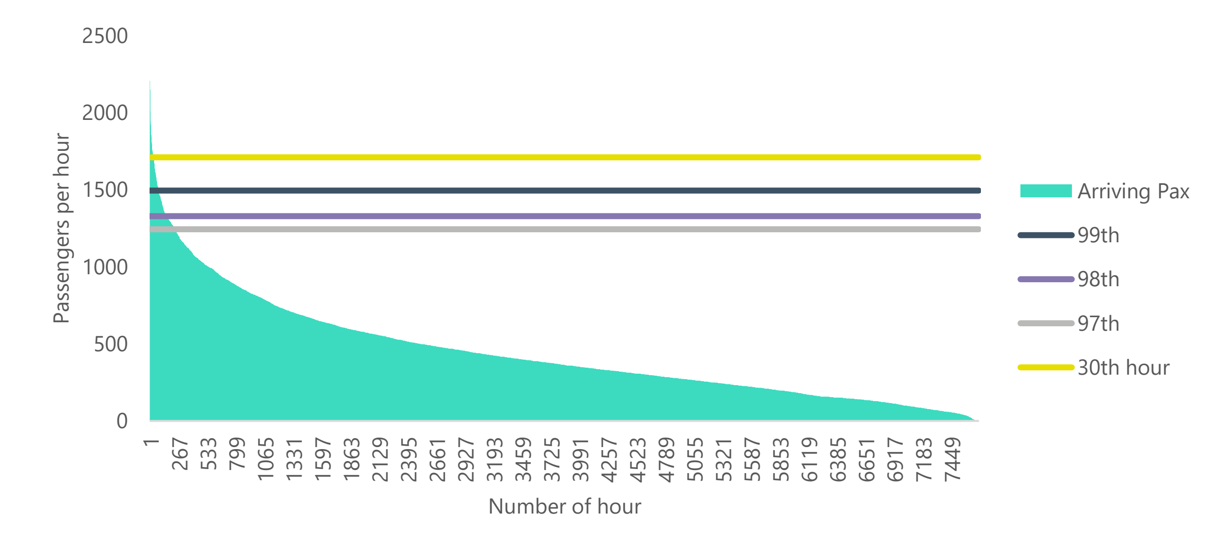


The 98th percentile passengers are used, in order to plan for efficient facilities while providing a good level of service to the domestic passengers.

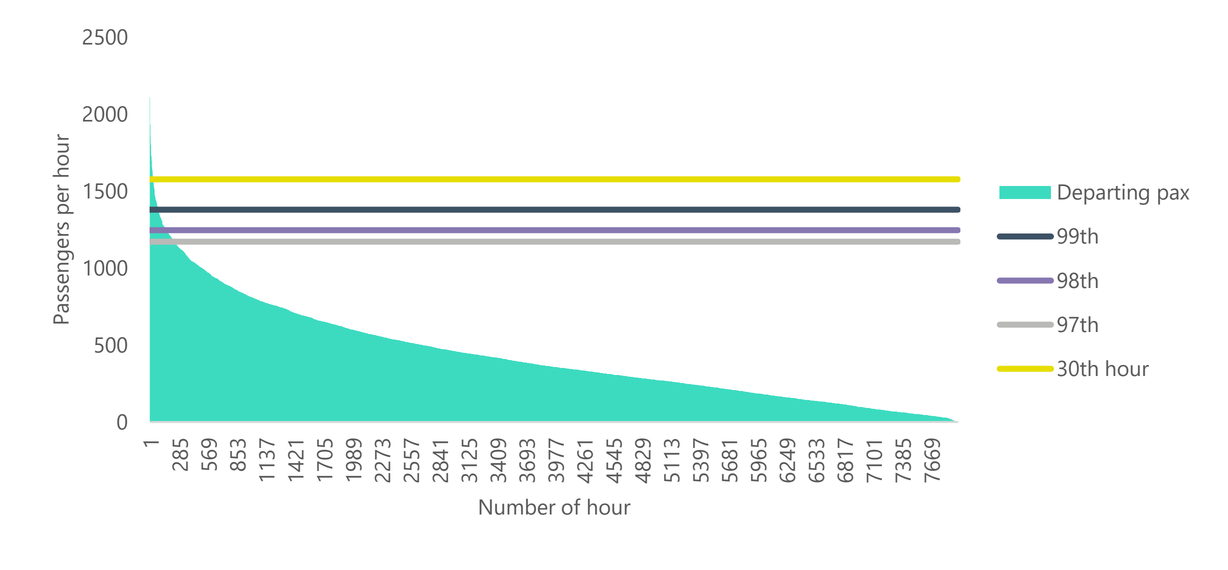
3.12.2.2 International Hourly Analysis

Similarly, international passengers per hour are analyzed for 2024. It is noted that this includes both O&D and transfer passengers. The transfer passengers are later separated by assuming a split based on the annual split.

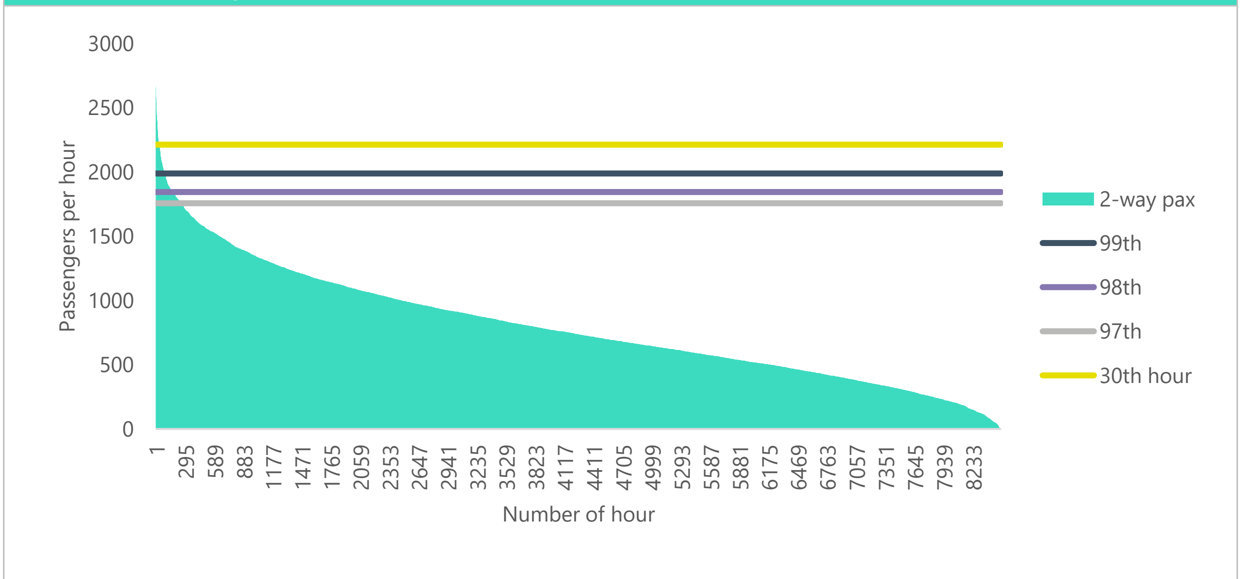
International Arrivals



International Departures



International two-way



As the 30th hour is significantly above the 98th percentile, and to provide the airport with optimal service quality, the 99th percentile is selected for international passengers.

3.12.2.3 2024 Design Parameters

The resulting design parameters starting values are shown below in summary. The ATMs are realized with a similar analysis, although taking the absolute peak of the year, to account for buffer in case of unscheduled movements.

Table 3.14: 2024 design hours

	Arrivals	Departures	Total
Passengers			
Domestic	408	387	603
International	1,496	1,379	1,990
Combined	1,663	1,490	2,227
ATMs			
Domestic	14	12	21
International	17	21	25
Combined	22	24	36

The annual transfer share of 15% of international passengers is applied to the international O&D numbers to obtain transfer passengers in the peak hour. This results in 295 peak hour transfer passengers which are distributed as follows:

Table 3.15: Assumed transfer design hours

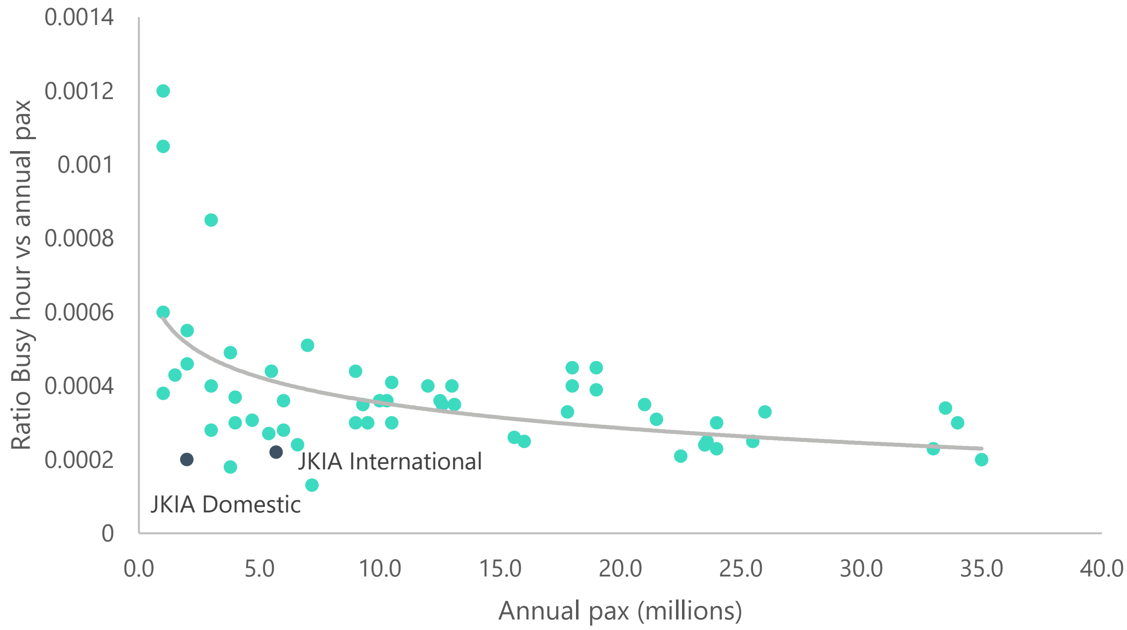
Flow	Transfer Pax
Total Transfer	295
Domestic - Domestic	0
Domestic - International	29
International - Domestic	15
International - International	250

There is no significant flow of domestic to domestic passengers identified. It can however be a strategic planning decision to plan for some minor facilities.

3.12.3 FORECAST DESIGN PARAMETERS

The design parameters obtained before are firstly analyzed in relation to the annual 2024 volume of each flow, to obtain the peak-to-annual-ratio. This ratio indicates if the peak is high or low compared to its annual volume, with reference to benchmark airports.

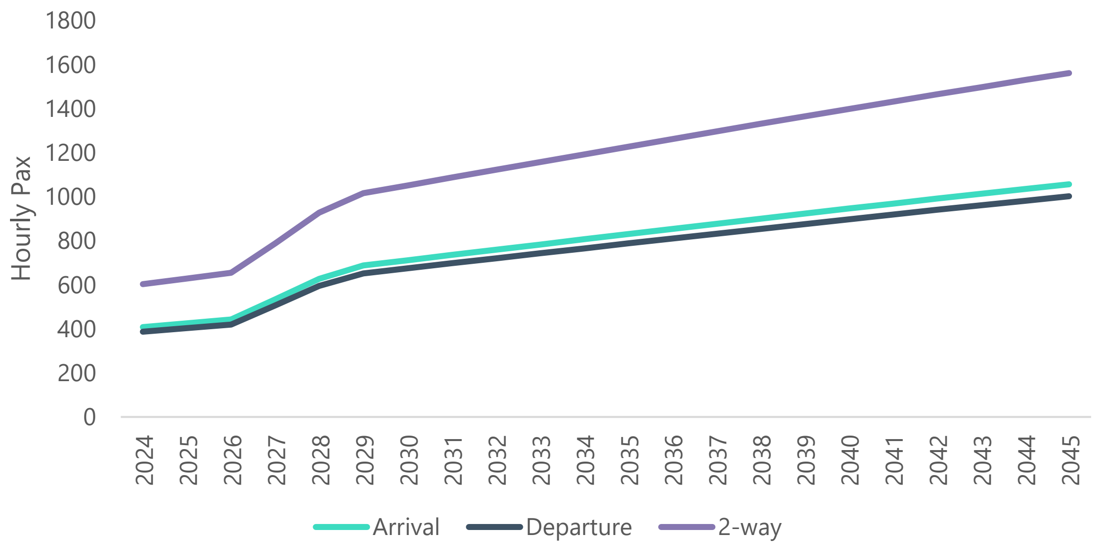
As can be seen in the benchmark below, JKIA peak hour are relatively low compared to the benchmark. This is partly due to the fact that traffic is evenly distributed throughout the year with little peaks in certain months. Additionally, while there are some arrival and departure banks throughout the day, the traffic is not as ´peaky´ as other hub airports.



As can be seen in the trendline of the benchmark above, normally the peak hour ratio declines over time, as with growing traffic volumes, the utilization throughout the day and year becomes more optimized. However, as the peak ratios are already well below the trend, and it is expected that Keny Airways will optimize its schedule throughout the forecast period, the peak ratios are maintained at a stable level, with the values of 2024. Therefore, the peaks will grow directly in line with the annual traffic.

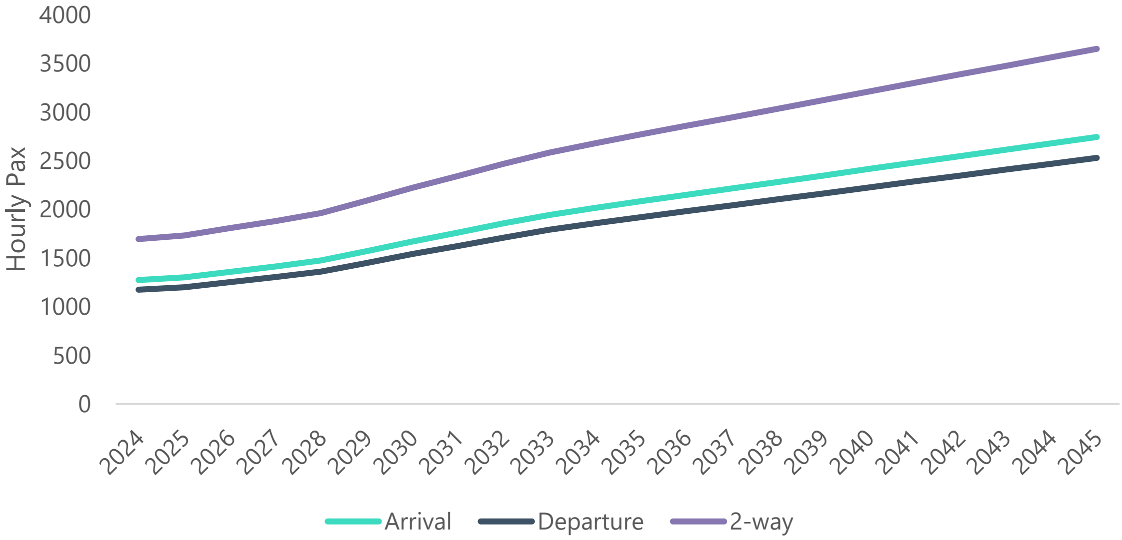
The resulting design hour forecasts are shown below.

3.12.3.1 Domestic Design Parameter Forecast



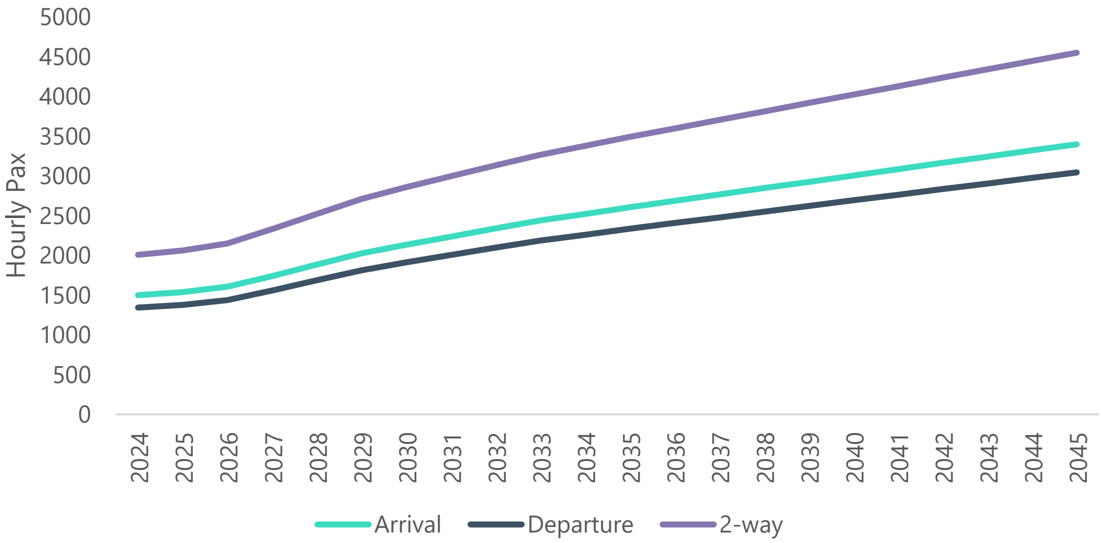
	2024	2030	2035	2040	2045
Arrival	408	711	830	946	1,056
Departure	387	675	788	897	1,002
2-way	603	1,051	1,227	1,398	1,561

3.12.3.2 International Design Parameter Forecast



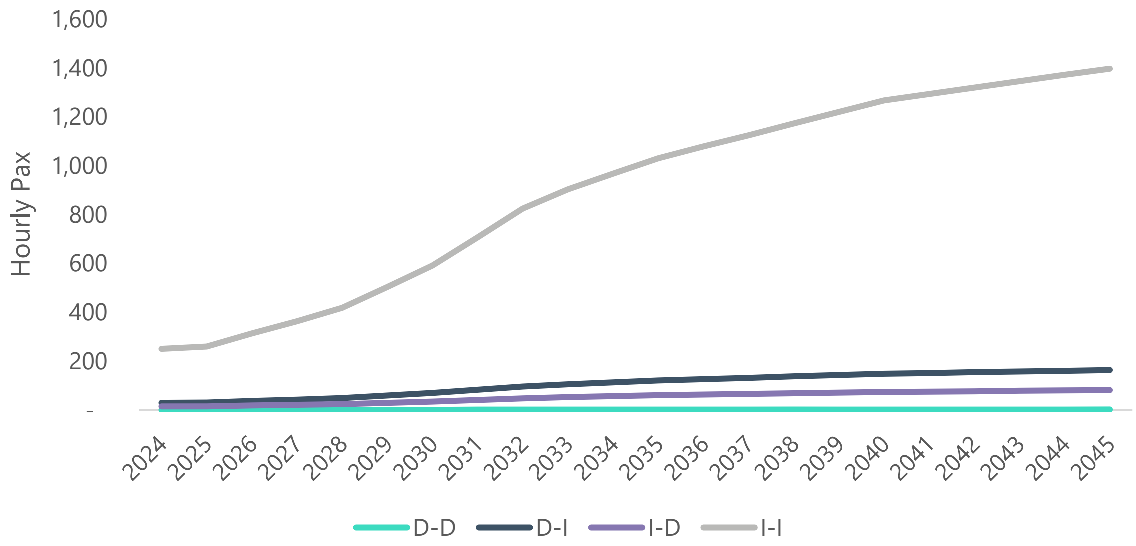
	2024	2030	2035	2040	2045
Arrival	1,275	1,671	2,084	2,415	2,745
Departure	1,175	1,541	1,921	2,226	2,530
2-way	1,695	2,223	2,772	3,212	3,652

3.12.3.3 Combined Design Parameter Forecast



	2024	2030	2035	2040	2045
Arrival	1,499	2,133	2,605	3,004	3,397
Departure	1,343	1,911	2,334	2,692	3,043
2-way	2,007	2,857	3,489	4,023	4,549

3.12.3.4 Transfer parameter forecast



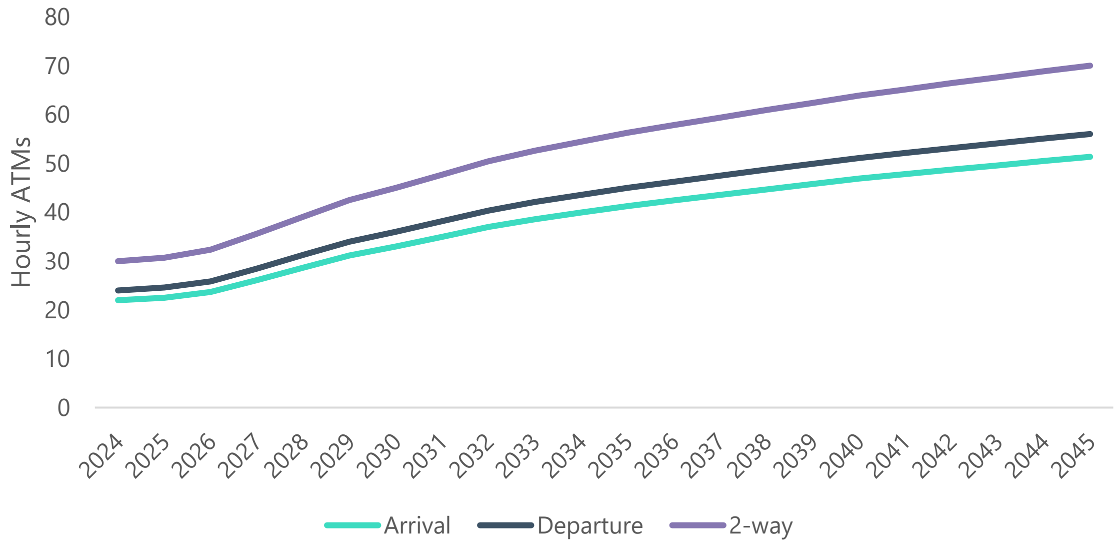
	2024	2030	2035	2040	2045
D-D	0	1	1	2	2
D-I	29	69	121	148	163
I-D	15	34	60	74	81
I-I	250	592	1,031	1,268	1,397

3.12.4 ATMS DESIGN PARAMETER FORECAST

The ATMs are growing in line with the overall ATM development and reach 70 hourly movements by the end of the forecast period, from a current 30. This includes all types of ATMs, (Passenger, Cargo and General Aviation & Other). This is the most robust demand. It is however noted that the baseline 2024 peak ATM number included 8 General Aviation movements. These type of movements could be displaced outside the peaks in case capacity saturation is reached.

Table 3.16: Forecast ATM design parameters

	2024	2030	2035	2040	2045
Domestic					
Arrival	14	24	27	30	33
Departure	12	20	23	26	28
2-way	21	35	40	45	49
International					
Arrival	17	24	31	36	40
Departure	21	29	39	45	49
2-way	25	35	46	53	58
Combined					
Arrival	22	33	41	47	51
Departure	24	36	45	51	56
2-way	30	45	56	64	70


Hourly ATMs
80
70
60
50
40
30
20
10
0
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
Arrival
Departure
2-way

4 DEMAND AND CAPACITY ASSESSMENT

4.1 INFRASTRUCTURE

4.1.1 AIRSIDE

4.1.1.1 AIRSIDE INFRASTRUCTURE

4.1.1.1.1 Introduction

The movement area at JKIA comprises all aerodrome surfaces and facilities that support aircraft operations, as defined by ICAO Annex 14. This includes both paved and unpaved areas designated for aircraft take-off, landing, taxiing, and parking. Key components of the movement area include runways, taxiways, aircraft parking stands, radio navigation aids, airfield lighting systems, surface markings, and other visual guidance elements essential for safe and efficient aircraft movement.

4.1.1.1.2 Runway System

Runways are among the most critical components of an airport's movement area, serving as the primary infrastructure for aircraft takeoff and landing operations. According to ICAO Annex 14, the movement area encompasses all paved and unpaved surfaces designated for aircraft movement, including runways, taxiways, aprons, and associated visual and navigational aids. The number, orientation, and physical characteristics of runways must be carefully planned to accommodate the full range of aircraft types expected to operate at the airport, while also ensuring safe and efficient operations under varying meteorological conditions.

Ideally, runway orientation should allow aircraft operations in at least 95% of prevailing weather conditions, minimizing disruptions due to crosswinds or visibility limitations. Runways are identified by a two-digit number ranging from 01 to 36, which corresponds to one-tenth of the magnetic azimuth of the runway's heading. For example, a runway aligned with a magnetic heading of 90° is designated as Runway 09, while headings of 180°, 270°, and 360° correspond to Runways 18, 27, and 36, respectively.

Each runway can be used in both directions and is therefore assigned two numbers that differ by 18, representing the 180° directional change. For instance, Runway 06 in one direction becomes Runway 24 when used in the opposite direction. In cases where multiple parallel runways share the same orientation, additional identifiers are used to distinguish them. These include suffixes such as Left (L), Center (C), and Right (R). For example, three parallel runways aligned to a heading of 150° would be designated as Runways 15L, 15C, and 15R. When used in reverse, Runway 03L becomes Runway 21R, reflecting the directional shift.

This standardized runway naming convention ensures clarity in air traffic control communications and supports safe navigation for pilots. It also plays a vital role in the planning and layout of airport infrastructure, particularly when considering future expansions, parallel runway operations, and integration with airside and landside facilities.

Jomo Kenyatta International Airport (JKIA) currently operates a single runway, designated 06/24, which is 4,117m long and 45 meters wide and serves both takeoff and landing operations. The runway is aligned in a northeast–southwest orientation, consistent with prevailing wind conditions, and supports a wide range of aircraft types under various operational scenarios.

Table 4.1 Declared Distances at JKIA

Runway Designator	Take-Off Run Available (TORA)	Take-Off Distance Available (TODA)	Acceleration-Stop Distance Available (ASDA)	Landing Distance Available (LDA)
06	4117	4457	4178	4117
24	4117	4178	4178	4117

Runway 06 is the predominantly used direction at JKIA, owing to prevailing easterly winds that Favor operations in the northeast orientation. This alignment ensures optimal runway usability and supports safe and efficient aircraft movements under typical meteorological conditions.

Runway 24 at JKIA is primarily used for aircraft operations when wind conditions shift to Favor a southwest orientation. While Runway 06 is more frequently utilized due to prevailing easterly winds, Runway 24 remains fully operational and is used as needed based on meteorological conditions, traffic flow, and air traffic control directives.

4.1.1.1.3 Taxiway System

According to ICAO Annex 14, taxiways are defined paths on an aerodrome designated for the taxiing of aircraft and intended to connect different parts of the airfield. ICAO classifies taxiways into several types based on their function:

4.1.1.1.3.1.1 Runway Entrance Taxiways

These taxiways connect the apron or other parts of the aerodrome to the runway threshold or beginning of the takeoff run. They are used by aircraft to enter the runway for departure.

4.1.1.1.3.1.2 Rapid Exit Taxiways (RETs)

Designed to allow aircraft to exit the runway at higher speeds (typically 50–60 knots), RETs are angled (usually 25°–30°) to facilitate quick clearance of the runway after landing. Their placement is optimized based on aircraft landing performance and runway occupancy time.

4.1.1.1.3.1.3 Regular Exit Taxiways

These are standard perpendicular or near-perpendicular taxiways that allow aircraft to exit the runway after landing. They are not optimized for high-speed exits and are typically used when RETs are not available or suitable.

4.1.1.1.3.1.4 Apron Taxiways

Located within the apron area, these taxiways guide aircraft between parking stands and the main taxiway system. They are designed to accommodate tight maneuvering and are often marked with centerline guidance and clearance limits.

4.1.1.1.3.1.5 Parallel Taxiways

These run alongside the runway and allow aircraft to taxi to and from runway ends without occupying the runway itself. They are essential for efficient ground movement and help reduce runway occupancy time.

4.1.1.1.3.1.6 Cross Taxiways

These connect parallel taxiways or link different parts of the airfield across the runway system. They are critical for routing flexibility and operational efficiency.

4.1.1.1.3.1.7 JKIA Existing Taxiway System

Jomo Kenyatta International Airport features a comprehensive taxiway network designed to support efficient aircraft movement between runways, aprons, and terminals. According to ICAO Annex 14 definitions, taxiways are designated paths for aircraft to taxis and connect various parts of the aerodrome, including runway entrances, exits, aprons, and terminals.

4.1.1.1.3.1.8 Taxiway Designations:

The following taxiways are currently in use at JKIA:

- Taxiway A
- Taxiway B
- Taxiway C
- Taxiway E
- Taxiway F
- Taxiway G
- Taxiway H
- Taxiway J

- Taxiway K
- Taxiway M

These taxiways vary in width and surface type, with most constructed of concrete and asphalt, and rated at PCN 65/F/A/W/T, suitable for Code E aircraft operations.

- **Rapid Exit and Runway Access:** Runway 06/24 is served by multiple exit taxiways, including:
  - **Taxiway D** – A loop taxiway connecting to Runway 24, used for turning onto the runway.
  - **Taxiway G and M** – Primary taxiways for aircraft transitioning between Apron 1 and the runway holding points.
  - **Taxiway M1, M2, M3** – Subsections of Taxiway M used for accessing specific stands (e.g., 22A–22F).
- **Apron Connectivity:**
  - **Apron 1 and Apron 2** are connected via taxiway G.
  - Taxiway G and M are critical for managing aircraft flow between Apron 1 and the runway.
  - **Apron 3** is connected via Taxiway A.

4.1.1.1.4 Apron

Jomo Kenyatta International Airport (JKIA) features a well-structured apron system designed to support a wide range of aircraft operations, including passenger, cargo, general aviation, and long-stay parking. The aprons are strategically located to optimize aircraft flow between terminals, taxiways, and the runway system.

Apron Types at JKIA:

1.1.1.1 Apron 1 – Passenger Terminal Apron:

Located adjacent to Terminals 1A through 1E, Apron 1 serves as the primary apron for commercial passenger operations. It accommodates a mix of Code C and Code E aircraft, with both contact stands (equipped with passenger boarding bridges) and remote stands. The apron is connected via Taxiways G and M and includes designated stands such as 3A–3C, 2A–2C, and 22A–22F. Stands are accessed through sub-taxiways M1, M2, and M3 depending on aircraft type and gate assignment.

1.1.1.2 Apron 2 – Cargo Operations Apron:

Apron 2 is dedicated to cargo handling and supports freighter aircraft operations. It is located near the cargo terminal and includes stands sized for wide-body aircraft. The apron is equipped with high-strength pavement.

1.1.1.3 Apron 3 – General Aviation and Long-Stay Parking:

Apron 3 is designated for general aviation and long-term aircraft parking. It does not have fueling facilities and is primarily used for small and medium aircraft. Aircraft parked here are typically towed into position under apron control guidance. This apron supports overflow operations and non-scheduled traffic.

All aprons at JKIA are surfaced with concrete or asphalt and rated at PCN 65/F/A/W/T. They are equipped with centreline markings, edge lighting, and marshalling services.

Figure 4.1: Existing Apron at Jomo Kenyatta International Airport

4.1.1.2 RUNWAY DEMAND & CAPACITY

4.1.1.2.1 Introduction

This section presents a comprehensive evaluation of the existing runway capacity at Jomo Kenyatta International Airport (JKIA), alongside an assessment of proposed future runway system configurations. The analysis is grounded in the airport's strategic development goals and considers multiple layout scenarios designed to accommodate evolving operational demands and traffic volumes. The study focuses on both the projected capacity requirements for the year 2045 and the long-term vision for JKIA's airside infrastructure, ensuring alignment with regional growth and international aviation standards.

Runway capacity is a fundamental metric that determines an airport's ability to handle aircraft movements—specifically takeoffs and landings—safely and efficiently within a given timeframe. It directly influences airside planning, airspace design, and investment prioritization. As JKIA continues to position itself as a key aviation hub in East Africa, understanding and optimizing runway capacity becomes essential to support future demand and maintain operational resilience.

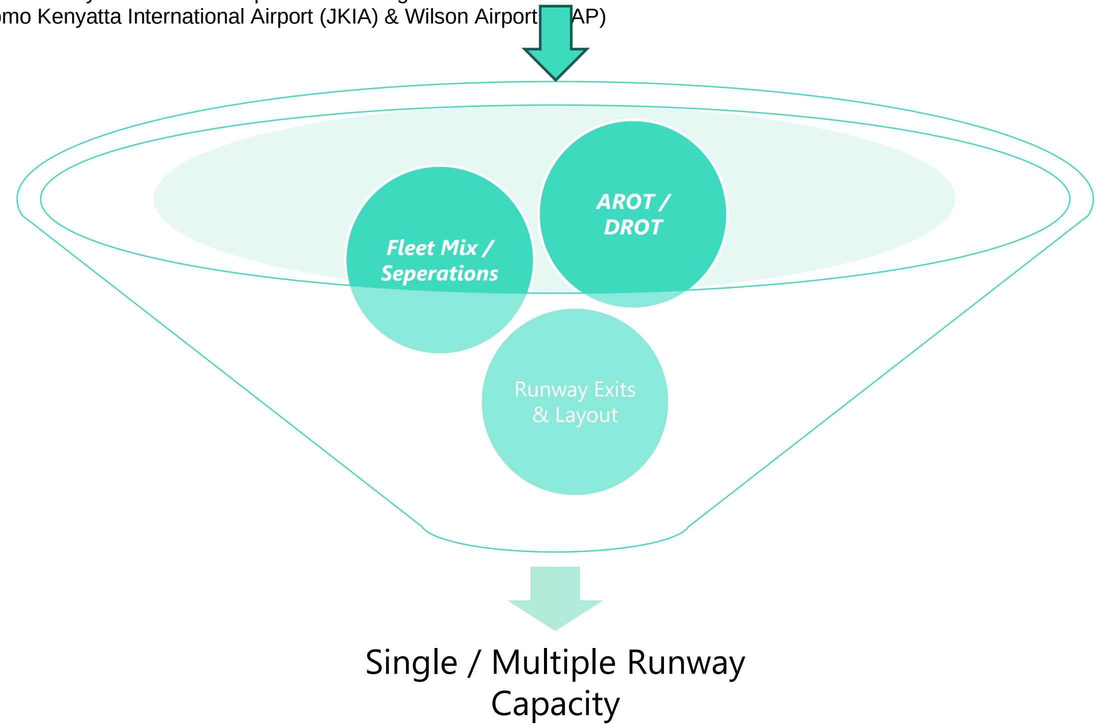
In line with international best practices, this chapter applies methodologies outlined in ICAO Annex 14 and FAA Advisory Circulars to evaluate JKIA's runway performance. The assessment incorporates a range of operational scenarios, including current and forecasted traffic volumes, aircraft fleet mix, and separation standards. These factors are used to estimate both hourly throughput and annual movement capacity, providing a robust foundation for infrastructure planning.

The chapter also introduces a phased development strategy for runway expansion, aimed at balancing immediate operational needs with long-term scalability. Each phase is designed to incrementally enhance capacity while minimizing disruption to ongoing airport operations. This strategic approach ensures that JKIA remains responsive to market dynamics and technological advancements in air traffic management.

By integrating technical analysis with strategic foresight, this chapter sets the stage for informed decision-making around JKIA's runway infrastructure, supporting its continued growth as a modern, efficient, and globally connected airport.

4.1.1.2.2 Methodology

To estimate the runway capacity at JKIA, a specialized simulation and analysis tool developed by **DAR** was employed. This tool enables detailed modeling of aircraft movements under various operational scenarios, incorporating international standards and local constraints. The methodology applied includes a step-by-step process that integrates traffic forecasts, fleet mix assumptions, and separation requirements to calculate both hourly and annual throughput. The following sections outline the analytical approach and key calculations used to derive capacity estimates for each proposed runway configuration.



The following diagram illustrates the methodology applied in the computation process, highlighting how Arrival runway Occupancy Time (AROT) and Departure runway Occupancy Time (DROT) influence the overall capacity estimates across different runway configurations and traffic conditions.

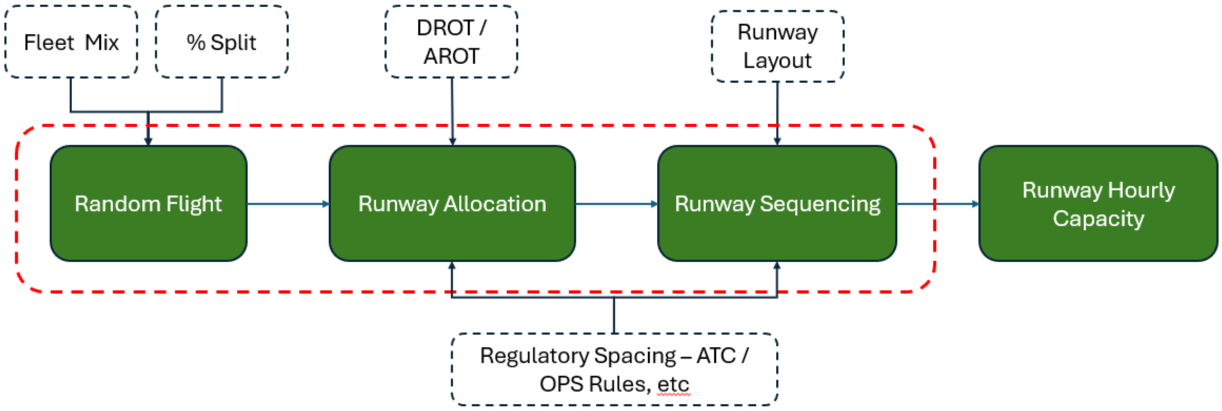


Figure 4.2 Runway Capacity Model - Evaluation Process

Once the runway capacity has been assessed in terms of aircraft movements, the Annual Service Volume (ASV) methodology, as defined by the Federal Aviation Administration (FAA), was applied to convert movement capacity into annual passenger estimates. This approach provides a reliable projection of an airport's yearly operational capacity based on its runway system. The ASV method accounts for a range of influencing factors, including variations in runway usage, aircraft type and mix, prevailing weather conditions, and operational constraints that typically occur throughout the year. By incorporating these variables, the ASV offers a more realistic and comprehensive estimate of JKIA's ability to accommodate passenger traffic over time.

4.1.1.2.3 Assumptions and Methodology

To estimate runway capacity at JKIA, a hybrid analytical approach was adopted. Central to this methodology was the FAA Airfield Capacity Spreadsheet Model, which was calibrated to reflect the existing operational conditions at JKIA. This calibration ensures alignment with the FAA's Annual Service Volume (ASV) method, providing a robust framework for translating hourly aircraft movements into annual passenger capacity.

The model calculates hourly movement capacity by integrating several key operational parameters:

- **Radar Separation**: A minimum separation of 3 nautical miles (NM) between aircraft, based on standard air traffic control practices.
- **Wake Turbulence Separation:** Derived from ICAO Doc 4444, aircraft are categorized into Medium Turboprop, Medium Jet, and Heavy Jet classes to determine appropriate spacing.
- **Buffer Times:** To account for ATC variability, buffer times of 12 seconds for arrivals and 15 seconds for departures were applied.
- **Fleet Mix:** The model incorporates projected traffic forecasts for the year 2045, reflecting expected aircraft types and operational patterns.
- **Arrival Runway Occupancy Time (AROT):** The time interval from threshold crossing to runway exit for arriving aircraft.
- **Departure Runway Occupancy Time (DROT):** The time from brake release to runway exit for departing aircraft.

Due to the lack of detailed information regarding the required parameters for this analysis—both for current operations at **JKIA** and future operations at **JKIA, DAR** made informed assumptions based on its professional expertise and experience in airport planning and operations.

4.1.1.2.3.1.1 Radar Separation

For the purpose of this analysis, it is anticipated that the minimum radar separation between two aircraft at JKIA will be 3 nautical miles (NM) in future operations. Accordingly, a 3NM separation has been assumed for both arrival-to-arrival and departure-to-arrival sequences.

4.1.1.2.3.1.2 Wake Turbulence Separation

Wake turbulence refers to the rotating air masses generated at the wingtips of aircraft, particularly large jets, during flight. These vortices can pose significant hazards to following aircraft, especially during approach and landing phases. To mitigate this risk, **minimum separation standards** between aircraft are defined in **ICAO Doc 4444**, based on the wake turbulence category of each aircraft.

At JKIA, aircraft are classified into three categories for the purpose of runway capacity modeling and separation calculations. These categories reflect the expected fleet mix based on current operations and traffic forecasts:

- **Medium Turboprop Aircraft**: Includes turboprop aircraft with a maximum take-off weight (MTOW) between 7 and 136 tons, such as the ATR 42 and ATR 72.

- **Medium Jet Aircraft**: Covers jet aircraft with an MTOW between 7 and 136 tons, including the Airbus A320 family and Boeing 737 series.

- **Heavy Jet Aircraft**: Refers to aircraft with an MTOW exceeding 136 tons, excluding the A380. Examples include the Boeing 777, Boeing 787, Airbus A330, and Airbus A350.

By combining **wake turbulence separation minima** with **radar separation requirements** (typically 3 nautical miles), the analysis establishes the necessary spacing between successive arrivals. These separation standards are critical inputs in the runway system capacity model used for JKIA, ensuring safe and efficient aircraft operations under varying traffic and weather conditions.

The following table outlines the separation distances applied between aircraft arrivals based on their respective categories and operational constraints.

Table 4.2 Wake Turbulence Separation Between Arrivals

Arrival Minima (NM)		Trailing Aircraft		
		MT	MJ	HJ
Leading Aircraft	MT	3	3	3
	MJ	3	3	3
	HJ	5	4	3

Additionally, standard time separations were considered between two departures:

Table 4.3 Wake Turbulence Separation Between Departures – With Diverging Sids

Departure Minima (s)		Trailing Aircraft		
		MT	MJ	HJ
Leading Aircraft	MT	60	60	60
	MJ	60	60	60
	HJ	120	100	60

It is assumed that air traffic controllers at JKIA will be trained to guide two departing aircraft onto diverging flight paths, with a minimum separation angle of 45 degrees, to enhance the overall capacity of the runway system. This operational strategy allows for reduced departure intervals and improved throughput, while maintaining safety standards in accordance with international air traffic control practices.

4.1.1.2.3.1.3 Buffer times

To account for operational variability and communication inefficiencies, air traffic controllers typically apply additional buffer times beyond standard separation minima. These buffers help mitigate the impact of positioning imprecision and ensure safe sequencing of aircraft during arrival and departure operations.

For the purpose of this analysis, a buffer time of 12 seconds has been applied to all arrivals, and a buffer time of 15 seconds to all departures. These values are added to the regular separation intervals and reflect conservative estimates based on industry practice. It is assumed that these buffer times will remain constant across all operational scenarios and weather conditions at JKIA.

4.1.1.2.3.1.4 Fleet Mix

As outlined in the previous assumptions, runway occupancy times and separation requirements vary significantly across different aircraft types. These differences are primarily driven by aircraft performance characteristics and wake turbulence categories. Consequently, the fleet mix—defined by the distribution of aircraft types operating at JKIA—plays a critical role in determining the overall capacity of the runway system.

In particular, the classification of aircraft into wake turbulence categories (e.g., Medium Turboprop, Medium Jet, Heavy Jet) directly influences the required separation minima and runway usage patterns. A fleet mix dominated by heavier aircraft will typically result in longer runway occupancy times and greater separation distances, thereby reducing throughput. Conversely, a higher proportion of lighter aircraft may allow for tighter sequencing and increased movement rates.

Therefore, accurately forecasting and modeling the fleet mix is essential for realistic capacity estimation and infrastructure planning. The runway system must be designed to accommodate the expected aircraft types while maintaining safety and operational efficiency under varying traffic conditions.

Appended below indicates the fleet mix considered for Runway capacity evaluation for JKIA and is extracted form current flight schedule at JKIA:

Table 4.4 JKIA Existing Fleet Mix

Operating Fleet Mix	% Distribution
Code A – B	3%
Code C - TP	27%
Code C - TJ	49%
Code D – E	21%

4.1.1.2.4 Existing Runway Arrival ROT & Departure ROT:

The Arrival Runway Occupancy Time (AROT) is defined as the time interval between an aircraft crossing the runway threshold and vacating the runway. Similarly, the Departure Runway Occupancy Time (DROT) refers to the time between brake release of a departing aircraft and its runway exit. These parameters are essential for accurately modeling runway throughput and are influenced by aircraft performance characteristics.

To ensure consistency and realism in the analysis, AROT and DROT values were applied based on aircraft type classifications / Airport elevation, Airport average temperature, Runway length and location of RET. These values reflect typical operational behavior and are derived from REDIM software based on existing Runway Condition (Exit locations / Runway Length / Dry / Wet Conditions / Runway elevation and Average temperature). The following table presents the occupancy times considered for each aircraft category:

Table 4.5: Existing Runway Occupancy Time – Runway 06

Operating Fleet Mix	% Distribution	Average Approach Speed (Kt/Hr)	Avg. Runway Occupancy Time (sec)
Code A – B	3%	92	76.24
Code C - TP	27%	122	61.32
Code C - TJ	49%	150	63.96
Code D – E	21%	162	75.27

Table 6 Existing Runway Occupancy Time – Runway 06

Operating Fleet Mix	% Distribution	Average Approach Speed (Kt/Hr)	Avg. Runway Occupancy Time (sec)
Code A – B	3%	92	53.04
Code C - TP	27%	122	61.77
Code C - TJ	49%	150	68.72
Code D – E	21%	162	92.34

Once the hourly movement capacity was established, the FAA's ASV method was used to convert these figures into annual passenger capacity for assuring match with forecasted ATM ASV. This method accounts for year-round variations in aircraft type, weather conditions, and runway usage patterns, offering a realistic and validated estimate of JKIA's long-term airside performance.

Table 4.7 Average Departure Runway Occupancy Time

	Small - S	Small - T	Small +	Large-TP	Large-Jet	Large-757	Heavy
Average Dep. Runway Occ. Times (sec)	34.0	42.0	34.0	34.0	46.0	38.0	51.0

4.1.1.2.5 Calibration and Results

The Aircraft Fleet Mix, Average Approach Speed and Average Runway Occupancy Time based on current operations was used to determine the runway capacity for exiting runway 06 - 24 (refer to Table 4.8). The model was further optimized to validate existing Runway capacity based on ROT (Runway occupancy time) from REDIM using REDIM 4.0.

4.1.1.2.5.1 Existing Runway Capacity

The existing runway capacity for JKIA has been evaluated under both Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC). The results are summarized in Table 3.9.

Under current operational configurations, the airport can handle up to 25 arrivals per hour and 40–42 departures per hour, depending on weather conditions. In mixed-mode operations—where arrivals and departures are processed concurrently, the runway supports a consistent throughput of 30 aircraft movements per hour.

Notably, the arrival share accounts for approximately 83% of total movements across both VMC and IMC scenarios. This reflects the current operational emphasis on inbound traffic and serves as a critical baseline for future capacity planning.

These figures represent the practical limits of the existing runway infrastructure and provide a foundation for evaluating necessary upgrades, including Rapid Exit Taxiways (RETs), parallel taxiways, and potential dual-runway configurations. The analysis will inform strategic decisions aimed at optimizing JKIA's runway system to accommodate projected traffic growth through 2045.

Table 4.8: Capacity Outputs – Runway 06

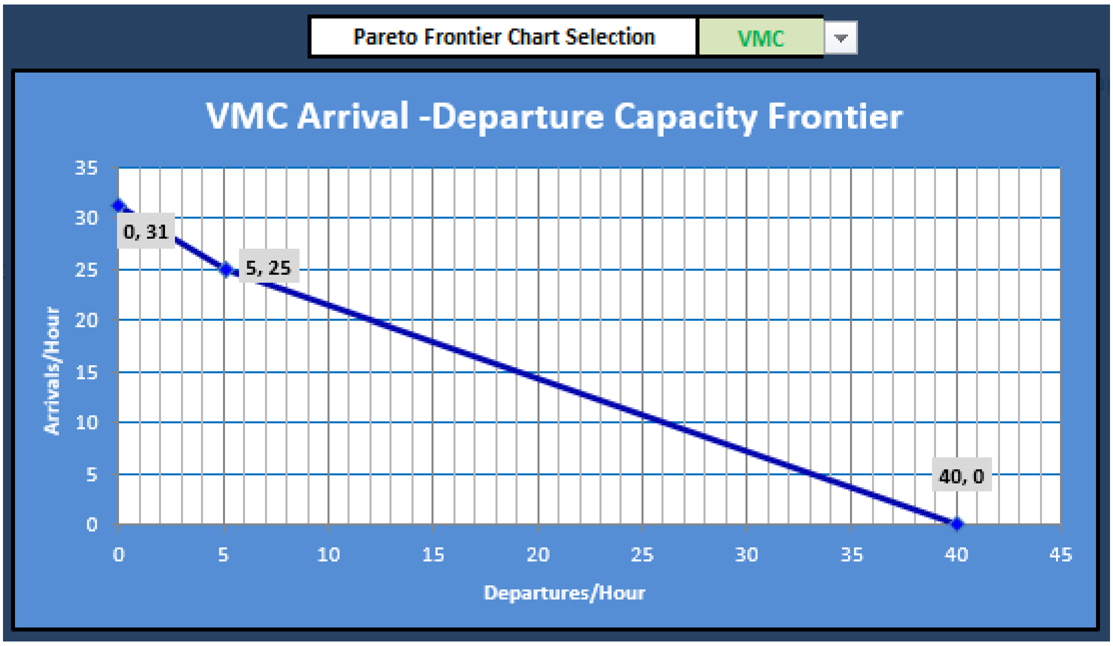
OUTPUTS			
	VMC	***IMC***	***Average***
Arrivals Only Capacity	25	25	25
Departures Only Capacity	40	42	40
Total Mixed Operations Capacity	30	30	30
Arrival Percentage	83%	83%	83%

Source: Consultants analysis.

Table 9 Capacity Outputs – Runway 24

OUTPUTS			
	VMC	***IMC***	***Average***
Arrivals Only Capacity	25	25	25
Departures Only Capacity	40	42	40
Total Mixed Operations Capacity	27	27	27
Arrival Percentage	93%	93%	93%

Source: Consultants analysis.



Source: Consultants analysis.

Figure 4.3: IMC Arrival- Departure Capacity Frontier – Runway 06

The runway capacity analysis under section 4.1.1.2.5.1 for Jomo Kenyatta International Airport (JKIA) provides a clear justification for phased infrastructure upgrades and the eventual development of a second runway. Under current operational conditions, JKIA's single runway (06–24) can accommodate up to 25 arrivals and 40–42 departures per hour, with a mixed-mode capacity of 30 aircraft movements per hour. These figures, consistent across both Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC), reflect the practical limits of the existing runway system.

A notable finding is the dominance of arrival operations, which account for approximately 83% of total movements. This operational emphasis highlights the need for capacity planning that prioritizes inbound traffic, especially during peak periods. The current capacity serves as a baseline for evaluating future demand and infrastructure requirements.

To meet short-term growth, the analysis recommends enhancements such as Rapid Exit Taxiways (RETs) and a full-length parallel taxiway. These upgrades are projected to increase runway efficiency and extend operational viability through 2027, supporting up to 10 million Annual Passengers (MAP).

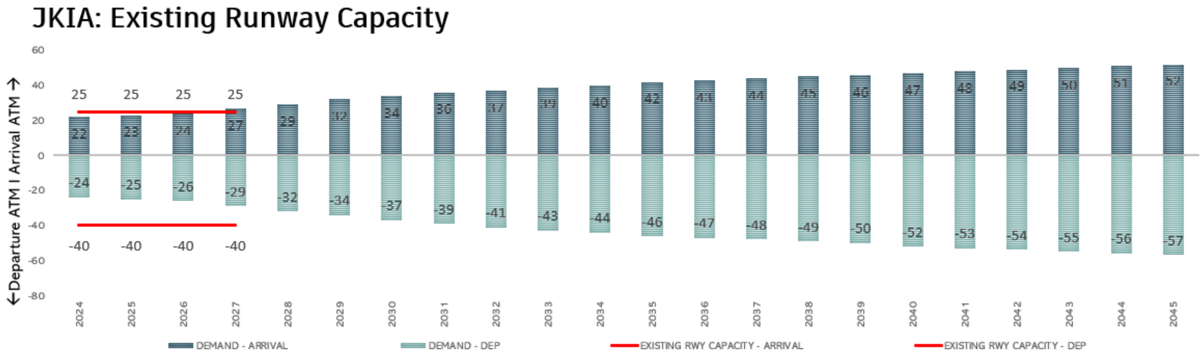


Figure 4.4: JKIA Existing Runway Demand vs Capacity

Forecasts indicate that by 2027, peak hour arrival demand will begin to exceed available capacity, particularly during high-traffic periods. To address this shortfall, the analysis recommends immediate upgrades to the existing runway infrastructure, including the implementation of Rapid Exit Taxiways (RETs) and a full-length parallel taxiway. These enhancements are expected to improve runway efficiency and extend operational viability for the next few years.

In conclusion, the analysis strongly supports a phased approach to runway development—starting with immediate upgrades and culminating in the addition of new runway infrastructure—to ensure JKIA remains a resilient and efficient regional aviation hub.

4.1.1.3 Apron Demand & Capacity

The traffic forecast for Jomo Kenyatta International Airport (JKIA) indicates a steady increase in aircraft stand requirements, driven by consistent growth in passenger volumes. This trend reflects the airport's role as a major regional hub and its expanding connectivity to domestic and international destinations.

By 2045, the projected demand for aircraft stands will reach a total of 90 positions, comprising 26 domestic stands and 64 international stands. These stands will be distributed across various aircraft code categories to accommodate a diverse fleet mix, including narrow-body, wide-body, and regional aircraft. The allocation strategy ensures operational flexibility and supports efficient turnaround times for both scheduled and charter services.

This anticipated growth underscores the need for proactive planning and phased development of apron and stand infrastructure. Meeting these requirements will be critical to maintaining JKIA's operational efficiency, minimizing congestion, and supporting future airline partnerships. The expansion will also align with international standards for safety and service quality, reinforcing JKIA's position as a leading aviation gateway in Africa.

Strategic investment in aircraft stand capacity is therefore essential to cater to long-term traffic growth and sustain the airport's competitiveness in the global aviation market.

4.1.1.3.1 Current Apron Overview

Currently, JKIA Commercial Apron is majorly divided in Terminal 1 and Terminal 2 Aprons. The Terminal Aprons are described below:

- Terminal 1:
  - Contact Stands : 12 Code E, 4 Code D and 2 Code C
  - Remote Stands : 4 Code E, 21 Code C

- Terminal 2:
  - Remote Stands : 6 Code C

- Total:
  - Contact Stands : 12 Code E, 4 Code D and 2 Code C
  - Remote Stands : 4 Code E, 27 Code C

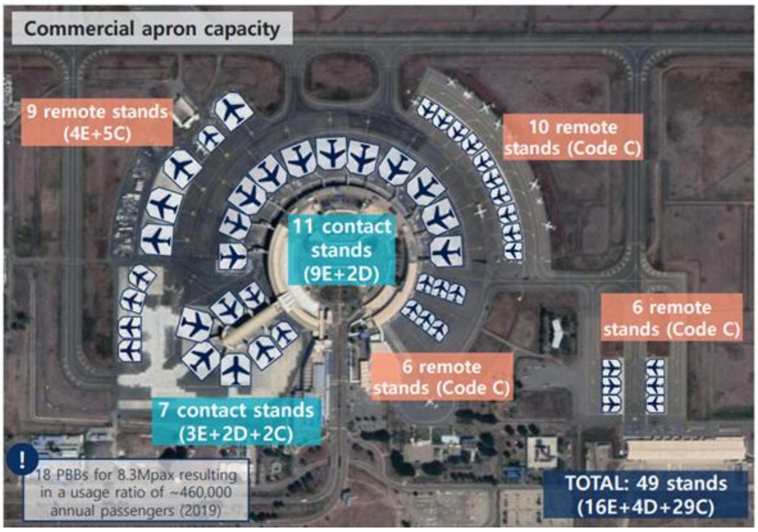


Figure 4.5: Existing Commercial Apron Overview

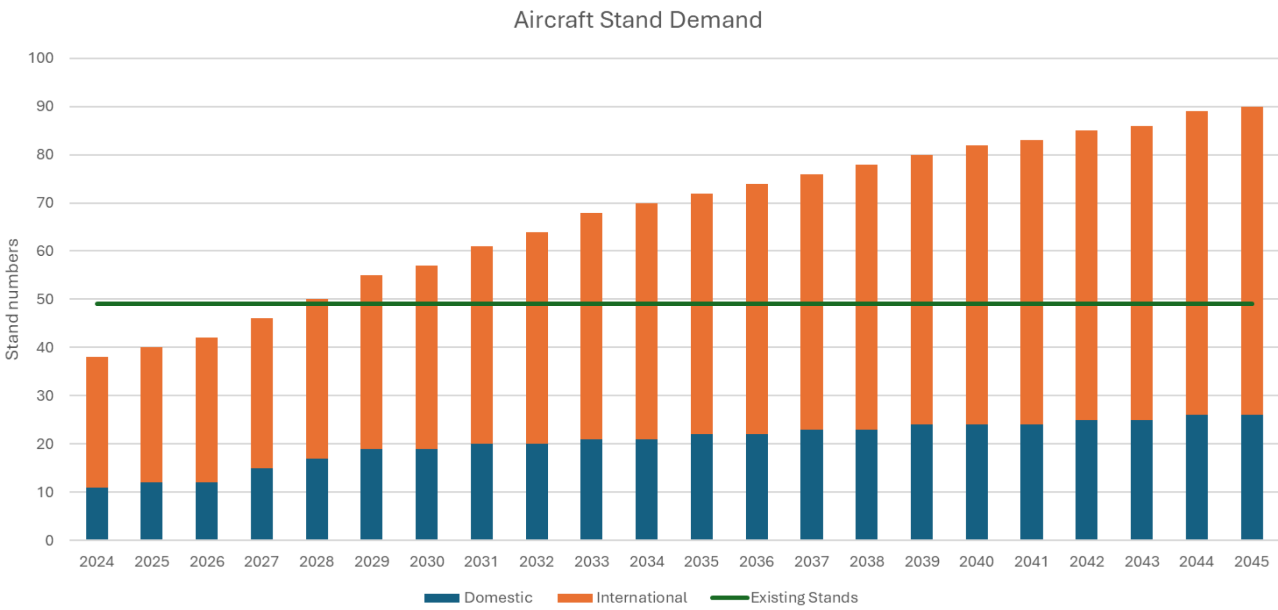


Figure 4.6 JKIA Commercial Aircraft Stand Demand vs Capacity

4.1.2 LANDSIDE AND TRANSPORT MOBILITY

4.1.2.1 Demand and Capacity Assessment

The landside and transport mobility assessment for Jomo Kenyatta International Airport (JKIA) evaluates the adequacy of landside infrastructure serving the New Passenger Terminal Building (New PTB) to accommodate forecast passenger demand for Phase 1 (20 MAP) and Phase 2 (25 MAP). The assessment focuses on curbside operations, car parking requirements, internal access roads, and the external road network, ensuring that facilities operate at acceptable levels of service during peak design conditions.

The analysis is based on the approved Design Day Flight Schedules (DDFS), passenger forecasts, landside mode share assumptions, vehicle occupancies, and dwell times. These inputs were developed using a combination of on-site survey data, client inputs, benchmark data from comparable airports, and professional judgement. Staff traffic volumes are included within the roadway and junction capacity assessments.

4.1.2.2 Passenger Landside Demand

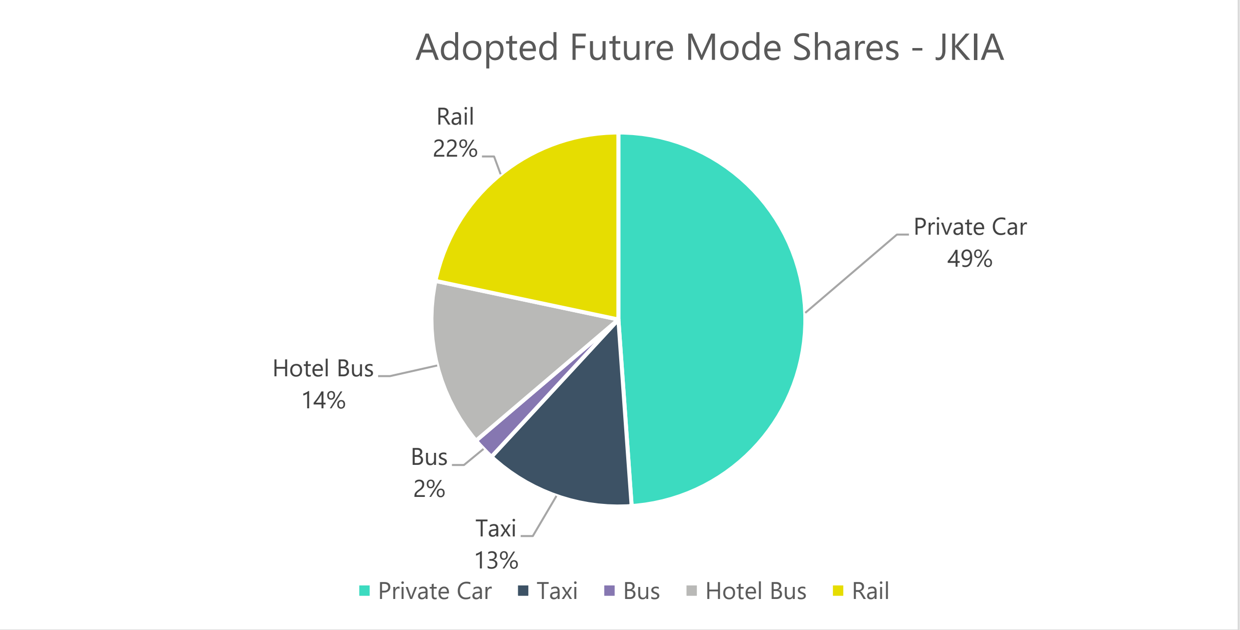
Landside demand was derived from the DDFS for each development phase, distinguishing between arriving and departing origin–destination passengers accessing the New PTB. Transfer passengers were excluded from the landside analysis, as they do not generate landside vehicle trips.

Peak hour passenger demand governs the sizing of curbside facilities, parking supply, and access roads. Separate demand profiles were developed for Phase 1 and Phase 2 to reflect passenger growth and associated with increases in landside vehicle movements.

4.1.2.3 Mode Share Assumptions

Passenger mode shares were informed by landside surveys undertaken at Terminal 1 (T1) and adjusted to reflect future transport strategies for JKIA. Over the long term, improved public transport accessibility, including a proposed rail connection from Embakasi Station, is assumed to increase public transport usage.

A rail mode share of approximately 22% is assumed in the long-term planning horizon, with corresponding reductions in private car and taxi usage. These adopted mode shares form the basis for estimating peak hour vehicle trips, accessing the New PTB for both development phases.



4.1.2.4 Vehicle Occupancies and Dwell Times

Vehicle occupancies were adopted based on observed survey data and benchmark assumptions. The following average occupancies were applied:

- Private cars: 1.42 passengers per vehicle
- Taxis: 1.44 passengers per vehicle
- Buses and hotel buses: 8.33 passengers per vehicle

Average dwell times for both curbside and car parks were also applied:

Table 4.10: Adopted Curbside Dwell Times

	Departure	Arrival
Private Cars	3 minutes	**Car Park**
Taxi	2 minutes	2 minutes
Bus	3 minutes	3 minutes

Table 4.11: Adopted ST Car Park Dwell Time

Car Park Dwell Times	
Private Car	70.3 minutes

4.1.2.5 Car Parking Demand and Capacity

Short-Term Car Parking

Short-term parking demand for the New PTB was assessed based on the assumption that:

- All arriving private vehicles use short-term parking
- Approximately 30% of departing private vehicles use short-term parking

An average parking duration of 70.3 minutes was adopted. Based on peak hour demand and parking turnover, the short-term parking requirements were estimated as:

- Phase 1: approximately 625 parking spaces
- Phase 2: approximately 870 parking spaces

These requirements represent the minimum short-term parking provision necessary to support New PTB operations during peak conditions.

Long-Term Car Parking

Long-term parking is assumed to serve domestic passengers departing only. In the absence of detailed data on parking duration, an average stay of three days was adopted as a planning-level assumption.
Based on daily vehicle demand:

- Phase 1: approximately 134 vehicles per day, requiring 402 spaces
- Phase 2: approximately 201 vehicles per day, requiring 603 spaces

4.1.2.6 Curbside Demand and Capacity

Curbside requirements for the New PTB were assessed separately for arrival and departure levels, with demand aggregated across international and domestic operations. Dedicated curbside spaces are provided for different vehicle types, including private cars, taxis, buses, and hotel buses, all operating on the same curbside level with distinct space allocations.

Phase 1 Curbside Requirements

Departure Curbside: 31 spaces, comprising:

- 18 private cars
- 6 taxis
- 1 bus

- 5 hotel buses

Arrival Curbside: 15 spaces, comprising:

- 8 taxis
- 1 bus
- 6 hotel buses

Phase 2 Curbside Requirements

Departure Curbside: 60 spaces, comprising:

- 37 private cars
- 12 taxis
- 1 bus
- 10 hotel buses

Arrival Curbside: 24 spaces, comprising:

- 12 taxis
- 1 bus
- 11 hotel buses

These requirements reflect peak hour demand and ensure sufficient curbside capacity for all vehicle types serving the New PTB.

4.1.2.7 Curbside Lane Requirements

Curbside approach lane requirements were assessed to maintain acceptable operational performance, targeting a volume-to-capacity ratio of less than 0.9 (Level of Service D or better). Lane capacities of approximately 860 vehicles per hour per lane were adopted, consistent with airport curbside operating conditions.

To accommodate forecast traffic volumes:

Two approach lanes are required at both arrival and departure levels. Additional lanes are provided at the curbside to account for friction effects and stopping vehicles.

Accordingly, the curbside cross-section includes:

- Four lanes at the departure curbside
- Four lanes at the arrival curbside

4.1.2.8 External Road Network and Junction Capacity

External access road and junction capacity assessments were undertaken using Phase 2 traffic volumes, representing the ultimate demand condition for the New PTB. These assessments include both passenger and staff traffic.
Two key junctions were assessed:

- Junction 1: T-Intersection serving the existing PTB
- Junction 2: Junction located near Terminal 2
- The New PTB is not directly served by a new junction; access is provided via internal airport access roads connecting to the wider airport road network.

4.1.2.9 Summary

The landside demand and capacity assessment confirms that, with the proposed curbside allocations, parking provision, and access road infrastructure, the New PTB can be adequately served during both Phase 1 and Phase 2. The inclusion of staff traffic within the roadway assessments further confirms the robustness of the proposed landside network.

4.2 BUILDINGS & SUPPORT FACILITIES

4.2.1 PASSENGER TERMINAL BUILDING

4.2.1.1 Current terminals overview

Currently, JKIA has got 2 Terminals i.e., Terminal 1 and Terminal 2. Terminal 1 is further divided into 5 different but connected buildings, T1A, T1B, T1C, T1D and T1E. The Terminals are being Operated as below:

- T1A: International Departures and Arrivals
- T1B: International Departures
- T1C: International Departures
- T1D: Domestic Departures and Arrivals
- T1E: International Arrivals
- T2: International and Domestic, Departures & Arrivals

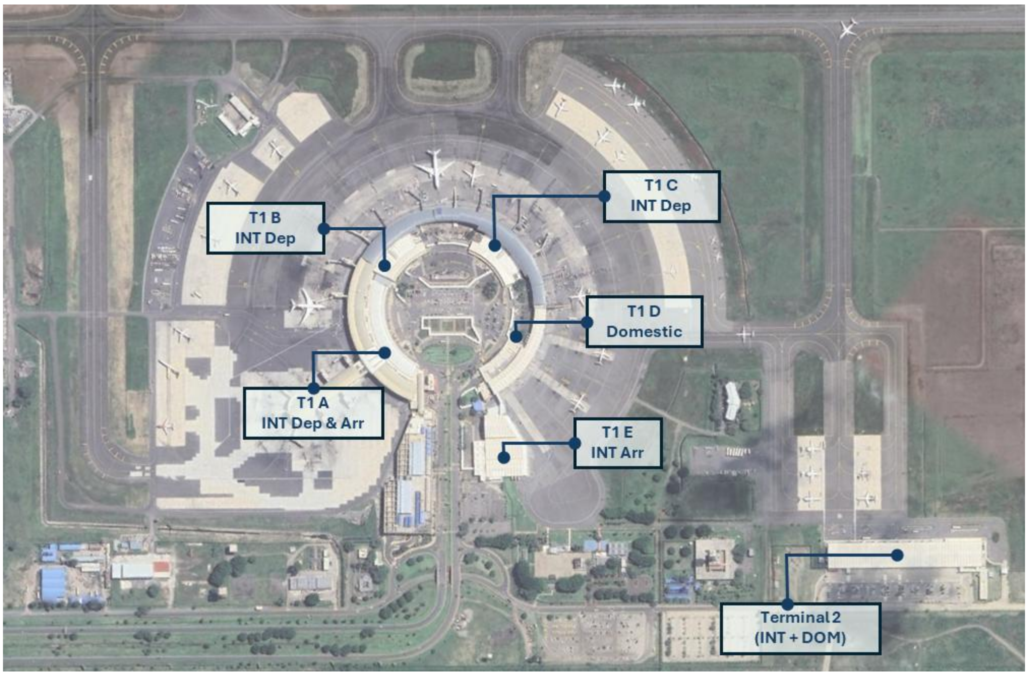


Figure 4.7: Terminals Overview

Overview of the Terminal Processing Facilities is shown in the below table. These facilities are assessed from the available cad files shared by KAA.

Table 4.12: Terminals Existing Facilities

Terminal	Type	Arrival / Departure	Facility	Number of Counters / Machines
1A	International	Departure(L0-L1)	Check-in counters	30
		Departure(L0-L1)	Emigration passport control	10
		Departure(L0-L1)	Security check screening	8
		Arrival(L2)	Immigration counters	16
		Arrival(L0)	Baggage claim/Belts	3
		Transfer(L1-L2)	Security check screening	3
1B	International	Departure(L0)	Check-in counters	28

Terminal	Type	Arrival / Departure	Facility	Number of Counters / Machines
		Departure(L0)	Emigration/ Passport Control Counters	8
		Departure(L0)	Central screening machines	3
1C	International	Departure(L0)	Check-in counters	28
		Departure(L0)	Emigration/ Passport Control Counters	8
		Departure(L0)	Central screening machines	3
Central Area (T1 Arrivals connected to T1 B and C)	International	Arrival	Immigration counters	14
		Arrival	Belts(90m)	2
		Arrival	Belts(60m)	2
1D	Domestic	Departure(L0)	Check-in counters	12
		Departure(L0)	Screening machines	2
		Transfers from 1E to 1D	Screening machines	4
		Arrival(L0)	Belt (33m)	1
1E	International	Arrival(L0)	Immigration passport counters	18
			Belts	5
T2	Domestic & Intl	Departure	Check-in counters	24
		Departure	Screening Machines	6
		Departure	Emigration/ Passport Control Counters	8
	Domestic	Arrival	Belts(50m)	1
	International	Arrival	Belts(50m)	2
		Arrival	Immigration Counters	4

According to information shared by KAA, Terminal building capacities and their future function are defined as:

- T1A: 2.5 MAP To be retained for Future Operations
- T1B: 1.0 MAP To be retained for Future Operations
- T1C: 1.0 MAP To be retained for Future Operations
- T1D: 0.5 MAP To be retained for Future Operations
- T1E: 1.5 MAP To be decommissioned/ demolished
- T2: 1.5 MAP To be retained for Future Operations

4.2.1.2 Passenger Demand

Currently, JKIA is handling around 9 million passengers per year. This number would increase significantly over the number of years as highlighted in Traffic forecast. The Airport is expected to handle around 22.3 MAP in 2045 as shown in following figure.

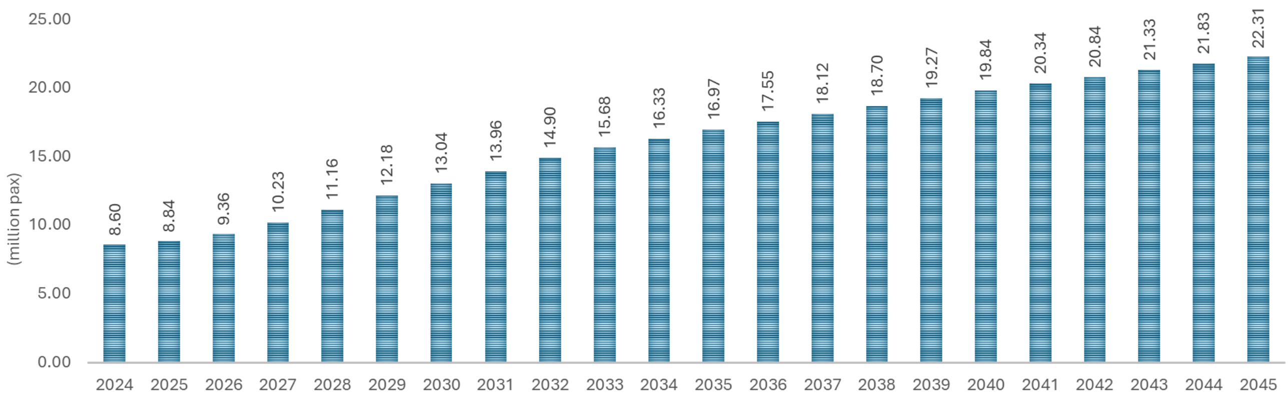


Figure 4.8: JKIA Passenger Demand

4.2.1.3 Current Terminals Potential

JKIA Terminals are having declared capacity of 8 MAP and they would be handling over 9 MAP passenger traffic in 2026. This would imply that to cater to the upcoming years demand, Airport need quick and short-term solutions to enhance the Terminal capacities.

It would be required for JKIA to assess and act on the quick capacity enhancement solutions to cater for demand getting generated in next 3-4 years. As the current year Operations are going on at around 9 MAP, this can be set as a base Operating Capacity of the existing Terminals.

Airport can perform various Operational changes like strategic relocation of Airlines, operate with digital processing facilities and expand the current Terminals e.g., utilize space between T1B and T1C to increase the current Operational capacity of 9 MAP. As per global Terminal Planning benchmarks, an Integrated Operational Airport can increase their Terminal capacities by 25-40% through above-mentioned strategies.

JKIA has the potential to significantly increase their Operational capacity of the existing Terminals. However, detailed feasibility assessment and planning works must be undertaken by KAA to analyse the potential of the Terminal buildings.

Below figure provides an indication of the short-term solution for potential Terminal capacities to cater to the growing passenger demand. T1E would need to be retained and kept operational for this phase.

With the probable 30% increase in the existing Terminals capacity, the Airport might be able to handle the operations by 2029. Beyond this, the Airport would need New Passenger Terminal building.

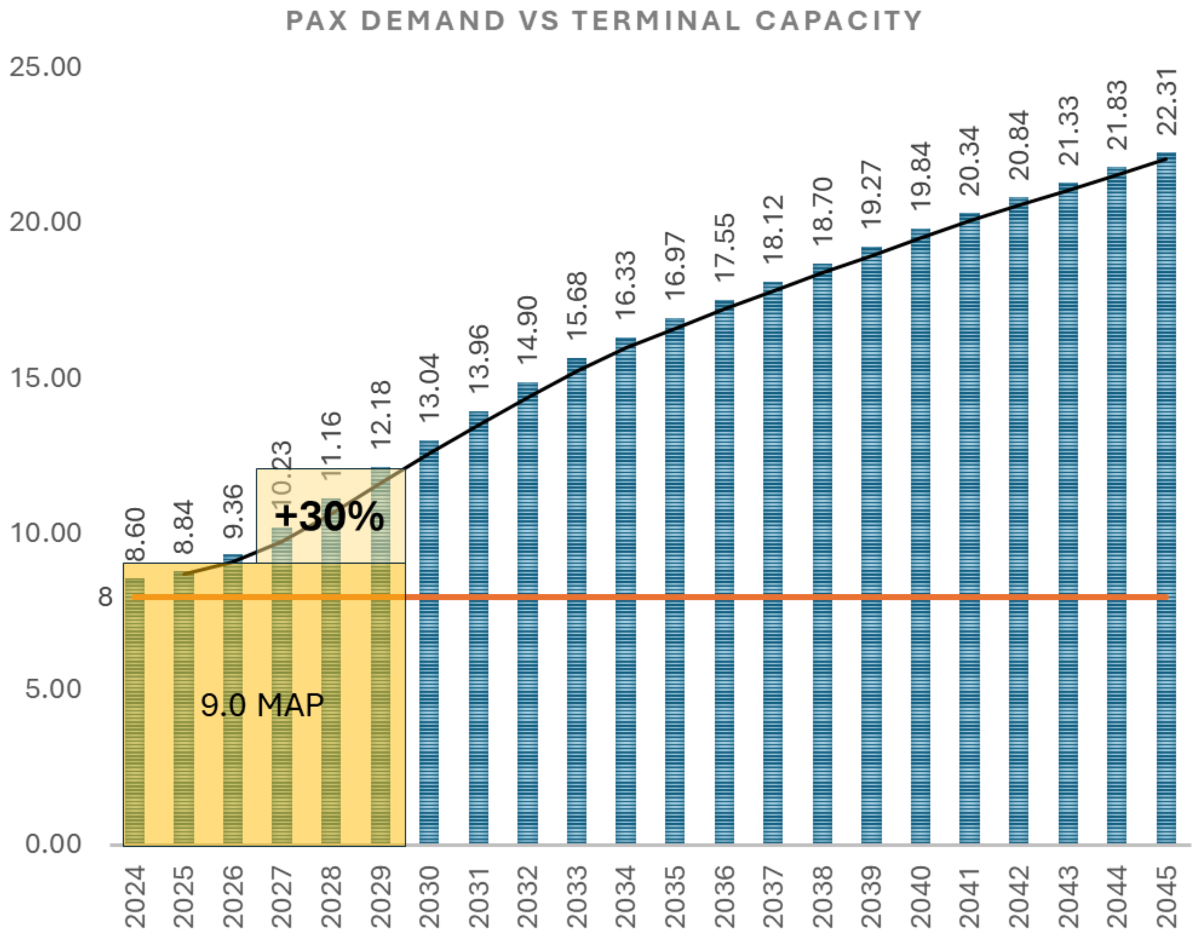


Figure 4.9: JKIA Current Terminals Potential

4.2.2 SUPPORT FACILITIES

JKIA support facilities are having declared capacity of 8 MAP and they would be handling over 9 MAP passenger traffic in 2026. This would imply that to cater to the upcoming years demand, Airport might need quick and short-term solutions to enhance their capacities.

It would be required for JKIA to assess and act on the quick capacity enhancement solutions to cater for demand getting generated in next 3-4 years. As the current year Operations are going on at around 9 MAPS, this can be set as a base Operating Capacity of the existing facilities.

With the probable 30% increase in the existing Terminals capacity, the Airport might be able to handle the operations by 2029. Beyond this, the Airport would need New Passenger Terminal building, thus new support facilities.

4.3 UTILITIES

JKIA utilities are having declared capacity of 8 MAP and they would be handling over 9 MAP passenger traffic in 2026. This would imply that to cater to the upcoming years demand, Airport might need quick and short-term solutions to enhance their capacities.

It would be required for JKIA to assess and act on the quick capacity enhancement solutions to cater for demand getting generated in next 3-4 years. As the current year Operations are going on at around 9 MAPS, this can be set as a base Operating Capacity of the existing utilities.

With the probable 30% increase in the existing Terminals capacity, the Airport might be able to handle the operations by 2029. Beyond this, the Airport would need New Passenger Terminal building, thus new utilities.

5 DEVELOPMENT PLAN

5.1 INFRASTRUCTURE

5.1.1 AIRSIDE

5.1.1.1 Introduction

Jomo Kenyatta International Airport (JKIA) serves as Kenya's primary gateway and a critical hub for regional and international air traffic. As air travel demand continues to grow, the airport's infrastructure must evolve to meet future operational requirements and maintain efficiency. Section 3 of this report highlights the existing capacity of JKIA's runway system and its limitations in handling projected traffic volumes.

Currently, the existing runway configuration can deliver a maximum capacity of 25 arrivals during peak arrival periods and 40 departures during peak departure periods. Under mixed-mode operations, the combined capacity is approximately 30 movements per hour. This operational threshold is insufficient to accommodate the anticipated traffic growth, particularly the projected demand for the year 2027, which exceeds these capacity limits. The inability to meet this demand poses significant risks to service quality, operational reliability, and the airport's competitiveness as a regional hub.

Given these constraints, an immediate upgrade of the runway infrastructure is essential to address the shortfall and ensure seamless operations beyond 2027. The upgrade will not only alleviate current capacity challenges but also position JKIA to handle the ultimate demand forecast for 2045, which requires a robust and scalable airside infrastructure.

This section provides a comprehensive capacity assessment of the existing runway system, identifies critical bottlenecks, and outlines the proposed runway enhancement strategies. The objective is to ensure that JKIA remains capable of supporting future traffic growth, improving operational resilience, and meeting international standards for safety and efficiency. By implementing these upgrades, JKIA will secure its role as a leading aviation hub in Africa and sustain economic growth through enhanced connectivity.

5.1.1.2 Upgraded Runway Capacity – Runway 06

As part of the strategic expansion of Jomo Kenyatta International Airport (JKIA), a detailed runway capacity analysis has been conducted to assess the effectiveness of infrastructure upgrades in meeting projected air traffic demand. The existing runway system, which includes three 90-degree exits and a partial parallel taxiway, currently supports a maximum of 25 arrivals per hour, 40 departures per hour, and 30 aircraft movements per hour in mixed-mode operations. However, traffic forecasts indicate that this configuration will reach its operational limits by 2027, particularly during peak arrival periods.

To address this constraint, Phase 1 of JKIA's airfield development strategy proposes a series of targeted upgrades aimed at enhancing runway throughput and operational efficiency. Central to this phase is the implementation of two Rapid Exit Taxiways (RETs) located at 2,000 meters and 2,450 meters from the runway threshold, along with a runway exit at the end of Runway 06. These RETs are designed to allow aircraft to vacate the runway more quickly after landing, thereby reducing Runway Occupancy Time (ROT) from an average of 66 seconds to approximately 60 seconds.

In addition to the RETs, a partial parallel taxiway is proposed to support aircraft movement, particularly during operations on Runway 24. This infrastructure will facilitate smoother ground handling and reduce taxiing delays, further contributing to overall airfield efficiency. The combination of RETs and parallel taxiways is expected to yield a 10–20% increase in runway capacity, enabling JKIA to accommodate short-term traffic growth without the immediate need for a second runway.

5.1.1.2.1 Fleet Mix and Operational Inputs

The upgraded runway capacity model assumes the following fleet mix:

- Code C Turbo Jets: 49%
- Code C Turbo Props: 27%
- Code D/E Aircraft: 21%
- Code A/B Aircraft: 3%

Average approach speeds and runway occupancy times were calculated for each aircraft category, ensuring that the model reflects realistic operational conditions. These inputs were critical in determining the revised capacity figures and validating the effectiveness of the proposed upgrades.

5.1.1.2.2 Rapid Exit Taxiways (RETs):

The determination of Rapid Exit Taxiway (RET) locations for JKIA's existing runway was conducted using advanced simulation and optimization techniques to ensure operational efficiency and compliance with international best practices. The planning team utilized the REDIM software—developed by Virginia Tech University in collaboration with the U.S. Federal Aviation Administration (FAA)—to model and optimize RET placement.

REDIM (Runway Exit Design Interactive Model) version 4.0.2 was employed during the planning phase to estimate the optimal number and positioning of RETs. Detailed traffic data from Traffic forecast for the ultimate planning horizon i.e. 2045 was used, the existing fleet mix of 2025 was used as a representative baseline. This assumption ensures continuity in aircraft performance characteristics and operational behaviour across planning phases.

The REDIM tool integrates a dynamic simulation model with a polynomial-time optimization algorithm. It accounts for aircraft-specific landing dynamics using kinematic equations, including approach speed, deceleration rates, and exit angles. The software evaluates multiple runway exit configurations and identifies the most efficient RET locations that minimize runway occupancy time (ROT) while maximizing throughput.

For JKIA, the analysis led to the selection of two RETs, including Code A/B aircraft from peak-hour operations. This adjustment allowed the planning to focus on Code C through E aircraft, which represent the majority of traffic. Two new RETs resulted as best combination form REDIM study at 2,000m and 2,450m from the runway threshold, achieving an average ROT of 60.1 seconds.

This data-driven approach ensures that JKIA's new runway infrastructure is optimized for current and future operational demands, balancing performance, safety, and cost-effectiveness.

5.1.1.2.2.1 Assumptions

The fleet mix considered for Evaluating Existing Runway RET locations was based on existing 2025 fleet mix as indicated in Table 5.1:

Table 5.1: JKIA Existing fleet Mix

Operating Fleet Mix	% Distribution
Code A – B	3%
Code C - TP	27%
Code C - TJ	49%
Code D – E	21%

Other assumptions have been taken into account:

- Runway length: 4,116 m
- Elevation: 1,625 meters
- Temperature: 21°C, which corresponds to the annual average temperature
- Wet conditions: 10%

5.1.1.2.2.2 Results

REDIM recommended adding 02 RET and 01 Runway end Exit will reduce the ROT to 60.1 sec.

Runway Exits Type	Distance from Threshold
01 – 90 Degree (Existing)	1,570m
02 – RET (Proposed)	2,000m
03 – 90 Degree (Existing)	2,300m
04 – RET (Proposed)	2,450m
05 – 90 Degree (Existing)	3,000m
06 – Runway End Exit (Proposed)	4,116m

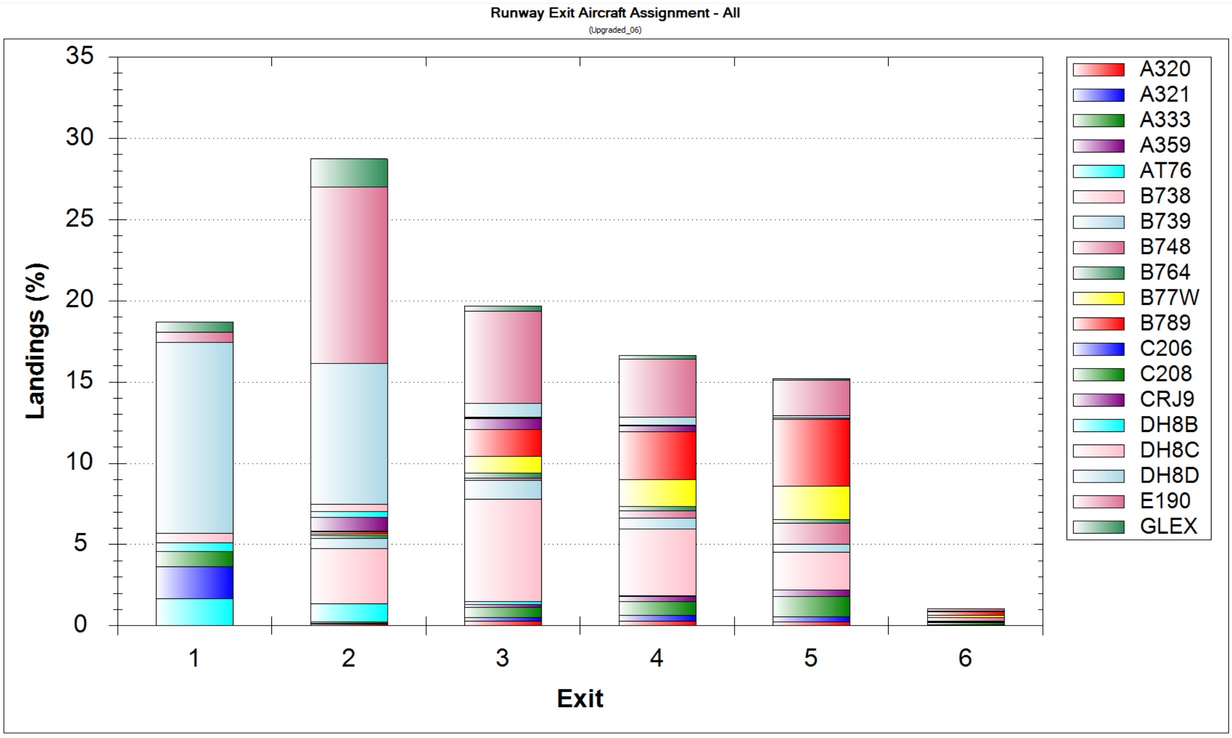


Figure 5.1: RET Usage per aircraft type

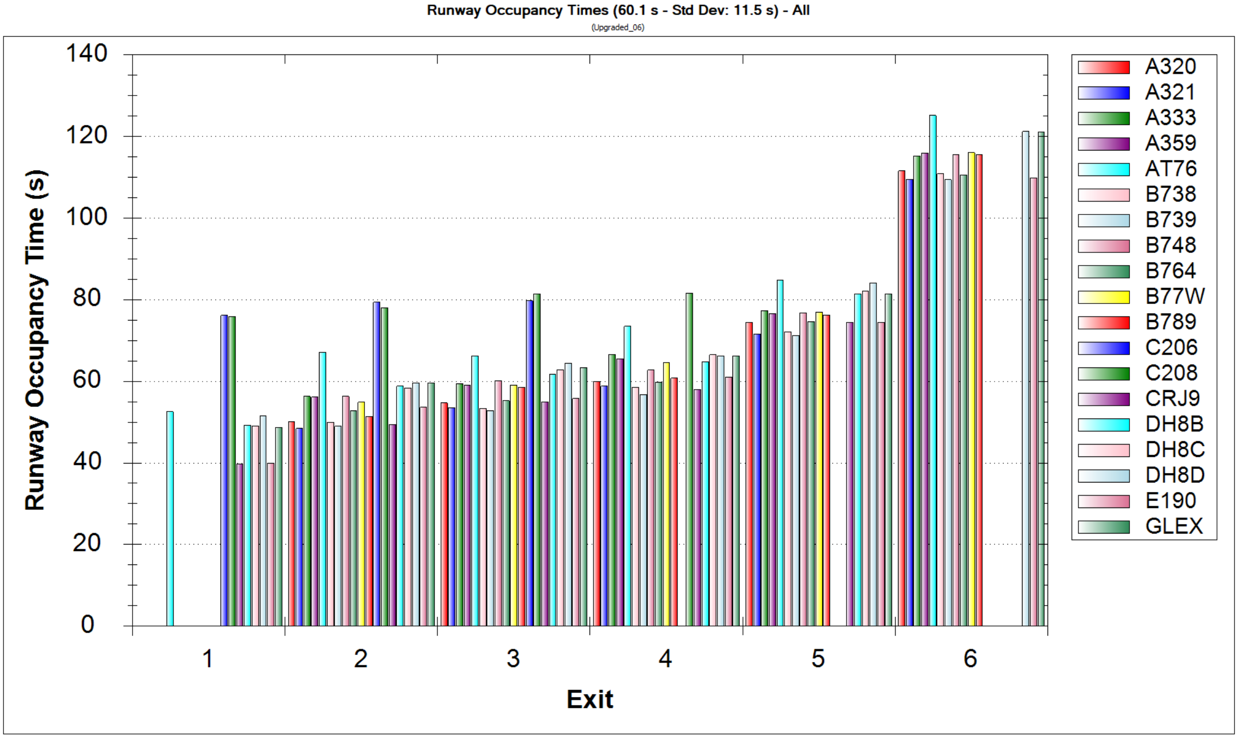


Figure 5.2: Upgraded Runway ROT

Based on REDIM analysis, existing Runway is proposed to be upgraded with following:

- **New Rapid Exit Taxiways (RET)**
  - Two RETs are introduced at 2,000m and 2,450m from the runway threshold.
  - Designed at 30-degree angles to enable high-speed exits, reducing ROT and improving runway throughput.
- **Runway End Exit**:
  - Positioned at 4,160m to facilitate efficient clearance for long-landing aircraft.
- **Partial Parallel Taxiway**:
  - Constructed to connect runway exits with apron areas, improving routing flexibility and reducing congestion.

Operational Benefits:

- **ROT Reduction**: From 66 seconds to 60.1 seconds
- **Arrival Capacity**: Increased from 25 to 31 ATM/hr
- **Mixed-Mode Capacity**: Increased from 30 to 36 ATM/hr
- **Safety**: Enhanced by minimizing runway incursion risks

These upgrades are expected to meet traffic demand until 2029, after which a second runway will be required to sustain growth.

Figure 5.3: JKIA Upgraded Runway Layout - 02 New RET & 01 Runway end Exit & Parallel Taxiway

5.1.1.2.3 Revised Capacity Outputs Post-Upgrade

Following the implementation of the proposed upgrades, the revised runway capacity figures are as follows:

- **Arrivals Only Capacity**: 31 aircraft movements per hour
- **Departures Only Capacity**: 40 aircraft movements per hour
- **Mixed Mode Operations**: 36 aircraft movements per hour
- **Arrival Share**: 83% across both VMC and IMC conditions

These figures represent a significant improvement over the existing configuration and are based on the FAA Airfield Capacity Spreadsheet Model, which incorporates JKIA's current fleet mix, aircraft approach speeds, and updated ROT values.

5.1.1.2.4 Strategic Implications and Demand Alignment

The enhanced runway configuration is expected to support JKIA's operational needs through 2029, aligning with traffic forecasts that project a steady increase in aircraft movements. According to the base scenario, arrival demand is expected to grow from 2 ATMs/hour in 2024 to 32 ATMs/hour by 2029, while departure demand will increase from 24 to 34 ATMs/hour over the same period. The upgraded runway system, with its increased capacity, will be able to accommodate this growth without compromising safety or efficiency

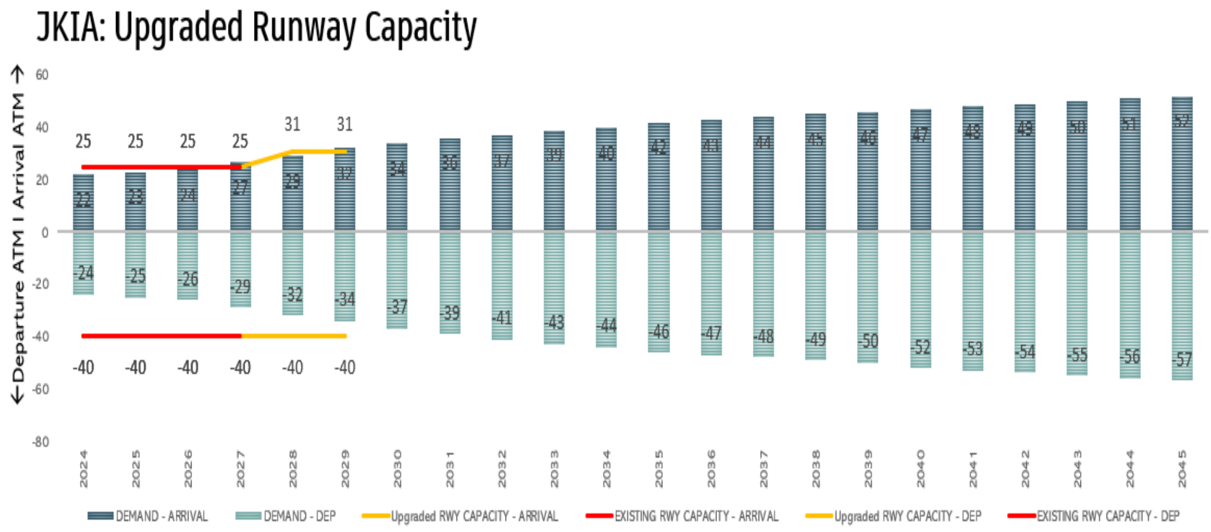


Figure 5.4: JKIA Upgraded Runway Capacity

5.1.1.2.5 Upgraded Runway Capacity Summary

The implementation of two RETs at 2,000m and 2,450m, along with a runway end exit and partial parallel taxiway, represents a cost-effective and operationally sound solution to JKIA's short-term capacity challenges. These upgrades will significantly enhance runway throughput, reduce aircraft delays, and improve overall airfield efficiency. By extending the viability of the existing runway system through 2029, JKIA can defer the substantial investment required for a second runway while maintaining high service standards and operational flexibility.

This phased approach to runway development—starting with immediate enhancements and culminating in the construction of a second runway—ensures that JKIA remains well-positioned to accommodate future growth and maintain its status as a leading international gateway in East Africa.

However, beyond 2029, the upgraded single-runway system will no longer be sufficient to meet peak hour demand. At this point, the construction of a **second runway** will become necessary to ensure continued operational resilience and support JKIA's role as a regional aviation hub. The second runway is envisioned as part of **Phase 2 (2030–2045)** of the airport's development strategy and will be designed to handle independent arrival and departure operations.

5.1.1.3 Upgraded Runway Capacity – Runway 24

As part of the strategic expansion of Jomo Kenyatta International Airport (JKIA), a detailed runway capacity analysis has been conducted to assess the effectiveness of infrastructure upgrades in meeting projected air traffic demand. The existing runway 24 system, which includes three 90-degree exits and a partial parallel taxiway, currently supports a maximum of 25 arrivals per hour, 40 departures per hour, and 27 aircraft movements per hour in mixed-mode operations with average ROT of 71.6 seconds. However, traffic forecasts indicate that this configuration will reach its operational limits by 2027, particularly during peak arrival periods similar to Runway 06.

Based on the wind flow analysis which was further validated through actual operational patterns, it has been confirmed that **Runway 24 is used minimally**, with operations occurring primarily during **westerly wind conditions**, which represent **less than 5%** of the overall wind occurrence, compared to the dominant easterly winds. Consequently, **any impact on runway capacity is limited to short periods**, specifically **during peak hours when the wind direction shifts to easterly**.

In order to enhance the capacity for 24, there will be requirement of New rapid exit taxiway which shall enhance the ROT and will subsequently enhance the runway capacity.

5.1.1.3.1 Fleet Mix and Operational Inputs

The upgraded runway capacity model assumes the following fleet mix:

- Code C Turbo Jets: 49%
- Code C Turbo Props: 27%
- Code D/E Aircraft: 21%
- Code A/B Aircraft: 3%

Average approach speeds and runway occupancy times were calculated for each aircraft category, ensuring that the model reflects realistic operational conditions. These inputs were critical in determining the revised capacity figures and validating the effectiveness of the proposed upgrades.

5.1.1.3.2 Rapid Exit Taxiways (RETs):

The determination of Rapid Exit Taxiway (RET) locations for JKIA's existing runway 24 was conducted using advanced simulation and optimization techniques to ensure operational efficiency and compliance with international best practices. The planning team utilized the REDIM software—developed by Virginia Tech University in collaboration with the U.S. Federal Aviation Administration (FAA)—to model and optimize RET placement.

The analysis led to the selection of one RETs, including Code A/B aircraft from peak-hour operations. One new RETs resulted as best combination form REDIM study located at a distance of 3,075m from runway 24 threshold, achieving an average ROT of 64.9 seconds.

5.1.1.3.2.1 Assumptions

The fleet mix considered for Evaluating Existing Runway 24 RET locations was based on existing 2025 fleet mix as indicated in Table 5.1:

Table 5.2: JKIA Existing fleet Mix

Operating Fleet Mix	% Distribution
Code A – B	3%
Code C - TP	27%
Code C - TJ	49%
Code D – E	21%

Other assumptions have been taken into account:

- Runway length: 4,116 m
- Elevation: 1,625 meters
- Temperature: 21°C, which corresponds to the annual average temperature
- Wet conditions: 10%

5.1.1.3.2.2 Results

REDIM recommended adding 01 RET will reduce the ROT to 64.9 sec from original ROT of 71.6 sec.

Runway Exits Type	Distance from Threshold
01 – 90 Degree (Existing)	1,095m
02 – 90 Degree (Existing)	1,795m
03 – 90 Degree (Existing)	2,525m
04 – New RET	3,075m
06 – Runway End Exit (Existing)	4,116m

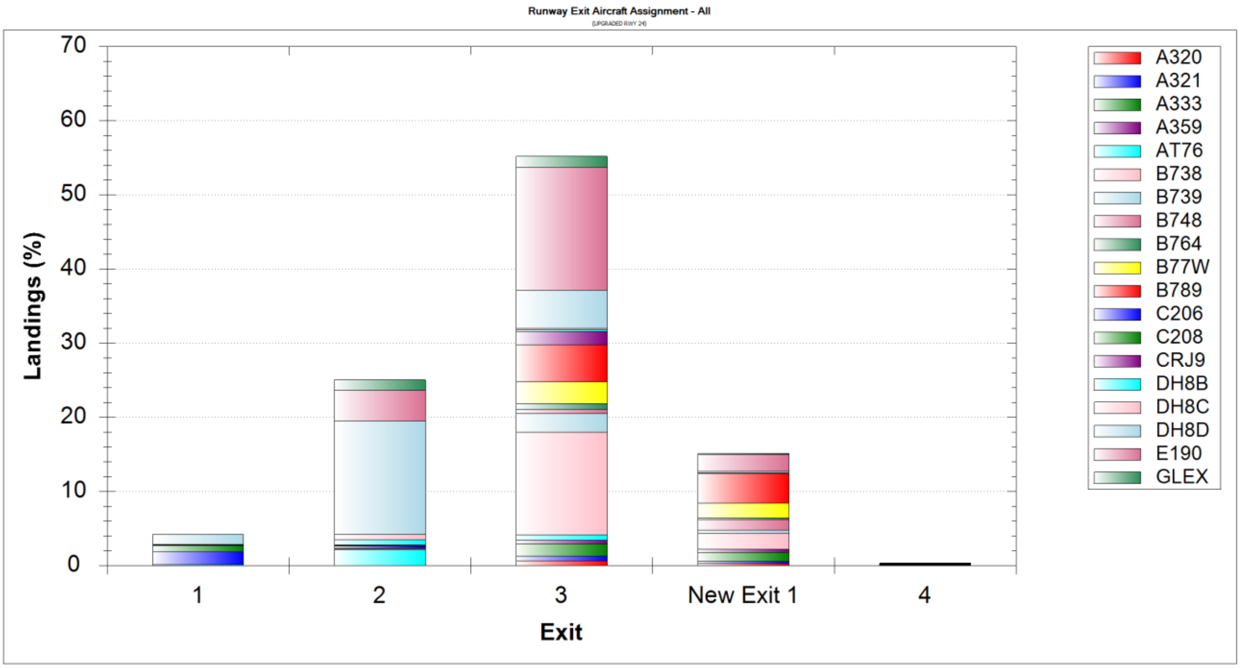


Figure 5.5: RET Usage per aircraft type – Runway 24

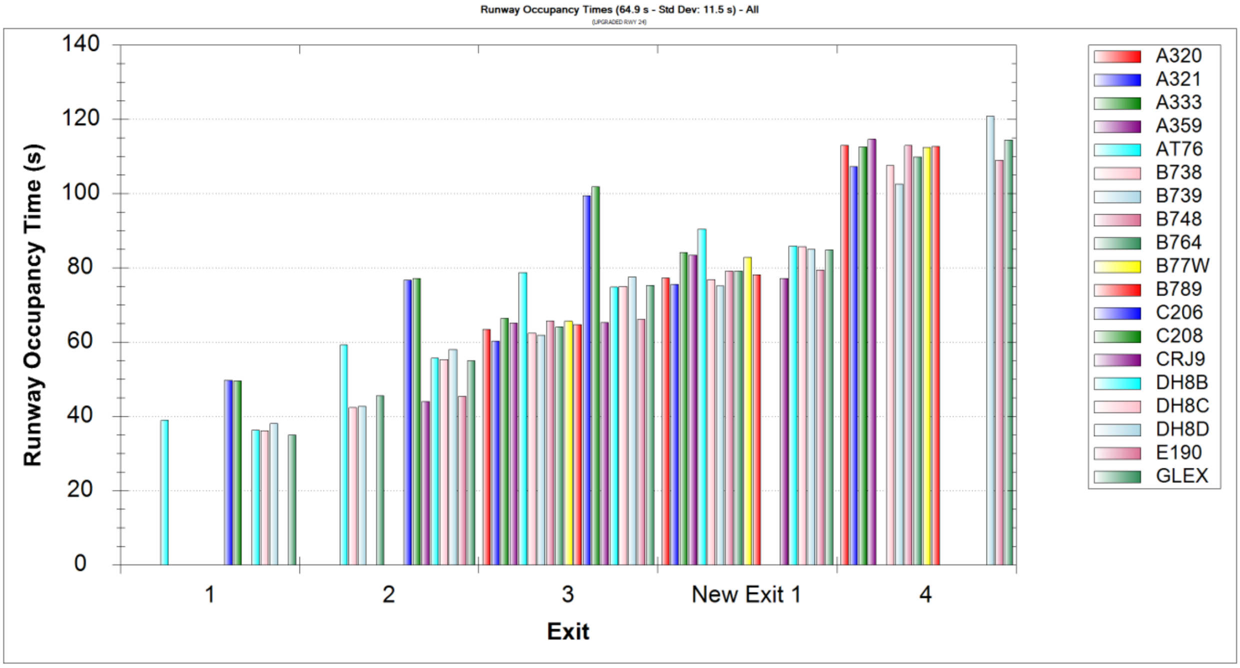


Figure 5.6: Upgraded Runway 24 ROT

Based on REDIM analysis, existing Runway 24 shall require upgrade with 01 New Rapid Exist taxiway.

Operational Benefits:

- **ROT Reduction**: From 71.6 seconds to 64.9 seconds
- **Mixed-Mode Capacity**: Increased from 27 to 30 ATM/hr

Considering the CAPEX required for constructing one new Rapid Exit Taxiway (RET), and noting that the resulting mixed-mode runway capacity increase is minor (e.g., comparable RET studies show only modest gains in mixed-mode throughput, such as increases from 28 to 30–32 ATMs/hr), while the primary capacity shortfall remains on the arrivals side, it is recommended that the construction of a new RET for Runway 24 be undertaken only if necessary to address operational safety mitigation requirements. Accordingly, this investment can be deferred to Phase 2, unless safety-driven justifications require earlier implementation.

5.1.1.3.3 Revised Capacity Outputs Post-Upgrade

Following the implementation of the proposed upgrades, the revised runway capacity figures are as follows:

- **Arrivals Only Capacity**: 25 aircraft movements per hour
- **Departures Only Capacity**: 40 aircraft movements per hour
- **Mixed Mode Operations**: 30 aircraft movements per hour

5.1.1.4 JKIA Airfield Runway Capacity – Dual Runway

Jomo Kenyatta International Airport (JKIA) is projected to experience significant growth in air traffic over the next two decades, driven by regional economic development, increased hub activity by Kenya Airways, and expanding international connectivity. While the Phase 1 runway upgrades—including two Rapid Exit Taxiways (RETs) at 2,000m and 2,450m, a runway end exit, and a partial parallel taxiway—are expected to support traffic growth through 2029, they will not be sufficient to meet peak hour demand beyond this period. This section presents a comprehensive technical analysis of the need for a second runway and evaluates multiple configuration options to determine the most suitable solution for JKIA's long-term operational resilience.

5.1.1.4.1 Capacity Limitations of Upgraded Runway

The upgraded runway system increases arrival capacity from 25 to 31 ATMs/hour and mixed-mode capacity from 30 to 36 ATMs/hour. These improvements are achieved by reducing average runway occupancy time from 66 seconds to 60.1 seconds through the addition of RETs and improved taxiway infrastructure.

However, traffic forecasts indicate that peak hour arrival demand will rise from 32 ATMs/hour in 2029 to 52 ATMs/hour by 2045, while departure demand will increase from 34 to 57 ATMs/hour. These figures exceed the upgraded runway's capacity, particularly during peak periods, making the construction of a second runway essential to maintain operational efficiency and avoid delays.

5.1.1.4.2 Traffic Forecast and Demand Alignment

The base scenario projects passenger growth from 8.6 million in 2024 to 22.3 million by 2045. The upside scenario, assuming enhanced hub activity and regional cooperation, forecasts up to 26 million passengers by 2045. Aircraft Traffic Movements (ATMs) are expected to grow at a compound annual growth rate (CAGR) of 4.1%, with peak hour ATMs reaching 109 movements (52 arrivals and 57 departures) by 2045.

The upgraded runway system can accommodate demand only until 2029. Beyond this point, the airport will face capacity constraints, particularly in arrival operations, necessitating the development of a second runway as part of Phase 2 (2030–2045).

5.1.1.5 DEVELOPMENT OF PRELIMINARY ALTERNATIVES

5.1.1.5.1 Methodology for Developing Preliminary Alternatives

A comprehensive traffic forecast has been developed for Jomo Kenyatta International Airport (JKIA), extending through the year 2045. This forecast serves as the cornerstone for the airport's Master Plan, which must be anchored in a clearly defined ultimate vision. Only once this vision is established can the design phase of the 2045 Master Plan proceed in a coherent and scalable manner. Accordingly, preliminary alternatives for the runway system have been formulated to support the airport's long-term operational goals.

Step 1: Development of Preliminary Runway System Alternatives

The initial phase of planning focused on identifying and evaluating potential runway system configurations. These alternatives were screened based on operational feasibility, spatial efficiency, and compliance with international standards, particularly ICAO Annex 14 and FAA Advisory Circulars. Key criteria included operability, convenience, and compatibility with projected traffic volumes. A subset of viable configurations was selected for detailed analysis, which incorporated capacity modeling and multi-criteria evaluation.

Step 2: Runway System Planning Parameters

The runway system is a foundational element of the airport's layout, influencing both aeronautical and non-aeronautical land use. Its configuration determines the spatial footprint of the airfield, the interaction between runways and taxiways, and integration with terminal and landside facilities. The study defined several critical parameters for JKIA's ultimate development phase:

- **Runway Orientation**: Based on wind data analysis and ICAO Annex 14 usability criteria, the preferred orientation ensures greater than 95% usability. Parallel runways aligned with the existing 06/24 axis are favored to maintain operational consistency and minimize crosswind impacts.

- **Runway Capacity**: Runway capacity assessments were conducted in accordance with FAA Advisory Circular 150/5060-5, Airport Capacity and Delay. The use of independent parallel runways with a minimum separation of 1,035 meters—as specified in ICAO Annex 14, Volume I, Chapter 3.5.1—allows for simultaneous arrivals and departures under all weather conditions, thereby maximizing throughput. However, to eliminate the need for specialized navigation equipment for monitoring aircraft during final approach, a minimum runway separation of 1,525 meters is recommended. This increased spacing not only removes the requirement for special NAVAIDs but also provides adequate room between runways to accommodate a terminal building, apron, and taxiway system designed to meet projected demand through 2045.

- **Runway Length**: New runway is proposed to be at least 4,500 meters long to accommodate Code E and F aircraft, in accordance with ICAO Annex 14 Table 3-1 and FAA AC 150/5325-4B (Runway Length Requirements for Airport Design).

- **Number of Runways**: The ultimate phase envisions a dual-runway system, with provisions for a third runway beyond 2045. This configuration supports projected peak-hour demand of approximately 60 arrivals and 65 departures per hour.

- **Phasing Strategy**: Development will occur in stages. Phase 1 (2025–2029) includes upgrades to the existing runway, such as Rapid Exit Taxiways (RETs) and partial parallel taxiways. Phase 2 (2030–2045) introduces a second independent runway. Long-term planning reserves land for a third runway to meet future demand.

- **Preferred Configuration**: A dual independent parallel runway layout with staggered thresholds is recommended. This configuration optimizes capacity, reduces taxi distances, and avoids interference with landside infrastructure. It adheres to ICAO and FAA separation standards, ensuring safe and efficient operations.

01 Runway system Alternatives

- Multiple Possible Runway configurations - Dependendt / Independendt / Parallel / Alligned Threshold / Staggered / Dependendt Arrival / Independendt Departure only
- Refined Multiple options of runway alternatives to preffered 02 alternatives
- Section of 01 Preffered runway system alternative after a multi criteria evaluation.

02 Zoning Alterntives

- Conducted high level dimensioning of core airport facilities to support strategic planning
- Explored 02 disting zoning layout alternatives to accmodate furture develppment needs
- Section of preffered zoning based on comprehensive multi criteri evaluation process.

03 Preffered Alternative

- Preferred alternative further developed in the next sections (year 2045 facility requirements, development of the Airport Layout Plan).

The runway system alternatives were rigorously evaluated using ICAO Annex 14 and FAA circulars to ensure compliance with global best practices. The selected configuration positions JKIA for transformation into a high-capacity, safe, and future-ready international hub, capable of meeting the demands of 2045 and beyond.

5.1.1.5.2 Runway Orientation Analysis

5.1.1.5.2.1 Introduction

Runway orientation is a foundational element in airport planning, directly influencing aircraft performance, safety, and operational efficiency. In accordance with the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs), particularly those outlined in Annex 14, runways should be aligned as closely as possible with the prevailing wind direction. This alignment allows aircraft to take off and land into the wind, minimizing the crosswind component and enhancing lateral stability during critical phases of flight.

ICAO recommends a minimum runway usability factor of 95%, meaning that the runway should be usable under prevailing wind conditions at least 95% of the time. This benchmark ensures that aircraft operations are not compromised by adverse wind conditions and that the runway orientation supports safe and efficient air traffic movement.

5.1.1.5.2.2 Methodology & Data Collection

To evaluate runway usability and determine optimal orientation for Jomo Kenyatta International Airport (JKIA), a comprehensive wind analysis was conducted. Meteorological data was sourced from the JKIA weather station, covering a continuous ten-year period from January 2015 to December 2024. This dataset includes daily records of wind speed and direction, providing a robust foundation for assessing wind patterns and their implications for runway design.

The analysis was guided by ICAO Doc 9157, Part 1, which defines allowable crosswind components for different aircraft categories:

- **20 knots** for larger aircraft (e.g., Code D/E)
- **13 knots** for smaller aircraft (e.g., Code A/B)

These thresholds are critical and derived from ICAO guidelines (Doc 9157, Part 1), as illustrated in Figure 5.7 below. in determining runway usability, as they represent the maximum crosswind conditions under which aircraft can safely operate.

Wind

2.1.6 The number and orientation of runways at an aerodrome should be such that the usability factor of the aerodrome is not less than 95 per cent for the aeroplane that the aerodrome is intended to serve.

2.1.7 In the application of the 95 per cent usability factor it should be assumed that landing or take-off of aeroplanes is, in normal circumstances, precluded when the cross-wind component exceeds:

a) 37 km/h (20 kt) in the case of aeroplanes whose reference field length is 1 500 m or over, except that when poor runway braking action owing to an insufficient longitudinal coefficient of friction is experienced with some frequency, a cross-wind component not exceeding 24 km/h (13 kt) should be assumed;

b) 24 km/h (13 kt) in the case of aeroplanes whose reference field length is 1 200 m or up to but not including 1 500 m; and

c) 19 km/h (10 kt) in the case of aeroplanes whose reference field length is less than 1 200 m.

Figure 5.7: Maximum allowable cross-winds; Source: ICAO Doc 9157, Part 1

For the purpose of wind analysis, comprehensive meteorological data was obtained from the Jomo Kenyatta International Airport (JKIA) weather station, covering a continuous ten-year period from January 2015 to December 2024. This dataset includes daily records of wind speed and direction throughout the year.

5.1.1.5.2.3 Wind Data Processing and Visualization

The collected wind data was processed to calculate the percentage of wind occurrences across various directions and speed ranges. Wind speeds were categorized into four bands:

- 0–3 knots
- 3–13 knots
- 13–20 knots
- 20–40 knots

Table 3.1 in the report presents these percentages, revealing that the vast majority of wind events fall within the 3–13 knot range. Notably, wind speeds exceeding 20 knots were virtually non-existent, indicating a stable and moderate wind environment at JKIA.

To visualize the wind patterns, wind rose diagrams were constructed. These diagrams graphically represent the frequency and direction of wind occurrences and are essential tools in airport planning. They help identify dominant wind directions and support decisions regarding runway alignment.

Table 5.3: Percentages of wind per direction and speed range; Source: Consultant Analysis.

	Percentages of wind			
	[0-3 Knot]	[3-13 Knot]	[13-20 Knot]	[20-40 Knot]
N	0	0.06	0	0

	Percentages of wind				
	[0-3 Knot]	[3-13 Knot]	[13-20 Knot]	[20-40 Knot]	
NNE	0.03	0.14	0	0	
NE	0.11	11.91	0.03	0	
ENE	0.06	21.15	0.03	0	
E	0.11	15.57	0	0	
ESE	0.11	13.56	0	0	
SE	0.2	13.78	0	0	
SSE	0.06	10.41	0	0	
S	0.11	8.54	0	0	
SSW	0.03	3.04	0	0	
SW	0	0.64	0	0	
WSW	0.03	0.14	0	0	
W	0.06	0.03	0	0	
WNW	0	0	0	0	
NW	0	0	0	0	
NNW	0	0	0	0	
VRB	0.06	0	0	0	
(blank)	0.03	0	0	0	
	0.98	98.97	0.06	0	100

5.1.1.5.2.4 Usability Assessment for Large and Small Aircraft

Two separate wind rose diagrams were developed to assess runway usability under the 20-knot and 13-knot crosswind thresholds.

- **20-knot threshold (large aircraft):** The wind rose analysis revealed a **100% usability factor**, indicating that the runway is usable under all recorded wind conditions. The maximum observed wind speed during the analysis period was 14 knots, well below the 20-knot threshold.

- **13-knot threshold (small aircraft):** A second wind rose confirmed a **100% usability factor** under this more stringent limit. This finding demonstrates that crosswind conditions at JKIA do not restrict operations for either large or small aircraft.

These results validate the current runway orientation and confirm its compliance with ICAO's recommended usability standards.

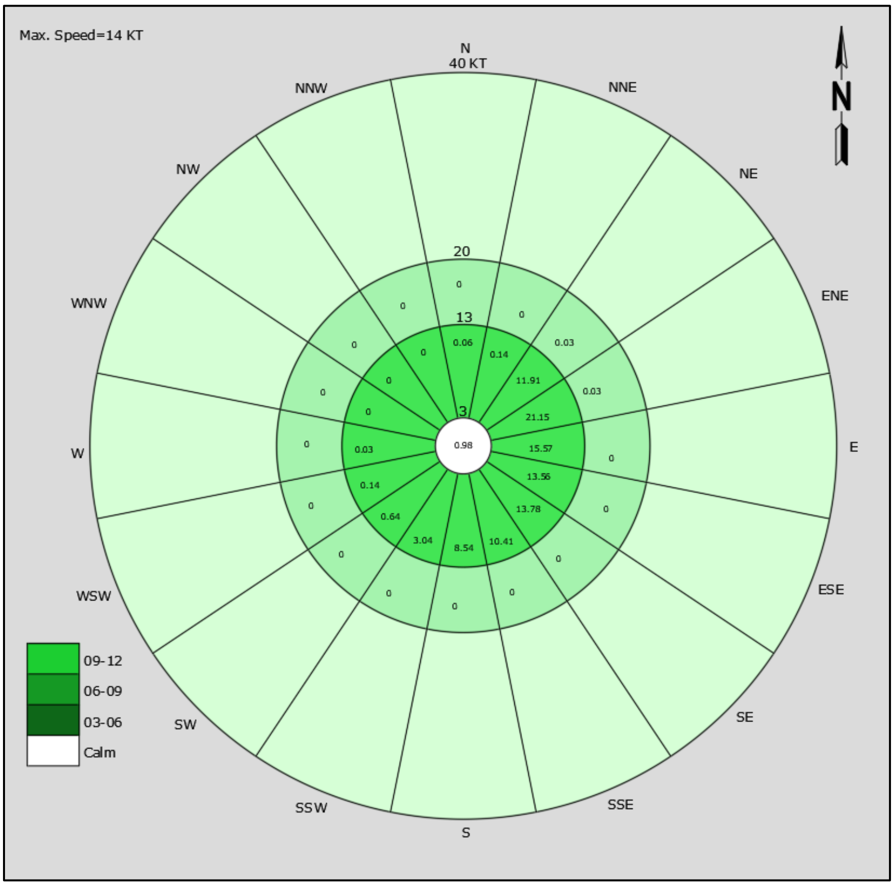


Figure 5.8: Wind Rose Diagram – 20 Knots; Source: Consultant Analysis.

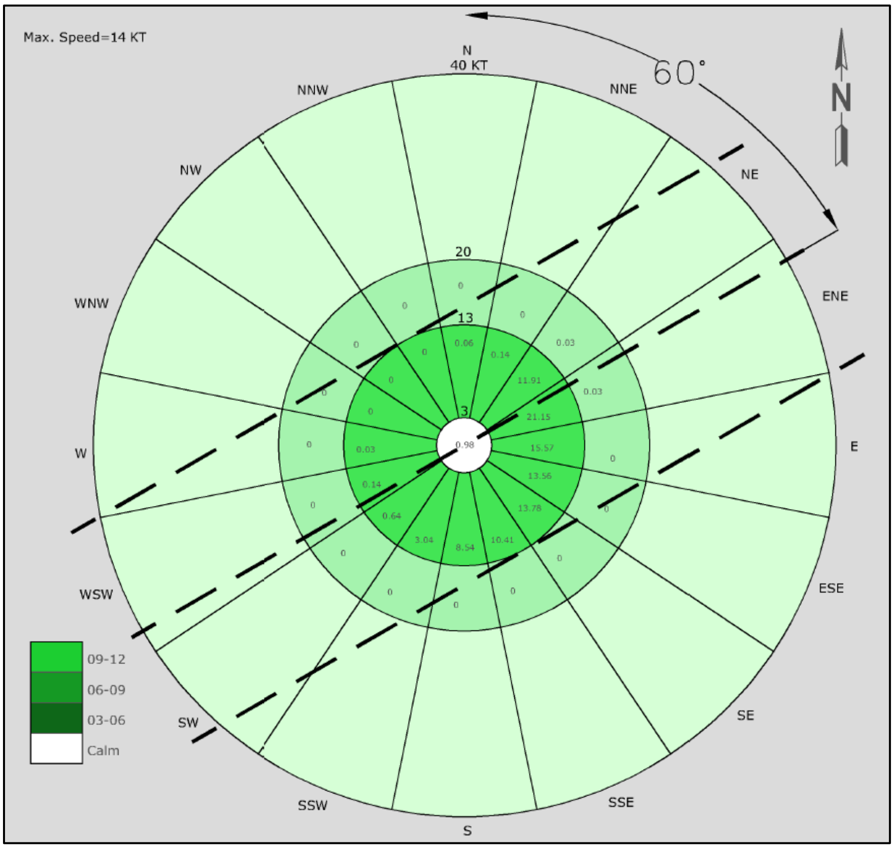


Figure 5.9: Wind Rose Diagram – 13 Knots; Source: Consultant Analysis.

5.1.1.5.2.5 Prevailing Wind Direction and Optimal Alignment

Further analysis of wind direction data was conducted to identify the dominant wind patterns at JKIA. The results indicate that winds most frequently originate from the east-northeast (ENE) direction. This prevailing wind direction corresponds to an optimal runway alignment of approximately 67.5 degrees, typically designated as Runway 07–25.

The existing runway at JKIA is oriented at 06–24, which closely aligns with the optimal direction identified in the wind analysis. This near-perfect alignment ensures compliance with ICAO standards and supports operational efficiency.

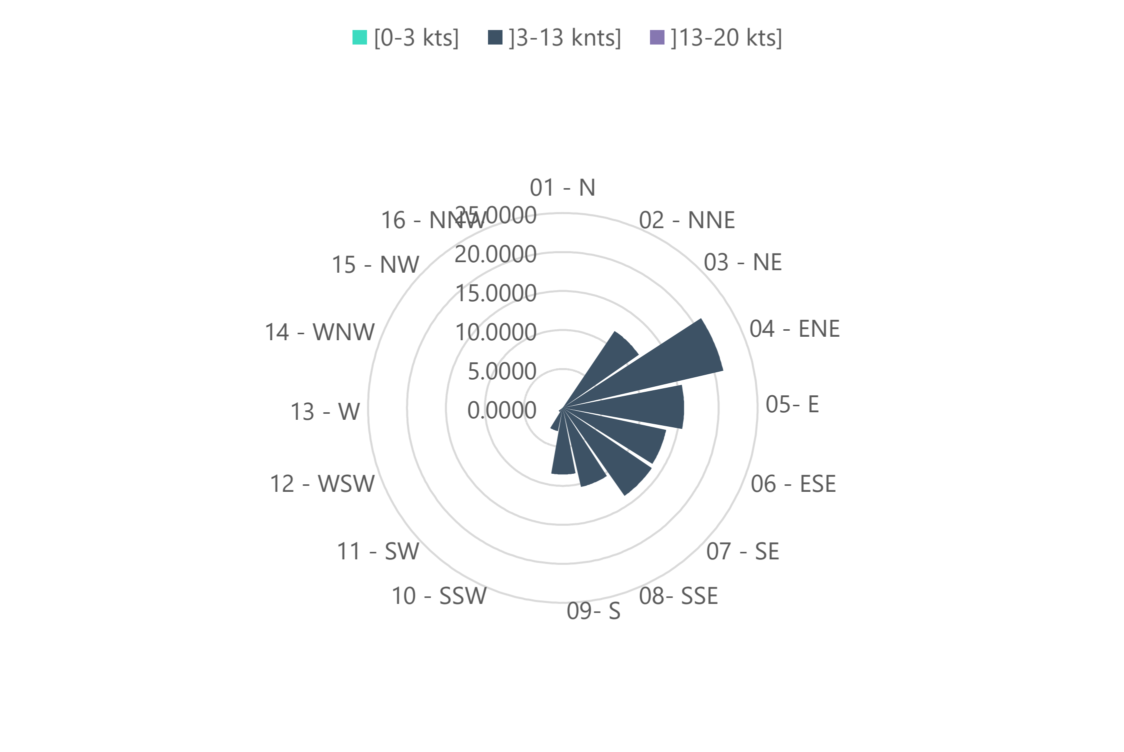


Figure 5.10: Prevailing Wind Direction; Source: Consultant Analysis.

5.1.1.5.2.6 FAA Circulars and Complementary Standards

in addition to ICAO guidelines, the analysis incorporated relevant FAA Advisory Circulars, particularly:

- **FAA AC 150/5300-13A**: Airport Design
- **FAA AC 150/5060-5**: Airport Capacity and Delay

These circulars provide methodologies for evaluating runway capacity, separation standards, and operational impacts. The FAA's approach to runway usability and capacity modeling complements ICAO's recommendations and reinforces the validity of the findings.

5.1.1.5.2.7 Proposed Runway Development and Strategic Alignment

As part of JKIA's long-term master plan, a new parallel runway is proposed. This runway will be aligned parallel to the existing 06–24 runway, facilitating dual independent parallel operations. Such a configuration is essential for maximizing airport capacity and operational flexibility, especially as traffic volumes increase toward the 2045 horizon.

The decision to maintain a parallel alignment is supported by the wind analysis, which confirms that the existing orientation is both compliant with ICAO standards and operationally efficient. By aligning the new runway with the prevailing ENE wind direction, JKIA ensures that aircraft can continue to operate safely and efficiently under typical wind conditions.

5.1.1.5.2.8 Strategic Implications and Long-Term Planning

The stability of wind direction and speed at JKIA minimizes the risk of crosswind-related disruptions. This makes the parallel runway configuration a sound investment in the airport's long-term operational strategy. Moreover, the 100%

usability factor under both crosswind thresholds reinforces the airport's capability to handle a diverse fleet mix without compromising safety or efficiency.

The proposed runway development aligns with ICAO Annex 14 Volume I, which outlines design standards for runway orientation, separation, and usability. It also adheres to FAA recommendations for runway layout and capacity optimization.

5.1.1.5.2.9 Summary

The wind analysis conducted for JKIA demonstrates a strong alignment between the existing runway orientation and the prevailing wind conditions. The proposed parallel runway will maintain this alignment, ensuring continued compliance with ICAO SARPs and supporting the airport's growth and modernization efforts.

By leveraging comprehensive meteorological data and adhering to international standards, JKIA is well-positioned to enhance its runway infrastructure, accommodate increasing air traffic demand, and uphold the highest levels of safety and operational performance.

The findings from this analysis provide a robust foundation for strategic runway planning and confirm that JKIA's runway system is optimally aligned for current and future operations. The integration of ICAO and FAA standards ensures that the airport's development is guided by global best practices, positioning JKIA as a leading aviation hub in the region.

5.1.1.6 Second Runway Optioneering

This section presents a detailed theoretical evaluation of three vertical separation configurations for the second runway. Each option is assessed based on its operational capacity, scalability, infrastructure impact, and alignment with international best practices in airfield planning.

5.1.1.6.1 Theoretical Framework for Runway Separation

Runway separation is a critical determinant of airfield performance. According to ICAO and FAA guidelines, the minimum separation between parallel runways influences whether operations can be conducted independently or must be staggered or dependent. The separation also affects the need for Precision Runway Monitor (PRM) systems, Obstacle Limitation Surfaces (OLS), and terminal building placement.

Three configurations were evaluated for JKIA:

- **Option A**: Dual Runway with 760m separation
- **Option B**: Dual Runway with 915m separation
- **Option C**: Dual Runway with 1,525m separation

Each option reflects a different operational philosophy and infrastructure requirement.

5.1.1.6.2 Proposed Taxiway System for the New Runway (Full Code F Compliance)

To support JKIA's long-term air traffic growth and optimize runway performance, a dedicated RET optioneering study was conducted for the new proposed runway. This analysis aimed to determine the optimal number and placement of Rapid Exit Taxiways (RETs) that would produce the optimum runway occupancy time (ROT), enhance throughput, and ensure compliance with ICAO and FAA standards.

The second runway at JKIA is planned with full ICAO Code F compliance, enabling independent arrival and departure operations. The design supports future scalability and aligns with international best practices.

5.1.1.6.2.1 Methodology and Software Application

The RET planning was carried out using the REDIM (Runway Exit Design Interactive Model) software, developed by Virginia Tech University in collaboration with the U.S. Federal Aviation Administration (FAA). REDIM integrates aircraft landing dynamics with a polynomial-time optimization algorithm to simulate and evaluate multiple RET configurations.

5.1.1.6.2.2 RET Optioneering

For JKIA's second runway, REDIM version 4.0.2 was used to assess RET performance under various fleet mix scenarios. To produce the best RET's for new runway, 03 options were analyzed which are as follows:

- Scenario 01: Existing Fleet mix of 2025 shall be continued for the ultimate phase considering the JKIA vision of increasing the domestic traffic and promoting local tourism, domestic airlines will continue growing using Code C aircraft for Domestic region and few Code A / B aircraft for short range operations.
- Scenario 2: Code A / Code B aircraft will not be operating during the peak hour, which will increase the runway capacity by reducing the ROT and resulting in optimum usage if new runway system with 03 RET.
- Scenario 4: Same as scenario 3 but with 4 RET to compare the cost benefit analysis compared to ROT improvement and CAPEX

Table 5.4: JKIA Second Runway RET Optioneering

	Option 01: 03 RET (With Code A/B aircrafts)	Option 02: 03 RET (Without Code A/B Aircrafts)	Option 03: 04 RET (Without Code A/B Aircrafts)
Code A / B	3%	0%	0%
Code C – Turbo Prop	27%	30%	30%
Code C – Turbo Jet	49%	49%	49%
Code D / E	21%	21%	21%
RET 01	1,700m	1,775m	1,600m
RET 02	2,300m	2,325m	2,100m
RET 03	2,825m	2,850m	2,450m
RET 04	4,500m	4,500	2,900m
RET 05	-	-	4,500m
Average Runway Occupancy Time	64.6 sec	63.8 sec	61 sec

5.1.1.6.2.3 Recommendations

Option 2 was selected as the preferred configuration for the new runway. It includes three RETs optimized for Code C to E aircraft, which dominate JKIA's fleet mix. The exclusion of Code A/B aircraft from peak-hour operations allowed the design to focus on larger aircraft with higher approach speeds, resulting in more efficient RET placement.

Key Justifications:

- **Cost Efficiency**: Option 3 offered only a 2.8-second improvement in ROT compared to Option 2, which did not justify the additional capital expenditure for a fourth RET.

- **Operational Optimization**: RETs in Option 2 are positioned to serve the most common aircraft types at JKIA, ensuring high-speed exits and reduced runway occupancy.

- **Strategic Planning**: The design supports future scalability and aligns with JKIA's dual independent runway strategy, which targets up to 61 arrivals and 80 departures per hour.

5.1.1.6.2.3.1 Assumptions – Option 02

The fleet mix considered for Evaluating Runway RET locations under option 02 was based on shifting Code A / code B aircraft types to non-peak hour as indicated in Table 5.5:

Table 5.5: JKIA Existing fleet Mix

Operating Fleet Mix	% Distribution
Code A – B	0%
Code C - TP	30%
Code C - TJ	49%
Code D – E	21%

Other assumptions have been considered:

- Runway length: 4,500 m
- Elevation: 1,625 meters
- Temperature: 21°C, which corresponds to the annual average temperature
- Wet conditions: 10%

5.1.1.6.2.3.2 Results

REDIM recommended adding 03 RET and 01 Runway end Exit will reduce the ROT to 63.6 sec.

Runway Exits Type	Distance from Threshold
RET 01	1,775m
RET 02	2,325m
RET 03	2,850m
Runway End Exit (90 Degree)	4,500m

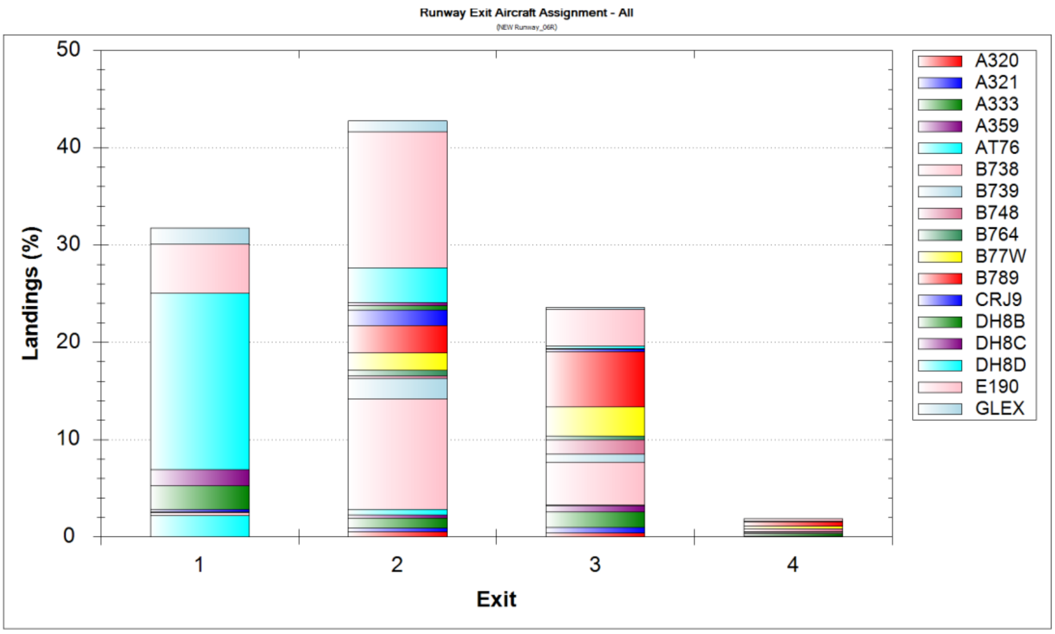


Figure 5.11: RET Usage per aircraft type – New Runway

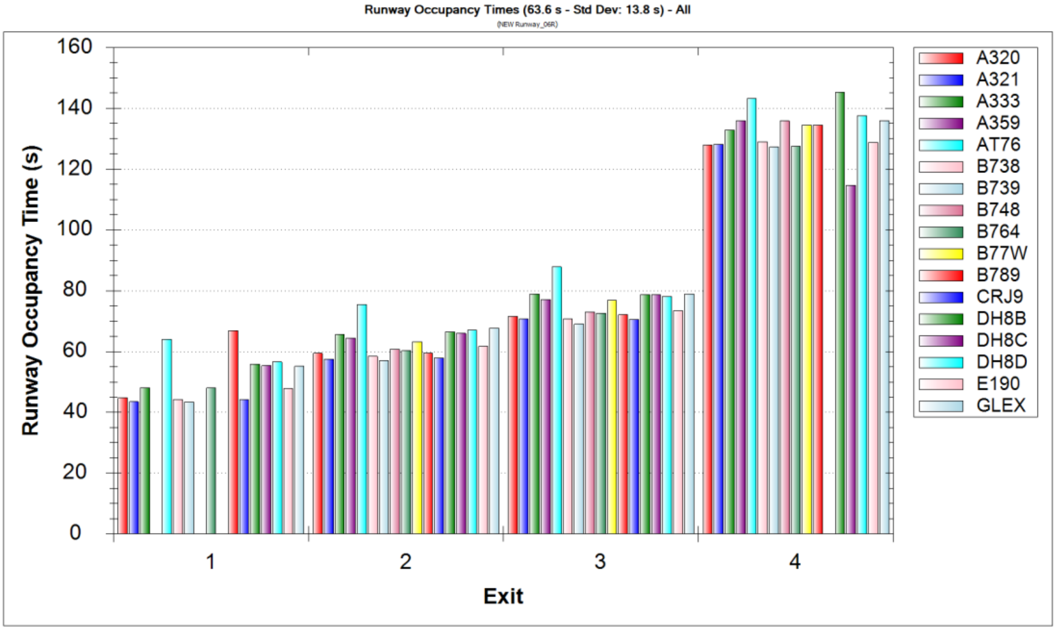


Figure 5.12: New Runway ROT

5.1.1.6.2.4 Additional Recommendations

- **Runway End Exit**: A full-length exit at 4,500m is included to accommodate long-landing aircraft and further reduce ROT.
- **Code A/B Aircraft Management**: These aircraft are recommended to operate during non-peak hours to avoid congestion and maximize runway efficiency.
- **Dual Parallel Taxiways**: To complement the RET system, full-length parallel taxiways are proposed on both sides of the new runway, ensuring seamless connectivity to apron and terminal areas.

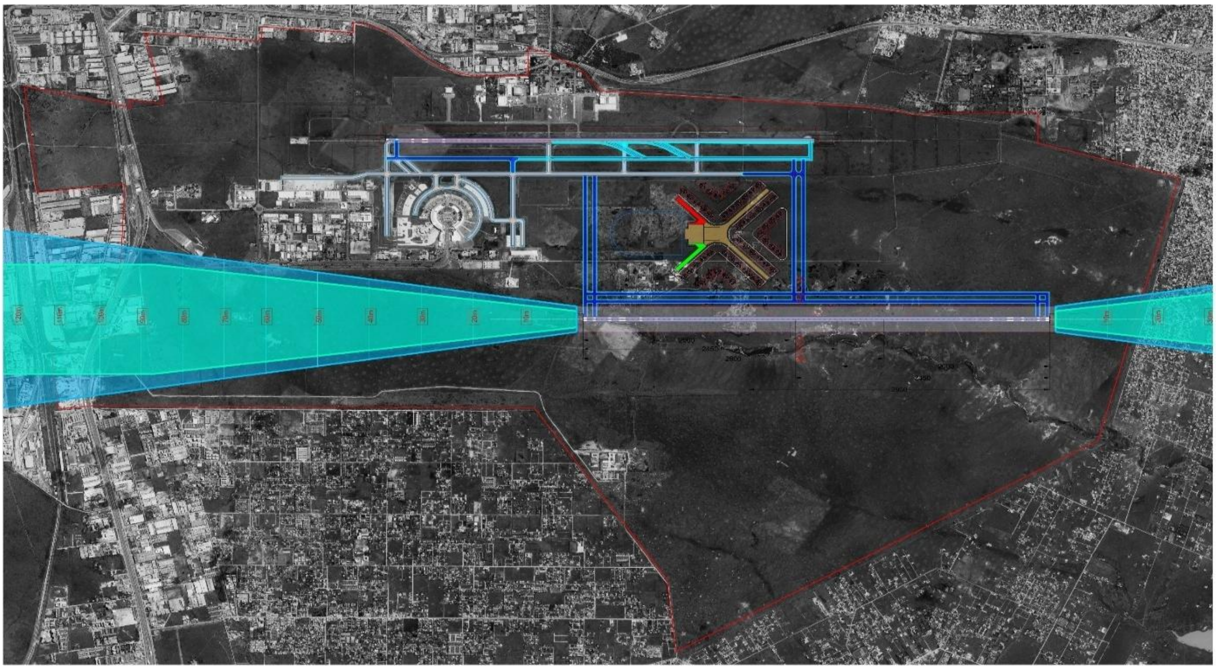


Figure 5.13: JKIA - Dual Runway Taxiway System

5.1.1.6.3 Dual Runway Vertical Separation Optioneering

5.1.1.6.3.1 Option A – Dual Runway with 760m Separation (Segregated Parallel Operations)

This configuration involves two parallel runways separated by 760 meters. One runway is dedicated to arrivals, while the other handles departures. This setup enables segregated parallel operations, which are suitable for managing overlapping peak traffic periods.

Operational Capacity

- **Arrivals**: 31 ATMs/hour
- **Departures**: 40 ATMs/hour
- **Mixed Mode**: 34 ATMs/hour

Advantages

- Simplified traffic management during peak periods
- Reduced runway occupancy conflicts
- Lower initial capital investment compared to wider separation options

Limitations

- Arrival capacity becomes insufficient beyond 2029
- Requires PRM system to ensure safe parallel operations
- Limited flexibility for independent arrival streams
- Not scalable for long-term growth
- Cannot support future third runway alignment due to spatial constraints

Conclusion

While operationally feasible in the short term, this configuration lacks the scalability and flexibility required for JKIA's long-term growth. It is best suited as a transitional solution but not recommended for Phase 2 implementation.

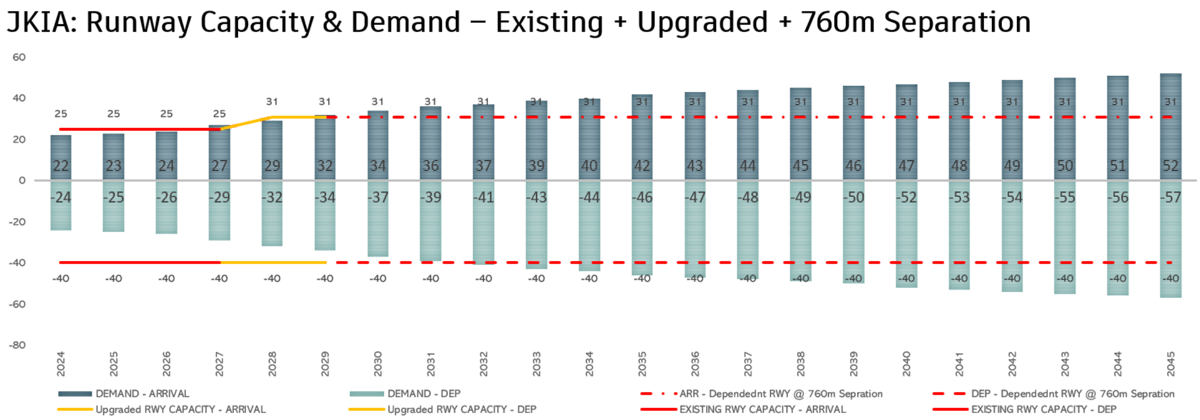


Figure 5.14: JKIA Dual Runway Capacity - 760m Separation

5.1.1.6.3.2 Option B – Dual Runway with 915m Separation (Dependent Arrivals and Independent Departures)

This option introduces staggered parallel approaches for arrivals and independent departure operations. The 915-meter separation allows for dependent arrival streams while enabling full independence for departures.

Operational Capacity

- **Arrivals**: 45 ATMs/hour
- **Departures**: 80 ATMs/hour
- **Mixed Mode**: 70 ATMs/hour

Advantages

- Meets traffic demand until 2037
- Supports high departure throughput
- Reduces delays during peak departure periods

Limitations

- Requires relocation of the Passenger Terminal Building (PTB) southward
- Impacts Airport City layout and airside infrastructure
- Imposes height restrictions on existing stands under the approach funnel
- Adds complexity and cost to landside development
- Requires PRM system and additional air traffic control coordination

Conclusion

Option B offers a moderate improvement in capacity and operational flexibility. However, its infrastructure implications—particularly the relocation of the PTB and impact on Airport City—make it less desirable. It may be considered if land constraints prevent wider separation, but it is not optimal for long-term scalability.

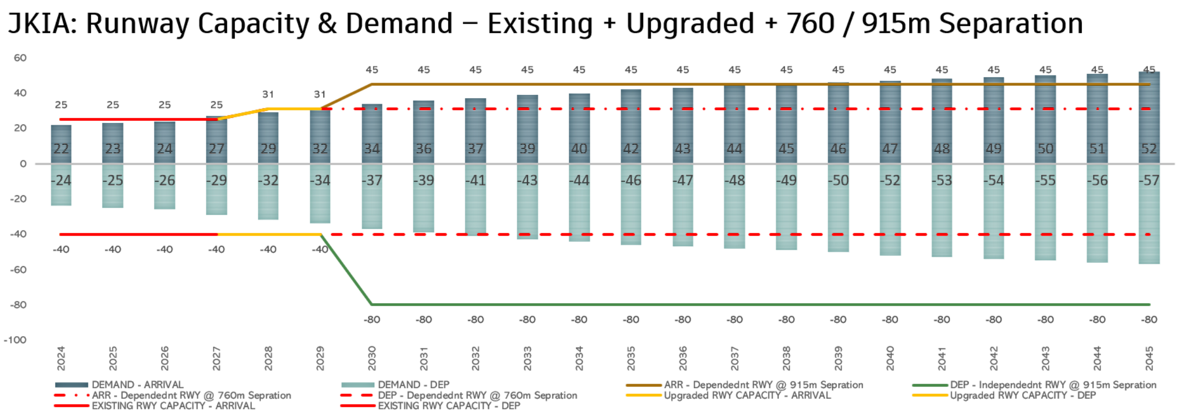


Figure 5.15: JKIA Dual Runway Capacity - 915m Separation

5.1.1.6.3.3 Option C – Dual Runway with 1,525m Separation (Independent Arrivals and Departures)

This configuration enables fully independent parallel operations for both arrivals and departures. The 1,525-meter separation exceeds ICAO's minimum requirement for independent operations without the need for PRM systems.

Table 5.7 represents the current runway capacity and capacity projection post existing runway RET upgrade and Dual Runway system capacity. Additionally, figure 3.6 indicates the corresponding runway capacity required to accommodate the future projected demand.

Operational Capacity

- **Arrivals**: 61 ATMs/hour
- **Departures**: 80 ATMs/hour
- **Mixed Mode**: 70 ATMs/hour

Advantages

- Meets traffic demand beyond 2045
- No PRM system required
- No impact on PTB or Airport City layout
- Supports future third runway development
- Highest operational flexibility and scalability
- Simplifies air traffic control and sequencing

- Compatible with ICAO and FAA standards for independent parallel operations

Conclusion

Option C is the most robust and future-proof configuration. It supports JKIA's strategic vision and ensures long-term operational resilience. It is recommended as the preferred solution for Phase 2 runway development.

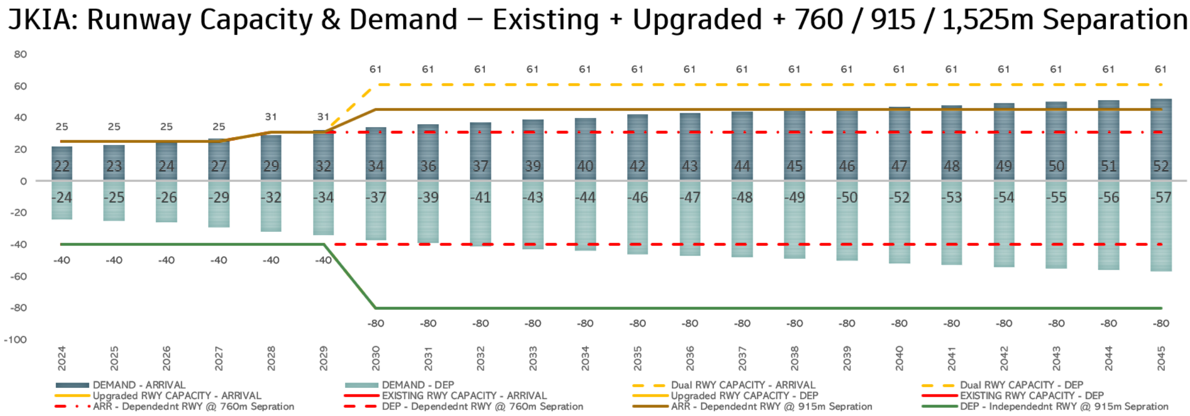


Figure 5.16: JKIA Dual Runway Capacity - 915m Separation

5.1.1.6.3.4 Comparative Summary of Configuration Options

The evaluation of three second-runway configurations for JKIA reveals distinct operational and strategic implications. Each option varies in terms of runway separation, capacity, infrastructure impact, and long-term scalability.

- **Option A (760m separation)** enables segregated parallel operations with one runway dedicated to arrivals and the other to departures. While it simplifies traffic management, its limited arrival capacity and reliance on PRM systems make it unsuitable beyond 2029.

- **Option B (915m separation)** supports dependent arrivals and independent departures, offering improved throughput and meeting demand until 2037. However, it requires significant infrastructure changes, including relocation of the Passenger Terminal Building and adjustments to the Airport City layout, which introduce complexity and cost.

- **Option C (1,525m separation)** allows fully independent arrival and departure operations. It provides the highest capacity—61 arrivals and 80 departures per hour—and meets projected demand beyond 2045. This configuration avoids PRM requirements and infrastructure conflicts, making it the most scalable and future-proof solution.

In conclusion, **Option C is recommended** for JKIA's Phase 2 expansion due to its superior capacity, operational flexibility, and alignment with long-term development plans.

Table 5.6 Summary for Dual Runway Capacity Optioneering

	Single Runway With RET	Dual Dependent Runway	Dual Independent Runway
100% Arrival	31	45*	62
100% Departure	40	80	80
Mixed Mode	34	70*	70

	Single Runway With RET	Dual Dependent Runway	Dual Independent Runway
Runway Separation	-	915m	1525m*
PRM Requirement		Yes	No
OLS Impact		Yes	No
New Terminal Location Impact		Yes	No
Relocation of ATC in Phase 1	-	Yes	No

5.1.1.6.4 Summary of Runway Capacity Scenarios

The runway capacity analysis for JKIA presents three distinct operational configurations—existing, upgraded, and future—each reflecting varying infrastructure enhancements and traffic handling capabilities.

5.1.1.6.4.1 Existing Runway (Without RETs / Partial Parallel Taxiway)

Under current conditions, the single runway supports:

- 25 arrivals/hour and 40 departures/hour in single-mode operations.
- 30 movements/hour in mixed-mode (15 arrivals, 15 departures).
- Arrival-priority mode allows 28 movements/hour (21 arrivals, 7 departures), while departure-priority mode increases throughput to 35 movements/hour (9 arrivals, 26 departures).

5.1.1.6.4.2 Upgraded Runway (With RETs / Full Parallel Taxiway)

With the addition of two RETs and a full parallel taxiway, capacity improves:

- Arrivals increase to 31/hour, while departures remain at 40/hour.
- Mixed-mode operations rise to 34 movements/hour (17 arrivals, 17 departures).
- Arrival-priority mode supports 32 movements/hour (24 arrivals, 8 departures), and departure-priority mode reaches 37 movements/hour (9 arrivals, 28 departures).

5.1.1.6.4.3 Future Runway Capacity (Dual Runway System)

In the long-term scenario, with a second runway and full infrastructure upgrades:

- Arrival capacity doubles to 62/hour, and departure capacity reaches 80/hour.
- Mixed-mode operations peak at 70 movements/hour (34 arrivals, 36 departures).
- Arrival-priority mode supports 66 movements/hour (50 arrivals, 16 departures), while departure-priority mode allows 74 movements/hour (18 arrivals, 56 departures).

These results demonstrate that while short-term upgrades offer moderate improvements, only a dual-runway system can meet JKIA's projected traffic demand beyond 2030.

Table 5.7: Runway Usage and Capacity

Existing Runway Capacity		
Single runway (Without RET / Partial TXWY)		
100% Arrivals = 25	25	
100% Departure = 40		40
Mixed Mode (ARR 50% / DEP 55%) = 30 (15/15)	15	15

Existing Runway Capacity		
Single runway (Without RET / Partial TXWY)		
Arr Priority (ARR 75% / DEP 25%) = 28 (21/07)	21	07
Dep Priority (ARR 25% / DEP 75%) = 35 (09/26)	09	26

Existing Runway Capacity		
Single runway (With RET / Full Parallel TXWY)		
100% Arrivals = 31	31	
100% Departure = 40		40
Mixed Mode (ARR 50% / DEP 50%) = 34 (17/17)	17	17
Arr Priority (ARR 75% / DEP 25%) = 33 (24/08)	25	08
Dep Priority (ARR 25% / DEP 75%) = 37 (09/28)	09	28

Future Runway Capacity		
Dual runway (With RET / Full Parallel TXWY)		
100% Arrivals = 61	31 30	
100% Departures = 80		40 40
Mixed Mode (ARR 50% / DEP 50%) = 68 (34/34)	17 17	17 17
Arrival Priority (ARR 75% / DEP 25%) = 66 (50/16)	25 25	08 08
Dep Priority (ARR 25% / DEP 75%) = 74 (18/56)	09 09	28 28

Source: Consultants analysis.

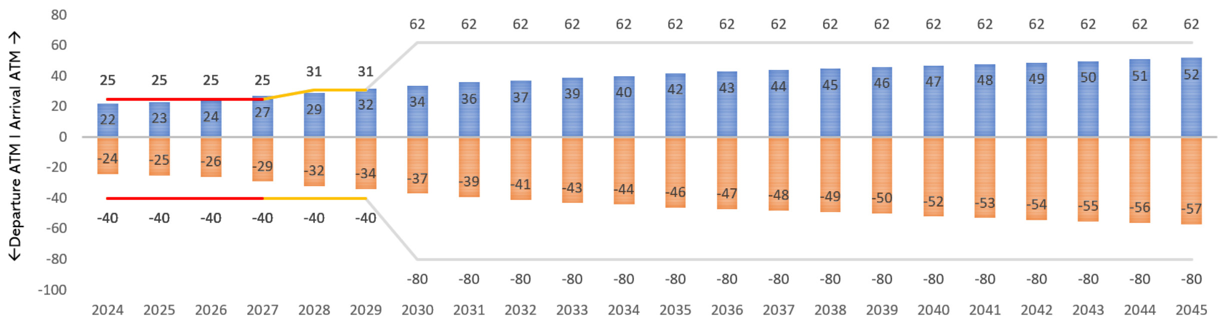


Figure 5.17: JKIA Dual Runway Capacity (Independent Arrival & Departure) vs Demand

Source: Consultants analysis.

5.1.1.6.5 Dual Runway Horizontal Separation Optioneering

5.1.1.6.5.1 Introduction

The layout optioneering exercise for Jomo Kenyatta International Airport (JKIA) is a critical component of the airfield master planning process. As JKIA anticipates significant growth in air traffic movements (ATMs), the development of a second runway becomes essential to meet future capacity demands. This report evaluates two horizontal alignment configurations for the second runway:

- **Option 01: Aligned Threshold** and
- **Option 02: Staggered Threshold**

This Horizontal planning of Runway threshold is done with a focus on operational efficiency, infrastructure integration, environmental impact, and long-term scalability.

The analysis is grounded in ICAO and FAA design standards and considers a minimum horizontal separation of 1,525 meters between runways to enable safe and efficient parallel operations. Each option is assessed against key parameters including taxi times, landside connectivity, Airport City development impact, third runway feasibility, and environmental constraints.

5.1.1.6.5.2 Horizontal Separation Analysis

5.1.1.6.5.2.1 Option 01 – Aligned Threshold

Option 01 proposes a dual-runway configuration with aligned thresholds and a horizontal separation of 2,000 meters. This layout is operationally feasible and aligns with international standards for independent parallel runway operations. However, it introduces several challenges that could affect airport efficiency and future development.

Advantages:

- **Environmental Benefits:** The second runway avoids height and noise limitations on eastern land parcels, reducing environmental constraints and enabling more flexible aircraft operations.

- **Compliance with ICAO Annex 14:** The aligned threshold configuration supports independent parallel operations, which are beneficial for peak-hour traffic management.

Challenges:

1. **Extended Taxi Times:**
    - Aircraft departing from the farthest stands at Terminal 1 and Terminal 2 would face taxi distances of approximately 6 kilometers.
    - This increases fuel burn, turnaround time, and operational costs.
2. **Impact on Landside Connectivity:**
    - The proposed alignment intersects with planned rail and Bus Rapid Transit (BRT) systems at grade level.
    - This could necessitate costly grade separations or rerouting, affecting project timelines and budgets.
3. **Airport City Development Constraints:**
    - Zone 2A, earmarked for Airport City development, lies directly in the path of the proposed runway alignment.
    - This could compromise the vision for a mixed-use commercial hub adjacent to the airport.
4. **Future Expansion Limitations:**
    - A third runway would need to be staggered due to land restrictions, complicated airfield geometry and operational planning.
    - Staggering introduces additional taxiway complexity and may reduce operational efficiency.
5. **Additional Land Requirements:**
    - Approach lighting systems for the third runway would require land acquisition beyond current airport boundaries.
    - This could lead to delays due to regulatory approvals and community engagement.

6. **Height and Noise Impacts:**

    - Although the second runway avoids eastern constraints, the third runway would reintroduce height and noise limitations on adjacent land parcels.

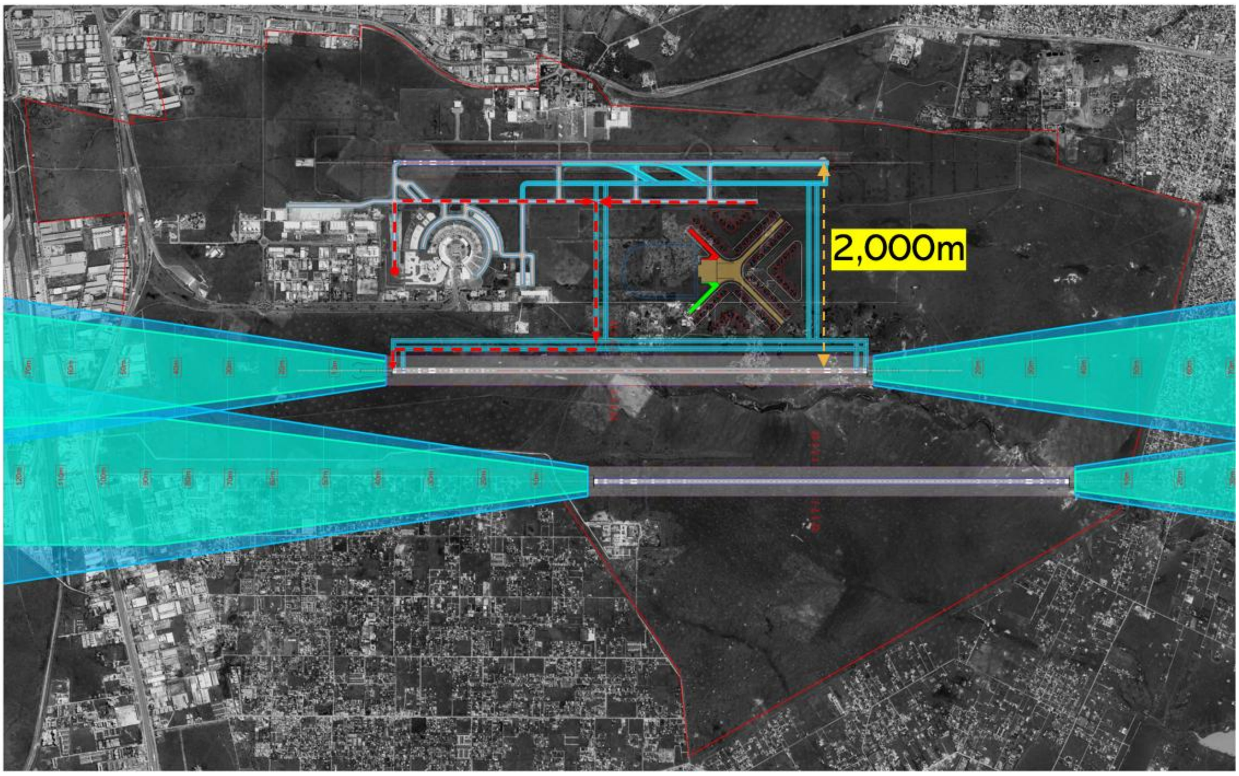


Figure 5.18: Runway Horizontal Placement Optioneering: Option 01 - Aligned Threshold & Third Runway Space Reservation

5.1.1.6.5.2.2 Option 02 – Staggered Threshold

Option 02 proposes a staggered threshold configuration for the second runway. This layout offers several operational and planning advantages over the aligned threshold option, particularly in terms of taxi efficiency and integration with landside infrastructure.

Advantages:

1. **Reduced Taxi Times:**

    - Aircraft departing from the farthest stands at Terminal 1 and Terminal 2 would face taxi distances of approximately 4.1 km and 3.1 km, respectively.

    - This results in lower fuel consumption and faster turnaround times.

2. **Uninterrupted Landside Connectivity:**

    - The staggered alignment avoids interference with planned rail and BRT systems.

    - This preserves multimodal connectivity and supports sustainable transport integration.

3. **Preservation of Airport City Development:**

    - Zone 2A remains unaffected, allowing full realization of the Airport City vision.

    - This supports economic development and enhances the airport's role as a regional hub.

4. **Future Expansion Flexibility:**
    - A third runway can be aligned with the second runway threshold, simplifying airfield geometry and operational planning.
    - This enables phased development without major disruptions.

Challenges:

1. **Height and Noise Constraints:**
    - Both the second and third runways would introduce limitations on eastern land parcels.
    - Mitigation measures such as noise barriers and zoning regulations may be required.
2. **Minimum Separation Requirement:**
    - A 2,000-meter separation is still necessary, which may pose challenges in land acquisition and community engagement.
3. **Additional Land Needs:**
    - Approach lighting systems for the third runway would require land beyond current airport boundaries.

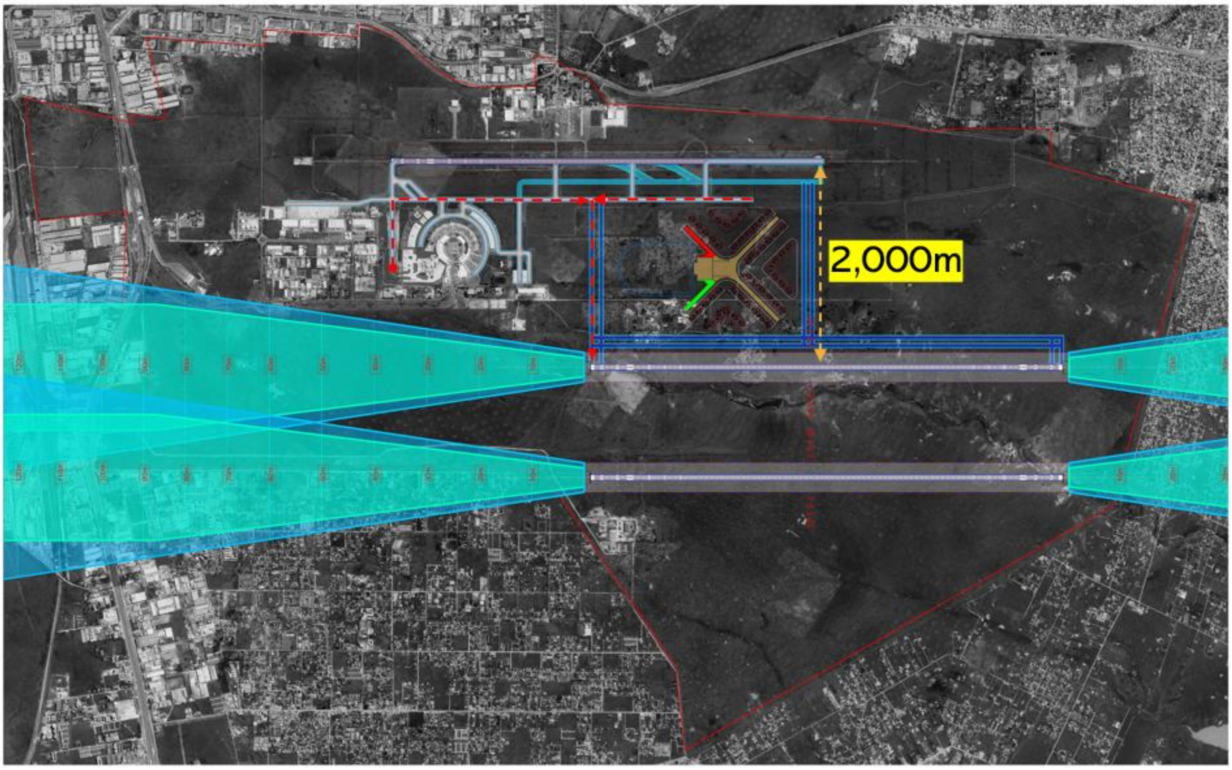


Figure 5.19: Runway Horizontal Placement Optioneering: Option 02 - Staggered Threshold & Third Runway Space Reservation

5.1.1.6.5.2.3 Comparative Analysis

A structured scoring methodology was applied to evaluate both options across multiple parameters:

	Option 01: Aligned Threshold	Option 02: Staggered Threshold	Justification
Departure Aircraft Taxi Time			06R the longer Runway will be preferred for DEP..
Minimum Separation			Both Option require min 2,000m separation.
Impact on Landside Infra – Rail			Rail network planned at Grid level.
Airport City Zone 2A Impact			Zone 2A ideal location for Airport city fragment.
3rd Runway Threshold Aligned			Aligned threshold is preferred for operational use.
Additional Land required for 3rd Runway Infra			RWT approach light - 920m falling outside airport land.
2nd Runway Impact on Western Landside			No Impact
2nd Runway Impact on Eastern Landside			Threshold at distance of 2km from Eastern city.
3rd Runway Impact on Eastern Landside			Threshold at distance of .6km from Eastern city.
Total	21	33	

Scoring Summary:

- Option 01: 21 points
- Option 02: 33 points

Based on cumulative scores, **Option 02 – Staggered Threshold** is the preferred solution. It offers superior operational efficiency, preserves critical landside infrastructure, and supports long-term airfield scalability.

5.1.1.7 Runway Length

This chapter outlines the methodology used to assess the optimal runway length required for future operations at Jomo Kenyatta International Airport (JKIA). The analysis is based on aircraft performance modeling, environmental conditions specific to JKIA, and operational requirements for long-haul and intercontinental routes. The goal is to ensure that the proposed runway infrastructure supports the safe and efficient operation of the largest aircraft types in the projected fleet mix, particularly Code E and Code F aircraft, under realistic operating conditions.

5.1.1.7.1 Methodology

The determination of runway length requirements for Jomo Kenyatta International Airport (JKIA) was conducted using a comprehensive methodology that integrates aircraft manufacturer planning manuals, ICAO-recommended adjustments, and site-specific environmental factors. This approach ensures that the proposed runway infrastructure will support the operational needs of the largest and most critical aircraft types in JKIA's future fleet mix, particularly **Code E aircraft** such as the Boeing 777, Airbus A350, Boeing 787, and Airbus A380.

Key parameters considered in the analysis included:

- **Airport Elevation:** JKIA is located at an elevation of approximately 1,625 meters above sea level. This high-altitude setting reduces air density, which in turn affects aircraft engine thrust and aerodynamic lift, increasing the required takeoff distance.
- **Ambient Temperature**: Average and peak temperature conditions were factored in, as higher temperatures further reduce aircraft performance.
- **Runway Slope:** The proposed slope of the runway was included in the calculations, as it influences acceleration and braking performance.
- **Maximum Takeoff Weight (MTOW)**: Aircraft performance was evaluated at allowable MTOW under JKIA's elevation and temperature conditions.

The methodology applied ICAO Annex 14 guidelines to adjust manufacturer data for local conditions. The analysis focused on identifying both the required runway length for allowable takeoff weights and the MTOW restrictions imposed by fixed runway lengths of 4,100 meters and 4,500 meters.

5.1.1.7.2 Aircraft Performance and Runway Length Iteration

The analysis focused on the performance of the largest aircraft types expected to operate at JKIA, including:

- Boeing 777-300ER
- Airbus A350-900 and A350-1000
- Boeing 787-8 and 787-9
- Airbus A380-800

Each aircraft was evaluated at its Maximum Takeoff Weight (MTOW) under JKIA's elevation and temperature conditions. The model calculated the required runway length to support these weights and also assessed the percentage of MTOW that could be supported by fixed runway lengths of 4,100 meters and 4,500 meters.

5.1.1.7.3 Runway Length Requirements at Allowable MTOW

The following table summarizes the runway length requirements for key aircraft types operating at their allowable take-off weights under JKIA's elevation and temperature conditions:

Table 5.8: Runway Length at Allowable MTOW

Aircraft	MTOW (kg)	Allowable TOW (kg) at 1,625m	Required Rwy Length (m) for Allowable TOW	Allowable MTOW @ RWY Length of 4,500 (m)	Allowable MTOW @ RWY Length of 4,100 (m)
Boeing B777-200L	*351,535*	*335,204*	*4,579*	***100%***	***94%***
Airbus A350-900	*280,000*	*271,750*	*5,631*	***98%***	***96%***
Airbus A350-1000	*318,350*	*299,563*	*5,626*	***96%***	***94%***
Boeing B787-900	*254,011*	*235,414*	*4,922*	***98%***	***96%***
Boeing B787-800	*227,930*	*211,147*	*5,312*	***98%***	***96%***
Airbus A380-800	*575,000*	*565,813*	*5,766*	***97%***	***95%***

Source: Consultants analysis.

The Airbus A380-800, being the heaviest aircraft in the fleet mix, requires the longest takeoff distance—approximately 5,766 meters—when operating at full MTOW. However, it is important to note that not all aircraft operate at maximum payloads on every route. Operational constraints such as elevation and temperature often necessitate reduced takeoff weights, which in turn affect payload capacity and route viability.

5.1.1.7.4 Payload Range Analysis

To assess the commercial viability of long-haul operations, a Payload-Range Analysis was conducted for two representative intercontinental destinations:

- John F. Kennedy International Airport (JFK), New York – 7,357 nautical miles
- Guangzhou Baiyun International Airport (CAN), China – 5,423 nautical miles

These routes represent the longest current and potential future destinations in Kenya Airways' network.

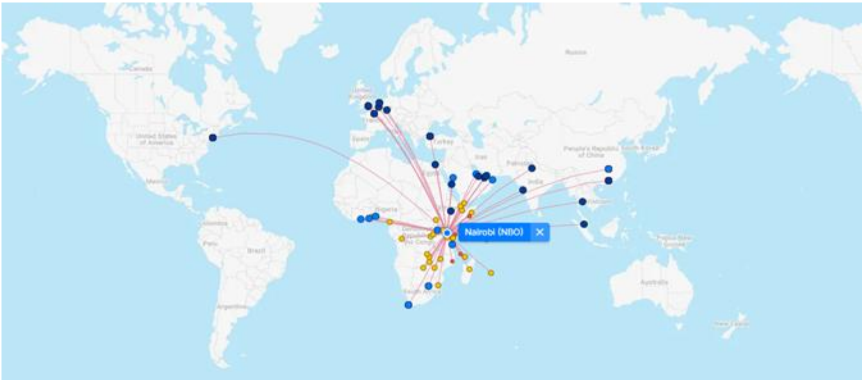


Figure 5.20 : JKIA Destinations

Source : Consultants analysis.

Table 5.9 : Payload Range Analysis

Aircraft	MTOW @ 4500m RWY Length	JFK (7,357NM)	
		Allowable Payload @ 4500m RWY	Allowable Payload @ 4100m RWY
B777-300	335,204	**100%**	**69%**
A350-900	266,375	**91%**	**80%**
A350-1000	286,938	**83%**	**76%**
B787-900	230,368	**100%**	**83%**
B787-800	205,931	**79%**	**66%**
A380-800	546,750	**79%**	**64%**

Source: Consultants analysis.

The payload-range analysis reveals that while most aircraft in the future fleet mix can operate to Guangzhou (CAN) with full payloads from a 4,500-meter runway, operations to New York (JFK) are significantly constrained. Specifically, the Boeing 787-8 and 787-9 are limited to approximately 79% and 100% payload capacity, respectively, under JKIA's elevation and temperature conditions. These limitations pose challenges for ultra-long-haul routes, particularly those requiring high cargo volumes or premium service configurations. The reduced payload capacity directly impacts route economics and operational viability, underscoring the need for strategic runway length planning to support full payload operations on key intercontinental routes.

5.1.1.7.5 Strategic Implications for Runway Design

The analysis confirms that a runway length of 4,500 meters at JKIA is adequate for most intercontinental operations, including routes to East Asia such as Guangzhou, which can be served with full payloads. However, ultra-long-haul destinations like New York (JFK) and potential future routes to Los Angeles (LAX) present operational challenges.

Aircraft such as the Boeing 787-8 and Airbus A380-800 experience significant payload limitations when operating from a 4,500-meter runway, with allowable payloads dropping to 79% and 83%, respectively. To support full payload operations on these routes and enhance commercial viability, a runway extension to 4,800 meters is recommended. This would improve payload capacity by approximately 7–10%, directly benefiting route economics and airline competitiveness. Despite such extensions, JKIA's elevation of 1,625 meters remains a critical constraint, as reduced air density continues to affect aircraft performance. Therefore, runway length planning must account not only for aircraft type but also for environmental conditions to ensure safe and efficient operations.

5.1.1.7.6 Recommendations

Based on the runway length and payload-range analysis, the following recommendations are proposed:

- **Minimum Runway Length:** A 4,500-meter runway is sufficient to support most intercontinental operations at JKIA, including full-payload flights to East Asia (e.g., Guangzhou). It enables near-optimal performance for Code E aircraft such as the Boeing 787-9 and Airbus A350-900, which can operate at 100% and 91% payload respectively on key long-haul routes.
- **Preferred Runway Length:** To ensure full payload capability on ultra-long-haul routes—particularly to North American destinations like JFK and potential future services to LAX—a runway extension to 4,800 meters is recommended. This would mitigate payload restrictions observed in aircraft such as the A380-800 and B787-8, which currently operate at reduced payloads (79% and 79% respectively) from a 4,500-meter runway.
- **Operational Flexibility**: The runway design should accommodate evolving fleet mixes and future aircraft types, including Code F operations. The Airbus A380-800, for example, requires longer takeoff distances and is already part of the projected fleet mix.
- **Environmental Considerations**: JKIA's elevation of 1,625 meters significantly affects aircraft performance due to reduced air density, impacting thrust and lift. Runway planning must continue to incorporate elevation, temperature, and slope factors to ensure safe and efficient operations under all conditions.
- **Phased Implementation**: If immediate construction of a 4,800-meter runway is not feasible, provisions should be made for future extension beyond 4,500 meters. This includes land reservation, grading, and alignment with long-term airfield development strategies.

5.1.1.8 Taxiways

5.1.1.8.1 ICAO Standards for Taxiway Widths and Separation Distances (Code C to F)

The taxiway system at Jomo Kenyatta International Airport (JKIA) is planned in accordance with ICAO Annex 14, Volume I, which defines the geometric and operational standards for safe and efficient aircraft movement. These standards are critical for accommodating a diverse fleet mix, including wide-body aircraft expected in JKIA's future operations.

Taxiway Width Requirements:

- **Code C aircraft**: Minimum width of 15 meters
- **Code E/F aircraft**: Minimum width of 23 meters

Taxiway Separation Requirements (Code F):

- **Centerline to centerline (between parallel taxiways)**: 91 meters
- **Centerline to object (e.g., lighting mast, building)**: 51 meters

These specifications ensure compatibility with aircraft such as the Boeing 777 and Airbus A380, supporting JKIA's ambition to become a regional hub for long-haul and high-capacity operations.

Taxiway center line to taxiway center line	91 m
Taxiway center line to object	51 m

Figure 5.21: Taxiways Separations

Rapid Exit Taxiway	
Maximum exit speed	93 kph
Angle between the RET and the runway	30º
Turn-off curve radius	550 m
Taxiway	
Width	23 m
Shoulder width	7,5 m
Clearance distance – outer main gear to taxiway edge	4 m
Taxiway Strip	
Width	87 m
Width of graded portion	19 m

Figure 5.22: Taxiway Design Geometric Criteria

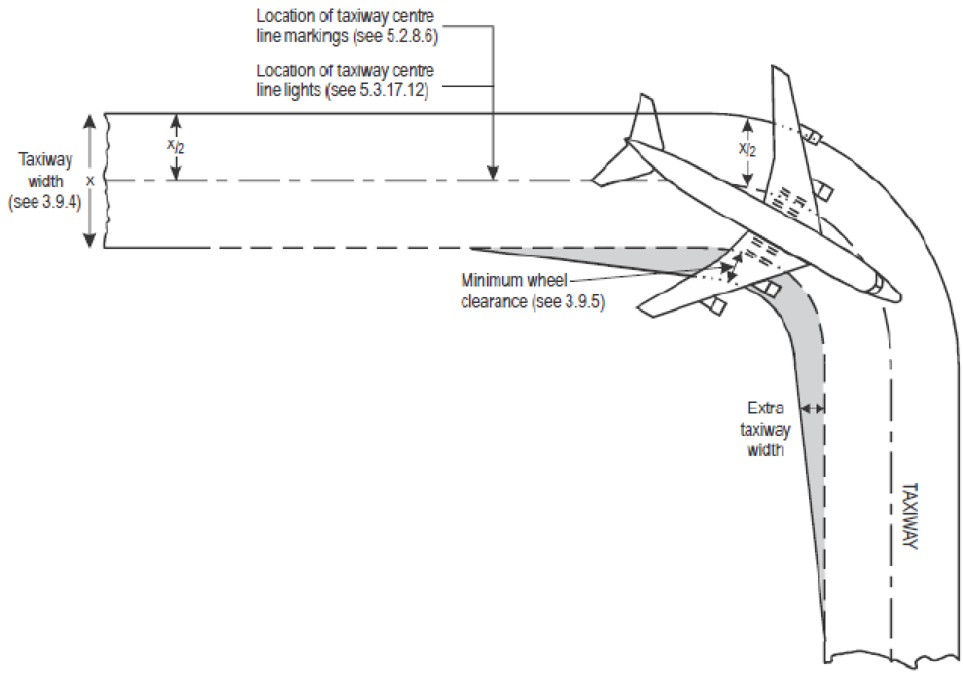


Figure 5.23: Taxiway Curve Design

5.1.1.8.2 Cross-Field Taxiways

To enhance connectivity between terminals and runways, two cross-field taxiways are proposed:

- **Eastern Cross Taxiway**:
  - Connects the existing runway to the new terminal
  - Facilitates aircraft arriving on the existing runway and departing from the new runway
  - Reduces taxiing time and improves turnaround efficiency

- **Western Cross Taxiway**:
    - Links existing terminal stands to the new runway
    - Enables aircraft to reach departure points without congesting the existing taxiway network

Justification:

- **Operational Separation**: Allows simultaneous use of both runways for arrivals and departures
- **Reduced Taxi Time**: Minimizes ground movement delays for aircraft departing from existing terminals
- **Improved Flow Management**: Supports peak-hour operations and reduces apron congestion

These cross-field taxiways are essential for maintaining fluid aircraft movement across the airfield, especially during mixed-mode operations

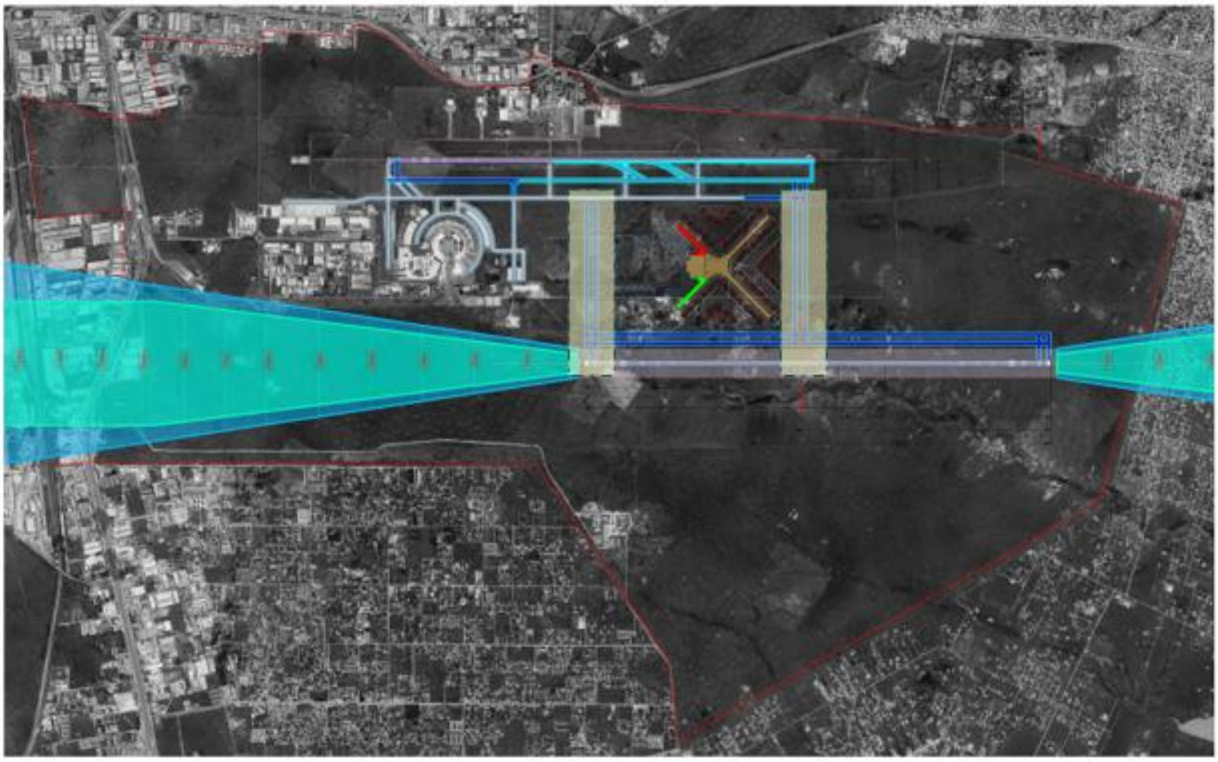


Figure 5.24: JKIA - Eastern / Western Cross-Filed Taxiway

5.1.1.8.3 Taxiway Usage and Flow Analysis (Runway 06 and 24)

The JKIA Master Plan includes detailed aircraft flow diagrams for Runway 06 and Runway 24 operations. These analyses highlight current limitations and future requirements.

Runway 06 Flow:

- Aircraft enter via right-angle taxiways
- RETs and end exits are underutilized due to limited parallel taxiway coverage
- Flow is constrained by apron-taxiway interfaces

Runway 24 Flow:

- Partial parallel taxiway supports smoother transitions
- RETs at 2,000m and 2,450m are more effectively used
- Aircraft movement is more streamlined, though still limited by taxiway geometry

Taxiway Utilization Insights:

- **Underutilization of RETs**: Without full parallel taxiways, RETs do not deliver optimal benefits
- **Need for Dual Parallel Taxiways**: Essential for maximizing runway throughput and minimizing ROT
- **Flow Bottlenecks**: Occur at apron interfaces and terminal access points

These insights reinforce the importance of completing the parallel taxiway system and integrating cross-field taxiways to support efficient aircraft movement.

Figure 5.25: JKIA: 2027-209 Layout: Aircraft flow – Runway 06

Figure 5.26: JKIA: 2027-209 Layout: Aircraft flow – Runway 24

Figure 5.27: JKIA: 2027-209 Layout: Taxiway Utilization

5.1.1.8.4 Conclusion

The taxiway system development at JKIA is a phased strategy designed to meet current and future air traffic demands. By aligning with ICAO standards and incorporating best practices in taxiway geometry, RET placement, and cross-field connectivity, the plan ensures:

- Safe and efficient aircraft movement
- Reduced runway occupancy time
- Enhanced terminal connectivity
- Scalable infrastructure for future growth

The integration of dual parallel taxiways, strategically placed RETs, and cross-field taxiways positions JKIA as a future-ready hub capable of handling over 240,000 annual aircraft movements by 2045

5.1.1.9 Aircraft Stand

In accordance with ICAO Annex 14, Volume I – Aerodrome Design and Operations, and ICAO Doc 9157 Part 1 – Aerodrome Design Manual, the aircraft stand layout for the new terminal at JKIA has been planned to ensure safe, efficient, and flexible operations. The design accommodates forecasted traffic volumes and aircraft types, while adhering to international standards for separation, maneuvring, and servicing.

5.1.1.9.1 Passenger Aprons Design

Passenger aprons are critical operational zones where aircraft are parked for boarding, disembarkation, refueling, and ground servicing. The design of these aprons must ensure:

- Adequate clearance between aircraft and adjacent structures.
- Safe maneuvering space for ground support equipment (GSE).
- Efficient passenger flow via Passenger Boarding Bridges (PBBs).
- Compliance with ICAO Code Letter specifications.

At JKIA, the critical aircraft types are the Airbus A321neo (Code C) and Boeing 777-9 (Code E). The apron layout incorporates Multiple Aircraft Ramp System (MARS) stands to maximize flexibility. Each MARS stand can accommodate either one Code E aircraft or two Code C aircraft simultaneously, optimizing gate utilization during peak and off-peak periods.

All stands include:

- A 20-meter-wide bi-directional head-of-stand road for GSE and service vehicles.
- A minimum 8-meter buffer between the terminal façade and the Vehicle Service Road (VSR).
- A 3.0-meter tail clearance between aircraft and the VSR, as per ICAO Doc 9157 recommendations.

Figure depicts specific Code C (A321neo) and Code E (B777-9) aircraft dimensions used to develop the passenger stand configurations on the passenger aprons. All stands include a 20-meter-wide, bi-directional head of stand road to facilitate smooth traffic flow, with dedicated two-lane access for each direction. Additionally, all stands include an 8-meter-wide buffer between the terminal edge and the VSR and a 3.0-meter separation between aircraft tail and the VSR.

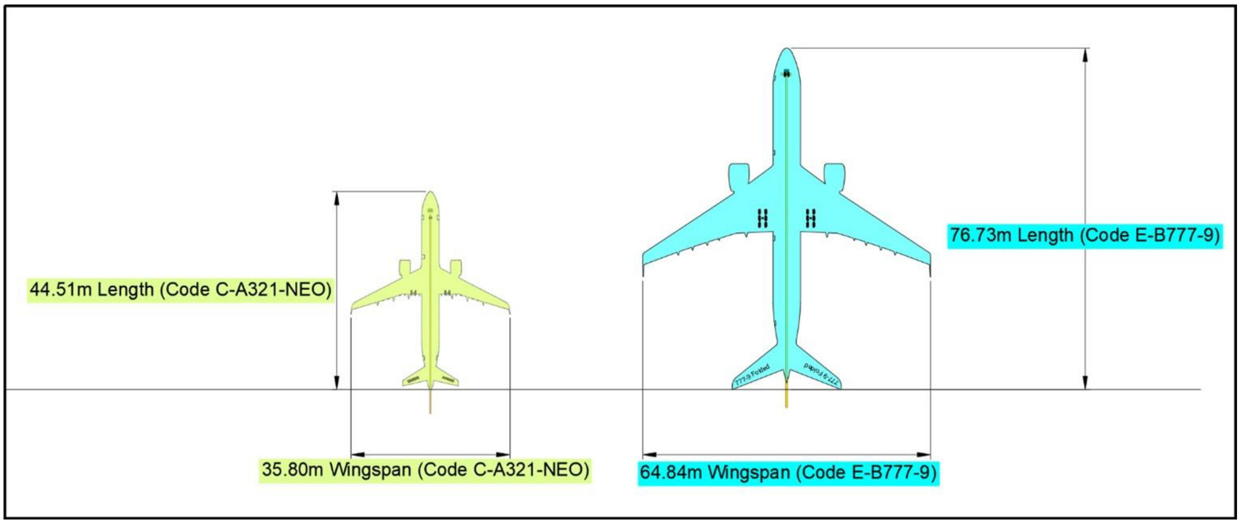


Figure 5.28 : Code C and Code E Aircraft Dimensions

Source: ICAO Annex 14 and Document 9157; Consultant analysis

5.1.1.9.1.1 Code C Stands

Code C stands are designed for narrow-body aircraft such as the Airbus A321neo. The layout parameters are derived from ICAO Annex 14 Table 1-1 and Doc 9157 guidance:

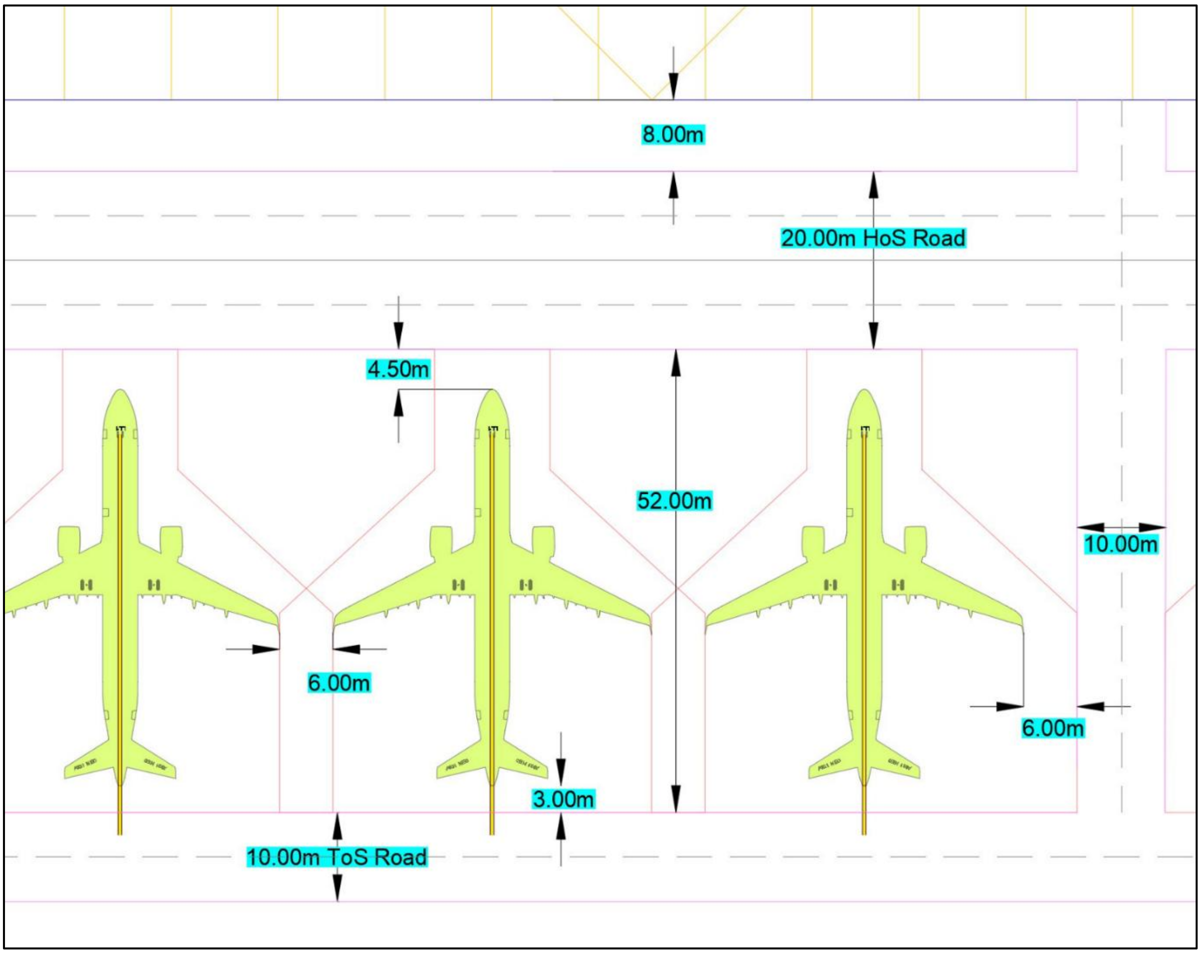
Table 5.10: Code C Layout

Code C (Airbus A321neo)	
Item	***Separation/Length captured***
Aircraft Length	44.51m
Aircraft Tail to ToS VSR	3.00m
Apron Depth	70.00m
ToS VSR Width	7.50m

Sources: ICAO Annex 14; Consultant analysis

The design ensures sufficient clearance for adjacent aircraft and includes space for vertical circulation cores connecting the terminal to the PBBs. The 6-meter wingtip separation meets ICAO's minimum clearance requirements for Code C aircraft in nose-in parking configurations

Figure 5.29 depicts Code C separations, including a 6.0-meter separation between aircraft wingtips. The design also incorporates sufficient room for a vertical circulation core, which will connect the terminal building to the aircraft via the passenger boarding bridge (PBB).



Source : ICAO Annex 14 and Document 9157 ; Consultant analysis

Figure 5.29: Code C Aircraft Separations

5.1.1.9.1.2 Code E Stands

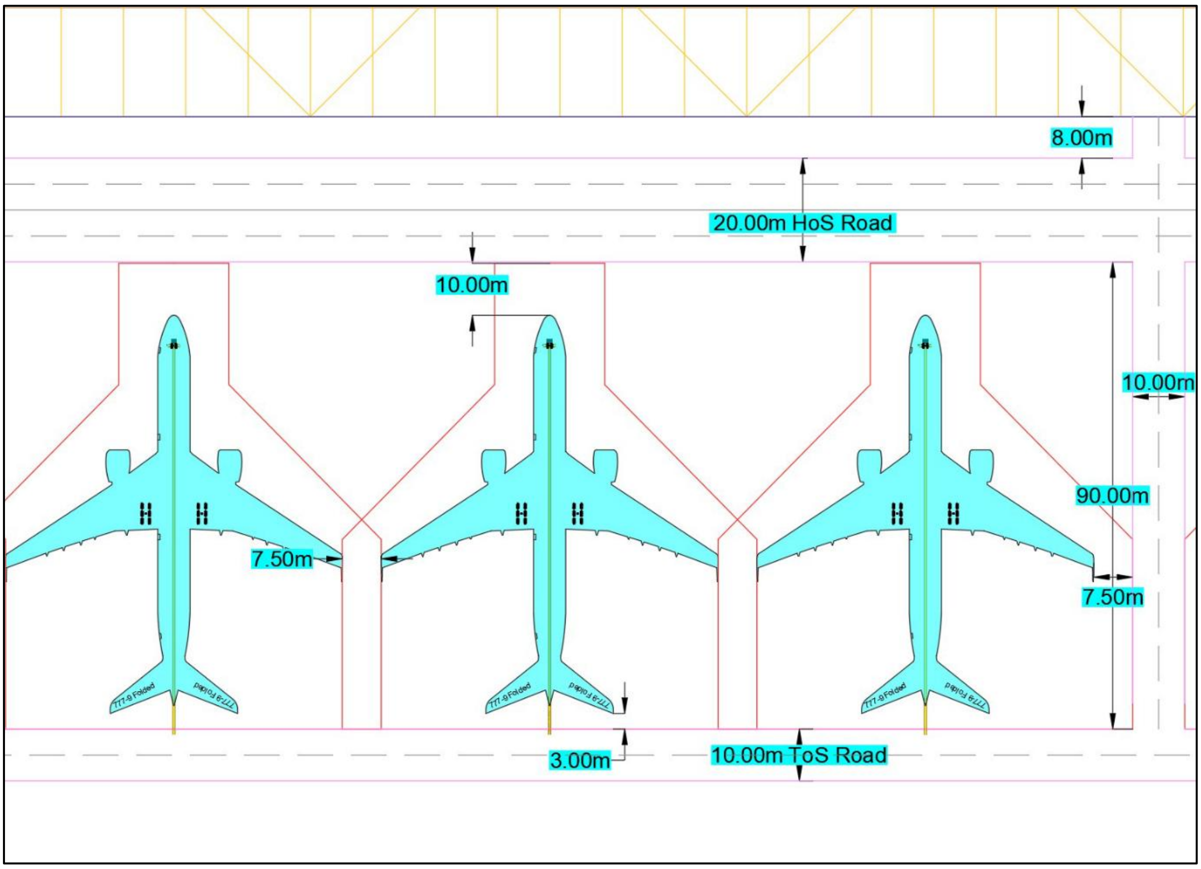
Code E stands are configured for wide-body aircraft such as the Boeing 777-9 (with folded wingtips). The layout complies with ICAO standards for Code E operations:

Table 5.11: Code E Layout

Code E (Boeing 777-9 Folded)	
Item	***Separation/Length captured***
Aircraft Length	76.73m
Aircraft Tail to ToS VSR	3.00m
Apron Depth	90.00m
ToS VSR Width	7.50m

Source : ICAO Annex 14 ; Consultant analysis

The increased apron depth and wingtip separation ensure safe maneuvring and servicing of large aircraft. The design also accommodates the turning radius and pushback requirements for Code E aircraft.



Source: ICAO Annex 14 and Document 9157; Consultant analysis

Figure 5.30: Code E Aircraft Separations

5.1.1.9.1.3 MARS Code C & E stands

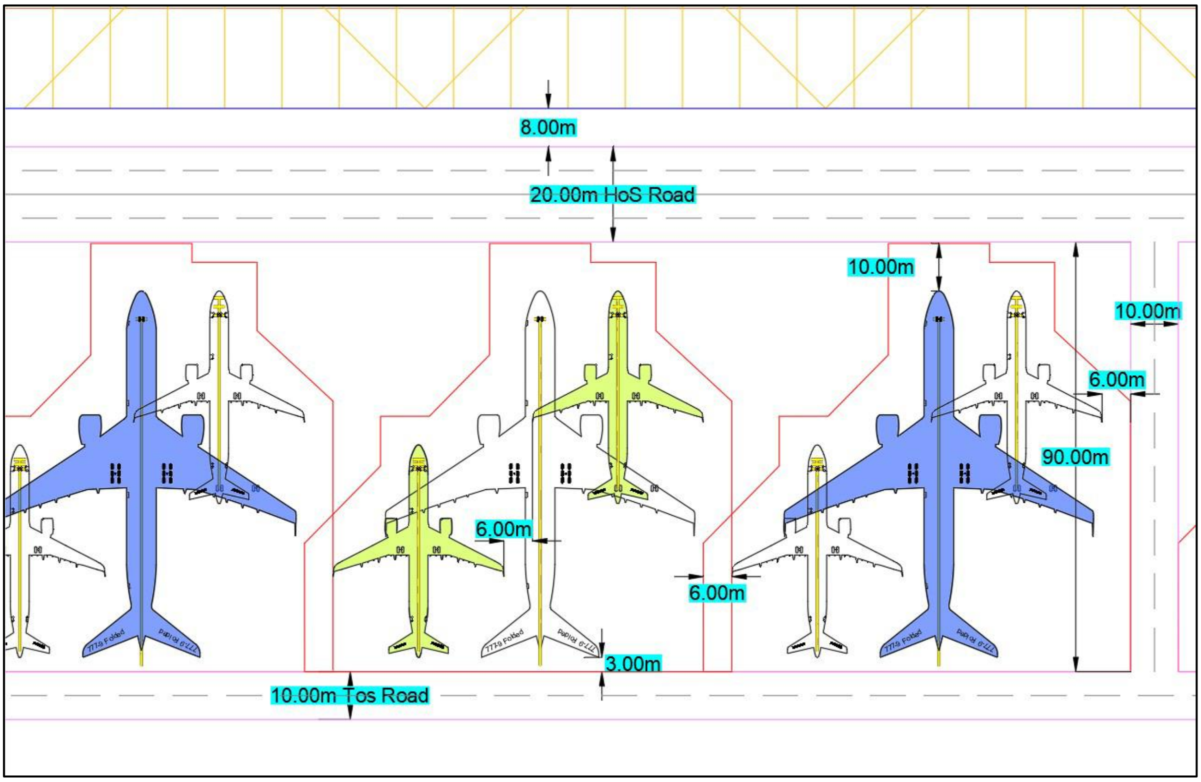
MARS stands are designed to accommodate either one Code E aircraft or two Code C aircraft simultaneously. This configuration enhances gate flexibility and operational efficiency.

Table 5.12: MARS Code C & E Layout

MARS Code E (Boeing 777-9 Folded/A321neo)	
Item	***Separation/Length captured***
Aircraft Length	76.73m
Aircraft Tail to ToS VSR	3.00m
Apron Depth	90.00m
ToS VSR Width	7.50m

Sources: ICAO Annex 14; Consultant analysis

For Code C aircraft parked in a MARS configuration, a separation of 6.0 meters is provided between aircraft wingtips parking at adjacent stands and between Code C aircraft wingtips at the same MARS stand. Greater wingtip clearance is available when accommodating either a mix of Code C and Code E aircraft or exclusively Code E operations.



Source : ICAO Annex 14 and Document 9157 ; Consultant analysis

Figure 5.31: MARS Code C & E Aircraft Separations

5.1.1.9.1.4 Design Compliance Summary

All stand designs conform to:

- ICAO Annex 14 Volume I, Chapter 3 (Aerodrome Reference Code and Aircraft Stand Design).
- ICAO Doc 9157 Part 1, Sections 2.3 and 3.2 (Apron Layout and Stand Configuration).
- Safety and operational guidelines for aircraft maneuvering, servicing, and passenger boarding.

These standards ensure that JKIA's new terminal aprons are future-ready, safe, and capable of supporting mixed fleet operations efficiently.

5.1.1.9.2 Expansion Strategy

JKIA Aprons are having a total of 49 stands, and they would be requiring over 50 stands starting from 2028. This would imply that to cater to the 2028 onwards demand, Airport might need quick and short-term solutions to enhance the Apron capacities until New Aprons are getting constructed. New Apron would be required to manage the long-term traffic demand. Based on these situations, Apron Expansion is proposed to be performed in 2 primary Phases as described below:

1. Phase 1:

   It would be required for JKIA to assess and act on the quick capacity enhancement solutions to cater for Stand demand getting generated post 2028.

   Airport can perform various Operational changes like strategic allotment of Aircraft stands, operate with faster turnaround times and expand the current Aprons (if required) e.g., utilize space near T1C and T2 remote Aprons to cater to the demand. As per global Apron Planning benchmarks, an Integrated Operational Airport can increase their Apron capacities by 10-20% through above-mentioned strategies.

   JKIA has the potential to significantly increase their capacity of the existing Aprons. However, detailed feasibility assessment and planning works must be undertaken by KAA to analyse the potential of the current Aprons.

   Below figure provides an indication of the short-term solution for potential Apron capacities to cater to the growing passenger demand.

   With the probable 15% increase in the existing Apron capacity, the Airport might be able to handle the operations by 2029. Beyond this, the Airport would need New Apron areas.

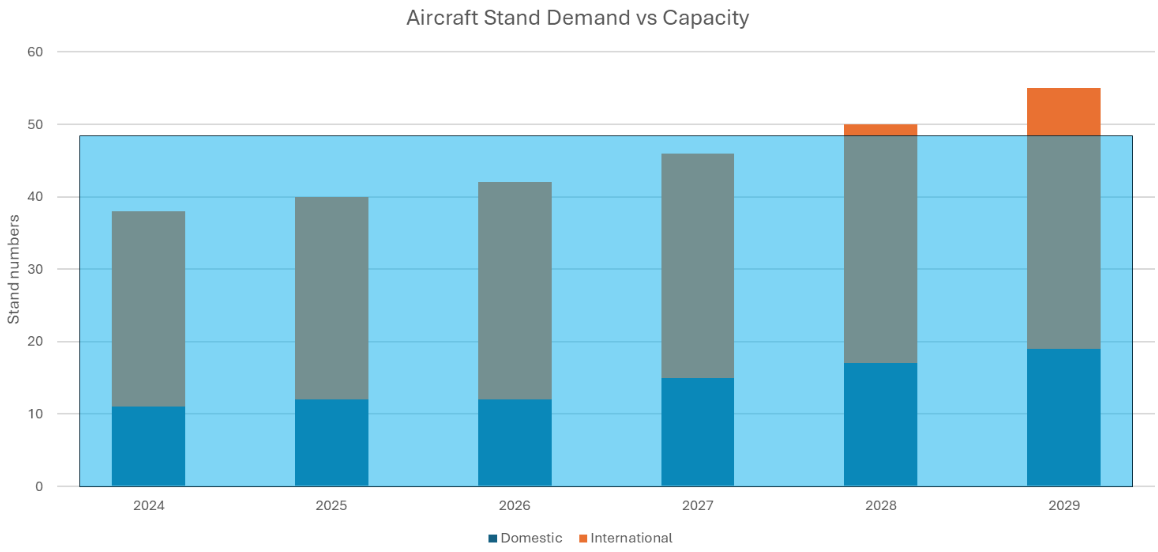


Figure 5.32: JKIA Phase 1 Apron Expansion Strategy

2. Phase 2:

   JKIA would require New Aprons adjacent to the New Terminal building post 2029. As the New PTB is proposed to be constructed in 2 sub-phases, Aprons would also follow the same strategy as below:

   a. Phase 2a: New Apron will manage the operations conveniently by 2040 in alignment with Terminal strategy.
   b. Phase 2b: Apron expansion to handle the 2045 traffic demand of 22.3 MAP and provide additional capacity to manage the Airport for some more years beyond 2045.

   JKIA New Aprons will be strategized maximizing the Contact gate operations to help Airport operate with better on-time performance and providing enhanced passenger convenience.

   Overview of the Phase 2 Apron capacities in relation to Stand demand is shown in below figures.

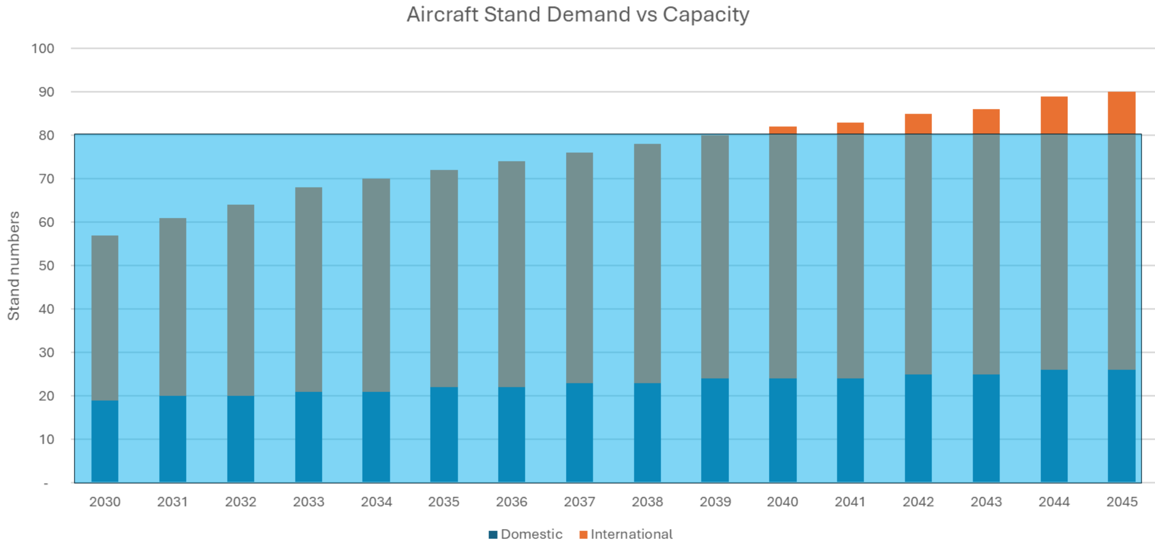


Figure 5.33: Phase 2a Apron Capacity

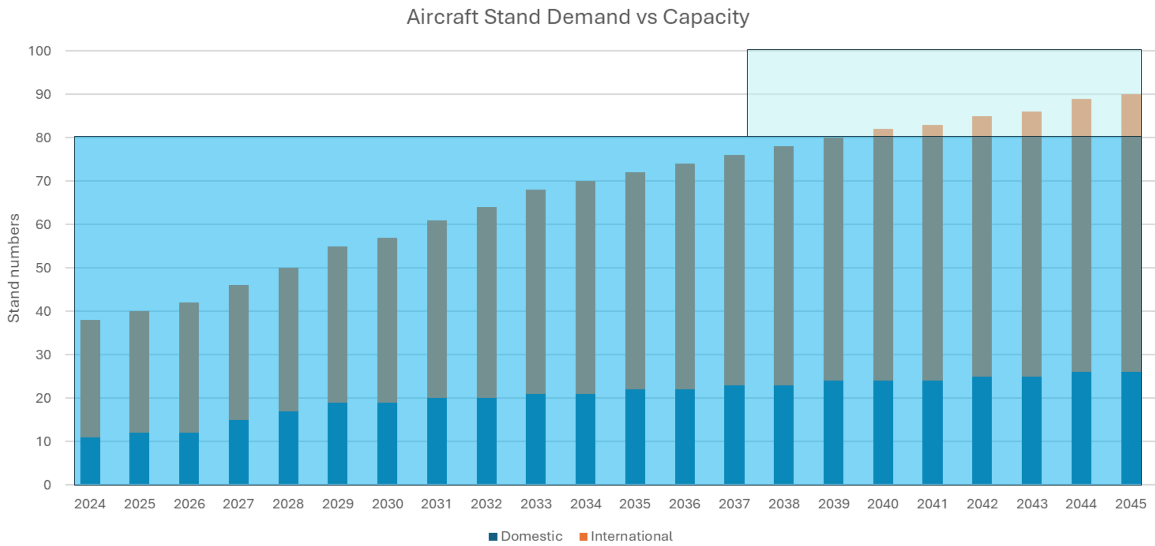


Figure 5.34: Phase 2b Apron Capacity

5.1.1.9.3 Future Requirement

JKIA Future Apron requirement is derived aligning with the Terminal requirement which is proposed in 2 phases i.e. Facilities for 10 MAP and additional facilities for 5 MAP.

Commercial Apron Requirement is derived from the Traffic forecast which evaluates the stands as per different Aircraft Code Categories.

Table 5.13: JKIA Stands Requirement

Stand Requirement			
Process	**Units**	**Requirement**	
		10 MAP	**15 MAP**
Peak Hour Pax Demand	*no.*	***2,195***	***3,292***
International			
Stand Frontage	***m***	**1,600**	**2,343**
Aircraft Stands	***no.***	**32**	**47**
Code C Tp	*no.*	4	5
Code C Jet	*no.*	19	29
Code E	*no.*	9	13
Domestic			
Stand Frontage	***m***	**690**	**1,092**
Aircraft Stands	***no.***	**16**	**25**
Code A	*no.*	6	9
Code C Tp	no.	5	8
Code C Jet	no.	5	8

5.1.2 LANDSIDE AND TRANSPORT MOBILITY

5.1.2.1 LANDSIDE ACCESS DEVELOPEMENT

The landside and transport mobility development plan for JKIA establishes a phased framework to support the operation of the New Passenger Terminal Building while ensuring efficient and reliable access for passengers, staff, and service vehicles. The development strategy aligns with the Phase 1 and Phase 2 passenger demand forecasts and supports future expansion without requiring major reconfiguration of the landside system.

5.1.2.1.1 Internal Access Roads

The internal access road network serving the New PTB provides segregated arrival and departure circulation, minimizing conflict points and improving operational clarity. A design speed of approximately 50 mph was adopted for primary access roads, corresponding to a nominal lane capacity of 1,520 vehicles per hour per lane.

Under Phase 2 peak conditions, inbound and outbound traffic volumes of approximately 2,021 vehicles per hour and 1,948 vehicles per hour, respectively, were forecast. Based on these volumes:

- Two inbound lanes are provided, operating at LOS C
- Two outbound lanes are provided, operating at LOS C

This configuration provides sufficient capacity while maintaining resilience to operational variability.

5.1.2.1.2 Curbside Layout and Operations

The New PTB curbside layout includes dedicated arrival and departure levels, each designed with a four-lane cross-section comprising:

- Through lanes
- Friction lanes
- Dedicated stopping lanes for drop-off and pick-up activity

Dedicated curbside spaces are allocated for private cars, taxis, buses, and hotel buses, with flexibility to adjust allocations in response to operational needs. The curbside layout is designed to accommodate both Phase 1 and

Phase 2 demand.

5.1.2.1.3 Car Parking Provision

Short-term and long-term parking facilities are provided to support New PTB operations. Short-term parking is located in close proximity to the terminal and primarily serves arriving passengers and short-duration departures. Long-term parking serves domestic departing passengers and is sized to meet forecast demand for both development phases. Parking facilities are planned to be expandable, allowing additional capacity to be delivered in line with passenger growth.

5.1.2.1.4 Public Transport and Bus Facilities

Bus facilities serving the New PTB are assumed to be operational in both Phase 1 and Phase 2. These facilities accommodate scheduled buses, shuttle services, and hotel buses and are integrated into the terminal access strategy. The landside layout safeguards space for future public transport enhancements, including a potential rail connection, ensuring long-term integration without disrupting terminal operations.

5.1.2.1.5 External Connectivity and Junction Strategy

The New PTB is accessed via internal airport roadways that connect to the existing airport road network. No new junction is provided directly into the New PTB.

Key junctions within the wider airport network include:

- Junction 1, serving the existing PTB
- Junction 2, located near Terminal 2

These junctions are upgraded as required to accommodate Phase 2 traffic volumes, ensuring acceptable levels of service across the airport landside network.

5.1.2.1.6 Futureproofing and Flexibility

The landside development plan incorporates flexibility to accommodate:

- Future changes in passenger mode share
- Operational adjustments to curbside usage
- Long-term expansion of parking and access road capacity

This approach ensures that the landside system remains resilient and adaptable throughout the planning horizon.

5.1.2.1.7 Summary

The proposed landside and transport mobility development plan provides a robust, scalable, and operationally efficient framework to support the New PTB during both Phase 1 and Phase 2. By aligning infrastructure delivery with forecast demand and safeguarding future enhancements, the plan ensures sustainable and reliable landside access for JKIA.

5.1.2.2 LANDSIDE INTEGRATION AND KEY LANDSIDE COMPONENTS

The Landside components of JKIA will need to integrate seamlessly with the airside components. This would include aspects related to the Airport City and the SEZ. The following section will summarise the key airside and landside integration components. Full details can be seen in the separate Integrated Master Plan Report for the Airport City, SEZ and Wilson Airport.

5.1.2.2.1 JKIA Landside Components

The total airport land area encompasses 4,380 hectares, which is split between airside and landside. The main distinction between the two areas lies in access and security. While the landside is open to the general public, the airside is a secure, restricted zone that supports the safe movement of passengers and aircraft. The key components within the JKIA landside are detailed below.

5.1.2.2.1.1 Special Economic Zone (SEZ)

Two spatial options have been created and analysed. The preferred option has subsequently been expanded upon and is explained in the succeeding text as illustrated in the figure below

Source: Dar Consultant

Figure 5.35: Preferred Land Use Plan for the JKIA SEZ

The Special Economic Zone is located to the west of JKIA land and covers a total of 219 hectares. The site is envisioned to primarily contain an industrial zone, comprising logistics and manufacturing, along with a bonded and non-bonded zone for customs clearance, and a business park that will facilitate the expansion of office and headquarters for business and organisations serving the airport.

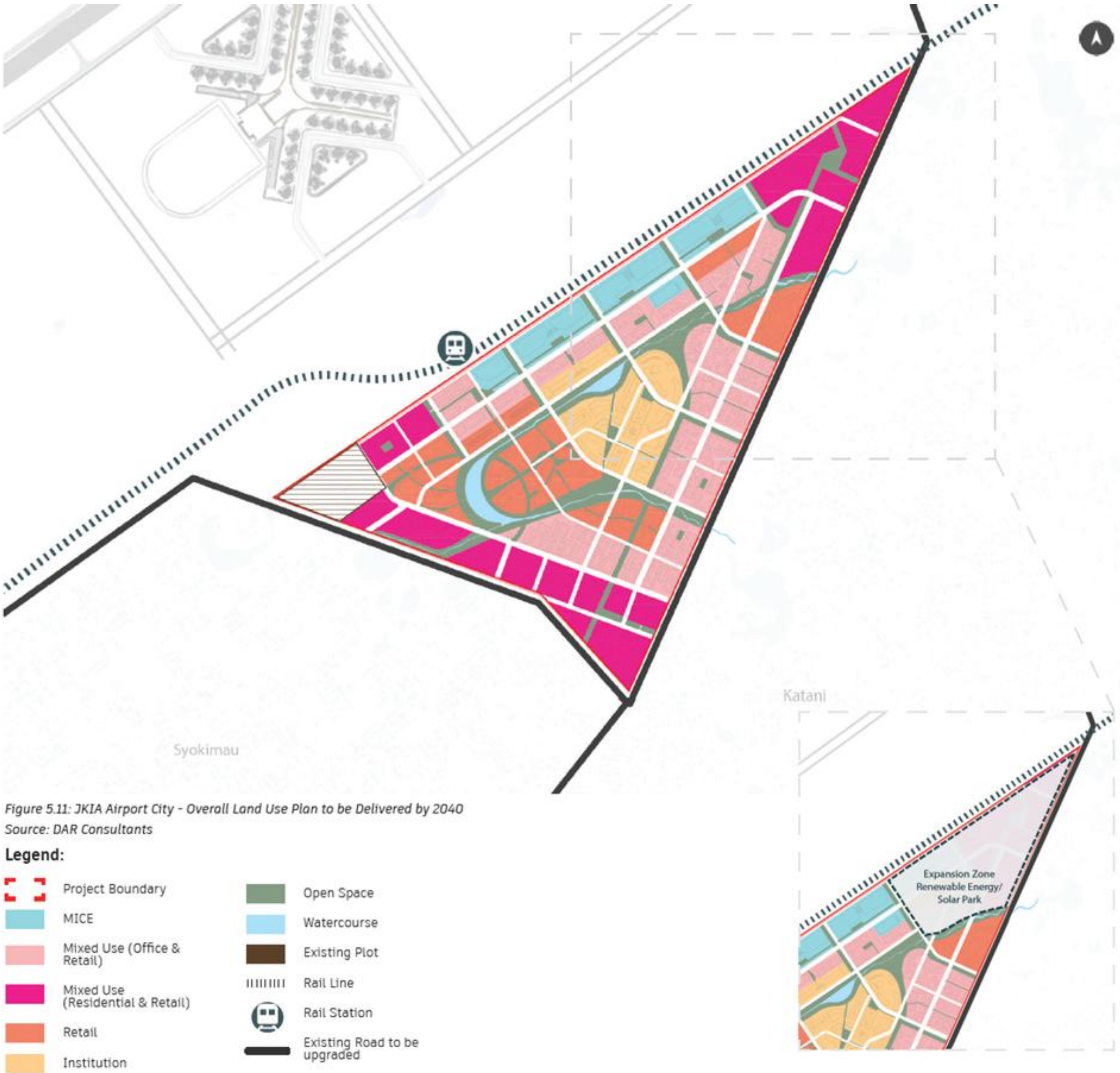
To the north, the site accommodates industrial plots arranged in a clear, efficient grid layout. Adjacent to these is a designated truck parking area.

To the south, the business park component spans approximately 15 hectares and integrates with existing office developments covering a further 20 hectares. These include the Kenya Civil Aviation Authority, the EAC CASSOA Centre for Aviation Medicine, the Kenya Urban Roads Authority Kisumu, the Horticultural Crops Development Authority (HCDA), and the fuel farm. Within this business area, two supporting facilities and a retail component are proposed to serve employees, alongside an additional truck parking area.

An existing stream running east–west across the site is proposed to be realigned to follow a straight course that complements the industrial grid layout, improving efficiency while forming a linear park. Additionally, the existing north–south pipeline corridor is retained as open space. Two utility plots are located within the site, together covering an area of 2.6 hectares.

5.1.2.2.1.2 Airport City

Two spatial options have been created and analysed. The preferred option has subsequently been expanded upon and is explained in the succeeding text as illustrated in the figure below.



Source: Dar Consultant

Figure 5.36: Preferred Land Use Plan for the JKIA Airport City

The Airport City is located to the south of JKIA land and covers an area of approximately 480 hectares. The site is envisioned as a sustainable, mixed-use business community anchored by key economic drivers, including a regional hospital, a university, and agri-business facilities.

The vision for this option is to create a versatile and diverse development, driven by innovation and new opportunities within the area and the wider region, aimed at attracting talent and supporting a range of business activities.

Adjacent to the proposed rail line, which runs parallel to the northern site boundary, the Meetings, Incentives, Conferences and Exhibitions (MICE) facilities will be positioned to ensure convenient access from both the airport and the Airport City CR Station.

Within the development, mixed-use areas combining office and retail functions are proposed next to the MICE zone and along the eastern boundary, which will also benefit from access via the upgraded road.

The mixed-use areas, comprising residential or serviced apartments and retail, are located in both the northern and southern parts of the site to integrate with the existing residential context.

The retail land use is positioned at the heart of the development, forming an island surrounded by a linear park. Its proximity to the rail station provides the opportunity to establish a pedestrian-friendly retail boulevard. Additional retail blocks are located to the north, acting as key activity nodes.

Opposite the retail hub lies the institutional cluster, envisioned to host universities specialising in agri-tech innovation, vocational education, and medical training, creating a dynamic and collaborative ecosystem.

In terms of open space, two existing streams run through the site, one to the north and one to the south. The concept connects these watercourses through a continuous linear park with ponds, alternating between wider and narrower sections to provide landscape variety, Secondary open spaces link the main park to the development's edges, ensuring integration with the surrounding context.

The existing roads along the eastern and southern boundaries are proposed to be upgraded to support improved accessibility and connectivity.

5.1.2.2.1.3 Strategic Transport Proposals and Enabling Infrastructure

Connectivity of both passengers and freight to the airports is key to their functionality. In the case of JKIA, limited public transport is available, and it is heavily reliant on road-based transport means through private vehicles. The primary access to the airport is via Mombasa Road and the Expressway from the West via Airport Road South. Both passengers and freight need to pass through a security checkpoint before proceeding west on Airport South Road to access the existing airport services area, including the existing Terminals 1 and 2, as well as the proposed new terminal for JKIA. The proposed SEZ and Airport City are planned for alternative locations within KAA land to minimise conflicting transport movements.

Regarding access to the Terminal structures, it is only served by Matatu Route 34. The proposals, as illustrated in the figure below include strengthening the public transport offering through the following:

- The rerouting of the proposed Bus Rapid Transit (BRT) Route 1 to include a stop at JKIA Terminals
- The rerouting of the proposed Bus Rapid Transit (BRT) Route 4 to include a stop and/or terminate at JKIA Terminals
- The extension of the Commuter Rail network from Nairobi SGR Terminal / Syokimau Station to the airport services and terminal structures
- The extension of the Commuter Rail network from JKIA Airport to Airport City and further safeguarded linkages east to Ruai.

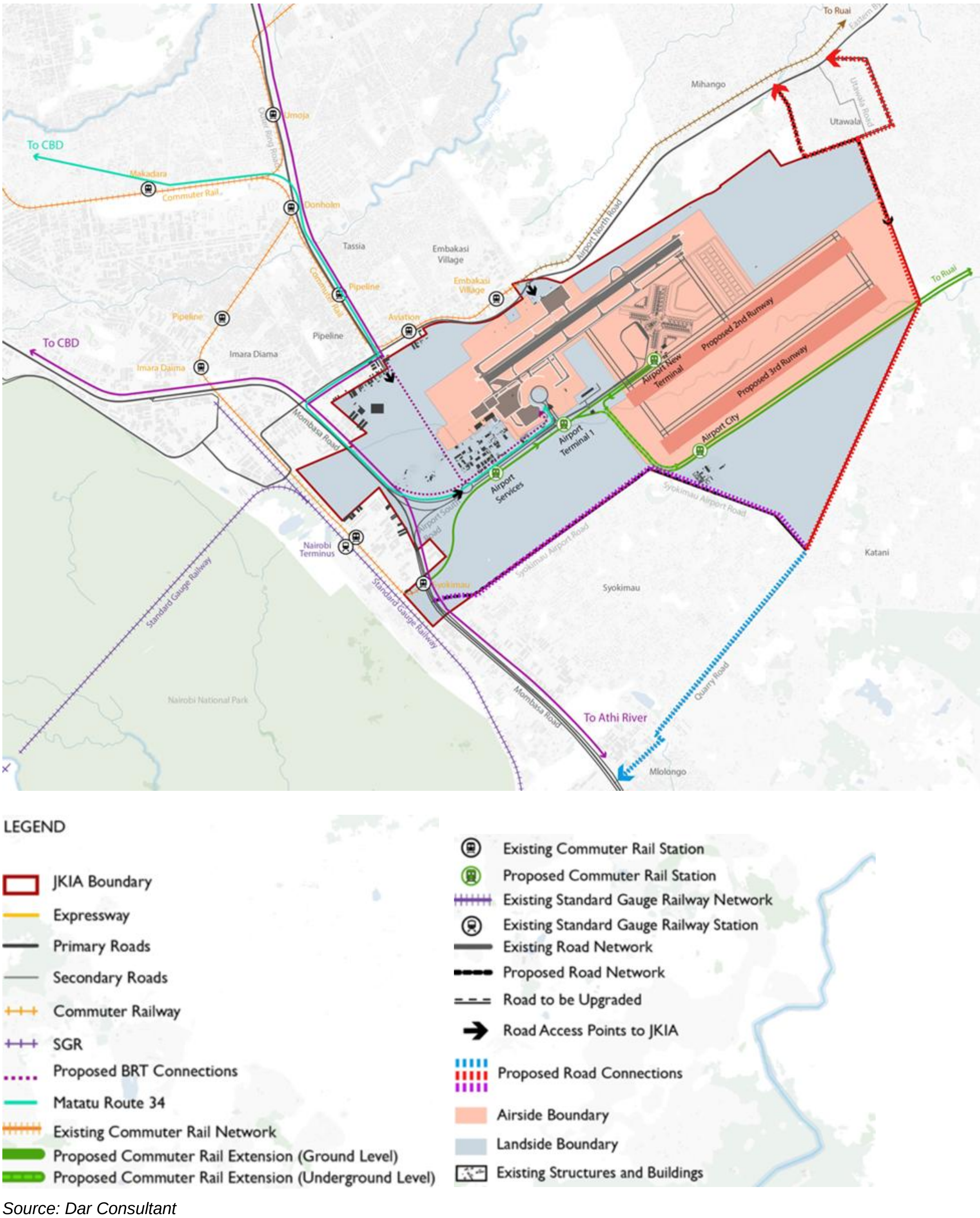
Regarding access to Airport City, public transport is also proposed, including a new local bus and matatu route to connect Airport City with Athi River, the Nairobi SGR Terminal, and the Nairobi CBD. As the new sub-centre is proposed to the south of the airport operations and bounds the residential communities of Katani and Syokimau, two new road connections are proposed for:

- Connecting the Syokimau Junction on Mombasa Road near the Gateway Mall to Airport City. This will be undertaken through small sections of new road and an upgrading strategy of the existing roads in Syokimau.
- Connecting the Eastern Bypass at Utawala to Airport City via the eastern side of the airport. This will be undertaken through largely new sections of road with an upgrading strategy for the existing roads in near Katani and Utawala. It should be noted that multiple road alignments and upgrades are being considered near Utawala.

Regarding access to the SEZ, the existing road network and a series of transport-based proposals have been considered which include:

- A series of new access routes has been proposed off the existing security checkpoint and Mombasa Road.
- The reopening of the Airport North Road to Airport South Road connector is considered; however, security checks will remain towards the southern portion of this road.

Truck parking and movements away from existing private car movement to the airport terminals.



Source: Dar Consultant

Figure 5.37: Strategic Transport and Enabling Infrastructure for JKIA

5.1.2.3 JKIA LANDSIDE TECHNICAL REQUIRMENTS ASSESSMENT

This section of the Master Plan presents a comprehensive assessment of the future landside and airside operational requirements for Jomo Kenyatta International Airport (JKIA). The analysis supports two development horizons aligned with forecasted airport growth:

- Phase 1: 20 million annual passengers (MAP)
- Phase 2: 25 million annual passengers (MAP)

The study integrates client-provided passenger and employee forecasts, detailed modal and occupancy assumptions, and benchmarking against comparable African and MENA airports. It also reflects the long-term development strategy for JKIA, including the construction of a new terminal that increases the airport's total passenger handling capacity from 10 MAP to 25 MAP.

The objective of this assessment is to clearly define the required infrastructure and operational provisions for passenger access and terminal approach traffic, vehicle and parking demand, employee transport and circulation, roadway and curbside performance, airside freighter operations, and junction capacity improvements.

5.1.2.3.1 Methodology and Assumptions

A structured, multi-layered methodology was adopted, consistent with international airport master planning practice. The analytical workflow included passenger demand forecasting and peak-hour factor development, mode share estimation, vehicle conversion, dwell-time modelling, curbside spaces and lane capacity analysis, employee mode share estimation, parking demand modelling, staff bus sizing, air cargo forecasting, freighter stand requirement analysis, and roadway capacity assessment.

Where detailed operational data was not available, benchmarking and consultant expertise were applied. Assumptions included mode share, vehicle occupancy, dwell time, and freighter stand occupancy.

Summary of Key Assumptions

- Passenger Demand: Phase 1 / Phase 2 – 20 MAP / 25 MAP
- Peak-Hour Factor: Hub airport benchmarks (African + MENA hubs)
- Mode Share: Consultant judgement + future rail (rail increases to 22%)
- Private Car Occupancy: 1.42 pax/vehicle
- Taxi Occupancy: 1.44 pax/vehicle
- Bus Occupancy: 8.33 pax/vehicle
- Car Park Dwell Time: 70.3 minutes
- Curbside Lane Capacity: 860 veh/hr/lane (ACRP)
- Target LOS: LOS D ($V/C \leq 0.90$)
- Employee Private Car Share: 27.75%
- Staff Bus Capacity: 40 employees/bus
- Peak Staff Window: 5 minutes
- Freighter Arrival Share: 65%
- Freighter Stand Occupancy: 2 hours
- Background Traffic: None assumed

5.1.2.3.2 Expanded Methodology

5.1.2.3.2.1 Passenger Landside Methodology

Peak-hour passengers were determined using forecasted annual volumes. Mode shares were assigned based on consultant judgement and future rail access. Vehicle conversion used occupancy values of 1.42 for private cars, 1.44 for taxis, and 8.33 for buses.

Parking demand included all arriving private cars and 30% of departing private cars

Curbside spaces requirements were determined based on queueing analysis

5.1.2.3.2.2 Employee Access and Circulation Methodology

Employee traffic was based on staffing levels and shift patterns.

Benchmarking indicated 27.75% private-car mode share. Parking was sized for maximum simultaneous staff.

Staff bus requirements used Buses Required = Peak 5-minute employees ÷ 40.

5.1.2.3.3 Passenger Landside Requirements

5.1.2.3.4 Passenger Car Park Requirements

Using mode share, occupancy, and dwell-time assumptions, the required number of car park spaces were determined

- **Phase 1:** 1,892 spaces
- **Phase 2:** 2,450 spaces

In total, 1,892 and 2,450 passenger car park spaces are required to accommodate passenger demand in Phases 1 and 2, respectively.

5.1.2.3.5 Curbside Space Requirements

The number of curbside space requirements were determined for each of Phase 1 and 2, for Arrivals and Departures, based on the vehicle type.

Phase 1 – 20 MAP

- Departures (82 total):
  - 50 Private Cars
  - 16 Taxis
  - 2 Buses
  - 14 Hotel Buses
- Arrivals (34 total):
  - 17 Taxis
  - 2 Buses
  - 15 Hotel Buses

Phase 2 – 25 MAP

- Departures (101 total):
  - 62 Private Cars
  - 20 Taxis
  - 2 Buses
  - 17 Hotel Buses
- Arrivals (43 total):
  - 21 Taxis
  - 3 Buses
  - 19 Hotel Buses

5.1.2.3.6 Curbside Lane Requirements

Lane requirements were determined for the roads leading into the curbside, and the curbside as well, with the goal of obtaining LOS D or above. An adopted speed of 30 mph was adopted, with an hourly lane capacity of 860 veh/hour

Phase 1:

- Departures: 2 lanes (1,104 veh/h; V/C = 0.64)
- Arrivals: 1 lane (440 veh/h; V/C = 0.51)
- Curbside: 4 lanes (Departures), 3 lanes (Arrivals)

Phase 2:

- Departures: 2 lanes (1,370 veh/h; V/C = 0.79)
- Arrivals: 1 lane (510 veh/h; V/C = 0.59)
- Curbside: 4 lanes (Departures), 3 lanes (Arrivals)

5.1.2.3.7 Employee Landside Requirements

The employee landside requirements were determined. This includes the car park requirements for employee private cars, as well as the staff buses required to transport employees from landside to airside

5.1.2.3.7.1 Employee Mode Shares

According to the adopted employee mode shares, the total number of employees making use of private cars was determined

- Phase 1: 1,094 private-car commuters
- Phase 2: 1,644 private-car commuters

5.1.2.3.7.2 Employee Car Park Requirements

The number of employee car park spaces was determined on a facility-by-facility basis for Phase 1 and 2.

List of Facilities	Phase 1	Phase 2
Passenger Terminal Building	798	1,209
Air Traffic Control Tower (ATC)	3	3
Technical Maintenance Hangars / Airport Maintenance Complex	9	14
Cargo Terminal Building	98	160
GSE Maintenance Facility	30	38
GSE Storage	2	2
Catering Facility	82	120
Aircraft Cleaning Facilities	12	16
Aircraft Maintenance & Repair (MRO)	48	68
Bomb Disposal Area	0	0
Airside Bus Facilities	8	10
Fuel Farm	3	3
Administrative and Operational Offices	2	2
ARFF	5	5
	1,100	**1,650**

In total, 1,100 car park spaces are required for Phase 1, and 1,650 for Phase 2

5.1.2.3.8 Staff Bus Requirements

Once these employees reach the car park, they will be transported to the airside and their respective facilities via a dedicated staff bus. On a 5-minute basis, the maximum required number of buses was determined

Inbound Employees (heading to facilities):

- Phase 1: 42 buses
- Phase 2: 63 buses

Outbound Employees (returning from facilities):

- Phase 1: 47 buses
- Phase 2: 71 buses

5.1.2.3.9 Airside Freighter Stand Requirements

The required number of stands to accommodate the expected freighter movements were determined based on the latest JKIA forecast data

5.1.2.3.10 Movements

Phase 1 showcases a total of 34,568 freighter aircraft movements yearly, while Phase 2 showcases a total of 50,539 movements. Based on the annual freighter aircraft movements, the hourly movements were determined

- Phase 1: 16 freighter movements per hour
- Phase 2: 23 freighter movements per hour

5.1.2.3.11 Stand Requirements

It was assumed that arrival flights constitute 65% of all freighter flights, leading to a total of 9 arrival freighters in Phase 1 and 13 in Phase 2

A stand occupancy time of 2 hours was adopted, based on the originally provided flight schedule data for JKIA, leading to a requirement of:

- Phase 1: 19 stands
- Phase 2: 27 stands

5.1.2.3.12 Roadway and Junction Requirements

Roadway and Junction Requirements were determined in accordance with the volumes for Phase 2 (25 MAP), which are higher than those of Phase 1

5.1.2.3.13 Access Roads

Based on Phase 2 traffic volumes, it was determined that a total of 4 lanes per direction are required at the main ingress and egress roadways into the airport

5.1.2.3.14 Junction Assignments

The junction types most appropriate for access into the Terminal 1 (existing terminal), and into Terminal 2 (GA) and support facilities were determined.

Junction 1 constitutes the main access into the existing terminal building, while Junction 2 leads towards Terminal 2 (GA) and support facilities. Access to the new terminal building is on a regular roadway section and will not require a junction to access

Junction 1 – Terminal 1 Access: Signalised T-intersection, 3 lanes per direction

Junction 2 – Terminal 2 and Support Facilities Access: Signalised 4-arm, supports employee and freight access

New PTB – 2 lanes per direction roadway (ingress and egress)

5.1.2.3.15 Summary and Conclusions

The assessment demonstrates that significant upgrades to JKIA's landside and airside systems are required to support growth to 25 MAP.

Passenger Landside

- Car park demand increases from 1,892 to 2,450 spaces.
- Curbside space requirements expand to 101 departure space.
- Access roads require 2–3 operational lanes per direction plus friction lanes.

Employee Landside

- Employee parking demand rises from 1,110 to 1,650 spaces from Phase 1 to Phase 2
- Staff transport requires up to 71 buses during peak 5-minute windows.
- Junction capacity and routing must prioritise employee movement efficiency.

Airside Cargo

- Freighter stand requirements increase from 19 to 27 stands, driven by growth from 16 to 23 peak-hour movements, for Phase 1 and 2 respectively

Roadway Network

- The main access road must be expanded to 4 lanes per direction.
- Two major junctions must be configured for Phase 2 volumes. Junction 1 (T1 Access) is a 3-lanes signalized t-intersection, while Junction 2 (T2 Access) is a signalized 4-way intersection.
- New PTB access would be handled via a 2-lanes per direction roadway

These requirements establish the operational and spatial foundation for the next stages of JKIA's Master Plan, informing terminal siting, roadway and junction design, parking strategy, staff transport systems, and cargo apron development.

5.1.2.4 SURFACE ACCESS INFRASTRUCTURE

The transport strategy focuses on enhancing accessibility to JKIA through integrated multimodal solutions, aligned with Nairobi's Vision 2030 and NIUPLAN objectives

Objectives:

- Improve Access: Improve accessibility to both airports via integrated road, rail, and BRT networks.
- Full Integration: Integrate airports with Nairobi's transport system, supporting Vision 2030 and NIUPLAN objectives
- Enhanced Experience: Boost efficiency, resilience, and sustainability while improving the overall passenger experience.

The proposed strategy is anchored on five core principles that collectively ensure its effectiveness, long-term sustainability, and inclusiveness for all airport users. These principles establish a coherent foundation for developing a resilient, integrated, and future-ready transport system serving the airport and its wider catchment.

1. Multimodal Integration

The strategy prioritizes connectivity across all transport modes, ensuring that passengers and employees can move efficiently between road, rail, public transport, and non-motorized networks. This principle supports a unified system in which each mode complements the others and enhancing the overall user experience.

2. Last-Mile Accessibility

A focus of the strategy is improving last-mile conditions through safe pedestrian pathways, dedicated walkways, and convenient shuttle services. These measures are intended to close existing mobility gaps, particularly for airport employees and public transport users, by ensuring that all key facilities are safely and easily reachable.

3. Phased Implementation

The strategy adopts a phased approach that aligns with short-, medium-, and long-term development horizons. This methodology ensures that investments are prioritized, resources are allocated efficiently, and the proposed improvements remain adaptable to evolving passenger demand and funding availability.

4. Institutional Coordination

Successful delivery of the strategy requires strong collaboration among all relevant stakeholders, including the Kenya Airports Authority (KAA), the Nairobi Metropolitan Area Transport Authority (NAMATA), and other government entities.

Effective coordination will streamline planning, avoid duplication of efforts, and support harmonized implementation across institutional mandates.

5. Sustainability and Equity

The strategy emphasizes sustainable and equitable mobility outcomes by promoting public transport, low-emission mobility, and universally accessible solutions. This approach aims to reduce the environmental footprint of landside access while ensuring that all airport users benefit from safe, affordable, and reliable transport options.

5.1.2.4.1 short-term strategies

The short-term strategies focus on delivering targeted, high-impact interventions that can be implemented quickly to address existing operational challenges and improve the immediate user experience. These measures prioritize efficiency, safety, and accessibility while laying the groundwork for medium- and long-term initiatives.

1. Road Junction Optimization to Ease Congestion

Targeted upgrades to key junctions along the airport access corridors will be undertaken to reduce queuing, streamline traffic flow, and minimize delays during peak periods. These improvements may include signal timing adjustments, minor geometric enhancements, channelization, and improved traffic management measures to address current bottlenecks with minimal capital investment.

2. Formalized Drop-Off and Pick-Up Areas

Dedicated and clearly delineated zones for taxis, ride-hailing services, and matatus will be established to organize vehicle movements and reduce conflicts at terminal forecourts. This formalization will improve circulation efficiency, enhance safety for passengers, and prevent the informal stopping and double-parking that currently contributes to congestion.

3. Enhanced Pedestrian and Non-Motorized Transport (NMT) Access

Improvements to pedestrian pathways, crossings, and lighting will be introduced along approach roads to ensure safe, uninterrupted access for airport employees and public transport users. These upgrades will support last-mile connectivity and promote more sustainable, low-emission travel modes within the airport precinct.

4. Shuttle Connection to BRT Line 2

A dedicated shuttle service will be introduced to provide a reliable link between the nearest BRT Line 2 station and the airport terminals. This connection will offer a more efficient public transport option for passengers and staff, supporting a modal shift away from private cars and reducing pressure on the landside road network.

5.1.2.4.2 medium-term strategies

The medium-term strategies focus on developing higher-capacity, structured, and technology-enhanced mobility solutions that address anticipated increases in passenger and employee demand. These measures strengthen the overall accessibility framework while reducing dependence on private vehicles and improving operational efficiency across the airport precinct.

1. Development of a Multimodal Access Terminal

A dedicated multimodal access terminal will be developed outside the terminal core to consolidate various transport services, including BRT, airport shuttles, taxis, and staff buses. This facility will function as a central interchange hub, enabling transfers between modes, reducing congestion at terminal frontages, and improving the efficiency of landside operations. Its location outside the terminal core allows for better spatial distribution of traffic and supports future expansion needs.

2. Structured Staff Shuttle Program

A formalized, scheduled staff shuttle program will be introduced to connect the airport with major residential catchment areas such as Embakasi, Nairobi West, and the Central Business District (CBD). This program will provide reliable, high-frequency transport options for airport employees, reducing reliance on informal or private transport and lowering congestion during shift change periods. The system will be designed to align with staff shift patterns and integrate with wider public transport networks.

3. Internal Circulator Service

An internal circulator service—potentially electric or automated—will be implemented to provide continuous connections between terminals, parking areas, and key modal hubs. This service will enhance intra-airport mobility, reduce walking distances, and improve the experience for passengers with luggage, as well as for staff. The adoption of electric or automated shuttles also supports sustainability objectives and lowers emissions within the airport precinct.

5.1.2.4.3 long-term strategies

The long-term strategies focus on delivering transformative, high-capacity infrastructure and institutional frameworks that fundamentally reshape how passengers and employees access the airport. These initiatives are designed to future-proof mobility systems, support projected growth horizons, and ensure full integration with Nairobi's wider metropolitan transport network.

1. Rail Spur from Embakasi Station to Provide Direct Rail Access to JKIA

A dedicated rail spur connecting Embakasi Station to the airport will be developed to offer direct, high-capacity rail access to JKIA. This link will significantly reduce travel times, provide a reliable alternative to road-based access, and accommodate long-term demand growth. The connection will integrate fully with the existing Nairobi Commuter Rail system, enabling interchange for both domestic and international passengers.

2. Development of a Multimodal Gateway Precinct

A comprehensive multimodal gateway precinct will be established, integrating rail services, BRT facilities, structured parking, logistics functions, and a dedicated people-mover system linking the hub to the passenger terminals. This precinct will serve as the airport's primary landside access node, consolidating all major transport modes into a unified, efficiently managed space. Its development will reduce congestion at terminal frontages, improve operational resilience, and support broader urban development objectives around the airport corridor.

3. Formal Airport Access Governance Group

A permanent governance structure will be formed to coordinate planning and operations across key agencies, including the Kenya Airports Authority (KAA), Nairobi Metropolitan Area Transport Authority (NAMATA), and Kenya Railways. This Airport Access Governance Group will provide a continuous platform for joint decision-making, investment coordination, data-sharing, and long-term access planning. Its establishment will ensure sustained alignment of multimodal transport initiatives and prevent fragmentation of responsibilities as infrastructure expands in future horizons.

5.2 FACILITIES

5.2.1 PASSENGER TERMINAL BUILDING

5.2.1.1 Expansion Strategy

Demand capacity assessment of the Passenger Terminal Building outlined that the current Terminals have the potential to suffice the demand till 2029. Post 2029, New PTB is required.

Terminal Expansion is proposed to be performed in 2 primary Phases as described below:

3. Phase 1:

   Expansion and Improvement projects for the current Terminals as defined in Demand Capacity Assessment section might be able to handle the proposed traffic demand by 2029.

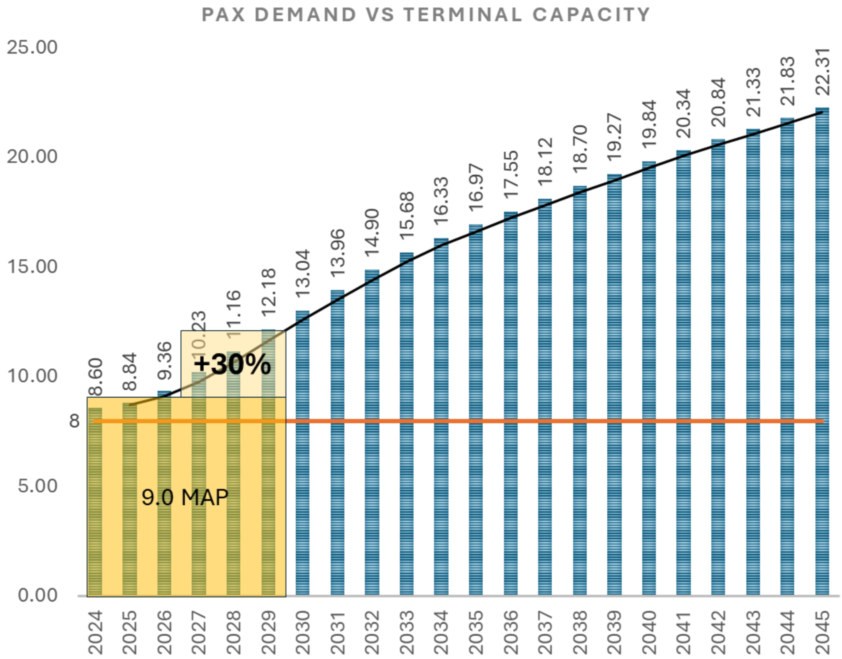


Figure 5.38: JKIA Phase 1 Terminal Capacity

4. Phase 2:

JKIA will consume all the potential of existing Terminals capacity by 2029. Hence, post 2029, a New Passenger Terminal building is a must to operate the Airport and handle the growing passenger demand. New PTB is proposed to be constructed in 2 sub phases as below:

c. Phase 2a: New PTB of 10 MAP capacity which will manage the operations conveniently by 2040.
d. Phase 2b: PTB expansion of 5 MAP capacity to handle the 2045 traffic demand of 22.3 MAP and provide additional capacity to manage the Airport for some more years beyond 2045.

Phase 2 will provide much flexibility to the Airport in many ways:

- If the passenger demand goes higher than the forecasted traffic, Phase 2b capacity will be able to suffice and manage the growth.
- If the passenger demand remains slower than the forecasted traffic, Phase 2b timeline can be postponed aligning with the actual demand.
- Integrated operations and higher capacity will be able to easily accommodate the complete operations of Kenya Airways and Partners including International and Domestic.

T1E can be demolished post construction and operationalization of Phase 2a. Existing Terminals might be having around 10 MAP capacity post 2029.

Phase 2 will also provide Aircraft stands adjacent to the New PTB maximizing the Contact gates operations to help Airport operate with better on-time performance and providing enhanced passenger convenience.

Overview of the Phase 2 Terminal capacities in relation to passenger demand is shown in below figures.

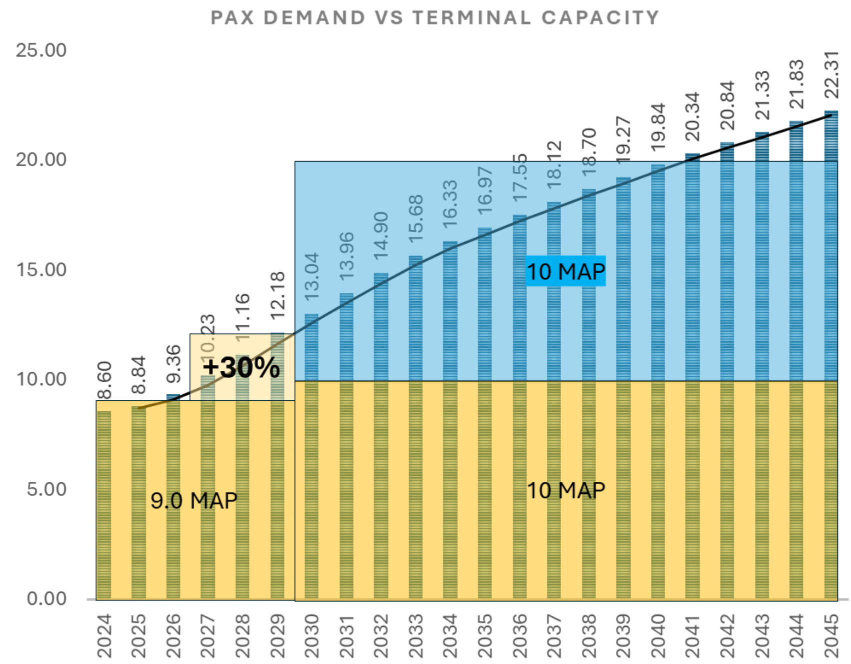


Figure 5.39: JKIA Phase 2a Terminal Capacity

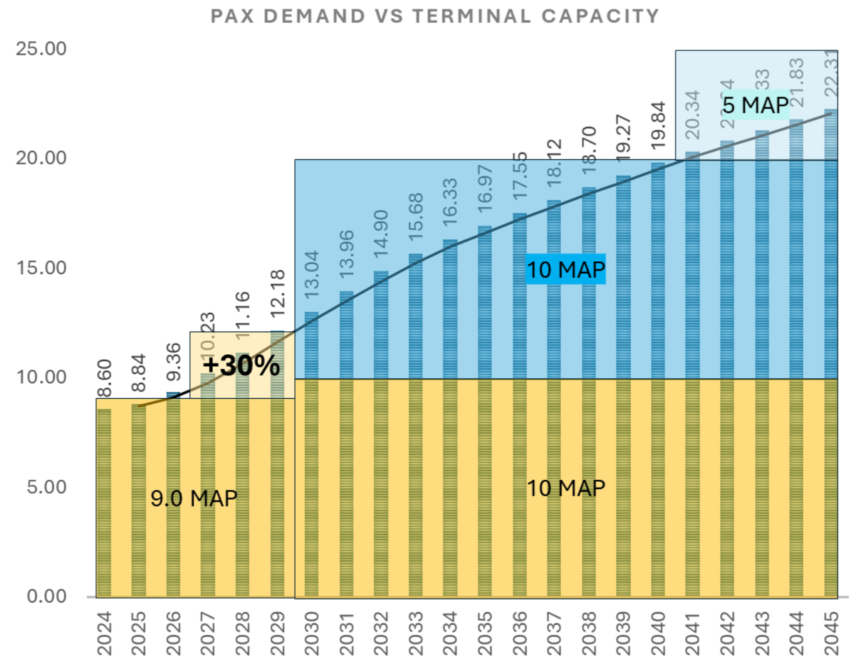


Figure 5.40: JKIA Phase 2b Terminal Capacity

5.2.1.2 Future Facility Requirement

The first and foremost task of Terminal planning after assessing Demand is the evaluation of Future Facilities. Terminals are operated with various Processing facilities which needs critical assessment for evaluating the requirement to cater the future demand.

Consultant has used the following assessment approach and methodology:

- Calculations are done based on IATA ADRM, version 12 which is the global standard for Airport development.
- 3 major components of the processing facilities are analysed:
  - Passenger Demand – These are derived from traffic forecasts
  - Processing Times – These are evaluated through
    - Data Shared by KAA

  - Benchmarking against similar Airports
  - Best-practice assumptions derived by Consultant's experts
- Waiting Times – These are aligned with 'Optimum' Level of Service mentioned in IATA ADRM 12

- Usage of Digital Facilities like Self Service Kiosks and electronic Gates for Passport Control Procedures are planned in the New PTB

There are numerous planning parameters which are fed into the model to calculate the Future facility requirements majorly comprised on processing times, queuing times and proportion of passenger using the facility.

Below tables summarise the planning parameters used for JKIA.

Terminal Planning Parameters					
Process	**Processing Time (in sec)** (based on Benchmarking + Previous studies)		**Maximum Queuing Time (in min)** (based on Optimum LoS, IATA ADRM 12)	**Proportion of passenger using the facility (% of PHP)** (based on Benchmarking + Previous studies)	
	International	Domestic	Int & Dom	Existing	From 2030
Entrance Security Control	20	20	10	100%	100%
Check-in					
Self Service Kiosk	90	90	2	0%	25%
Traditional Desk				100%	20%
Business/ First Class	210	210	5		
Economy	210	210	20		
Baggage Drop				0%	80%
Business/ First Class	60	60	3		
Economy	75	75	5		
Security Control	20	20*	10	100%	100%
Emigration					
Traditional Desks	60		10	100%	75%
e-Gates	45		5	0%	25%
Immigration					
Traditional Desks	80		10	100%	75%
e-Gates	45		5	0%	25%
Customs					
Inspection Booth	10		5	100%	100%
X-Ray Lane	5		5	100%	100%

Figure 5.41: JKIA Terminal Planning Parameters

Terminal Planning Parameters - Baggage Reclaim		
Process	**Pax Type**	
	International	Domestic
Ratio of Passenger with bags	100.00%	85.00%
Ratio of Bags per passenger	1.5	1
Average Claim Device Occupancy Time (in min)		
Narrow Body	20	
Wide-Body	45	

Figure 5.42: JKIA Terminal Planning Parameters - Baggage Reclaim

Consultant has fed these planning parameters into the model to obtain the requirements for New PTB Phase 1 (10 MAP) and Phase 2 (15 MAP). The result of the calculation model is explained in the tables below:

JKIA Terminal Processors Summary			
Process	Units	Requirement	
		10 MAP	15 MAP
Total Traffic (in mppa)		***10.00***	***15.00***
JKIA - International (in mppa)		*5.54*	*8.31*
JKIA - Domestic (in mppa)		*2.33*	*3.50*
JKIA - Transfer (in mppa)		*2.13*	*3.19*

Figure 5.43: JKIA Traffic Demand

Departures			
Peak Hour Demand - International	*no.*	***1,134***	***1,701***
Peak Hour Demand - Domestic	*no.*	***572***	***858***
Entrance Security Control	*no.*	***8***	***11***
Combined	*no.*	*8*	*11*
Self-Service Kiosks	*no.*	***17***	***24***
International	*no.*	*11*	*16*
Domestic	*no.*	*6*	*8*
Check-In Desks Total	*no.*	***56***	***84***
Baggage drop Desks - International	*no.*	*25*	*37*
Baggage drop Desks - Domestic	*no.*	*13*	*19*
Traditional Check-in Desks - International	*no.*	*12*	*18*
Traditional Check-in Desks - Domestic	*no.*	*6*	*10*
Security Control - Total	*no.*	***11***	***15***
Security - International	*no.*	*7*	*10*
Security - Domestic	*no.*	*4*	*5*
Emigration Desks	*no.*	***15***	***22***
Emigration e Gates	*no.*	***5***	***7***
Gate Lounges - Total (Code C Eq)	*no.*	***38***	***58***
International (Code C Eq)	*no.*	*31*	*47*
Code C Tp		*3*	*5*
Code C Jet		*18*	*26*
Code E		*8*	*12*
Domestic (Code C Eq)	*no.*	*7*	*11*
Code A		*4*	*6*
Code C Tp		*4*	*6*
Code C Jet		*4*	*6*

Figure 5.44: JKIA Departures Requirement

Arrivals			
Peak Hour Demand - International	*no.*	***1,230***	***1,846***
Peak Hour Demand - Domestic	*no.*	***594***	***890***
Immigration Desks	*no.*	***23***	***34***
Immigration e Gates	*no.*	***5***	***8***
Baggage Reclaim - Total	*no.*	***9***	***14***
International - 60m	*no.*	*3*	*5*
International - 90m		*3*	*5*
Domestic - 60m		*2*	*2*
Domestic - 90m		*1*	*2*
Customs - Inspection Booths	*no.*	***5***	***7***
Customs - X-Ray Machines	*no.*	***3***	***4***
Transfer			
Peak Hour Demand: I-I	*no.*	***626***	***939***
Security Transfer I-I	*no.*	*4*	*6*

Figure 5.45: JKIA Arrivals and Transfers Requirement

The above tables are the minimum requirement for various processing facilities in the Terminal. These were then assessed and used for preparing the Terminal layouts, refer further sections.

5.2.1.3 Terminal Configuration

Passenger Terminal buildings are often categorized based on their shape, layout, and aircraft–passenger interface. Terminal Shape Configuration is decided based on various factors:

- Airport Size: Small (less than 5MAP), medium (5-15MAP) or large (more than 15 MAP)
- Airport Operations: Only Domestic, Integrated (Domestic + International)
- Passenger Type: Only O&D (Originating & Destination)/ Less Transfers, Heavy Transfers proportion
- Minimum Connection Time
- Scalability
- Maximization of Revenues

Each shape has operational, spatial, and capacity implications. Broadly, terminal shapes can be grouped as follows:

- Classical Shapes
- Modern Shapes

Classical Shapes

Classical shapes are simple geometrical shapes. These are generally suited best for point-to-point operations except Concourses (good for transfers). Classical shapes are easy for construction. These shapes are generally cost-friendly. Some of the common examples are:

- Linear
- Curvilinear
- Satellite
- Concourses

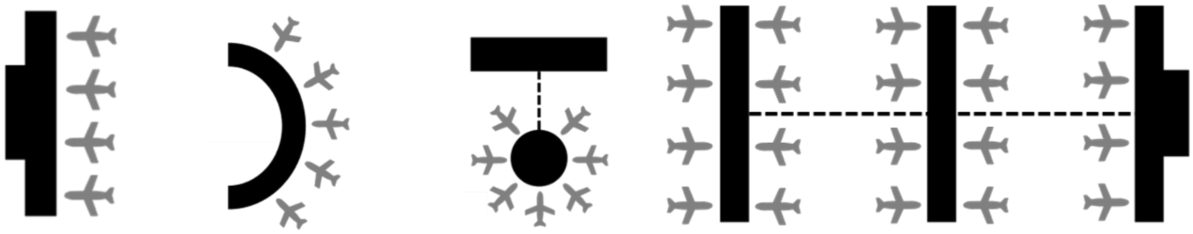


Figure 5.46: Classical Terminal Shapes

Modern Shapes

Modern shapes are commonly the Alphabetical geometries. These are generally suited best for Hub operations and Transfers. Modern shapes are often combined into Hybrid layouts for scalability. Some of the common examples are:

- X- shape
- Y-shape
- H-shape
- Star / Starfish

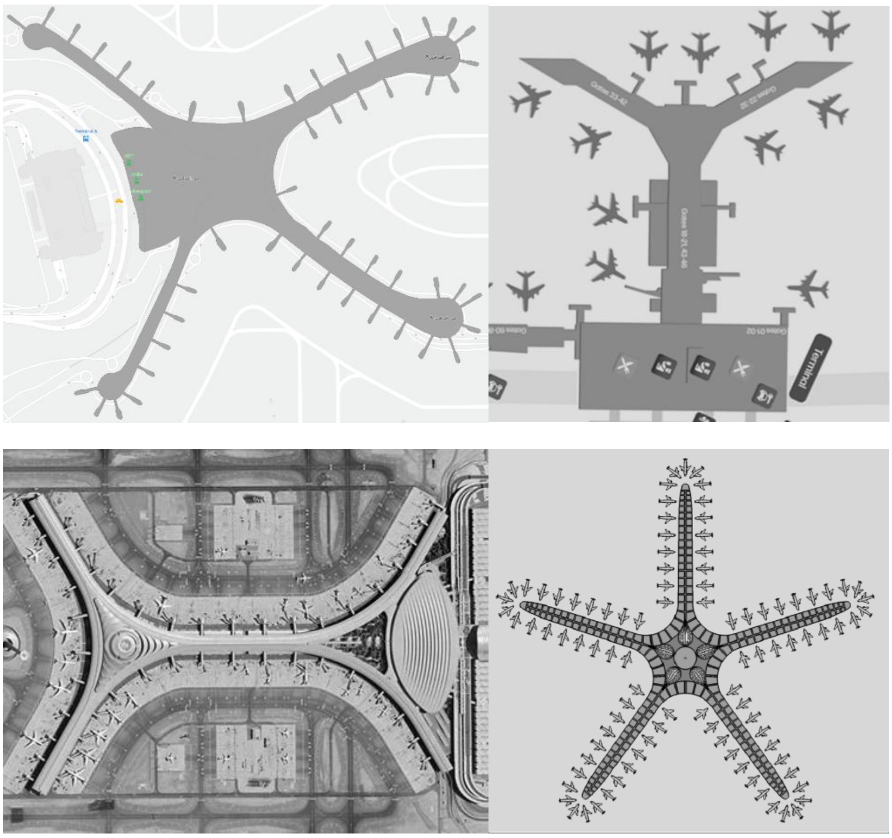


Figure 5.47: Modern Terminal Shapes

Below are the detailed overview and assessment of these configurations including pros and cons:

Table 5.14: Terminal Shapes Overview

Terminal Shapes Overview					
S. No.	**Category**	**Shape**	**Pros**	**Cons**	**Examples**
1	**Linear/ Pier**	Straight concourse (single or multiple)	Simple, expandable, efficient for O&D traffic	Long walking distances, transfer inefficiency	Frankfurt, Heathrow T2
2	**Curvilinear**	Arc or U-shape terminal	Short walking, good curb access	Expansion difficult, limited gate frontage	Dallas/Fort Worth (original), Paris CDG T2
3	**Satellite/ Concourses**	Detached island(s)/ concourse buildings linked by tunnel/APM	Compact gate clustering, efficient transfers	High cost for APM/tunnels, complex baggage systems	Paris CDG T1, Atlanta, Orlando, Heathrow T5
4	**X-Shape**	Four concourses radiating diagonally	Balanced gates, efficient transfers, expandable	Expensive, complex circulation	Abu Dhabi
5	**Y-Shape**	Central stem with two diverging arms	Good for split ops (domestic/international), simple expansion	Less compact than star	Qatar, Zurich
6	**H-Shape**	Two parallel piers linked by a central bar	Maximizes gate frontage, supports separation (e.g., Domestic/International)	Requires people movers, can be confusing	Jeddah, Hong-Kong Midfield
7	**Star/ Starfish**	Central core with 3–8 concourses radiating like spokes	Very efficient for transfers, scalable hub design	Complex baggage/APM, high cost	Beijing Daxing

Considering the JKIA Traffic Forecast, Airline mix and Operational Demand, the below Terminal Configurations are best suited for the New Terminal Building at JKIA:

- Linear/ Pier
- Satellite/ Concourses
- X-Shape
- H-Shape

Consultant analysed all the above configurations in detail for JKIA to finalize the Best Configuration. The configurations were assessed for Phase 2 i.e., 15 MAP Terminal on the proposed Midfield location.

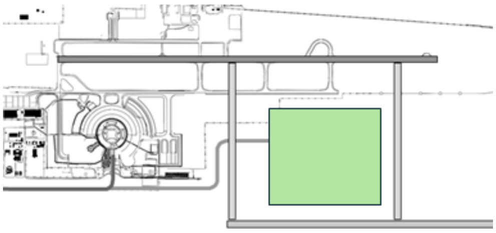


Figure 5.48: JKIA New PTB Proposed Location

5.2.1.3.1 Linear / Pier

Linear shape for JKIA New PTB Proposed Location comes out to be a compact plan with a Tentative Terminal area of 220,000 sqm.

Conceptual Layout and detailed features are described below:

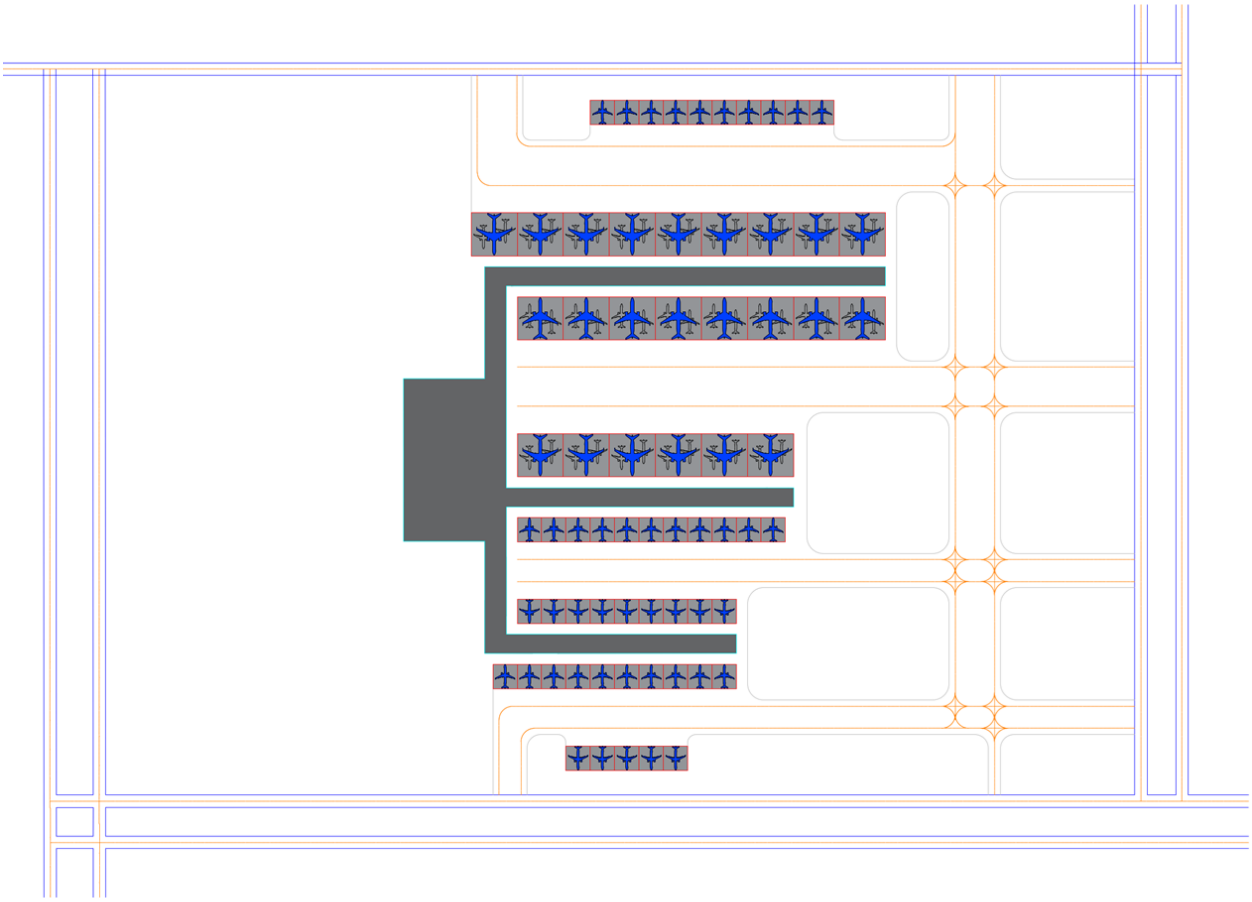


Figure 5.49: Linear Shape – JKIA Conceptual Terminal Layout

Below table indicates various features of the Linear shape planned for JKIA New PTB.

Table 5.15: Linear Shape Features

Features		
1	**Terminal Footprint**	**120,000 sqm**
2	**Terminal Area (tentative)**	**200,000 sqm**
3	**Contact Stands – International**	**80%**
4	**Contact Stands – Domestic**	**80%**
5	**Gate/ Stand Frontage**	**5,100 m**
6	**Walking Distances**	**High**
7	**Connection Time**	**High**
8	**Ease of Future Expansion**	**Medium**
9	**APM requirement**	**No**
10	**Site/ Design Compactness**	**High**

5.2.1.3.2 Concourse

Configuration of Concourses for JKIA New PTB Proposed Location comes out to be very compact plan with a Tentative Terminal area of 240,000 sqm.

Conceptual Layout and detailed features are described below:

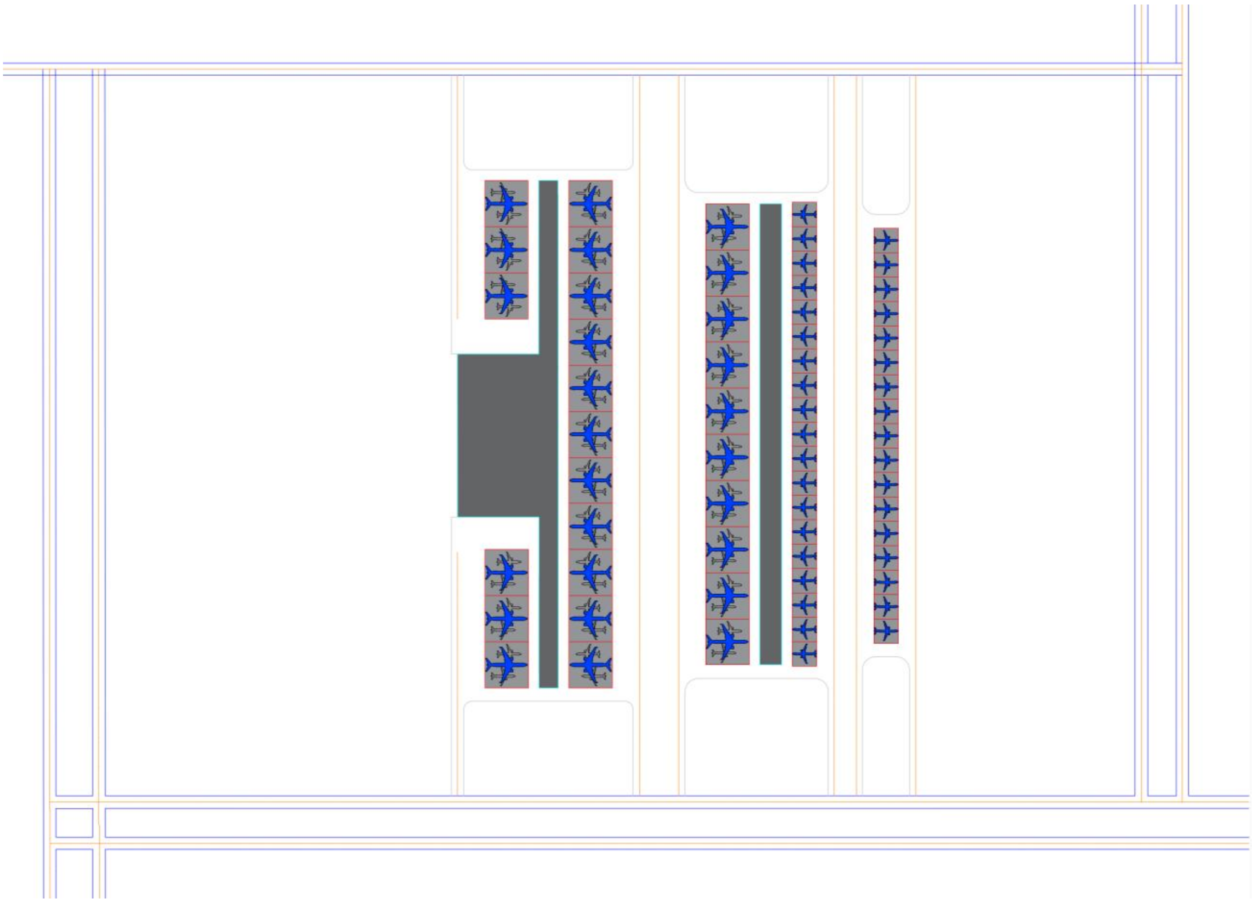


Figure 5.50: Concourse – JKIA Conceptual Terminal Layout

Below table indicates various features of the Concourse planned for JKIA New PTB.

Table 5.16: Concourses Features

Features		
1	**Terminal Footprint**	**110,000 sqm**
2	**Terminal Area (tentative)**	**220,000 sqm**
3	**Contact Stands – International**	**80%**
4	**Contact Stands – Domestic**	**80%**
5	**Gate/ Stand Frontage**	**4,100 m**
6	**Walking Distances**	**High**
7	**Connection Time**	**Medium**
8	**Ease of Future Expansion**	**High**
9	**APM requirement**	**Yes**
10	**Site/ Design Compactness**	**High**

5.2.1.3.3 X-Shape

Configuration of X-shape for JKIA New PTB Proposed Location turns out to be a symmetrical plan with a Tentative Terminal area of 250,000 sqm.

Conceptual Layout and detailed features are described below:

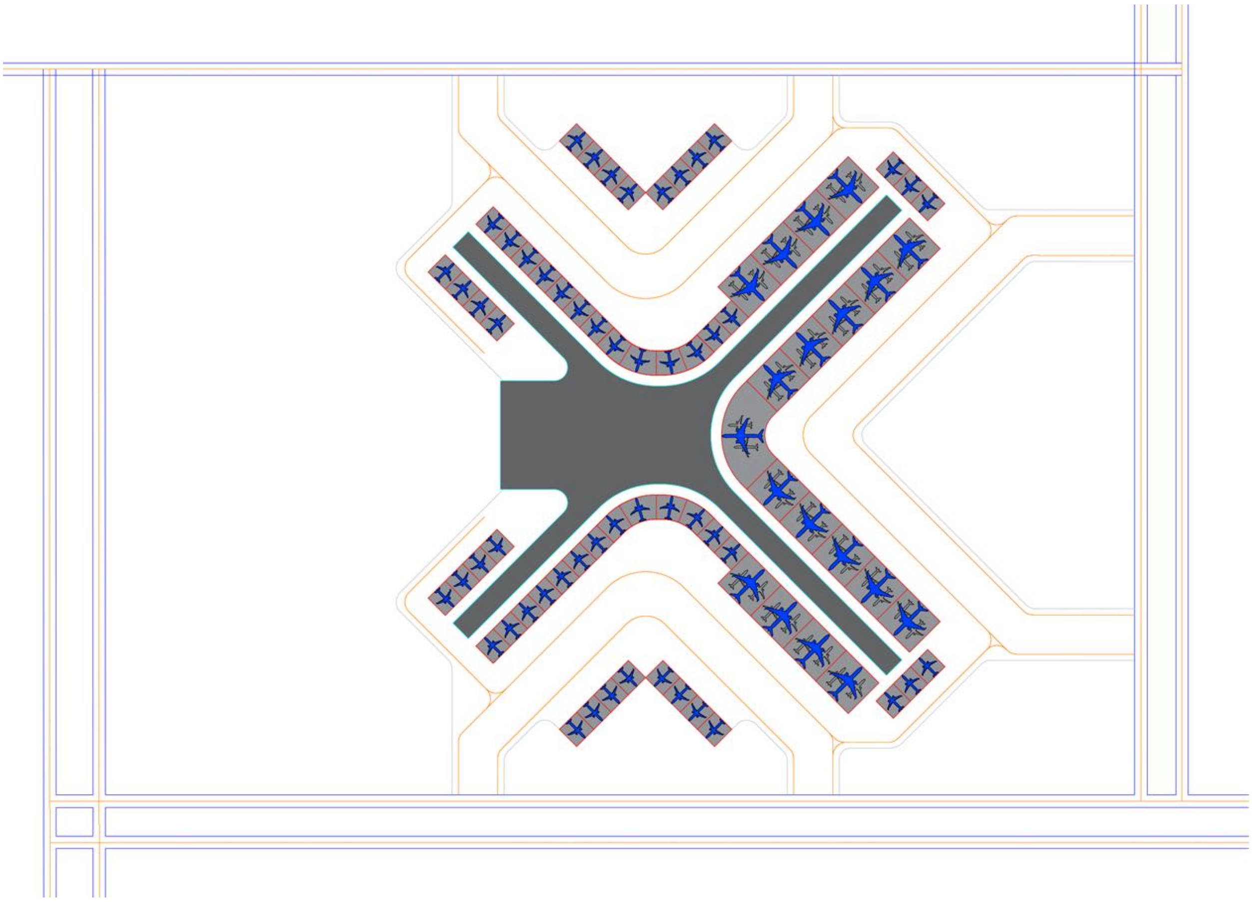


Figure 5.51: X- Shape – JKIA Conceptual Terminal Layout

Below table indicates various features of the X- shape planned for JKIA New PTB.

Table 5.17: X-Shape Features

Features		
1	Terminal Footprint	140,000 sqm
2	Terminal Area (tentative)	230,000 sqm
3	Contact Stands – International	80%
4	Contact Stands – Domestic	80%
5	Gate/ Stand Frontage	4,400 m
6	Walking Distances	Medium
7	Connection Time	Low
8	Ease of Future Expansion	Low
9	APM requirement	No
10	Site/ Design Compactness	Medium

5.2.1.3.4 H-Shape

Configuration of H-shape for JKIA New PTB Proposed Location turns out to be a widespread plan with a Tentative Terminal area of 320,000 sqm.

Conceptual Layout and detailed features are described below:

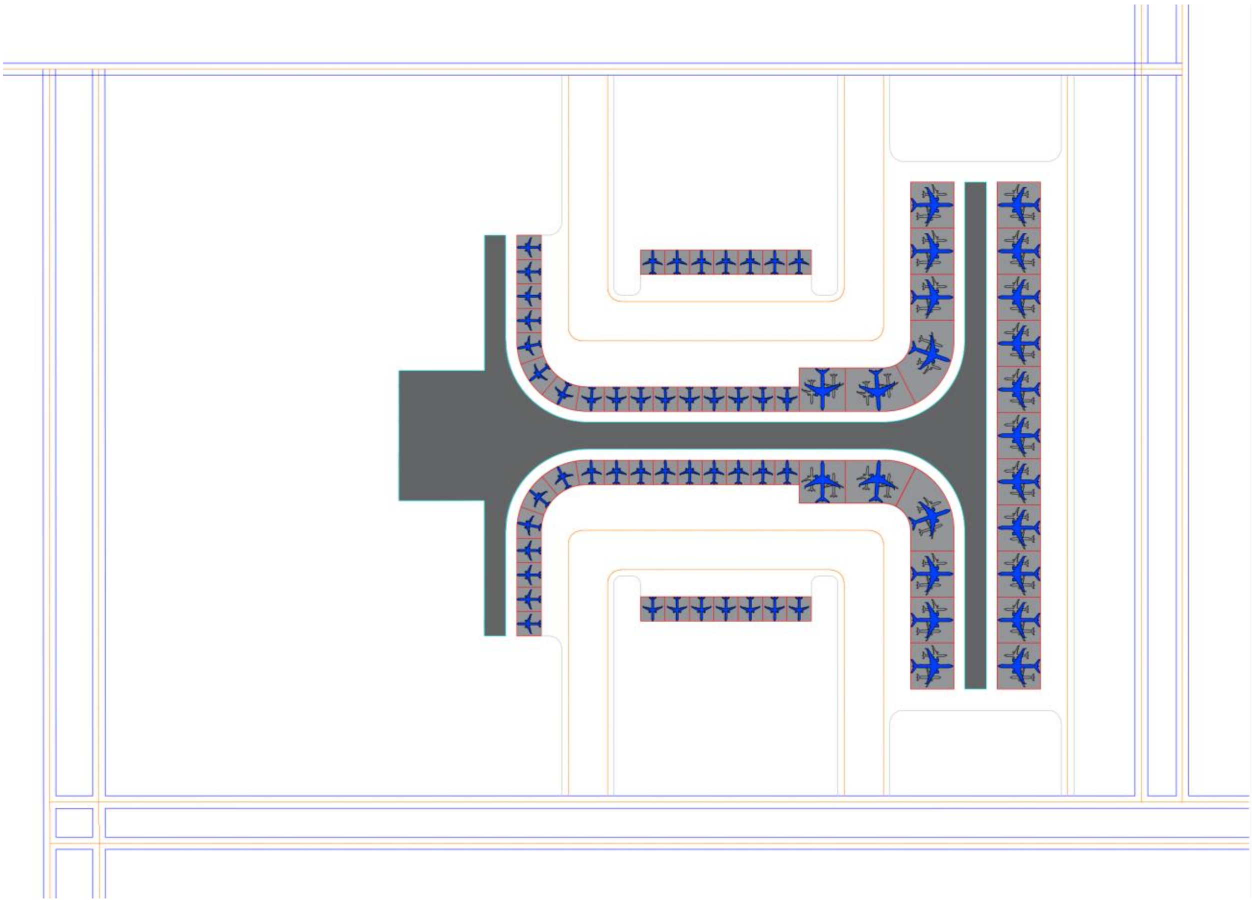


Figure 5.52: H - Shape – JKIA Conceptual Terminal Layout

Below table indicates various features of the H- shape planned for JKIA New PTB.

Table 5.18: H-shape Features

Features		
1	**Terminal Footprint**	**160,000 sqm**
2	**Terminal Area (tentative)**	**300,000 sqm**
3	**Contact Stands – International**	**80%**
4	**Contact Stands – Domestic**	**80%**
5	**Gate/ Stand Frontage**	**5,100 m**
6	**Walking Distances**	**Medium**
7	**Connection Time**	**Medium**
8	**Ease of Future Expansion**	**Low**
9	**APM requirement**	**Yes**
10	**Site/ Design Compactness**	**Low**

5.2.1.3.5 Configuration Evaluation

All the above 4 proposed configurations fulfill some of the assessment criteria for selecting the ultimate configuration for JKIA. Detailed assessment is as follows:

Table 5.19: Configurations Evaluation

Configurations Feasibility Evaluation					
S. No.	**Criteria**	**Linear/ Pier**	**Concourses**	**X-Shape**	**H-Shape**
1	Passenger Convenience	Red	Yellow	Green	Green
2	Terminal Area	Green	Green	Green	Red
3	Gate/ Stand Frontage	Red	Green	Green	Red
4	Construction Phasing	Green	Green	Green	Green
5	Walking Distances	Red	Yellow	Green	Yellow
6	Connection Time	Red	Yellow	Green	Yellow
7	Ease of Future Expansion	Yellow	Green	Red	Red
8	APM requirement	Green	Red	Green	Red
9	Site/ Design Compactness	Green	Green	Yellow	Red
10	CAPEX (Cost Impact)	Green	Yellow	Green	Red

Each configuration is assessed against the 10 given criteria and based on the evaluation matrix; X-shape has turned out to be the recommended Terminal Configuration for New PTB of Jomo Kenyatta International Airport.

5.2.1.4 Terminal Benchmarking

5.2.1.4.1 Introduction

To support the planning and design development of the proposed new JKIA Terminal Building, a benchmarking exercise was undertaken to analyze comparable international airport terminals.

The selected reference airports were chosen based on their design excellence, operational efficiency, architectural form, passenger experience, and overall product aspiration.

These terminals represent globally recognized examples of contemporary airport design, each reflecting innovative solutions that align with or surpass the functional and aesthetic ambitions envisioned for the new JKIA Terminal.

The following four international airports have been identified as relevant benchmarks for this study:

- Terminal 1 – Hong Kong International Airport (HKIA), Hong Kong
- Terminal 5 – Changi International Airport (SIN), Singapore
- Istanbul Airport (IST), Istanbul, Turkey
- Beijing Daxing International Airport (PKX), Beijing, China

For each example, a brief narrative has been provided to explain the project's relevance and identify any features of note: regional competitor, airport expansion strategy, etc. In addition, several benchmark criteria will be compared across all benchmark examples.

The outcome of the benchmarking report will serve as a good input to the initial space planning for the final design stage.

5.2.1.4.2 Overall Building Benchmark

This section provides information on the terminals and satellite concourses used in the benchmark study.

5.2.1.4.2.1 Terminal 1 - Hong Kong International Airport, Hong Kong (HKIA)

Figure 5.53: Photograph of Terminal 1

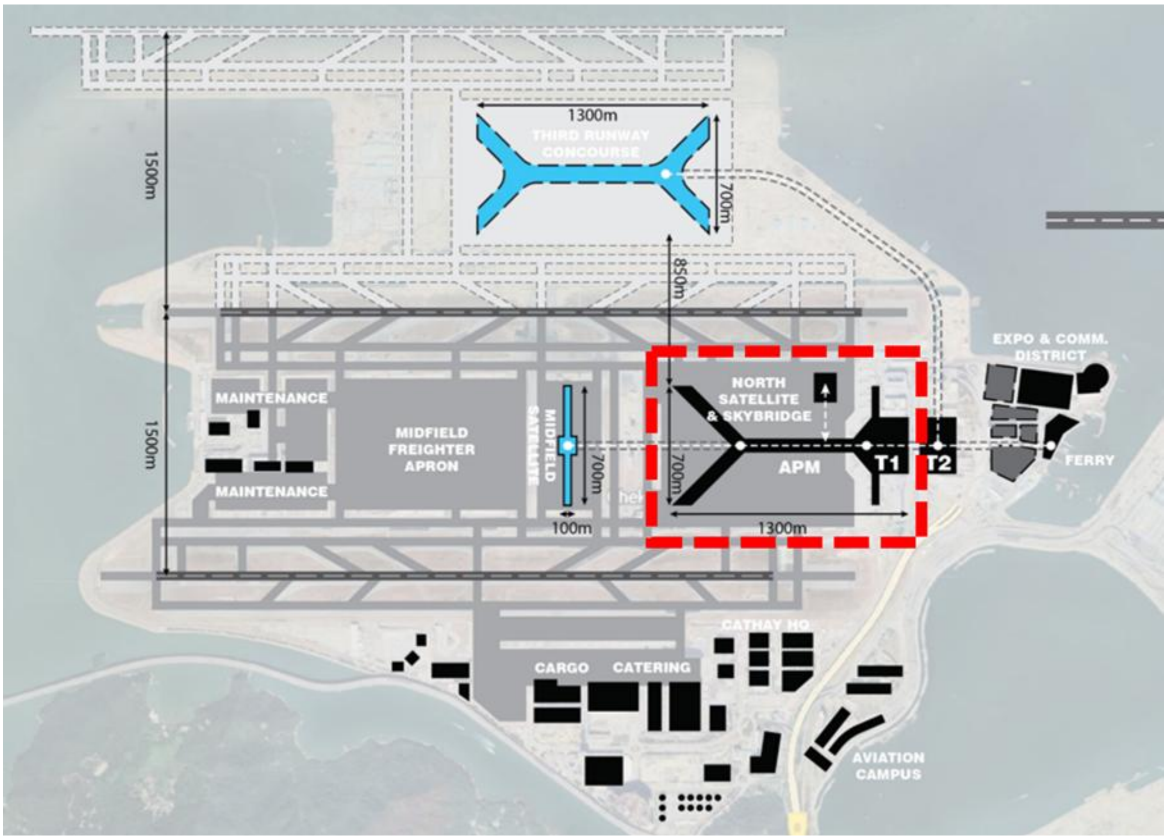


Figure 5.54: Satellite Image & Map Location of Terminal 1

HKIA is located in Hong Kong Special Administrative region. It is a major Asian and international hub and is the hub airport for Cathay Pacific which achieves a high Skytrax rating for the airline product.

Terminal 1 is 1300 m (l) and 700m (w) with 47 contact stands and caters for 71 million passengers annually. Approximately 50MPAX is served by T1 with the remainder provided in Midfield Concourse and North Satellite Concourse

Physical variables

- **Section strategies**
  The Terminal has the arrivals below the departures level with the APM system below grade.
  Main Vertical circulation happens at the base of the Y at both nodes. This provides access to the APM system and remote bussing facility.
- **Horizontal setting out**
  The Terminal has a Y form fed from the terminal head house at the one end. Gate lounges are positioned next to the façade around the perimeter of the building with a circa 12m width. Central circulation with travellators run through the middle of the piers with occasional retail and toilets flanking this route.
- **Number of Stands**
  47 contact stands.
- **Areas**
  Terminal 1 of the HKIA, with an area measuring 570,000 square meters is one of the largest passenger airport terminal buildings in the world.

Concept of Operations

- **Airline operations**
  Terminal 1 is predominantly used by Cathay Pacific Airways with its head office and main hub located at Hong Kong International Airport.
- **Airport operations**

Arriving and departing passengers are fully segregated. Staff circulation between levels is restricted/controlled.

5.2.1.4.2.2 Changi T5 Terminal - Changi International Airport, Singapore (SIN)

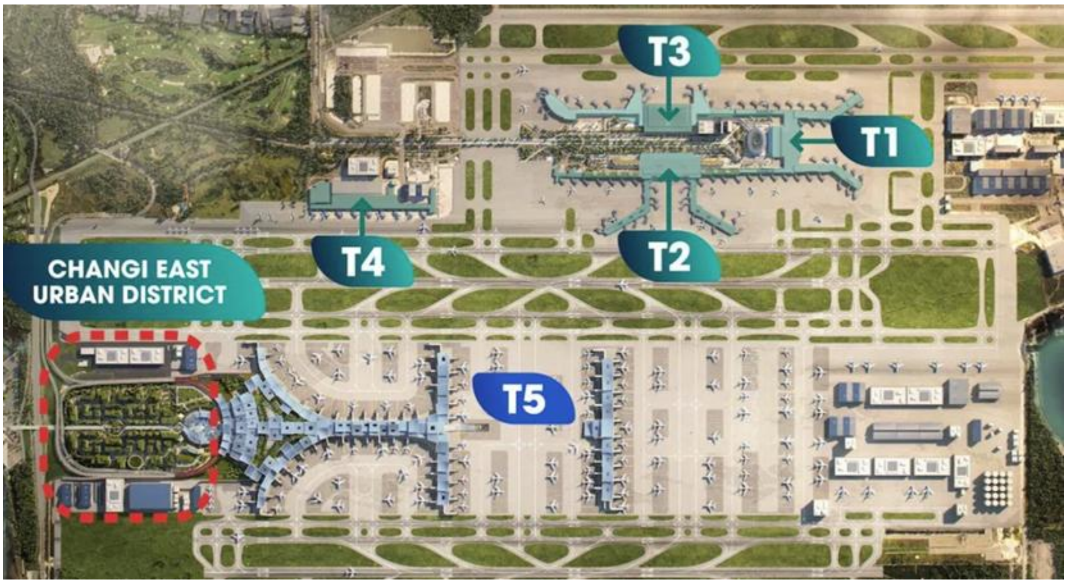


Figure 5.55: Map Location of the Changi T5 Terminal

Changi Airport is constructed on reclaimed land on the East side of Singapore. It has two parallel runways and four terminal buildings three of which are linked both airside and landside to form a multi terminal precinct.

Changi has commenced work on an ambitious expansion with the aim of adding an additional 50 MPPA which will take the capacity of the airport beyond 100 MPPA.

New land has been reclaimed to the East of the existing terminal and a third parallel runway has been brought into operation.

T5 will be designed with the flexibility to be built in two phases, in line with traffic growth, and is expected to be operational around the mid-2030s.

Physical variables

- **Section strategies**
  The satellite has four main above ground levels and several basement levels. Apron level comprises two transfer baggage handling facilities, ramp support and plant spaces. The main arrivals level is located below departures at about 6m above apron and the main departures concourse is located at about 12m above apron level. There is an upper level mezzanine with potential for a food court or airline lounges above departures level.
- **Horizontal setting out**
  The plan to accommodate all the functions needed in the middle of the building.
  The furthest gate is located approximately 450m from the centre. Walking assistance is provided by moving walkways in the centre. The gates have open seating areas approximately 20m deep. The open spine circulation is approximately 45m wide with occasional placement of commercial and general seating.
- **Number of Stands**
  22 contact stands.
- **Areas**
  The satellite building is approximately 90m X 1000m creating a footprint of about 90,000 sqm.

Concept of Operations

- **Airline operations**
  The Terminal 5 complex is intended to be used by Singapore Airlines and its associated carriers. It will be a new hub for the airline. There will be a mixture of transferring and originating/departing passengers.

- **Airport operations**
  Changi currently operated both centrally and disaggregated security strategies in various terminal buildings.

5.2.1.4.2.3 Istanbul Airport (IST) , Istanbul ,Turkey

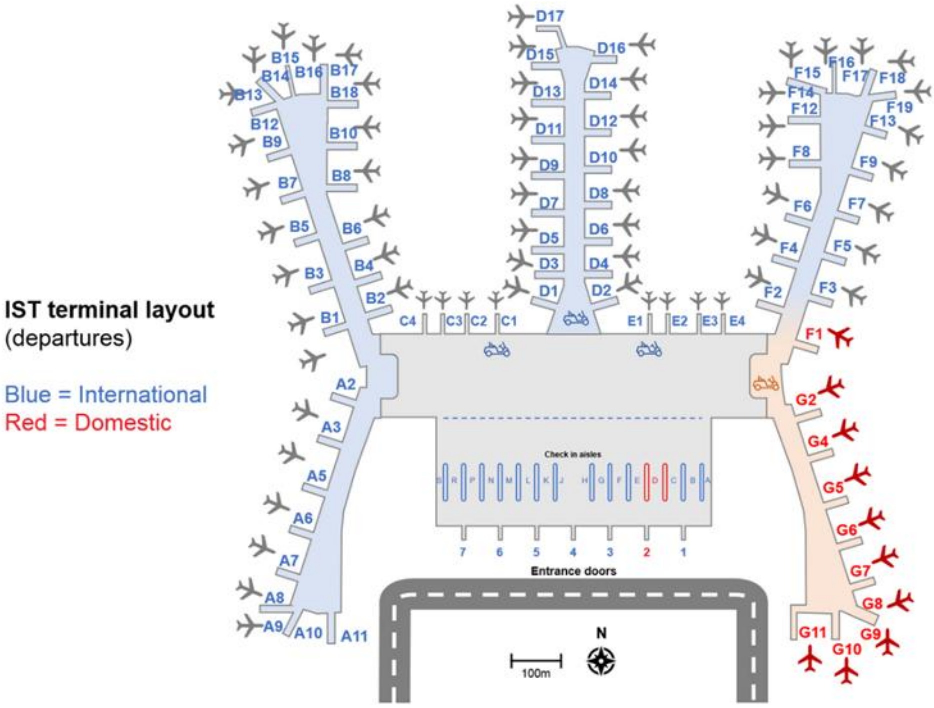


Figure 5.56: Istanbul Airport Keyplan

Istanbul Airport is located in the European side of Istanbul, Turkey. It serves as the main international and domestic hub for the national carrier Turkish Airlines, and is designed as a major global transfer point linking Europe, Asia and Africa.

<u>Physical variables</u>

- **Section strategies:**
  The terminal building spans both arrival and departure functions under one roof. Departures and arrivals are arranged on separate levels; the main terminal hall features a large central spine with radiating piers (five concourses labelled A, B, D, F, G) served by escalators, elevators and moving walkways. Some of the remote piers serve domestic flights, with international operations grouped on other piers
- **Horizontal setting out:**
  The building is enormous in footprint — reported at approx 1,440,000 m² for the main terminal. The layout comprises a central hub/spine from which 5 large finger-like concourses extend. Gate lounges are around the perimeter of each pier.
- **Number of Stands / Boarding Bridges:**
  The terminal includes 143 passenger boarding bridges (contact stands) in the first phase.
- **Area & Capacity:**
  The main terminal building covers ~1,440,000 m² and was designed to handle 90 million passengers per annum in its first phase.

<u>Concept of Operations</u>

- **Airline operations**
  Istanbul Airport serves as the primary hub for Turkish Airlines, the national flag carrier, which operates an extensive global network connecting Europe, Asia, Africa, and the Americas. The terminal layout and facilities are optimized for transfer efficiency to support hub-and-spoke operations.
- **Airport operations**

Departing and arriving passengers are vertically segregated, with clear separation between Schengen-equivalent and international transfer flows.

The terminal operates through an integrated coordination system supported by an Airport Operations Control Center (AOCC), where airlines, air traffic control, and airport authorities work collaboratively in real time to optimize flight scheduling, gate allocation, and passenger processing efficiency

5.2.1.4.2.4 Beijing Daxing International Airport (PKX) – Beijing, China

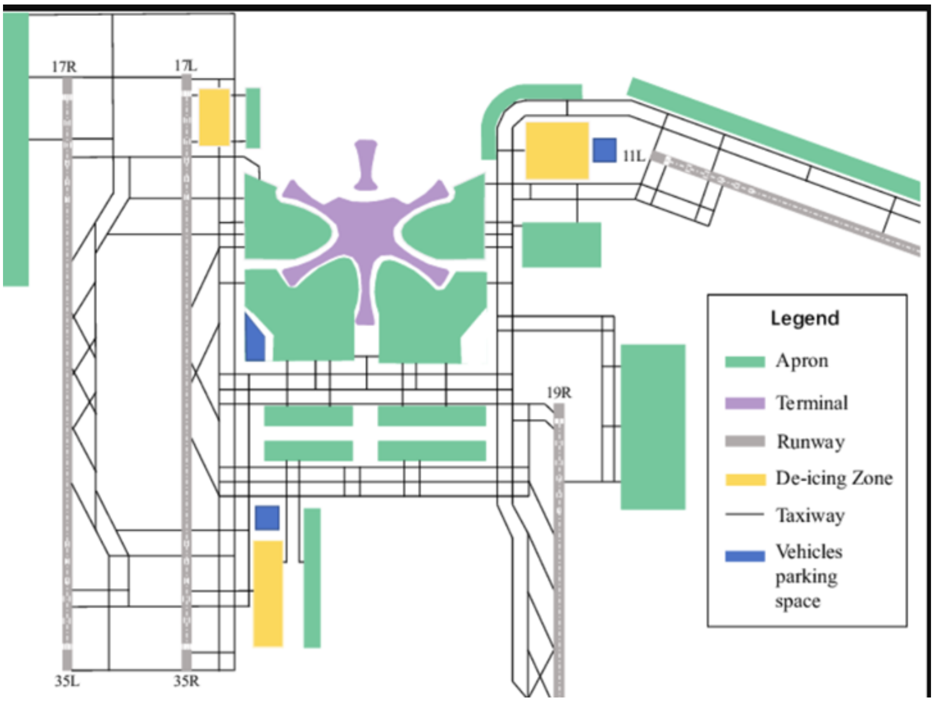


Figure 5.57: Beijing Daxing International Airport keyplan

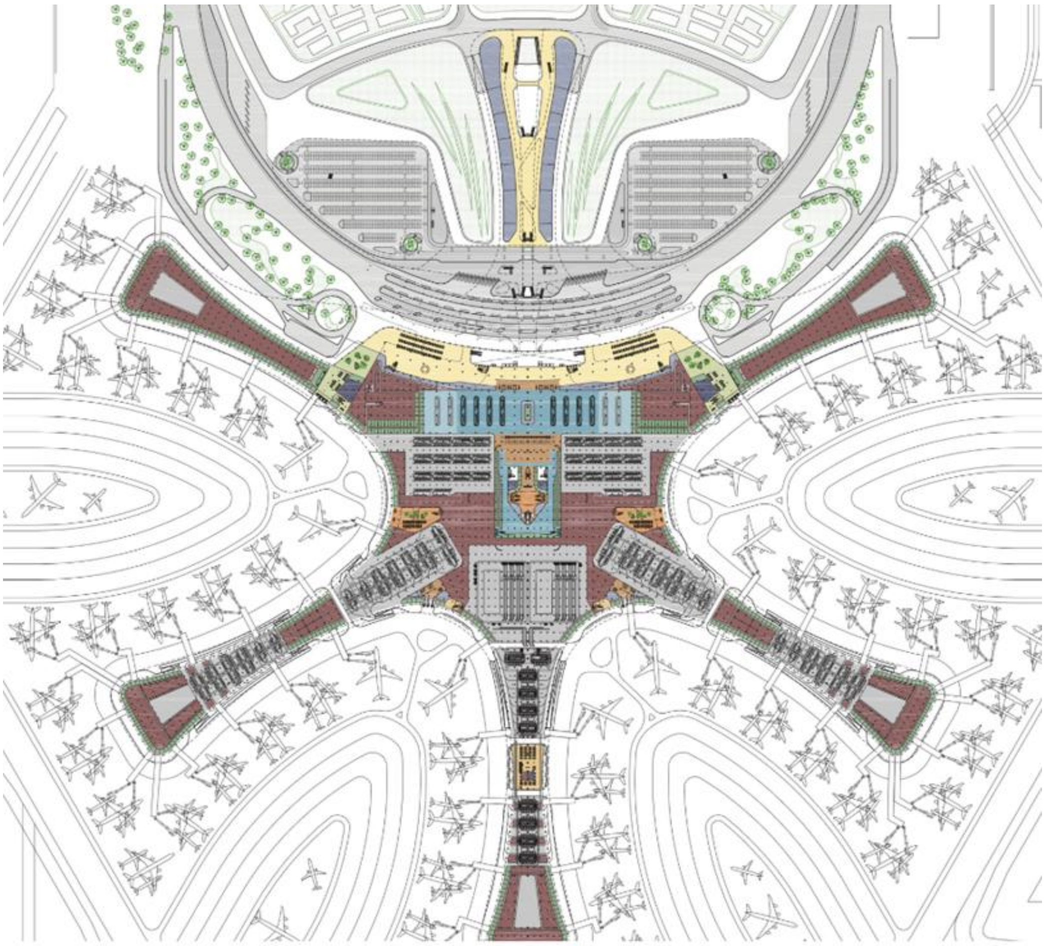


Figure 5.58: Beijing Daxing International Airport layout

Beijing Daxing International Airport is located approximately 46 km south of Beijing city center. It serves as a major hub for Air China and China Southern Airlines, designed to alleviate capacity constraints at Beijing Capital Airport (PEK) and to become one of the primary international gateways for northern China.

The terminal is conceived as a radial, starfish-shaped hub that allows short transfer distances and efficient aircraft circulation around a central core.

The compact design means that passengers can move seamlessly from one area to the next without having to rely on shuttles. In fact, the longest walking time to any of the 79 gates is less than 8 minutes.

Physical Variables

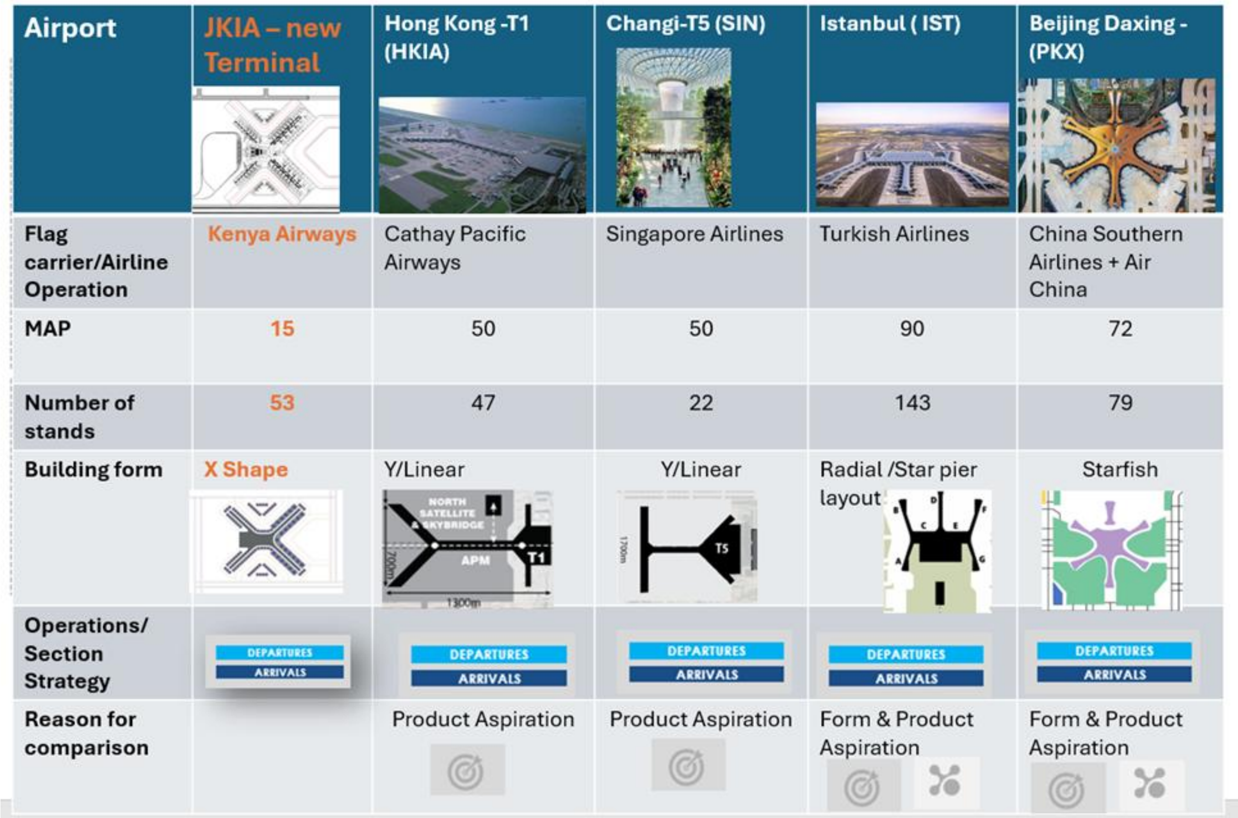
- **Section strategies:**
  The terminal integrates departure and arrival functions within a single structure organized across multiple levels. Departures occupy the upper levels with arrivals and ground transport connections located below. Centralized vertical circulation cores link each of the radial arms with the central processing hall, minimizing passenger walking distances.
- **Horizontal setting out:**
  The terminal adopts a five-arm “starfish” configuration radiating symmetrically from a central atrium. This layout maximizes aircraft contact stands around the perimeter and provides direct sightlines to all gates. Retail and passenger amenities are concentrated in the central zone, with automated people movers connecting the far ends of the concourses. Natural daylight is a key design feature, achieved through a large-span steel roof with continuous skylights.
- **Number of Stands / Boarding Bridges:**
  The initial phase includes 79 contact stands, expandable in later phases.

- **Area & Capacity:**
  The terminal building covers approximately 700,000 m² and is designed to handle 72 million passengers per annum (MPAX) in its initial phase, expandable to over 100 MPAX at full build-out.

Concept of Operations

- **Airline operations**
  Daxing Airport functions as a dual-hub platform primarily for China Southern Airlines and Air China, serving as a key national and international transfer node. The terminal's star-shaped design enables efficient hub-and-spoke operations with minimal connection times between domestic and international flights.
- **Airport operations**
  Passenger flows are vertically segregated with clear separation between arrivals and departures. The airport employs advanced automation systems, facial-recognition boarding, and a central Airport Operations Control Center (AOCC) to coordinate all stakeholders, ensuring efficient turnaround and consistent service performance.

5.2.1.4.3 Summary of Benchmark Examples



Airport	JKIA – new Terminal	Hong Kong -T1 (HKIA)	Changi-T5 (SIN)	Istanbul (IST)	Beijing Daxing - (PKX)
Flag carrier/Airline Operation	Kenya Airways	Cathay Pacific Airways	Singapore Airlines	Turkish Airlines	China Southern Airlines + Air China
MAP	15	50	50	90	72
Number of stands	53	47	22	143	79
Building form	X Shape	Y/Linear	Y/Linear	Radial /Star pier layout	Starfish
Operations/ Section Strategy	DEPARTURES / ARRIVALS	DEPARTURES / ARRIVALS	DEPARTURES / ARRIVALS	DEPARTURES / ARRIVALS	DEPARTURES / ARRIVALS
Reason for comparison		Product Aspiration	Product Aspiration	Form & Product Aspiration	Form & Product Aspiration

Figure 5.59: Summary of Benchmark Examples

5.2.1.4.4 Conclusion

The benchmarking analysis provided valuable insights into the best global practices in terminal design, operation, and passenger experience.

By comparing the proposed JKIA new Terminal with leading international examples such as **Hong Kong T1, Changi T5, Istanbul, and Beijing Daxing**, the study identified relevant strategies in terms of building form, operational efficiency, passenger processing, and product aspiration.

These references guided the planning and design of the new JKIA terminal, helping it achieve a balance of function, flexibility, and passenger comfort, while reflecting a modern, world-class image that supports Kenya's growing aviation goals.

5.2.1.5 Terminal Functional Design

5.2.1.5.1 Terminal Location

The proposed Terminal building will be located to the east of the existing terminal.

The Terminal includes a two-level curb, with one level for arrivals (ground level) and one for departures (second level).

Passenger flows are detailed in the following sections.

The figure below shows the layout of the new JKIA terminal. Full drawings of the passenger terminal building layout are presented in Appendix K.

Figure 5.60: Jkia Terminal location

5.2.1.5.2 Terminal Planning Concept

The proposed Terminal Building adopts an X-shaped configuration, designed to efficiently serve 10 million passengers per annum (MPPA) in Phase I, with expansion capacity to 15 MPPA at the ultimate phase. The layout provides a clear functional separation between international and domestic operations, with the longer front piers dedicated to international traffic and the lateral piers accommodating domestic flights. This configuration optimizes passenger circulation, facilitates efficient aircraft operations, and allows for balanced airside and landside connectivity.

The overall configuration of the passenger terminal building is primarily driven by the apron layout, particularly the number and size of the contact stands. The terminal comprises a central processing zone linked to the four extending piers, with the X-shaped geometry enabling direct and efficient distribution of passengers to each pier while minimizing walking distances.

The configuration of the central processing hall is established according to functional and queuing requirements, as defined in the IATA ADRM, 12th Edition.

The sizing of each pier reflects the allocation of aircraft contact stands and their related passenger holding areas.

The initial phase of the X-shaped terminal presents a larger overall footprint, given the minimal increase in contact stands projected for the ultimate phase.

The total terminal GFA is 231,000 sqm, which can be reduced to 217,500 sqm by optimizing the ratio of contact to remote stands in coordination with the client during the design stage.

5.2.1.5.3 Planning Principles and Flexibility

The New Terminal design is guided by core planning principles that ensure operational efficiency, passenger comfort, and adaptability for future growth:

- **Functional clarity and efficient passenger processing**: The terminal layout separates arriving, departing, and transfer passengers, with clearly defined circulation paths, and appropriately sized check-in, security, immigration, boarding, and baggage reclaim areas. Gate lounges, concessions, and service areas are strategically located to support smooth flows and reduce congestion.
- **Modularity and scalability for phased expansion**: The terminal is designed for phased construction and future growth, allowing the addition of new boarding gates, processing areas and piers without disrupting operations.
- **Optimized walking distances and operational efficiency**: The layout minimizes walking distances between check-in, security, gates, and baggage reclaim, while incorporating central processing zones.

Transfer passenger flows are efficiently integrated to maintain smooth connections.

5.2.1.5.4 Functional Layout Description

- **Central Processing Area:**
  The main terminal core includes the check-in hall, security screening, passport control and central retail/services area.
  From this core, passengers are distributed to the respective international or domestic piers.
- **International Piers (Front Piers):**
  Accommodate departing (at L02 Level) and arriving (at L01 Level) international passengers.
  Include outbound and inbound immigration, customs, and duty-free retail areas.
  Bus gates connect to remote stands at L00 Level.
- **Domestic Piers (Side Piers):**
  Serve domestic departures (at L02 Level) and arrivals (at L01 Level) with simplified processing and direct access to baggage reclaim.
  Flows are fully separated from international passengers for both security and operational efficiency.
- **Arrivals Hall:**
  Located at the lower level, providing direct connection to ground transport and landside pickup areas.
  Includes immigration at the Intermediate level (international only), baggage reclaim, customs, and public hall.
- **Support and Service Areas:**
  Include airline offices, operations control, staff facilities, technical rooms, and maintenance zones
- **Basement level:** Required for the in-bound Baggage screening below the baggage claim area.
- **Public Facilities:**
  Retail, food and beverage, and passenger amenities are distributed across the central and concourse areas to enhance passenger experience.

5.2.1.5.5 Circulation and Passenger flow

DEPARTURE LEVEL – L02

The Upper Level forms the main departures floor within the central processing area, accommodating all outbound passenger processing facilities and systems. These include check-in halls, emigration control, and security screening zones, organized to ensure efficient passenger flow and operational flexibility.

Within both international and domestic piers, the upper-level houses departure gate lounges dedicated to international and domestic operations.

The generous footprint of the upper-level piers provides adequate space for commercial areas, and circulation zones, supporting both operational efficiency and passenger comfort.

Approximate area: 70.900 m² (Phase 1) -87.600 m² (Ultimate phase).

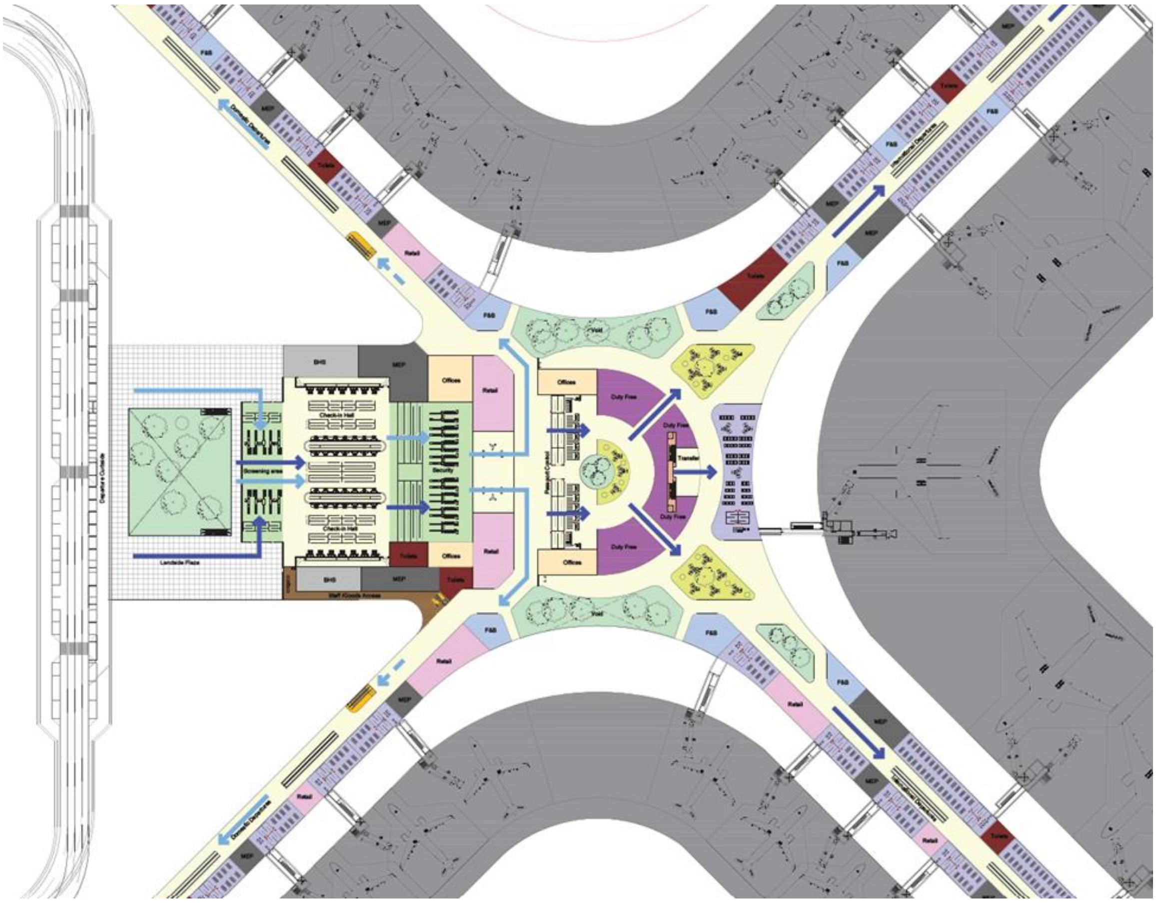


Figure 5.61: JKIA proposed layout departure level- L02

Passengers access the Terminal via the elevated departure curb, leading directly to the central pre–check-in screening area.

All individuals entering the Terminal are subject to security screening. Following screening, passengers enter the main check-in hall, accommodating both conventional counters and self-service facilities (self-check kiosks and automated baggage drop units).

After completing check-in, domestic passengers proceed towards the domestic departure lounges distributed along the two domestic piers or descend to the ground level to access remote domestic gates. International passengers proceed from check-in to passport control, then directly into the international departure piers.

The central duty-free zone forms the core of the commercial area, offering visual connectivity to the landscaped greenery below.

F&B outlets, dwell seating areas, and additional retail units are provided adjacent to MEP spaces with service access via dedicated corridors.

INTERMEDIATE LEVEL – L01

The Intermediate Level facilitates International and Domestic arriving passenger flows.

This level also accommodates facilities for connecting and transfer passengers, ensuring seamless integration between arrival and departure streams.

The area is primarily dedicated to arrival corridors extending along the piers, featuring central openings enclosed with glass panels that visually connect to the lower level, enhancing spatial transparency and ensuring smoother circulation. Within the central processing area, the voids located above the Baggage Handling System (BHS) are fully enclosed, while other glazed openings remain open to the level below, allowing natural light penetration and visual continuity between floors.

These design measures contribute to a more open and cohesive passenger environment, though the introduction of the openings has reduced the overall footprint of this level.

Approximate area: 42.300 m² (Phase 1) - 59.000 m² (Ultimate phase)

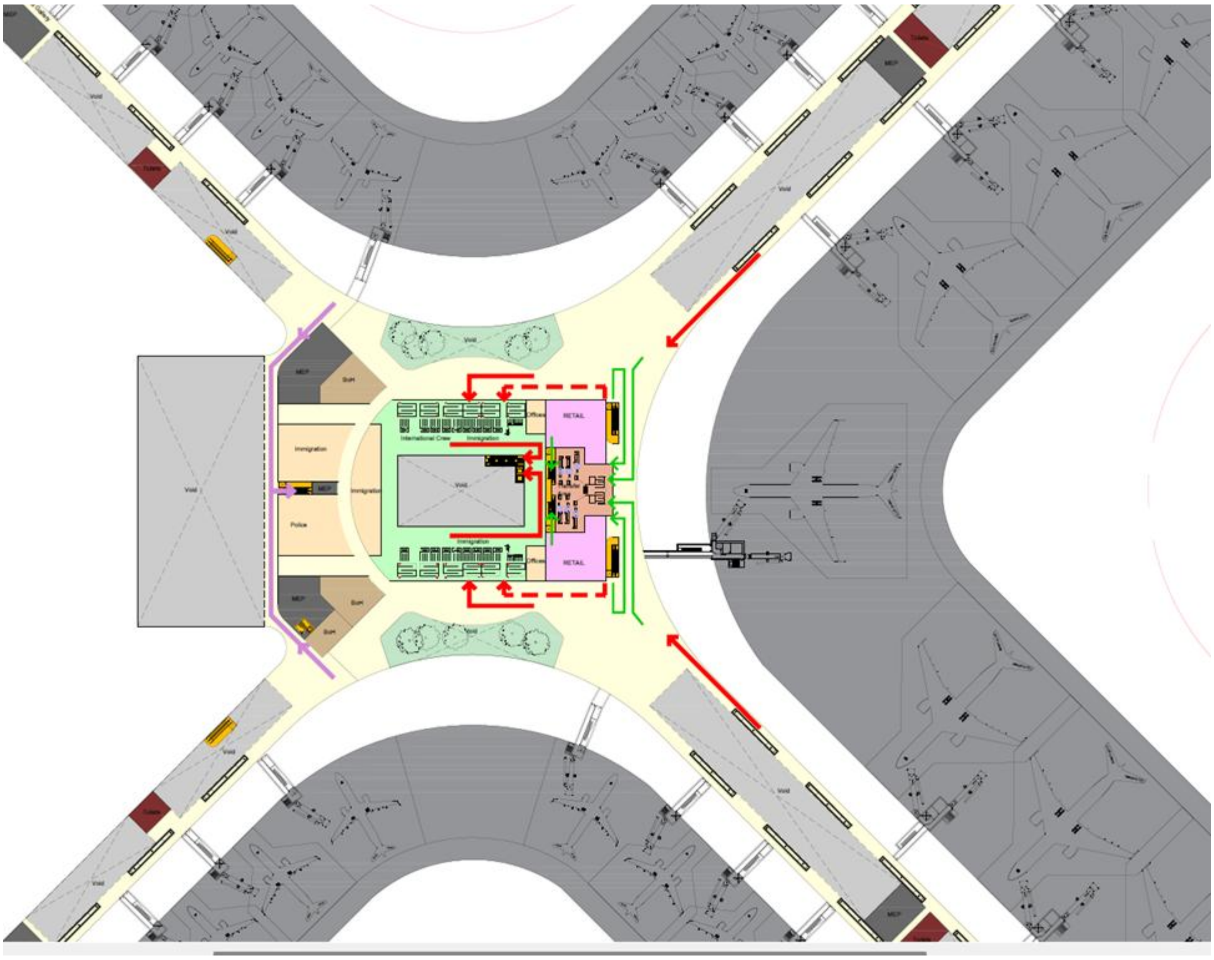


Figure 5.62: JKIA proposed layout intermediate level- L01

The spatial layout of the Intermediate level ensures efficient segregation of passenger movements while preserving an open, visually connected environment that facilitates intuitive wayfinding.

International Arriving passengers are processed to the central immigration area, then descend to the ground (apron) level for baggage reclaim, customs, and access to the public arrivals hall.

Transfer passengers are directed to a dedicated transfer processing area centrally located between the two international piers. After completing screening, they go up to the concessions zone before continuing to their departure gates.

Domestic arriving passengers descend to the lower level, where a dedicated domestic baggage reclaim hall is provided, leading directly to the public arrivals hall and exit.

APRON LEVEL – L00

The Apron Level primarily supports arrival functions, including baggage reclaim, customs, and passenger processing.

The front (main) piers are dedicated to international gate lounges, while the lateral piers accommodate domestic gate lounges for passengers boarding aircraft at remote stands.

Although the apron-level pier footprint is smaller than that of the upper levels, it provides sufficient space for gate lounges, seating areas, circulation paths, technical rooms, and limited commercial facilities.

In the expansion zones, the lower levels of the piers remain unoccupied, with the upper levels supported by structural pillars.

The front piers also house the Baggage Handling System (BHS) make-up area and associated technical and service spaces, ensuring efficient operational support while maintaining smooth passenger flows.

Approximate area: 68,980 m² (All phases)

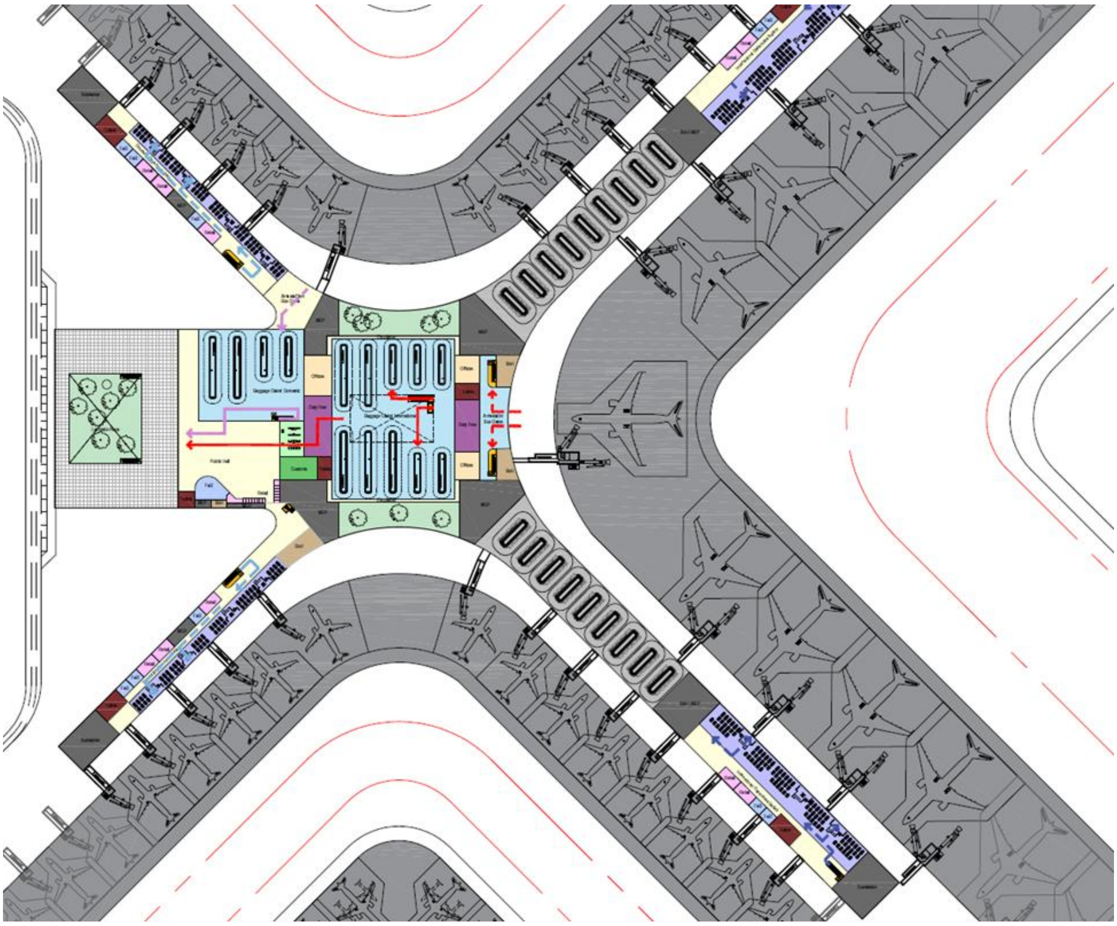


Figure 5.63: JKIA proposed layout Apron level- L00

5.2.2 SUPPORT FACILITIES

5.2.2.1 GROUND SERVICE EQUIPMENT GSE STORAGE/STAGING AREA

Ground Service Equipment (GSE) includes vehicles and machinery used to service parked aircraft between flight operations. GSE encompasses a variety of equipment and requires dedicated space for the staging and storage of the equipment.

According to the International Air Transport Association (IATA) Airport Development Reference Manual, GSE should be parked in areas adjacent to the aircraft parking apron to ensure accessibility and operational efficiency. These staging areas must be adequately sized to accommodate all regularly used equipment for serving parked aircraft.

The analysis assumes that all GSE vehicles, except Unit Load Devices (ULDs), catering trucks, and fuel bowsers, are parked inside the storage facility. These exclusions are deliberate because ULDs are typically stored in cargo handling areas, catering trucks operate from dedicated catering facilities, and fuel bowsers are housed in specialized fuel farm zones. By focusing on core passenger-related GSE, the design optimizes space utilization and simplifies operational logistics.

5.2.2.1.1 GSE STORAGE/STAGING REQUIREMENTS

The GSE storage facility is designed as an open shaded area, following industry practice where 12% of equipment remains staged on-stand and 88% is stored under shade. This approach ensures that most equipment is protected from environmental exposure while maintaining operational readiness for peak-hour demands.

The storage requirements for GSE are determined by forecasted peak hour aircraft movements (ATMs), which represent the number of aircraft operating at the airport during the busiest hour. Each aircraft requires a specific set of GSE units to support arriving and departing flights. Therefore, the total GSE fleet directly corresponds to the number of aircraft operating during the peak hour.

The analysis distributes peak hour ATMs according to the projected fleet mix. It assumes that 20 percent of the aircraft are Code E aircraft (wide-body) and 80 percent are Code C aircraft (narrow-body).

Table 5.20 summarizes the forecasted peak hour ATMs and corresponding active stands for each planning phase:

Table 5.20: Summary of FORECASTED PEAK HOUR ATMs AND ACTIVE STANDS

Phase	Million Annual Passengers (MAP)	Peak Hour ATMs	Code E ATMs	Code C ATMs
Phase 1	10	48	10	38
Phase 2	15	57	11	46

Source: Consultant Analysis

With the number of Code E and Code C peak hour ATMs established, the next step identifies the equipment set required for each aircraft. The analysis assumes that each stand is fully equipped with its own dedicated GSE, without accounting for shared or overlapping equipment. This approach ensures sufficient space allocation for all operational scenarios. Per-aircraft service ratios are applied based on aircraft code, with Code E aircraft requiring more and larger equipment than Code C aircraft. Multiplying these ratios by the number of stands yields the total GSE fleet for each planning phase.

Table 5.21 presents the total GSE fleet calculated for Phase 1, and Table 5.22 presents the total GSE fleet calculated for Phase 2.

Table 5.21: Summary of TOTAL gse fleet FOR PHASE 1

Vehicle Type	Denominator	Number of Vehicles for Code E	Total Number of Vehicles for Code E	Number of Vehicles for Code C	Total Number of Vehicles for Code C
Cleaning/Lavatory Code E&F	per Aircraft	1	10	1	38
Potable Water Code E&F	per Aircraft	1	10	1	38
Loaders Code E&F	per Aircraft	0.5	5	0.25	9.5
Conveyor Belts Code E&F	per Aircraft	0.5	5	0.25	9.5
Pushback/Tow Tractor Code E&F	per Aircraft	0.5	5	0.25	9.5
Pax. Busses Code E&F	per Aircraft	1	10	0.5	19
Passenger Stairs	per Aircraft	2	20	2	76
GPU vehicles	per Aircraft	1	10	1	38
PCA vehicles	per Aircraft	1	10	1	38

Vehicle Type	Denominator	Number of Vehicles for Code E	Total Number of Vehicles for Code E	Number of Vehicles for Code C	Total Number of Vehicles for Code C
Ambulift	per Aircraft	0.5	5	0.5	19
Follow me vehicles	per Aircraft	0.5	5	0.5	19

Source: Consultant Analysis

Table 5.22: Summary of TOTAL gse fleet FOR PHASE 2

Vehicle Type	Denominator	Number of Vehicles for Code E	Total Number of Vehicles for Code E	Number of Vehicles for Code C	Total Number of Vehicles for Code C
Cleaning/Lavatory Code E&F	per Aircraft	1	11	1	46
Potable Water Code E&F	per Aircraft	1	11	1	46
Loaders Code E&F	per Aircraft	0.5	5.5	0.25	11.5
Conveyor Belts Code E&F	per Aircraft	0.5	5.5	0.25	11.5
Pushback/Tow Tractor Code E&F	per Aircraft	0.5	5.5	0.25	11.5
Pax. Busses Code E&F	per Aircraft	1	11	0.5	23
Passenger Stairs	per Aircraft	2	22	2	92
GPU vehicles	per Aircraft	1	11	1	46
PCA vehicles	per Aircraft	1	11	1	46
Ambulift	per Aircraft	0.5	5.5	0.5	23
Follow me vehicles	per Aircraft	0.5	5.5	0.5	23

Source: Consultant Analysis

Each GSE type is then mapped to a bay category (Small, Medium, or Large) based on its physical dimensions and operational requirements. This classification ensures that the facility accommodates the full range of equipment sizes while maintaining efficient use of space. Small bays are assigned to compact vehicles such as GPU units and follow-me cars, medium bays accommodate equipment like potable water trucks, lavatory service vehicles, PCA units, conveyor belts, and ambulifts, while large bays are reserved for loaders, pushback tractors, passenger buses, and passenger stairs.

After assigning bay categories, the total number of bays required for each size is calculated by summing the equipment quantities within each category. These bay counts are then multiplied by their respective standard footprints to determine the base storage area for each category. The combined total of these areas represents the initial storage footprint before contingency.

To ensure operational flexibility and allow for circulation space, maneuvering clearance, and future growth, a 30 percent contingency is added to the base storage area. This adjustment results in the final GSE Storage Building Area for each planning phase.

Table 5.23summarizes the bay allocation and corresponding built-up area calculations for Phase 1 and 2.

Table 5.23: Summary of gse storage/staging requirements

Bay Category	GSE Type	Bay Dimensions	Total Bays for Phase 1	BUA for Phase 1 (m2)	Total Bays for Phase 2	BUA for Phase 2 (m2)
Small (S)	GPU vehicles, Follow me vehicles	6 m x 3 m	72	= 6 x 3 x 72 = 1,296	85.5	= 6 x 3 x 85.5 = 1,539
Medium (M)	Potable Water, Cleaning/Lavatory, PCA, Conveyor Belt, Ambulift	9 m x 4 m	182.5	= 9 x 4 x 182.2 = 6,570	216.5	= 9 x 4 x 216.5 = 7,794
Large (L)	Loaders, Pushback/Tow Tractor, Pax. Busses, Passenger Stairs	16 m x 4 m	154	16 x 4 x 154 = 9,856	182	16 x 4 x 182 = 11,648
Total	-	-	408.5	17,722	484	20,981
BUA with Contingency (m2)	-	-	-	= 17,722 x 1.3 = 23,038.6	-	= 20,981 x 1.3 = 27,275.3
Shaded Area (88%)	-	-	-	23,038.6 x 0.88 = 20,274	-	27,275.3 x 0.88 = 24,002

Source: Consultant Analysis

Moreover, the number of employees is estimated based on the Built-Up Area (BUA), using the formula: Number of Employees = BUA X 0.0021.

Accordingly, the total number of employees is approximately 51 (17 per shift) for 15 MAP and 45 (15 Per shift) for 10 MAP.

5.2.2.1.2 GSE STORAGE/STAGING LOCATIONS

GSE storage and staging areas should be located on the airside and conveniently situated close to the active stands to support the storage and staging of vehicles. Furthermore, the remaining areas created from the terminal building layouts and associated taxilanes usually present several opportunities within the terminal area to support GSE areas. The GSE areas will be spread across the terminal area. The proposed location is shown in Figure 5.64

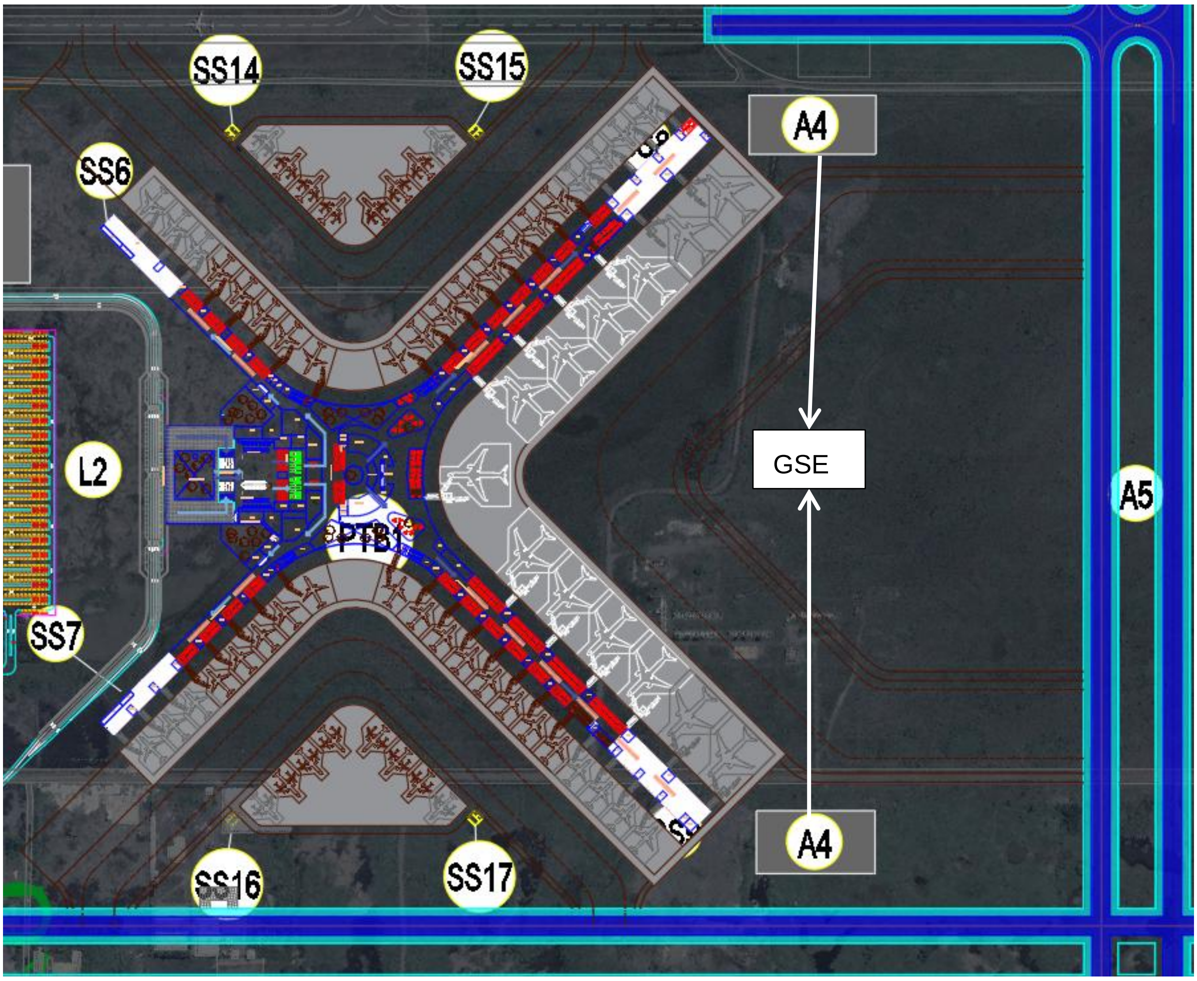


Figure 5.64: LOCATION OF GSE STORAGE/STAGING AREAS

5.2.2.2 GSE MAINTENANCE BUILDING

GSE maintenance is a critical component in supporting passenger operations by ensuring the readiness and reliability of GSE vehicles and equipment used in airside operations. GSE encompasses a wide range of specialized vehicles and equipment that require both routine maintenance and on-demand repairs.

This facility is designed to handle the maintenance, repair, and operational needs of these assets. It includes dedicated workshops equipped with the tools and systems required for routine servicing and complex repairs, as well as secure storage areas for spare parts, tools, and specialized equipment. In addition to the maintenance areas, the facility incorporates administrative offices, staff amenities such as break rooms and locker areas, and spaces for training and meetings.

5.2.2.2.1 GSE MAINTENANCE AREA REQUIREMENTS

To determine the optimal size and layout of the GSE maintenance facility, the analysis applied industry-standard assumptions and operational benchmarks. The size is based on the projected GSE fleet required to support peak-hour aircraft operations and assumes that 10 percent of the total GSE fleet will be in maintenance at any given time. This concurrency factor ensures that the facility can accommodate routine servicing and corrective repairs without disrupting airside operations. Additionally, baggage and cargo ULDs are excluded from the facility, and only tugs are included, focusing the design on passenger-related operations.

The total number of GSE vehicles identified in the storage analysis forms the basis for estimating maintenance demand. Applying the 10 percent concurrency factor to the total fleet yields the number of vehicles expected to be under maintenance at any given time. These vehicles are then categorized by size (Small, Medium, or Large) based on their physical dimensions and operational characteristics. Small bays are allocated for compact equipment such as

GPU units and follow-me vehicles, medium bays accommodate potable water trucks, lavatory service vehicles, PCA units, conveyor belts, and ambulifts, while large bays are reserved for loaders, pushback tractors, passenger buses, and passenger stairs.

The total number of bays required in each category is then calculated by summing the equipment quantities within the maintenance subset. These bay counts are multiplied by their respective footprints to determine the base maintenance area for each category. The combined total represents the initial built-up area before any adjustments.

The area computed does not account for workshops and offices. As such, a ratio of 0.6 is used to get the total area of the GSE maintenance building. This conservative ratio avoids oversizing while maintaining flexibility for peak conditions.

Thus, the final GSE maintenance facility size is approximately 3,087 m² for Phase 1 and 3,617 m² for Phase 2.

Table 5.24 summarizes the bay allocation and corresponding built-up area calculations for Phase 1 and 2.

Table 5.24: Summary of gse MAINTENANCE requirements

Bay Category	GSE Type	Bay Dimensions	Total Bays for Phase 1	BUA for Phase 1 (m2)	Total Bays for Phase 2	BUA for Phase 2 (m2)
Small (S)	GPU vehicles, Follow me vehicles	6 m x 3 m	= 72 x 0.1 = 8	= 6 x 3 x 8 = 144	= 86 x 0.1 = 9	= 6 x 3 x 9 = 162
Medium (M)	Potable Water, Cleaning/Lavatory, PCA, Conveyor Belt, Ambulift	9 m x 4 m	183 x 0.1 = 19	= 9 x 4 x 19 = 684	= 217 x 0.1 = 22	= 9 x 4 x 22 = 792
Large (L)	Loaders, Pushback/Tow Tractor, Pax. Busses, Passenger Stairs	16 m x 4 m	154 x 0.1 = 16	16 x 4 x 16 = 1,024	= 182 x 0.1 = 19	16 x 4 x 19 = 1,216
Total	-	-	43	1,852	50	2,170
BUA with Contingency (m2)	-	-	-	= 1,852 / 0.6 = 3,087	-	= 2,170 / 0.6 = 3,617

Source: Consultant Analysis

The building will consist of one level, with 100% of the Built-Up Area (BUA) located on the ground floor.

Moreover, the number of employees is estimated based on the Built-Up Area (BUA), using the formula: Number of Employees = BUA / 20.4.

Accordingly, the total number of employees is 178 (89 per shift) for 15 MAP and 152 (76 Per shift) for 10 MAP .

Assumption: Only 60% of the total employees are expected to be working simultaneously on site, reflecting operational and shift-based workforce distribution.

5.2.2.2.2 GSE MAINTENANCE LOCATIONS

The GSE maintenance facility should be located on the airside with landside-airside adjacency, enhancing operational efficiency. Landside adjacency supports the delivery of spare parts and employee access, while direct airside access eliminates the need to pass through security checkpoints for GSE repairs. To prevent traffic congestion, the facility should be positioned away from the main airport access road, reducing employee and delivery traffic near the terminal access route.

The proposed location is illustrated in Figure 5.65 below.

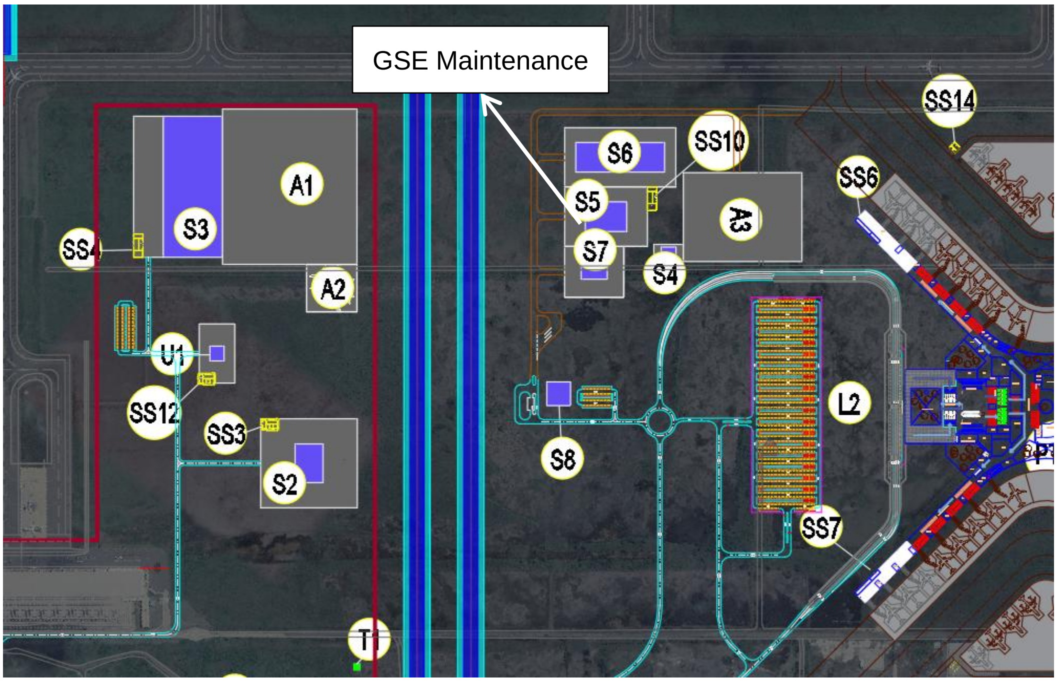


Figure 5.65: Location Of GSE Maintenance Facility Area

5.2.2.3 AIRPORT MAINTENANCE COMPLEX

Airport maintenance facilities include airside vehicle maintenance, storage, training areas, and office buildings. Their primary role is to perform repairs and regular upkeep on various airport assets, such as the airfield, terminals, hangars, parking structures, landside buildings, and airport equipment. These facilities are essential for motor vehicle repairs, electrical work (covering buildings, radio, and visual navigational aids), painting (for buildings and runway markings), and mechanical repairs. Additionally, maintenance facilities should provide storage for materials, replacement parts, and a fireproof area designated for flammable materials.

5.2.2.3.1 AIRPORT MAINTENANCE REQUIREMENTS

The planning requirements for airport maintenance facilities included a standard ratio of 300 square meters per MAP. This ratio was applied to the projected annual passenger forecast to estimate the facilities needed for each planning level. However, the actual square meters per MAP varies significantly between airports worldwide, reflecting different levels of space dedicated to maintenance functions.

To account for additional site needs, a 250% factor was applied to the building area requirement, providing extra space for vehicle parking, storage, and other landside features essential to the facility's operations.

The analysis adopts the following assumptions from the previous Master Plan to calculate the daily staff count:

- The staff number is calculated based on a ratio of one employee per 50 square meters of Built-Up Area (BUA), expressed as: Staff = BUA / 5

- Existing BUA is assumed to be 0 m², as maintenance functions are currently scattered, a centralized, full-fledged maintenance facility is therefore recommended.
- The building will consist of one level, with 100% of the Built-Up Area (BUA) located on the ground floor.

Therefore, a summary of the requirements is provided in Table 5.25

Table 5.25: Summary of airport maintenance requirements

Airport Maintenance	Phase 10 MAP	Phase 15 MAP
Total Plot Area (m^2)	15,225	18,750
Total Built-Up Area (m^2)	6,090	7,500
Number of Building Levels	1	1
Total Staff	123	150

5.2.2.3.2 AIRPORT MAINTENANCE LOCATION

The location of the airport maintenance provides landside access for staff and deliveries and is positioned adjacent to an airside access gate to ensure operational efficiency. The proposed location is illustrated in Figure 5.66 below.

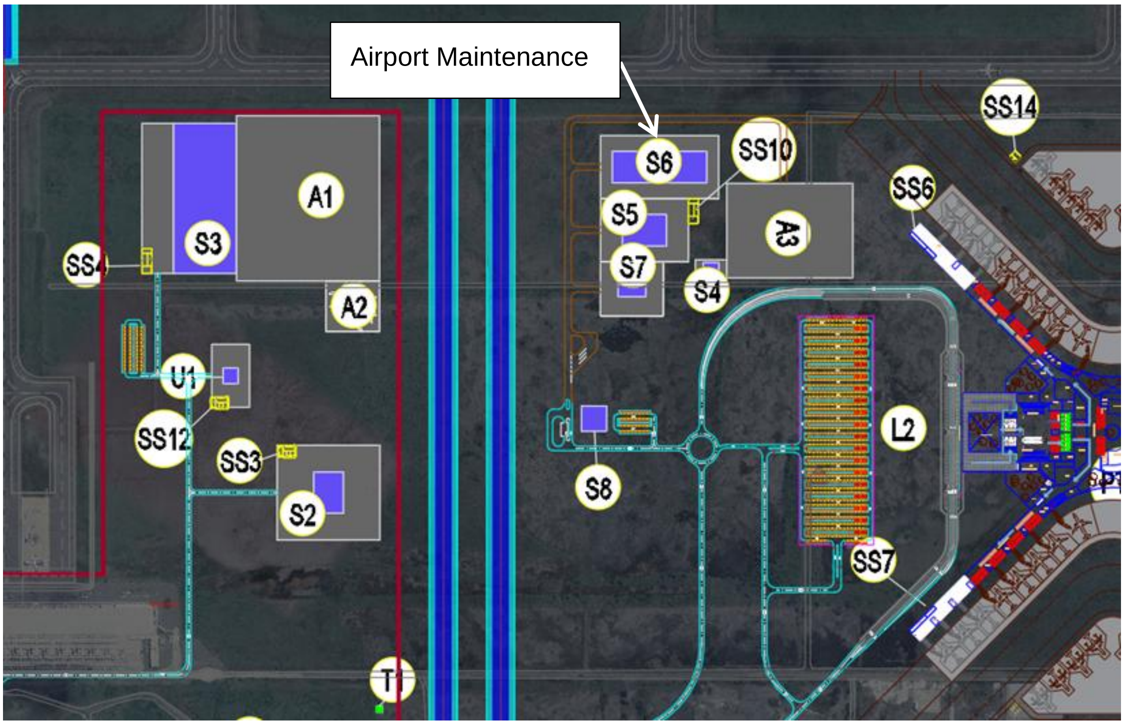


Figure 5.66: Location Of Airport Maintenance Facility

5.2.2.4 AIRCRAFT CLEANING FACILITIES

Aircraft cleaning standards are regulations set by Civil Aviation Authorities to ensure operators maintain a minimum level of cleanliness onboard, prioritizing passenger health, safety, and comfort while enhancing the overall quality of service. To meet these standards, dedicated aircraft cleaning facilities are essential. The aircraft cleaning facilities should be equipped with all necessary tools, vehicles, and supplies for aircraft cleaning, as well as providing sufficient parking space, storage, and adequate office and employee space.

5.2.2.4.1 AIRCRAFT CLEANING FACILITY REQUIREMENTS

The overall facility needs for the aircraft cleaning facilities are driven by the ability of the cleaning trucks and staff to service the aircraft movements during their peak. The requirements were calculated to accommodate each demand level's peak hour, providing minimum cleaning trucks and staff to serve each departure operation. The analysis used the following planning assumptions to calculate the facility requirements for the aircraft cleaning facilities, shown in Table 5.26.

Table 5.26: Aircraft Cleaning facilities assumptions

Aircraft Cleaning Assumption	Metric
Cleaning Truck Service Throughput (per truck/per hour)	2 Services (per truck/per hour)
Number of Employees per Truck – Code C	4 Employees
Number of Employees per Truck – Code E	8 Employees
% of Peak Hour Departures require cabin cleaning services	80%
PH Departures for 10 MAP (from forecasts)	53
PH Departures for 15 MAP (from forecasts)	63
Code C PH ATM Departures 10 Map	43
Code C PH ATM Departures 15 Map	50
Code E PH ATM Departures 10 Map	11
Code E PH ATM Departures 15 Map	13

Source: Consultant Analysis.

The total number of cleaning trucks required for aircraft cabin cleaning operations was determined based on the projected Peak Hour Departures (PHD) for each development phase. Each cleaning truck is assumed to service two aircraft per hour, ensuring efficient turnaround operations and alignment with peak activity levels.

For Phase 10 MAP and Phase 15 MAP, the fleet mix between Code C and Code E aircraft was used to estimate the number of trucks required. The resulting figures indicate a progressive increase in fleet requirements to accommodate future operational demand.

To estimate the facility size, planning ratios from the previous Master Plan were adopted. Each truck requires a building area of 35.5 square meters, while the total plot area was derived by applying a multiplier of eight times the built-up area. This total plot area accounts for vehicle parking, circulation, service bays, equipment storage, and other supporting landside infrastructure. Since there is currently no dedicated aircraft cleaning facility on-site, the existing Built-Up Area (BUA) is considered zero, and the proposed facility areas are designed to fully support projected future operations.

The staffing requirement for the Aircraft Cleaning Facility is based on the number of cleaning trucks operating during the peak hour, with each truck assigned a team according to aircraft type. Code C cleaning trucks are operated by four employees per vehicle, while Code E cleaning trucks require eight employees per vehicle due to their larger.

A summary of the aircraft cleaning facilities requirements is provided in Table 5.27

Table 5.27: AIRCRAFT CLEANING FACILITIES REQUIREMENTS

Aircraft Cleaning	Phase 10 MAP	Phase 15 MAP
Number of trucks needed - Code C	Code C PH ATM Departures/2 = 43/2 = 22	Code C PH ATM Departures/2 = 50/2= 25
Number of trucks needed - Code E	Code E PH ATM Departures/2 = 11/2= 6	Code E PH ATM Departures/2 = 13/2= 7
Number of Trucks	28	32
Total Plot Area (m^2)	8×BUA =7,952	8×BUA =8,619

Aircraft Cleaning	Phase 10 MAP	Phase 15 MAP
Total Built-Up Area (m^2)	35.5 m² × Total number of Trucks needed = 994	35.5 m² × Total number of Trucks needed =1,078
Number of Building Levels	1	1
Number of Employees Code C	Number of trucks needed - Code C *4 =88	Number of trucks needed - Code C *4=100
Number of Employees Code E	Number of trucks needed - Code E*8 = 48	Number of trucks needed - Code E*8 = 56
Total Employees	(Code C Employees) +(Code E Employees) = 136	(Code C Employees) +(Code E Employees) =156

Source: Consultant Analysis

5.2.2.4.2 AIRCRAFT CLEANING FACILITIY LOCATIONS

Aircraft cleaning facilities should provide both airside and landside access, with convenient access to the terminal area to provide their services and maintain an efficient operation.

The proposed location is illustrated in Figure 5.67 below.

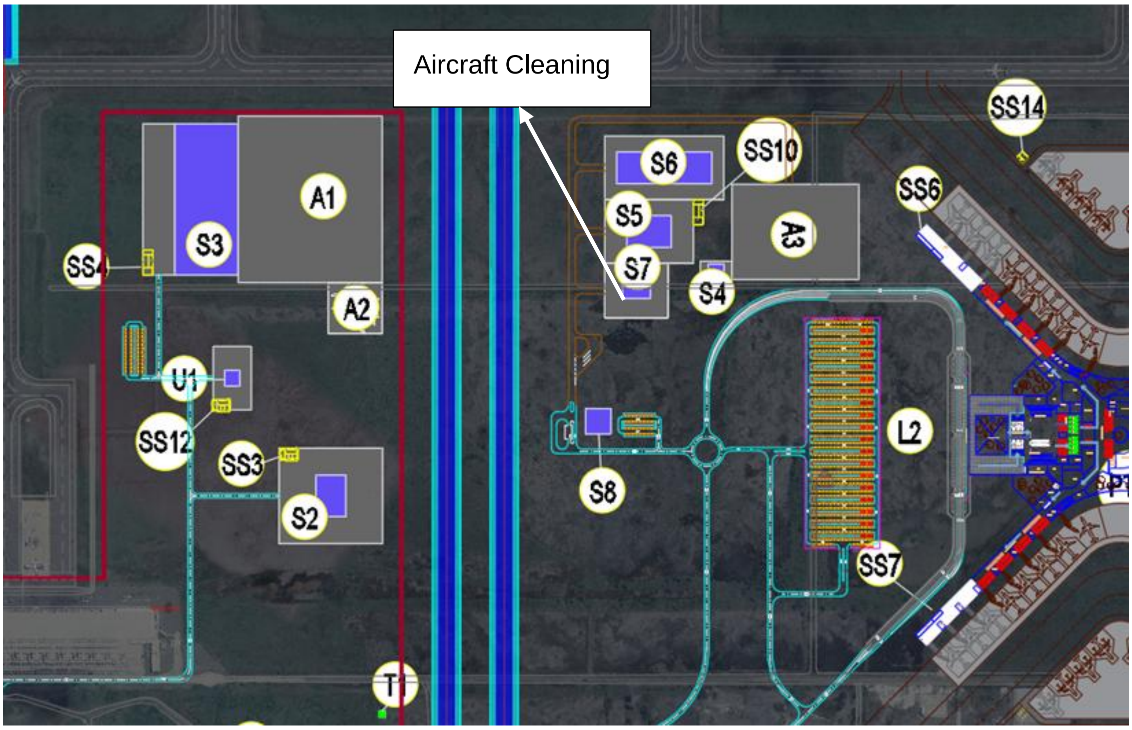


Figure 5.67: Location Of Aircraft Cleaning Facility Area

5.2.2.5 AIRLINE OFFICES

Airline offices are dedicated spaces used by airlines at airports to support their operational, administrative, and customer service activities. These offices typically house functions essential for the daily running of the airline's operations at the airport. The airport will support airline offices for both Kenys Airlines (KA), as well as all other airlines (OALs).

5.2.2.5.1 AIRLINE OFFICES (KENYA AIRLINES) REQUIREMENTS

The methodology used to calculate the required areas for the offices utilized a reduced planning factor (compared to the OAL headquarters) of one airline administration staff member for every 40,000 annual passengers. BUA was calculated by assuming 15 square meters per total staff member. Total plot areas were calculated by applying a 2x factor to the building area requirement. These calculations are presented in Table 5.28

Table 5.28: Total Number Of Staff For Airline Offices

	Phase 10 MAP	Phase 15 MAP
Number Of Staff= Annual Passengers / 40,000		
Total Staff	344	420

5.2.2.5.2 AIRLINE OFFICES (OAL HEADQUARTERS) REQUIREMENTS

The methodology used to calculate the required areas for the airline offices for the OALs utilized a planning factor of one airline administration staff member for every 20,000 annual passengers. These calculations are presented in Table 5.29.

Table 5.29: TOTAL NUMBER OF STAFF FOR oal AIRLINE OFFICES

	Phase 10 MAP	Phase 15 MAP
Number Of Staff= Annual Passengers / 20,000		
Total Staff	330	393

Source: Consultant Analysis

5.2.2.5.3 AIRLINE OFFICES SIZING

The Built-Up Area (BUA) for the administration building was determined based on the total number of staff required for each phase combined for both KA and OAL.

It is assumed that each staff member requires 15 square meters of built-up space, which accounts for operational areas, administrative offices, staff amenities, and circulation spaces within the facility. Moreover, the existing BUA is considered 0, as a new building will be constructed to accommodate the airline administration offices.

BUA = 15 m^2 × Total number of Staff

- Phase 10 MAP Total Number of Staff = 344+330 = 674
- Phase 15 MAP Total Number of Staff = 420+393= 813

Thus, the total BUA is equal to:

- Phase 10 MAP BUA: 10,110 m^2
- Phase 15 MAP BUA:12,197 m^2

The Total Plot Area for the Aircraft Cleaning Facility was determined by applying a 2× multiplier to the calculated Built-Up Area (BUA).

This factor accounts for additional site requirements such as vehicle parking, internal circulation, service access, landscaping, and building setbacks, ensuring adequate functional and spatial efficiency of the facility.

Plot Area = 2 × BUA (includes building, parking, circulation, set backs, etc.)

- Phase 20 MAP: 20,220 m^2
- Phase 25 MAP: 24,395 m^2

A summary of the OAL and KA airline office headquarters requirements is provided in Table 5.30.

Table 5.30: Airline Offices (OAl headquarters) requirements

Airline Offices (ET)	Phase 10 MAP	Phase 15 MAP
Total Plot Area (m^2)	20,220	24,395
Total Built-Up Area (m^2)	10,110	12,197
Number of Building Levels	4	4
Total Staff	675	813

5.2.2.5.4 AIRLINE OFFICES LOCATION

The airline offices will be located within the new Terminal Building.

5.2.2.6 FLIGHT CATERING FACILITIES

The flight catering facilities are a critical element to the overall passenger operation. Flight catering facilities serve as the designated area for preparing in-flight meals for departing flights at the airport. Once prepared, the meals are loaded onto vehicles and delivered to the aircraft on the passenger apron via catering trucks. The design and location of catering facilities, access to runways and terminal gates, and the integration of technology for inventory and order management are essential factors that influence operational efficiency.

5.2.2.6.1 FLIGHT CATERING REQUIREMENTS

The methodology for determining the required built-up area (BUA) for catering facilities is based on daily meal demand, which varies according to passenger type and flight duration. The calculation begins by estimating the number of meals per passenger using ratios derived from operational benchmarks. Table 5.31 summarizes the assumed ratios applied in the catering facility sizing calculations:

Table 5.31: Flight Catering assumptions

Passenger Type	Flight Duration	Meals per Passenger (Assumption)
Domestic	< 1.5 hours	0.5
International – Short Range	1.5 – 5 hours	1.0
International – Long Range	5 – 8 hours	1.5

Source: Consultant Analysis

These unit area values will be applied to future passenger and meal projections to determine the BUA required for Phase 1 and Phase 2 of the catering facility development.

For Phase 1 (10 MAP), the projected daily meal demand is 8,988 domestic meals and 51,476 international meals, totalling 60,464 meals. Applying the unit area factors results in a BUA of 28,434 m², which increases to 36,964 m² when a 30% contingency is included.

For Phase 2 (15 MAP), the corresponding BUA with contingency is 46,096 m².

Table 5.32 presents the projected flight catering requirements for Phase 1 and 2.

Table 5.32: Summary of Flight Catering requirements

Flight Catering	Phase 1 10 MAP	Phase 2 15 MAP
Number of daily domestic meals	8,988	10,906
Number of daily international meals	51,476	64,372
Total number of daily meals	60,464	75,278
BUA (m^2)	28,434	35,458.5
BUA with contingency (m^2)	36,964	46,096
Number of Building Levels	4	4

Source: Consultant

To determine the additional built-up area (BUA) required for each development phase, the existing catering facility area of 8,000 m² was deducted from the projected BUA with contingency. For Phase 1, the total requirement is 36,964 m², resulting in an additional area of:

$$Additional\ BUA\ (Phase\ 1) = 36{,}964 - 8{,}000 = 28{,}964\ m^2$$

For Phase 2, the total requirement is 46,096 m², leading to an additional area of:

$$Additional\ BUA\ (Phase\ 2) = 46{,}096 - 8{,}000 = 38{,}096\ m^2$$

Moreover, the number of employees is estimated based on the Built-Up Area (BUA) using the formula: Total Employees = BUA ÷ 19.4.

Accordingly, the number of employees is 1,906 (636 per shift) for 10 MAP and 2,377 (793 per shift) for 15 MAPS.

5.2.2.6.2 FLIGHT CATERING LOCATIONS

Flight catering facilities should provide both airside and landside access, with convenient access to the terminal area and a road network to accommodate deliveries. However, in this case, the new catering facility is located next to the existing one. This needs to be studied further in terms of accessibility and operations. The location of the new facility is shown in Figure 5.68.

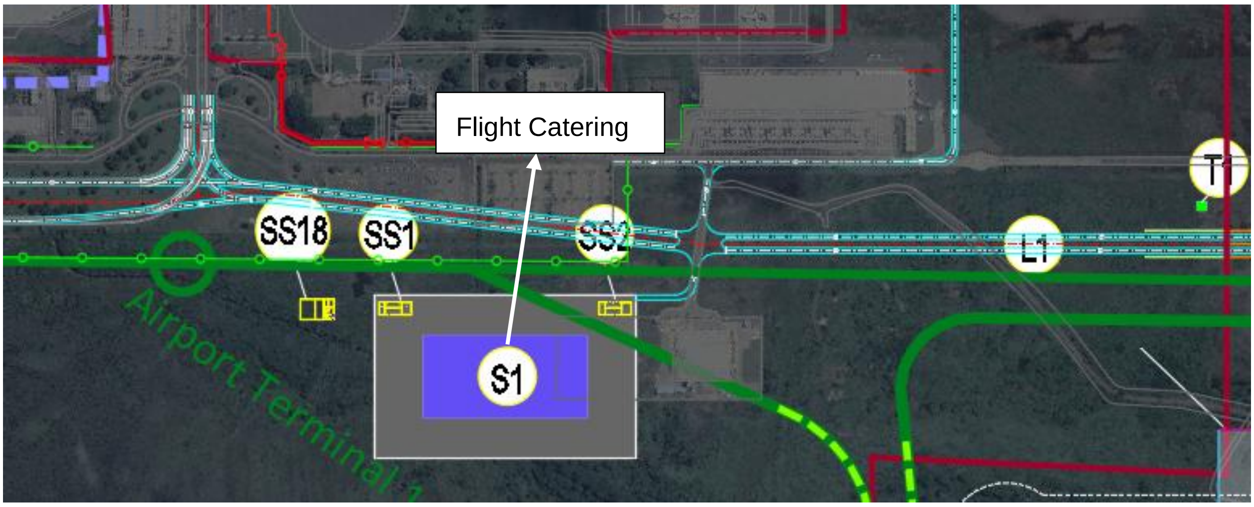


Figure 5.68: LOCATION OF FLIGHT CATERING FACILITIES AREAS

5.2.2.7 AIRCRAFT MAINTENANCE HANGAR + LINE MAINTENANCE

The aircraft maintenance facilities will offer a wide range of facilities to support the maintenance, repair, and overhaul (MROs) of all airlines operating at the airport. The complex will offer space for hangars, maintenance workshops, stores, offices, and engine run-up capabilities.

5.2.2.7.1 AIRCRAFT MAINTENANCE REQUIREMENTS

The sizing of aircraft maintenance facilities is driven by projected annual air traffic movements (ATMs) and a set of planning factors that ensure adequate capacity for all maintenance activities. These factors are summarized in Table 5.33.

Table 5.33: AIRCRAFT MAINTENANCE assumptions

Aircraft Maintenance Assumption	Metric
Overall Building Areas	0.17m^2 / Annual ATM
Portion of Building Areas dedicated to Hangars	60%
Maintenance Hangar Size for Narrowbody	3,000 m^2
Maintenance Hangar Size for Widebody	7,300 m^2
Hangar Apron	250% of Hangar Area
Portion of Hangar Areas dedicated to Stores/Workshops/Offices/Storage	40%
Aircraft Stands	% Portion of Fleet / ATMs
Total Number of Employees	33.6 m^2 / Person

Source: Consultant Analysis.

The projected ATMs for each development phase are 241,760 for Phase 1 (10 MAP) and 292,818 for Phase 2 (15 MAP). Using the benchmark of 0.17 m² per annual ATM, the overall building area is equal to:

$$Overall\ BUA\ (Phase\ 1) = 41{,}100\ m^2$$

$$Overall\ BUA\ (Phase\ 2) = 49{,}780\ m^2$$

The existing MRO facility occupies 26,670 m². Thus, the additional BUA for each phase is:

$$Additional\ BUA\ (Phase\ 1) = 41{,}100 - 26{,}670 = 14{,}430\ m^2$$

$$Additional\ BUA\ (Phase\ 2) = 49{,}780 - 26{,}670 = 23{,}110\ m^2$$

This expansion will accommodate the full range of maintenance activities, including A-, B-, C-, and D-checks, which include the following:

- A-Check (Visual Inspection): Includes visual inspections of the engines (with cowlings open), checks and lubrication of landing gear, and inspections of seats, equipment, and lavatories. These checks occur approximately every 600 flight hours, which equates to about every 100 days, typically on a dedicated aircraft maintenance apron, and are considered lighter maintenance.
- B-Check (Lighter Intermediate Maintenance): Includes both routine and more detailed inspections of various aircraft systems and components and is intended to catch potential issues before they become serious. These checks typically occur between 1,000 and 1,5000 flight hours and may be done on a dedicated maintenance apron keeping aircraft out of service for 1 to 2 days.
- C-Check (Intermediate Maintenance): Involves cleaning and restoring seats, repainting, and plating the aircraft. These checks take place approximately every 6,000 flight hours, or around every 20 months, and are conducted in dedicated maintenance hangars.

- D-Check (Heavy Maintenance): Includes the removal and inspection of movable parts and engines, dismantling of the cabin and accessories for a thorough examination, repairs to the main frame, reassembly and ground testing, aircraft repainting, and engine testing outside hangars, often followed by a test flight. This extensive maintenance is conducted within dedicated hangars.

It is anticipated that at the airport, many of the line maintenance A- and B- checks will occur at the aircraft stands in the terminal area or on the apron. Only C- and D-checks will be conducted in a dedicated maintenance hangar.

5.2.2.7.2 Aircraft Maintenance Hangar

Maintenance hangars are essential for aircraft MRO operations, providing large, open spaces for major repairs and C- and D-checks. These hangars support work that requires the removal and installation of engines, accessories, and major structural components. They also house maintenance stands, scaffolding, tools, test equipment, and component overhaul areas. Effective hangar design ensures that support equipment is readily accessible, with on-site parts storage and shipping and receiving areas for efficient operations.

Two sizes of aircraft maintenance hangars should be developed to support the anticipated Code C and Code E fleet at the airport. The projected number of hangars was calculated by dividing the total hangar footprint by the standard hangar sizes defined in the planning assumptions—3,000 m² for narrowbody aircraft (Code C) and 7,300 m² for widebody aircraft (Code E). The two hangars consists of one level, with 100% of the Built-Up Area (BUA) located on the ground floor.

The Aircraft Maintenance Hangar requirements are provided in Table 5.34

Table 5.34: Aircraft Maintenance Hangar requirements

Aircraft Maintenance Hangar	Phase 1 10 MAP	Phase 2 15 MAP
Total Hangar Footprint (m^2)	= 41,100 x 0.6 = 24,660	29,780
Maintenance Hangar Narrowbody - Code C	8	9
Maintenance Hangar Narrowbody - Code E	3	4

Source: Consultant Analysis.

5.2.2.7.3 Aircraft Maintenance Workshop

Additional space is essential to support aircraft maintenance activities at the airport. These spaces will include functional areas for maintenance workshops, storage, offices, and additional support facilities. The maintenance workshops are designed to manage the repair, refurbishment, and inspection of various aircraft components. Key components typically serviced in these workshops may include but are not limited to:

- Structures and Composites: Repairs to the aircraft’s structural framework and composite materials, addressing wear, damage, or modifications.
- In-Flight Entertainment Systems: Inspection, repair, and testing of audio and video systems to ensure passenger comfort and functionality.
- Engines: Disassembly, inspection, maintenance, and testing of engine components.
- Wheels and Brakes: Maintenance, replacement, and testing of landing gear wheels and braking systems.
- Cabin Interior: Refurbishment of seating, upholstery, and interior fixtures.
- Galley Equipment: Repair and servicing of kitchen and galley equipment, including ovens, coffee makers, and storage units.
- Safety and Survival Equipment: Inspection and maintenance of emergency equipment, including life vests, oxygen masks, and fire extinguishers.
- Avionics: Calibration, repair, and testing of avionics systems, such as navigation, communication, and flight control systems.
- Batteries: Charging, testing, and replacement of various types of batteries used in avionics, emergency, and backup systems.
- Hydraulic Systems: Maintenance of hydraulic components used in landing gear, control surfaces, and cargo doors.

- Fuel Systems: Inspection and servicing of fuel pumps, valves, and lines to ensure efficient fuel delivery.

These workshops and support areas ensure that all critical aircraft systems can be effectively maintained, repaired, and evaluated to uphold safety and operational standards. The aircraft maintenance workshop requirements are provided in Table 5.35

Table 5.35: Aircraft Maintenance workshop requirements

Phase	Total Aircraft Maintenance Workshop Footprint (m2)
Phase 1	= 41,100 x 0.4 = 16,440
Phase 2	19,912

Source: Consultant Analysis.

5.2.2.7.4 Aircraft Maintenance Stands

The aircraft maintenance stand requirements are provided in Table 5.36

Table 5.36: Aircraft Maintenance Stands requirements

Aircraft Maintenance Stands	Phase 1 10 MAP	Phase 2 15 MAP
Maintenance Hangar Narrowbody - Code C	8	9
Maintenance Hangar Widebody - Code E	3	4
Total	11	13

Source: Consultant.

5.2.2.7.5 MRO Employee Requirements

Employee facilities within the aircraft maintenance complex are sized based on a planning factor of 33.6 m² per person, which accounts for offices, rest areas, and support spaces. Using this benchmark, the required space for personnel has been calculated for each development phase. For Phase 1, the total area allocated for employee facilities is 16,440 m², which accommodates approximately 490 employees. For Phase 2, the allocation increases to 19,912 m², supporting around 593 employees.

5.2.2.7.6 AIRCRAFT MAINTENANCE LOCATIONS

The aircraft maintenance sites will include MRO hangars, an apron, and an aircraft washing bay, along with workshops. The proposed location is shown in Figure 5.69.

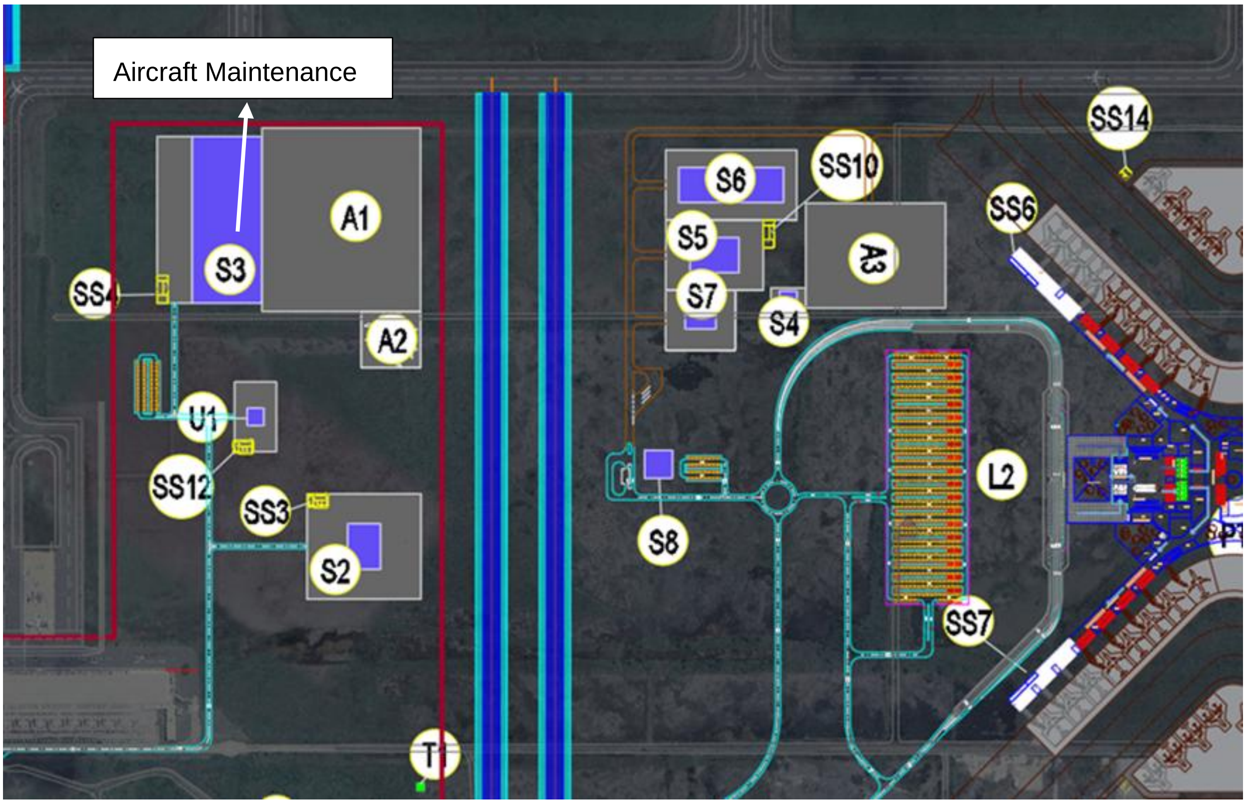


Figure 5.69: Location Of Aircraft Maintenance Facilities Areas

5.2.2.8 ARFF – STATIONS

The primary function of the Aircraft Rescue and Fire Fighting (ARFF) services is to respond to aircraft incidents or accidents occurring within or near an aerodrome. ARFF objectives include:

- Establishing and maintaining survivable conditions.
- Creating egress routes for passengers.
- Assisting in the rescue of occupants who cannot self-evacuate.

This section outlines general guidelines for ARFF station siting, including foundational design concepts and support requirements. The key responsibilities of ARFF facilities are to effectively allow personnel and equipment to provide prompt response, protect life and property, and minimize the impact of aircraft incidents, particularly within airport boundaries. Strategically locating ARFF stations and designing them to maximize response effectiveness are critical for operational success and personnel efficiency.

5.2.2.8.1 ARFF STATION REQUIREMENTS

The ARFF station design is based on ICAO Annex 14 standards for Aerodrome Category 10, which defines the level of protection and resources required for safe and efficient aircraft rescue and firefighting operations. The facility must accommodate 3 ARFF vehicles, 1 ambulance, and provide adequate space for personnel and operational support.

5.2.2.8.2 ARFF Facility Requirements

Assumptions for ARFF Facility Requirements:

- Vehicle Dimensions: Each ARFF truck assumed as Oshkosh 8x8 (approx. 14 m × 3.1 m), requiring sufficient clearance and maneuvering space
- Staffing for Phase 1 and 2: 45 personnel, organized into 3 shifts of 15 staff each for 24/7 coverage
- Functional Spaces: Includes vehicle bays, operational rooms, dormitories, storage, and support areas sized as per ICAO and NFPA guidelines

- Considerations: Additional space for circulation, mechanical/electrical systems, and contingency for future expansion

Built-up Area Calculation:

The total BUA for the ARFF station was calculated by summing functional space and applying allowances for MEP systems and contingency, as shown in Table 5.37.

Table 5.37: ARFF STATION FACILITY REQUIREMENTS

Element	Area (m^2)
Parking bays (3 firetrucks + 1 ambulance)	450
Watch/Alarm room	15
Medical decontamination room	15
Gear Wash drying room	20
First Aid and medical Storage	15
Complementary Agent Storage	35
SCBA and fire extinguishers storage	35
Administration offices	30
Conference room (5 people)	15 (3 m^2 / person)
Workshop	40 (vehicle + storage)
Hose Drying room	15
Day room + TV Room (25 people per shift)	50 (2 m^2 / person)
Dormitory (25 people)	100 (4 m^2 / person)
Locker room	10
Laundry room	10
Kitchen	30
Trash and Recycling	8
Subtotal	**893**
MEP (20% of above)	178.6
Sub Total	**1071.6**
Total + Contingency	**1,285.92**

Source: Consultant.

MEP systems typically add 20%:

$$MEP\ systems = 893 * 0.2 = 178.6\ m^2$$

$$Subtotal\ with\ MEP = 893 + 178.6 = 1071.6\ m^2$$

Contingency for circulation and flexibility = 20%:

$$Total\ BUA\ with\ contingency = 1071.6 * 1.2 = 1285.92\ m^2$$

The building will consist of a multi-storey structure of 3 floors (GF 920 + FFL 450 + Watch Tower 130).

Although, the calculated BUA is 1,286 m², the 2,000 m² allocation was selected to:

- Include vehicle manoeuvring space for large ARFF trucks and ambulance
- Provide future expansion capacity for additional equipment or staff

- Ensure compliance with clearance requirements and operational efficiency
- Accommodate outdoor apron and circulation areas adjacent to the station

Moreover, the total number of employees is 45 (15 per shift) for 15 MAP and 10 MAP.

5.2.2.8.3 ARFF STATION LOCATIONS

ICAO requires a fire response time not exceeding 3 minutes be provided for fire trucks to reach any point of the runway. Concurrently ICAO recommends that the fire response time does not exceed 2 minutes.

A fire response time study is conducted to check the response time needed for fire trucks to reach the runway from the newly proposed ARFF.

The response time depends largely on the following:

- Performance specifications of the fire truck in terms of speed and acceleration/deceleration capabilities
- The response route geometry
- The ability of the emergency team responding to the incident/accident to achieve the set turn-out time

The design vehicle used is the Oshkosh Striker 8x8 which is the most demanding vehicle in terms of size and manoeuvrability.

The specifications of this vehicle as given by the www.oshkoshairport.com website are as follows:

- Gross weight = 56,245 kg
- Height = 3.81 m
- Elevated Height = 19.8 m
- Width = 3.10 m
- Length = 13.6m
- Wheelbase = 6.78m
- Acceleration = 0 to 80 km/hour in 35 seconds
- Top Speed = 112 km/hour
- Gradeability = Ascend/descend a 60% grade

The acceleration from 0 to 80 km/hour is achieved in 25 seconds and the top speed can reach up to 120 km/hour. Accordingly, these values are adopted in the analysis.

The analysis shows that the fire trucks can reach the runway thresholds within the required 3 minutes time frame.

The ARFF proposed location is South of the Runway, midway between the runway end to ensure a convenient response time, as shown in Figure 5.70 below.

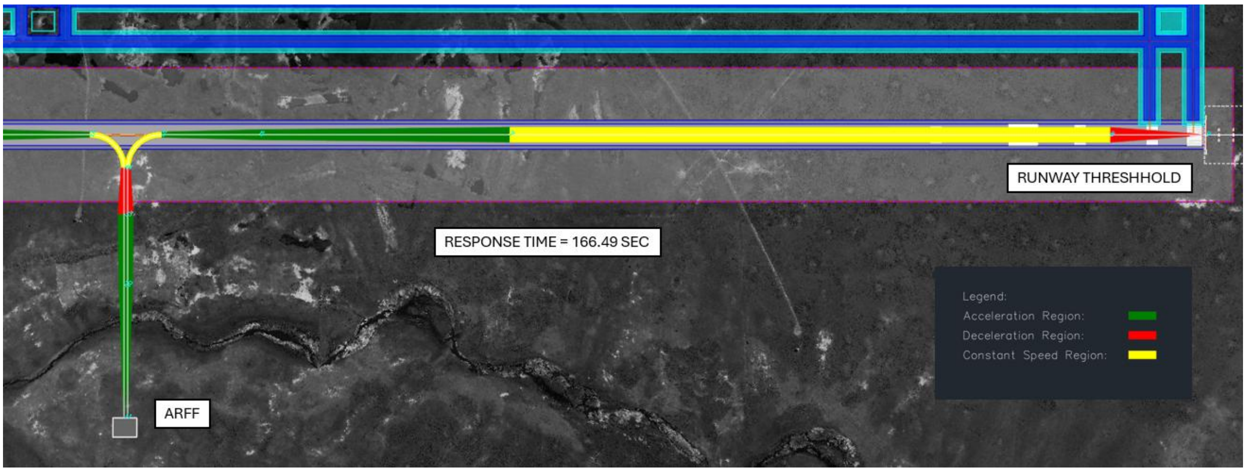


Figure 5.70: ARFF Location

AIRSIDE BUS FACILITIES

Airside buses are used for remote stands to transfer passengers to and from passenger terminal to remote stand. Remote stands are anticipated to be used to serve all demand levels. The requirements for the following bus facilities are detailed below:

- Airside Bus Storage Area
- Airside Bus Drivers Building

5.2.2.8.4 Airside bus storage area

The methodology for calculating the required area of airside bus storage area is based on the peak 90-minute demand for passenger buses serving the remote gates. This approach uses assumptions about the share of peak aircraft movements will dedicated to remote gate operations, the amount of passenger buses needs for different aircraft sizes, the travel time needed for each passenger bus, and a maintenance contingency. These are depicted in Table 5.38Error! Reference source not found..

Table 5.38: Airside Bus Storage Assumptions

Airside Bus Storage Assumption	Metric
Share of Peak Hour (90-min) Movements	36% (40 MAP) / 30% (60 MAP)
Passenger Buses per Narrowbody A/C	3 Buses
Passenger Buses per Widebody A/C	5 Buses
Bus Block Time	30 min
Maintenance Rate	10%
Area per Passenger Bus	200 square meters

Source: Consultant Analysis

The analysis calculates the requirement of parking airside busses lots, a bus storage facility, and total plot area. A metric of 200 square meters per airside bus to calculate the space needs for the bus storage facility. To accommodate additional operational needs, the total plot area is calculated applying a 3 factor to the building footprint requirement, providing extra space for vehicles and maneuverability. The resulting requirements are provided in Table 5.39Error! Reference source not found..

Table 5.39: Summary Of AIRSIDE BUS STORAGE AREA Requirements

Airside Bus Storage	Phase 10 MAP	Phase 15 MAP
Bus Parking Lots	69	83
Bus Storage Facility	Bus Parking Lots x 200 = 13,800	16,600
Total Plot Area	Bus Storage Facility x 3= 41,400	51,270

Source: Consultant Analysis

5.2.2.8.5 Airside Bus Drivers Building

A facility will be provided with the support bus driver daily operations, offering services such as restrooms for bus drivers and must be located near the bus storage area for an easy access to the buses. The size of this building depends on the number of employees.

The analysis also adopts the following assumptions from the previous Master Plan to calculate the daily staff count and vehicle utilization rate:

The Total Building Area (BUA) for the Airside Bus Driver Building was estimated based on the projected number of employees required to support airside bus operations. A factor of 6 square meters per employee was assumed to account for individual workspace, circulation areas, and shared facilities such as restrooms and staff amenities.

Additionally, it was assumed that only 80% of the total staff would be present on-site simultaneously, considering shift rotations and off-duty periods. As well as, a total of 1.2 employees are assumed per airside bus.

The building consists of one level, with 100% of the Built-Up Area (BUA) located on the ground floor.

The resulting requirements are provided in Table 5.40.

Table 5.40: Summary of airside bus driver building requirements

Airside Bus Driver Building	Phase 10 MAP	Phase 15 MAP
Total Plot Area (m^2)	1,170	1,446
Total Built-Up Area (m^2)	6 x Number of Staff x 0.8 = 398	492
Number of Building Levels	1	1
Total Staff	1.2 x number of buses = 84	105

Source: Consultant Analysis

5.2.2.8.6 AIRSIDE BUS FACILITIES LOCATIONS

Airside bus facilities will provide both airside and landside access, with convenient connectivity to the terminal area and a road network to accommodate deliveries. The complex will consist of bus storage and a dedicated bus facility to support operational requirements. The proposed location is shown in Figure 5.71.

Figure 5.71: Location Of Airside Bus Facility

5.2.2.9 AIR TRAFFIC CONTROL TOWER (ATCT)

The line of sight and visibility study were done to check whether the location and height of the existing ATCT can cover all airfield area. It turned out that the existing ATCT can cover the existing and new runways, as well as parallel taxiways. As for the cross taxiways and aprons, solutions such as CCTV cameras can be added.

Refer to Appendices I and H for the Option 1 and Option 2 layouts of the JKIA Masterplan, which illustrate the proposed locations of the facilities and utilities.

5.2.2.10 CARGO

5.2.2.10.1 IATA Sizing Guidelines

The size of cargo terminal facilities is determined from the total annual cargo tonnage estimates. The total space that is required to be allocated is a function of the proposed processing capabilities of the facilities. As shown in Table 5.41, and extracted from IATA Airport Development Reference Manual (ADRM) – Edition 11, Exhibit 3.5.8.1a, titled Generic Terminal Size Calculations, IATA recommends sizing the facilities accordingly if no site-specific information is available.

Table 5.41: IATA Generic Terminal Size Calculations

Exhibit 3.5.8.1a: Generic Terminal Size Calculations

Low Automation (mostly manual)	5 tons per square meter
Automated (Average)	10 tons per square meter
Highly Automated	17 tons per square meter

Source: IATA

Based in above IATA recommendations, the estimated footprint for the 2 Phases is depicted in Table 5.42 below.

Table 5.42: Estimated Footprint For Cargo Facility

Type of Automation	Footprint	10MAP (739,838 TPA)	15MAP (1,022,930 TPA)
Low Automation (Mostly Manual)	5 tons per square meter	147,967.60	204,613.00
Medium Automation	7 tons per square meter	105,691.14	146,152.10
Automated (Average)	10 tons per square meter	73,983.80	102,307.00
Highly Automated	17 tons per square meter	43,519.88	60,180.27

Source: Consultant Analysis.

The evaluation is based on a Medium Automation (Semi-Automated) operational model, a handling density of 7 tons per square meter was applied to estimate the required built-up area for cargo operations. Accordingly, the calculated BUA values for each development phase are depicted in Table 5.43.

Table 5.43: Calculated Bua For Cargo Facility

BUA for Phase 10 MAP (739,838 TPA)	BUA for Phase 15 MAP (1,022,000 TPA)
BUA (m²) = Annual Cargo Tonnage (TPA) ÷ 7	
105,691 m²	146,152 m²

The existing Cargo Terminal Building BUA is 167,400 m², which is greater than the total BUA required for both 20 MAP and 25 MAP phases. This indicates that the current cargo terminal provides sufficient capacity to accommodate future growth in cargo handling without the need for expansion or new construction.

The number of staff required to support cargo operations is estimated based on the following ratio: The number of staff required to support cargo operations was estimated using a standard manpower ratio that correlates workforce needs with the projected annual cargo throughput. The following formula was applied to determine the total number of employees:

Staff=0.002×Annual Cargo Tonnage (TPA)

A summary of the requirements is provided in Table 5.44.

Table 5.44: Total Number Of Staff For Cargo Facility

	Phase 10 MAP	Phase 15 MAP
Number Of Staff=0.002 X Annual Cargo Tonnage (TPA)		
Total Staff	1,482	2,046

5.2.2.10.2 Freighter Stand Methodology

Annual freighter movements were converted to hourly demand:

- Phase 1: 34,568 annual movements → 16/hr
- Phase 2: 50,539 annual movements → 23/hr

With 65% arrivals and 2-hour occupancy, stand requirements are:

- Phase 1: 19 stands
- Phase 2: 27 stands

5.3 UTILITIES

5.3.1 ELECTRICAL

5.3.1.1 Section Description

This Section describes the proposed electrical installations for the power supply of the different facilities at Jomo Kenyatta Airport. Furthermore, an order of magnitude of the power demand for the Airport Development is estimated to indicate the power required to be supplied by the Local Authorities.

The Section also describes the electrical works which include:

- Load estimate values and applicable diversities factors.
- Distribution schemes at the various voltage levels.
- Emergency power supply scheme.
- Distribution scheme reliability.
- Airfield Lighting systems and Infrastructure works to facilitate for CAT III operations for both the existing and new runway

5.3.1.2 Regulations and Standards

All electrical installations shall be designed in compliance with the latest edition of the following Standards and Regulations:

- NFPA 70 “National Electrical Code (NEC)” where not in contradiction with the Local Regulations
- Nominal characteristics of equipment forming part of the electrical works shall be specified to conform to the relevant standards of the International Electrotechnical Commission (IEC), British Standards (BS) or other equivalent international standards such as IEEE, ANSI, and NEMA
- Earthing system shall conform to NFPA 70 “National Electrical Codes (NEC)”
- Local standards, where enforced and relevant, are to have precedence over the other standards

5.3.1.3 Design Criteria and Standards

5.3.1.3.1 Objectives, Constraints and Other Considerations

The design of the electrical installations shall be based on the main objectives summarized below:

- To comply with applicable Codes and Standards
- To meet the specific power and communications requirements of the airport's systems, components and equipment
- To achieve reliability and durability of systems and components
- To implement safety and protection measures for people and equipment

While achieving the design objectives, other important factors, as listed hereunder, will be considered carefully:

- Cost effectiveness
- Efficiency and energy conservation
- Simplification of installations, operation and maintenance

5.3.1.3.2 Data Collection

The collected data, as received from the Client and authority KPLC can be summarized as follows:

- Existing Primary substation (M-station) 2x10MVA within the Airport premises, with current loading of 5.6MW serving the critical and technical facilities of the airport
- Existing Primary substation 2x23MVA outside the Airport limits, serving the airport facilities like the cargo terminals and the street lighting
- Complete airport feeding the existing Technical and Critical facilities are Backed up by MV generators with spare provision for future addition of generator.

5.3.1.3.3 Ambient Conditions

All electrical equipment and material shall be designed, specified and de-rated for continuous and trouble-free operation in the ambient conditions within JKIA Airport. All equipment shall be rated for the outdoor ambient temperature, direct sunlight, regardless of their location of installation. The site ambient conditions are considered as listed below:

- Ambient Temperature : 25 °C
- Altitude : 1795m Above Mean Sea Level
- Soil resistivity : 200 °C.cm/W

5.3.1.4 Power Supply Distribution Scheme

5.3.1.4.1 Estimate of Maximum Power Demand

The estimate of the airport maximum power demand will be based on the electrical load density criteria in (VA/m2) and built up areas of the different airport buildings/facilities in addition to the load estimate of the infrastructure elements and mechanical loads. Load estimate is proposed for two Phases 1 & 2.

Phase 1: existing capacity of the airport will be 10MAP, a new PTB and additional facilities are added to increase the capacity to 20MAP.

Phase 2: New PTB shall be expanded to increase the total capacity to 25MAP

Table 3.1. Load estimate of Phase 1 and **Table 3.2** shows the load estimate of the Phase 2 Facility; these facilities shall be fed from the existing primary substation (M-station) and the existing primary substation 2x23MVA located outside the project limit.

Table 5.45: Electrical Load estimate (PHASE 1)

Building (Phase 1)	BUA (m2)	VA/m2	C.L. (KVA)	D.F.	D.L. (KVA)
Passenger Terminal Building	170000	127	21590	0.64	13818
GSE Maintenance Facility	3087	150	463	0.68	315
Airport Maintenance Complex	6090	150	914	0.68	621
Airport Maintenance & Repair (MRO)	14429	150	2164	0.68	1472
ARFFs	1500	130	195	0.64	125
ATC	3000	170	510	0.80	408
Catering	28964	250	7241	0.60	4345
Administration and operation office	10110	130	1314	0.64	841
Airport Cleaning Facility	994	60	60	0.80	48
Data Centre	**2400**		1500	0.8	1200
AGL Substation including Nav Aids & Apron Lighting	**900**	-	1500	0.8	1200
Rotunda Loads for contact stands CODE E (9No.s)			3600	0.6	2160
Rotunda Loads for contact stands CODE C (26No.s)			6500	0.6	3900
Remote stands (12 No's)			4800	0.6	2880
Street Lighting, Apron Flood lighting etc	**-**	-	50	0.8	40
			TCL (KVA)		**TDL (KVA)**
Total Connected & Demand Load at Substation level		TOTAL	51401		32612
Total Connected & Demand Load at 11 kV Loop level (DF:0.85)		TOTAL	51401		27720
Total Connected & Demand Load at Primary substation level (DF:0.80)		TOTAL	51401		22176

Table 5.46: Electrical Load estimate (PHASE 2)

Building (Phase 2)	BUA (m2)	VA/m2	C.L. (KVA)	D.F.	D.L. (KVA)
Civilian Assets					
Passenger Terminal Building	235000	127	29845	0.64	19101
GSE Maintenance Facility	3617	150	543	0.68	369
Airport Maintenance Complex	7500	150	1125	0.68	765
Airport Maintenance & Repair (MRO)	23800	150	3570	0.68	2428
ARFFs	1500	130	195	0.64	125
ATC	3000	170	510	0.80	408
Catering	38096	250	9524	0.60	5714
Administration and operation office	12197	130	1586	0.64	1015

Building (Phase 2)	BUA (m2)	VA/m2	C.L. (KVA)	D.F.	D.L. (KVA)
Civilian Assets					
Airport Cleaning Facility	1078	60	60	0.64	42
Data Centre	2400		1500	0.8	1200
AGL Substation including Nav Aids & Apron Lighting	900	-	1500	0.8	1200
Rotunda Loads for contact stands Code E (13No.s)			5200	0.6	3120
Rotunda Loads for contact stands Code C (39No.s)			9750	0.6	5850
Remote stands (16 No's)			6400	0.6	3840
Street Lighting	-	-	50	0.8	40
			TCL (KVA)		TDL (KVA)
Total Connected & Demand Load at MV/LV Substation Level		TOTAL	71763		45473
Total Connected & Demand Load at 11 kV Loop level (DF:0.85)		TOTAL	71763		38652
Total Connected & Demand Load at Primary substation level (DF:0.80)		TOTAL	71763		30921

Table 5.45 and Table 5.46 illustrate the electrical load estimate criteria and the corresponding diversity factors for each building facility and the contact and remote stands of the airport facilities as listed below for the airport. The "Total Demand Load at 11kV Distribution Level" will be based on the following diversity factors as applicable to each type of facility:

- Diversity Factor between Buildings MV/LV transformers = 0.85
- Diversity factor between Data Centers MV/LV transformers = 1.00
- Diversity factor between Utility Facilities (Mechanical loads) MV/LV transformers = 0.80
- Diversity factor between Navigational Facilities (ATCT, AFL Substations) MV/LV transformers = 1.00

Furthermore, a 0.85 DF shall be applied on the 11kV Distributor (Loop level) and another 0.80 DF shall be applied on the 11kV Switchgear (primary substation level).

Based on the above, the estimated Maximum Demand Load of JKIA Airport at 11kV MV level shall be estimated in 22 MVA for Phase 1 and 31 MVA for Phase 2.

5.3.1.4.2 Incoming Medium Voltage Power Supply

The power supply is proposed to be delivered to JKIA Airport at 11kV Medium Voltage level.

In this respect the Airport is supplied from two independent 66 kV feeders from KPLC yard supplying power to the airport in a redundant manner to provide the first level of reliability at the 11 KV Medium Voltage level; i.e. each feeder shall be capable of supplying the MDL of the airport to provide backup for the other incoming feeder. Furthermore, it is recommended that the two incoming feeders shall be independent in terms of both power supply sources and routing paths.

As per the current as built condition the 66KV Medium Voltage incoming feeders are terminated at the 66KV switchgear and are further stepped down to 11KV to feed the Internal Medium Voltage distribution network level, through two 10MVA (ONAN rating) type power transformers. The 66kV switch gear is located in the main substation located within the Airport limit.

In addition to the above, As per the current as built condition there is also a new primary substation outside the project limit of work supplied from Two different super primary substation (220kV/66kV) Athi river and Embakasi. The 66KV Medium Voltage incoming feeders are terminated at the 66KV switchgear and are further stepped down to 11KV to feed the Internal Medium Voltage distribution network level, through two 23MVA (ONAN rating) type power transformers. The 66kV switch gear is located in the primary substation located just outside the Airport limit. However, the current capacity of the existing primary substation outside the project limit (2x23MVA) shall be verified if the overall load of the facility can be fed from the existing primary substation. If not, then additional feeders shall be coordinated with the Authority to feed the overall estimated Load of Phase 2. The below is a brief of the Overall maximum demand load at the primary substation level and its proposed distribution

- Phase 2 Emergency Loads (Data Centre, AGL substation, MRO and GSE/Airport maintenance facility: 4.05 MW (to be fed from existing M station) as shown in the Figure 5.74.
- Phase 2 Emergency Loads (PTB Building and Admin Building): 17.5 MW (Assumed to be fed from the existing Primary substation, however these needs to be verified with Authority KPLC) for MV distribution refer to figure 5.73.
- Phase 2 Normal Loads (Contact Stands and Remote stands): 8.72 MW (Assumed to be fed from the existing Primary substation, however these needs to be verified with Authority KPLC) for MV distribution refer to figure 5.73.

The 11KV MV transformers and 11KV switchgear shall be controlled, operated and monitored by the Airport SCADA system. The transformers along with the switchgear shall be equipped as applicable with the necessary control and monitoring equipment to achieve the operation envisaged by the SCADA system in the Airport. In addition, full telemetry of instantaneous values, switchgear and transformers faults shall be reported to the SCADA system via Remote Terminal Units (RTUs) or PLC based control and communication equipment and connected to the Master Station Unit.

5.3.1.4.3 Internal Medium Voltage Network

As per the current As built condition, Two 66/11 kV power transformers at each primary substation will step down the incoming 66KV Medium Voltage to 11 kV (The Internal Medium Voltage Level)

The internal Medium Voltage network shall consist of copper (CU) cables, XLPE insulated with Steel Wire Armouring (SWA) and PVC sheath that will distribute power to the local distribution MV/LV transformer substations located at loads centers. Furthermore MV cables will be installed in concrete-encased duct banks. Monitoring of MV/LV transformers and remote operation of11kV RMUs shall be permitted through the Airport SCADA system.

The internal MV network shall be configured in 11kV MV open loop configuration which ensures the second level of reliability, as each leg of the loop shall be fed from a different bus section of the MV Distributor in order to achieve reliability and continuity of power supply.

Furthermore, in order to achieve the required reliability for TIER III operations of the Data Centers, the transformers supplying the Data Centers shall be connected to the MV network in a primary selective configuration whereas each leg of the RMU shall tie to a different MV loop.

MV cables routes shall be selected in accordance with ICAO to ensure the required clearances between the electrical installations and the runway and associated taxiways. Furthermore, redundant paths shall be selected to provide high reliability levels in case of accidental breakdown for the cable trenches.

Similar to the KV MV switchgear and transformers, Control and Communication equipment shall be provided for the 11KV Distributor and 11/0.4KV distribution transformers and Ring Main Units (RMUs) as applicable to allow the remote control and monitoring of telemetry values and faults in each substation by the Airport SCADA system. In addition, RTUs or PLC based equipment shall be provided and located in each substation to allow for local and remote control and supervision of equipment.

Below images shows the proposed internal MV network from both the primary substations and its related MV schematic distribution. The MV network are to be proposed inside a concrete encased duct banks supplying different facilities in a loop configuration. Maximum capacity of each loop shall be 6.6MVA as per standards, spare capacities of 15 % is considered on the MV loop to allow for any future expansion. 25% spare duct shall be considered in the 11kV infrastructure network for any future use.

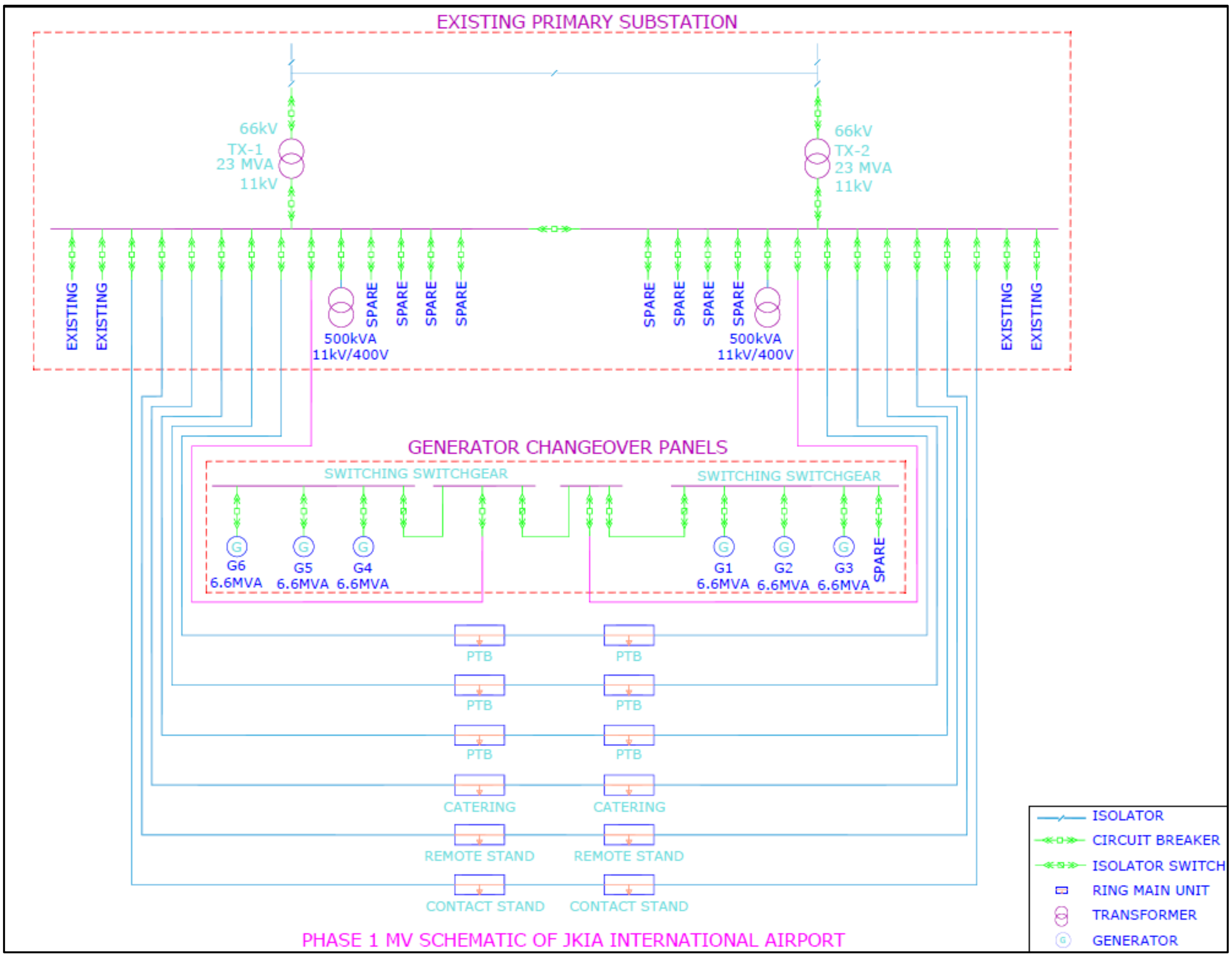


Figure 5.72: MV single line diagram of Existing primary substation (2x23MVA) feeding Phase 1 Facilities

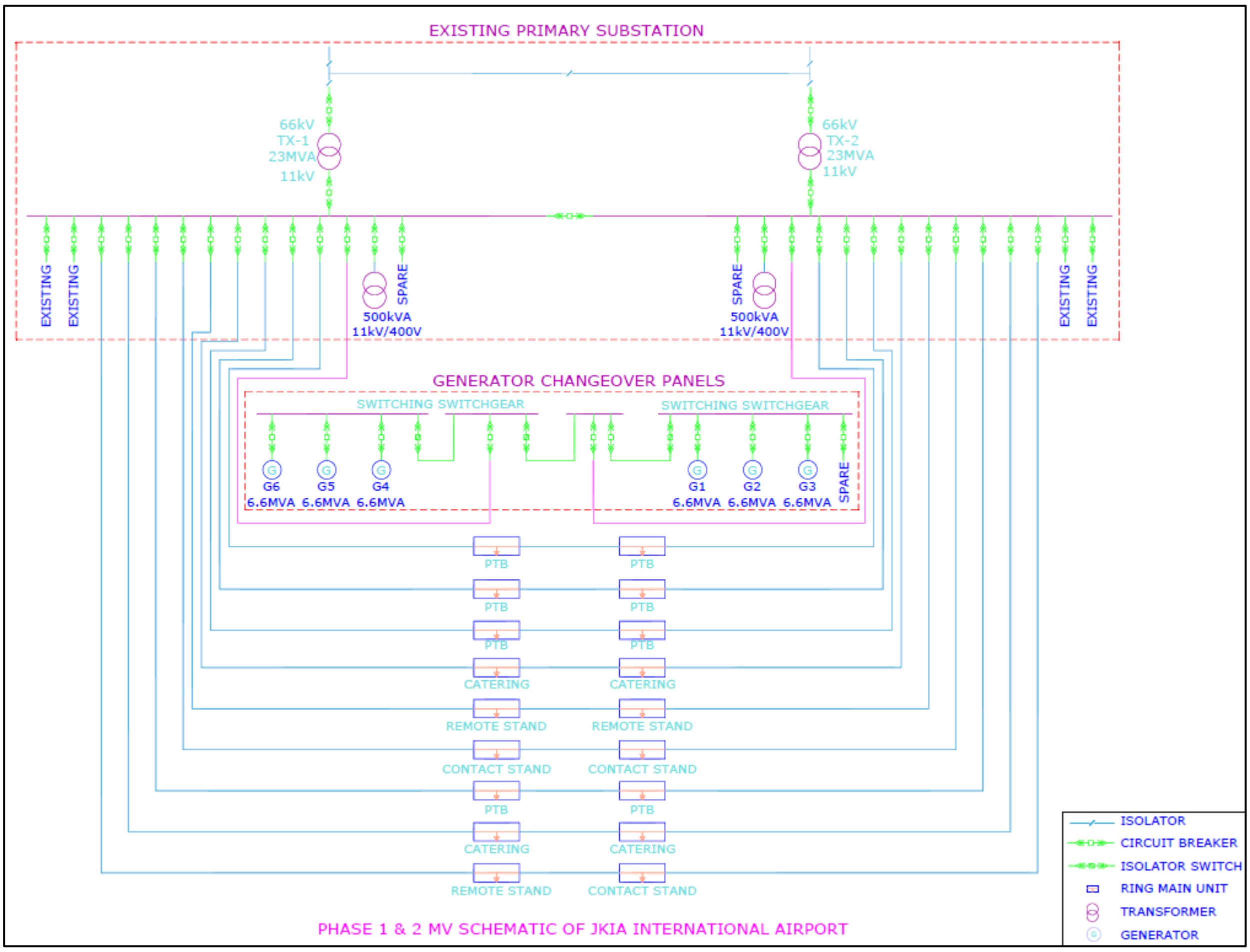


Figure 5.73: MV single line diagram of Existing primary substation (2x23MVA) feeding Phase 1 & 2 Facilities

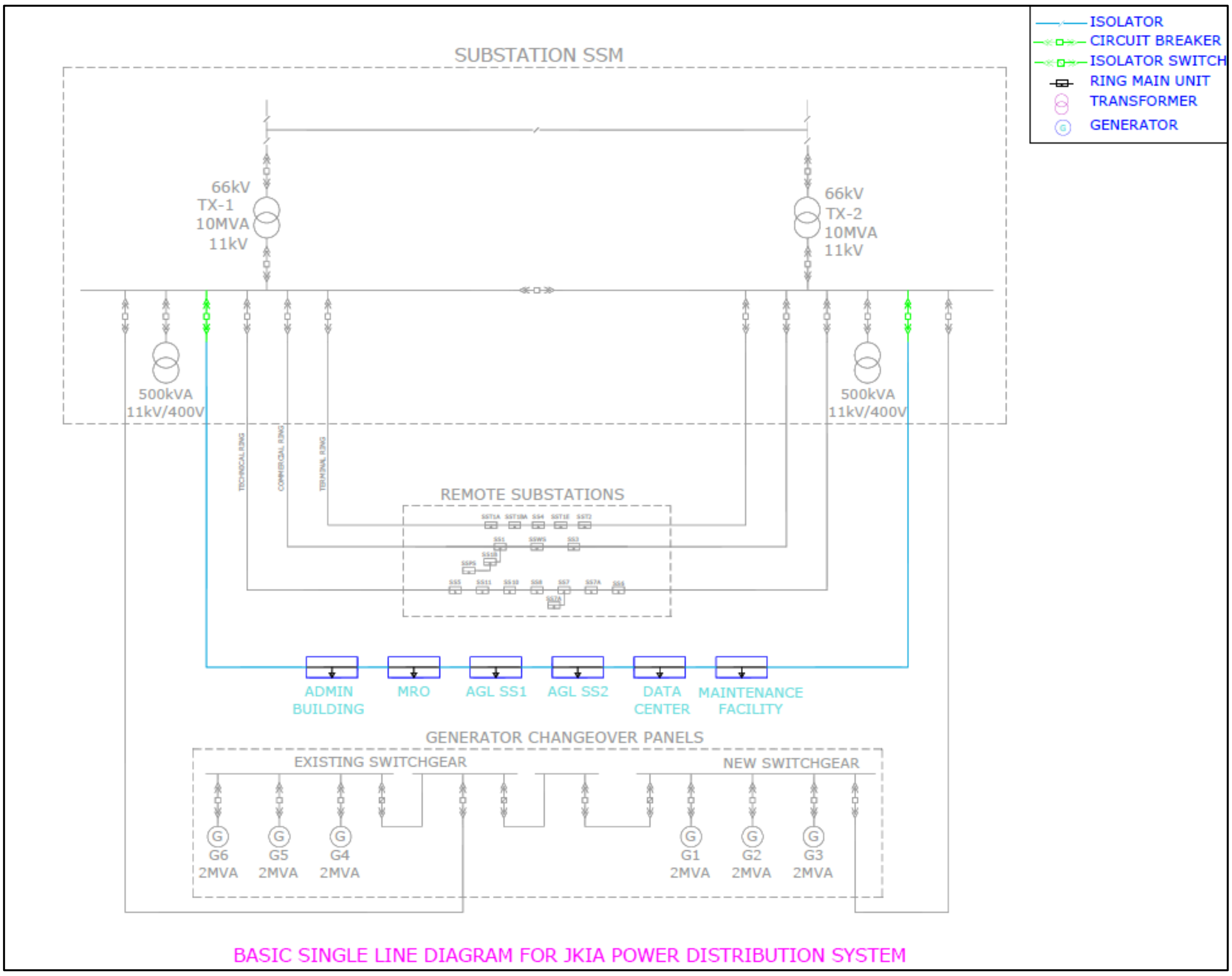


Figure 5.74: MV single line diagram of Existing SSM Primary substation

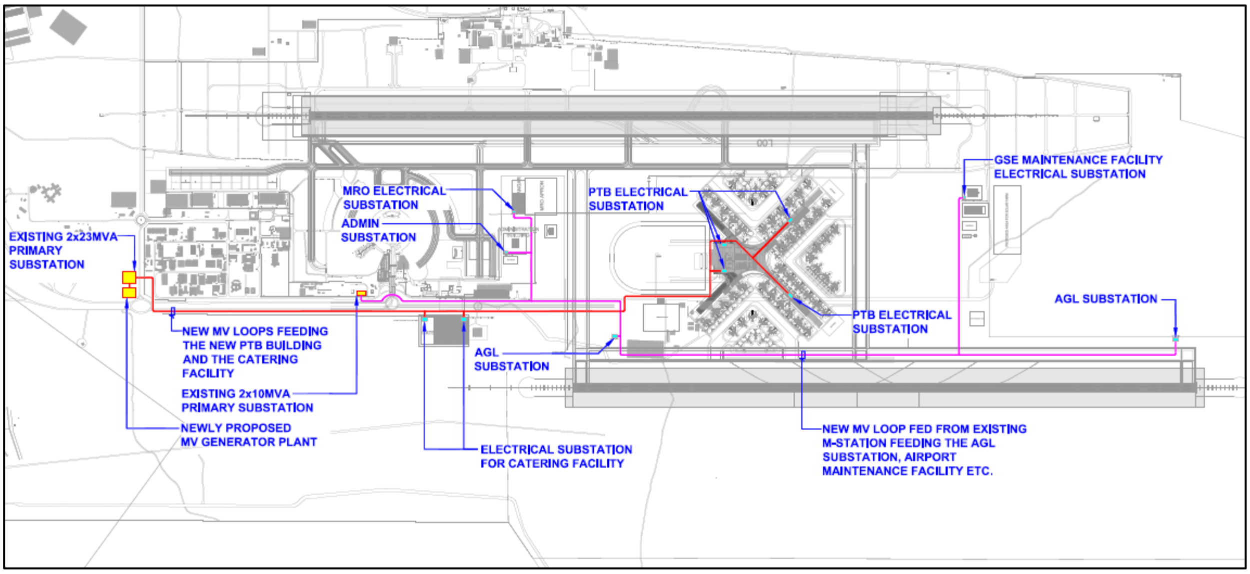


Figure 5.75: MV Network Layout

5.3.1.4.4 Low Voltage Power Supply

Low Voltage (LV) power supply will be made available at 400V/230V, 3 wires, 50 Hz, TN-S.

The low voltage installations shall reflect a high level of supply reliability and flexibility. Redundant MV/LV transformers shall be adopted for critical loads as per the power requirements of the serviced loads. In addition, localized low voltage emergency generators will be provided for critical loads to secure the emergency power supply in case of a power failure.

Transformers shall be provided with Main Distribution Board (MDB). Depending on the required power demand, sub main distribution boards (SMDB) shall be allocated to individual areas or load centers. Motor Control Center and Panels (MCC/MCP) shall supply the different mechanical loads. Final distribution boards (LP, PP, etc.) shall feed final sub-circuits for lighting and small power outlets. Each board shall serve a defined zone.

Necessary SCADA equipment shall be provided at the MDB level for telemetry of instantaneous values (Voltage, Current, Frequency, Power and Energy), and for control and monitoring of MDBs.

The low voltage network shall be made through low voltage CU/XLPE/PVC to distribute power from MDBs to SMDBs and CU/PVC/PVC to distribute power to final distribution panel boards. And the final branch circuits shall be copper wires CU/PVC.

The low voltage cables shall be installed at cable trenches within the substation areas and shall be installed on cable trays/cable raceways elsewhere. Furthermore, the cable current carrying capacities shall be derated according to the installation method and the ambient conditions.

Below are the Typical substation layouts for the different facilities at the Jomo-Kenyatta International airport.

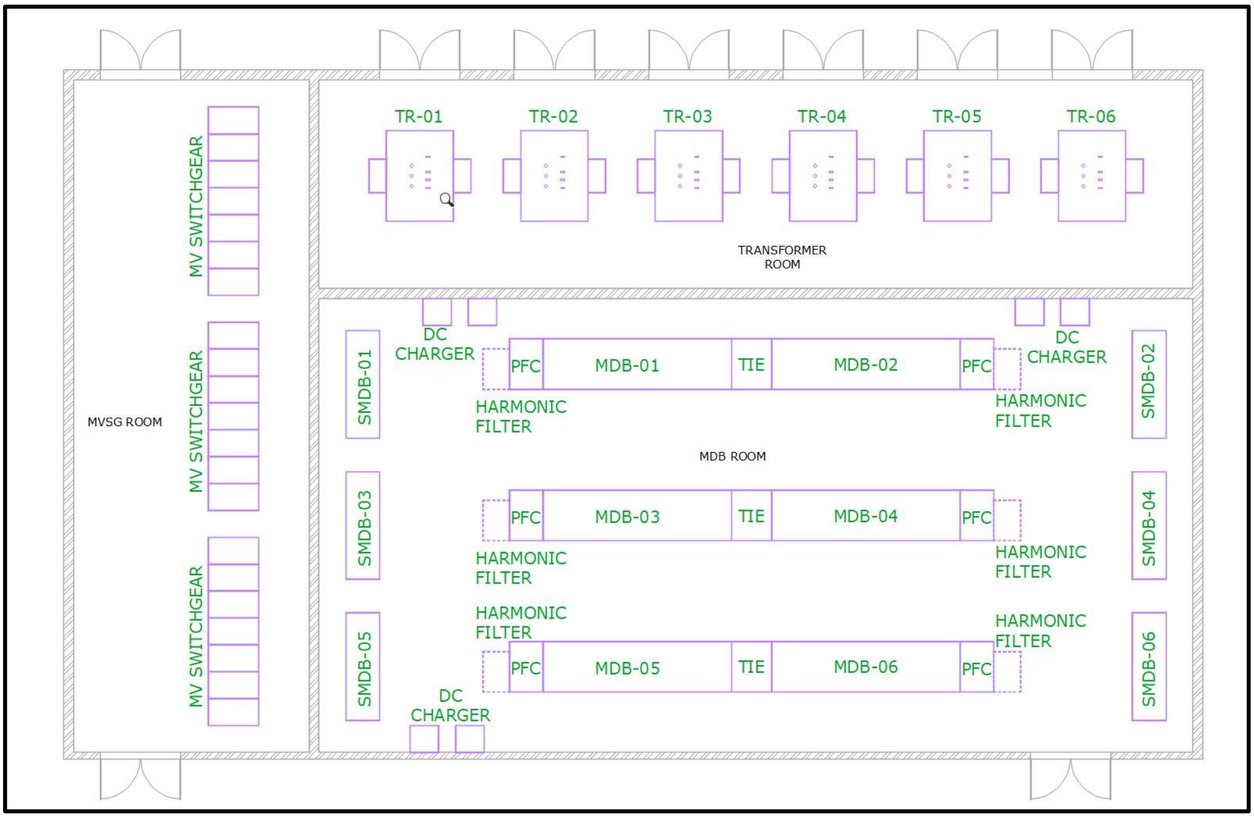


Figure 5.76: Electrical substation layout for PTB Building

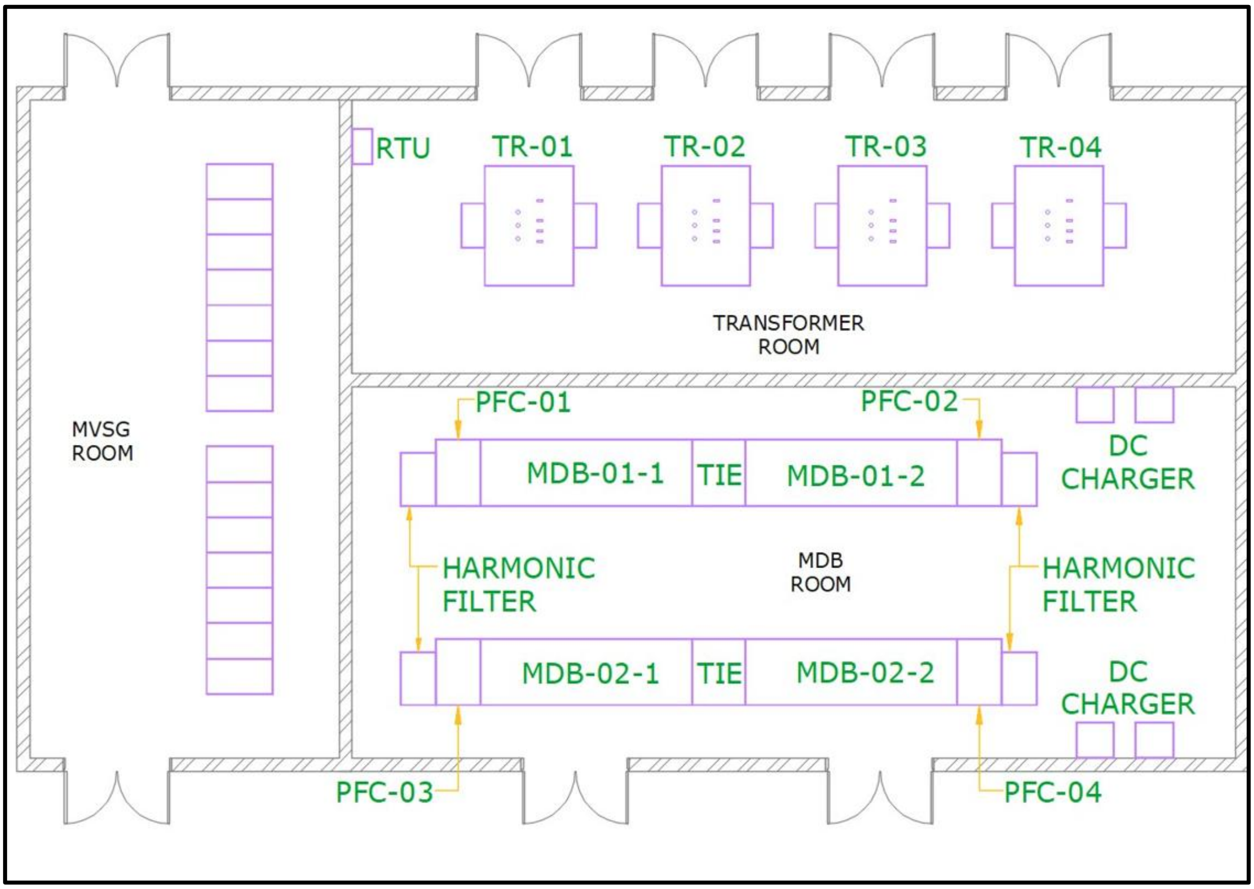


Figure 5.77: Electrical substation for Catering Facilities & MRO

Figure 5.78: Electrical substation for Data Centre & Admin Offices

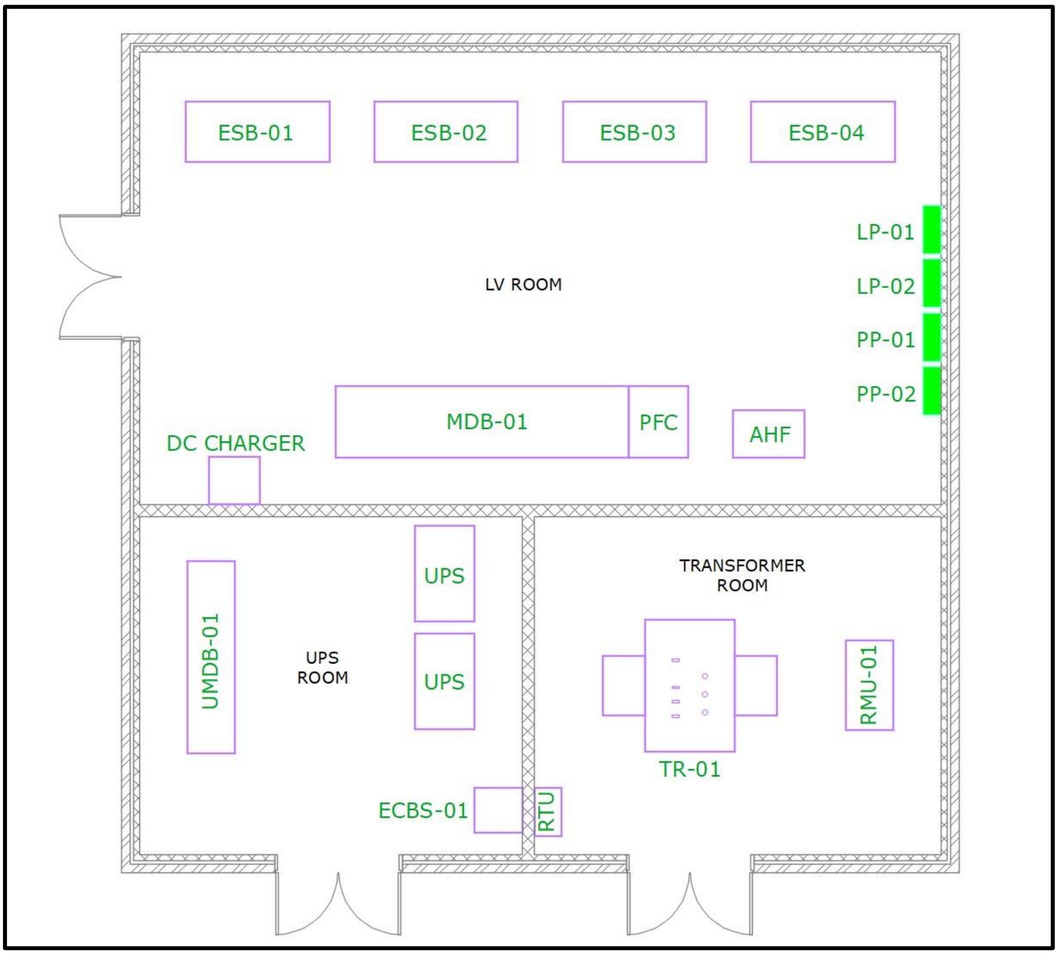


Figure 5.79: Electrical substation for Remote Stands

5.3.1.4.5 SCADA and Network Management Installations

A SCADA system shall be provided in the Airport to control and monitor the 33kV, 11kV and 400V installations. Equipment to be controlled and monitored shall include the following:

- MV and LV switchgear;
- Transformers;
- RMUs;
- MDBs;
- MV Generators;
- Local Generators as applicable;

The Airport SCADA system shall be of the distributed control type and shall consist of one Master Station location shall be coordinated in the later stages and of Remote terminal Units (RTUs) or PLC based equipment located in each substation to be controlled by the SCADA system. Master Station and local equipment shall be connected together via a dedicated ring, “self-healing” communication network.

In addition, the Airport SCADA system shall comprise the necessary interfaces with the specialized equipment management systems, including BMS, fire alarm systems and generators management system if any.

5.3.1.4.6 Emergency supply scheme

As per the current A- built condition, The emergency supply scheme is already provided for the full electrical loads of all the building/facilities of the airport. MV voltage diesel prime generators and connected to the MV Distributor at the M Station.

The emergency power will be distributed through the same MV loops supplying the normal power and the switching from normal supply to the emergency supply will be done through the MV Distributor.

New MV generator Plant and switching station is proposed within the airport premises to provide complete back up to the Different facility at the JKIA international airport (Phase 2 loads) refer to below Figure: 5.81, the Rating of the MV generator is proposed to be 6.3MVA providing complete backup to the different proposed facilities. The Emergency power will be distributed in the through the same MV loop supplying normal power and the switching of the Normal to emergency supply will be done through the proposed MV distributor. For details refer to the MV single diagram of the Phase 1 & Phase 2 facilities and the MV network layouts for the Phase 2 facilities.

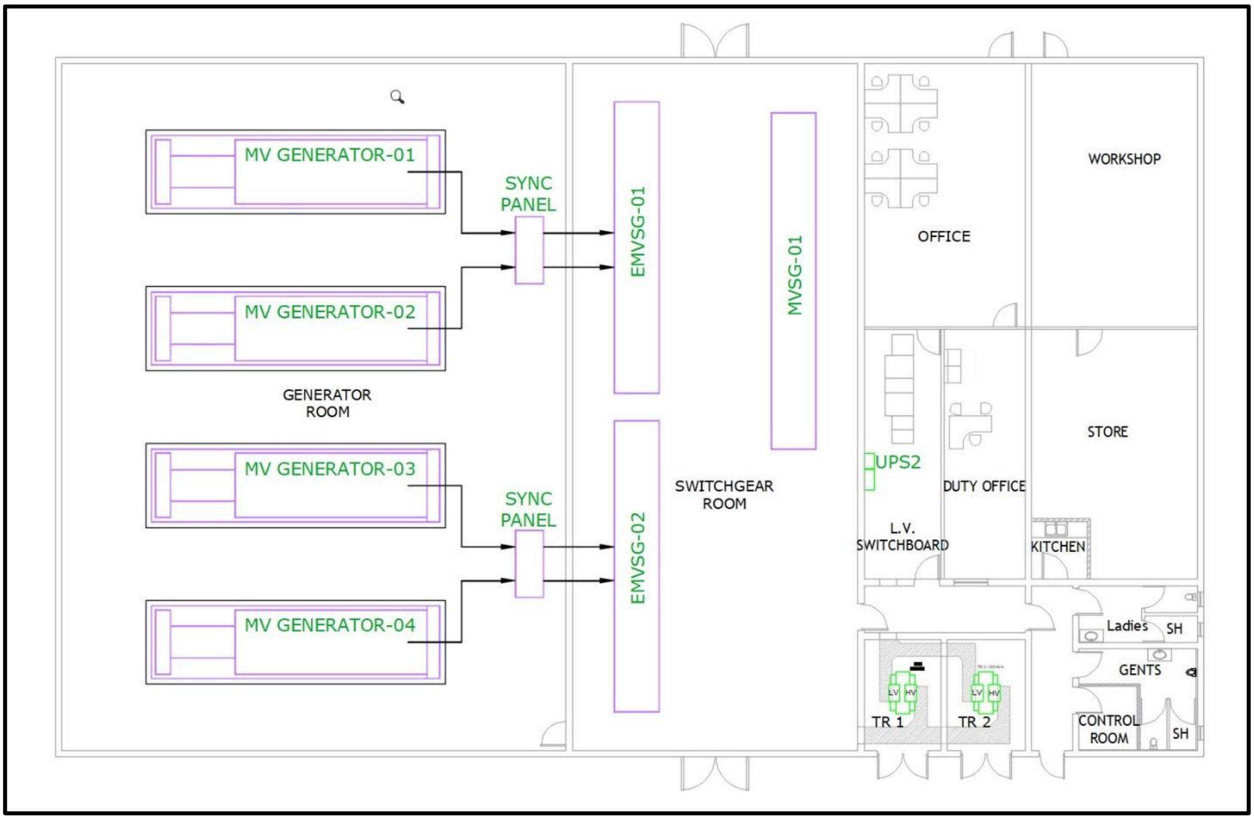


Figure 5.80: Emergency Scheme: New MV Generator & MV switching station

For the expansion of the JKIA airport similar concept shall be followed and spare provisions shall be utilized in the generator plant to serve the additional critical and technical loads.

In addition to the Emergency Power distributed at the Internal Medium Voltage Network the following buildings/Facilities shall be backed up with local LV Generators due to their critical loads.

- Data Center loads
- Airfield Substations 1 & 2 for CAT III operations.

An interface shall be provided between local Generators and the Airport SCADA system to allow for remote control and monitoring of standard telemetry values, paralleling, and faults for the installed generators.

5.3.1.5 ACCESS ROADS ELECTRICAL INSTALLATIONS

The electrical installations that shall be proposed for the landside access roads shall be as follows:

- Street and Parking Lighting
- Car Parking Management System
- Power Supply

5.3.1.5.1 Street and Parking Lighting

5.3.1.5.2 Lighting Levels

Based on the CIE, the recommended lighting levels at the different roads shall be as shown in Table 5.47.

Table 5.47: Lighting Levels at Roads

Road	Minimum Average Luminance L_{avg} (cd/m^2)	Minimum Overall Uniformity U_0	Minimum Longitudinal Uniformity U_L
Primary Roads	1.5	0.4	0.7
Secondary Roads	1	0.4	0.5

Elimination of glare shall be catered for by restricting Threshold Increments (TI) above a value of 15. As for the parking areas, based on the CIBSE "The Outdoor Environment", the recommended lighting levels shall be as shown in Table 5.48

Table 5.48: Lighting Levels at Parking Areas

Parking	Minimum Horizontal Illuminance (lux)	Minimum Uniformity
Cars & Buses	20	0.3

5.3.1.5.3 Luminaires and Lighting Columns

Luminaires shall be of the LED type with appropriate ratings in order to achieve the above recommended lighting levels. Luminaires construction shall be as per the Specifications. Lighting Columns heights shall be as appropriate for the selected luminaires ratings in order to achieve the recommended lighting levels.

5.3.1.5.4 Power Supply

Power supply for the street and parking lighting shall be from dedicated feeder pillars. The feeder pillars shall be fed from nearby substation or otherwise from package outdoor substations distributed along the access roads also feeding power to the parking management systems.

Package outdoor substations if required shall be of the compact type, housing three compartments: the MV, Transformer and LV compartments. Transformers shall be of the oil type with appropriate ratings for the different demand loads. The package substations shall be fed from the airport MV network at the 11kV level.

5.3.1.6 Electrical charging stations

Outdoor EV Charging stations feeding the Doolies, Tow Tractors, transporters etc at the Apron areas of the airport. All DC Charging Stations shall be equipped with off-board charger of IGBT technology. The following has to be adopted in the selection of the Electrical charging station.

- DC chargers' type (mode 4) to be used
- Multiple ratings are utilized depending on required charging points
- Combining two charging vehicles in single charging station, as applicable.
- Number and location of charging points were aligned with each stand blueprinting.
- Required Charging power per equipment are considered as received from the relevant stake holders.

Charging stations supplying Airside GSE shall be fed from Normal Power Supply from the nearby Apron 11/0.4kV substations. Below is the specification of the proposed EV Chargers.

Charging station Type CSDC01: Floor mounted D.C. EVSE having the following characteristic:

- Nominal Input Voltage: 400 V, three phase, 50 Hz, 4 wires with earth.
- Rated D.C. charging power: 50 kW.
- Maximum D.C. output voltage: 500V.
- Maximum D.C. output current: 125 A.
- Mounting: Floor Mounted.

- Number of D.C. charging guns: 2.
- Type of vehicle connector: CHAdeMO connector and CCS/Combo2 connecter.
- Retain any of the following points as applicable. Coordinate the below with project's requirement, manufacturer's requirement, and available network.
- Push Buttons to operate and control the charging.
- LED status indicator to indicate power, charging status, and system faults with color coding according to IEC 60073 and as per manufacturer recommendation.
- Display screen to indicate power, charging status, and system faults as per manufacturer recommendation.
- Touch screen to operate the EVSE and indicate power, charging status, and system faults as per manufacturer recommendation.
- Energy metering: Measurement of voltage, current and apparent power.
- Energy management: Load shedding, Deferred charging start, Charging current limitation, load balancing etc..
- Authorization: Keylock, RFID authorization, Pin code authorization and combination of any.
- Communication: EVSE shall be able to communicate with the EVSE central monitoring system or Building Management System for monitoring and control. EVSE shall be provided with all necessary gateways, communications devices and accessories to ensure proper operation of the system as required by manufacturers.
- Connectivity: [Wired Ethernet][Wi-Fi][Cellular].
- Retain the below sub-paragraph if payment platform is required for the application.
- Payment Platform: [RFID card payment][Credit card payment][Integrated with parking billing system].

5.3.1.7 APRON ELECTRICAL INSTALLATIONS

5.3.1.7.1 General

Several electrical systems are considered for the aprons. These include:

- Ground Power Supply.
- Apron Floodlighting.
- Visual Docking Guidance Systems along with CCTV, Stand Identification Signs and INS signs.
- In addition, electrical supply provisions are considered to the following apron services:
    - Aircraft service pits (400HZ & PCA).
    - PCA Units on remote aprons.
    - Fuel valves within fuel valve chambers.
    - Remote IO fuel control cabinet
    - Feeder pillars.
    - EV chargers
    - Low Current Installations

5.3.1.7.2 Ground Power Supply

Design Criteria

All stands within Apron Stands packages are provided with fixed Ground Power Units (GPUs – static 400Hz Converters):

- For Remote stands:
    - The GPU will consist of 400Hz converters units mounted at the apron level within the staging area along with 400Hz pop-up pits located at the head of the stand beside the stand lead-in stop positions.

- The GPUs will be covered by shelters to protect them from direct sunlight.
- The usable cable range will be of 15m. Accordingly, the location of the pit was checked against the fleet mix aircraft connections to confirm that these latter can be reached from the pit.
- For code C aircraft stands, a minimum of 2.5m offset from the lead-in line for the inner edge of the pit rising column.
- For code D/E/F aircraft stands, a minimum of 3m offset from the lead-in line for the inner edge of the pit rising column.
- The control over the GPU will be directly from the GPU built in control panel directly accessible by the ground personnel.

5.3.1.7.3 Aircraft Requirements

The following requirements apply for each Aircraft Code:

Table 5.49: 400Hz requirements for Aircrafts

Aircraft Code 400Hz Requirements	Code C	Code D	Code E	Code F
400Hz Connections (Nr. x KVA Rating)	1x90	2x90	2x90	4x90

Table 5.50: PCA requirements as per Aircraft Code

Aircraft Code PCA Requirements	Code C	Code D	Code E	Code F
PCA Connections (Nr. x KVA Rating)	1x150	1x150	1x150	2x150

The rating of the PCA units are just an estimate can vary during the design stages

Accordingly, each aircraft at remote stands shall be equipped with one of the following pits:

- 400Hz pop-up pit for one or two connectors for Code C, D or E lead-in alignments.
- 400Hz pop-up pit for four connectors for Code F lead-in alignments.

5.3.1.7.4 Ground power Supply at Aircraft Stands

Based on the proposed Aircraft Fleet Mixes, the following installations shall be proposed for each new aircraft stand:

Table 5.51: 400HZ installation at Aircraft stands

Stand Aircraft Code 400Hz Installations	Code E	Code F	MARS Code F/2C
400Hz Converters (Nr. x KVA Rating)	2x90	4x90	4x90
400Hz Pits (Nr. per Code)	1/E	1/F	1/F & 1/C
400Hz Connectors (Nr. per Code)	2/E	4/F	4/F & 1/C

5.3.1.7.5 Apron Floodlighting

Generally, all aprons (contact or remote) and staging areas will be provided with floodlighting. The floodlighting installations consisting of high masts with winching system, floodlights and obstruction lights.

The high masts will be located in the alignment of the head of stands midway between every two consecutive stands such that to achieve the required illumination levels and uniformities at different zones of the apron (stands and GSE roads) as well as to minimize the shadow of aircraft. The floodlights wattage and lamps type are selected to provide the illumination levels and uniformity requirements as well as to ensure the correct color identification for all aircraft markings connected with apron routine servicing, as required per ICAO.

The high masts are thus proposed as follows:

- On remote stands, the high masts are proposed at the ground level while making sure that they do not cause restrictions in the maneuvering of GSE vehicles on the apron.

Lighting requirements

The following minimum lighting levels and uniformities shall be achieved as required by ICAO:

Table 5.52: Required Apron Lighting levels

Area	Horizontal Illumination E_{av} (Lux)	Uniformity U_0	Vertical Illumination E_{av} (Lux)	Uniformity U_0
Aircraft Stands	**20**	**0.25**	**20**	**-**
Staging Area	**20**	**0.25**	**-**	**-**
GSE Road	**10**	**-**	**-**	**-**

High Mast

The high masts will be equipped with movable mechanism consisting of a motor and gear driving the mast head, guidance rails, limit switches, and torque limiter. The high mast will be provided with a weatherproof door access at its base, housing the electrical distribution panel. A multi-pair heat resistant rubber insulated power cable will connect the base distribution box to the head distribution box, in order to distribute power to the floodlights and obstruction lights. Each high mast will be fed from a separate cable rising from the apron feeder pillar (for remote stands) are protected with the necessary circuit breakers.

Control of the Floodlighting will be locally from switching / photocells / timer arrangement or remotely from BMS through a selector switch. This shall be achieved from the feeder pillars on remote stands and from common control arrangements for contact stands to ensure coordination of the floodlighting control on the contact stands.

Floodlighting Fixtures

Floodlights shall be of LED type. The use of LED floodlights provides several benefits which lead to a reduced overall carbon footprint at the level of the airport. LED floodlights help achieve this target as they require reduced maintenance and less energy. Moreover, the use of LED floodlights provides improved control over spill light, thereby reducing glare, light pollution and increasing energy efficiency.

Obstruction Lights

Each high mast will be provided with a dual head LED obstruction light unit, low intensity, to be equipped with automatic change-over relay switch. Obstruction lights shall be monitored from BMS to ensure remote detection of their failure.

Remote Monitoring

Remote monitoring from airport BMS system is provided for the main circuit breaker and obstruction lights status of each high mast.

Lighting Calculation

Appropriate Maintenance Factor and Ambient Temperature Factor are considered in the calculations of LED applications, as follows:

Maintenance Factors

As per BS5489-1, the Maintenance Factor of an LED luminaire is calculated as follows:

MF = LLMF x LSF x LMF

Where:

- LLMF (Lamp Lumen Maintenance Factor) is the ratio of the luminous flux of the LEDs at the end of their rated lifetime to the initial luminous flux of the LEDs. Based on DAEP master specifications, the required guaranteed rated life is of 50,000 hours at the end of which the luminous flux will not get lower than 80% of the initial flux (L80). Accordingly, a LLMF of 0.8 is considered.

- LSF (Lamp Survival Factor) is the fraction of the total number of LEDs which continue to operate at the end of their rated lifetime. Considering a spot replacement strategy, a LSF value of 1 is considered, following Annex C of BS5489-1.

- LMF (Luminaire Maintenance Factor) is the reduction in light output owing to the accumulation of dirt on the light emitting parts of the luminaire. A value of 0.92 is considered as per Table B.1 of BS5489-1, for a cleaning frequency of 72 months and mounting heights above 6m.

Substituting the values into the formula above gives a MF value of 0.736. Accordingly, a MF of 0.72 is used in the design by rounding down the calculated value.

Ambient Temperature Factor

The Ambient Temperature Factor accounts for the effect of ambient temperature on the Lumen output of LED luminaires.

5.3.1.7.6 Visual Docking Guidance System

VDGS units will be based on the laser technology and comply with ICAO Annex 14 and Design Manual Part 4. The units will be fed from low voltage UPS supply

One VDGS unit is proposed to be provided per aircraft stand per lead-in line alignment. VDGS units shall be mounted on poles or cantilevers as suitable for the foreseen GSE traffic in its surrounding.

The location of the AVDGS has been checked with respect to the following AVDGS performance requirements and criteria:

- Distance from AVDGS to the aircraft nose should be between 2m and 65m.
- Vertical and horizontal scanning range of the AVDGS:
  - **Horizontally:**
    - The view from the AVDGS unit towards the stand should be clear from any obstacle within a range of +/- 10 degrees either side of the centerline and out to the clip distance of 100m.
    - The aircraft’s engine should be within +/- 30 degrees from the AVDGS axis, this is checked when the aircraft is at least 15m before the stop position
    - The deviation between the aircraft lead in alignment and the AVDGS axis shall be maximum 20 degrees.

        - The stopping position indicator should be located in conjunction with, or sufficiently close to, the azimuth guidance unit so that a pilot can observe both the azimuth and stop signals without turning the head.

    - **Vertically,** the aircraft nose should be within +5 to -24 degrees from the AVDGS unit axis when the aircraft is parked at the stop position.

- Visibility of the AVDGS unit from the aircraft cockpit.
    - The AVDGS display should be within the pilot eye angle, considered as +15 degrees to -15 degrees vertically from the location of the cockpit.

- Non-interference of GSE traffic on the AVDGS operation within an angle of -24 degrees from the AVDGS unit axis (in case where this latter is positioned on the opposite side of the Head of Stand GSE road).

It is worth noting that final height and location of the VDGS units shall be subject to the VDGS supplier requirements.

In addition, VDGS remote control panels will be installed at apron level on the Emergency Contact Point.

5.3.1.7.7 Aprons power Distribution Scheme

Contact Aprons power Supply

The power supply to contact aprons electrical services will be provided from the Concourse/Rotunda electrical rooms as follows:

- The following equipment will be fed from normal power supply:
    - Ground Power Supply (400Hz GPU).
    - Pre-Conditioned Air (PCA).
    - EV Chargers
- The following equipment will be fed from essential power supply through UPS:
    - VDGS units
    - Apron ELV installations
    - Remote IO fuel control cabinet
- The following equipment will be fed from emergency power supply:
    - Apron floodlighting
    - Fuel network motorized valves

Remote Aprons Power Supply

The power supply to remote aprons electrical services will be provided from outdoor package substations.

Low Voltage Distribution

The low voltage power supply for the remote aprons' installations shall be as follows:

- Normal Power Supply: normal power supply is ensured from dedicated Apron Normal Package Substations (fed from Normal MV Loops), for the following equipment (with secondary power supply source considered to be from the aircraft Auxiliary Power Units (APU) for the 400hz and PCA supply of the aircraft):
    - Ground Power Supply (400Hz GPU).

    - Pre-Conditioned Air (PCA).
    - EV chargers
    - Air-conditioning and interior lighting / power of Apron Package Substations

- Essential Power Supply: The following equipment are required to be fed from essential power supply:
    - VDGS units (Through UPS)
    - Apron and substations ELV installations (Through UPS)
    - BMS equipment (Through UPS)
    - Remote IO fuel control cabinet (Through UPS)
- Emergency Power Supply: The following equipment shall be fed from emergency power supply:
    - Apron floodlighting
    - Fuel network motorized valves

5.3.1.8 AIRFIELD LIGHTING SYSTEMS

The airfield lighting system section facilitates the CATIII operation and the similar approach should be followed when considering the rehabilitation of the existing runway and the taxiways with AFL LED technology.

5.3.1.8.1 Codes and Standards

The airfield lighting installations shall be planned and designed to:

- Comply with the applicable local standards and regulations
- Allow integration of the existing airfield lighting installations while ensuring their continuous operations.
- Achieve durability and reliability of systems and components.
- Implement measures for the protection and safety of airside operations.

Design of Airfield Lighting (AFL) installations shall comply with the latest edition of the following standards and codes:

- National Code
- ICAO Annex 14, Volume I, “Aerodrome Design and Operations”
- ICAO Aerodrome Design Manual, Part 4, “Visual Aids”
- ICAO Aerodrome Design Manual, Part 5, “Electrical Systems”
- ICAO Aerodrome Design Manual, Part 6, “Frangibility”
- Federal Aviation Administration (FAA), Advisory Circulars
- IEC International Electro-technical Commission
- TS 61827, “Electrical installations for lighting and beaconing of aerodromes Characteristics of inset
- and elevated luminaires used on aerodromes and heliports”.

Light Emitting Diode (LED) airfield lights shall comply, in addition to the above standards, with the latest editions of the following regulations:

- FAA Federal Aviation Administration
- Engineering Brief EB-67D, Light Sources other than Incandescent and Xenon for Airport and
- Obstruction Lighting Fixtures.
- IES Illuminating Engineering Society
- LM-79-08 “Approved Method for the Electrical and Photometric Measurements of Solid-State
- Lighting Products”.
- LM-80-08 “Approved Method of Measuring Lumen Maintenance of LED Light Sources”.
- TM-21-11 “Projecting Long Term Lumen Maintenance of LED Light Sources”.

Where equipment or installation practices are according to the Federal Aviation Administration (FAA), they shall be approved unless in contradiction with the ICAO regulations or the regulations of the local Authority.

5.3.1.8.2 Airfield Lighting Fixtures

Generally, all airfield lighting fixtures shall comply with the following:

- All fixtures' lamps shall be rated for constant 6.6A circuits
- Fixtures Construction and Photometric outputs shall comply with the relevant Standards
- Inset Lighting Fixtures shall be of the shallow can type, and shall be mounted to have their top matching the runway level while keeping their protrusion to a minimum
- Elevated Lighting Fixtures and guidance signs shall be installed so as to conform to the relevant ICAO Standards for frangibility and obstacle clearance
- All AFL fixtures shall be of the LED type

The airfield lighting installations within the JKIA Airport shall comprise the following LED-based lighting systems:

Approach Lighting Systems:

- Approach Lighting.
- Threshold Lighting.
- Runway Threshold Identification Lighting.
- Touchdown Zone Lighting.
- Precision Approach Path Indicator Lights.

Runways Lighting Systems:

- Runway Centerline Lighting.
- Runway Edge Lighting.
- Runway End Lighting.

Taxiways Lighting Systems:

- Taxiway Centerline Lighting.
- Taxiway Edge Lighting.
- Rapid Exit Taxiway Indicator Lights.
- Intermediate Holding Position Lighting.
- Stop Bar Lighting.
- Runway Holding Position Lighting.
- Stand Maneuvering Lighting.
- Taxiway Guidance Signs.
- Traffic Signal Lights.

This section describes the proposed airfield lighting arrangements for the above-mentioned systems.

5.3.1.8.3 Approach lighting systems

Error! Reference source not found. illustrates the different Approach & Runway AFL installations as described hereafter:

Approach Lighting

- Unidirectional approach lights shall be located at the approach areas at both sides of the runways, showing white.
- Supplementary unidirectional lights, showing red, shall be added to ensure precision approach category II and III lighting system.
- Sequence flashing lights shall also be installed for each approach lighting system.
- Each approach light fixture shall be fed from one isolation transformer and a single channel addressable Remote Control and Monitoring Unit (RCMU).
- Sequence flashing lights shall be fed from a dedicated LV network through their control cabinets located in the airfield lighting substations.

Touchdown Zone Lighting

- Unidirectional touchdown zone lights shall be installed at the CAT III approach touchdown marked area within a length of 900m, showing white.
- Fixtures shall be of the inset type.
- Each Light fixture shall be fed from one isolation Transformer and a single channel addressable RCMU.

Threshold Lighting

- Unidirectional inset threshold lights shall be installed across the runway threshold, showing green.
- Unidirectional threshold wing bar lights, shall be installed in-line with the threshold lights, showing green in the runway approach direction. Threshold wing bar lights shall be elevated if located outside paved areas and inset otherwise.
- Each threshold or threshold wing bar light shall be fed through one isolation transformer and a single channel addressable RCMU.

Precision Approach Path Indicator (PAPI) Lighting

- Precision Approach Path Indicator (PAPI) elevated light units shall be located on both sides of each runway, showing red or white.
- Each approach direction will be equipped with two sets of four PAPI units, one set on the right side and another on the left side.
- Each unit shall have one or two optical assemblies. Each optical unit shall be fed through one isolation transformer and a single channel addressable RCMU.

Runway Threshold Lighting system

- Unidirectional inset runway threshold identification flashing lights shall be installed in-line with the threshold wing bar lights, showing flashing white in the runway approach direction.
- RTILs shall be fed from the Low Voltage system of the Approach Sequence Flashing Lighting Systems.

5.3.1.8.4 Runway lighting system

Runway Centreline Lighting

- Bidirectional inset centerline lights shall be installed along the runway centerline, showing:
    - White from threshold up to the 900m point from runway end, then
    - Alternate white and red from 900m point to 300m point before the runway end, afterwards
    - Only red up to the runway end.
- Each light fixture shall be fed through one isolation transformer and a dual channel addressable RCMU.

Runway Edge Lighting

- Bidirectional inset runway edge lights shall be installed in two parallel rows located on both shoulders along the full length of the runway, showing:
    - White from threshold up to the 600m point from runway end, and then
    - Showing yellow up to the runway end.
- Each light fixture shall be fed through one isolation transformer and a dual channel addressable RCMU.

Runway End Lighting

- Unidirectional inset runway end lights shall be installed across the end of the runway showing red.
- The number of end lights shall ensure that a minimum of six lights will stay operational in case of failure of a single circuit.
- Runway end lights shall be combined with the runway threshold lights.
- Each light fixture shall be fed through one isolation transformer and a single channel addressable RCMU.

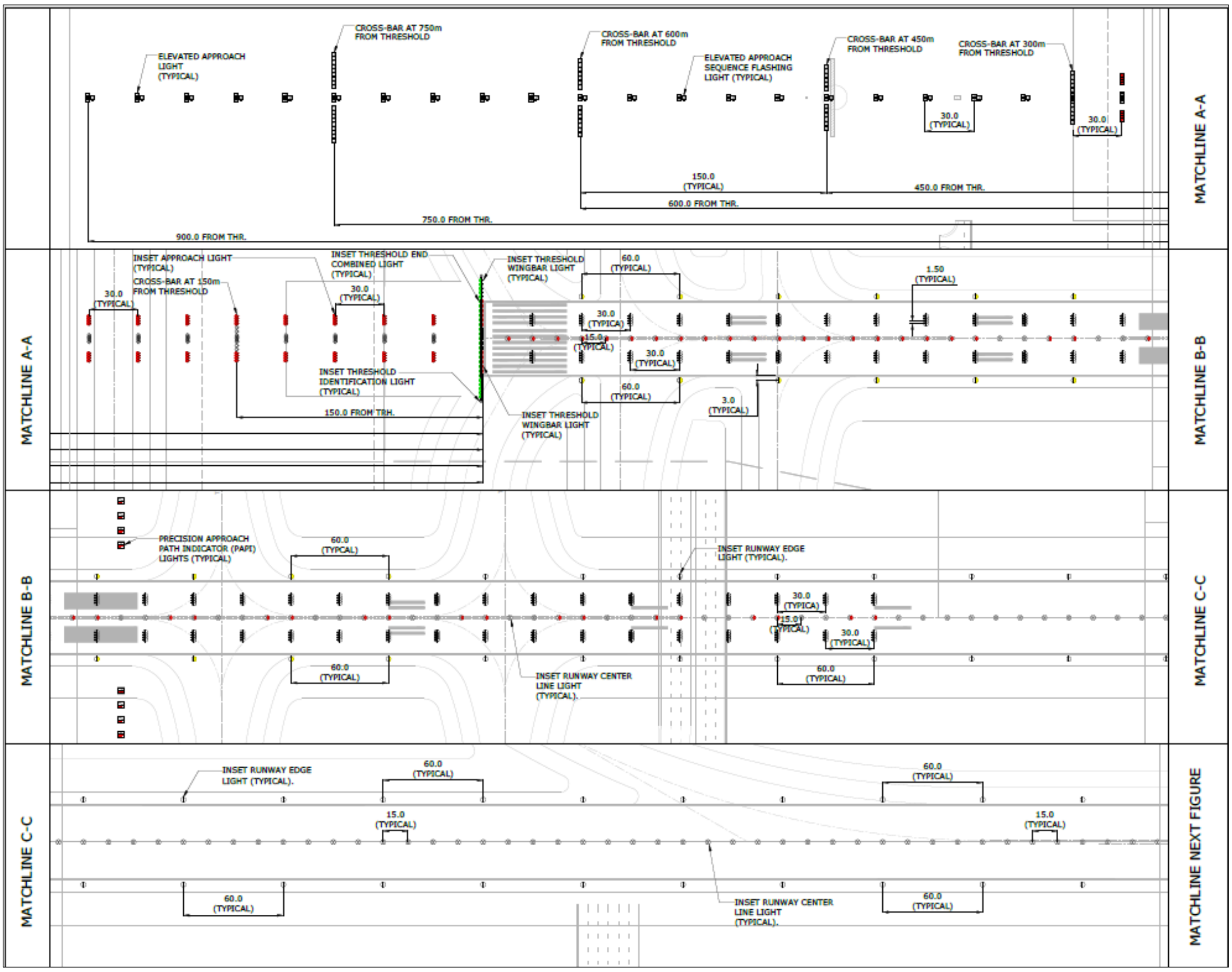


Figure 5.81: Sample overview of Approach and Runway lighting systems

5.3.1.8.5 Taxiway Lighting system

Taxiway Centreline lights

- Bidirectional inset taxiway centreline lights shall show:
  - On exit taxiways, alternate green and yellow from their beginning near the runway centre line up to the limit of the runway holding position. However, they shall show only green for an aircraft entering the runway.
  - On other taxiways, showing green from both directions.
  - Each Light fixture shall be fed from one isolation Transformer and a dual channel addressable RCMU.

Taxiway Edge Lights

- Omni-directional elevated taxiway edge blue lights installed outside the edge of curved sections of taxiways
- Taxiway edge lights shall be installed only at the curved sections of the taxiway edge with the intention to avoid the “sea of blue” affect and provide additional guidance on the curved taxiways in compliancy with ICAO Design Manual Part 4 Section 9.2.
- Each light fixture shall be fed through one isolation transformer and a single channel addressable RCMU.

Intermediate Holding Position Lights

- Unidirectional inset intermediate holding position lights, showing yellow, shall be installed along the intermediate holding positions where it is not desired to control traffic by visual means.
- Each light fixture shall be fed through one isolation transformer and a single channel addressable RCMU.

Stop Bar and Runway Guard Lights (RGL)

- Unidirectional or bidirectional stop bar inset lights, showing red, shall be installed at:
  - Intermediate Holding Positions (IHPs) where it is desired to provide traffic control by visual means.
  - All Runway Holding Positions (RHPs).
- Each RHP shall also be equipped with wig wag yellow Runway Guard Lights (RGLs):
  - Elevated type where the side of the RHP marking extends up to the edge of the taxiway.
  - Inset type where the side of the RHP marking does not reach the taxiway edge.
- Each unidirectional/bidirectional stop bar light fixture shall be fed through one isolation transformer and a single/dual channel addressable RCMU.
- Each RGL light fixture shall be fed through one isolation transformer and a dual channel addressable RCMU (controlling the wig wag function).

Rapid Exit Taxiway indicator Lights (RETIL)

- Unidirectional RETIL yellow inset lights shall be installed at all Rapid Exit Taxiways.
- Each light shall be fed through one isolation transformer and a single channel addressable RCMU.
- RETIL lights shall be automatically switched off if one light within the set is down.

Taxiway Guidance Signs

- Internally illuminated taxiway guidance signs shall be fed from one isolation Transformer and one single channel addressable RCMU outside the Taxiway edge as recommended by ICAO Annex 14

Stand Maneuvring Lighting

- Omnidirectional stand maneuvring inset lights shall be collocated with the stand maneuvring lead in marking, showing yellow.
- Unidirectional stand maneuvring stop position inset lights shall be installed at the last stop position marking, showing red.
- Each two light fixtures shall be connected to one isolation transformer and one dual channel addressable RCMU.

Traffic Signal Lights

- Traffic signal lights (with appropriate number of heads) shall be located at GSE road to control vehicular traffic, showing green/ amber/ red signals. They shall be fed through an appropriate number of isolation transformers and appropriate number and configuration of addressable RCMU based on their intended operation.

5.3.1.8.6 Induction Loops

The use of stop bars is an effective means of controlling ground movements of aircraft and vehicles on the maneuvring area and will reduce the number of incidents and accidents due to runway intrusions. Stop bars locations shall be provided with two aircraft positions sensors (induction loops):

- Position sensor 1: located across the taxiway around 70m before the stop bar
- Position sensor 2: located across the taxiway immediately after the stop bar
- Position sensor 3: located across the runway around 120m beyond the threshold

When an aircraft is cleared to taxi for take-off, the taxiway centre line lights remain on only up to the stop bar at the runway-holding position. When, while taxiing, the aircraft crosses position sensor 1, a signal is transmitted to the control tower indicating that an aircraft is nearing the stop bar. If clearance is given to the awaiting (or taxiing) aircraft, the stop bar switches off automatically illuminating that part of the taxiway centre line lighting beyond the stop bar. When the aircraft crosses position sensor 2, the stop bar automatically switches on again to protect the runway. When the aircraft, while commencing the take-off run, crosses position sensor 3, that portion of taxiway centre line lighting between the stop bar and position sensor 3 is automatically switched off. Position Sensor 2 also protects the runway from unauthorized aircraft crossing the stop bar by alerting the control tower in case of runway intrusions.

5.3.1.8.7 Airfield Lighting Patterns

Airfield Lighting Patterns shall be as follows:

- The runway centerline lights shall be located along the full length of runway and at a longitudinal spacing of 15m
- Runway edge lights shall be placed along the full length of the runway and shall be in two parallel rows equidistant from the centerline at longitudinal spacing of 60m
- All approach, touchdown zone, threshold/end, PAPI lighting patterns shall be installed as per ICAO spacing recommendations
- Taxiway centre line lights on taxiways shall be spaced at a 15 m longitudinal spacing on curves with a radius length of less than 400 m and at a 7.5 m longitudinal spacing on curves with a radius length between 401 m and 899 m. Spacing on straight sections shall be 30m
- Stop bar lights, runway guard lights, intermediate holding position lights shall be installed as per ICAO spacing recommendations
- Stand maneuvering lights shall be spaced at maximum 15m longitudinal spacing on straight sections and
- maximum 7.5m longitudinal spacing on curved sections.
- Rapid exit indicator lights shall have their pattern as shown in ICAO, Annex 14, Figure (5-25).
- Taxiway centerline lights on rapid exit taxiways shall be spaced at a maximum 15m longitudinal spacing.
- Taxiway Centerline lights on other exit taxiways shall be spaced at a maximum 7.5m longitudinal spacing.
- On exit and rapid exit taxiways, the lights shall commence at least 60m before the beginning of the taxiway
- Centerline curve.

5.3.1.8.8 Airfield Lighting Cabling Scheme

The cabling scheme shall be in full compliance with ICAO Aerodrome Design Manual Part 5 “Electrical Systems” requirements for interleaved supply of the airfield lighting fixtures under CAT III operations. Accordingly, all runway lighting fixtures shall be fed in an interleaved manner from two CCRs located in the two airfield lighting substations to ensure a high degree of reliability. And all taxiway lighting fixtures shall be fed from single CCRs subject to civil aviation approval.

Airfield lighting fixtures shall be fed from dedicated CCRs as per their application as follows:

- CAT I Approach lighting
- CAT II/III Approach lighting

- Touchdown Zone Lighting
- Runway Threshold lighting
- Runway Edge along with Runway End lighting
- Runway Centerline lighting
- PAPI lighting
- Taxiway Centerline along with Intermediate Holding Position lighting and RETILs
- Stop Bar along with Runway Guard lighting
- Taxiway Edge lighting
- Guidance Signs
- Traffic Signals

The cabling scheme for the airfield lights shall comprise single core primary cables, 6mm^2 cross section, screened and insulated to 5 kV. Isolating transformers shall supply power to the LED light, through the RCMUs via copper secondary cables 4 mm^2, two core rated at 1kV.

In this regard, it is important to note that the approach sequence flashing lights shall be fed from dedicated LV power supply sources.

5.3.1.8.9 Airfield Lighting Power Supply Equipment

The power supply for the airfield lights shall be provided via Constant Current Regulators rated at 6.6A, with the appropriate kVA rating. CCR loading shall cater for 20% spare for future expansion as per ICAO recommendations. CCR ratings shall cater for the following loads/losses:

- Losses in Primary Cables
- Losses in Isolating Transformers
- Consumption of field control units (where applicable)
- Losses in Secondary Cables
- Consumption of Fixtures

Power supply to airfield lighting fixtures shall be through 6.6A/6.6A isolating transformers ensuring continuity of current in case of fixture failure. Rating of isolating transformers shall cater for the following loads/losses:

- Losses in Secondary Cables
- Consumption of field control units (where applicable)
- Consumption of Fixtures

5.3.1.8.10 Airfield Lighting Earthing System

Airfield Lighting Counterpoise Earthing shall comprise the following:

- Earth bar in each manhole
- Earth rod every 150m to 300m of primary duct run
- Earth Counterpoise Wiring running above all airfield lighting duct banks interconnecting Earth Bars in Manholes and terminated at the earth bar of the airfield substation.
- Earth conductors connecting the following components to the earth bar within each manholes:
    - Airfield lighting fixtures
    - Airfield lighting base cans
    - Airfield lighting masts and poles
    - Isolating transformers
    - Field control units, as applicable
    - Airfield lighting primary cable shields
    - Earth pit
    - Cable supports
    - Manhole steel structure
    - Pulling hooks
    - Etc…

5.3.1.8.11 Airfield Lighting Infrastructure

The airfield cabling installations shall be routed in newly constructed ducts and manholes located outside the runway/taxiways shoulder. The sizing of the manholes shall be designed to cater for the isolating transformers, addressable control units as applicable, cabling and connectors, etc.

Sizing of primary duct banks shall ensure capacity for the primary circuits' spare and space requirements as per ICAO Design Manual Part 5 recommendations.

Airfield lighting civil works shall include but not be limited to excavation, backfilling, construction of manholes, bases and foundations, ducting, sealing materials and other related works.

The general requirements for the civil works shall include the following:

- All inset fixtures shall be mounted in shallow base cans
- All elevated fixtures shall be equipped with frangible couplings as per ICAO frangibility requirements.
- All duct banks within paved areas shall be of the concrete encased type
- The secondary cables shall run in concrete encased duct banks under paved portions and in sand surround duct banks elsewhere
- Groups of maximum eight isolation transformers and a maximum of four field addressable control and monitoring units, supplying power to different types of airfield lighting fixtures, shall be installed in a reinforced concrete manhole located outside the runway's/ taxiways' shoulder limits
- Each manhole shall be supplied with watertight cover
- Manholes located within aircraft movement areas shall be designed for aircraft loading and shall have an ultra heavy duty F-900 cover. In other areas, the manholes shall be designed for aircraft loading and shall have a heavy duty D-400 cover.
- Manholes shall be drained in the soil
- Segregation between power and communication ducts and manholes shall be as per ICAO Part 5 recommendations
- All airfield lighting civil works shall follow ICAO Part 5 recommendations

5.3.1.8.12 Airfield Lighting Control and Monitoring System (AFLCMS)

The master plan for the airfield lighting control and monitoring system will be based on ICAO standards for CAT III conditions.

The AFLCMS for the runway shall be based on an addressable type communication with the intention to fulfil ICAO serviceability requirements for Cat III operations, and shall allow for the control and monitoring of each lamp of the AFL fixture (Single Lamp Monitoring and Control) along the Runway and Taxiways. The communication system shall allow for a fast control and easy monitoring of the different airfield lighting installations. The communication system shall be of the wave carrier type. The system will control the AFL lamps by interposing an addressable single or double channel remote control unit between the AFL isolating transformer and the controlled lamp, thus achieving the required "Single Lamp Control and Monitoring" criteria, i.e. independent switching ON and OFF as well as monitoring of each lamp.

The AFLCMS shall make use of circuit selector switches for the control and monitoring of the airfield lighting along the aprons. The communication system shall follow the latest technology to allow for a fast control and easy monitoring of the different airfield lighting installations.

A main control desk station will be provided at the Air Traffic Control Tower, which will enable the control of the lighting arrangements as well as the selection among the different illumination levels available for the airfield. The control desk will be linked to the main server located within the control tower technical block.

A control and monitoring cabinet in each AGL substation communicates control commands from the main control desk station at the control tower to the Constant Current Regulators (CCR) master units of addressable lighting fixtures and circuit selector switches (CSS) It also returns the status of the lighting circuits, the generating sets, the UPSs, and announces ground faults, open circuits and fire alarms to the main control desk and to the maintenance monitoring board.

The control and monitoring shall include all the required software and hardware of the system to ensure a complete, successful and reliable mode of operation to be used comfortably by the Air Traffic Controllers.

The control system shall include, yet not be limited to, in accordance with ICAO recommendations and the Air Traffic Controllers' requirements:

- The Runway change direction,
- The stop bars activation,
- The approach flashing lights activation,
- The control of the different CSS,
- The running of the generators, in Cat III operations.

The control system shall interface with the METEO, and other Navaids equipment. The system must also monitor induction loop sensors which shall be located before and after stop bars, at runway/taxiway intersections where an incursion can occur.

The AFL system shall employ a Human Machine Interface (HMI) system, which shall allow for the interfacing and control of all the system components. The HMI will comprise a graphical display with the ability to zoom in and out of the airfield plan, with full capabilities to program the system software. The software must be of the open type protocol allowing full access to the program parameters to enable updating or changing to those parameters.

The communication network for the AFL system will comprise the following:

- A fiber optic network fully redundant shall interface the airfield lighting substation to the control tower.
- An Ethernet switch which shall be provided in the airfield ground lighting substation and will interface the computer of the substation to the fiber optic network.
- The substation equipment comprising the hardware and the software needed to interface with the lighting installations.
- The main equipment installed at the control tower

5.3.1.9 Airfield Lighting Substations

The electrical power supply for the airfield lighting installations will be from two Airfield Lighting Substations located at both runway ends as per ICAO Part 5 recommendations. The AFL Substations shall be connected to the Airport MV distribution network in such a manner to ensure a redundant and reliable power supply at the MV level.

The design of the AFL Substation will ensure a reliable and redundant power supply for the airfield and navigational aids installations and shall comply with ICAO Cat II requirements.

5.3.1.9.1 Substation Spaces

In general, the substation equipment rooms can be summarized as follows:

- Generator Room
- Medium Voltage Room
- Low Voltage Room
- CCR's Room

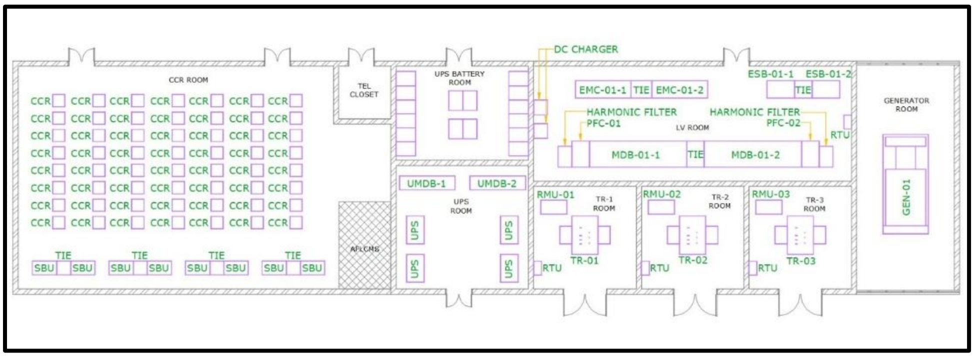


Figure 5.82: Typical AGL Substation Layout for CAT III operation

5.3.1.9.2 Substation Electrical Installations

Each substation will house two MV/LV transformers working in a redundant arrangement to feed the demand load. Moreover, each Substation will house two redundant Diesel Generator Sets, each capable of supplying the full demand load.

Loading of the redundant MV/LV transformers shall cater for full redundancy of the transformers on the MDB side.

In addition to the two main transformers, a third transformer shall step-up power to feed the Non Visual Navigational Aids Systems and Meteorological Systems within the airfield. Rating of this later transformer shall cater for the navigational and meteorological aids demand loads.

Each AFL substation will be provided with two Low Voltage Diesel Generator Sets, each rated for the full demand load. Moreover, the airfield lighting installations and navigational aids shall be fed via two Uninterruptible Power Supply (UPS) connected in a redundant configuration and rated for their full demand load. The UPS shall also feed all communication and control cabinets of the airfield lighting systems, as well as other equipment such as BMS, Fire Alarm and Fire Fighting Control equipment. The system will ensure a no break power to the AFL installations in case of normal power failure where the diesel/generator will take over and supply all the loads.

Necessary control and monitoring equipment shall be provided in the substations to allow for SCADA remote control and monitoring of the RMU, Transformer, Generator and MDB, as applicable. In addition, necessary equipment shall be provided for the interface between the local BMS and the SCADA system.

5.3.1.9.3 Substation Extra Low Voltage System

The airfield lighting substation fire alarm system and other systems will have to be controlled and monitored from the Airport Central Fire Alarm and Building Management Systems.

For that purpose, an interface cabinet, comprising the main fiber optic and data patch panels with space for future switch and power supply unit shall be proposed in each substation and connected with fiber optic cables to the Airport Fiber Optic network.

- Fire Alarm System
    - Each AFL Substation will be provided with a fire alarm control panel, detectors and modules in compliance with NFPA72 and NFPA101 requirements
- SCADA Remote Terminal Unit (RTU)
    - A SCADA Remote Terminal Unit (RTU) shall be provided in each substation to allow communication with the SCADA Master Station Unit located in the CUC.
- Building Management System (BMS)
    - Building Management Cabinet will be installed within each AFL Substation. The BMS cabinets will control and monitor the mechanical equipment (HVAC) and the electrical equipment (the Generator, the UPS, the MCC's, and the LV panels)

5.3.1.9.4 Solar study

A solar photovoltaic (PV) power generation facility is proposed to supply clean electrical energy to the airport and its associated facilities. The conceptual design and performance simulations for the proposed solar farm have been carried out using PVSyst software. The plant is designed as a grid connected PV system with an installed DC capacity of approximately 50.82 MWp, capable of delivering up to 43.40 MW AC power at the 11 kV distribution level. The DC-to-AC ratio is 1.17.The proposed site is located at a latitude of 1.32°S and a longitude of 36.97°E, at an elevation of 1,599meters above sea level, providing favourable solar irradiation levels throughout the year. The system is designed with fixed-tilt mounting structures set at a 5° tilt angle, optimized for the site's latitude to maximize annual energy yield while minimizing structural complexity and maintenance requirements.

The plant configuration comprises approximately 84700 high-efficiency bifacial monocrystalline PV modules, each rated at 600 Wp, arranged in 3850 strings with 22 modules per string. The bifacial technology allows additional energy capture from reflected and diffused sunlight, enhancing overall energy generation. Albedo of the plant location is considered to be 0.2. DC energy from the PV modules will be converted to AC through 280 string inverters, each rated at 155 kW, strategically located to minimize cable losses and optimize system reliability.

While performing the preliminary calculations, the azimuth angle of the panels is assumed to be zero. However, at the detailed design stage, the azimuth angle may be adjusted according to the runway or approach paths to reduce glare reflected from the panel surfaces. This could affect the plant's generation capacity.

The total installation will occupy an estimated 800,000 square meters (80 hectares) of land, positioned to minimize shading, facilitate maintenance access, and maintain adequate separation from critical airport infrastructure. Based on local solar resource data and system configuration, the plant is expected to generate approximately 79127.01 MWh of electricity annually, corresponding to a performance ratio (PR) of 85.48%.

Table 5.53: Solar Study

Parameter	Description / Value
Solar plant capacity	~ 50.82 MWp
Power generation	~ 43.40 MWac
Type of system	Grid connected Solar system
Solar panel rating	600 Wp
Total number of panels	~ 84700
Inverter Capacity	155 kW
Number of Inverters	280
DC:AC ratio	1.17
Performance ratio	85.47 %
Mounting Structure	Fixed Tilt
Tilt angle	5 deg.
Module Area	~ 236475 sq.m.
Total Land required	~ ,8,00,000 sq.m.
Expected annual production	79127.018 MWh/year

There are 3,850 strings, each consisting of 22 modules. Each table accommodates three rows of 22 modules. These strings will be individually connected to the string inverters. The 155 kW inverters will convert the DC power to 400 V AC, operating at a DC/AC ratio of 1.17. This 400 V AC power will then be stepped up to 11 kV using step-up transformers and subsequently fed into the grid.

The image below shows the arrangement of fixed-tilt module tables with the necessary spacing required for the placement of BOS (Balance of System) equipment and for manoeuvring during module cleaning and plant maintenance activities.

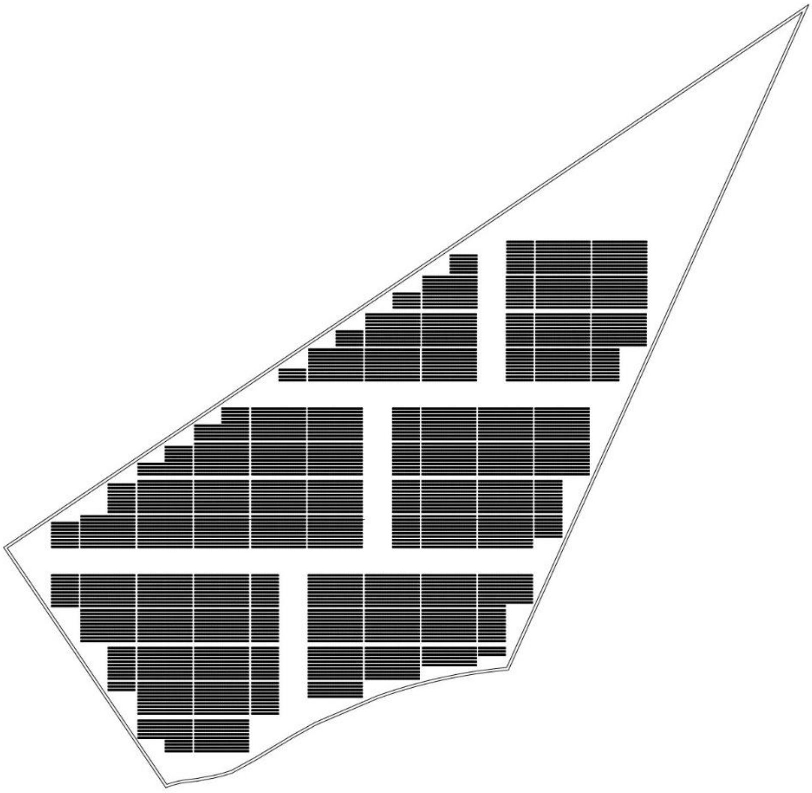


Figure 5.83: PV Module table arrangement

The following snippets are extracted from the PVsyst calculation report.

PVsyst V7.4.5
VC0, Simulation date:
01/12/26 10:54
with v7.4.5

Project: Jomo Kenya airport

Variant: New simulation variant

Dar Al Handasah Consultants (Shair & Partners) S.A.L Verdun (Lebanon)

Project summary

Geographical Site	Situation		Project settings	
Kenya airport	Latitude	-1.32 °S	Albedo	0.20
Kenya	Longitude	36.97 °E		
	Altitude	1599 m		
	Time zone	UTC+3		

Meteo data
Kenya airport
Meteonorm 8.1 (1991-2007) - Synthetic

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	5 / 0 °		

System information

PV Array		Inverters	
Nb. of modules	84700 units	Nb. of units	280 units
Pnom total	50.82 MWp	Pnom total	43.40 MWac
		Pnom ratio	1.171

Results summary

Produced Energy	79127018 kWh/year	Specific production	1557 kWh/kWp/year	Perf. Ratio PR	85.47 %

PV Array Characteristics

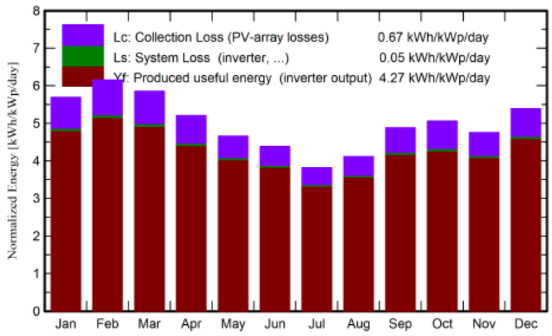
PV module		Inverter	
Manufacturer	Hanwha Q Cells	Manufacturer	Kaco new energy
Model	Q.Peak-Duo-XL-G11S.3 / BFG-600	Model	Blueplanet 155 TL3-INT
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	600 Wp	Unit Nom. Power	155 kWac
Number of PV modules	84700 units	Number of inverters	280 units
Nominal (STC)	50.82 MWp	Total power	43400 kWac
Modules	3850 string x 22 In series	Operating voltage	875-1300 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.17
Pmpp	46.50 MWp		
U mpp	913 V		
I mpp	50929 A		
Total PV power		**Total inverter power**	
Nominal (STC)	50820 kWp	Total power	43400 kWac
Total	84700 modules	Number of inverters	280 units
Module area	236475 m²	Pnom ratio	1.17

Main results

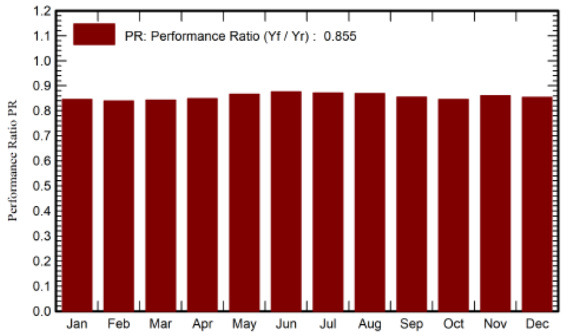
System Production

Produced Energy	79127018 kWh/year	Specific production	1557 kWh/kWp/year
		Perf. Ratio PR	85.47 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	182.8	72.81	20.35	176.6	171.5	7683880	7585463	0.845
February	176.1	61.07	21.00	172.3	168.2	7441661	7344648	0.839
March	182.0	77.89	21.30	181.3	177.0	7859401	7758420	0.842
April	153.6	64.87	20.04	156.1	152.2	6820517	6732991	0.849
May	140.9	75.50	19.28	144.5	140.4	6440285	6361028	0.866
June	127.8	72.84	17.88	131.7	127.9	5929806	5857108	0.875
July	115.7	64.01	17.54	118.5	115.2	5315427	5249205	0.871
August	126.0	77.91	17.94	127.7	124.1	5708951	5639124	0.869
September	146.0	78.39	18.86	146.5	142.4	6450399	6368905	0.856
October	158.9	72.94	20.25	156.9	152.6	6825683	6738492	0.845
November	146.3	79.56	19.20	142.7	138.4	6320463	6240663	0.861
December	173.6	70.58	19.74	167.1	162.2	7344282	7250970	0.854
Year	1829.7	868.37	19.44	1821.7	1772.1	80140755	79127018	0.855

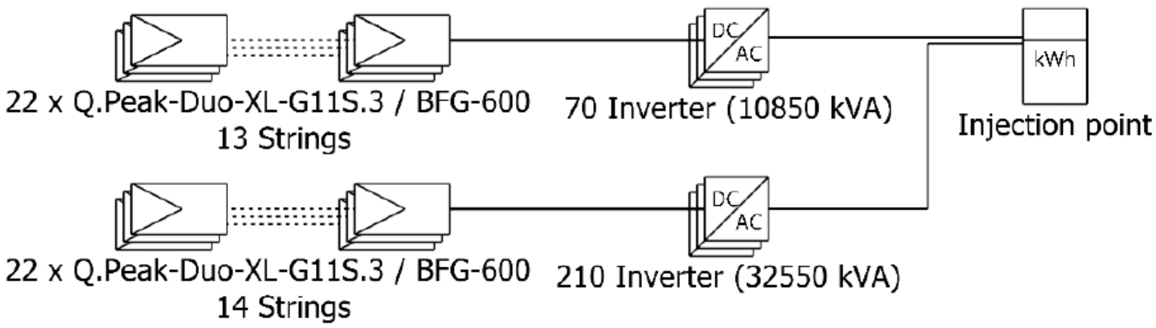


Figure 5.84: PVSyst Report extracts

5.3.2 TELECOMMUNICATIONS

5.3.2.1 SECTION DESCRIPTION

This section shall define the design strategy and guidelines for Jomo Kenyatta Internal Airport (JKIA) Telecom systems and infrastructure.

The Telecom systems and infrastructure will be designed to foster a sustainable Airport ecosystem, boasting state-of-the-art converged networks aimed at enhancing operations, ensuring safety and security measures, enriching passengers' experience, while accommodating requirements for future expansion.

The first step to establishing a smart and sustainable airport is to establish a solid engineering framework, which will support the different airport operations and processes.

The foundation is represented by the ICT infrastructure systems which provides the tools to support distribution of information for all systems, and enables communication with high availability, performance and data security. The infrastructure layers shall provide the media that allows for the interconnectivity of all airport-wide systems. The airport wide systems within the new terminal shall be of the latest technology and designed based on the latest relevant international standards, codes, best practices as well as the requirements set by the local authorities. These systems shall include, but not limited to, the following:

- Information and Communication Technology (ICT) systems, which include Structured cabling Network (SCN), IP-Based Telephony Communications System (IP-Tel), Wireless Local Area Network (WLAN), IP-based Television System (IPTV), Master Clock System (MCS), etc.
- Special Technology systems which would include Fire Detection and Alarm System (FADS), Public Address (PA), Parking Guidance and Management System, Building Management System (BMS), Audio-visual System (AV), Disabled Toilet Alarm System, Smart Airport systems, etc.
- Special Airports systems, such as Electronic Visual Information Display System (EVIDS) with all its sub-systems (FIDS, etc.), Baggage Reconciliation System (BRS), Common Use Systems (CUS) including Common Use Terminal Emulator (CUTE) and Common Use Passenger Processing System (CUPPS), Common Use Self Service System (CUSS), Airport Operation Database (AODB), etc
- Security and life safety systems which include Security Access Control System (SACS), Video Surveillance System (VSS), Security Screening systems (SSS), Perimeter Intrusion Detection System (PIDS) and Suspect Baggage Tracking System (SBTS), etc.
- Other Systems would also be provided by the stakeholders, airport tenants, or other entities that may make use of JKIA systems, particularly the Airport Campus Networks (ICT and security), the supporting infrastructure, and data or services provided by JKIA. Some of these systems would include back-office information technology systems (human resources, finance, accounting, and alike systems). Coordination shall be done to ensure proper integration between JKIA and these systems.

It should be noted here that no available infrastructure drawings for the existing airport were received from any of the stakeholders and/or authorities.

5.3.2.1.1 LIST OF ACRONYMS

ANPR	Automatic Number Plate Recognition
AODB	Airport Operation Database
ARFF	Aircraft Rescue and Firefighting
ATC	Air Traffic Control
ATRS	Automated Tray Return System
AV	Audio Visual
AVSEC	Aviation Security
BD	Building Distributer
BDR	Building Distribution Room
BER	Telecom Building Entrance Room
BMS	Building Management System
BRS	Baggage Reconciliation System
BUA	Built-up area
BW	Bandwidth
CCTV	Closed-circuit Television
CPSRA	Critical Part Security Restricted Area
CRAC	Computer Room Air Conditioning
CT	Computed Tomography
CTX	Computed Tomography X-ray
CUS	Common Use Systems
CUSS	Common Use Self Service System
DAS	Distributed Antenna System
EDS	Explosive Detection System
ELV	Extra Low Voltage
ETD	Explosive Trace Detection
EVIDS	Electronic Visual Information Display System
FADS	Fire Detection and Alarm System
FCC	Federal Communications Commission
FD	Floor Distributors
FDR	Floor Distribution Rooms
FIDS	Flight Information Display System
GEA	Government Enterprise Architecture regulations,
GSM	Global System for Mobile Communications
HHMD	Hand held metal detectors
HVM	Hostile Vehicle Mitigation
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICT	Information Communication Technology
IDF	Intermediate Distribution Frame
IEC	International Electro-Technical Commission standards,
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IPTV	Internet Protocol Television
ISO	International Organization for Standardization
JKIA	Jomo Kenyatta International Airport
KAA	Kenya Airports Authority

KCAA	Kenya Civil Aviation Authority
LADAR	Laser Detection and Ranging
LTE	Long-Term Evolution
MAP	Million Annual Passengers
MCS	Master Clock System
MEP	Mechanical, Electrical, and Plumbing
MER	Main Equipment Room
NAVAIDS	Navigational Aid
NEC	National Electrical Code
NFPA	National Fire Protection Agency
NOC	Network Operations Center
NPISPA	National Project for Integrated Security and Protection of Airports
NSAA	National Safe Skies Alliance, Guidelines for protection of boundaries of airports
OMU	Optical Master Unit
ORU	Optical Remote Unit
OSP	Outside Plant
PA	Public Address
PIDS	Perimeter Intrusion Detection System
PSTN	Public Switched Telephone Network
PTB	Passenger Terminal Building
SACS	Security Access Control System
SBTS	Suspect Baggage Tracking System
SCADA	Supervisory Control and Data Acquisition
SCN	Structured cabling Network
SFC	Safaricom
SOC	Security Operations Center
SP	Service Provider
SPR	Service Provider Room
SSS	Security Screening systems
TDMM	BICSI - Telecommunications Distribution Methods Manual
TETRA	Terrestrial Trunked Radio
TIA/EIA	Telecommunication Industries Association/Electronics Industries Alliance
TSA	Transportation Security Administration
UL	Underwriters Laboratory
UPVC	Un-plasticized Vinyl Chloride
UVSS	Under Vehicle Search System
VBIED	Vehicle Borne Improvised Explosive Device
VOR, DME	VHF omnidirectional range, distance-measuring equipment
VSS	Video Surveillance System
WLAN	Wireless Local Area Network
WTMD	Walk-through metal detector

5.3.2.1.2 REVIEW OF THE COLLECTED DATA RELATED TO SITE TELECOM INFRASTRUCTURE

Telecom Service Providers

Figure 5.85 represents the received data from Safaricom reflecting the Fibre route layout.

It depicts the Safaricom fibre optic cable installation intended for JKIA airport. The red line represents the route of the Safaricom fibre optic cable, while the yellow pins highlight the various buildings within the airport.

Main Communication Rooms

Based on the findings and the reviewed data, the main communications rooms within the existing JKIA site consist of the following: Primary Data Centre, T1A Main Equipment Room and Exchange building.

Figure 5.86 outlines the locations of the Primary Data centre, the Main Equipment Room located in Terminal 1A and Exchange Building.

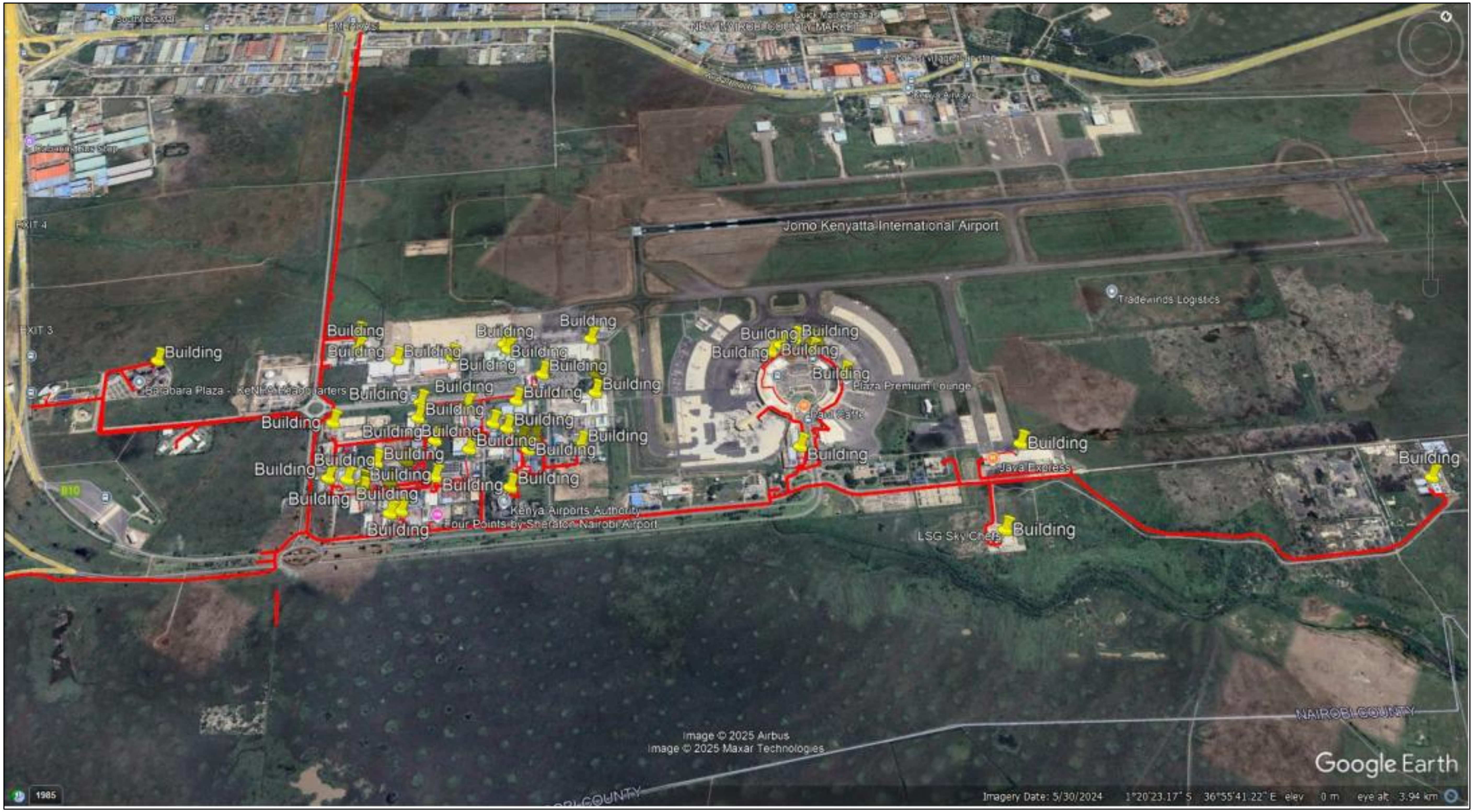


Figure 5.85: JKIA Safaricom Fiber Layout, extracted from document no." JKIA SFC Fiber Layout"

Figure 5.86: Map showing the locations of T1A MER, Primary Data Center and Exchange Building

5.3.2.1.3 APPLICABLE CODES AND STANDARDS

The Telecom master plan infrastructure shall be developed within the latest revisions of the following codes, specifications, regulations, governing bodies/authorities, and industry standards, where applicable. Local codes shall have precedence over other codes:

- National Electrical Code (NEC),
- National Fire Protection Agency (NFPA),
- International Organization for Standardization (ISO),
- Institute of Electrical and Electronics Engineers (IEEE),
- BICSI - Telecommunications Distribution Methods Manual (TDMM),
- Telecommunication Industries Association/Electronics Industries Alliance (TIA/EIA),
- Underwriters Laboratory (UL),
- International Electro-Technical Commission (IEC) standards,
- International Air Transport Association (IATA),
- International Civil Aviation Organization (ICAO),
- Local Kenyan codes and Regulatory requirements
- Government Enterprise Architecture (GEA) regulations,
- Kenya Civil Aviation Authority (KCAA) regulations.

5.3.2.1.4 DESIGN CRITERIA

The Telecom systems and infrastructure design of JKIA will conform to the main objectives listed below:

- Complying with the applicable codes and standards;
- Meeting the specified communication performance requirements of various systems and equipment;
- Achieving reliability and durability of systems and components;
- Implementing safety and protection measures for people and equipment;

In addition, the following important factors shall be considered carefully:

- Cost effectiveness;
- Efficiency and energy conservation;
- Coordination with other design elements; and
- Simplicity of installations, operation, and maintenance.

5.3.2.2 TELECOM INFRASTRUCTURE PLANNING

The primary purpose of the infrastructure is to provide the physical media that allows for the interconnectivity of all airport-wide communications systems. This is the key to implementing a durable telecom system transport network.

Since the passive infrastructure is the longest living component of the communications infrastructure and cannot be easily replaced, careful design and solid engineering practices are to be employed during the planning and design stages in order to provide a future-proof based design which allows for flexible network growth and upgrading.

The passive infrastructure covers two main components: the outside utilities consisting of manholes and duct works, and the required Telecom utilities, which consists of the main standalone telecom buildings and spaces within the building (housing the telecom equipment) and the associated containment (cable trays, cabinets, etc.); from a Master planning perspective.

The following section provides high-level Telecom Infrastructure design assumptions to guide the infrastructure designers. These inputs are intended to serve solely as strategic direction and do not constitute detailed design requirements. They should be further elaborated, refined, and validated during subsequent design phases.

5.3.2.2.1 TELECOM OUTSIDE PLANT CIVIL WORKS INFRASTRUCTURE

A new duct bank containment system shall be designed to house the JKIA cabling serving the newly proposed PTB and facilities. Two separate civil infrastructures shall be provided for the JKIA, both of which shall be designed to comply with international standards and local authorities’ requirements. One civil works network shall be dedicated for the NAVIAD's network, while the other one shall be utilized by the remaining Telecommunications and Security systems and networks.

More specifically, the Telecom infrastructure shall serve the following systems:

- Airport Campus Area Networks (ICT network and Security Network),
- Telecom Service Providers network connectivity,
- Fire Alarm and Detection Network,
- Tetra/LTE Network,
- Commercial Cellular (3G/4G/etc.) Networks.
- Stakeholders Requirements

Ducts shall be installed mainly under sidewalks or under pavement where needed. All ducting shall be concrete encased. Duct will be of un-plasticized vinyl chloride (UPVC) type of 110mm outer diameter. Duct sizing, for both Telecom and NAVAIDS infrastructures shall cater for applicable systems and provide additional space for future cabling expansion. Ducting shall also be coordinated with other utilities and proper measures shall be taken to solve any crossing between these utilities.

Manholes and handholes shall be selected to house all the Telecom, Security and NAVAIDS cables, and the exact type shall depend on the duct sizes. For manholes which happen to be on aircraft paths, special consideration will be taken to reinforce the manhole to support the load of the aircraft.

5.3.2.2.1.1 OSP Networks' General Requirements

The following represents the general guidelines that shall be followed for both the Telecom and NAVAIDS networks design:

- The network infrastructure shall be designed in a physical ring topology (ICT and security networks follow a logically star connectivity), providing physically redundant separate routes connecting the different airport facilities, as needed, for all networks (ICT, security, Fire, NAVAIDS, etc.). The Primary and secondary routes shall never occupy the same manhole/ductway.
- Manholes and Handholes
- Manholes/handholes shall be installed adequately along duct routes to allow access for pulling and splicing of cables. They shall be located outside of roadways wherever possible, and shall be constructed in locations where unrestricted access is possible, without impacting operations (as applicable). Manholes/handholes shall be located at:
    - Every change in direction
    - On both side of road crossings
    - On straight stretches at every 250m maximum duct stretch.
    - At every junction between the main duct ring and building entry point, at 1500mm away from the building foundation. In cases where more than one building entry point is required, separate manholes shall be provided and the entry points shall be separated by the maximum distance physically possible (i.e. opposite ends of a building). A minimum separation distance of 20 metres shall be required,

The Manholes/Handholes' walls shall be waterproof, and they shall be covered by a flat lid on which the size and the depth of the manhole/handhole are written. The area around the manhole shall be compacted. Upon final acceptance of the conduit/duct system all manholes shall be free of debris. The manholes and handholes shall bear have a minimum compressive load of 21 MPa, utilizing reinforced concrete, with approved waterproof membrane on external surfaces and with cable support accessories (stainless steel) where necessary, pull-eyes, and drain pit and drain pipe as required. The below figure depicts a sample manhole that shall be used along the 9-way duct routes.

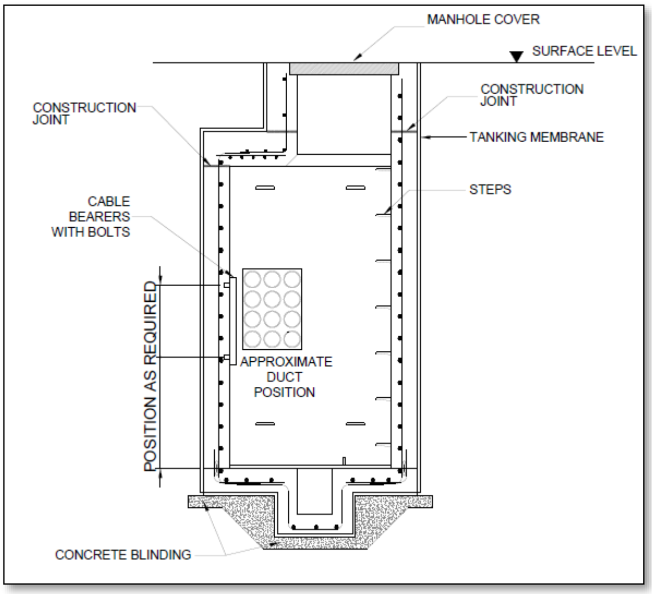


Figure 5.87: Sample Manhole Detail

- Ducts
  - Duct banks shall be sized in a manner allowing for proper cabling and future expansions. In general, the guidelines for the duct banks are as follows:
  - The Telecom network will be served by:
    - 9-way 110mm duct-banks, when providing connectivity for all buildings/facilities and the service provider.
    - 4-way 110mm duct-banks, along the perimeter fence only
  - The NAVAIDs network will be served by:
    - 4-way 110mm duct-banks
  - Each uPVC duct shall house five 32mm sub ducts, housing one fibre cable, thus maximising the capacity of the duct and reducing the number of needed duct banks.

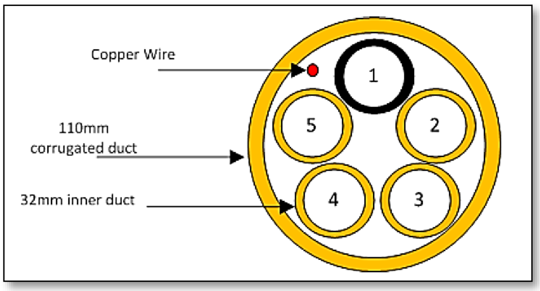


Figure 5.88: Standard Duct Configuration

All ducts within manholes shall be covered with end caps to prevent foreign materials and water entering the chamber.

<u>Cabling</u>

All Fiber Optic cable joint/splicing shall be housed inside the manhole/handhole. The cables shall not be crushed or forced around a sharp corner. Sufficient slack shall be left at each end of the cable to allow proper cable termination. The cables shall be marked and labelled at each manhole and at all entry and end points of the cable and in accordance with TIA-606 requirements.

5.3.2.2.1.2 Telecom Network Corridors

The Telecom OSP network infrastructure shall be designed to provide connectivity for different services and networks, as previously mentioned. Generally, the main routes will be provided with 9Nos. ducts, out of which, 2Nos. ducts are kept as spare.

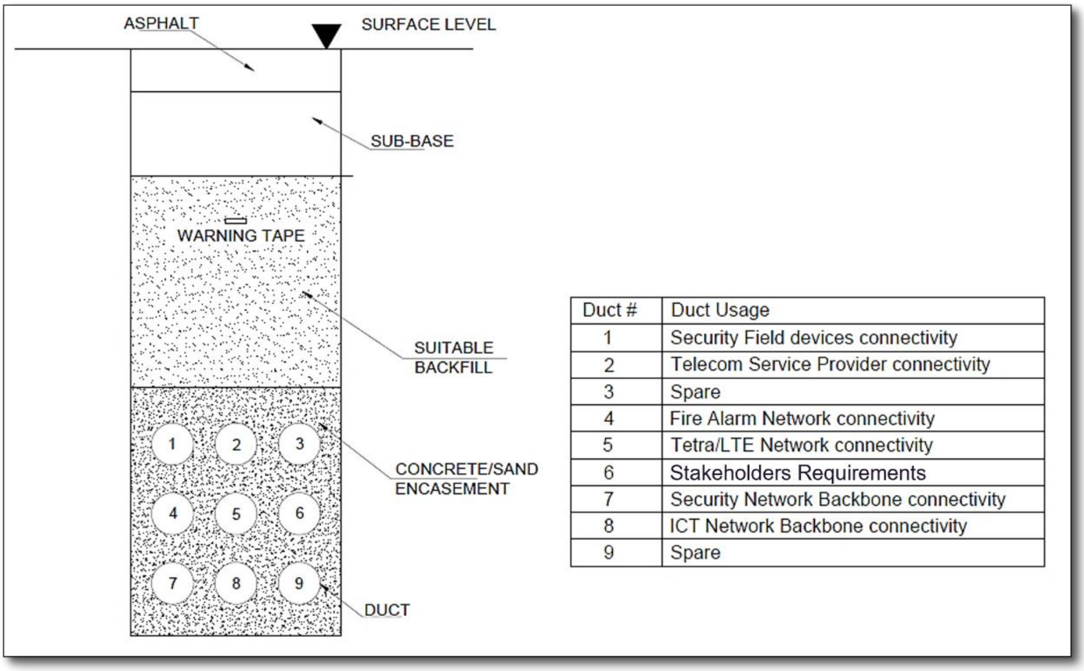


Figure 5.89: Telecom Duct Bank Design

The above duct bank is sized based upon the following requirements:

- Airport Campus Area Network Backbone connectivity for Security and ICT networks (2Nos. ducts)
  Fiber Optic backbone cabling shall be housed within the duct bank network in a physical ring configuration which will link the new airport facilities to the two newly proposed data centres (referenced in the "Required Telecom Utilities" Section) through redundant routes. This is applicable to both the ICT and the security networks. The backbone cabling for each of the two networks however shall utilize separate ducts.
- Field equipment connectivity (1No. duct)
  The Telecom network will also cater for outdoor and perimeter field devices such as CCTV cameras, Perimeter Intrusion Detection (PIDS) devices, etc. that will be connected to near or designated switches.
- Telecom Service Providers network (1No. duct)
  Connectivity to the service provider (SP) telecom network shall be coordinated with TESCOM and planned in a redundant manner, connecting to the existing SP network from two separate tie-in points and reaching the two service provider rooms within the data center facilities via two distinct routes. The infrastructure shall be provided by the airport contractor; the cabling however shall be provided by the service provider.
- Fire Alarm and Detection Network (1No. duct)
  The Fire Detection and Alarm System (FADS) involves the early detection and notification of fire threats. The control of the fire alarm system for the overall airport will be based on connecting all the fire alarm panels in all the buildings and facilities via the Fire Alarm network's fiber optic loop. The new facilities of the airport shall be monitored and controlled from the new ARFF station.
- The panels, the FCC within the different buildings, and the ARFF stations shall be connected through Single Mode Fiber Optic cable, running inside the OSP network in a ring topology to ensure redundancy.
  Campus fire alarm loops' cabling shall be housed within this duct, in order to connect the various Fire Alarm Control Panels in the new proposed buildings of the airport.
- Tetra/LTE Network (1No. duct)
  Duct reserved for TETRA/LTE safety communication system cabling.
- Stakeholders requirements (1No. duct)
  Duct reserved for the Stakeholders requirements.

5.3.2.2.1.3 NAVAIDS Infrastructure

The NAVAIDs infrastructure shall be coordinated with the system specialists. The network shall be designed to provide redundant connectivity to the different systems and facilities including the Air Traffic Control (ATC) Tower, the

Navigational equipment (VOR, DME, Glide Path, Localizer, etc.), the Aprons, Electrical Substations, meteorological equipment, etc.

5.3.2.2.2 REQUIRED TELECOM UTILITIES

Telecommunications spaces provide the physical infrastructure for voice, data, video and security within the airport. Telecom rooms are sized taking into consideration the following criteria:

- The current needs for the ICT, airport and security systems to satisfy the airport's requirements, based on international standards and best practices.
- Future provisions (spare) providing design flexibility and expandability to avoid future architectural or buildings' services disruptions due to technology advancement or added requirements.

Data Centers

As per stakeholders requirements, it was mentioned during Cluster 4 meeting that there is currently no available space to expand the existing main Telecom facilities to server future needs. Consequently, new data centers shall be proposed to accommodate the expansion areas.

For both Phase 1 and Phase 2, the primary solution is to consider two standalone Data Centers: Data Center 1 and Data Center 2, serving as dedicated Telecom facilities. Both Data Centers are planned to be located in the vicinity of the Airside/Landside fence. The preliminary locations of the two Data centers is illustrated in Figure 5.90.

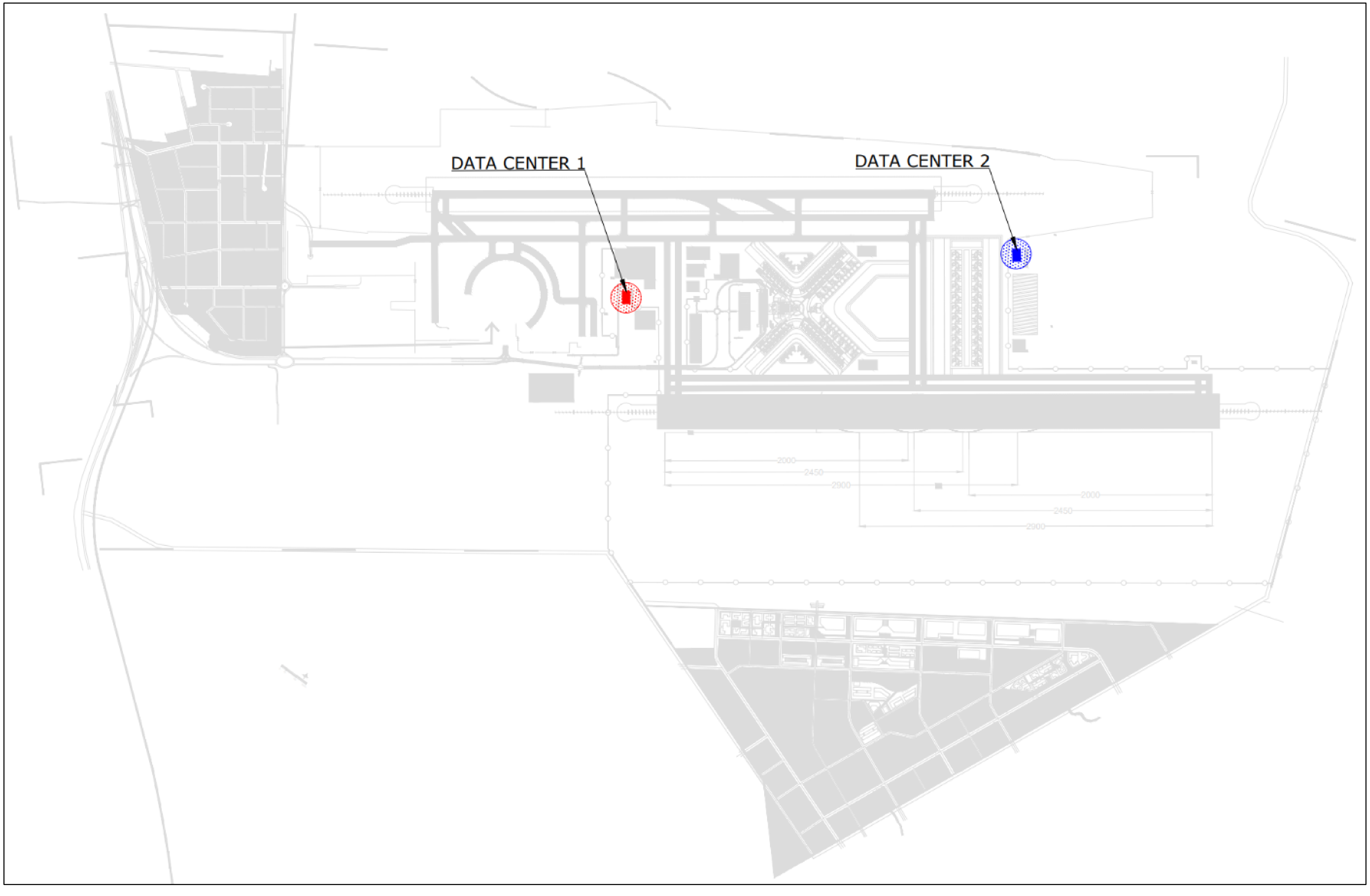


Figure 5.90: Proposed Data Center Locations

A secondary alternative would be to consider a single standalone Data Center and a Data Hall integrated within the newly proposed Passenger Terminal Building.

The data centers are the main communication rooms, serving the new airport campus, and housing the core switches and all ICT, security, Airport related systems' headend equipment as well as storage, and other stakeholders servers and airline servers. Having two completely redundant and distant data centers with diverse routing eliminates single point of failure and therefore ensures a robust, highly reliable and available infrastructure necessary for the continuous uninterrupted operation of the airport.

The two data centers shall be rated as tier-3, in accordance with TIA-942 standard. Hence, all requirements mentioned in the standard shall apply including but not limited to: redundant entrance room, redundant backbone cabling and pathways, etc.

Data Center (Main Equipment hall)

The Main Equipment hall, also known as the Server Room or Data Hall, is the core and most protected center-piece of the data center standalone facility, and is the main driving factor behind the overall building design. The room is designed with the objective of being efficient, flexible, resilient, and scalable, and shall be designed as per the applicable standards and best practices including, but not limited to TIA-942 and BICSI.

The following is a tentative breakdown of the cabinets that would be located within the Data Halls of the data centers.

- ICT network active and passive equipment: including core switches, distribution switches, servers (IP-Telephony, WAN connectivity, etc.).
- Security network active and passive equipment: including core switches, distribution switches, servers (CCTV servers, Access control, storages, etc.).
- ELV Systems (Smart systems, SCADA, Audio-visual and Public Address system)
- Airport operations systems (EVIDS servers, AODB, CUSS, etc.).
- Cabinets reserved for Airlines (national and host airlines).
- Cabinets reserved for the stakeholders (Authorities, customs, police, etc.).
- Future expansion cabinets for Phase 2.

The room layout, sizing and supporting systems shall be compliant with international standards and the industry's best practices to ensure that the systems are fully functional, operational and as per specified performance.

The below figure shows the preliminary racks distribution within the Data Hall of each of the two Data Centers.

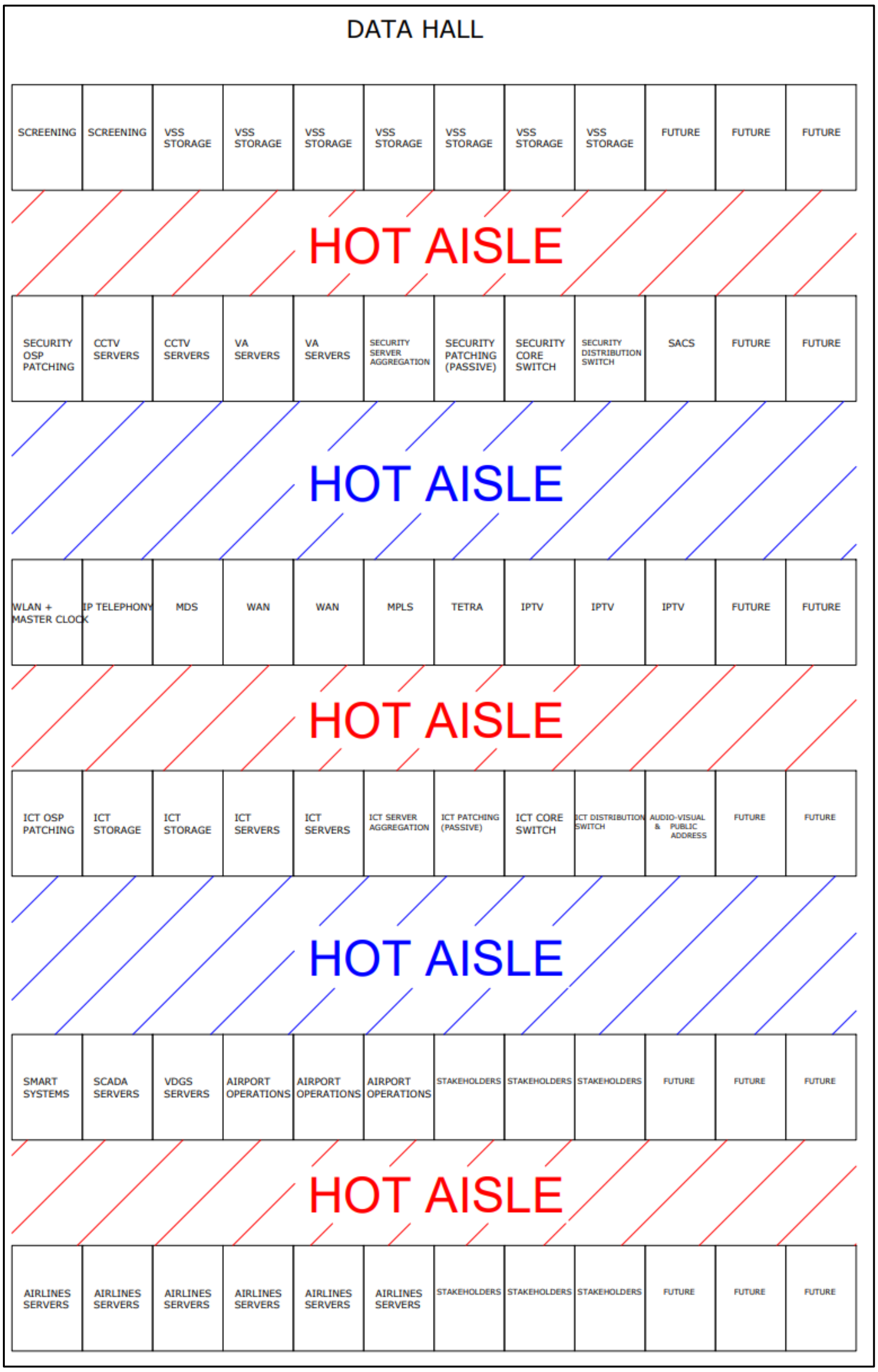


Figure 5.91: Preliminary Racks Distribution within the Data Hall

Row	F											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	Screening	Screening	VSS Storage	VSS Storage	VSS Storage	VSS Storage	VSS Storage	VSS Storage	VSS Storage	Future	Future	Future

Row	E											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	Security OSP Patching	CCTV Servers	CCTV Servers	VA Servers	VA Servers	Security Server Aggregation	Security Patching (Passive)	Security Core Swith	Security Distribution Switch	SACS	Future	Future

Row	D											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	WLAN + Master Clock	IP Telephony	MDS	WAN	WAN	MPLS	TETRA	IPTV	IPTV	IPTV	Future	Future

Row	C											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	ICT OSP Patching	ICT Storage	ICT Storage	ICT Servers	ICT Servers	ICT Server Aggregation	ICT Patching (Passive)	ICT Core Switch	ICT Distribution Switch	Audio-Visual & Public Address	Future	Future

Row	B											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	Smart Systems	SCADA Servers	VDGS Servers	Airport Operations	Airport Operations	Airport Operations	Stakeholders	Stakeholders	Stakeholders	Future	Future	Future

Row	A											
Cabinet	1	2	3	4	5	6	7	8	9	10	11	12
Function	Airlines Servers	Airlines Servers	Airlines Servers	Airlines Servers	Airlines Servers	Airlines Servers	Stakeholders	Stakeholders	Stakeholders	Future	Future	Future

(dark grey)	Future expansion (Phase 2)
(green)	Airport Systems
(yellow)	Stakeholders
(red)	ELV Systems
(peach)	ICT Systems
(light blue)	Security Systems

Figure 5.92: Preliminary Racks Distribution within the Data Hall

Building services requirements for the data center equipment hall

DX CRAC units, with N+1 redundancy, will be used to provide the required cooling for the data hall.

The floor system of the data center features tile access flooring. The space under the access flooring system is used exclusively for the distribution of supply air.

The front of the equipment cabinets is oriented face-to-face with adjacent rows of cabinets so that perforated tiles supply air in "cold aisles". The rear of the cabinets is oriented back-to-back with adjacent rows of cabinets for return air to create "hot aisles". Provisions to contain hot aisles are recommended for improved cooling efficiency and to prevent mixing of supply and return air.

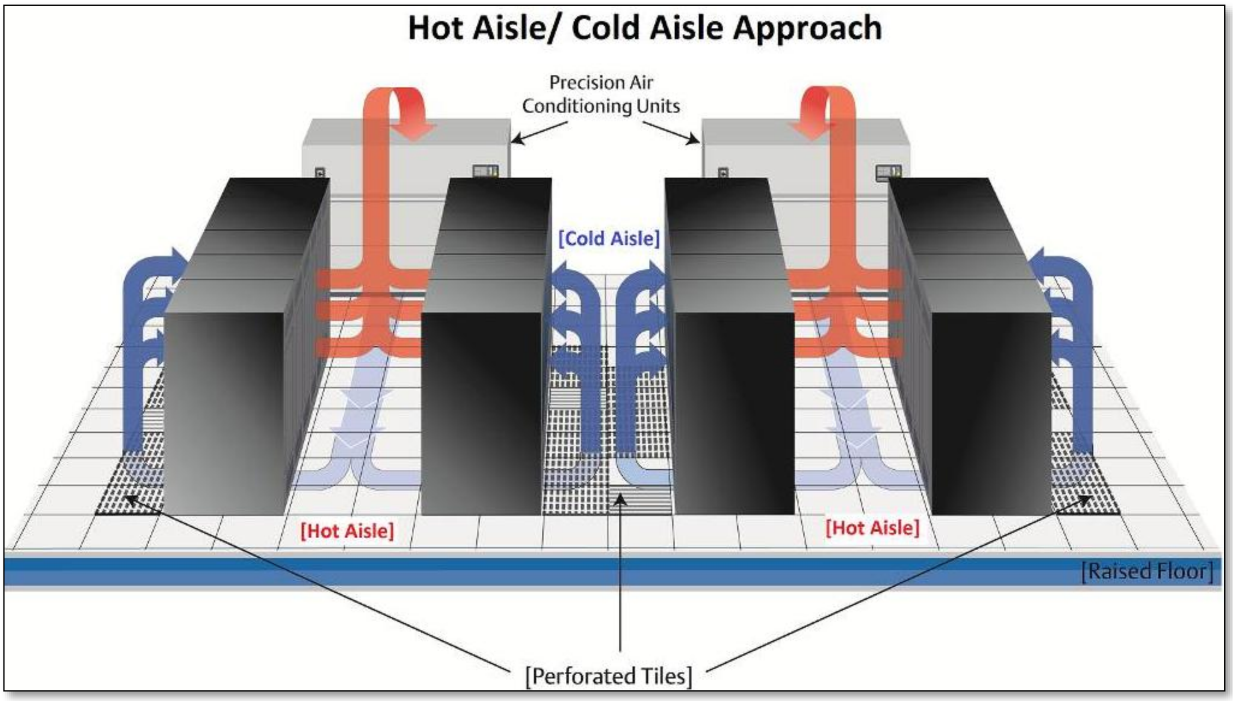


Figure 5.93: CRAC Hot-Cold Aisle, extracted from binaryroute.net

Cabling for both data and power is distributed above the equipment cabinets. At the lowest level (closest to the cabinet), the fiber cable tray system is used predominantly for connections across rows of cabinets and between cabinets within the same row. Above the telecom cabling layer, power is distributed through redundant suspended steel trunking with fixed industrial socket outlets.

The data center main equipment hall shall be protected by early warning smoke detection and clean agent fire protection, both above and below the access flooring. Equipment dedicated to the clean agent system are located outside the room in adjacent MEP rooms.

Physical access to the data center equipment hall shall be protected by hardened construction (two-hour fire rated wall enclosures) and electronic access control (i.e. SACS). A room dedicated for equipment staging is also provided in the vicinity of the data center equipment room. CCTV camera coverage will be provided at all entry points and throughout the entire data hall.

Separation of Services

The ICT containment system shall be designed such that power and data cable separation fully complies with minimum requirements of the telecom codes, standards and guidelines (BICSI-TDMM, etc.) and manufacturer installation guidelines. ICT cabling shall be installed in dedicated containment and shall not be installed in containment with electrical or any other building system services cabling.

Minimum Clearance Requirements:

The following are the minimum clearance requirements to be respected when planning the data center equipment hall.

- 1.8m of space front clearance
- 1.2m of space back clearance
- 300mm clearance above cable ladder tray/conduit
- 300mm clearance above top-most item cable ladder tray or other to any ceiling or overhead condition.

Fire Stopping

At all locations where ICT containment passes through wall openings, fire separation barriers or fire compartments shall be fire stopped in accordance with the buildings fire strategic code and regulation.

Only insert fire stop materials approved by the SCN cable manufacturer shall be used. The material shall enable addition of further cables to routes in the future with only minor rework required to reinstate the barrier material.

Data Center sizing

The calculations to identify the overall plot size and BUA of each of the data centers are generally based on the following working assumptions:

- Data Hall sizing:
    - For Phase 1, the estimated total number of racks is 57.
    - For Phase 2, the estimated total number of racks is 57, with an additional 15 racks allocated to accommodate the expansion; resulting in a total of 72 racks.
    - Telecom Racks shall:
        - Have the following dimensions: 800mm x 1200mm (42U),
        - Have minimum clearance requirements to be respected when planning the data center equipment:
            - 1.8m of space front clearance
            - 1.2m of space rear clearance
    - Based on the above estimated total number of racks and clearance requirements, a 300m2 data hall shall be required.
- Estimated Data center Built-up-area (BUA):
    - The Built-up-area of the Data center is estimated around 1200m2, including the Data Hall and necessary space to accommodate ancillary office and technical areas; Ensuring the systems are fully functional, operational and compliant with international standards and the industry’s best practices.
- Estimated Data Center Plot size:
    - Around the building we need 20m buffer zone for security setback, internal networks, access road, parking, and loading area.
    - The data center should have two entrance rooms preferably at opposite ends of the data center but a minimum of 20 m physical separation between the two rooms.
    - Based on the above considerations, a total plot size of 6000 m2 shall be required

Network Operations Center (NOC)

The network operations center (NOC) is a centralized location where IT teams shall continuously monitor the performance and health of the airport networks and systems. The NOC acts as the first line of defense against network disruptions and failures.

The NOC shall enable the monitoring, troubleshooting and management of the various networking and head-end components within the data centers. Dedicated personnel located within these rooms shall enable the monitoring, programming, upgrading, testing and repairing of the Telecom room’s equipment. The room shall consist of workstations and a video wall to present and monitor the network and server farm equipment information also allowing for troubleshooting, and test/repair interventions.

It is anticipated that the NOC(s) shall be located in the Data Center(s), and shall be sized to house around six operators and one supervisor, in coordination with the stakeholders’ requirements.

Dedicated space for Cybersecurity Operations Center shall be considered within the Data Center.

Service Provider Rooms

The Service Provider Room (SPR) acts as a demarcation point for the incoming Telecom services from the Service Providers (SPs). The SPR represents the end of the SPs' scope of work; containment and cabling within the premises serviced after the SPR will be treated as customer-owned. Each SPR will contain any active or passive SP equipment needed to offer the services required in the project, as well as direct services from the SP to designated areas within the project, such as ATMs, payphones, etc.

Two SPRs shall be provided for the airport, both located in the data center facilities. The locations of the tie-in points shall be coordinated with the service providers, and each tie-in points will be connected to both SPRs for additional redundancy. The electromechanical requirements for these rooms shall be coordinated with the involved disciplines based on the Service Provider's recommendations.

In addition, one room shall be reserved in the new PTB, and shall house the equipment serving the Commercial Cellular DAS solution equipment (base-stations, master units, etc.). This space shall be coordinated with the service providers, as well as other MEP disciplines, to ensure that all the requirements are met.

Building Distribution rooms (BDR)

Building distributer (BD) rooms shall house distribution level switches for each of the ICT and the security networks. 1No. or 2Nos. BDR(s) shall be provided within each building, apart from the smaller buildings (substations, etc.), depending on the size and the data outlet density within each facility. This room might also be used to house access level equipment, within separate cabinets, if deemed necessary.

Floor Distribution Rooms (FDR)

The floor distributor room or closet acts as a transitional point between the backbone cabling and the horizontal cabling, and also accommodates the network access function. The FD would house equipment related to distributed communications systems (such as PA amplifiers where applicable, etc.) as well as active components (access switches) for the IP networks considered in the project (ICT and Security). Within each FD, each switch stack shall be connected to both distribution switches for their respective networks within the BD rooms.

The security and ICT network equipment will have separate dedicated containment (cabinets, racks, pathways, etc.) except for small buildings with limited number of outlets the same compartmented cabinet will be used to house both ICT and security switches. The equipment however shall share the same IDF space and vertical shafts.

The FD rooms' and closets' locations and quantities per floor are based upon a maximum running distance (within common accessible areas such as corridors, lobbies, etc.) of 90 meters from the FD to the farthest outlet whenever possible.

Telecom Building Entrance Rooms (BER)

Building Entrance Rooms provide the limit between the airport owned OSP cabling and will generally contain only passive equipment. Cabinets with fiber optic cabling storage, management and splice trays will facilitate the transition from OSP cable type to indoor cable type.

5.3.2.3 TELECOM NETWORKS DESIGN

The following section provides high-level Telecom Network design assumptions to guide the building designers. These inputs are intended to serve solely as strategic direction and do not constitute detailed design requirements. They should be further elaborated, refined, and validated during subsequent design phases.

High-speed telecommunications networks shall be constructed at JKIA delivering quad play services (data, video, telephony and mobile) to travelers, staff, and authorities. Two separate networks shall be provided in the airport: one serving the ICT and airport systems, and another network for the security systems. The networks shall enable the diverse users to draw upon a wide array of services aimed at enhancing operations, ensuring safety and security measures, and enriching passengers' traveling experience.

5.3.2.3.1 ADOPTED NETWORKS

The ICT services will be founded on an IP converged network enabling an integrated IP-based voice system, high speed data network, wireless technologies for video, voice, data, location-based applications as well as other systems requiring data connectivity. The technology systems within the project that are designed to be supported by this ICT network infrastructure include:

- Data Network equipment (servers, storage, etc.)
- IP-based Telephony
- Wireless LAN (WLAN)
- IP Television (IPTV)
- Special Airport Systems,
- Connectivity for airport and special technology systems such as the Fire Alarm System, Master Clock system, Public Address and Voice Evacuation system, Audio-visual systems, etc. as applicable per facility.

On the other hand, the Security systems considered in this project will run over a dedicated separate IP network, referred to as the Security Network. The security systems will consist of the following main systems:

- Security Access Control System (SACS)
- Video Surveillance System (VSS)
- Security Screening systems (SSS) and Suspect Baggage Tracking System (SBTS)
- Perimeter Intrusion Detection System (PIDS)

Redundancy for both networks shall be provided at the relevant head-end equipment as well as within the IP networking components and main pathways (physically separated backbone routes), wherever feasible in order to avoid single points of failure.

5.3.2.3.2 OVERALL NETWORK TOPOLOGY

The head-end equipment serving all networks and systems will be located in the two redundant data centers. The data center infrastructure shall provide a highly redundant, available and expandable communication backbone consisting of both active and passive components. This backbone infrastructure shall be utilized by airport-wide systems, and shall connect all airport buildings and facilities.

The design of the ICT and security systems and associated infrastructure shall be scalable and capable of accommodating anticipated technology trends and interfaces with disparate systems. The design of the technology systems will be made with a clear understanding of current trends and anticipated future of each technology.

Overall reliability shall be considered not only in regards to system redundancy but shall also consider the expected end of life cycles for the technology components. Connectivity will be provided to the two data centers in the project, so that continuous operations may be maintained as additional facilities and expansions come on-line.

Network Architecture

The underlying infrastructure to support the ICT and security systems shall each be designed to provide a high performance, resilient, scalable and secure foundation that meets the airports requirements on day one and beyond. This foundation will allow the network to transport large quantities of digital information quickly and reliably to wherever it is needed, when it is needed.

The Structured Cabling Network will consist of high speed fiber optic backbone cabling. Connectivity between the core and distribution switches is using a physical ring, logical star topology, with dual homed connectivity. Furthermore, each access level stack is dual homed to two distribution layer switches. By combining redundant connections with low-latency network equipment using high performance protocols a fault-tolerant network is created to support mission critical operations.

The architecture of each of the ICT and the security networks is organized in different layers: Core, Distribution and Access. This hierarchical model is a modular topology using scalable “building blocks” that allow the network to meet evolving business needs. The modular design makes the network easy to scale, understand, and troubleshoot by promoting deterministic traffic patterns. The principle advantages of this model are its hierarchical structure and its modularity.

This hierarchical model, for each network, will provide a ‘dual homed’ connectivity between the core, the distribution and the access layers.

- **Core layer:** The core is the highest level in the physical network hierarchy. The core layer serves as a major traffic highway inter-connecting the distribution components, high-end servers, and gateways to the WAN connecting the airport to the outside world (e.g., PSTN gateways, data gateways). The core will be located in the two newly proposed data centers of the airport.
- **Distribution layer:** The distribution switches will provide the connectivity between the core switches and the access level switches. Duplicated distribution switches shall be provided in the buildings that are critical in nature (ATC Tower, etc.) and those that "larger" in size (with high data outlets' density). The distribution switches shall be located in each building's Building Distributer Room (BDR). Less critical and smaller buildings (for example substations, etc.) shall be connected to the distribution level switches at the nearest critical building or at the data centers. Each distribution switch shall be connected to both core switches in the data centers.
- **Access layer**: The access layer provides connection between the distribution switches and the data network users end devices such as PCs, printers, IP phones, etc. End devices will utilize data outlets and Wireless Access Points (WAPs) to connect to the access layer of the data network. The access layer equipment will be installed in the floor telecom rooms and will cover a floor or part of a floor (depending on the reach of the distance limitations which is mainly dictated by the 90m maximum cable run for the Cat6a copper cables). The IEEE 802.3bt standard shall be adhered to for the PoE and PoE+ requirements for the converged network devices. Each switch stack shall be connected to both distribution switches at the respective facility and for its respective network for redundancy.

5.3.2.3.3 CLASSIFICATION OF FACILITIES

The OSP within the Airport shall be extended to provide connectivity requirements for the newly proposed developments. Tie-in connection points for these developments will be proposed based on the criticality classifications of these developments. In modern network and infrastructure planning, developments are typically classified based on their level of criticality. This classification plays a vital role in determining the design and redundancy requirements of communication paths and connectivity.

Facilities will be generally categorized into high-critical, low-critical and special cases as follows:

High Critical Buildings

Facilities that are classified as High Critical from a Telecom perspective are the ones crucial for the proper functioning of the airport. These buildings shall be provided with two diversely routed paths to the data centers and served from two different manholes to support complete redundant connections. Utilizing redundant paths as well as redundant equipment, at the active and passive levels shall provide a high degree of fault tolerance.

Low Critical Facilities

Low Critical facilities on the other hand will have redundant connections to the data centers, but these connections will share common paths (underground ducts), and shall be provided with a single building entry point (same manhole). Low-critical facility connections provide a more economical solution while still providing a level of fault tolerance in line with the less critical functions on these facilities.

Special Cases

There are some situations whereby certain facilities such as car park areas have no space for the provision of communications cabinets. In these situations, the facility is treated as a horizontal extension of the building housing the necessary access switches stack to which they are connected.

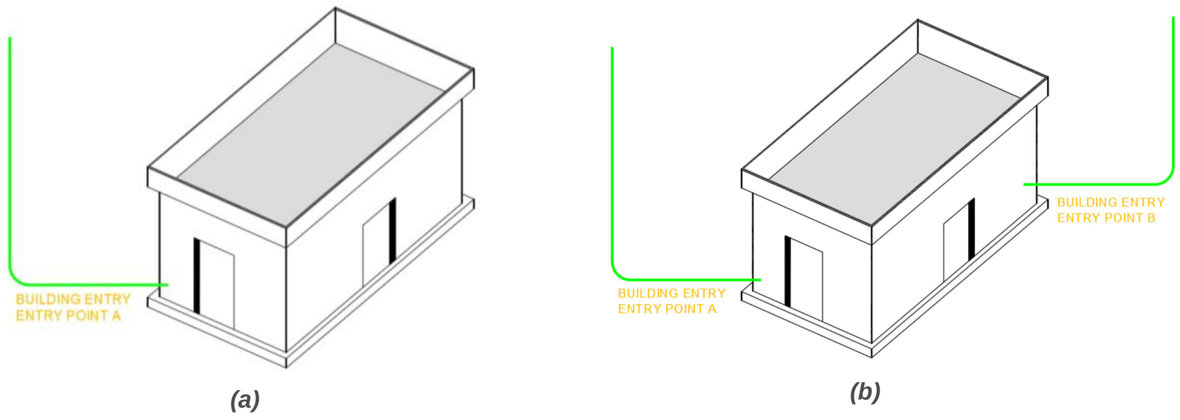


Figure 5.94: (a) Illustrative Diagram for Low Critical Building. (b) Illustrative Diagram for High Critical Building

Table 5.54: Proposed Criticality Classification for JKIA newly proposed buildings

List of Facilities	Master Plan Reference	Criticality Level	Distribution Switch Location (1)
Passenger Terminal Building	PTB1	High	PTB1
Catering Facility	S1	High	Catering Facility
Administration Building	S2	High	Data Center 1
Aircraft Maintenance & Repair (MRO)	S3	Low	Data Center 1
Airside Bus Driver Facilities	S4	Low	Data Center 1
GSE Maintenance Facility	S5	Low	Data Center 1
Airport Maintenance Complex	S6	High	Data Center 1
Aircraft Cleaning Facility	S7	Low	Data Center 1
Airside/Landside Gate	S8	Low	Data Center 1
ARFF	S9	High	Data Center 2
Data center 1	U1	High	Data Center 1
Data center 2	U2	High	Data Center 2
Water Pump Station	U4	Low	Data Center 2
Fire Pump Station	U6	Low	Data Center 2
Waste Treatment Plant	U7	Low	Data Center 2
Sewage Pump Station	U8	Low	Data Center 2
Electrical Substation for Catering Facility	SS1	Low	Catering Facility
Electrical Substation for Catering Facility	SS2	Low	Catering Facility
Admin Substation	SS3	Low	Data Center 1
MRO Electrical Substation	SS4	Low	Data Center 1
AGL Substation	SS5	Low	Data Center 1
PTB Electrical Substation	SS6	Low	PTB1
PTB Electrical Substation	SS7	Low	PTB1
PTB Electrical Substation	SS8	Low	PTB1
PTB Electrical Substation	SS9	Low	PTB1
GSE Maintenance Facility Electrical Substation	SS10	Low	Data Center 1
AGL Substation	SS11	Low	Data Center 2
Data Center Substation	SS12	Low	Data Center 1
Data Center Substation	SS13	Low	Data Center 2
Remote stand Substation	SS14	Low	PTB1
Remote stand Substation	SS15	Low	PTB1
Remote stand Substation	SS16	Low	PTB1
Remote stand Substation	SS17	Low	PTB1

List of Facilities	Master Plan Reference	Criticality Level	Distribution Switch Location (1)
MV generator Plant & Switching Station	SS18	Low	Catering Facility

(1) 2Nos. Distribution switches will be provided for redundancy

Note: The proposed locations of the distribution switches have been identified at a master planning level. These locations are indicative and shall be further reviewed, validated, and developed by the designer/contractor during the subsequent infrastructure detailed design stages.

5.3.2.3.4 FIBER CORES ASSIGNMENT

Backbone cabling, for both the ICT and Security networks shall consist of single mode fibre optic cabling which provides 10/40/100 Gbps Ethernet backbone and allows for the deployment of new higher bandwidth technologies in the future. The backbone network shall provide connectivity between the core switches in the data centers to all distribution level switches within the different airport buildings.

The number of fiber cores assigned for each building, connecting the distribution switches to the core level switches, for both the ICT and the Security network was determined based on the expected occupancy and usage. Buildings where a higher number of stakeholders is expected, such as the terminal building, were provided with a higher fiber count.

The critical buildings were previously defined as the buildings housing major systems and which are critical to the functioning of the airport. These buildings require a highly available network connectivity with little to no downtime, therefore, the fiber connectivity from each data center to these buildings shall be provided via diverse separate routes. The less critical buildings shall be connected also to both data centers (as indicated in the below table) however the paths do not need to be diverse.

In addition to the below table, which shows the connectivity between the core and distribution level switches, additional fiber optic cable shall be provided to connect each of the ICT network's and security network's core switches. 2Nos. 72-core fiber optic cables shall be routed via separate ducts/routes connecting the main and redundant core switches for each network.

Table 5.55: Fiber Counts for connectivity between Distribution and core switches

List of Facilities	Primary Connection FO Cores (From Data Centre 1)		Secondary Connection FO Cores (From Data Centre 2)	
	ICT	**Security**	**ICT**	**Security**
Passenger Terminal Building	72	24	72	24
Catering Facility	24	12	24	12
Data center 1	-	-	72	24
Data center 2	72	24	-	-
Total	168	60	168	60
	(1Nos. 192 core FOC)	(1Nos. 72 core FOC)	(1Nos. 192 core FOC)	(1Nos. 72 core FOC)

Below Table shows the fiber counts for the connectivity between the Distribution switches and access switches.

Table 5.56: Fiber Counts for the connectivity between Distribution and access switches

List of Facilities	Primary Connection FO Cores (From Distribution Switch)		Secondary Connection FO Cores (From Distribution Switch)	
	ICT	**Security**	**ICT**	**Security**
Catering Facility	24	12	24	12
Electrical Substation for Catering Facility	24	12	24	12
Electrical Substation for Catering Facility	24	12	24	12
MV generator Plant & Switching Station	24	12	24	12
Total	96 (1Nos. 144 core FOC)	48 (1Nos. 72 core FOC)	96 (1Nos. 144 core FOC)	48 (1Nos. 72 core FOC)

List of Facilities	Primary Connection FO Cores (From Distribution Switch)		Secondary Connection FO Cores (From Distribution Switch)	
	ICT	**Security**	**ICT**	**Security**
PTB1	24	12	24	12
PTB Electrical Substation	24	12	24	12
PTB Electrical Substation	24	12	24	12
PTB Electrical Substation	24	12	24	12
PTB Electrical Substation	24	12	24	12
Remote Stand Substation	24	12	24	12
Remote Stand Substation	24	12	24	12
Remote Stand Substation	24	12	24	12
Remote Stand Substation	24	12	24	12
Total	216 (1Nos. 288 core FOC)	108 (1Nos. 144 core FOC)	216 (1Nos. 288 core FOC)	108 (1Nos. 144 core FOC)

List of Facilities	Primary Connection FO Cores (From Distribution Switch)		Secondary Connection FO Cores (From Distribution Switch)	
	ICT	**Security**	**ICT**	**Security**
Data Center 2	24	12	24	12
ARFF	24	12	24	12
Water Pump Station	24	12	24	12
Fire Pump Station	24	12	24	12
Waste Treatment Plant	24	12	24	12
Sewage Pump Station	24	12	24	12
AGL Substation	24	12	24	12
Data Center Substation	24	12	24	12
Total	192	96	192	96

List of Facilities	Primary Connection FO Cores (From Distribution Switch)		Secondary Connection FO Cores (From Distribution Switch)	
	(1Nos. 288 core FOC)	(1Nos. 144 core FOC)	(1Nos. 288 core FOC)	(1Nos. 144 core FOC)

List of Facilities	Primary Connection FO Cores (From Distribution Switch)		Secondary Connection FO Cores (From Distribution Switch)	
	ICT	**Security**	**ICT**	**Security**
Data Center 1	24	12	24	12
Administration Building	24	12	24	12
Aircraft Maintenance & Repair (MRO)	24	12	24	12
Airside Bus Driver Facilities	24	12	24	12
GSE Maintenance Facility	24	12	24	12
Airport Maintenance Complex	24	12	24	12
Aircraft Cleaning Facility	24	12	24	12
Airside/Landside Gate	24	12	24	12
Admin Substation	24	12	24	12
MRO Electrical Substation	24	12	24	12
GSE Maintenance Facility Electrical Substation	24	12	24	12
AGL Substation	24	12	24	12
Data Center Substation	24	12	24	12
Total	312	156	312	156
	(1Nos. 288core and 1Nos. 48core FOC)	(1Nos. 192 core FOC)	(1Nos. 288core and 1Nos. 48core FOC)	(1Nos. 192 core FOC)

Note: The estimated fiber counts are provided for the ICT and Security networks only. Fiber requirements for other networks including Service provider and external Stakeholders shall be defined and developed by the relevant stakeholder during the subsequent design stages.

5.3.2.3.5 TELECOM BANDWIDTH CALCULATIONS

The following section depicts the required bandwidth for the telecom network serving Jomo Kenyatta International Airport.

Required Planning Parameters

In order to properly assess the bandwidth requirements for the telecom network, it is essential to have proper estimations of the following:

- Number of visitors per facility during the peak hour (including passengers, well-wishers, etc.)
- Number of employees per development/facility.

Industry Recommendations

In order to determine the minimum required bandwidth, the following industry references, among others, were considered.

For personal mobile use:

- The US Federal Communications Commission (FCC) recommends minimum download/upload speed of 100 Mbps/20 Mbps for fixed broadband and 35 Mbps/ 3 Mbps for mobile broadband.
- Skype recommends the following download/upload speeds for video calling: HD video calling (1.5 Mbps/1.5 Mbps), group video of five people (4 Mbps/512 Kbps), and group video of seven people (8 Mbps/512 Kbps).
- Live streaming from mobile phones through Facebook Live requires 4 Mbps.
- Netflix recommends at least 5 Mbps for HD quality and 25 Mbps for Ultra HD or 4K quality
- Zoom recommends at least 2 Mbps upload and 6 Mbps download seeds for triple screen.

Calculation Criteria

Based on the above, the bandwidth (BW) calculation criteria are depicted in **Error! Reference source not found.**Table 5.57, taking into consideration the cited contention (oversubscription) ratios.

Table 5.57: Bandwidth Calculation Criteria

	Visitors	Employees
Required minimum BW per user	15 Mbps per visitor	10 Mbps per employee
Total uncontended bandwidth required	$= \text{a} * 15 \text{ Mbps}$	$= \text{b} * 10 \text{ Mbps}$
Contention ratio	1:20[(1)]	
Total bandwidth required	$= \frac{\text{a} * 15\ Mbps}{20}$	$= \frac{\text{b} * 10\ Mbps}{20}$

[(1)] Based on industry network contention ratio best practices

Where:

- "a" is the average number of visitors which includes passengers, meet and greeters, etc. per peak hour;
- "b" is the number of employees for the facilities per shift;

Table 5.58: Bandwidth Calculations

	PAL 1		PAL 2		PAL 1		PAL 2	
List of Facilities	Employees	Visitors	Employees	Visitors	Employees	Visitors	Employees	Visitors
Passenger Terminal Building	3722	22060	4,584	27956	1861	16545	2292	20967
Catering Facility[(1)]	636	5	793	6	318	3.75	396.5	4.5
Administration Building[(1)]	225	30	271	36	112.5	22.5	135.5	27
Aircraft Maintenance & Repair (MRO)[(1)]	245	0	297	0	122.5	0	148.5	0
Airside Bus Driver Facilities[(1)]	28	4	35	5	14	3	17.5	3.75
GSE Maintenance Facility[(1)]	76	8	89	10	38	6	44.5	7.5
Airport Maintenance Complex[(1)]	41	8	50	10	20.5	6	25	7.5

	PAL 1		PAL 2		PAL 1		PAL 2	
List of Facilities	Employees	Visitors	Employees	Visitors	Employees	Visitors	Employees	Visitors
Aircraft Cleaning Facility(1)	46	5	49	6	23	3.75	24.5	4.5
Airside/Landside Gate(1)	5	0	6	0	2.5	0	3	0
ARFF(1)	15	0	15	0	7.5	0	7.5	0
Data center 1(2)	25	0	30	0	12.5	0	15	0
Data center 2(2)	25	0	30	0	12.5	0	15	0
Water Pump Station(2)	4	1	5	2	2	0.75	2.5	1.5
Fire Pump Station(2)	2	1	3	2	1	0.75	1.5	1.5
Waste Treatment Plant(2)	10	2	12	3	5	1.5	6	2.25
Sewage Pump Station(2)	3	1	4	2	1.5	0.75	2	1.5
Electrical Substation for Catering Facility(2)	3	1	4	2	1.5	0.75	2	1.5
Electrical Substation for Catering Facility(2)	3	1	4	2	1.5	0.75	2	1.5
Admin Substation(2)	3	1	4	2	1.5	0.75	2	1.5
MRO Electrical Substation(2)	4	1	5	2	2	0.75	2.5	1.5
AGL Substation(2)	3	1	4	2	1.5	0.75	2	1.5
PTB Electrical Substation(2)	4	2	5	3	2	1.5	2.5	2.25
PTB Electrical Substation(2)	4	2	5	3	2	1.5	2.5	2.25
PTB Electrical Substation(2)	4	2	5	3	2	1.5	2.5	2.25
PTB Electrical Substation(2)	4	2	5	3	2	1.5	2.5	2.25
GSE Maintenance Facility Electrical Substation(2)	3	1	4	2	1.5	0.75	2	1.5
AGL Substation(2)	3	2	4	3	1.5	1.5	2	2.25
Data Center Substation(2)	4	2	5	3	2	1.5	2.5	2.25
Data Center Substation(2)	4	2	5	3	2	1.5	2.5	2.25
Remote stand Substation(2)	3	2	4	3	1.5	1.5	2	2.25
Remote stand Substation(2)	3	2	4	3	1.5	1.5	2	2.25
Remote stand Substation(2)	3	2	4	3	1.5	1.5	2	2.25

	PAL 1		PAL 2		PAL 1		PAL 2	
List of Facilities	Employees	Visitors	Employees	Visitors	Employees	Visitors	Employees	Visitors
Remote stand Substation(2)	3	2	4	3	1.5	1.5	2	2.25
MV generator Plant & Switching Station(2)	6	3	8	4	3	2.25	4	3
Total per Employees/visitors	5172	22156	6356	28087	2586	16617	3178	21065.25
Grand Total	27328		34443		19203		24243.25	

(1) Visitor figures, for the following facilities, are based on assumed values
(2) Both visitor and employee figures, for the following facilities, are based on assumed values

Based on the data summarized in the table above and the applied calculation criteria, the total bandwidth requirement for Phase 1 is approximately 20 Gbps, divided into 2.586 Gbps for employees and 16.617 Gbps for visitors. Similarly, the total bandwidth requirement for Phase 2 is approximately 25 Gbps, divided into 3.178 Gbps for employees and 21.066 Gbps for visitors.

5.3.2.3.6 COMMERCIAL CELLULAR COVERAGE AND PUBLIC SAFETY RADIO SYSTEM

5.3.2.3.6.1 TETRA/LTE

The primary business objective of an airport is to provide a better experience in terms of faster passenger processing, efficient baggage and freight handling operation while maintaining the highest levels of security and safety. Communication systems play a major role in better coordination and fast service delivery.

In order to meet the above-mentioned objectives, a distributed antenna system (DAS) comprising TETRA and LTE services shall be provided in JKIA, to deliver a complete radio coverage throughout indoor and outdoor areas of the new expansion areas of the airport. The PTB shall be provided with an indoor infrastructure.

This radio system would allow communication between staff that are constantly moving throughout the airport for operation, maintenance, security and safety purposes. The design shall be conducted to allow for sufficient quality of radio transmission and reception for equipment operating in a TETRA / LTE DAS system. The system shall comprise of main head-end equipment and distribution components including splitters, repeaters, antennas, etc.

Space requirements:

Dedicated Radio Rooms shall be allocated in the PTB to accommodate the TETRA and the LTE base-stations and OMU serving these facilities.

Within the PTB building, the floor distributors (FDs) shall house a dedicated rack that would accommodate the optical remote units (ORU) as needed.

Provision for spare and expansion capacity shall be considered when determining room sizes and / or equipment spaces. The equipment rooms used shall have adequate mechanical and electrical services.

Basis of design:

The design of the TETRA / LTE DAS shall consider the following criteria:

- Have the capability to cater for future technologies with minimal reworks required for integration.
- Meet the capacity requirements / demand.
- Be modular in construction to ensure ease of upgrade and expansion.
- Provide dedicated LTE services for governmental uses.

5.3.2.3.6.2 Cellular

Proper GSM (Mobile) Coverage is vital for airport users. The need to stay connected, either through voice calls or through the web, is very important for travellers. To ensure a full coverage throughout the airport outdoor areas, GSM towers/ antennas shall be provided by the Service Providers.

Reservations should be allocated for infrastructure related to provisional mobile network towers (5G), in coordination with the telecom service providers.

The Figures below show the existing tower locations and coverage in JKIA

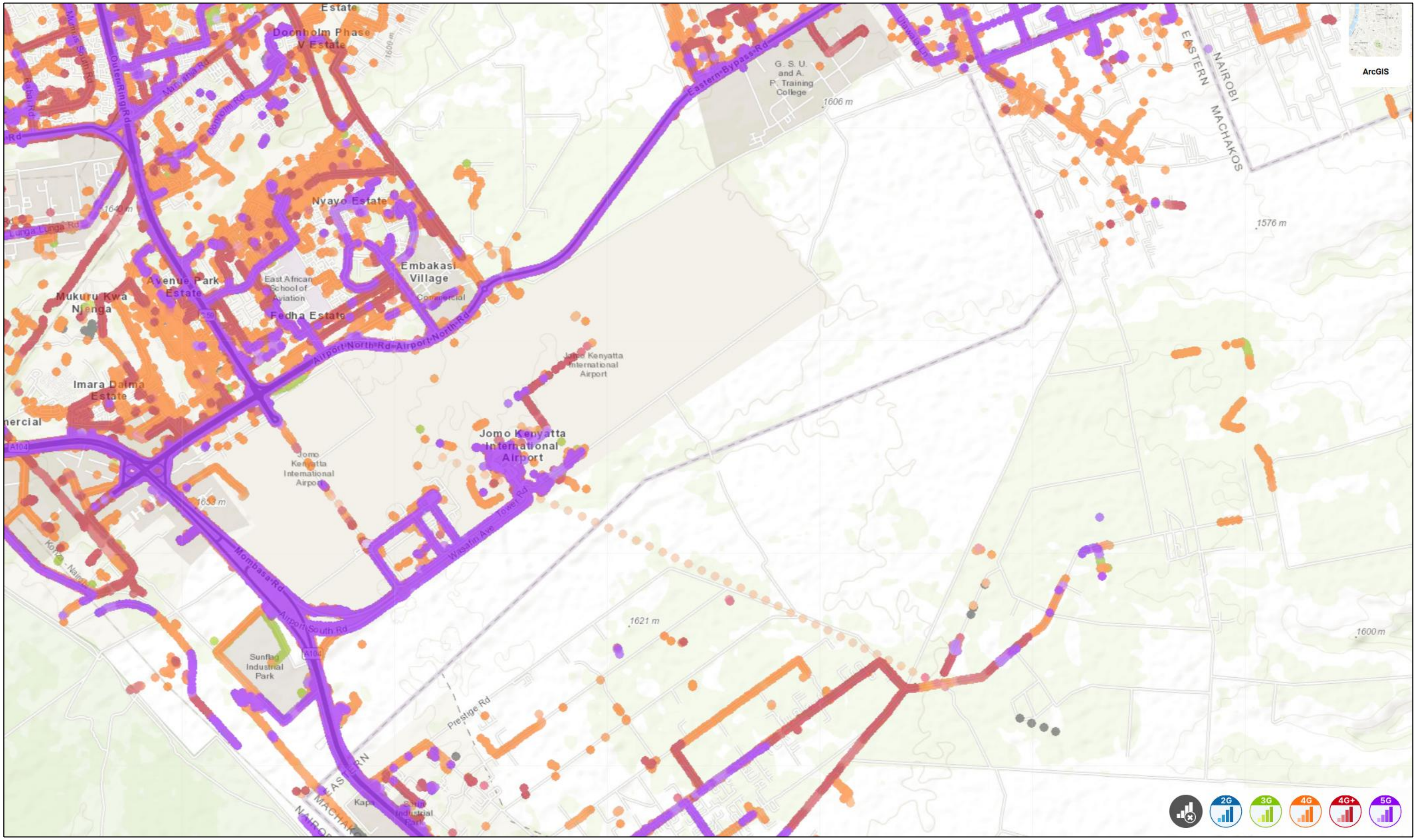


Figure 5.95: Illustration of Safaricom coverage within JKIA site area, extracted from nPerf.com

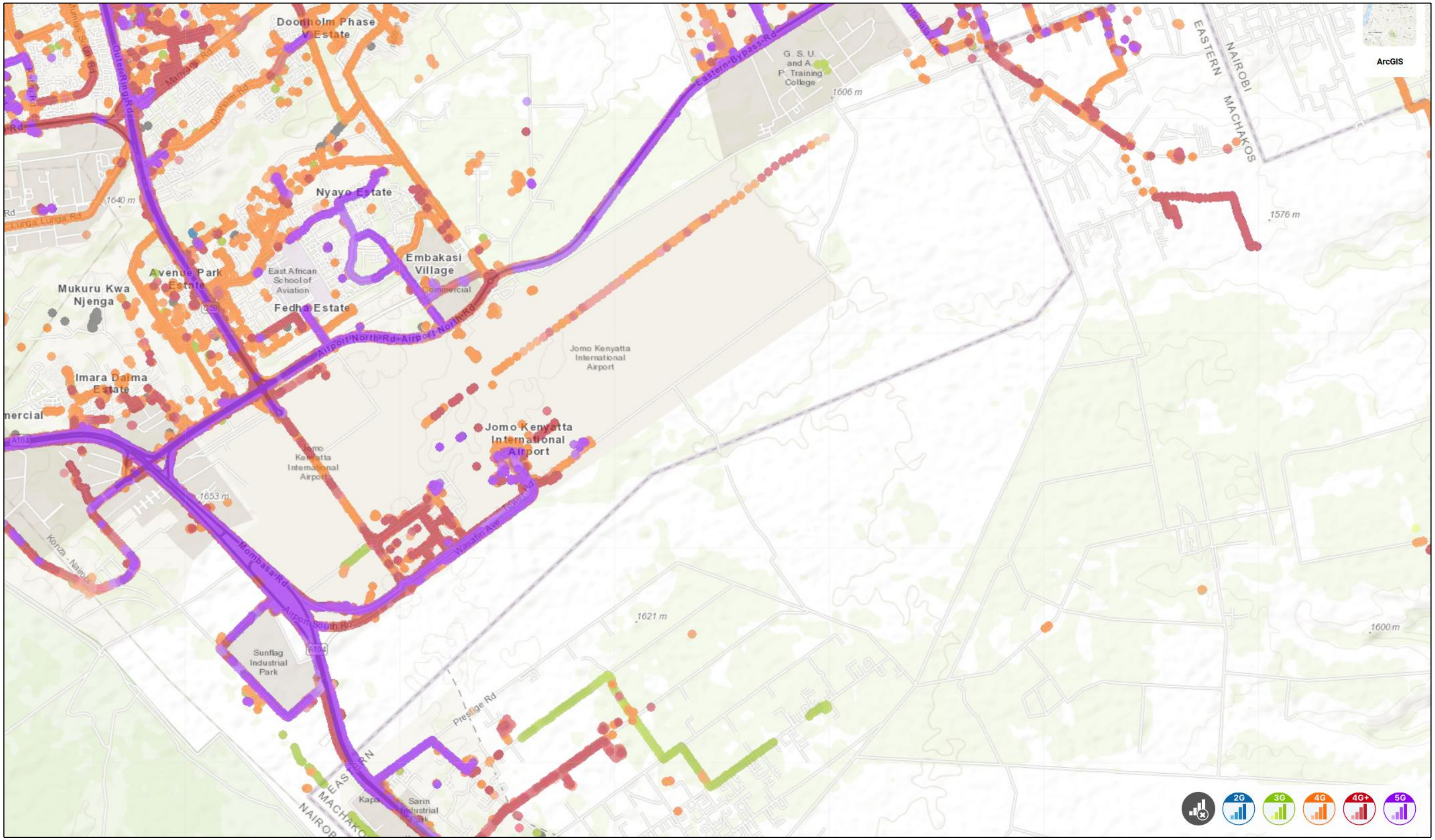


Figure 5.96: Illustration of Airtel coverage within JKIA site area, extracted from nPerf.com

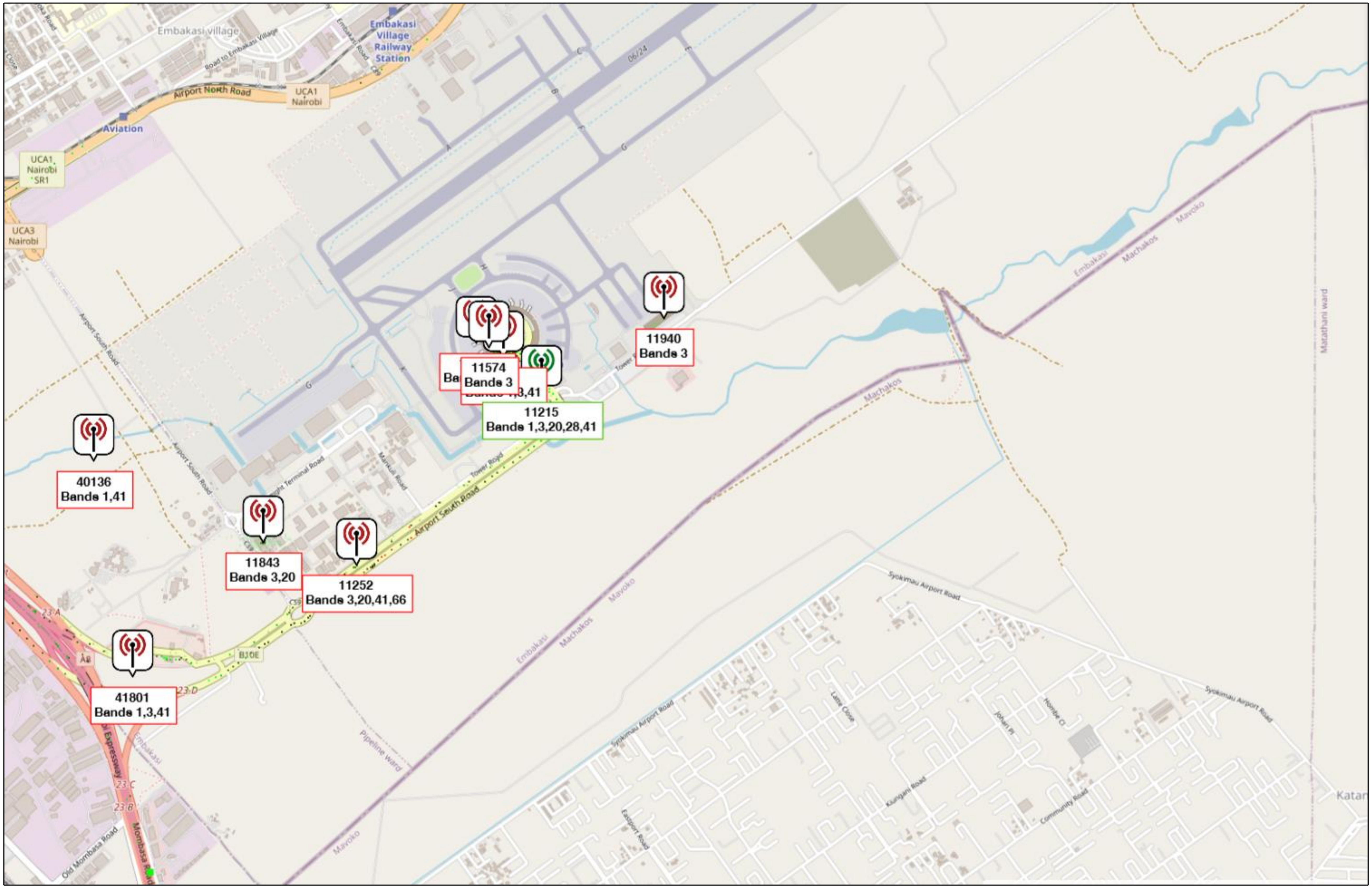


Figure 5.97: Illustration of Telecom Antenna locations within JKIA site area, extracted from cellmapper.net

Figure 5.98: View of existing Telecom tower currently installed within JKIA site boundaries, extracted from Google Earth

Co-location is the practice of locating equipment of multiple service providers on a single telecom tower. At all towers/masts, the design of all buildings and related structures shall use materials, colours, textures, screening, and landscaping that will blend the tower facilities with the natural setting and building environment. Provision for Tower locations (10m x 10m) shall take into consideration mobile coverage with radius of 1000 meters for those located near the new utilities and positioned on the highway. Further coordination with Service Providers shall be established during infrastructure design for final confirmation on tower's plot dimensions.

The heights of Towers will vary depending on the technology used and the area of concern, with Macro cell towers reaching heights of over 30 meters.

The GSM system shall be coordinated with local Telecom operators to ensure a fully functional system with total coverage, quality of service, and based on the latest technology. In addition, the Telecom Service Providers shall advise on the quantity and location of micro cell antennas inside the PTB.

The scope of work of the project Contractor will be to provide the necessary reservation and containment for the GSM system network infrastructure.

The GSM system shall use the Telecommunications infrastructure (duct-bank) to connect the PTB with the GSM site Antennas and shall be interfaced with the GSM incoming connections from the operators

.

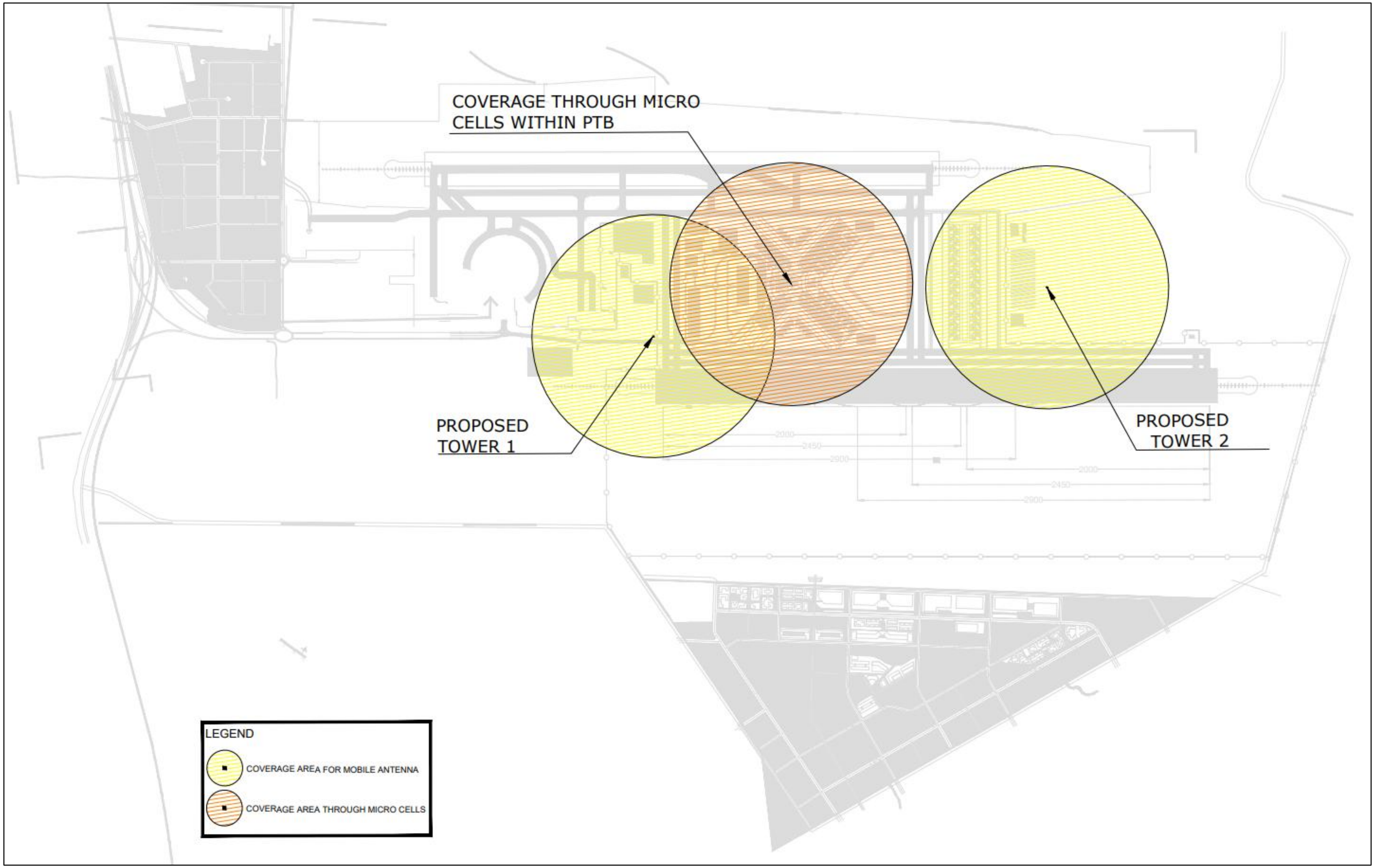


Figure 5.99: Locations and Coverage of the Proposed Towers

5.3.2.3.7 FIRE ALARM AND DETECTION NETWORK

The Fire Detection and Alarm System (FADS) involves the early detection and notification of fire threats. The system shall be designed to provide an early detection, accurate localization of zones and points of origin, and automatic control of the ventilating air-conditioning systems and other life safety and MEP systems for all buildings in JKIA. The system shall be of the addressable type with voice command feature where applicable, microprocessor based, audibly and visually supervised, with detection and alert devices distributed where dictated by codes; Visual notification devices, based on light strobes, shall be provided in public and common areas as prescribed by the code.

The Fire Detection and Alarm System shall be in accordance with the local fire protection regulations and in compliance with NFPA codes.

The control of the fire alarm system for the overall airport will be based on connecting all the fire alarm panels in all the buildings and facilities via the Fire Alarm network's fiber optic loop. The whole airport shall be monitored and controlled from the ARFF.

The proposed concept is to provide the large buildings, such as the Terminal Building, etc. with a local fire command center for monitoring and control. The fire panels within each building shall also be monitored at the fire station (as applicable), along with all other panels within the airport. The number of panels within each building shall be determined during the design phases.

The panels, the FCC within the different buildings, and the ARFF shall be connected through Single Mode Fiber Optic cable, running inside the OSP network in a ring topology to ensure redundancy. Workstations shall be provided in each FCC and ARFF to monitor and control all the fire alarms and transactions. All workstations shall be equipped with a graphical user interface that supports, controls and monitors all the fire alarm panels in JKIA.

5.3.3 STORM WATER DRAINAGE

5.3.3.1 DESCRIPTION

A hydrological and hydraulic analysis is conducted following the next steps:

1. Watershed delineation, Curve Number analysis/runoff coefficient calculation, Time of Concentration estimation, and identification of flood hazard-prone locations around the Jomo Kenyatta International Airport (JKIA).
2. Develop a HEC-HMS model to simulate discharges around the Jomo Kenyatta International Airport (JKIA) study area for a 100-year storm and Climate Change events using IDF curves provided by JKIA (2024).
3. Develop a model to simulate water depth, water velocity, water surface elevation, and flood hazard rating maps to evaluate the impact in and around Jomo Kenyatta International Airport (JKIA) & Wilson Airport (WAP) location.

5.3.3.2 General maps of the study area

The area surrounding Jomo Kenyatta International Airport (JKIA), situated in the Embakasi sub-county of Nairobi, presents a striking convergence of urban and natural environments, defined primarily by its role as a major regional transport hub. It is characterized by high-density urban development and industrial logistics, especially along the heavily trafficked Mombasa Road, contrasting sharply with the expansive, open savanna of the Nairobi National Park directly to the southwest. The most significant recent feature is the towering, toll-based Nairobi Expressway, a double-decker highway that dramatically cuts through this busy corridor, providing a fast and efficient access route for travelers aiming to bypass the notorious ground-level traffic congestion between the airport and Nairobi's Central Business District (CBD). The project sites, situated in the center of Nairobi-Kenya Region, are designated for Airport function, red circle in Figure 5.100.

Figure 5.100: Study area with a Google Earth map.

Located on the south center of Kenya near the city of Nairobi, Figure 5.101 shows the location of the JKIA Study Area with a Google Satellite map background.

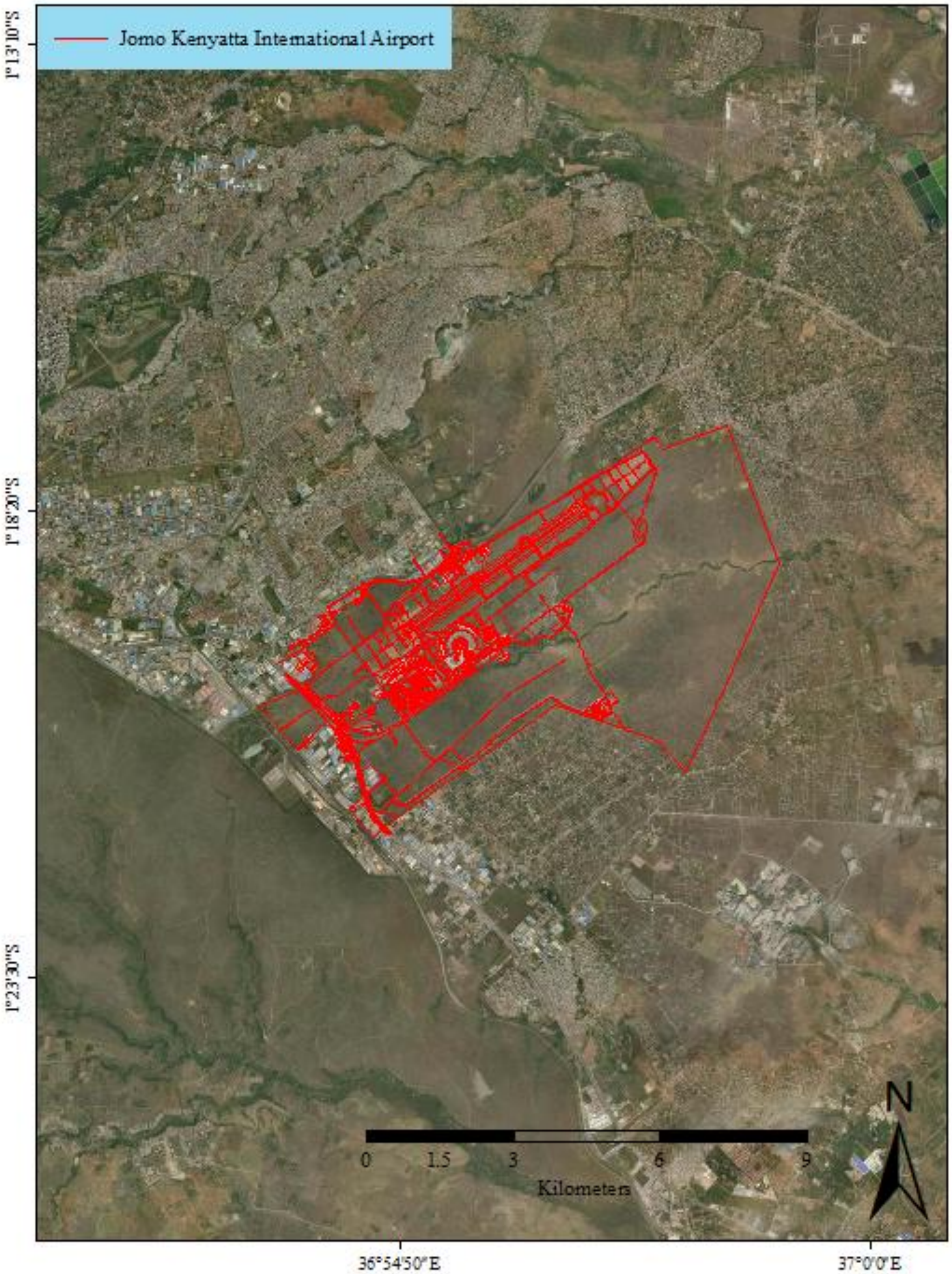


Figure 5.101: Study area with a google satellite map background.

5.3.3.3 Digital Elevation Map (DEM) map

Figure 5.102 shows the location of the study area with a 30-m resolution DEM map as background.

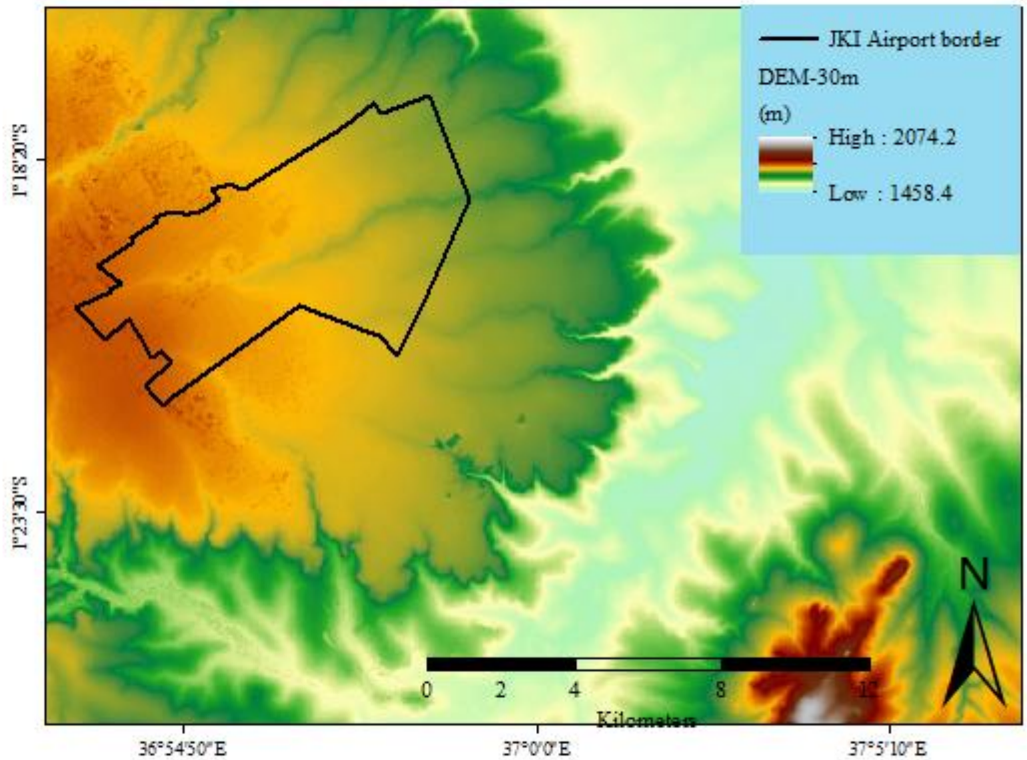


Figure 5.102: DEM map of the Study area.

5.3.3.4 Identification of the drainage basins

The primary and secondary drainage basins and their characteristics were identified using a digital elevation model (DEM) with a 30-m resolution. To determine the drainage basins and waterways, the DEM was analyzed using the following standard procedures such as terrain preprocessing, sink filling, flow direction, and flow accumulation. Figure 9 shows the streams and watershed around where the buildings of Study area is located with a Google satellite map as background.

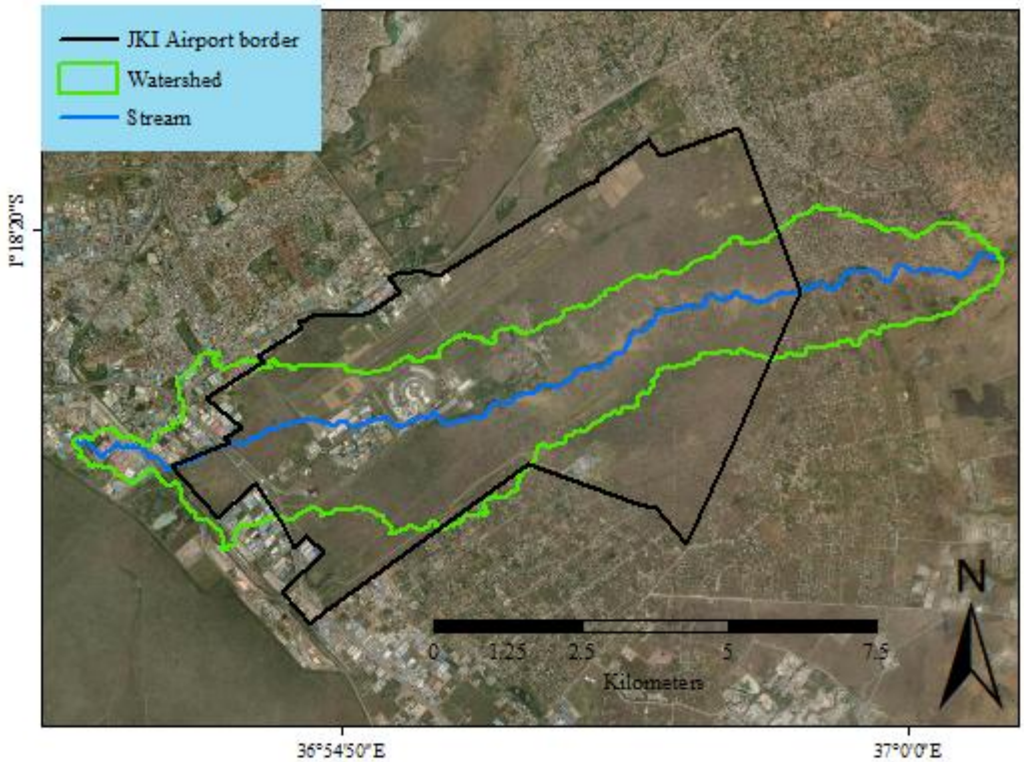


Figure 5.103: Watershed of the study site.

Table 5.59 summarizes the physiographic characteristics of the Basins where the JKIA is located, surface area, length of the wadis, slope.

Table 5.59: Characteristics of watershed.

	Area	Longest path	Slope
	(Km^2)	**(Km)**	**(m/m)**
Watershed	31.6	19.85	0.00509

Figure 5.104 shows a cross section of the watershed along the road in front where the JKIA is located.

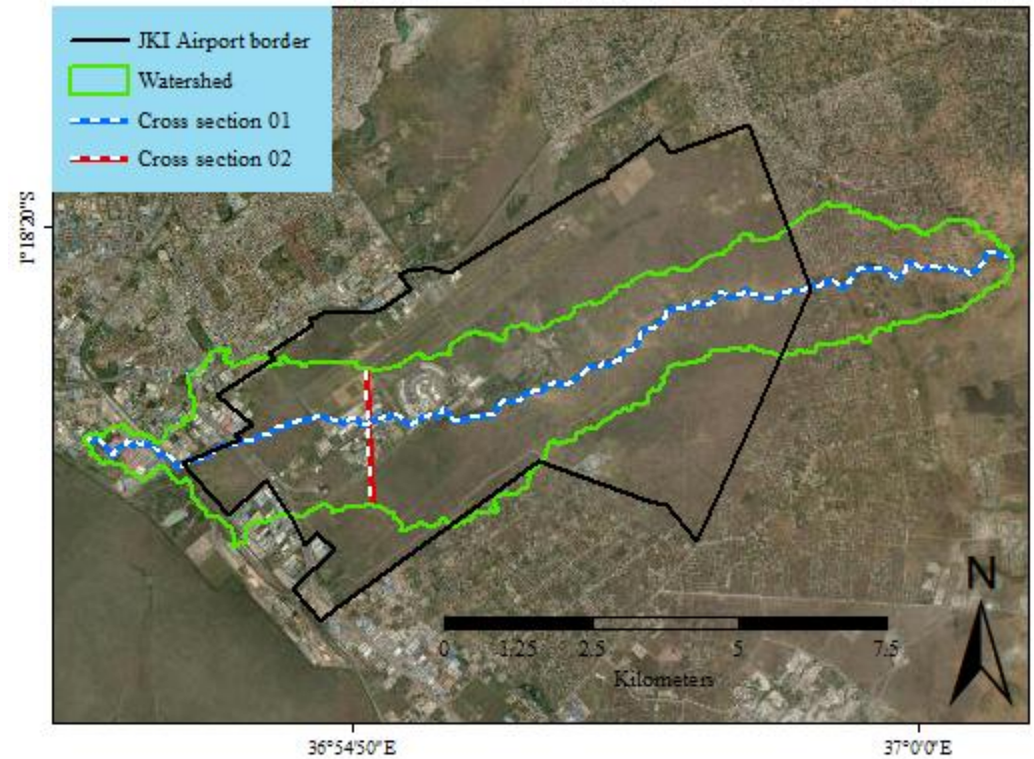


Figure 5.104: Cross sections transversal to the watershed.

5.3.3.5 Curve number calculation

The characteristics and structure of drainage basins play a crucial role in determining the relationship between the amount of rainfall a basin receives and the resulting surface runoff. In the Curve Number method, soils are classified into four main categories based on their infiltration rates. These categories, which reflect the soil's ability to absorb water, are described as follows:

- **Group A**: This category includes sandy soils or gravel, which have low runoff potential and high infiltration rates, even when fully saturated. Consequently, drainage basins with these soils tend to produce minimal surface runoff.
- **Group B**: This group consists of soils like medium sand, sandy loam, and moderately coarse soils. These soils have medium to high infiltration rates when saturated, leading to surface runoff that ranges from weak to moderate in drainage basins with these soil types.
- **Group C**: This category includes clay loam soils. These soils have a thick surface layer, low organic matter content, and fine to moderately fine grains. They are characterized by medium to low infiltration rates, resulting in moderate to high surface runoff in basins with such soils.
- **Group D:** This group encompasses clay soils with high swelling potential, shallow soils underlain by an impervious layer, or soils with consistently high groundwater levels. These soils have very low infiltration rates, leading to high surface runoff in the corresponding drainage basins.
    - The project site is situated in the western region of Jabal al-Lawz Mountain, which is centrally located within the Midyan Terrane. The area is underlain by Precambrian crystalline basement rocks of the Arabian Plate, which in many locations are overlain by Phanerozoic rocks.
    - The exposed geological units primarily consist of monzogranite, which has been intruded by mafic dikes. Surrounding areas feature outcrops of syenogranite and monzogranite belonging to the Al Lawz Complex.

- Structurally, the geology of this region is shaped by rifting processes associated with the Gulf of Aqaba and the Red Sea. This has resulted in two dominant fault trends: the NNW-SSE trend, linked to Red Sea rifting, and the NNE-SSW to NE-SW trends, associated with transform faults perpendicular to the rift axis (Mirage Visitor Center Book 2 Stage C, Site investigations).

Figure 5.105 shows the Soils Hydro Group map for the Study area.

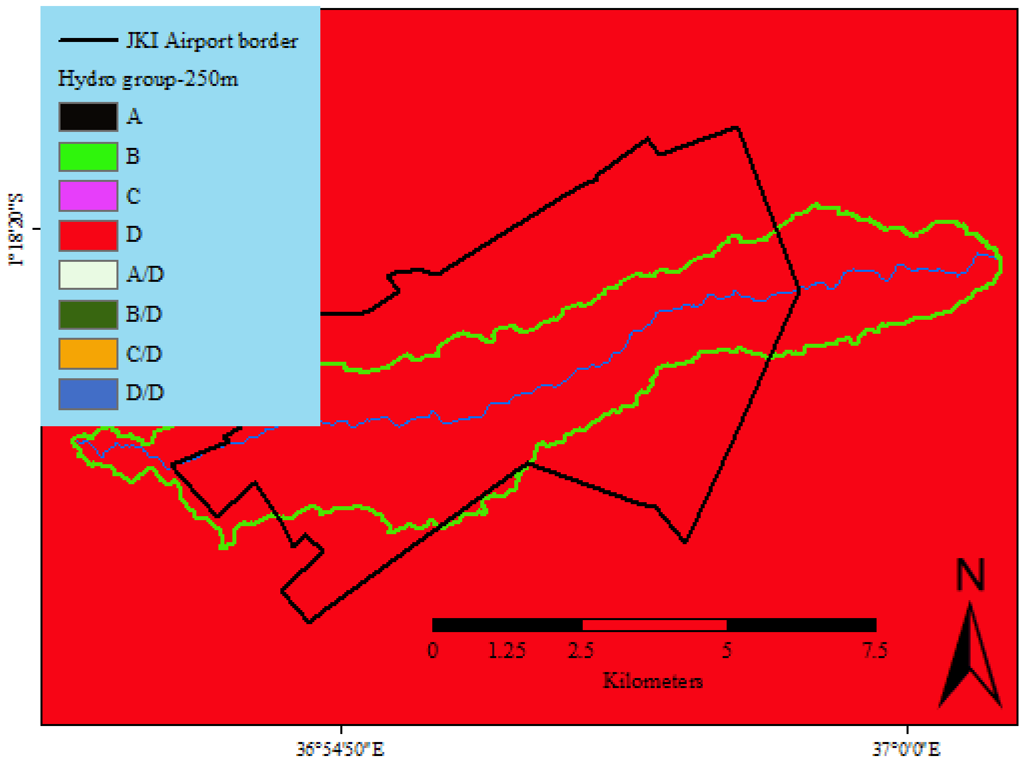


Figure 5.105: Hydro group map of the Study area.

The Soil Conservation Service (SCS) method, now known as the Natural Resources Conservation Service (NRCS) method (USDA, 1986), is a widely adopted approach for estimating surface runoff depth post accounting for initial losses. The SCS-CN method is universally recognized in hydrological practices and is also recommended by the Ministry of Transportation (MOT). This method considers not only rainfall amounts but also factors such as the characteristics of the drainage basin, soil moisture content, soil type and properties, initial losses, and land use. These factors are represented by the Runoff Curve Number (CN), which typically ranges from 25 (indicating low runoff in depressions) to 98 (for paved, impervious areas). The USDA curve-number (CN) method is essential for rainfall-runoff modelling, yet high-resolution global CN data is lacking. To address this, GCN250 (2019) new global gridded curve numbers for hydrologic modelling and design. The USDA curve-number (CN) method is essential for rainfall-runoff modelling, yet high-resolution global CN data is lacking. Table 5.60 shows Curve number values (Tillman, 2015).

Table 5.60: Curve Number values by Land cover and Hydro Group.

	Hydro group							
Land cover	**A**	**B**	**C**	**D**	**A/D**	**A/B**	**A/C**	**No data**
water	100	100	100	100	100	100	100	100.0
ice/snow	40	40	40	40	40	40	40	40.0
developed open	49	69	79	84	54	74	87	70.9
developed low	77	86	91	94	80	89	94	87.3
developed medium	89	92	94	95	92	95	98	93.6
developed high	98	98	98	98	98	98	98	98.0
barren	77	86	91	94	82	91	96	88.1
deciduous forest	32	48	57	63	37	53	62	50.3
evergreen forest	39	58	73	80	44	63	78	62.1
mixed forest	46	60	68	74	51	65	73	62.4
shrub	49	68	79	84	54	73	84	70.1
grassland	64	71	81	89	69	76	86	76.6
pasture	49	69	79	84	54	74	84	70.4
crops	71	80	87	90	76	85	92	83.0
woody	88	89	90	91	93	94	95	91.4
herbaceous	89	90	91	92	94	95	96	92.4
No data	70.5	80.3	86.5	90.1	74.5	84.3	90.9	82.4

GCN250 (2019) developed a 250-meter resolution dataset, using recent global land cover and soil data. This dataset integrates the 2015 ESA global land cover data with 2018 hydrologic soil group data (HYSOGs250m). GCN250 can be used for hydrologic design, land management, flood risk assessment, and groundwater recharge modelling (GCN250, 2019). For the estimation of the Curve Number, GCN250 layer was used (GCN250, 2019). Figure 5.106 shows the 250-meter resolution Curve Number map for the Study area.

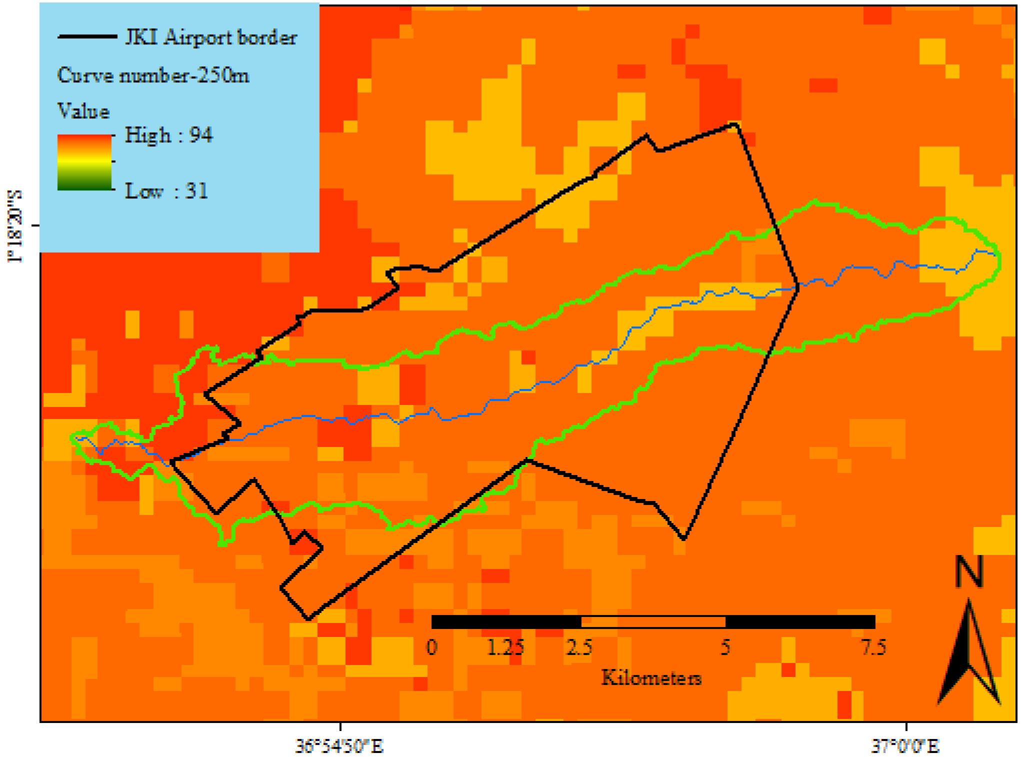


Figure 5.106: Curve Number map of the Study area.

5.3.3.6 Meteorological study and rainfall analysis

Jomo Kenyatta International Airport (HKJK) in Nairobi operates within a subtropical highland's climate, which is characterized by generally mild temperatures throughout the year, typically ranging from a low of about 13º to a high of around 27º. The area experiences two distinct rainy seasons driven by the migration of the Inter-Tropical Convergence Zone (ITCZ). The "Long Rains" occur from March to May, with April being the wettest month, averaging around 81 to 155-mm of rainfall. The second, shorter rainy season, the "Short Rains," typically falls between November and December. Conversely, the driest period is the cool season from June through September, with July often receiving the least precipitation, sometimes as little as 2.5-mm, offering clearer skies and better visibility for operations (The General Authority for Meteorology and Environmental Protection, World Meteorological Organization, National Center for Meteorology, 2024).

5.3.3.7 Daily, Short Rainfall Analysis and Intensity-Duration-Curves

Daily data at JKI Airport meteorological station, position and altitude are given in Table 5.61

Table 5.61: Coordinates of Airport Meteorological Station.

Station#	Latitude	Longitude	Altitude	Period
41024	21°42'00.0"N	39°10'59.9"E	15-m	1970-2020

Figure 5.107 shows the IDF curves provided by the JKIA.

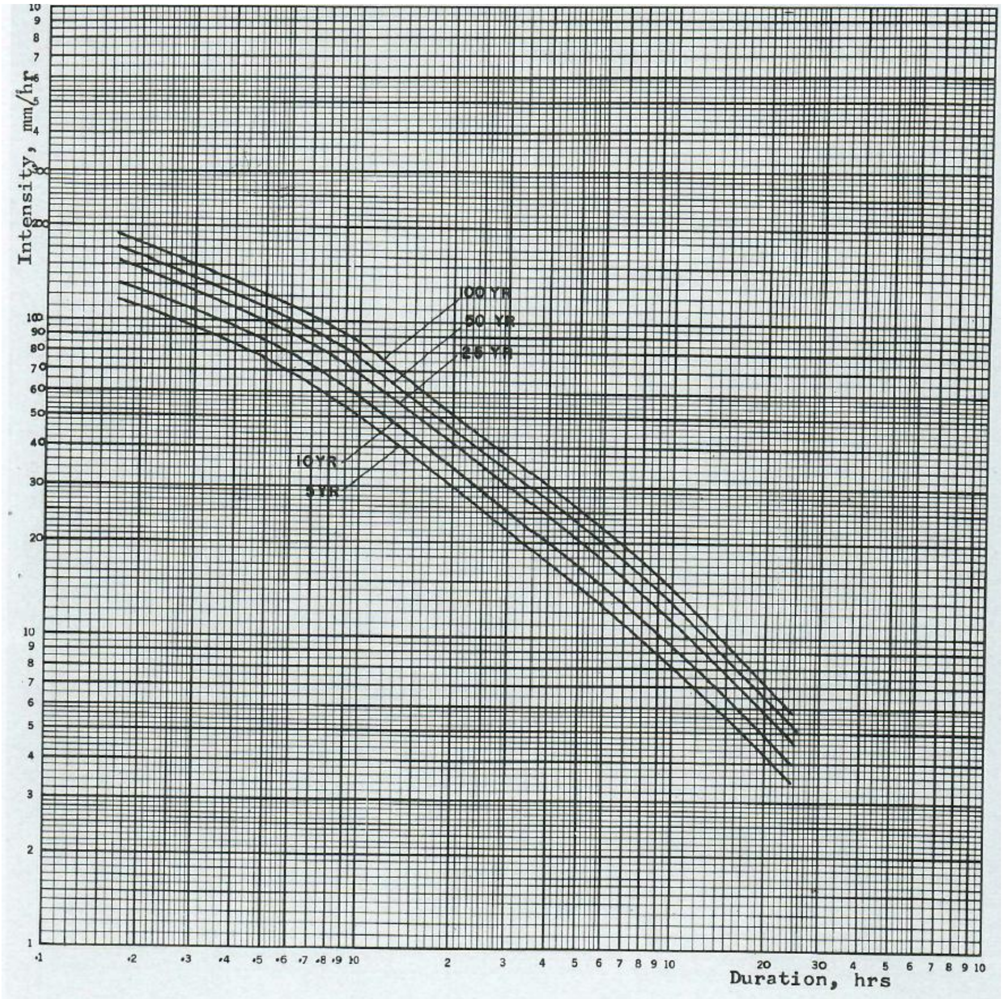


Figure 5.107: IDF curves (JKIA, 2025).

5.3.3.8 Hydrological modelling

5.3.3.8.1 Time of Concentration estimation

The time of concentration is the duration between the start of a rainfall event and the moment when water from the furthest point in the catchment area reaches the basin's outlet. This value is influenced by the nature of the surface and the length of the pathways water must travel to reach the basin's end. Additionally, it depends on the type of water flow across the basin's surface, which can range from sheet flow to shallow-concentrated flow or fully developed open channel flow. For drainage basins smaller than 1 km² and situated in urban areas, the time of concentration is typically calculated using the Kirpich Equation (Kirpich, 1940). Various formulas exist for estimating Tc, including Ventura, Passini, and Giandotti, each tailored to specific conditions. However, in this context, the Kirpich method was employed (Equation 1) as it aligns best with the characteristics of bare land watersheds (Kent, 1972).

$$Tc = 0.0195 \left(\frac{L}{\sqrt{S}}\right)^{0.77} \quad (1)$$

Where:

Parameter	Name	Unit
Tc	Concentration time	min
L	Length of the stream	m
S	Average slope of the stream	m/m

Various researchers, including Mockus (1957) and Simas (1996), found that under typical natural watershed conditions, with a roughly uniform distribution of runoff, Equation 2 applies.

$$T_L = 0.6xT_c \quad (2)$$

Where:

Parameter	Name	Unit
Tc	Concentration time	min
T_L	Lag time	min

Table 5.62 summarizes Time of concentration and Lag time calculated by Kirpich Equation for the basin around the JKIA.

Table 5.62: Time of concentration.

Parameter	T_c	T_{Lag}
Unit	**(min)**	**(min)**
Value	303.5	182.1

5.3.3.9 Hydrologic method

5.3.3.9.1 HEC-HMS model SCS Curve number

The USACE (2022) models such as HEC-HMS and HEC-RAS have become essential tools for hydrologic modeling, hydraulic design, water management and, are widely used in numerous studies and applications and can perform unique functions (Halwatura and Najim, 2013), also these models can be linked for the simulation of major storm events (Garcia et al., 2020).

HEC-HMS was designed to simulate the precipitation-runoff processes of dendritic watershed systems (USACE, 2022), the model can be applied for a wide range of geographic areas for solving a broad range of problems, such as: large river basin water supply, flood hydrology for a small urban or natural watershed (Halwatura and Najim, 2013), with the simulation of surface runoff and peak discharges in the watershed (Chu and Steinman, 2009). The result of the modeling process is the computation of stream flow hydrographs at the watershed outlet (Oleyiblo and Li, 2010). The HEC-HMS model is an ideal tool for simulating stream discharges in the mountains of Afruica due to its versatility in modeling diverse hydrologic processes, including steep terrain and arid climate dynamics, its ability to integrate local soil, land cover, and meteorological data, and its effectiveness in addressing critical issues like flash flood prediction and flood risk management. The model seamlessly incorporates GIS and remote sensing data, allowing detailed representation of the region's unique topography and hydrology, while its capabilities for scenario testing support the assessment of climate change impacts, urbanization, and infrastructure development in the Airport area. As a globally recognized and widely used tool, HEC-HMS provides reliable outputs for hydrologic modeling, making it essential for sustainable water resource planning and infrastructure design in this complex and rapidly developing region.

The Soil Conservation Service (SCS) method, now referred to as the Natural Resources Conservation Service (NRCS) method (USDA, 1986), is a widely used approach for estimating surface runoff depth by accounting for various rainwater losses within a drainage basin. Recognized globally in hydrological practices, the SCS-CN method is also endorsed by the Ministry of Transportation (MOT). This method considers not only rainfall amounts but also key characteristics of the drainage basin, including soil moisture content, soil type and properties, initial losses, and land use. These factors are represented by the Runoff Curve Number (CN), which typically ranges from 18 (indicating low runoff in areas with significant depressions) to 98 (representing paved, impervious surfaces).

For large watersheds, the SCS Unit Hydrograph method will be employed to transform runoff depth into a complete runoff hydrograph. This method requires the runoff depth, as determined by the SCS curve number method, and the lag time, which is typically calculated as 0.6 times the time of concentration for the watershed. Alternatively, the Rational method may be applied to estimate peak discharges for drainage basins smaller than 100 hectares (1-km²). The surface runoff coefficient, which is crucial for this method, will be determined using data and maps from the Global Curve Number. The consultant will calculate the surface runoff coefficient based on the soil types and land uses within each basin. Subsequently, peak discharge values will be calculated using the average surface runoff coefficient for each drainage basin and the rainfall intensity.

The SCS Runoff Curve Number method, pioneered by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS), offers a means of predicting rainfall excess based on precipitation data (Hjelmfelt, 1991). Detailed instructions for employing this method are available in the National Engineering Handbook (2004). The Soil Conservation Service (SCS) has introduced a Unit Hydrograph (UH) model that is parametric in nature. This SCS unit hydrograph method relies on a dimensionless, curvilinear unit hydrograph to guide the distribution of excess precipitation towards the outlet of the sub basin. Additionally, the Soil Conservation Service (SCS) Curve Number (CN) model provides an estimate of precipitation excess by considering cumulative precipitation, soil cover, land use, and antecedent moisture conditions (Cronshey, 1986). The SCS Curve Number method is described by equations 3, 4, 5, 6, and 7.

$$Pe = \frac{(\mathrm{P}-0.2*S)^2}{(P+0.8*S)} \qquad (3)$$

4.

$$S = \frac{25400-254*\mathrm{CN}}{CN} \qquad (4)$$

Where:

Parameter	Name	Units
Pe	Accumulated precipitation excess	mm
P	Cumulative rainfall	mm
S	Maximum soil storage	mm
CN	Curve number	-

$$Qp = \frac{\mathrm{A*Pe}}{Tp} \qquad (5)$$

$$T_p = \frac{D_{st}}{2} + T_{lag} \quad (6)$$

Where:

Parameter	Name	Units
Qp	Peak discharge	m^3/s
Tp	Time to peak	s
A	Basin area	m^2
D_{st}	Duration of designed storm	hr

5.

$$T_{lag} = \frac{L^{0.8} * [Sr+1]^{0.7}}{1900 * \sqrt{S}} \quad (7)$$

Where:

Parameter	Name	Units
T_{lag}	Time lag	Hour
L	Basin lenght	m
Sm	Soil moisture	cm
S	Basin slope	%

A hydrology study of the site of interest was conducted using the rainfall-runoff method SCS, applying the HEC-HMS model integrating design rainfall data, findings from the catchment physiography study, and surface flow runoff parameters derived from geospatial analysis of land use and soil type layers in GIS. Pilgrim et al. (1988) highlighted the distinct hydrological processes in arid zones, where some humid zone phenomena such as base flow are essentially absent, while transmission losses play a critical role. Given the hydro-geological conditions of the study area, base flow was excluded from the simulation process. The loss method selected was SCS Curve Number Loss, and SCS Unit Hydrograph was selected as Transform method to run the model during a 100-year event storm. Figure 5.108 shows HEC-HMS model.

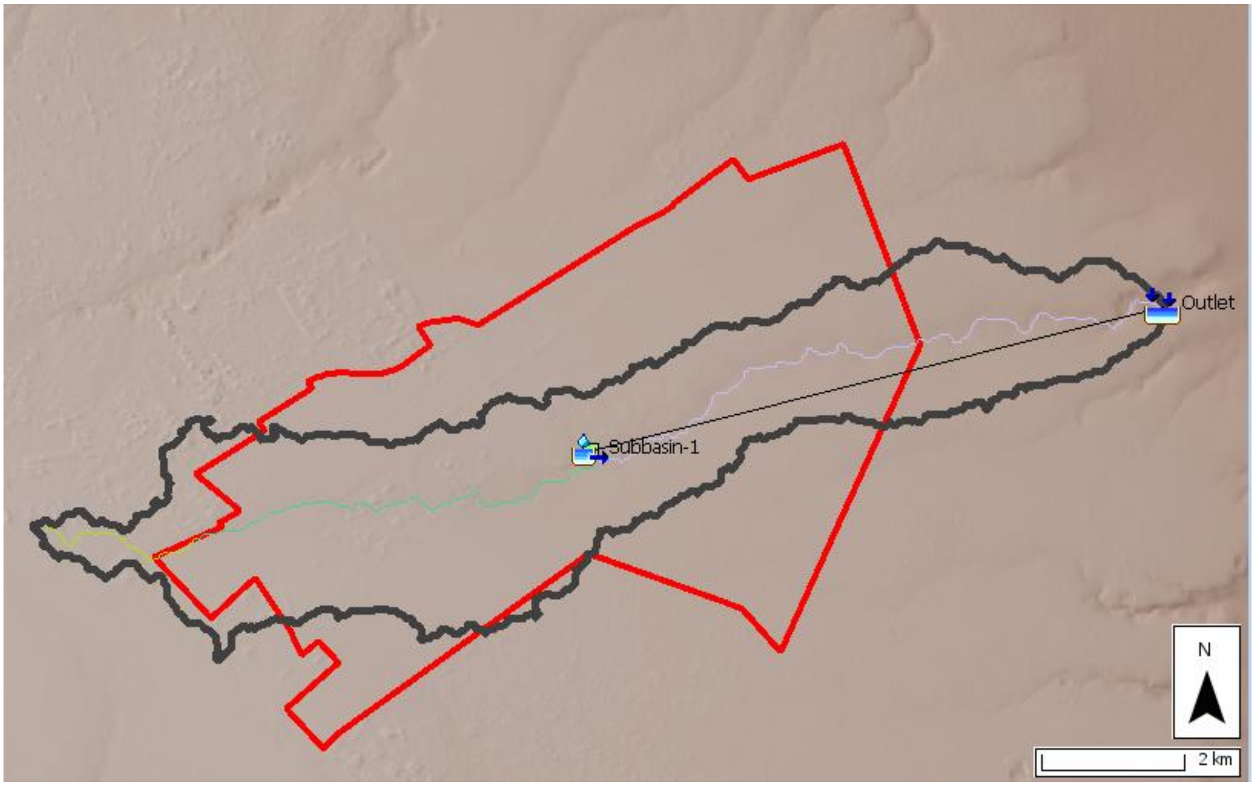


Figure 5.108: HEC-HMS model.

A Curve Number Study of the watershed, Curve numbers were extracted as weighted average from GCN250 dataset. GCN250 layer was calculated with wet, dry and average antecedent runoff conditions for every sub basin. Table 7 summarize the Curve Number Estimated for every sub basin in the watershed in function of the initial conditions of the soil.

Table 5.63: Curve number in the watershed in function of the initial conditions.

Sub-basin	Dry	Average	Wet
1	80	91	97

The Soil Conservation Service (SCS) Curve Number Method applies the curve number approach to estimate incremental losses (NRCS, 2007). This method is specifically designed for event-based simulations. Initially, it was developed to determine the total infiltration occurring during a storm. The HEC-HMS program calculates incremental precipitation by updating the infiltration volume at the end of each time step. The infiltration for each interval is determined by the difference in volume between two consecutive time steps.

Initial Abstraction (Iabs) represents the amount of precipitation required before surface runoff begins, the initial abstraction defines the amount of precipitation that must fall before surface excess results in runoff. However, it differs from Initial Interception or Initial Loss because modifying the Initial Abstraction affects the infiltration response later in the storm. If left unspecified, it is automatically set to "0", the potential retention will be by Equation 8.

$$Iabs = (\frac{25400}{CN} - 254) * 0.2 \qquad (8)$$

For the Curve number (CN), the average condition (91) from Table 13, was selected to simulate discharges in the watershed.

The percentage of Impervious (PctImp) of the sub basin consists of directly connected to impervious areas no loss calculations are carried out on the impervious area; all precipitation on that portion of the sub basin becomes direct runoff. It was calculated using a Land cover layer by Table 5.64.

Table 5.64: Percent of Impervious Land.

Land cover	Percent of Impervious (%)
No data	**0**
Open water	**0**
Developed, open space	**10**
Developed, low intensity	**20**
Developed, medium intensity	**40**
Developed, high intensity	**60**
Barren land rock/sand/clay	**10**
Shrub/Scrub	**0**
Grassland/Herbaceous	**0**
Pasture/Hay	**0**
Cultivated crops	**0**
Woody wetlands	**0**
Emergent herbaceous	**0**

Table 5.65 shows the Surface area (Area), Initial abstraction (I_{Abs}), Curve number (CN), Percentage of impervious land (PctImp) and Lag time (T_{lag}) by sub basin.

Table 5.65: Parameters of the HEC-HMS model by sub basin.

Sub-basin	IAbs	CN	PercImp	T_{lag}
#	**(mm)**	**(-)**	**(%)**	**(min)**
1	8.83	85.2	10.17	182.1

Below, Table 5.66 shows the Peak discharges for 100-year and Climate Change events by sub basin.

Table 5.66: Peak discharges by sub basin.

Sub-basin	100-year	Climate Change
(#)	**(m^3/s)**	**(m^3/s)**
1	144.6	159.0

5.3.3.10 Hydraulic calculations

HEC-RAS stands as a cornerstone hydraulic model crafted by HEC of the USACE (Beavers, 1994). Renowned for its versatility, HEC-RAS offers a comprehensive modelling environment capable of tackling a wide array of challenges pertaining to river networks, including the generation of flood maps (Pistocchi and Mazzoli, 2002). Leveraging various input parameters for hydraulic analysis, HEC-RAS features a user-friendly geographic information system interface known as RAS Mapper (Tate and Maidment, 1999; Djokic and Maidment, 1991). Recognized as an indispensable tool in hydrologic modelling, hydraulic design, and water management, HEC-RAS has been instrumental in simulating major storm events and producing flood maps (Halwatura; Najim, 2013; Garcia and Bedient, 2020; Pistocchi and Mazzoli, 2002; Beavers, 1994). Its efficacy has been demonstrated in a myriad of case studies, spanning from the Fenton River in Connecticut (Stella, 2022) to the Copper Slough Watershed in Illinois (Thakur et al., 2017) and the San Antonio River Watershed in Texas (Knebl et al., 2005). Research indicates that the integration of both one-dimensional (1D) and two-dimensional (2D) components in HEC-RAS yields superior results, particularly when employing topographic data of high spatial resolution (Vozinaki et al., 2017; Dasallas et al., 2019). This combined approach enables the representation of channel flows in 1D and overbank flows in 2D, enhancing the accuracy of flood modelling (Dasallas et al., 2019). While HEC-RAS 2D offers flexibility in handling complex hydraulic systems and can accommodate subcritical, supercritical, and mixed flow regimes, it demands substantial computational time and a high computational grid (Brunner *et al.*, 2015; Ghimire et al., 2022; Vozinaki et al., 2017). Nevertheless, research suggests that despite these challenges, the HEC-RAS 2D model consistently outperforms its 1D counterpart in providing detailed two-dimensional information for floodplain areas (Ghimire et al., 2022). The HEC-RAS model is ideal for simulating water surface elevation and velocity in West Center of Kenya due to its advanced hydraulic modelling capabilities, ability to handle steep gradients, and compatibility with high-resolution terrain data. It provides precise water surface profiles and velocity fields, critical for floodplain mapping, erosion studies, and ecological assessments, while its flexibility to incorporate upstream hydrologic inputs, such as from HEC-HMS, ensures comprehensive simulations of flash floods and extreme events common to the region. HEC-RAS is also invaluable for designing and analyzing hydraulic structures like culverts, bridges, and reservoirs enabling scenario testing to address climate change impacts, urbanization, and sediment transport. As a globally recognized and validated tool, it ensures reliable outputs for managing the complex hydrodynamics of this rapidly developing region.

5.3.3.10.1 HEC-RAS model setup

A two-dimensional (2D) grid of the HEC-RAS model was crafted for the study area with a Manning number calculated by Table 5.67 equal to 0.035 for the whole grid, focusing on bare lands around the JKIA (NOAA C-CAP, 2016).

Table 5.67: Suggested Manning's and percent of impervious for land cover.

Class	Value	Land cover type	HEC-RAS manual	Suggested	% Impervious
No data	0	N/A	N/A	N/A	N/A
Unclassified	1	N/A	N/A	N/A	N/A
Developed land	2	Developed, high intensity	0.12-0.20	0.150	90
	3	Developed, medium intensity	0.08-016	0.120	65
	4	Developed, low intensity	0.06-0.12	0.080	35
	5	Developed, open space	0.03-0.05	0.035	10
Agriculture land	6	Cultivated crops	0.020-0.05	0.050	0
	7	Pasture/hay	0.025-0.05	0.045	0
Grassland	8	Grassland/herbaceous	0.025-0.05	0.040	0
Forest land	9	Deciduous forest	0.025-0.05	0.100	0
	10	Evergreen forest	0.10-0.20	0.150	0
	11	Mixed forest	0.08-0.20	0.120	0
Scrub land	12	Shrub/Scrub	0.08-0.16	0.080	0
Palustrine forested wetland	13	Palustrine forest wetland	0.045-0.15	0.080	50
	14	Palustrine Scrub/Shrub wetland	0.045-0.15	0.080	50
	15	Palustrine emergent wetland	0.05-0.085	0.060	75
	16	Estuarine forest wetland	0.045-0.15	0.080	50
Estuarine wetlands	17	Estuarine Scrub/Shrub wetland	0.045-0.15	0.080	50
	18	Estuarine emergent wetland	0.05-0.85	0.060	75
Barren land	19	Unconsolidated shore	0.023-0.03	0.030	0
	20	Barren land (rock/Sand/Clay)	0.023-0.03	0.030	0
Water and submerged lands	24	Tundra	0.023-0.03	0.030	0
	25	Perennial ice/sow	0.023-0.03	0.030	50
	21	Open water	0.025-0.05	0.035	100
	22	Palustrine aquatic bed	0.025-0.05	0.035	100
	23	Estuarine aquatic bed	0.025-0.05	0.035	100

One two-dimensional 2D Grid model of HEC-RAS software was created around the area of interest with a 10-m grid resolution and with two boundary conditions, one inflow with the discharges estimated by the HEC-HMS model with from a 100-year event and one outflow downstream of the grid to permit the water flow out of the grid. Figure 5.109 shows the 2D Grid HEC-RAS model of the watershed.

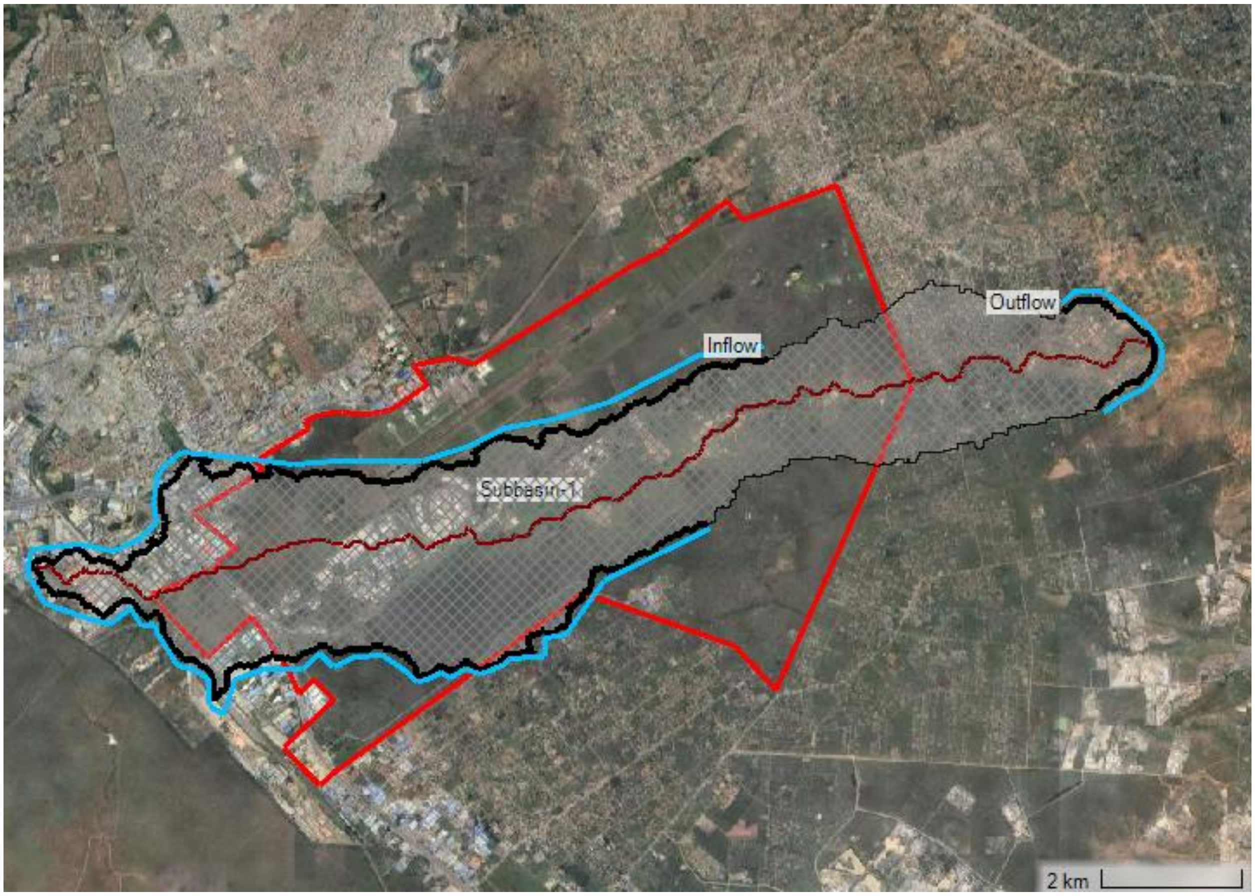


Figure 5.109: HEC-RAS model with a 10-m Grid.

Table 12 shows the HEC-RAS 2D break lines characteristics.

Table 5.68: HEC-RAS 2 D break line characteristics.

Break line	Near spacing	Near repeat	Far spacing
1	10	1	0

5.3.3.11 Results

Depth of water map, was simulated using, for 100-years Storm scenario, the model was run for 24 hours and 1.0-second time step. Figure 5.110 shows the maximum depth of water (m) map of the Study area.

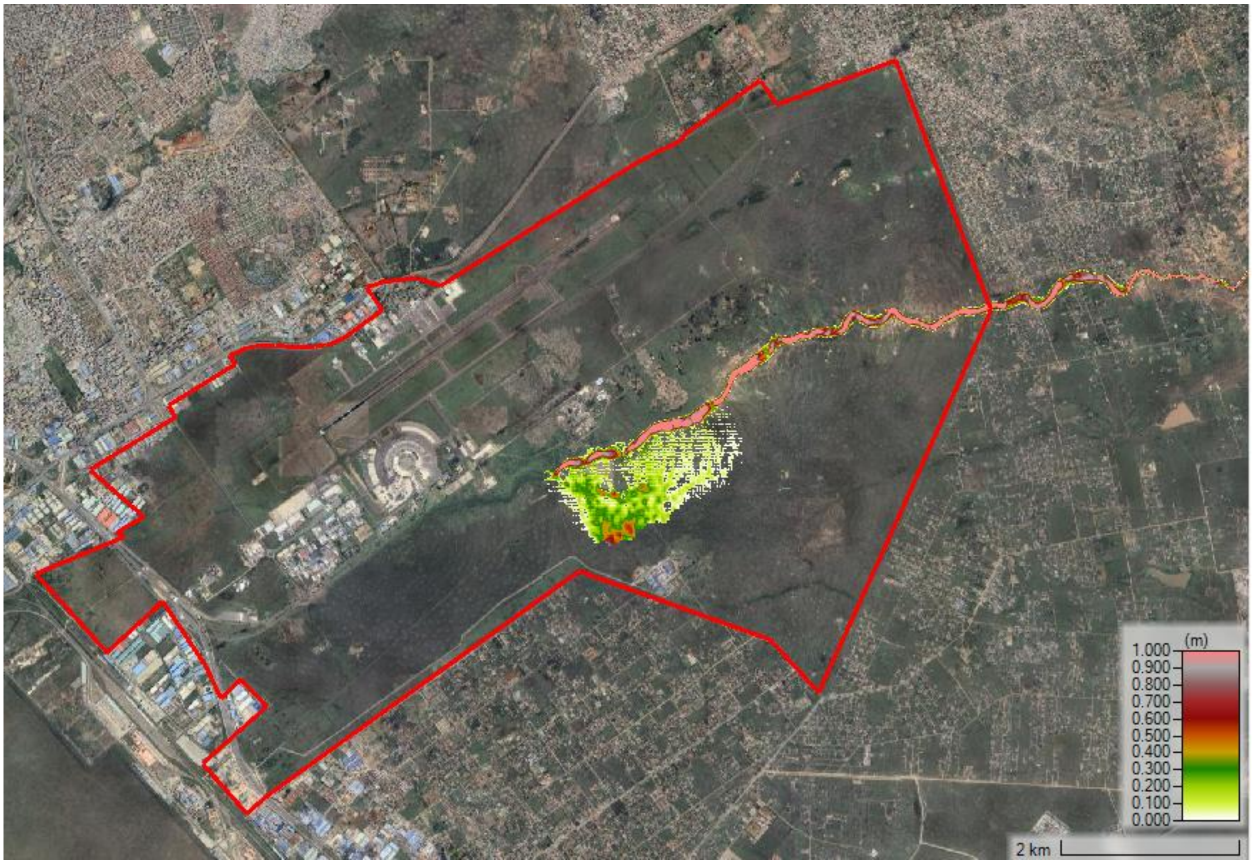


Figure 5.110: Water depth map of the Study area.

Figure 5.111 shows the maximum velocity of water (m/s) map of the Study area.

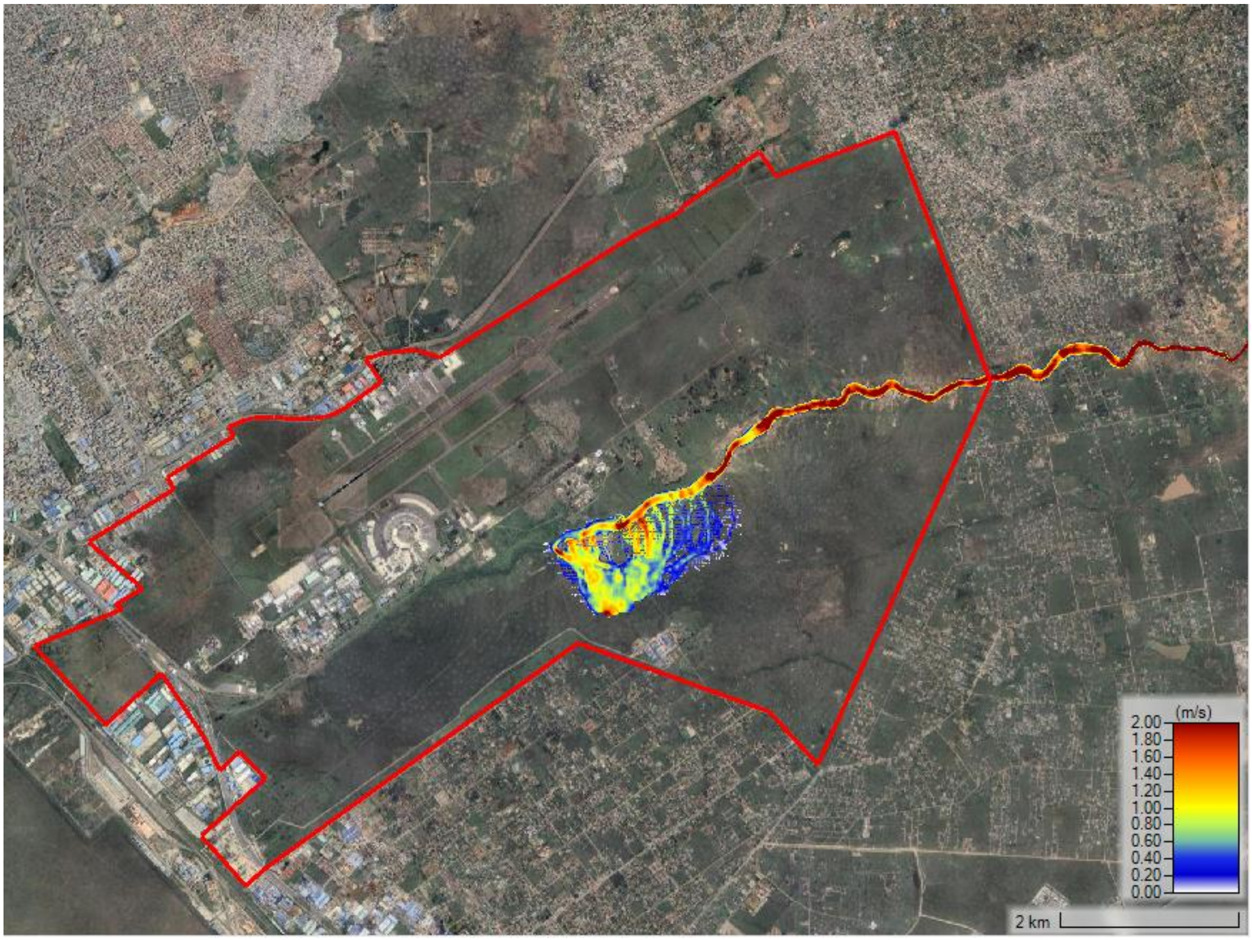


Figure 5.111: Velocity of water of the Study area.

Figure 5.112 shows the maximum Flood Hazard Rating map of the Study area.

Figure 5.112: Flood Hazard Rating map of the Study area.

The Flood Hazard Rating shows that outside the study area flood hazard rating is bigger than 1.0, east of the JKIA, that means small danger.

A Profile line was drawn around the JKI Airport perimeter to assess the risk of flood hazard in the building with the 100-year event simulated. Figure 5.113 shows a cross section around where the JKIA is located with a Google map as background.

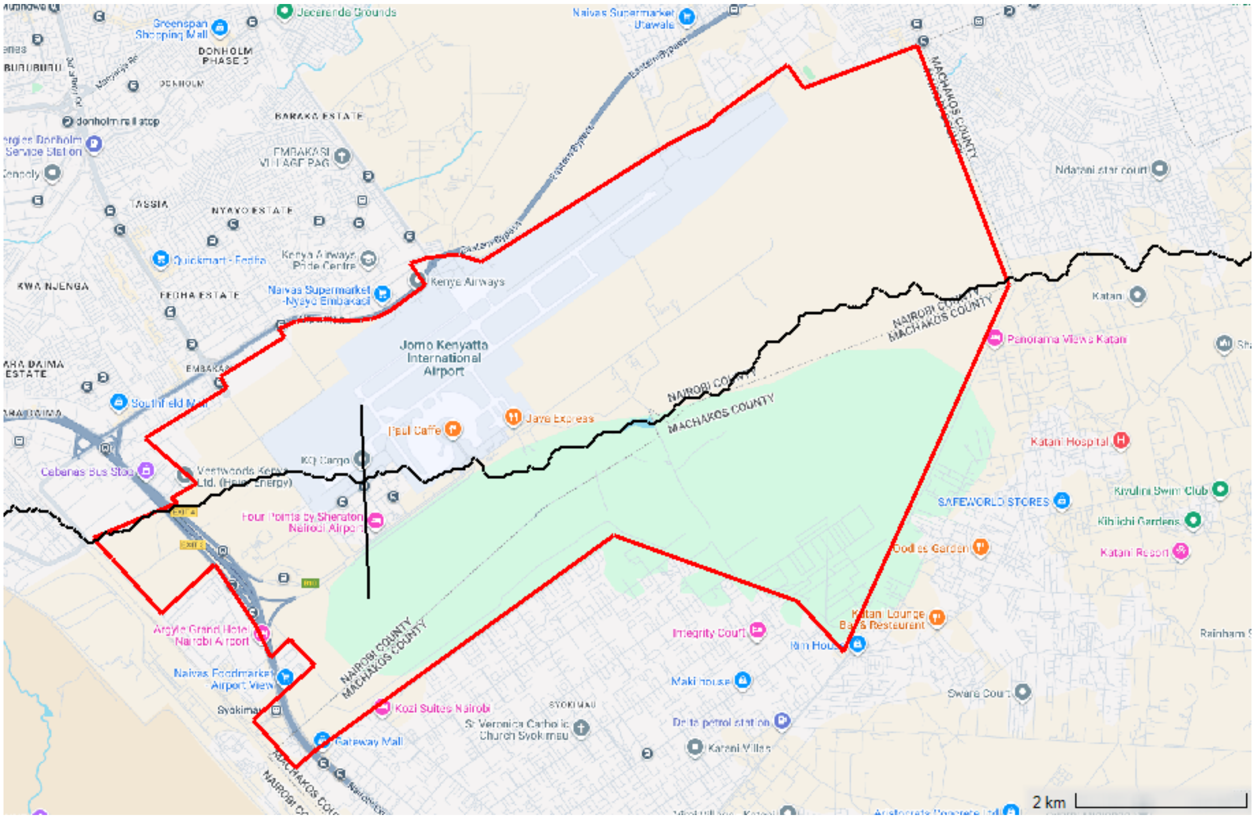


Figure 5.113: Cross sections inside the watershed.

Figure 5.114 shows the maximum water surface elevation simulated for a 100-year event.

Figure 5.114: Maximum water surface elevation simulated.

Figure 27 shows the maximum water surface elevation along the Profile line in the main stream.

5.3.3.12 Conclusions

Based on the above points, the existing stream must be diverted to prevent encroachment onto the new runway. The diversion should be designed and implemented to ensure that the 100-year flood event does not extend into or affect the runway graded strip.

5.3.4 POTABLE WATER, SEWAGE, AND FIREFIGTHING

The water and sewage demands were calculated based on the planning parameters provided for the airport, including both expansion phases (Phase 1 and Phase 2). The demand estimates were derived using water consumption rates for various occupancy types, with an assumed conversion rate of 85% from water consumption to sewage generation.

Water Consumption Rate

Occupancy	Water Consumption rate (l/Cap/day)
Employee	60
Visitor	20
meal (l/meal/day)	5

In The table below presents the total average water and sewage demands for Phase 1 and Phase 2, respectively.

Demand Calculations

Phase 1		Phase 2	
Water Demand (m3/day)	**Sewage Average Flow (m3/day)**	**Water Demand (m3/day)**	**Sewage Average Flow (m3/day)**
2,420	2,263	3,352	3,134

The table below presents the capacities of the water storage tank, fire water tank, and sewage treatment plants. The water storage tank has been designed to provide a minimum of two days of storage capacity, ensuring a reliable and uninterrupted water supply to meet operational and emergency requirements.

Phase 1			Phase 2		
Water Tank (m3)	Fire Tank (m3)	Sewage Waste Water Treatment Plant (m3/day)	Water Tank (m3)	Fire Tank (m3)	Waste Water Treatment Plant (m3/day)
5500	1500	2500	7500	1500	3500

Dedicated water, sewage, and firefighting pump stations are required to serve the newly proposed JKIA airport facilities. Each station is sized to accommodate projected flows and pressures, with capacities increasing in later phases to match the expansion of facilities and associated infrastructure.

The following are the pump stations characteristics of each phase:

	Phase 1		Phase 2	
Pump Station	**Flow (L/s)**	**Head (m)**	**Flow (L/s)**	**Head (m)**
Water Pump Station	60	65	80	65
Fire Pump Station	220	145	220	145
Sewage Pump Station	80	25	110	25

5.3.5 DEVELOPMENT COOLING

High level thermal demand calculations for the development buildings have been estimated based on the provided planning parameters, including building typologies and built-up area. The total cooling demands for Phase 1 and Phase 2 are summarized below.

	Pal - 1			Pal - 2		
List of Facilities	**Plot - Pal1 -20 MAP**	**BUA - Pal1 - 20 MAP**	**Cooling Load (TR) - Pal1**	**Plot - Pal2 - 25 MAP**	**BUA - Pal2 - 25 MAP**	**Cooling Load (TR) - Pal2**
Passenger Terminal Building	-	170,000	**4,900**	-	235,000	**6,750**
Air Traffic Control Tower (ATC)	2,000	-		2,000	-	
Airport Maintenance Complex	15,225	6,090	**175**	18,750	7,500	**225**
Cargo Terminal Building						
GSE Maintenance Facility	12,347	3,087	**100**	14,467	3,617	**120**
GSE Storage	20,274	-		24,002	-	
Catering Facility	59,532	47,625	**1,600**	83,501	66,801	**2,250**
Aircraft Cleaning Facilities	7,952	994	**30**	8,619	1,078	**35**
Aircraft Maintenance & Repair (MRO)	14,862	14,429	**450**	23,802	23,109	**680**
Airside Bus Facilities	1,170	398	**10**	1,446	492	**20**
Administrative and Operational Offices	20,220	10,110	**290**	24,395	12,197	**350**
ARFF	2,000	-		2,000	-	
Data Centre 1	6,000	1,200	**350**	6,000	1,200	**350**
Data Centre 2	6,000	1,200	**350**	6,000	1,200	**350**
TOTAL			**8,255**			**11,130**

**the above values are high level estimates of indicative nature.*

Based on the above, due to general low thermal load of most buildings and the general dispersion of the otherwise high load buildings, a decentralized cooling approach is to be adopted for the masterplan, and each building will have its own local building-specific cooling system.

5.3.6 FUEL DEPOT

5.3.6.1 General

The existing jet fuel infrastructure at Jomo Kenyatta International Airport (JKIA) comprises a fully operational depot that supplies the airport's hydrant fueling network.

This facility plays a vital role in ensuring the continuous and reliable distribution of aviation fuel across the airport.

The depot encompasses several key components, including an unloading facility where fuel tankers discharge jet fuel into the system. The fuel received is subsequently transferred to the main storage tanks for containment and quality control. From the storage area, the hydrant pumping station—fitted with jet fuel pumps, water/fuel separators, and all necessary auxiliary systems—delivers fuel to the existing hydrant distribution network serving the airport.

Operational oversight and control of the entire fueling system are centralized within a dedicated control room, which enables continuous monitoring and management of depot and hydrant operations.

In addition to the fueling infrastructure, the depot is equipped with a comprehensive firefighting system comprising a water storage tank, fire pumps, and a dedicated foam generation and distribution system, ensuring rapid and effective response in case of emergencies.

5.3.6.2 Storage Tanks

Fuel storage requirements were determined based on airport traffic data and the types of aircraft operating at Jomo Kenyatta International Airport (JKIA). The assessment confirmed that the existing jet fuel depot currently provides a total storage capacity of approximately 52,000 tons. Jet fuel is stored in purpose-built tanks comprising three large tanks of 12,000 m^3 each and two smaller tanks of 8,000 m^3 each

According to updated demand projections, the existing jet fuel farm requires expansion to achieve a total capacity of 74,000 m^3. To meet this requirement, two additional storage tanks, each with a capacity of 12,000 m^3, shall be added. The first tank shall be available before the year 2033, while the second shall be made available before the year 2045. The storage infrastructure has been developed in phases in line with the progressive increase in jet fuel demand.

New tanks shall be internally epoxy-lined and equipped with twin floating suction units and open vents fitted with flame arrestors. Water drain-off connections to fuel recovery systems and product sampling points are already integrated. The tanks shall be enclosed within a bund to contain any fuel spillage.

Access provisions, including stairways, platforms, and walkways made of galvanized or coated steel, have been installed to facilitate safe operation and inspection of valves, dip points, and hatches. Tank heights shall be approved by the airport authority in consideration of radar coverage limitations, OLS, and other Navigational Aids systems.

5.3.6.3 Hydrant Pumps

The total jet fuel flow was calculated based on the airport's peak hourly demand. The existing hydrant network is supplied through a hydrant pumping station located within the depot. The current configuration comprises eight electrically driven pumps and two diesel-driven standby pumps, each rated at 280 m^3/hr. Thus, the total available pumping capacity is 2,240 m3/hr

The current capacity is found to be suitable up to the year 2041, after which two additional pumps of same capacity shall be installed, to achieve a total pumping capacity of 2800 m^3/hr.

Under the new configuration, two additional electrically driven pumps with a capacity of 280 each will be installed, while the remaining existing units will be modified to operate as duty and standby.

The hydrant network shall be fed through the hydrant pumping station at the depot, which is equipped with duty and standby jockey pumps for very low-flow operations and system pressurization. Pump operation is based on continuous pressure and flow monitoring and is automatically controlled through the hydrant control system located in the depot's main control room.

5.3.6.4 Discharge Filtration/Water Separation

Filter/water separators are already installed at the discharge of each hydrant pump.

Additional filters for the new pumps shall be provided.

Separators shall be sized to accommodate a maximum flow rate equivalent to 110% of the hydrant pump duty, ensuring efficient separation performance and system reliability.

5.3.6.5 Fire Protection Facilities

It is assumed the existing storage and refueling system, along with all associated equipment and buildings, has been designed to minimize fire risk in full compliance with the Institute of Petroleum Model Code of Safe Practice, Part 19 — *Fire Precautions at Petroleum Refineries and Bulk Storage Installations*, and relevant National Fire Protection Association (NFPA) codes.

The capacity of the existing firefighting system shall be validated during the design to ensure that enough water storage, water flow, and foam discharge are available to extinguish and fire event and cool the tanks as deemed necessary in compliance with NFPA and IP requirements.

The new tanks shall be equipped with water deluge system for tank cooling and foam pourers for extinguishing the tanks on fire. The dikes shall also be equipped with foam pourers. The existing system shall be sufficient to cater for the additional tanks, considering that one fire event will occur, however the existing system shall be revised based on the proposed design during the design stages, noting that the tanks configuration will have an impact on the cooling water requirements.

5.3.6.6 Fuel Drain and Recovery Facilities

It is assumed that all principal equipment drains are collected through a closed drain fuel recovery system. Product drainage is directed by gravity to a collection tank, where separation and fuel recovery are carried out. Residual slops are disposed of via drums or road tankers in accordance with established procedures.

New pumps, filters, and sampling vessels shall be connected to the existing product recovery and drain systems

5.3.6.7 Oily Water Treatment Facilities

It with monitoring devices that automatically prevent discharge in the event of contamination detection is assumed that the existing oily water drainage system comprises an API-type oil/water interceptor located at the lowest point of the site. At this interceptor, fuel-contaminated water is separated to ensure that only treated water is discharged into the surface water drainage system.

The new Dike area shall be connected to the existing drainage system.

5.3.7 AIRCRAFT FUEL HYDRANT NETWORK

5.3.7.1 Depot Supply

Jet fuel is supplied to the fuel depots where it is stored and pumped into the fuel hydrant networks. The fuel depot is supplied from different sources via trucks.

5.3.7.2 Hydrant Distribution Network

The Airport will be provided with a jet fuel hydrant network to feed the aircraft stands serving the new terminal.

The network will be provided with twin feeder lines from the depot, which will facilitate periodic recirculation of the product, and it will help in reducing the pump head at higher flows.

Each of the networks will consists of primary and secondary loops. The primary loop consists of a 24" ring pipe that conveys fuel from the respective depot into the secondary loops which consist of 16" to 12" depending on the number of aircraft stands to be feed. Connection to the hydrant valves at the aircraft stands will be via a 6" riser pipe.

Hydrant lines will be laid to minimum gradients of 1:400 and will be provided with high-point and low-point vents and drains/sampling points for line filling.

5.3.7.3 Valves

Sectional valve chambers will be provided at each junction between primary and secondary networks and at other locations on the primary network as dictated by leak detection sectionalization requirements. In the early development of the hydrant networks, SVCs will be provided at future network connection locations, such that system expansion can be achieved without disruption to ongoing refueling operations. SVCs will be located outside the areas trafficked by aircraft but will be provided with covers suitable for tracking by airside equipment, including tugs.

The SVCs will contain motorized valves for sectionalization and will house pressure and temperature transmitter instrumentation for leak detection. Drain sump instrumentation within the SVCs will be provided to alarm on water ingress or product leakage.

5.3.7.4 Emergency Shutdown System

All aircraft stands will be supplied with emergency shutdown (ESD) buttons. In case of any fuel spillage or any other incident, the ESD button is pushed and the hydrant pumps and the sectional motorized valves feeding the hydrant sub-loop, will shut down.

5.3.7.5 Leak Detection System

A leak detection system, known as tightness monitoring system (TMS), will be provided to monitor any leakage. The TMS is based on the comparative pressure technique, facilitating accurate short cycle leak testing. The hydrant network, including the feeder lines, will be divided into sections of 250m3 to 350m3 contained volumes.

5.3.7.6 Pipework Protection

To prevent cast iron piping from corrosion, buried pipes will be internal and externally coating with appropriate coating in addition to a buried network which is fitted with an impressed current cathodic protection.

All pipes shall have a minim cover of one meter above the pipes that protects it from any physical damage, and a double encasement shall be added where the fuel pipeline crosses the taxiways.

5.3.7.7 Intoplane service Area

Intoplane satellite area will be provided within the apron area. The intoplane area will reduce the refueling vehicles traffic between the aprons and the fuel depot, especially that the depots are located at a considerable distance from the aprons.

In general the intoplane facility will be designed to cater for a loading and unloading facilities, storage for refuller loading and defuelling, parking areas for refuellers and dispensers and will be provided with an administration building with and control room To oversee the control and operation of the dispenser vehicles and to link the airport wide information and management system for relay of intoplane control data to the respective fuel depot control room.

Every intoplane service areas shall include a position for fuel return from defulled aircraft by means of a refueller vehicle, pumped to a buried jet fuel storage tank using the refueller vehicle's on board pump. In addition a metered refueller loading facility served via a branch from the jet Fuel Hydrant Network shall be provided to refueling.

A horizontal bulk storage underground tanks shall be installed for defuel operations.

A product drainage and fuel recovery system shall be provided. The system consists of a closed drainage system for collection of products from sampling collection drums. The product shall be stored in a buried collection tank and pumped into a separation tank. Seperated product shall be transferred to the fuel/defuel storage tank via a fuel water separator using a fuel pumping unit. Waste slops shall be pumped to the loading bay area for disposal.

Dispenser vehicles shall be provided for fuelling operations on the aprons. Consideration shall be given to the use of Diesel Truck dispensers, Solar Electric Carts, Static Carts or a combination of these types. Generally dispensers shall be provided with an electrically operated access platform, two platform hoses, a 30m reel hose and a 10m inlet hose. Onboard equipment shall include Filter Water Separator (FWS), Pressure Control Valve (PCV) and metering plus onboard ticketing and data storage equipment.

Refueller vehicles shall be $20m^3$ proprietary truck/trailer units complete with FWS, PCV and metering equipment along with onboard ticketing and data storage facilities. Refueller vehicles shall be utilized for off-stand refueling and defueling operations.

6 IMPLEMENTATION PLAN / PHASING STRATEGY

Jomo Kenyatta International Airport (JKIA) is the principal gateway to Kenya and a critical hub for East African air transport. As air traffic demand continues to rise, a robust, phased development strategy is essential to ensure the airport's infrastructure evolves in line with projected growth, operational efficiency, and international standards. This chapter outlines the phasing strategy for JKIA's airfield and terminal expansion, focusing on the period from 2025 to beyond 2045.

The strategy is structured into three main phases:

- **Phase 1 (2025–2029):** Immediate airfield upgrades, terminal / Landside / Support Facility & utilities capacity enhancement.
- **Phase 2 (2030–2045):** Major airfield expansion, new terminal construction, and supporting infrastructure.
- **Phase 3 (Post-2045):** Long-term land safeguarding for ultimate capacity, including a third runway, additional terminals, and airport city development.

Each phase is designed to address specific capacity triggers, operational bottlenecks, and future-proofing requirements, ensuring JKIA remains competitive and resilient in the face of evolving aviation demands.

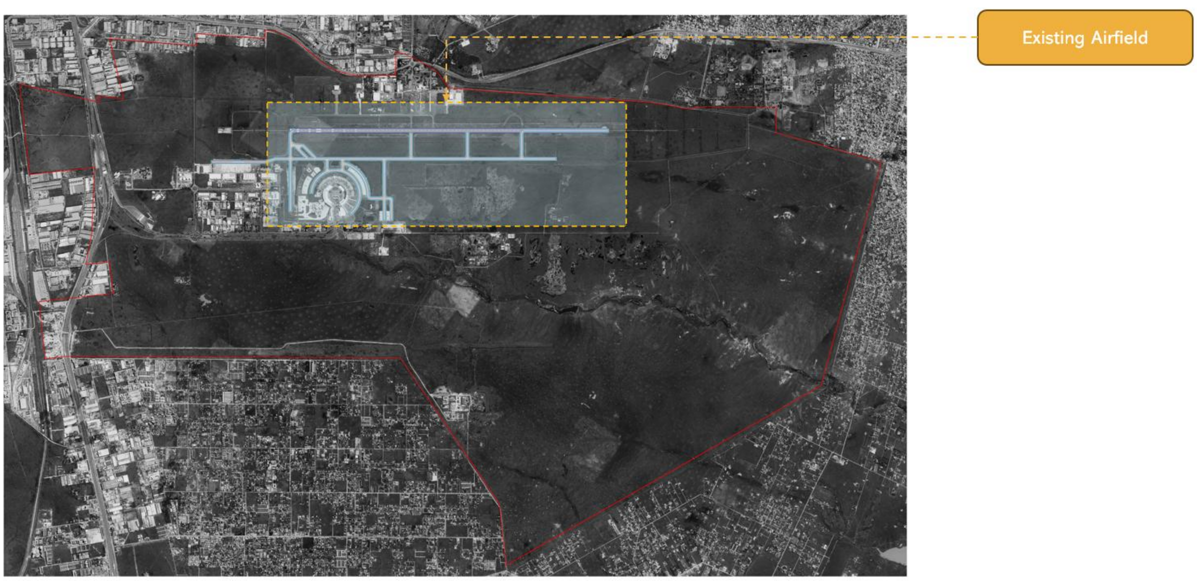


Figure 6.1: JKIA Airfield: Existing Layout

6.1 PHASE 1: IMPROVEMENT WORKS (IMMEDIATE UPGRADES) - (2025 – 2029)

6.1.1 AIRFIELD IMPROVEMENTS

6.1.1.1 Rationale & capacity Assessment

The airfield development strategy for Jomo Kenyatta International Airport (JKIA) is structured into a phased implementation plan that aligns with projected traffic growth and evolving operational requirements. This approach ensures that infrastructure upgrades are both timely and cost-effective, enabling JKIA to maintain its role as a regional aviation hub while responding to increasing demand.

The strategy is underpinned by a comprehensive demand and capacity assessment, which indicates that the existing runway configuration—comprising three 90-degree exits and a partial parallel taxiway—is insufficient to accommodate traffic volumes beyond 2027. Without intervention, JKIA risks operational bottlenecks, increased delays, and reduced service quality. Therefore, immediate upgrades are required to extend the viability of the current airfield system through 2029, after which a second runway becomes essential.

6.1.1.2 Key Airfield Infrastructure Enhancements

Rapid Exit Taxiways (RETs)

Two new Rapid Exit Taxiways will be constructed at distances of 2,000 meters and 2,450 meters from the runway threshold. These RETs are designed at 30-degree angles to facilitate high-speed exits, significantly reducing runway occupancy time from 66 seconds to approximately 60.1 seconds.

- **Operational Benefit**: Increased arrival capacity from 25 to 31 ATMs per hour.
- **Design Rationale:** RETs are positioned to match the deceleration profiles of JKIA’s fleet mix, which includes Code A/B, C, D, and E aircraft.
- **Strategic Impact**: Enhances runway throughput and minimizes delays during peak operations.

Partial Parallel Taxiway

A partial parallel taxiway will be constructed to complement the RETs and support efficient aircraft movement along the runway. This taxiway will:

- Reduce taxiing delays and congestion.
- Improve aircraft flow during simultaneous arrivals and departures.
- Serve as a critical link to the new Passenger Terminal Building (PTB) planned for Phase 2.

The partial parallel taxiway is essential for maintaining operational flexibility and ensuring that aircraft can access runway exits without interference.

Runway End Exit

An additional runway exit will be developed at the end of Runway 06, located approximately 4,160 meters from the threshold. This exit will:

- Improve departure efficiency by allowing aircraft to vacate the runway quickly after takeoff.
- Reduce backtracking and turnaround time.
- Support contingency operations and emergency procedures.

This enhancement is particularly valuable for long-haul aircraft requiring full-length runway utilization.

6.1.1.3 Capacity Impact and Strategic Value

The combined effect of these Phase 1 improvements is a 10% increase in runway capacity, enabling JKIA to handle up to 31 arrivals and 40 departures per hour under Visual Meteorological Conditions (VMC). Mixed-mode operations capacity will rise to 34 ATMs per hour, ensuring that the airport can accommodate forecasted traffic growth through 2029.

These upgrades are modelled using FAA spreadsheet tools and are based on JKIA's existing fleet mix, approach speeds, and runway occupancy times. They represent a cost-effective solution to immediate capacity constraints and provide a foundation for future expansion.

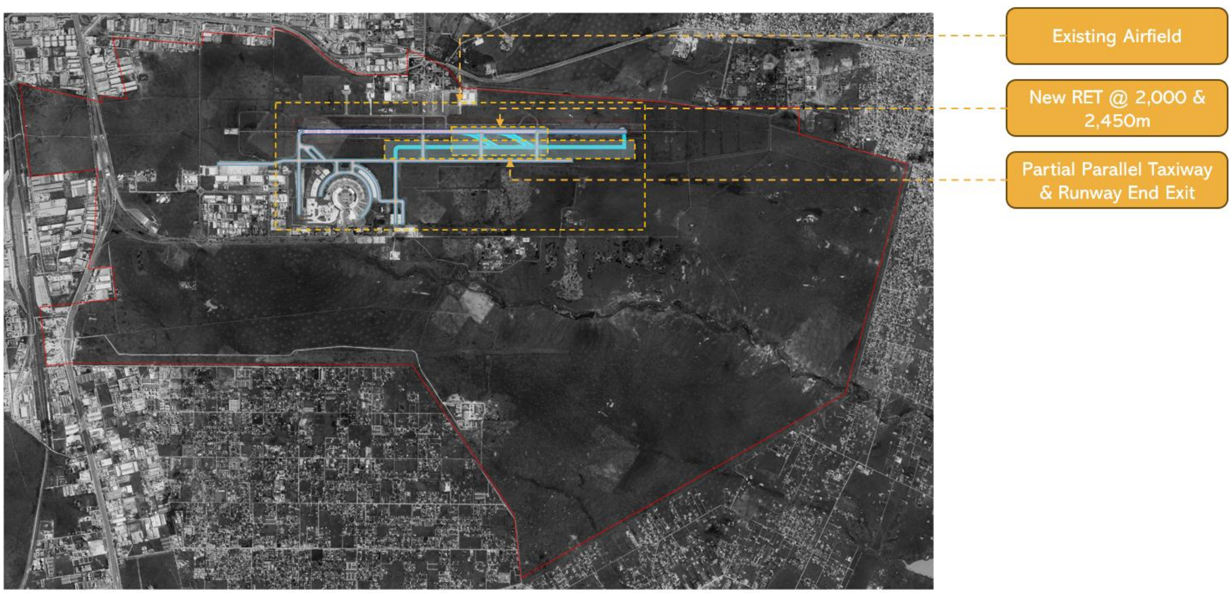


Figure 6.2: JKIA Layout: PHASE 1: IMMEDIATE IMPROVEMENTS

6.1.2 TERMINAL DEVELOPMENT STRATEGY

Phase 1 of Terminal development will be the quick capacity enhancement solutions to cater for growing passenger demand for the next 4 years i.e. 2029 until New Passenger Terminal building will be ready for Operations in 2030.

Airport can perform various tasks to increase the existing operational capacity of 9MAP as below:

- Operational changes like strategic relocation of Airlines,
- Operate with digital processing facilities and
- Expand the current Terminals e.g., utilize space between T1B and T1C

As per global Terminal Planning benchmarks, an Integrated Operational Airport can increase their Terminal capacities by 25-40% through above-mentioned strategies.

Below figure provides an indication of the short-term solution for potential Terminal capacities to cater to the growing passenger demand. T1E would need to be retained and kept operational for this phase.

With the probable 30% increase in the existing Terminals capacity, the Airport might be able to handle the operations by 2029. Beyond this, the Airport would need New Passenger Terminal building.

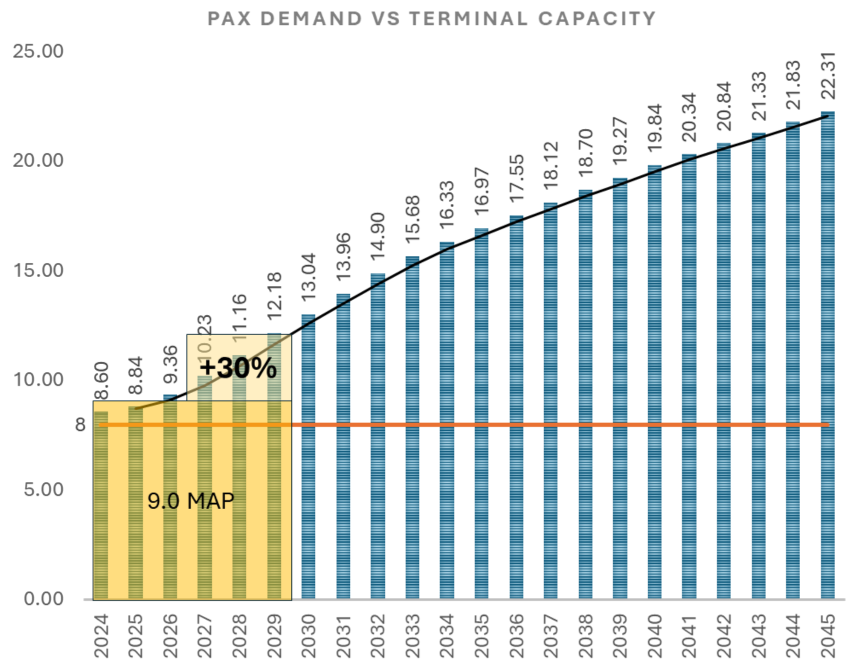


Figure 6.3: JKIA Phase 1 Terminal Capacity

6.2 PHASE 2: NEW/EXPANSION WORKS (2030–2045)

6.2.1 AIRFIELD LAYOUT IMPLEMENTATION STRATEGY PHASE 2

6.2.1.1 Phase 2: Dual Parallel Runway & Taxiway System Projects (2030–2045)

Phase 2 of JKIA's airfield development plan marks a transformative stage in the airport's capacity enhancement strategy. Scheduled for implementation between 2030 and 2045, this phase introduces a dual parallel runway and taxiway system designed to accommodate forecasted growth in air traffic movements (ATMs), improve operational efficiency, and support JKIA's evolution into a high-capacity regional hub.

The Phase 2 projects are informed by traffic forecasts indicating a rise in ATMs from 104,398 in 2024 to over 241,000 by 2045. With Phase 1 upgrades sustaining single-runway operations only until 2029, Phase 2 is essential to meet demand beyond this threshold.

6.2.1.2 Key Infrastructure Components

Second Runway Construction

The centerpiece of Phase 2 is the construction of a second runway, designed to operate in parallel with the existing runway. This new runway will be equipped with:

- **Rapid Exit Taxiways (RETs):** Located at optimal distances (1,775m, 2,325m and 2,850 m), these RETs are engineered to reduce runway occupancy time and enhance throughput. The configuration is based on FAA capacity modeling and tailored to JKIA's fleet mix.

- **Dual Parallel Taxiways:** These taxiways will enable segregated operations, allowing simultaneous arrivals and departures without interference. This layout supports independent runway usage and minimizes taxi delays.

The second runway is expected to significantly increase JKIA's capacity, supporting up to 61 arrivals and 80 departures per hour under independent operations.

Western and Eastern Cross-Taxiways

To improve airfield connectivity and reduce taxi distances, Phase 2 includes the development of cross-taxiways on both the western and eastern sides of the airfield. These taxiways will:

- Facilitate efficient aircraft movement between terminals and runways.
- Reduce congestion and turnaround times.
- Support flexible routing during peak operations or maintenance closures.

The cross-taxiways are strategically positioned to integrate with both existing and new airside infrastructure, ensuring seamless connectivity across the expanded airfield.

Extension of Existing Runway Partial Parallel Taxiway

Building on Phase 1 improvements, the partial parallel taxiway will be extended to support increased aircraft movements. This extension is critical for:

- Enhancing runway access during simultaneous operations.
- Reducing ground delays and improving fuel efficiency.
- Supporting the operational needs of the new Passenger Terminal Building (PTB) and future apron expansions.

The extended taxiway will be designed to accommodate Code C, D, and E aircraft, ensuring compatibility with JKIA's evolving fleet profile.

Second Runway Entry Point for Runway 06L

An additional entry point at Runway 06L will be constructed to enhance operational flexibility. This feature allows:

- Multiple access routes for aircraft, reducing bottlenecks.
- Improved sequencing of arrivals and departures.
- Enhanced safety through better traffic distribution.

This entry point is particularly valuable during peak periods and supports contingency operations in case of disruptions on primary taxi routes.

6.2.1.3 Strategic Implications

The Phase 2 projects are designed not only to meet immediate capacity needs but also to future-proof JKIA's airfield infrastructure. By enabling independent parallel operations, the dual runway system ensures scalability, operational resilience, and alignment with international best practices.

Furthermore, the integration of RETs, cross-taxiways, and extended parallel taxiways supports JKIA's strategic goals of minimizing delays, optimizing aircraft flow, and enhancing passenger experience. These developments also preserve critical landside infrastructure and Airport City development zones, ensuring that airside expansion does not compromise broader master plan objectives.

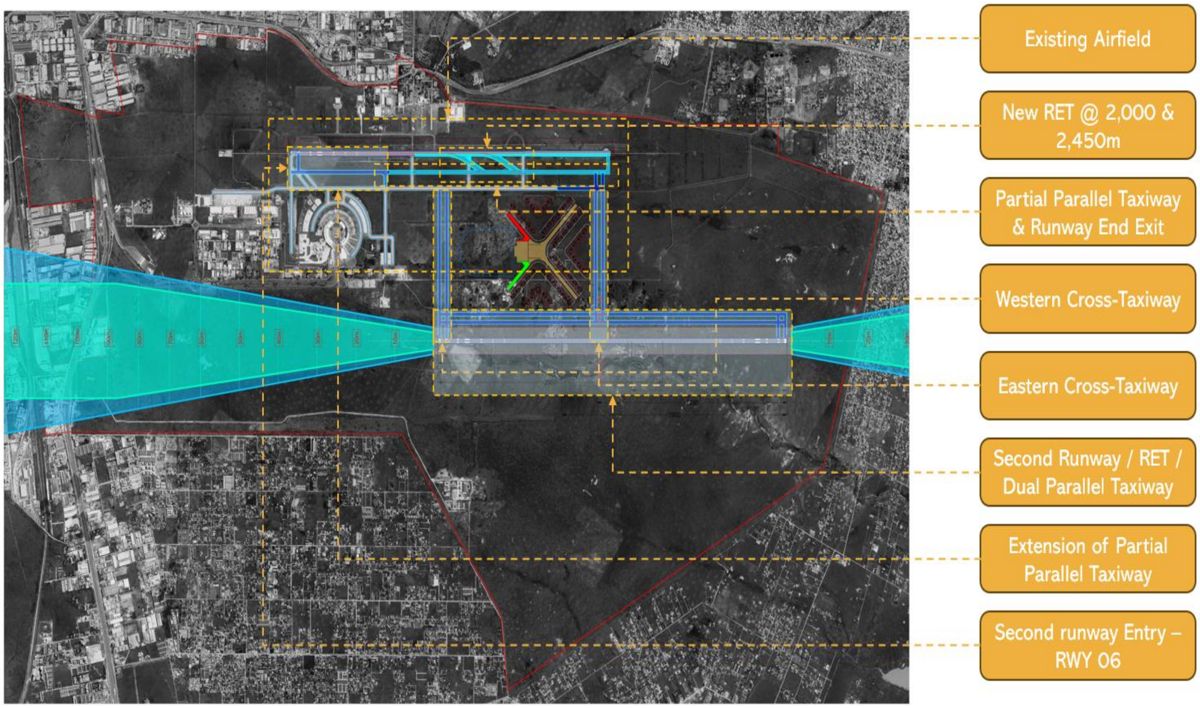


Figure 6.4: PHASE 2: DUAL PARALLEL RUNWAY & TAXIWAY SYSTEM PROJECTS

6.2.2 TERMINAL DEVELOPMENT STRATEGY

Phase 2 of Terminal development will be the Long-term capacity solution to cater for growing passenger demand until 2045. New Passenger Terminal building is proposed to be constructed as midfield facility in 2 phases explained below:

- Phase 2a: New PTB of 10 MAP capacity which will manage the operations conveniently by 2040.
- Phase 2b: PTB expansion of 5 MAP capacity to handle the 2045 traffic demand of 22.3 MAP and provide additional capacity to manage the Airport for some more years beyond 2045.

T1E can be demolished post construction and operationalization of Phase 2a. Existing Terminals might be having around 10 MAP capacity post 2029.

Phase 2 will also provide Aircraft stands adjacent to the New PTB maximizing the Contact gates operations to help Airport operate with better on-time performance and providing enhanced passenger convenience.

Overview of the Phase 2 Terminal capacities in relation to passenger demand is shown in below figures.

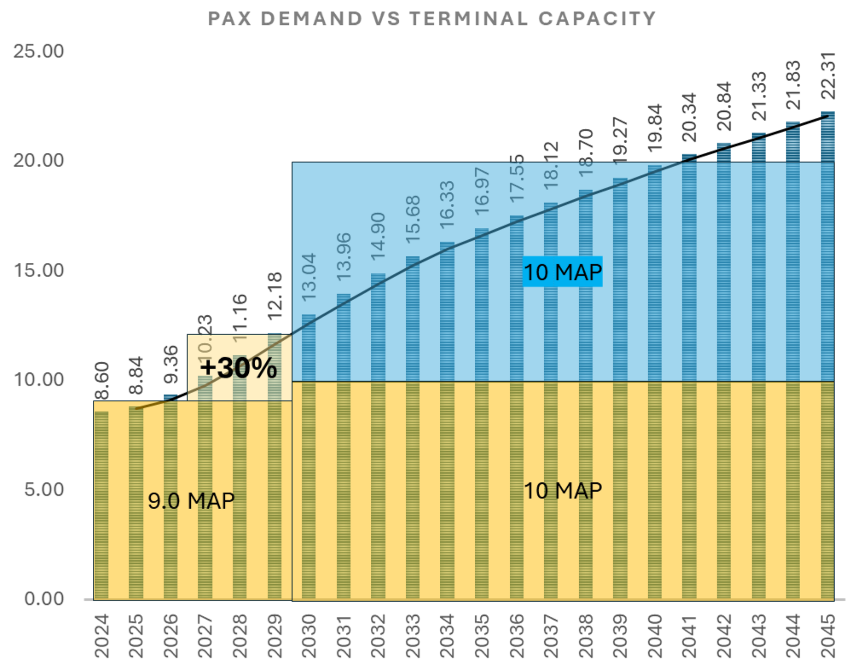


Figure 6.5: JKIA Phase 2a Terminal Capacity

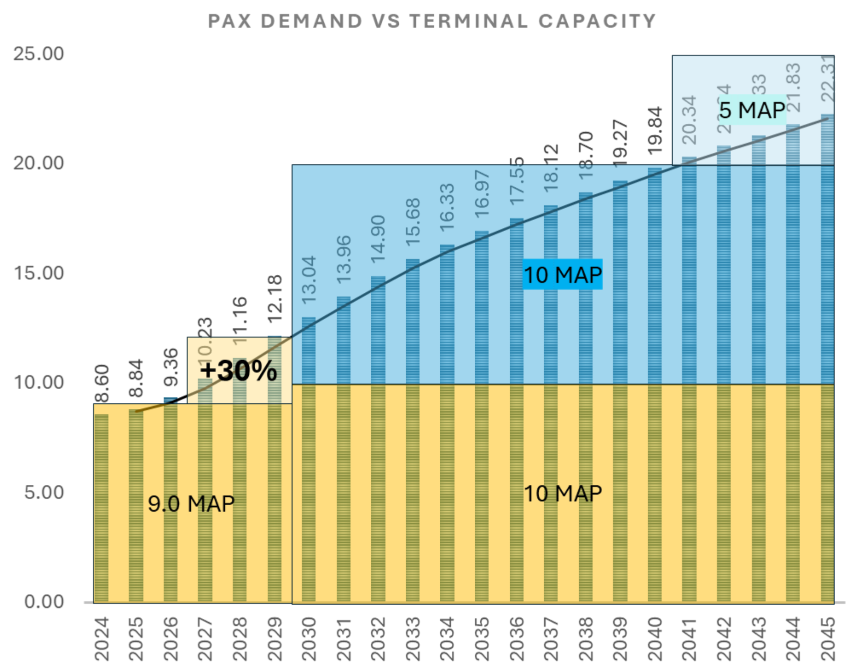


Figure 6.6: JKIA Phase 2b Terminal Capacity

6.3 PHASE 3: ULTIMATE EXPANSION - LONG TERM SAFEGUARDING AND LAND / PROPERTY TAKE

Future planning is essential for ensuring growth capabilities of JKIA. With challenges such as land encroachment already presenting challenges for the airport, a zoning plan has been produced in order to safeguard land, which will cater for the future growth of the airport. It is structured around various land uses, integrating both existing developments and proposed future uses, as shown in Figure 6.7

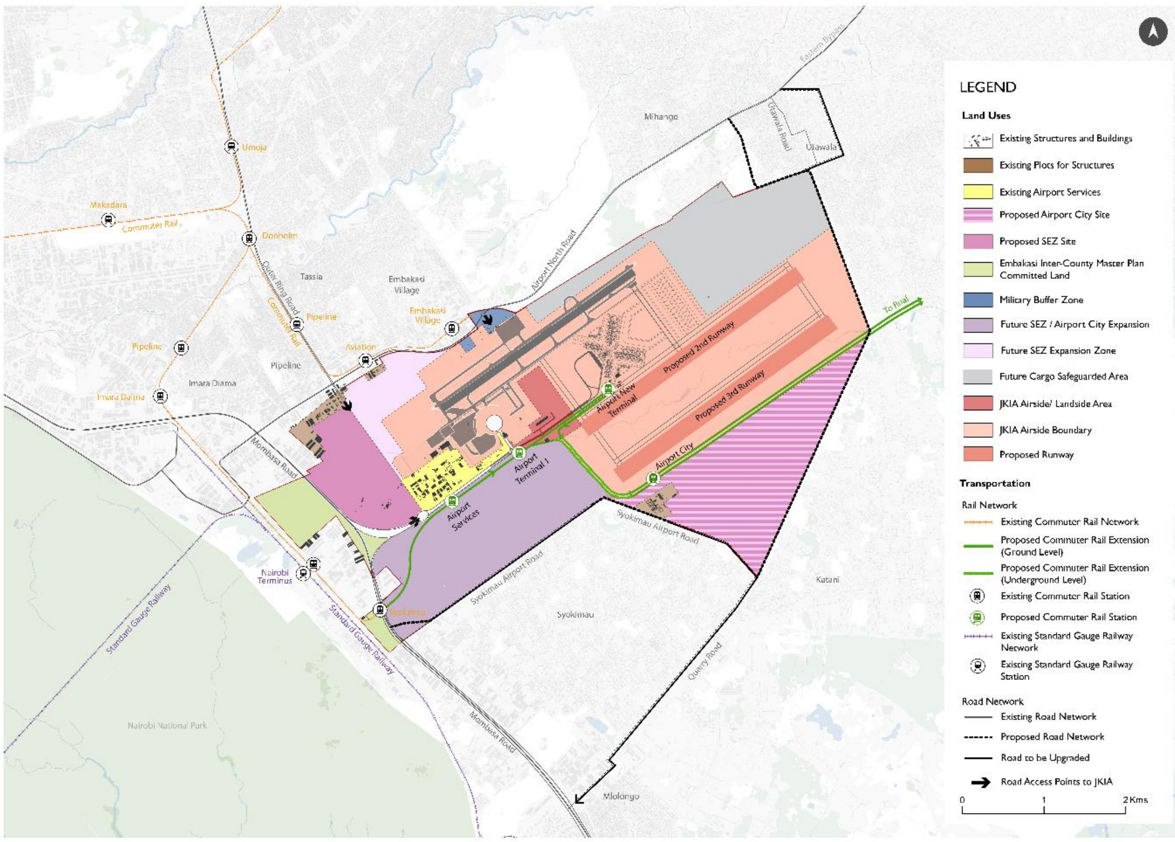


Figure 6.7: JKIA ZONING PLAN

Source: DAR Consultants

The land uses are divided across various land uses which are described below:

6.3.1 AIRSIDE

The airside zone primarily comprises of a secure zone primarily for aircraft and customer cleared operations. It will consist of the existing and proposed runways, terminal buildings, and associated airport service facilities. The airside boundary is extended from its to-date boundary in order to cater for the proposed terminal extension and the planned third runway, which are key components highlighted within this area.

6.3.1.1 Third Runway Reservation

As part of the long-term airfield development strategy for Jomo Kenyatta International Airport (JKIA), the reservation of space for a third runway is a critical planning measure. This provision is not merely a contingency but a proactive response to projected traffic growth, evolving operational requirements, and the airport's ambition to maintain its role as a leading regional hub in East Africa.

Forecasts indicate that annual air traffic movements (ATMs) at JKIA will increase from approximately 104,398 in 2024 to over 241,000 by 2045. While Phase 1 upgrades—including Rapid Exit Taxiways (RETs), partial parallel taxiways, and runway end exits—will extend the viability of the existing single-runway system until 2029, the implementation of a second runway becomes essential thereafter. However, even with dual-runway operations, capacity thresholds will eventually be exceeded, particularly during peak hours and under mixed-mode operations post 2045. This necessitates the strategic reservation of land for a third runway to ensure JKIA's long-term scalability and resilience.

6.3.1.2 Location and Integration

The third runway is planned to be located south of the existing and proposed second runways, with alignment considerations that support independent operations. The reserved corridor is designed to accommodate full-length runway infrastructure, dual parallel taxiways, and associated approach lighting systems. This spatial planning ensures that the third runway can be developed without disrupting existing terminals, airside facilities, or the Airport City development zone.

The alignment of the third runway is intended to mirror the threshold of the second runway, particularly under Option 02 (Staggered Threshold), which simplifies future integration and minimizes geometric complexity. This configuration supports independent arrival and departure operations, which are essential for maximizing throughput and maintaining operational flexibility.

6.3.1.3 Operational Benefits

The strategic reservation of a third runway offers several operational advantages:

- **Capacity Assurance:** Enables JKIA to handle future peak-hour demand beyond 2045, supporting up to 61 arrivals and 80 departures per hour under independent dual-runway operations if the future fleet domination persisted by Code "C" aircrafts. Requirement of 3rd Runway can be mitigated if future fleet domination is shifted from Code "C" flight to wide body aircrafts. With domination of Code "E" aircrafts, Dual runway system can produce demand beyond 25 Million annual Passengers.
- **Redundancy and Resilience:** Provides operational redundancy in case of maintenance, emergencies, or disruptions on the primary runways.
- **Segregated Operations:** Facilitates the segregation of aircraft types, flight profiles, or airline operations, enhancing safety and efficiency.
- **Scalable Infrastructure:** Allows phased development aligned with traffic triggers, avoiding premature capital expenditure while ensuring readiness.

6.3.1.4 Planning Considerations

To safeguard the third runway reservation, the following planning measures are recommended:

- **Land Protection:** The designated corridor must be protected from encroachment, incompatible land uses, and infrastructure developments that could compromise future runway construction.
- **Environmental Buffering:** Noise and height limitations on adjacent eastern land parcels must be addressed through zoning regulations and environmental impact assessments.
- **Infrastructure Coordination:** Approach lighting systems and taxiway connections must be pre-planned to ensure seamless integration with existing and future airfield layouts.
- **Terminal and Landside Compatibility:** The third runway must not interfere with the location of the new Passenger Terminal Building (PTB) or the Airport City master plan. Option 02 supports this compatibility by preserving Zone 2A and avoiding southward terminal relocation.

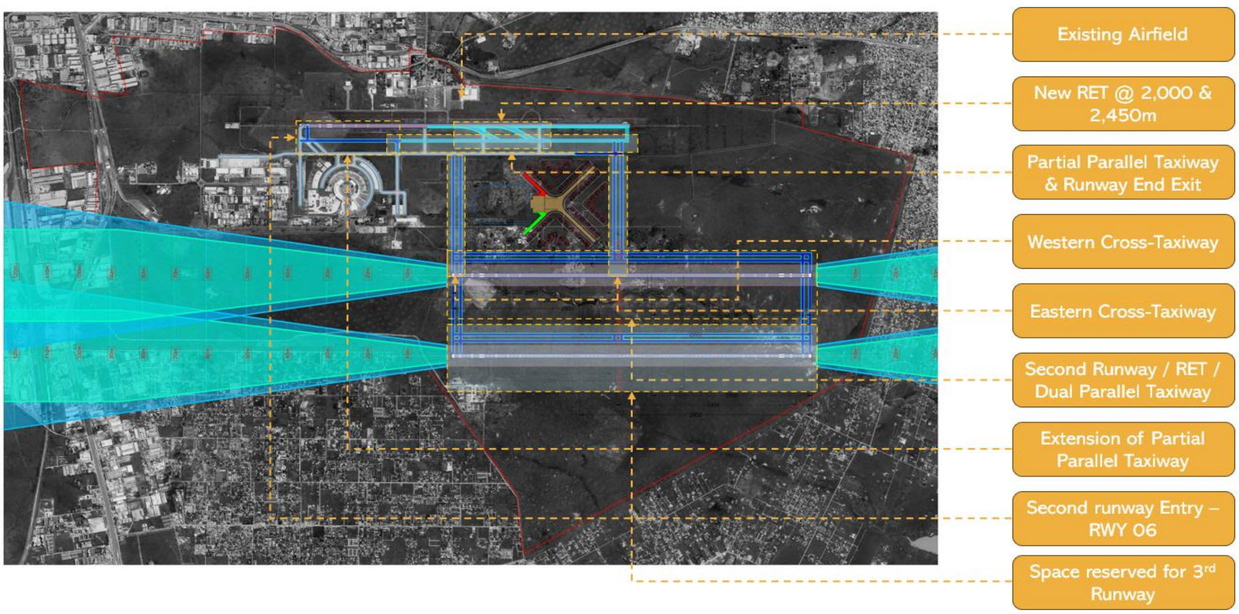


Figure 6.8: THIRD RUNWAY RESERVATION

6.3.1.5 Strategic Implications

The strategic implications of third runway development at Jomo Kenyatta International Airport (JKIA) are multifaceted, encompassing traffic growth forecasts, infrastructure capacity triggers, runway separation impacts, landside integration, and environmental considerations. This section outlines the long-term planning rationale and operational consequences associated with the phased expansion of JKIA's airfield infrastructure.

6.3.1.5.1 Traffic Growth and Capacity Triggers

6.3.1.5.2 Runway Separation Impact

The configuration and separation of the third runway are pivotal to JKIA's long-term capacity and operational flexibility. Three separation scenarios have been evaluated:

- 760 m Separation: Enables segregated parallel operations (one runway for arrivals, the other for departures) and supports marginal improvement for arrivals per hour. However, this configuration offers limited capacity gains.

- 915 m Separation: Supports dependent parallel approaches and independent departures, increasing capacity by 50%.
- 1,525 m Separation: Facilitates fully independent arrival and departure operations, meeting traffic demand beyond 2045.

The strategic recommendation is to adopt the 1,525 m separation for the third runway and his can be further reduced to 1,050m in accordance to ICAO & FAA recommendation if deployment of advanced NAVAIDS equipment is found feasible operationally & financially, ensuring scalability and minimizing disruption to existing and planned infrastructure.

6.3.1.5.3 Landside Integration

Preserving landside infrastructure is essential for JKIA's transformation into a multimodal transport hub. The airport's expansion must align with the development of rail and Bus Rapid Transit (BRT) systems, which are planned at grade level adjacent to the airfield.

Strategic coordination with national transport authorities is recommended to synchronize timelines and optimize integration.

6.3.1.5.4 Environmental Considerations

Runway development introduces environmental challenges, particularly in relation to noise and height restrictions on eastern land parcels. Both the second and third runways, depending on their alignment and separation, may impose operational constraints on adjacent communities and land uses.

To mitigate these impacts, strategic zoning and environmental buffers should be incorporated into the master plan. Detailed Environmental Impact Assessments (EIAs) must be conducted to evaluate noise contours, approach path limitations, and land use compatibility. Mitigation measures may include noise barriers, operational curfews, and land acquisition for buffer zones.

6.3.1.6 Recommendations

Following a comprehensive technical evaluation and structured scoring methodology applied to the horizontal alignment options for JKIA's second and third runway, this report presents a set of strategic recommendations aimed at optimizing operational efficiency, safeguarding future scalability, and ensuring seamless integration with existing and planned infrastructure. These recommendations are grounded in international best practices, ICAO and FAA standards, and the long-term vision for JKIA as a regional aviation hub.

6.3.1.6.1 Adoption of Option 02 – Staggered Threshold Configuration for second and third runway

The staggered threshold layout for the second runway is recommended as the preferred option. This configuration offers significant operational advantages, particularly in terms of reduced taxi times for departing aircraft. With taxi distances of approximately 4.1 km from the farthest Terminal 1 stand and 3.1 km from Terminal 2, this option enhances fuel efficiency, reduces turnaround times, and improves overall airfield throughput. Furthermore, the staggered alignment avoids interference with landside infrastructure such as rail and BRT systems, preserving multimodal connectivity and minimizing construction conflicts. The configuration also supports future expansion by allowing the third runway to be aligned with the second, simplifying airfield geometry and operational planning.

6.3.1.6.2 Preservation of Zone 2A for Airport City Development

Zone 2A has been designated for the development of Airport City, a strategic initiative aimed at fostering economic growth through commercial, hospitality, and logistics activities adjacent to the airport. Option 02 ensures that this zone remains intact, thereby preserving the integrity of the Airport City master plan. Protecting this area from runway encroachment is essential to maintaining JKIA's competitiveness and attractiveness to investors and stakeholders. The preservation of Zone 2A also aligns with national development goals and supports the airport's role as a catalyst for regional economic integration.

6.3.1.6.3 Integration of Rapid Exit Taxiways (RETs) and Parallel Taxiways in Phase 1

To extend the operational viability of the existing runway system and defer the need for immediate capital-intensive expansion, it is recommended that Phase 1 include the construction of two RETs at 2,000 m and 2,450 m from the threshold, along with a partial parallel taxiway and a runway end exit. These enhancements will reduce runway occupancy time, improve aircraft flow, and increase arrival capacity from 25 to 31 ATMs per hour. This incremental approach allows JKIA to accommodate traffic growth through 2029 while maintaining high levels of operational efficiency.

6.3.1.6.4 Strategic Planning for a Third Runway with Aligned Thresholds

Long-term scalability of JKIA's airfield infrastructure necessitates the reservation and planning of a third runway. Aligning the thresholds of the third runway with the second will simplify future development and enable independent parallel operations. This approach avoids the complexities associated with staggered or offset configurations, which can introduce operational inefficiencies and increase land acquisition requirements. Early planning and land reservation for the third runway will ensure that JKIA remains resilient and capable of handling projected traffic volumes beyond 2045.

6.3.1.6.5 Environmental Assessment and Mitigation Measures

Both runway options introduce potential height and noise constraints on eastern land parcels. It is therefore imperative to conduct detailed environmental impact assessments (EIAs) to evaluate the implications of runway development on surrounding communities and ecosystems. Mitigation strategies such as noise barriers, zoning regulations, and operational curfews should be considered to minimize adverse effects. These assessments should be integrated into the planning and design phases to ensure regulatory compliance and community acceptance.

6.3.1.6.6 Coordination with Transport Authorities for Landside Integration

The success of JKIA's expansion depends on seamless integration with landside infrastructure, particularly the planned rail and BRT systems. Option 02 supports this objective by avoiding interference with grade-level transport corridors. Close coordination with national and regional transport authorities is recommended to align construction timelines, ensure interoperability, and optimize passenger and cargo connectivity. This coordination will enhance JKIA's accessibility and support its transformation into a multimodal transport hub.

6.3.2 LANDSIDE

The landside portion of JKIA comprises of several proposed development zones, again to cater for the airport's growth as shown in the figure below.

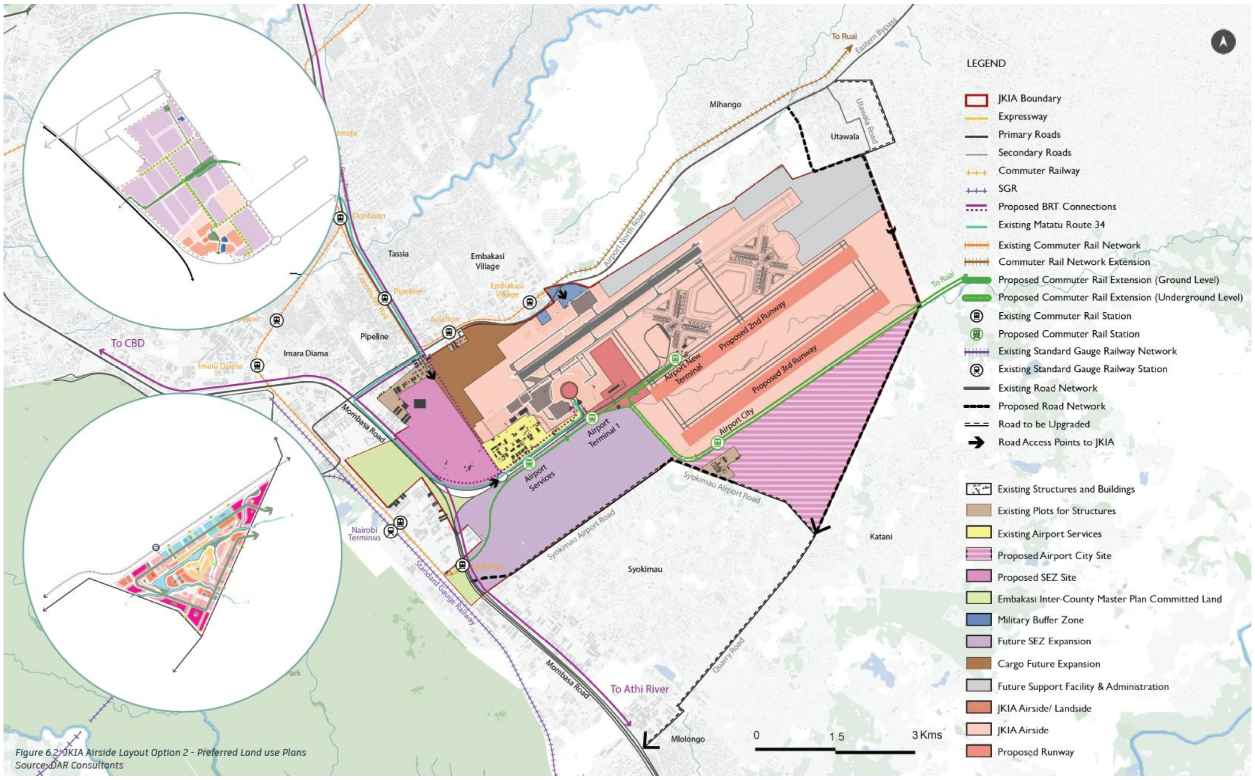


Figure 6.9: JKIA Landside Development Zones

The landside portion is considered to be any land use which is not included in the Airside Boundary. These are detailed as follows:

1. Existing Plots and Structures

Within the JKIA boundary are a number of existing structures, highlighted in brown in the figure above. Several industrial / warehouse style structures and the existing headquarters of various agencies – Kenya Urban Roads Authority (KURA), BaraBara and Kenya Civil Aviation Authority (KCAA) – lie to the far west of the current terminal structure. Another cluster of existing plots and structures are to the South of the proposed 3rd runway. It is understood that many of these plots are leases and structures on these plots should remain until the leases expire.

2. Existing Airport Services

Existing airport services are concentrated to the southwest of the current cargo and passenger terminals. These services are bounded by the Airport Road South and the Airport Road North to Airport Road South link road. The primary use of this are cargo operations. This area and its land uses will be retained.

3. Proposed Airport City

This area is envisioned as a mixed-use development incorporating residential zones, commercial spaces, and green buffers. It also features a direct connection to the new commuter rail extension, which includes a station located at the border of the Airport City, known as the Airport City Station. There are some existing plots and structures which fall within the Proposed Airport City location, as explained previously. These plots should be retained until the lease expires.

4. Proposed Special Economic Zone (SEZ) Site

The SEZ includes an industrial component connected to the Industrial Development Cluster (IDC) on the northern side, incorporating existing infrastructure. The SEZ site has access from Mombassa Road to the southwest and south east, and the existing commuter rail line with nearby stations.

5. Embakasi Inter-County Master Plan – Committed Land

Portions of the land have been set aside in line with the Embakasi Inter-County Master Plan commitments. This master plan previously delineated land uses in the area surrounding JKIA which must be respected. This will be a mix of land uses including residential and commercial. This master plan has been assented by law and adopted into the Inter-County Plan for the SGR and adjoining areas.

6. Military Buffer Zone

Located in the northern section adjacent to Embakasi Village and the commuter railway station, this area serves as a buffer for military use, primarily by the Kenyan Airforce. There is an existing footbridge connection between the military land to the north of the Airport North Road and the Military Buffer Zone. The buffer zone should be maintained to allow for growth and expansion of the Kenya Air Force in the future.

7. Future SEZ / Airport City Expansion Area

This area is designated for the potential expansion of the SEZ, extending in a south-easterly direction from the initially proposed SEZ zone, or for the expansion of the Airport City in a westerly direction. This zone is strategically located to accommodate either SEZ expansion, or Airport City Expansion.

Located to the southeast of the Proposed SEZ site, this multipurpose expansion zone boasts many of the same strategic benefits that the Proposed SEZ site has. Primarily, these include proximity to the Existing Airport Services and the current Airport terminal. This expansion area has the added benefit of adjoining the JKIA Bonded Area, improving integration into operational airport facilities.

Alternatively, the expansion area can also facilitate the growth of the Airport City. Expanding the Airport City into this area would improve the integration of the mixed-use area into the Commuter Rail Extension, with access to up to 3 further proposed commuter rail stations.

It is possible for this expansion area to accommodate both SEZ and Airport City uses if it is deemed necessary by demand and there is sufficient land use remaining. There are no existing plots or structures within this area.

8. Future SEZ Expansion Zone (Southern Landside)

Positioned in the southern portion of the landside, this area will facilitate connectivity between the main SEZ zone and future developments, including the Airport Services Station and Airport Terminal 1 Station.

9. Future Cargo Area (Safeguarded Zone)

Located in the northernmost corner of the site, this area is reserved for future cargo-related activities and connections from Embakasi Village or other SEZ/industrial zones. This land should not be developed on unless to support cargo uses relating to JKIA given current cargo handling and processing capacity is met and there is demand for increased

10. JKIA Bonded Area (Airside/Landside Interface)

This section serves as a transitional bonded area between the airside and landside, potentially accommodating future airport expansion or facility upgrades. This area is centralised between the existing and new terminals, and the existing and proposed runways. This should allow for the efficient movement, storage and processing of cargo and other transit goods through JKIA.

11. JKIA Airside Boundary

The defined boundary delineates the operational airside area, ensuring controlled access and future planning considerations.

12. Proposed Runways

The airport master plan includes two new proposed runways, identified by the airport planning team to meet future demand for JKIA's capacity expansion. These runways run parallel and are located to the south east of the Airport New Terminal. These runways sit within the JKIA Airside Boundary. To the north is the Future Cargo Safeguarded Area, allowing for proximity between cargo operations and the runways. This will create operational efficiency.

Transportation Networks

The transportation framework integrates both existing and proposed connections:

1. Existing Network:

The current Nairobi Commuter Railway (NCR) network connects Syokimau Station northwards along Mombasa Road, serving key transport nodes.

2. Proposed Commuter Rail Extension:

The proposed extension runs from Syokimau Station through Airport Terminal 1, terminating at the new Airport New Terminal Station. The route includes both ground-level and underground segments, linking the existing and proposed terminals and extending to the Airport City Station before proceeding towards Ruai. An additional proposed line connects the Airport New Terminal directly to Airport City Station and further to Ruai.

3. Proposed Road Connectivity:

A new road corridor is proposed from Mombasa Road, traversing the future SEZ and Airport City Expansion areas, passing through Airport City, and continuing north towards Utawala. This new link aims to enhance accessibility to and from the airport and its surrounding developments.

7 AIRPORT CITY

7.1 LAND USE PLAN

This section outlines the existing and proposed land use within Jomo Kenyatta International Airport (JKIA). It defines the spatial organization of key functional zones, mainly airside and landside, and evaluates how land use planning supports the airport's long-term operational, commercial, and environmental objectives.

7.1.1 EXISTING LAND USE

The current land use within the airport boundary can be categorized as follows:

- Airside Operations: Runways, taxiways, aprons.
- Passenger Terminal Area: Main passenger terminals, parking areas, and access roads.
- Cargo and Logistics Zone: Cargo terminals, freight forwarders, and warehousing facilities.
- Maintenance and Support Services: Aircraft maintenance hangars, fuel farms, fire stations, and administrative buildings.
- Open and Undeveloped Areas: Reserved land intended for future expansion, green buffers, and restricted safety zones.

7.1.2 PROPOSED LAND USE PLAN

The proposed land use concept for JKIA divides the airport into the following main functional zones:

- Airfield Expansion Zone: Allocation for future runway(s), taxiways, and apron development to accommodate forecast traffic growth.
- Passenger Terminal Building: a new Terminal Building with landside access and parking facilities.
- Airport City and Special Economic Zone (SEZ): A dedicated Airport City and SEZ cluster to the southeast and west of the airport.
- Support and Utility Zones: Areas allocated for maintenance, fuel storage, and utility infrastructure, positioned to ensure operational efficiency and safety.

7.2 SMART CITY AND TECHNOLOGY

BACKGROUND

Jomo Kenyatta International Airport (JKIA) is Kenya's primary international gateway and a vital hub in East and Central Africa. Located in Nairobi, JKIA serves as the main connection point for global and regional air traffic. In 2023, it handled over 8.2 million passengers and 372,200 tonnes of cargo, reinforcing its role in facilitating regional trade and logistics.

Strategically, JKIA is a major economic driver, with Kenya's aviation sector contributing over KES 521 billion to GDP, about 5% of the national total. With passenger volumes projected to reach 20 million by 2035, the airport's market value and strategic importance are expected to rise significantly, positioning it as a central pillar of Kenya's long-term economic vision.

On the sustainability front, JKIA has achieved Level 1 (Mapping), Level 2 (Reduction), and most recently Level 3 (Optimization) accreditation under the Airport Carbon Accreditation (ACA) programme. These milestones reflect progressive steps, from identifying carbon sources, implementing reduction initiatives, to engaging airport stakeholders to collaboratively manage and optimize carbon emissions, all aligning with its carbon neutrality goal by 2030 and net-zero target by 2050.

7.2.1 SMART AIRPORT FRAMEWORK ROADMAP

7.2.1.1 SMART Airport Definition

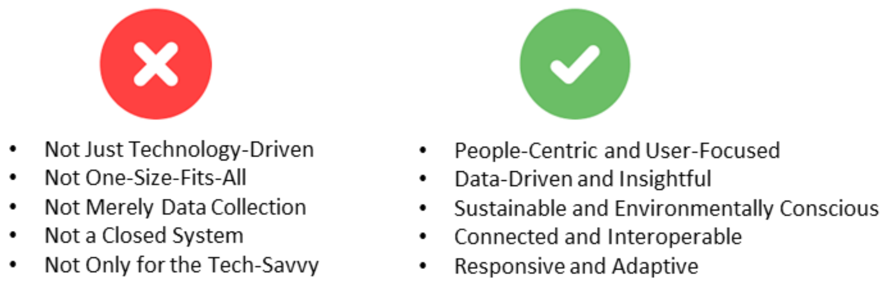


Figure 7.1: SMART Airport Definition

We believe a truly SMART airport leverages technology with a purpose focusing on people, using data to drive informed decisions, enhancing sustainability and creating connected, adaptive systems. It's not just about implementing technology for the sake of it but about integrating intelligent solutions that improve efficiency, safety and overall experience while ensuring long-term environmental and operational benefits.

7.2.1.2 SMART Airport Benefits

Implementing a smart airport creates attractive investment opportunities by fostering innovation, improving infrastructure and enhancing commercial potential. It drives operational efficiency through automation and real-time monitoring, reducing costs and optimizing resource use. Data-driven decision-making ensures improved services and proactive problem-solving. By integrating sustainable solutions, a smart airport enhances traveller experience, improves safety and promotes cleaner environments. Additionally, futureproofing through adaptable and scalable technology ensures long-term resilience, making airports more connected, efficient and prepared for evolving challenges.

Figure 7.2: Benefits of Smart Solutions and Technologies

7.2.1.3 Smart Airport Roadmap

Defining the SMART Roadmap for JKIA is critical to ensure the project's success in becoming Africa's premier gateway to the world. A roadmap provides a clear, structured framework for implementing SMART solutions, aligning them with the city's vision, goals and objectives. It ensures that the project progresses systematically, from strategic planning to detailed design, minimizing risks of misalignment or inefficiencies.

A well-defined roadmap establishes a foundation for integrating advanced technologies such as IoT systems, renewable energy and data driven governance. By doing so, it facilitates scalability and future adaptability, ensuring the airport and city can evolve with technological advancements and growing urban demands.

The roadmap also helps in aligning stakeholder expectations, fostering collaboration and ensuring that the needs of residents, passengers and investors are addressed. It allows for benchmarking against global best practices and helps mitigate potential challenges by identifying and planning for risks early in the process. Ultimately, the SMART Roadmap for JKIA airport is essential for creating a cohesive, integrated and future ready facility that meets its environmental, economic and social objectives while enhancing the quality of life for its users and passengers.

As the next step we would recommend carrying out the following tasks within the roadmap to ensure we are fully aligned with the client's objectives and vision for JKIA while weaving in Smart solutions and technologies:

1) Smart Vision – Align on the Smart Vision based on the project's overall goals and objectives.
2) Smart Intelligence – Identify and recommend the key themes, Smart use cases and supporting technologies for the project for consideration moving forward throughout the project.
3) Smart Infrastructure – Based on the selected use cases begin detailing the implementation of these use cases and design the data strategy for the project.
4) Smart Documentation – Where relevant start to produce drawings and specification documentation. We will also support by providing the necessary details for MSI (Master Systems Integrator) or specialist contractors for implementation.

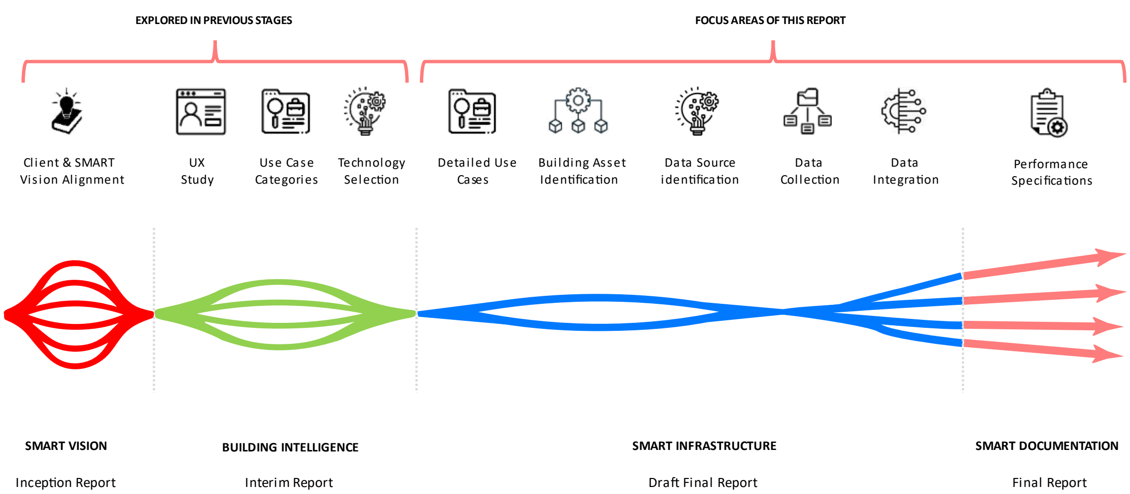


Figure 7.3: JKIA Smart Design Roadmap

7.2.2 SMART VISION ALIGNMENT

7.2.2.1 Kenya Vision 2030

Understanding Kenya's National Vision is crucial before addressing the client's goals for JKIA, as it provides the national strategic framework within which the project must align.

Kenya Vision 2030, now being implemented through its Fourth Medium-Term Plan (2023–2027), is the country's long-term development blueprint aimed at transforming Kenya into a newly industrializing, middle-income economy by the year 2030. The current plan advances the Bottom-Up Economic Transformation Agenda (BETA), emphasizing inclusive growth, sustainable infrastructure, green transition, digital transformation, and enhanced regional connectivity.

Vision 2030 envisions a nation anchored on inclusive growth, citizen empowerment, and sustainable development, serving as a unifying framework to guide sectoral strategies, infrastructure development, and public–private investment. It provides critical context for national infrastructure projects such as airports, ensuring alignment with Kenya's broader socioeconomic goals and its positioning in regional and global markets. The Vision is built on three interconnected pillars: Economic, Social, and Political.

Figure 7.4: Kenya Vision 2030

7.2.2.1.1 Economic and Macro Pillar

The Economic Pillar seeks to achieve sustained GDP growth of 10% per annum and position Kenya as a regional hub for trade, logistics, and investment. Key sectors driving this growth include tourism, agriculture, manufacturing, transport, and financial services, all supported by robust infrastructure and innovation ecosystems.

Under the Fourth Medium-Term Plan, emphasis is placed on improving transport and logistics networks, expanding industrial capacity, and accelerating green infrastructure to support the Bottom-Up Economic Transformation Agenda. Within this context, the Kenya Airports Authority (KAA) plays a pivotal role. Its mandate to modernize and expand airport infrastructure directly contributes to national economic growth by improving regional and international connectivity, facilitating trade, and enhancing tourism competitiveness. Efficient, world-class airports such as JKIA are key enablers of Kenya's ambition to become Africa's premier business and logistics gateway.

7.2.2.1.2 Social Pillar

The Social Pillar aims to build a just, equitable, and cohesive society that enjoys shared prosperity within a clean and secure environment. It prioritizes human capital development, access to quality services, and improved urban living conditions. Infrastructure projects, including airports, are central to this agenda, enabling accessibility, inclusivity, and social mobility while creating new opportunities for employment and community engagement.

Through this lens, JKIA's modernization contributes to broader social goals by enhancing the passenger experience, improving accessibility for all users, and fostering a more inclusive, connected, and service-oriented environment that supports national wellbeing.

7.2.2.1.3 Political Pillar

The Political Pillar focuses on strengthening democratic governance, transparency, and citizen participation as foundations for sustainable development. For major infrastructure projects, this means upholding accountability, environmental governance, and inclusive stakeholder engagement throughout the planning and implementation process.

In alignment with this pillar, KAA's smart airport initiatives embody good governance and international compliance, promoting transparency in operations, environmental responsibility, and collaborative decision-making that reinforces Kenya's reputation as a secure, well-governed, and globally competitive nation.

7.2.2.2 Client Vision & Objectives

Kenya Airports Authority is a state corporation established in 1991 responsible for operating and maintaining the entire airport infrastructure in Kenya. KAA recognizes the importance of aviation in the country's economic growth and connectivity, with one of its primary objectives being the development of the necessary infrastructure to meet the increasing air traffic demand.

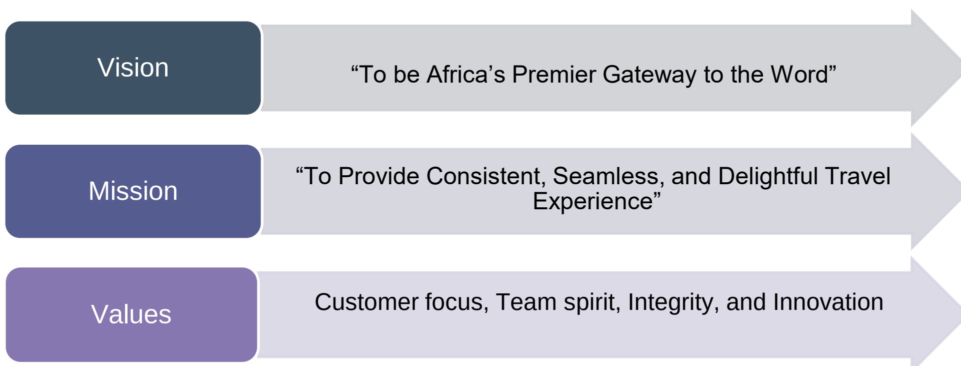


Figure 7.5: Client's Vision, Mission, and Values

KAA's vision and mission play a strategic role in advancing Kenya's position as a regional and global aviation hub. Guided by its core values, they are committed to world-class service delivery and stakeholder engagement. These values shape how KAA approaches every aspect of its mandate, from passenger experience to infrastructure development and sustainability.

To achieve its vision and mission, KAA has rolled out various strategies that includes:

- Developing and maintaining world-class airport infrastructure, focusing on the modernization and expansion of facilities to improve capacity, efficiency, and safety.
- Enhancing the customer experience by optimizing airport services, streamlining processes, and investing in passenger-centric innovations.
- Promoting aviation safety and security, maintaining international standards to ensure secure environments for passengers, personnel, and aircraft.
- Fostering regional connectivity by expanding domestic and international routes, supporting Kenya's role as a strategic aviation and logistics hub.
- Committing to sustainable development, ensuring all operations contribute positively to environmental preservation and social well-being.

A major milestone in KAA's sustainability journey is its recent achievement of Level 3 Certification under the ACA programme by Airports Council International, where 4 KAA-managed airports were recognized for reaching this level, which emphasizes Optimization and Airport Stakeholder Engagement. This certification is a testament to KAA's robust environmental initiatives since achieving Level 1 (Mapping) in 2021 and Level 2 (Reduction) in 2023. Those achievements were rewards of continuous efforts in deploying energy-efficient infrastructure, adopting renewable energy, and managing waste effectively.

KAA's pursuit of higher levels of ACA certification, including eventual carbon neutrality by 2030 and net-zero emissions by 2050, demonstrates its alignment with global sustainability standards and national goals under Kenya Vision 2030. Through continuous innovation, strategic infrastructure development, and environmental stewardship, KAA is not only facilitating seamless air travel but also contributing to the nation's long-term development.

7.2.2.3 JKIA SMART Airport Vision

It is essential to ensure that the SMART City Framework aligns with the unique vision, priorities, and regional context of JKIA.

The Client goals and objectives, highlighted in the previous sections, serve as the foundation for defining SMART Themes, which act as strategic pillars to translate high-level ambitions into actionable, technology-driven solutions tailored to the airport's needs. By grounding smart solutions in the client's objectives, such as sustainability, innovation, and customer-centric development, each theme ensures that technological interventions directly address the airport's challenges, opportunities, and long-term vision. This approach not only fosters efficient resource use, innovation, and resilience but also guarantees that smart solutions support social inclusivity, environmental stewardship, and economic growth, ultimately creating a sustainable and liveable smart city that fulfils the client's strategic aspirations.

Once we have aligned on the smart city definitions and the overall vision, we will begin to build out the 'smart themes' for the airport targeting the relevant user personas. This helps us tailor and prioritize use cases and technology selections throughout this process.

This diagram outlines the strategic framework for JKIA, aligning Kenya's National Vision 2030 and sustainability goals with client objectives and leveraging cutting-edge technologies.

The framework identifies four core SMART themes:

- Passenger Experience
- Sustainable Environment
- Safety & Security
- Operations & Maintenance

These themes will be supported by advanced technologies such as IoT infrastructure, artificial intelligence, digital twins, and cloud computing, ensuring alignment with global frameworks such as ICAO ASBU & TAM, providing a holistic and forward-thinking approach to creating a sustainable and innovative urban ecosystem.

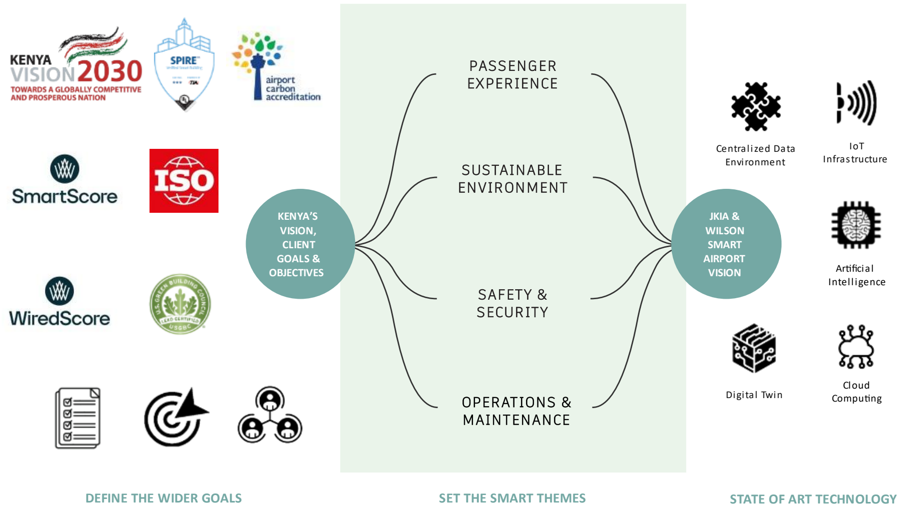


Figure 7.6: JKIA SMART Airport Vision

7.2.3 IDENTIFIED SMART THEMES

Establishing a clear vision and identifying smart themes such as Passenger Experience, Sustainable Environment, Safety & Security, and Operations & Maintenance are critical first steps in designing a smart city, as they provide focus and purpose to the project. The vision articulates the long-term goals, while these themes break them into actionable areas, enhancing residents' quality of life through safety, comfort and convenience. This ensures efficient and sustainable asset management, while integrating advanced technologies for seamless operations, building resilient, and future-ready infrastructure. This foundational clarity ensures alignment among stakeholders, addresses unique urban challenges and drives resource allocation to achieve measurable and impactful outcomes.

The following section provides a detailed explanation of the purpose of each proposed SMART Theme and how they align with the Client's goals and objectives, as well as Kenya's broader vision.

Figure 7.7: JKIA SMART Themes

7.2.3.1 Passenger Experience

This theme targets the creation of a seamless, efficient, and enjoyable journey. By leveraging smart technologies such as automated check-ins, real-time information systems, personalized services, and intuitive wayfinding solutions, JKIA aims to deliver on KAA's mission of providing a "consistent, seamless, and delightful travel experience." Enhancing the user experience not only elevates JKIA's reputation as a leading African hub but also aligns with Kenya Vision 2030's economic pillar, which seeks to boost tourism and trade by providing world-class infrastructure and services that meet international standards.

7.2.3.2 Sustainable Environment

The Sustainability theme focuses on ensuring that JKIA's development and operations are environmentally responsible, resilient, and aligned with global sustainability standards. This includes adopting green building principles, renewable energy solutions, smart waste management, and innovative carbon reduction strategies to support KAA's target of achieving carbon neutrality by 2030 and net-zero emissions by 2050. Achieving these goals reflects KAA's strong environmental leadership, recently recognized through Level 3 ACA certification. This commitment directly supports Vision 2030's emphasis on sustainable development, responsible resource management, and environmental conservation as key components of Kenya's long-term social and economic growth.

7.2.3.3 Safety & Security

This theme is dedicated to enhancing the protection of passengers, staff, and airport infrastructure through the deployment of smart, integrated security systems. Advanced surveillance technologies, biometric access control, AI-driven threat detection, and efficient emergency response systems are central to this strategy. Ensuring a safe and secure environment upholds KAA's responsibility to provide world-class airport services while adhering to international aviation security standards. Furthermore, it strengthens Kenya's national image as a stable and secure investment destination, fully aligning with the political pillar of Vision 2030, which focuses on building a secure and democratic society founded on the rule of law.

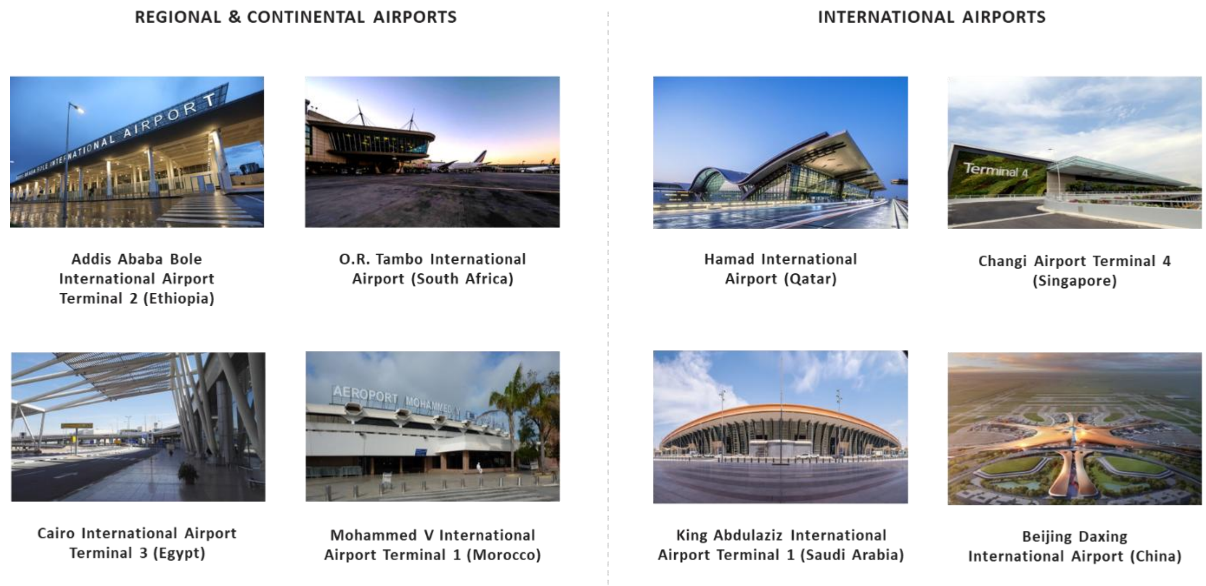
7.2.3.4 Operations & Maintenance

The Operations & Maintenance theme targets the optimization of JKIA's operational efficiency and asset longevity through smart technologies such as predictive maintenance, IoT-enabled monitoring, and AI-driven resource management. These innovations will reduce operational costs, minimize downtime, and enhance service reliability, ensuring that JKIA continues to perform at peak efficiency. This strategic focus supports KAA's vision of being Africa's premier gateway and aligns with Vision 2030's economic pillar by promoting infrastructure that is globally competitive, resilient, and capable of supporting Kenya's ambition to become a major regional business and transport hub.

7.2.4 SMART AIRPORT BENCHMARKING

7.2.4.1 SMART Benchmarking Approach

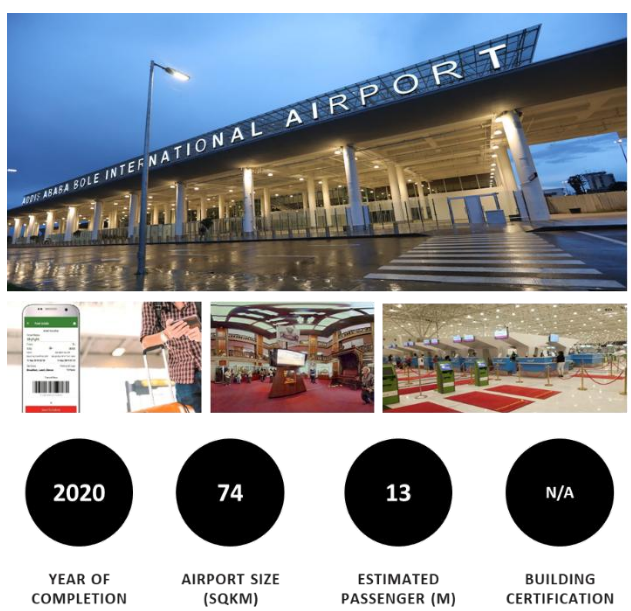
Conducting an extensive benchmarking study is a critical step before delving into the details of smart solutions, as it provides a clear understanding of best practices, emerging trends, and proven technologies that can be adapted to the specific context of JKIA. By analysing both regional and international case studies, the benchmarking process ensures that the project draws from a diverse knowledge base, addressing unique local challenges while integrating globally recognized solutions. This dual approach not only enhances the relevance and feasibility of the proposed smart solutions but also reduces implementation risks, ensuring that the project remains competitive, resilient, and aligned with both local and global sustainability goals.



7.2.4.2 Regional & Continental SMART Airport Benchmarking

As part of the strategic development process for the JKIA project, it is critical to first conduct a regional and continental benchmarking analysis. This ensures that JKIA's future vision and smart airport development align competitively within the African context while positioning Nairobi as a leading hub in the region. By comparing JKIA with peer airports that hold strong influence over regional traffic and economic activity, we can better understand both the baseline expectations and emerging innovations in smart airport management across the continent. For this purpose, four key airports have been selected based on their size, strategic importance, and adoption of smart technologies: Addis Ababa Bole International Airport (Ethiopia), O.R. Tambo International Airport (South Africa), Cairo International Airport (Egypt), and Mohammed V International Airport (Morocco).

7.2.4.2.1 Addis Ababa Bole International Airport Terminal 2 (Ethiopia)



Description

Main hub for Ethiopian Airlines and a critical gateway between Africa, Europe, and Asia. Rapidly expanded to support Addis Ababa's position as a major African hub.

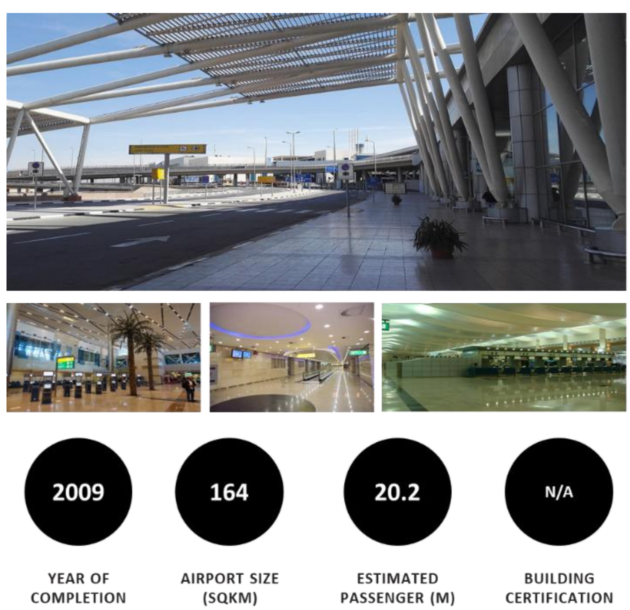
Vision

Position Addis Ababa as the largest aviation hub in Africa, focusing on smart, efficient, and seamless connectivity to global markets.

SMART Systems & Technologies

- **Biometric Technology:** At Addis Ababa, biometric verification is integrated into immigration and boarding processes. Ethiopian Airlines utilizes facial recognition at select immigration kiosks and boarding gates to speed up identity verification.
- **Self-Service Check-In and Bag Drop Counters:** The terminal features self-service kiosks deployed near the main entrances, allowing passengers to print boarding passes and baggage tags. Ethiopian Airlines supports automated bag drop counters for international routes, particularly for high-volume early-morning departures to Europe and Asia.
- **SMART Gates:** SMART e-gates are implemented at departure passport control, where enrolled passengers can pass using biometric passports. These gates support integration with immigration databases, allowing faster throughput while maintaining high security.
- **Advanced Baggage Handling System:** The baggage handling system includes high-speed conveyors with automated sorting linked to passenger flight data. Integrated with security screening and real-time tracking.
- **Interactive Digital Signage:** Large touch-enabled displays placed near check-in halls and boarding gates, providing real-time updates on gate changes, flight status, and services.

7.2.4.2.2 Cairo International Airport Terminal 3 (Egypt)



Description

One of Africa's largest airports, Cairo International is Egypt's principal airport, serving as a key gateway between Africa, Europe, and the Middle East.

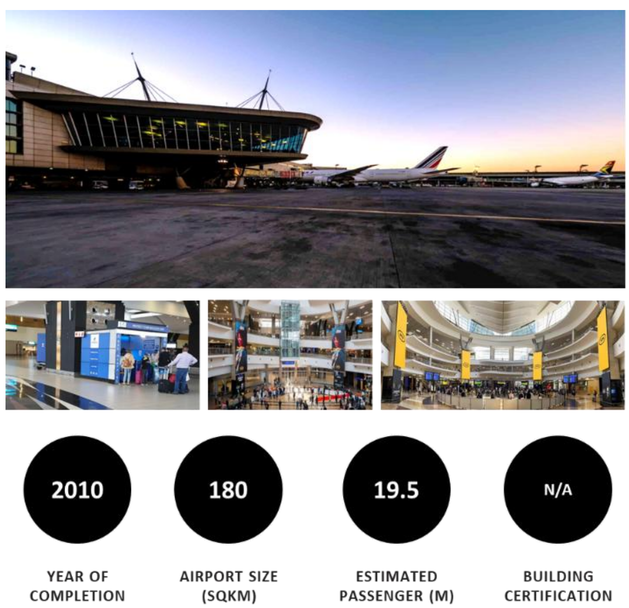
Vision

Envisioned and built to significantly increase capacity, modernize facilities with advanced technology, and enhance passenger experience.

SMART Systems & Technologies

- **Biometric Technology:** Implemented at security and immigration checkpoints to facilitate quick identity verification, especially for travellers from the EU and Gulf regions. Cairo Airport utilizes e-gate systems that scan biometric passports and facial features.
- **Advanced Baggage Handling System:** Features a high-capacity, automated baggage system designed to handle a large volume of international traffic. Bags are scanned, sorted, and routed in real-time using RFID/barcode integration, improving baggage delivery accuracy.
- **Automated People Movers:** Terminal 3 is connected to Terminal 2 via an Automated People Mover (APM), streamlining passenger movement across the airport's expansive footprint. This system is essential for fast and accessible inter-terminal transit.
- **Interactive Digital Signage:** Digital signage displays multilingual (Arabic, English, French) flight info, gate directions, and real-time alerts. Signage in baggage reclaim areas helps with lost luggage claims and customs directions.
- **Advanced Air Traffic Control System:** Cairo operates one of the most modern control towers in North Africa, integrated with radar surveillance and digital coordination systems. It manages high-density international traffic across Africa, Europe, and Asia routes.

7.2.4.2.3 O.R. Tambo International Airport (South Africa)



Description

Africa's busiest airport, located near Johannesburg, serving as the primary hub for South African Airways and connecting Africa to global destinations. Opened in 1952, received major upgrades ahead of 2010 World Cup.

Vision

To be the leading world-class African airport, providing sustainable, smart, and seamless customer experiences.

SMART Systems & Technologies

- **Biometric Technology:** Biometric screening is used at immigration and priority gates for frequent flyers. South Africa's Department of Home Affairs has integrated facial and fingerprint scanners for secure and expedited border processing.

- **Advanced Baggage Handling System:** The system includes centralized baggage screening and automated transfer bag routing — crucial for high volumes of domestic-to-international transfer traffic. Conveyor systems are linked to airline IT systems for real-time tracking.

- **Interactive Digital Signage:** Large vertical and horizontal digital displays guide passengers throughout the terminal. These include queue wait times, baggage belt assignments, and multilingual navigation for connecting flights.

- **Wireless Connectivity:** High-speed Wi-Fi is provided in both domestic and international terminals. Business lounges and gates feature dedicated bandwidth.

- **Mobile Application:** The ACSA (Airports Company South Africa) app delivers boarding info, facility maps, loyalty programs, and alerts. Integration with car parking and retail promotions makes it a seamless digital concierge.

7.2.4.2.4 Mohammed V International Airport Terminal 1 (Morocco)

Description

The busiest airport in Morocco and a major hub for Royal Air Maroc, serving as a strategic link between Africa and Europe. Originally opened in 1943, received major upgrade for Terminal 1 in 2019.

Vision

Position Addis Ababa as the largest aviation hub in Africa, focusing on smart, efficient, and seamless connectivity to global markets.

SMART Systems & Technologies

- **SMART Gates:** Newly renovated Terminal 1 includes biometric-enabled SMART gates at boarding and immigration. These facilitate faster processing, especially for passengers on Royal Air Maroc's Schengen and Gulf routes.

- **Advanced Baggage Handling System:** The terminal uses a fully automated sorting and screening system. Luggage from international flights is scanned and rerouted with minimal manual intervention, enhancing efficiency and security.

- **Interactive Digital Signage:** Touch-enabled and sensor-based displays provide passengers with bilingual (Arabic/French) updates on flights, services, and safety protocols. Signage helps passengers orient themselves in the modernized layout post-renovation.

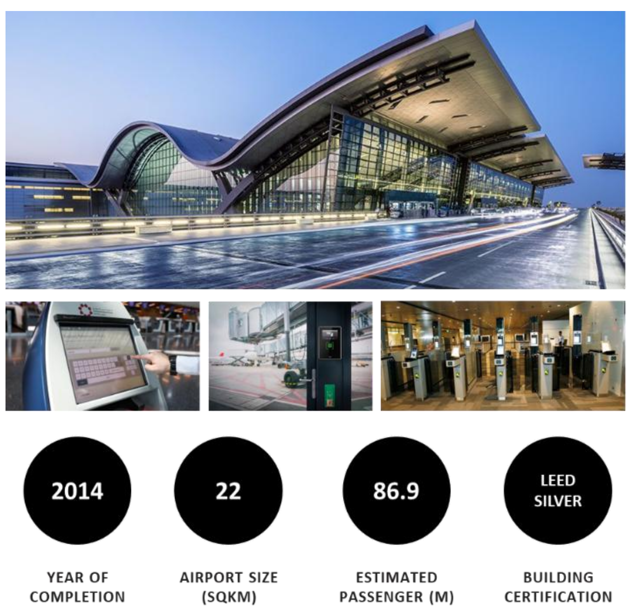
- **Wireless Connectivity:** Wi-Fi is offered throughout the terminal, particularly in check-in zones and waiting lounges. The upgraded infrastructure supports app-based services and airline operations.

7.2.4.3 International SMART Airport Benchmarking

To complement the regional assessment and set global performance standards, an international benchmarking exercise has also been undertaken. This aims to draw lessons from world-leading airports known for their advanced smart systems, iconic design, sustainability leadership, and exemplary passenger experiences.

Learning from these airports will help JKIA define an internationally competitive vision while adapting innovations to the local context. The selected international airports represent a diverse set of best practices from different regions: Beijing Daxing International Airport (China), Changi Airport Terminal 4 (Singapore), King Abdulaziz International Airport Terminal 1 (Saudi Arabia), and Hamad International Airport (Qatar).

7.2.4.3.1 Hamad International Airport (Qatar)



Description

State-of-the-art facility in Doha, known for its striking architecture, luxurious amenities such as a tropical garden and art installations, and it's ranking as one of the world's best airports.

Vision

To be the world's leading digital air hub, offering a seamless and efficient passenger experience through continuous innovation and technology integration.

SMART Systems & Technologies

- **Digital Twin Technology:** A real-time digital replica of Hamad’s infrastructure simulates everything from passenger flows to equipment performance. This virtual model allows airport authorities to run “what-if” scenarios, such as gate reassignments or HVAC load balancing, improving operational readiness and reducing energy costs.
- **Wireless Charging Stations:** Wireless charging pads are integrated into seats and counters across lounges and gate areas. They support Qi-enabled smartphones and tablets, eliminating the need for passengers to carry adapters or cables.
- **Smart Restroom Sensors:** IoT sensors monitor restroom usage, cleanliness, and supply levels (soap, towels, etc.) in real time. These are connected to the airport’s central facilities management system, alerting staff for timely maintenance and improving hygiene standards, especially in premium lounges and high-traffic gates.
- **Open Data Platform:** Real-time open data platform is available for stakeholders (airlines, customs, ground services) to access operational metrics such as flight movements, gate allocations, and baggage delivery times. This fosters coordination, especially in high-traffic events like the World Cup, enabling predictive decision-making and reducing disruptions.

7.2.4.3.2 King Abdulaziz International Airport Terminal 1 (Saudi Arabia)

Description

Primary international gateway serving the cities of Jeddah and Mecca in Saudi Arabia, making it the third-largest airport in the Kingdom by land area. KAIA is the busiest airport in Saudi Arabia and ranks among the most active hubs in the Middle East.

Vision

To serve as a modern gateway to the Kingdom, enhancing the travel experience and supporting economic growth in line with Saudi Vision 2030.

SMART Systems & Technologies

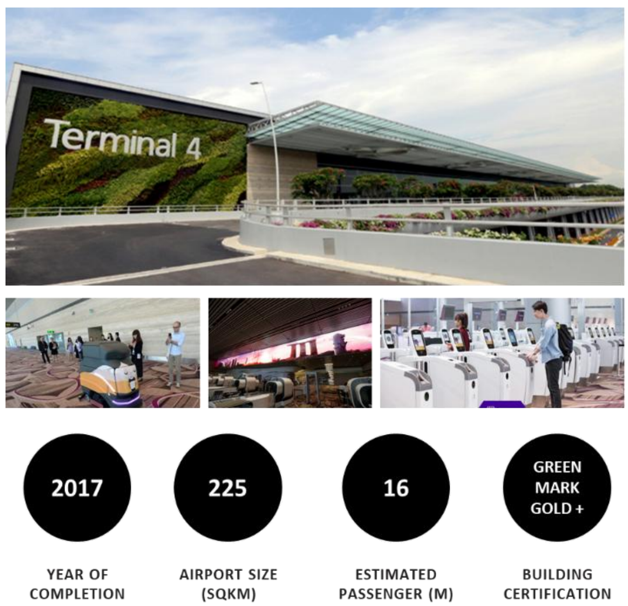
- **Automated People Mover System:** The airport operates an electric tram system that connects Terminal 1 with multiple transport hubs. It eases the transit of elderly and Hajj pilgrims over long distances, with dedicated boarding zones.

- **Centralized Operations Control Centre:** This command centre consolidates real-time data from all major airport systems, including security, baggage, HVAC, and lighting, into one integrated dashboard. Staff monitor events across 800+ SQKM of the facility, improving situational awareness and incident response coordination.

- **Advanced Air Traffic Control (ATC) Systems:** Equipped with modern ATC technologies including radar surveillance, satellite navigation, and AI-powered decision aids. These systems are critical for managing high-density air traffic and ensuring safe routing.

- **Integrated transport centre linking to the Railway:** Terminal 1 is directly connected to the Haramain high-speed rail, allowing seamless passenger transfers between Jeddah, Mecca, and Medina. The transport centre supports ticketing, wayfinding, and schedule syncing between flight arrivals and train departures, promoting multimodal efficiency.

7.2.4.3.3 Changi Airport Terminal 4 (Singapore)



Description

Highly automated, state-of-the-art Airport known for its seamless travel experience, featuring extensive self-service technologies and a compact yet efficient design.

Vision

To provide a seamless and efficient travel experience through innovation and technology, enhancing passenger convenience and operational efficiency.

SMART Systems & Technologies

- **Automated Tray Return System (ATRS):** Deployed at centralized security, ATRS reduces bottlenecks by automatically collecting and resetting trays after passenger screening. It minimizes manual handling and supports faster lane turnover.

- **Real-Time Flight Information Display Systems (FIDS):** FIDS across Terminal 4 sync with airport databases to reflect real-time flight changes. Displays are multilingual, dynamically updated, and integrated with mobile alerts and wayfinding kiosks, keeping passengers constantly informed and reducing missed flights.
- **Robot Cleaning:** Autonomous robots clean terminal floors using smart mapping and SLAM (Simultaneous Localization and Mapping) navigation. Robots are programmed to avoid passengers, operate off-peak, and integrate with facilities management systems for route updates and scheduling.
- **Experiential Screen:** A massive, curved LED wall in the departure hall showcases immersive animations and cultural narratives. This not only entertains waiting passengers but is also used for public messaging and promotional campaigns, making the screen a functional and artistic element of terminal design.

7.2.4.3.4 Beijing Daxing International Airport (China)

Description

Major aviation hub in China known for its starfish-shaped design, cutting-edge smart technologies, and role as a key gateway to the Beijing-Tianjin-Hebei region.

Vision

To serve as a major international hub, integrating advanced technologies for efficient and passenger-friendly services.

SMART Systems & Technologies

- **High-Resolution Real-Time Tracking Sensors:** Thousands of ceiling-mounted sensors track passenger location and movement density. This data helps dynamically allocate resources (like staff or e-gates), optimize passenger flow, and avoid crowding, especially important in a starfish layout with long walking distances.
- **Robotic Passenger Assistance:** AI-powered service robots assist with wayfinding, flight info, and even language translation. They patrol terminals and interact via touchscreens and voice commands, especially aiding international travellers and those with limited mobility.
- **SMART Waste and Water Management Systems:** Sensors in bins and restrooms monitor fill levels, water leaks, and flow rates. The system triggers cleaning schedules or water shut offs automatically, reducing environmental impact while ensuring high facility standards.

- **Renewable Energy:** The terminal uses integrated rooftop solar panels and energy-efficient lighting systems. Some airside vehicles, including shuttles and baggage carts, are electric, reducing carbon emissions. Energy use is monitored via the airport's smart grid for real-time efficiency tuning.

Table 7.1: SMART Airport Benchmarking Summary

SMART SYSTEM / TECHNOLOGY	Addis Ababa Bole International Airport Terminal 2	Cairo International Airport Terminal 3	O.R. Tambo International Airport	Mohammed V International Airport Terminal 1	Hamad International Airport	King Abdulaziz International Airport Terminal 1	Changi Airport Terminal 4	Beijing Daxing International Airport
Biometric Technology	•	•	•		•	•	•	•
Self-Service Check-In and Bag Drop Counters	•						•	•
SMART Gates	•			•	•	•		•
Automated People Movers (APM)		•				•		•
Automated Tray Return System							•	
Advanced Baggage Handling System	•	•	•	•	•	•		
Smart Security Screening System							•	•
High-Resolution Real-Time Tracking Sensors								•
Smart Lighting System					•	•	•	•
AI-Powered Operations Control Center						•		•
Robotic Passenger Assistance								•
Interactive Digital Signage / FIDS	•	•	•	•		•	•	•
SMART Waste and Water Management								•
Intelligent Passenger Flow Management					•	•		•
Data Analytics							•	•
SMART BMS / HVAC / IoT					•	•	•	•
Renewable Energy								•
Passenger-Centric Features								•
Integrated ICT Systems					•	•		
Wireless Connectivity	•	•	•	•	•	•	•	•
Robot Cleaning / Automated Guided Vehicles							•	
Digital Signage & Wayfinding							•	
SMART Restroom					•		•	
Digital Twin					•			
Artificial Intelligence					•			•
Multimodal Transportation System						•		
Wireless Charging Station					•	•		
Advanced Air Traffic Control System		•			•	•		
Experiential Screen							•	
Mobile Application	•	•	•		•		•	•
Integrated Data Platform					•		•	•

7.2.5 USER EXPERIENCE ANALYSIS

Our process for building smart city intelligence begins by understanding the airport's assets and infrastructure, ensuring a solid foundation for smart integration. We then identify key user groups, from passengers to airport staff, to ensure technology meets real-world needs. By defining practical use cases, we focus on solutions that enhance efficiency, security and sustainability. Finally, we carefully select the right technologies that seamlessly integrate with operations, creating a connected, adaptive and future-ready smart airport environment.

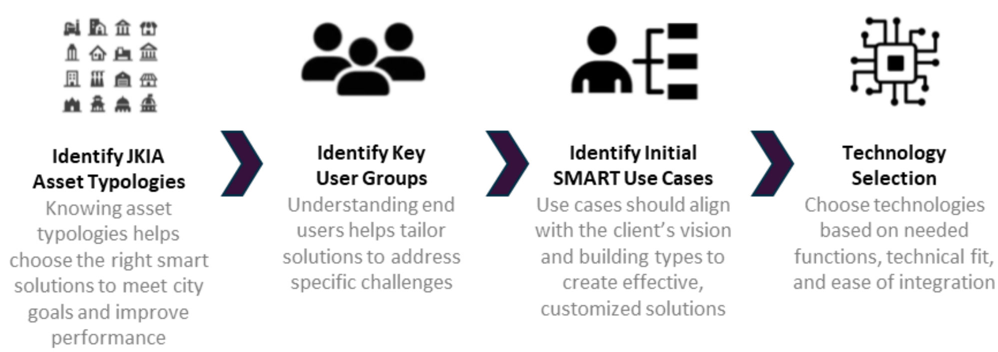


Figure 7.8: Smart Use Case Selection Process

7.2.5.1 Assets Typology

A. Passenger Processing Facilities

- Check-In Halls
- Security Screening Zones
- Immigration & Emigration Control
- Customs Inspection Points
- Boarding Gates

B. Passenger Experience & Access Areas

- Departure Lounges
- Baggage Reclaim Areas
- Commercial Areas
- Public Transport Access
- Parking

C. Security & Safety Infrastructure

- Security Control Rooms
- Access Control Points
- Emergency Response Facilities
- Airside Safety Systems (Runways, Taxiways, and Aircraft Stands)

D. Operation & Maintenance Amenities

- Airport Operations Control Centre
- Water & Waste Management Facilities
- Utility Plants & Technical Rooms
- Cargo Terminals & Warehouses
- Airfield Systems & Ground Support Equipment Areas

User Groups Identification

User groups represent the diverse stakeholders and end-users interacting with the airport's infrastructure and services. Understanding these groups is pivotal to designing SMART initiatives that are inclusive, efficient, and responsive to varied needs.

- **Passenger:** These are the core users of the airport. They constitute the individuals moving through JKIA for domestic, regional, or international journeys. Their interaction with the airport spans across terminal facilities, checkpoints, lounges, commercial spaces, and transport links. Their experience is central to airport planning and service delivery.
- **Service & Support Personnel:** This group includes all staff involved in delivering front-facing services to passengers or managing commercial operations within the terminal. They directly shape the travel experience and keep passenger-facing operations running smoothly.
- **Airport Operators & Regulators:** These are the teams responsible for the management, security, and regulatory oversight of the airport, including, air traffic control, emergency and security services, and government agencies. They use centralized systems to maintain safe, efficient, and compliant operations across the airport campus,
- **Visitors:** These are people who come to the airport not to travel themselves, but to accompany others, access public services, or use retail and mobility amenities. Though their dwell time may be shorter, their presence impacts landside planning, traffic flow, and public accessibility.

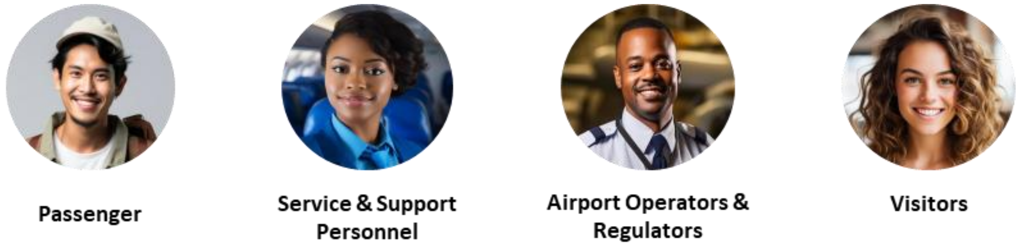


Figure 7.9: JKIA Key User Groups

Understanding the needs, behaviours, and key activities of each user group at JKIA is essential for shaping a smart airport environment that is inclusive, efficient, and future-ready. By tailoring smart initiatives, such as seamless passenger flow technologies for travellers, advanced control systems for operations teams, or responsive environments for staff, the airport can optimize resource allocation, enhance stakeholder experiences, and ensure high-impact results.

This user-centred approach supports the airport's broader goals of efficiency, safety, and sustainability while aligning with Kenya's national vision for innovation and connectivity. A deep understanding of JKIA's diverse user base enables the selection of the most relevant and effective smart systems, ensuring that technology enhances not only functionality but also equity, accessibility, and long-term value across the entire airport ecosystem.

Passenger

"I need a smooth, stress-free travel experience with minimal delays, clear directions, and easy access to services."

Need/Wants

- Seamless check-in
- Clear wayfinding
- Fast processing
- Reliable information
- Safety & security
- Shopping & dining

Key Activities

- Checking in, clearing security and immigration, and boarding flights with minimal delays.
- Spending time in lounges, retail areas, or dining outlets while waiting for departures.
- Navigating terminals using digital signage or mobile apps.
- Receiving real-time gate changes or disruption alerts on personal devices.
- Enjoying a comfortable indoor environment with monitored air quality and reduced noise.

Service & Support Personnel

"I need reliable systems and secure access so I can do my job efficiently and support passengers with confidence."

Need/Wants

- Secure access
- Workflow efficiency
- Functional equipment
- Communication tools

Key Activities

- Assisting Passengers at check-in, boarding gates, and customer service points.
- Adjusting roles and tasks dynamically based on crowding, passenger flow, or disruptions.
- Supporting mobility-impaired passengers by accessing up-to-date schedules and locations of needed equipment or supplies.
- Executing maintenance and cleaning tasks based on real-time sensor alerts, ensuring facilities are serviced promptly and maintained to established quality standards.

Airport Operators & Regulators

"I need full visibility across airport systems, with smart tools that help monitor, coordinate, and optimize operations in real time."

Need/Wants

- Real-time data
- Regulated access
- System integration
- Incident response

Key Activities

- Implementing security protocols in collaboration with airport security and emergency response while coordinating via an integrated command platform
- Overseeing operations to ensure safe, smooth airport functioning.
- Managing regulatory compliance, infrastructure, and daily coordination through control centres.
- Coordinating crowd movement using real-time occupancy and camera data.

Visitors

"I need to easily reach the terminal, find the right location, and have comfortable, accessible spaces to wait or interact."

Need/Wants

- Easy navigation
- Parking amenities
- Waiting areas
- Live information

Key Activities

- Accessing passenger drop-off and pick-up points with clear signage and minimal congestion.
- Using public-facing facilities like food courts, ATMs, or retail stores without entering sterile zones.
- Benefiting from signage and alerts that adjust dynamically.
- Waiting in designated landside zones with access to comfort amenities.
- Accessing Wi-Fi and charging stations to stay connected

7.2.6 SMART AIRPORT INITIATIVES

The smart airport initiatives at JKIA are designed to seamlessly integrate advanced technology and sustainability, transforming the airport into a dynamic, efficient, and inclusive travel hub. Grounded in a deep understanding of user groups, including passengers, staff, operational teams, and visitors, these initiatives are focused on enhancing experience, optimizing flow, and ensuring long-term resilience. By aligning with both national strategic goals and global best practices, JKIA's smart systems aim to deliver tailored, data-driven solutions that support seamless journeys, safe operations, and sustainable growth.

7.2.6.1 Passenger Experience

The table below highlights key SMART initiatives proposed under the Passenger Experience theme for the JKIA Smart Airport development. Each initiative is supported by a brief description, explaining how the use case aims to optimize the passenger experience, along with the main problems it addresses. Additionally, the key technology enablers are listed, demonstrating how technologies such as IoT sensors, AI-powered systems, and digital platforms can transform the travel experience. These initiatives are designed to streamline passenger journeys, enhance convenience, reduce wait times, and create a more intuitive, comfortable, and connected environment. All proposed solutions align with the Client's goals and Kenya Vision 2030, emphasizing world-class service delivery, inclusive design, and a people-first approach to airport development.

Table 7.2: Passenger Experience Proposed SMART Initiatives

SMART Initiative		Description
1	Seamless Self-Service Journey	End-to-end self-service flow integrating check-in, bag drop, biometric ID, and boarding, reducing touchpoints and wait times
2	Biometric-Enabled Smart Gates	Faster identity verification and passenger flow through gates using facial recognition or fingerprint scans
3	Personalized Passenger Information System	Live, context-aware travel updates and navigation assistance through multiple digital touchpoints tailored to each traveller
4	Multilingual Virtual Concierge	Kiosks or mobile AI chat assistants offering real-time multilingual support, FAQs, and airport services information
5	Dynamic Queue & Flow Management System	AI-driven crowd sensing and real-time adjustments of queue lanes and staff deployment

7.2.6.1.1 Seamless Self-Service Journey

Allows passengers to independently complete key travel steps from check-in to boarding, enhancing efficiency and consistency. Passengers can use intuitive kiosks or mobile apps to check in, print baggage tags, drop bags at automated stations, and proceed through biometric-enabled gates without needing staff assistance. This ensures smoother processing, especially during peak hours, and supports end-to-end automation.

Bottleneck / Problem it Addresses

- Long check-in and boarding queues causing delays and dissatisfaction
- Language and accessibility barriers impacting diverse passengers
- Inconsistent staff availability and service quality

Key Technology Enablers

- Biometric-Enabled Kiosks
- Automated Bag Drop Units
- E-Gates with Smart ID Verification
- Multilingual AI-Powered Interface
- Integrated Passenger Flow Analytics

7.2.6.1.2 Biometric-Enabled Smart Gates

Automated smart gates, integrated with national and airline databases, enable touchless identity verification and access control at security and boarding zones. Facial recognition systems and fingerprint scans match travellers with digital profiles captured at check-in or via mobile onboarding. These gates reduce processing time while ensuring higher security integrity.

Bottleneck / Problem it Addresses

- Staff misread or overlook documents leading to security breaches or misidentification
- Manual ID verification processes at security and boarding zones result in significant slowdowns

Key Technology Enablers

- Facial Recognition & Liveness Detection

- API Integration with Border Control Systems
- Edge AI Processing at Gate Level
- Adjustable User Interface for Accessibility
- Secure Data Transmission & Encryption Protocols

7.2.6.1.3 Personalized Passenger Information System

A context-aware information system delivers personalized updates through mobile apps and terminal displays. It dynamically provides gate and boarding information, estimated wait times, walking directions, baggage carousel info, and real-time alerts based on the passenger's current location and flight data.

Bottleneck / Problem it Addresses

- Missed gate changes or late arrivals due to unclear signage
- Lack of tailored passenger guidance
- Inefficient passenger distribution and dwell-time planning

Key Technology Enablers

- Indoor Positioning Systems (IPS) using BLE beacons or Wi-Fi
- AI-Based Recommendation Engines
- Integration with flight and boarding systems
- Mobile app notification system

7.2.6.1.4 Multilingual Virtual Concierge

An AI-powered concierge platform accessible through mobile apps and touch kiosks, offers passengers real-time support on wayfinding, airport services, retail and dining options, and other amenities in multiple languages. The virtual assistant includes a conversational interface and incorporates accessibility features like sign language avatars and screen readers. It can proactively suggest the nearest washroom, prayer room, duty-free outlet, or lounge based on flight time and dwell patterns, reducing passenger reliance on staff and minimizing service friction during peak hours.

Bottleneck / Problem it Addresses

- Language barriers increasing confusion for non-native speakers, especially during disruptions
- Limited human resources to support real-time inquiries across terminals
- Poor accessibility for visually or hearing-impaired passengers
- High dependency on static signage that lacks personalization

Key Technology Enablers

- Multilingual NLP chatbots with contextual awareness
- Voice recognition and modulation for clarity and inclusivity
- Integration with flight databases and wayfinding systems
- Cloud-based AI engines for scalability and adaptability
- Mobile app Integration

7.2.6.1.5 Dynamic Queue & Flow Management System

AI-driven flow management tracks passenger movement through overhead sensors and computer vision systems. It analyses real-time footfall data to identify and predict congestion hotspots, rerouting foot traffic via nearby dynamic digital signs that guide passengers to alternative routes, less crowded gates, or service areas.

Bottleneck / Problem it Addresses

- Unbalanced passenger flow creating unnecessary congestion
- Staffing inefficiencies during unexpected peaks
- Lack of real-time responsiveness to delays or disruptions

Key Technology Enablers

- Computer vision-based footfall analytics
- Machine learning-based demand forecasting
- Real-time IoT sensor data integration

7.2.6.2 Sustainable Environment

The table below outlines key SMART initiatives under the Sustainable Environment theme at JKIA, aimed at embedding resilience and resource efficiency into airport operations. Leveraging technologies such as smart water, energy, and waste management systems, focus on reducing carbon emissions, optimizing natural resource use, and enhancing overall environmental performance. These efforts directly support the Kenya Airports Authority's goal of achieving carbon neutrality by 2030 and align with Kenya Vision 2030's sustainability targets, including green infrastructure, low-carbon operations, and climate-conscious development.

Table 7.3: Sustainable Environment Proposed SMART Initiatives

SMART Initiative		Description
6	Smart Waste & Water Management	IoT-based systems that monitor and optimize waste sorting, recycling, and water consumption across airport zones
7	Air Quality & Noise Monitoring	Sensor networks measuring air pollutants, temperature, humidity, and noise to ensure environmental compliance and comfort
8	Dynamic Energy Zoning System	Zonal control of HVAC, lighting, and ventilation systems based on occupancy and usage patterns to reduce energy waste
9	Energy Demand Forecasting System	AI-powered tool that predicts energy consumption patterns across terminal facilities to optimize load balancing and peak demand
10	Wildlife Predictive Model	AI and IoT-based systems to accurately predict and detect bird and wildlife activity near critical airspaces in real time

7.2.6.2.1 Smart Waste & Water Management

A real-time, sensor-integrated waste and water management system automates monitoring and optimization of collection, sorting, treatment, and disposal across terminals and airside zones. Smart bins equipped with fill-level and contamination sensors send alerts to cleaning crews, enabling optimized routing and collection scheduling. Leak detection sensors, and IoT valves regulate water flow, ensuring conservation. Dashboards track usage patterns and compliance for continuous optimization and sustainability reporting.

Bottleneck / Problem it Addresses

- Overflowing or inefficient waste collection due to static schedules
- Undetected water leaks and overuse
- Lack of granular visibility for sustainability reporting and audit readiness

Key Technology Enablers

- IoT fill-level sensors
- Ultrasonic leak detectors
- Smart valves and actuators
- Predictive analytics dashboards

7.2.6.2.2 Air Quality & Noise Monitoring

A zone-based smart energy control system regulates lighting, HVAC, and ventilation across airport areas based on real-time occupancy, sunlight, and outdoor temperature. Occupancy sensors inform system behaviour, while staff use an override dashboard to adjust conditions in real time. This significantly reduces peak demand and improves passenger comfort without over-conditioning or unnecessary lighting.

Bottleneck / Problem it Addresses

- Constant energy use regardless of occupancy or climate
- Overheating or under-conditioning due to manual controls
- Difficulty isolating energy performance by area

Key Technology Enablers

- Smart zoning algorithms
- Motion/thermal sensors
- Integrated BMS with override capabilities

7.2.6.2.3 Dynamic Energy Zoning System

A zone-based smart energy control system regulates lighting, HVAC, and ventilation across airport areas based on real-time occupancy, sunlight, and outdoor temperature. Occupancy sensors inform system behaviour, while staff use an override dashboard to adjust conditions in real time. This significantly reduces peak demand and improves passenger comfort without over-conditioning or unnecessary lighting.

Bottleneck / Problem it Addresses

- Constant energy use regardless of occupancy or climate
- Overheating or under-conditioning due to manual controls
- Difficulty isolating energy performance by area

Key Technology Enablers

- Smart zoning algorithms
- Motion/thermal sensors
- Integrated BMS with override capabilities

7.2.6.2.4 Energy Demand Forecasting System

An AI-powered system that predicts short- and medium-term energy demand by analysing diverse data sources, such as utility trends, weather data, flight schedules, and passenger forecasts. It enables smarter grid balancing and HVAC control while optimizing the use of renewable sources like solar panels and battery storage to reduce peak-time grid dependency.

Bottleneck / Problem it Addresses

- No visibility on future energy demand, hence inefficient load management.
- Reactive system operations, leading to excessive peak-time energy consumption

- Limited coordination with renewables, preventing optimal use of energy assets

Key Technology Enablers

- AI/ML energy modelling and forecasting tools
- Weather and traffic data integration
- API connectivity with HVAC, and renewable energy

7.2.6.2.5 Wildlife Predictive Model

This system uses radar, AI pattern recognition, and ecological sensors to predict bird movements and wildlife encroachment risks based on climate, migratory patterns, food availability, and noise signatures. The system recommends mitigation actions such as ultrasonic repellents, scheduled habitat clearance, or modified runway lighting patterns. By proactively minimizing bird strike risks and maintaining ecological harmony, the model supports operational and environmental goals simultaneously.

Bottleneck / Problem it Addresses

- Reactive approach to bird strikes and wildlife incursion
- Conflicts between biodiversity and operational priorities
- Lack of predictive insights for environmental-risk planning

Key Technology Enablers

- Radar and acoustic sensors
- Machine learning models trained on ecological data
- Integration with airfield lighting and alert systems

7.2.6.3 Safety & Security

The table below highlights SMART initiatives proposed under the Safety & Security theme at JKIA, emphasizing the integration of intelligent systems to ensure passenger safety, regulatory compliance, and security interventions. Through the deployment of AI-based surveillance, automated screening technologies, and real-time threat detection platforms, the airport aims to proactively manage risks while improving passenger flow and confidence. These innovations are directly aligned with national security priorities and global aviation safety standards, reinforcing JKIA's status as a secure, efficient gateway for international and domestic travellers.

Table 7.4: Safety & Security Proposed SMART Initiatives

SMART Initiative		Description
11	AI-Powered Surveillance	CCTV analytics that detect unusual behaviour, intrusions, or unattended objects, alerting security teams instantly
12	Drone Surveillance & Response	Drones equipped with thermal imaging or HD cameras for airside perimeter monitoring, or during emergencies
13	Smart Access Control Systems	RFID or biometric-enabled access control to restrict unauthorized vehicle and staff movement into sensitive zones
14	Unified Incident Command System	Platform that integrates police, fire, medical, and airport operations to coordinate and simulate emergency responses
15	Airfield Ground Lighting	Intelligent lighting systems that adjust intensity and colours to support visibility and safe aircraft movements

7.2.6.3.1 AI-Powered Surveillance

AI-driven video analytics system overlays existing CCTV infrastructure with deep learning models that detect anomalies in real-time: unattended bags, unusual movement, perimeter breaches, etc. AI identifies suspicious patterns and automatically prompt alerts. Security operators are supported by automated threat prioritization dashboards and heatmaps that indicate high-risk areas.

Bottleneck / Problem it Addresses

- Security blind spots due to limited human capacity to monitor multiple feeds
- Delayed threat response due to lack of real-time detection
- Manual analysis bottlenecks after incidents

Key Technology Enablers

- IoT cameras
- Deep learning video analytics
- Edge-based processing units
- License Plate Recognition (LPR) systems
- Integrated security data lake

7.2.6.3.2 Drone Surveillance & Response

An integrated drone fleet conducts scheduled perimeter patrols and is deployed on-demand for emergency incidents (fire, intrusion, crash). Equipped with thermal imaging, drones can detect human movement in low-visibility or night-time conditions and send real-time HD footage to the Security Operations Centre (SOC). Drones interface with the AI surveillance system and airfield sensors, responding autonomously to alerts such as fence breaches or unauthorized vehicles.

Bottleneck / Problem it Addresses

- Limited human patrolling capacity across vast perimeter areas
- Delayed situational awareness during incidents
- Ineffective nighttime or poor visibility surveillance

Key Technology Enablers

- Autonomous drones with thermal/infrared cameras
- Drone fleet management system
- Emergency incident integration

7.2.6.3.3 Smart Access Control Systems

Biometric access control system governs entry into restricted airside and secure landside zones. Staff authenticate using facial recognition, fingerprint, or RFID-enabled wearables. The system dynamically adjusts access rights based on role, shift timing, and zone risk profile. AI detects tailgating or access misuse and automatically revokes or adjusts credentials during suspicious activity.

Bottleneck / Problem it Addresses

- Badge sharing between different personnel
- Unauthorized access into restricted areas

Key Technology Enablers

- Biometric authentication (face/fingerprint)
- RFID and mobile credential systems
- AI-based access misuse detection

7.2.6.3.4 Unified Incident Command System

A centralized emergency coordination platform integrates feeds from fire alarms, surveillance, access control, HVAC, and emergency systems. During an incident, the platform visualizes real-time status, initiates predefined emergency workflows, and provides a single dashboard for all responders.

Bottleneck / Problem it Addresses

- Fragmented emergency response systems
- Delays in coordination among multiple stakeholders
- Lack of centralized visibility during incidents

Key Technology Enablers

- Real-time command dashboard
- System interoperability middleware
- Dynamic GIS mapping and alerts
- Digital SOPs and emergency simulations

7.2.6.3.5 Airfield Ground Lighting (AGL)

A smart, sensor-integrated airfield lighting system adjusts runway and taxiway lighting based on visibility, occupancy, and aircraft proximity. Integrated with air traffic control systems, the AGL supports safer aircraft guidance in all conditions. Sensors monitor lighting health, detect anomalies, and send predictive maintenance alerts to avoid failures during operation. AGL also contributes to ground collision prevention during low-visibility operations.

Bottleneck / Problem it Addresses

- Inadequate visibility and lighting-related ground incidents
- Manual monitoring of lighting failures
- Increased safety risks during adverse weather

Key Technology Enablers

- LED airfield lighting with embedded sensors
- Air Traffic Control (ATC) Integration & Occupancy Sensors
- Smart lighting controllers and predictive diagnostics

7.2.6.4 Enhanced Operations & Maintenance

The table below presents key SMART initiatives under the Enhanced Operations & Maintenance theme at JKIA, focused on improving operational efficiency, predictive maintenance, and infrastructure resilience. By implementing advanced systems such as asset tracking, and centralized data platforms, the airport can optimize energy use, reduce downtime, and enhance service delivery across all systems.

These initiatives align with KAA's commitment to world-class infrastructure and operational excellence, while also supporting Kenya's broader goals for innovation, infrastructure development, and economic growth under Vision 2030.

Table 7.5: Enhanced Operations & Maintenance Proposed SMART Initiatives

SMART Initiative		Description
16	Digital Twin for Operations	Real-time 3D digital replica integrating data from HVAC, asset condition, and flight schedules to simulate and optimize operations
17	IoT-Enabled Predictive Maintenance System	Sensor-based monitoring system that uses AI to predict equipment failures, enabling proactive maintenance and minimizing disruptions
18	Real-Time Asset Tracking & Optimization	Live tracking and management of all airport assets, equipment, and critical infrastructure-across indoor and outdoor environments
19	Automated Fault Detection & Diagnostics	Intelligent system that continuously detects and diagnoses faults and alerts maintenance teams with corrective actions
20	Smart Cleaning System	Semi-automated system that improves cleanliness across the airport by using basic occupancy sensors and digital feedback stations

7.2.6.4.1 Digital Twin for Operations

A centralized digital twin platform mirrors airport's real-time operational state using data streams from BMS, HVAC, asset sensors, and many other integrated systems. This spatially accurate, 3D environment is accessible to operations managers, enabling predictive scenario planning, bottleneck diagnosis, and remote asset control. During disruptions, the twin simulates ripple effects across terminals, enabling faster and more coordinated recovery responses.

Bottleneck / Problem it Addresses

- Isolated operations with limited real-time visibility
- Manual coordination of cross-terminal impacts during disruptions
- Delayed response to capacity bottlenecks
- Limited integration between infrastructure and airline systems

Key Technology Enablers

- Digital Twin Platforms
- IoT-enabled asset data integration
- Predictive simulation engine
- AI-driven anomaly detection and insights
- Cloud & Edge Computing

7.2.6.4.2 IoT-Enabled Predictive Maintenance System

An IoT-enabled predictive maintenance system monitors critical airport assets, such as HVAC, baggage systems, and grids, using embedded sensors that track real-time conditions like vibration, temperature, and load. AI/ML algorithms analyse this data to forecast failures and recommend maintenance before breakdowns occur. Technicians receive automated alerts and optimized work orders, reducing downtime, avoiding disruptions, and extending asset lifespan.

Bottleneck / Problem it Addresses

- Reactive maintenance that leads to unexpected equipment breakdowns and service interruptions
- Lack of visibility into the real-time condition of critical airport assets
- High maintenance costs and spare part wastage due to lack of preventive servicing

Key Technology Enablers

- Embedded IoT sensors on infrastructure and machinery
- AI-based failure prediction algorithms
- Real-time dashboards and maintenance analytics

7.2.6.4.3 Real-Time Asset Tracking & Optimization

Mobile and fixed operational assets (e.g., baggage tugs, carts, wheelchairs) are tagged with IoT or RFID devices that continuously relay real-time location, operational status, and utilization frequency. A centralized asset intelligence dashboard visualizes availability across airport zones, helping dispatch teams quickly identify and assign assets based on proximity and current demand.

Bottleneck / Problem it Addresses

- Inability to track and locate operational assets in real time
- Low availability of essential equipment in the right zones when needed

Key Technology Enablers

- IoT asset tags and RFID trackers
- Centralized asset management platform

7.2.6.4.4 Automated Fault Detection & Diagnostics

This system enables real-time fault detection and diagnostics across airport infrastructure like power, baggage, lighting, and HVAC systems. Using edge devices and smart controllers, it monitors performance thresholds, identifies anomalies, and runs automated diagnostics to classify faults. Alerts with recommended actions are sent to maintenance teams, while integration with digital twins helps visualize and simulate issues before intervention.

Bottleneck / Problem it Addresses

- Delayed fault identification, often noticed only after full failure or complaints
- Inefficient manual troubleshooting leading to prolonged downtime
- Limited ability to proactively monitor distributed airport systems in real time

Key Technology Enablers

- Edge-based fault detection controllers and smart meters
- Integration with BMS and digital twin platforms
- Automated alerting and diagnostic workflows

7.2.6.4.5 Smart Cleaning System

Dynamic cleaning management system uses real-time occupancy and sensor data (e.g., restroom usage, spills, trash fill levels) to prioritize cleaning tasks. Staff receive optimized task routes via handheld devices. Feedback panels and QR codes allow passengers to report cleanliness levels. Data analytics improve shift allocation and supply restocking.

Bottleneck / Problem it Addresses

- Static cleaning schedules misaligned with real-time needs
- Lack of cleanliness visibility for both staff and passengers
- Resource waste due to inefficient dispatch

Key Technology Enablers

- Occupancy sensors and usage meters
- Smart bins and restroom monitoring
- Cleaning staff mobile dispatch app
- Feedback-integrated analytics dashboard

7.2.7 SMART PRIORITIZATION STRATEGY

7.2.7.1 Prioritization & Scoring Criteria

We have developed a prioritization strategy. To help further assess and select the needed use cases.

We have created a scoring strategy. Against each use case we will attribute a score out of 25. This will be based on the following five criteria:

- **Maturity** – how widely the feature/technology is being used in the industry in general, and specifically on this project
- **Flexibility** – complexity in deploying the feature/technology in terms of infrastructure requirement and physical changes
- **Sustainability** – feature/technology's contribution to sustainable operation in terms of efficiency gains and resources savings
- **User Experience** –feature/technology's contribution to overall user experience and well-being
- **System Cost** – initial cost of investment of the feature/technology

Table 7.6: Prioritization Criteria

Evaluation	Maturity	Flexibility	Sustainability	User Experience & Well-being	System-Cost
1	Not mature – in development	Need of re-planning and lot of infrastructure and physical adaptation	No efficiency gains and resources saving	No effect on user experience and overall well-being	Very Expensive
2	Developed and prototype	A lot of infrastructure and physical adaptation	Some effect on either efficiency gains or resources saving	Some effect on user experience and overall well-being	Expensive
3	Developed and first installations	Adaptation with some infrastructure upgrade and physical changes	Either efficiency gains or resources saving	Supporting on user experience and overall well-being	Medium High
4	Regularly used	Easy adaptation (plug-in-and-play)	Some effect on both efficiency gains and resources saving	High effect on user experience and overall well-being	Medium
5	Industry standard	Easy adaptation – without supplier involvement	Full effect on both efficiency gains and resources saving	Full effect on user experience and overall well-being	Low cost

Table 7.7: Scoring Results and Meaning

Category	Must-Have	Should-Have	Could-Have
Score	≥ 20	15-19	≤ 14
Description	Technology is very matured, used regularly or is industry standard, and have huge impact at reasonable cost	Technology is less matured and used not as extensively in the industry, have some impact currently at higher cost	Technology in this category has not reached a commercialisation level to have huge impact
Recommendation	Deploy in Day 1	Deploy in Day 1 to be a competitive SMART leader in the industry	Future. Can be considered for pilot testing to be innovative

Each smart use case will be evaluated against these criteria, with a maximum total score of 25 points. Based on their total scores, we'll classify the use cases into Must-Have, Should-Have, and Could-Have.

The features in the Must-Have and Should-Have categories should be considered and moved into the next Design stage, while those in the Could-Have category can be reserved for future consideration.

7.2.7.2 SMART Initiatives Priority Strategy Results

Table 7.8: Prioritization Strategy Results

No.	Smart Initiative	Maturity	Flexibility	Sustainability	User Experience & Well-being	System Cost	Total Score
1	Seamless Self-Service Journey	4	3	5	5	3	20
2	Biometric-Enabled Smart Gates	4	4	4	4	4	20
3	Personalized Passenger Information System	3	4	4	4	3	18
4	Multilingual Virtual Concierge	3	4	4	4	3	18
5	Dynamic Queue & Flow Management System	3	4	4	4	3	18
6	Smart Waste & Water Management	4	4	5	3	4	20
7	Air Quality & Noise Monitoring	4	4	5	4	4	21
8	Dynamic Energy Zoning System	4	4	5	3	4	20
9	Energy Demand Forecasting System	3	4	5	3	3	18
10	Wildlife Predictive Model	2	2	4	3	3	14
11	AI-Powered Surveillance	3	3	3	4	3	16
12	Drone Surveillance & Response	2	2	3	4	2	13
13	Smart Access Control Systems	4	3	3	3	4	17
14	Unified Incident Command System	3	3	4	4	3	17
15	Airfield Ground Lighting	5	4	4	4	3	20
16	Digital Twin for Operations	3	2	5	4	2	16
17	IoT-Enabled Predictive Maintenance System	4	3	5	3	3	18

No.	Smart Initiative	Maturity	Flexibility	Sustainability	User Experience & Well-being	System Cost	Total Score
18	Real-Time Asset Tracking & Optimization	4	4	4	4	4	20
19	Automated Fault Detection & Diagnostics	4	4	4	4	4	20
20	Smart Cleaning System	3	4	4	4	3	18

This study is the result of a qualitative exercise.

7.2.7.3 SMART Initiatives Summary

Table 7.9: Initiative Prioritization Summary

Must-Have | Should-Have | Could-Have

Passenger Experience	Sustainable Environment	Safety & Security	Enhanced Operations & Maintenance
Seamless Self-Service Journey	Smart Waste & Water Management	AI-Powered Surveillance	Digital Twin for Operations
Biometric-Enabled Smart Gates	Air Quality & Noise Monitoring	Drone Surveillance & Response	IoT-Enabled Predictive Maintenance System
Personalized Passenger Information System	Dynamic Energy Zoning System	Smart Access Control Systems	Real-Time Asset Tracking & Optimization
Multilingual Virtual Concierge	Energy Demand Forecasting System	Unified Incident Command System	Automated Fault Detection & Diagnostics
Dynamic Queue & Flow Management System	Wildlife Predictive Model	Airfield Ground Lighting	Smart Cleaning Scheduling & Monitoring System

7.2.8 DETAILED SMART USE CASES

As part of this phase, we will proceed with the full design and implementation of the Must-Have Use Cases, ensuring all necessary systems and integrations are in place. For the Should-Have and Could-Have Use Cases, we will provide infrastructure design only, allowing for future implementation without major rework. This ensures flexibility while keeping the system future ready.

Must-Have Use Cases

7.2.8.1 Seamless Self-Service Journey

The Seamless Self-Service Journey initiative transforms the passenger experience by enabling travellers to independently complete all key steps of their journey, from check-in and bag drop to boarding, using fully integrated digital systems. Through biometric identification, self-service kiosks, and automated bag-drop counters, passengers can move through terminals with minimal physical contact or staff intervention. This initiative reduces wait times, improves operational throughput, and enhances convenience, particularly during peak travel periods.

Objectives:

- Streamline passenger processing by automating check-in, bag drop, and boarding procedures
- Reduce queuing times and improve throughput during peak hours
- Enhance accessibility and inclusivity through multilingual and intuitive self-service interfaces
- Strengthen operational efficiency and data synchronization across airport and airline systems

This use case supports the vision of delivering a SMART, passenger-centric airport experience that emphasizes digital transformation, service excellence, and operational efficiency.

7.2.8.1.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Self-Service Kiosks:**
  Floor-mounted kiosks positioned within terminal check-in halls using reinforced base plates anchored to concrete flooring. ADA-compliant design allowing accessibility and stability.
- **Automated Bag Drop Units:**
  Fixed conveyor and weighing modules integrated into existing baggage handling counters with vibration-resistant mounting brackets and anti-slip bases.
- **E-Gates and Access Barriers:**
  Stainless steel or aluminium gate housings with tempered glass panels; surface-mounted on embedded conduits for power and data cabling.
- **Peripheral Devices:**
  Wall-mounted document scanners, boarding pass printers, and signage displays using concealed brackets; protection against tampering and vandalism.

Power Supply Infrastructure

Specifications:

- **Primary Power Supply (AC 230V):**
  Dedicated circuits from the terminal's low-voltage distribution network supplying kiosks, gates, and conveyor modules.
- **Power Protection:**
  Each unit fitted with miniature circuit breakers (MCBs) and surge protection for equipment safety and operational continuity.
- **Uninterruptible Power Supply (UPS):**
  Local UPS (1–2 kVA) units installed for kiosks, e-gates, and servers to maintain functionality during short outages.
- **Emergency Backup:**
  Integration with the airport's central backup generators to ensure continuous operation of critical passenger processing systems during extended power loss.

Communication Network Infrastructure

Specifications:

- **Network Backbone:**
  High-speed Cat6A or fiber-optic cabling linking kiosks, gates, and bag-drop units to the terminal network via local communication cabinets.
- **Wireless Connectivity:**
  Secure Wi-Fi 6 or private LTE/5G for data exchange with central servers and mobile applications.

- **System Integration:**
  Encrypted API connections between self-service devices, airline DCS (Departure Control Systems), and the airport's passenger data management platforms.
- **Security Protocols:**
  End-to-end encryption (TLS 1.3) and network segmentation for data integrity and cyber protection.
- **Redundancy:**
  Dual-network routing and edge data caching for uninterrupted service during network congestion or failure.

7.2.8.1.2 Technology Requirements

Self-Service Kiosks

Self-service kiosks form the first step in the passenger journey, allowing travellers to independently check in, select seats, and print boarding passes or baggage tags. These kiosks connect directly to the airline Departure Control System (DCS) and the airport's Passenger Data Platform, ensuring secure, real-time synchronization.

Specifications:

- Functions: Passenger check-in, seat selection, boarding pass and tag printing
- Display: 21–27" touchscreens with ADA-compliant height adjustment
- Authentication: Passport, ID scan, or facial recognition integration
- Connectivity: Ethernet or Wi-Fi 6 connection to airline DCS via industry standard protocols or API
- Security**:** TLS 1.3 encryption, privacy shutter for camera, PCI DSS compliance

Automated Bag-Drop Units

Automated bag-drop counters allow passengers to deposit tagged luggage without staff assistance. Each unit integrates weighing scales, barcode scanners, RFID readers, and baggage conveyor interfaces. Cameras verify baggage dimensions and handle detection to ensure compliance with airline safety standards before automatic dispatch to the baggage handling system (BHS).

Specifications:

- Components: Weighing scales, bag tag readers (barcode/RFID), conveyor interface
- User Interface: 15–19" touchscreen with multi-language and accessibility options
- Capacity: Up to 60 bags per hour per unit
- Security: Integrated CCTV and anomaly detection for untagged or oversized bags

Biometric Identity Verification Module

This module validates passenger identity during each key checkpoint (check-in, security, boarding) using facial recognition or fingerprint matching. AI algorithms perform real-time liveness detection and compare captured biometrics against pre-registered digital profiles to prevent spoofing and ensure compliance with border-control standards.

Specifications:

- Technology: Facial and fingerprint recognition with liveness detection
- Accuracy: ≥99% verification success under varied lighting conditions
- Processing: Edge-AI inference for latency <1.5 seconds per passenger
- Data Handling: Encrypted data capture, GDPR/ICAO-compliant storage

Passenger Flow Analytics Engine

An AI-powered analytics platform that aggregates data from kiosks, gates, and sensors to predict queue times, monitor dwell areas, and dynamically allocate resources. It provides operators with real-time insights into passenger distribution and identifies bottlenecks to optimize service allocation during peak periods.

Specifications:

- Data Inputs: IoT sensors, CCTV footfall analytics, and check-in timestamps
- Analytics: Predictive queue modelling and congestion heat-mapping
- Dashboard: Role-based web interface for operational teams
- Data Security: Cloud-hosted with encrypted API communication (TLS 1.3)

Passenger Mobile Integration Layer

The mobile integration layer enables passengers to complete digital pre-check-in, receive e-boarding passes, and link their identity to biometric gates through the airport's app or airline applications. This ensures a consistent, contactless journey across all touchpoints

Specifications:

- Functions: Pre-check-in, e-boarding pass, flight alerts, biometric enrolment
- Platform: iOS/Android mobile SDK integration
- Communication Protocols: RESTful APIs over HTTPS for transactional operations, and WebSocket protocol for real-time synchronization
- Security: Biometric login, two-factor authentication, encrypted data storage

7.2.8.1.3 Implementation Requirements

The implementation of the Seamless Self-Service Journey system is designed to streamline the passenger experience by automating all key travel processes, from check-in and bag drop to boarding. This involves deploying biometric-enabled kiosks, automated bag-drop units, and e-gates across passenger processing zones. Each location is strategically selected based on passenger flow, terminal layout, and traffic density to ensure efficient throughput, reduced queue times, and minimal staff dependency.

Table 7.10: Seamless Self-Service Journey Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Self-Service Check-In Kiosks	Departures Hall, Check-In Areas	Enable passengers to check in, print boarding passes, and manage bookings independently	1 kiosk per 2–3 check-in counters
Automated Bag Drop Units	Check-In Zones	Facilitate self-service baggage drop, weight validation, and tag verification	1–2 units per airline zone
Biometric-Enabled E-Gates	Security & Boarding Gates	Verify passenger identity and boarding credentials via facial recognition or fingerprint	1 gate per 2 traditional lanes
Integrated Passenger Flow Analytics	Check-In & Departure Zones	Monitor real-time passenger movement, queue length, and service efficiency	Sensors per lane cluster (approx. 1 per 100 m²)

7.2.8.1.4 Main Data Requirements

The Seamless Self-Service Journey system relies on the continuous exchange of passenger, flight, baggage, and biometric data across multiple airport subsystems. This data integration enables passengers to move independently through check-in, bag drop and boarding while maintaining full synchronization between airport and airline systems. The following outlines the main data requirements necessary for accurate identity verification, service automation, and operational coordination.

Passenger Identity & Biometric Data

Specifications:

- Data Fields: Passenger name, passport/ID number, biometric templates (face, fingerprint)
- Source: Self-service kiosks, biometric enrolment stations, airline databases
- Transmission: Event-based during check-in, bag drop, and gate access
- Ingestion Method: Secure API exchange with identity management and airline systems

Flight Operations & Scheduling Data

Specifications:

- Data Fields: Flight number, departure gate, boarding time, airline routing updates
- Source: Airline Operations System (AOS), Airport Operations Database (AODB)
- Transmission: Real-time sync and periodic updates (every 5–10 min)
- Ingestion Method: API or message bus integration with passenger journey systems

Baggage Tracking & Tagging Data

Specifications:

- Data Fields: Baggage tag ID, passenger ID, weight, screening status, transfer route
- Source: Automated bag drop units, Baggage Handling System (BHS)
- Transmission: Event-based per baggage transaction
- Ingestion Method: Direct integration with BHS and airline DCS via middleware

Passenger Flow & Checkpoint Status Data

Specifications:

- Data Fields: Queue length, service time, kiosk availability, congestion metrics
- Source: IoT sensors, computer vision analytics, passenger flow dashboards
- Transmission: Real-time continuous stream
- Ingestion Method: IoT gateway and API integration into operational analytics layer

System Performance & Service Logs

Specifications:

- Data Fields: Device status, uptime, error codes, user session logs
- Source: Self-service kiosks, e-gates, API endpoints
- Transmission: Continuous real-time monitoring with periodic summaries
- Ingestion Method: Centralized system log aggregator and maintenance monitoring platform

7.2.8.2 Biometric-Enabled Smart Gates

The Biometric-Enabled Smart Gates initiative enhances the efficiency and security of passenger processing by introducing automated gates equipped with facial recognition and fingerprint verification technologies. Integrated with airline and border control databases, these gates enable touchless identity verification and boarding authorization, minimizing manual checks and reducing congestion at key control points. The system accelerates passenger flow, enhances safety through real-time identity validation, and ensures compliance with international aviation security standards.

Objectives:

- Automate passenger verification and access control for faster processing
- Improve security by reducing human error in ID validation
- Enhance passenger convenience through contactless, technology-driven screening
- Align airport operations with global biometric security protocols and standards

This use case supports the vision of creating a secure, efficient, and contactless passenger journey.

7.2.8.2.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Smart Gate Units**:

  Floor-mounted modular gate structures made of stainless steel or anodized aluminium with anti-tamper enclosures. Each unit includes integrated turnstiles, biometric cameras, and LED guidance panels.

- **Camera Mounts:**

  Overhead or embedded mounts designed for facial recognition cameras, ensuring proper height and lighting angles for passengers of varying heights.

- **Barrier Integration:**

  Retractable glass or polycarbonate swing panels with embedded sensors for motion control, integrated within gate housings.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**

  Individual power lines routed through underfloor conduits or ceiling trays to each gate module, protected with dedicated circuit breakers and surge suppressors.

- **Low-Voltage Supply (DC 12/24V):**

  Power adapters for biometric scanners, card readers, and gate sensors, integrated into the gate's internal power management unit.

- **Backup Power:**

  UPS (1–2 kVA) deployed for each gate cluster to maintain operation during short interruptions, ensuring uninterrupted passenger flow.

Communication Network Infrastructure

Specifications:

- **Data Connectivity:**

  High-speed Ethernet (Cat6A) linking biometric gates to local processing servers and the airport's security operations centre.

- **Edge Computing Nodes:**

  Local edge servers housed in secure network cabinets near gate clusters for real-time biometric data processing and low latency response.

- **Integration Interfaces:**

  Secure API and middleware facilitating communication between gates, airline DCS, immigration, and security databases.

- **Network Security:**

  End-to-end encryption (TLS 1.3) and role-based access control for data exchange; all biometric data anonymized and compliant with data protection regulations.

- **Redundancy:**

  Dual Ethernet links with failover routing; local data caching to sustain gate operation in case of temporary network disruption.

7.2.8.2.2 Technology Requirements

Biometric Recognition Cameras

High-resolution biometric cameras capture passenger facial or fingerprint data at gates for identity verification and access authorization. These cameras are equipped with infrared and 3D depth sensors to ensure accurate recognition under variable lighting conditions.

Specifications:

- Technology: 3D/IR cameras with AI-based facial and fingerprint recognition
- Accuracy: ≥99% under mixed light and motion conditions
- Processing: Edge inference with latency ≤1.5 seconds per transaction
- Security: Encrypted data transmission (TLS 1.3), automatic data deletion post-verification

Smart E-Gate Modules

Automated smart gates manage passenger entry and exit at key checkpoints such as boarding and security zones. Each unit integrates biometric scanners, access barriers, and embedded controllers that communicate with authentication servers. Adaptive LED indicators and display panels guide passengers through the verification process seamlessly.

Specifications:

- Components: Gate barrier unit, control module, biometric interface, LED guidance
- Operation Speed: 10–15 passengers per minute per gate
- Access Control: Role-based permissions for security zones and boarding validation
- Safety Features: Anti-tailgating sensors, emergency manual override

Edge Computing Gate Controllers

Edge computing units process biometric and passenger data locally to minimize network latency and ensure continuous gate operation even during connectivity disruptions. These controllers store temporary credentials and manage gate logic, communicating with cloud servers only for verification and synchronization.

Specifications:

- Latency: Sub-2 second total transaction cycle
- Connectivity: Dual Ethernet and Wi-Fi redundancy
- Security: Role-based access control, local encryption, automatic sync with AIMS

7.2.8.2.3 Implementation Requirements

The implementation of Biometric-Enabled Smart Gates enhances passenger flow efficiency and strengthens security at key control points such as immigration, security, and boarding. The system combines facial recognition, fingerprint scanning, and secure data exchange with national and airline databases to enable touchless, real-time identity verification. Gates are strategically positioned in high-traffic processing zones to minimize manual checks and optimize throughput, particularly during peak operational hours.

Table 7.11: Biometric-Enabled Smart Gates Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Biometric Verification Gates	Security & Boarding Checkpoints	Automate passenger identity verification through facial or fingerprint recognition	1 gate per 2–3 manual lanes
Facial Recognition Cameras & Liveness Detection Sensors	Integrated within Smart Gates	Capture high-resolution images and verify passenger authenticity against pre-enrolled data	1 unit per gate
Biometric Enrollment Kiosks	Departure & Arrival Halls	Register passenger biometrics for authentication during check-in and boarding	1 kiosk per terminal zone
Edge AI Processing Units	Security & Border Control Rooms	Enable local biometric matching, reducing latency and dependency on cloud connectivity	1 unit per 4–6 gates

7.2.8.2.4 Main Data Requirements

Biometric-Enabled Smart Gates depend on secure, low-latency data exchange between biometric sensors, identity management platforms, airline/immigration systems, and gate controllers. These streams enable touchless verification, access authorization, exception handling, and auditability while meeting privacy and security obligations. The following outlines the primary data requirements.

Biometric Identity & Watchlist Data

Specifications:

- Data Fields: Biometric templates (face/fingerprint), passenger ID, watchlist flags, liveness score
- Source: Gate cameras/scanners, Identity Management System (IMS), border/airport security databases
- Transmission: Event-based at enrollment/verification; sub-second responses required
- Ingestion Method: Encrypted API to IMS/security systems; edge cache for temporary matching data

Travel Document & Boarding Entitlement Data

Specifications:

- Data Fields: Passport/ID OCR, visa status, boarding pass (barcode/RFID), flight/gate assignment
- Source: Airline DCS/AODB, document readers at gates, mobile/app wallets
- Transmission: Event-based on approach/scan; periodic sync for flight updates (5–10 min)
- Ingestion Method: REST/WebSocket APIs via secure gateway to DCS/AODB and document verification services

Gate Transaction & Access Control Logs

Specifications:

- Data Fields: Time-stamped pass/fail events, reason codes (mismatch, expired doc), gate ID, operator overrides
- Source: Gate controllers, access control layer, operator console
- Transmission: Real-time streaming with periodic batch archival
- Ingestion Method: Secure syslog/API to central security log repository and AOCC analytics

7.2.8.3 Smart Waste & Water Management

The Smart Waste & Water Management initiative promotes resource efficiency and sustainability by integrating IoT-enabled monitoring and control systems across waste collection and water distribution networks. Smart bins equipped with fill-level and contamination sensors optimize collection schedules, while automated leak detection and smart valves ensure responsible water use and conservation. Real-time dashboards track usage patterns, recycling performance, and resource consumption, supporting proactive maintenance and data-driven sustainability reporting.

Objectives:

- Optimize waste collection and water management through real-time monitoring and automation
- Reduce resource wastage by identifying inefficiencies and leakages early
- Enable data-driven sustainability performance tracking and reporting
- Enhance operational efficiency through predictive analytics and remote-control capabilities

This use case supports the vision of advancing sustainable airport operations through intelligent resource management, operational efficiency, and environmental stewardship.

7.2.8.3.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Smart Waste Bins:**
  Floor-mounted or recessed waste bins fitted with ultrasonic fill-level and contamination sensors. Outdoor units equipped with weatherproof (IP65+) housings and internal mounting brackets to prevent sensor damage during servicing.
- **Water Flow Sensors & Valves:**
  In-line installation within existing plumbing networks using corrosion-resistant stainless-steel fittings and quick-release couplings for easy maintenance.
- **Leak Detection Sensors:**
  Surface-mounted or under-floor probes with adhesive backing or clip brackets for installation in restrooms, technical rooms, and water supply areas.

Power Supply Infrastructure

Specifications:

- **Battery-Powered Sensors:**
  IoT waste and leak detection sensors powered by long-life lithium batteries (3–5 years lifespan) with low-battery alerts integrated into the monitoring dashboard.
- **Mains Power (AC 230V):**
  Fixed water control systems, smart valves, and data gateways powered via protected electrical circuits with miniature circuit breakers (MCBs).
- **Backup Power:**
  UPS (500–1000 VA) supporting gateways and communication nodes to ensure data continuity during short-term outages.

Communication Network Infrastructure

Specifications:

- **Wireless Connectivity:**
  LoRaWAN or NB-IoT for low-power, wide-area communication between distributed sensors and central servers.

- **Data Aggregation:**
  Local IoT gateways positioned in service zones to collect and transmit data to the central sustainability management system via secure APIs.
- **System Integration:**
  API-based communication with facility management and environmental monitoring platforms for unified reporting.

7.2.8.3.2 Technology Requirements

Smart Waste Bin System

Smart waste bins use embedded ultrasonic and optical sensors to detect fill levels, waste types, and contamination levels in real time. The system classifies waste (e.g., recyclable, organic, hazardous) and communicates with a central platform to optimize collection routes and schedules.

Specifications:

- Sensors: Ultrasonic and optical waste detection (range: 10–80 cm)
- Data Communication: LoRaWAN or NB-IoT for low-power connectivity
- Power Source: Battery-powered (3–5 years) or solar-assisted units for outdoor areas

Smart Water Flow & Leak Detection Sensors

IoT-enabled flow meters and leak detectors continuously monitor water usage and detect abnormalities such as excessive consumption or pipeline leakage. These sensors provide real-time data to the building's water management system, allowing automatic isolation of affected zones and preventing wastage.

Specifications:

- Technology: Ultrasonic or electromagnetic flow measurement
- Accuracy: ±1% of reading with real-time flow anomaly detection
- Connectivity: Wired communication using BACnet/IP protocol or wireless connectivity via LoRaWAN or NB-IoT networks
- Response Time: Leak detection within 30 seconds

Smart Valves & Automated Control Modules

Automated smart valves regulate water flow based on occupancy patterns, maintenance schedules, or detected anomalies. Equipped with electric actuators, they can automatically shut off sections during leak events or optimize flow during peak and off-peak hours.

Specifications:

- Valve Type: Motorized ball or butterfly valves with actuator feedback
- Control Protocols: BACnet/IP or Modbus TCP
- Power: 24V DC or PoE-enabled control modules
- Safety: Manual override and fault detection capability

Environmental Monitoring Platform

A cloud-based management platform aggregates data from waste and water systems, providing real-time dashboards, analytics, and sustainability reports. The platform supports predictive insights, KPI visualization, and trend-based optimization for consumption and collection cycles.

Specifications:

- Interface: Web-based dashboard with customizable alerts and reporting
- Analytics: Predictive models for usage forecasting and optimization

7.2.8.3.3 Implementation Requirements

The Smart Waste & Water Management system is deployed to improve environmental performance and resource efficiency through intelligent monitoring, automation, and data-driven decision-making. IoT-based sensors and smart collection units are strategically placed throughout terminals, airside areas, and utility facilities to track fill levels, detect leaks, and optimize maintenance schedules. This ensures timely waste collection, efficient water consumption, and continuous sustainability reporting aligned with operational and environmental goals.

Table 7.12Smart Waste & Water Management Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Smart Waste Bins with Fill-Level Sensors	Terminal Halls, Food Courts, Airside Zones	Monitor bin fill levels and send alerts for optimized waste collection routing	1 unit per 100–150 m² of public area
Smart Water Meters	Utility Rooms, Restrooms, Maintenance Areas	Measure water usage in real-time for leak detection and consumption analysis	1 unit per water circuit or main line
Ultrasonic Leak Detection Sensors	Plumbing Networks, Restrooms, Underground Pipelines	Detect abnormal flow, leakage, or pressure drops in water supply lines	1 sensor per 50–75 m of pipeline
IoT Control Valves	Utility Shafts, Technical Rooms	Enable remote regulation of water flow and automatic shut-off during leaks	1 per major supply branch
Sustainability Dashboard	Facility Management Control Center	Aggregate real-time waste and water data for reporting, optimization, and compliance monitoring	1 centrally managed instance

7.2.8.3.4 Main Data Requirements

The Smart Waste & Water Management system relies on synchronized telemetry from distributed sensors, meters, and control valves, combined with location and routing data. These streams enable real-time collection optimization, early leak detection, automated shutoffs, sustainability reporting, and targeted maintenance. The following outlines the primary data requirements.

Waste Bin Telemetry & Contamination Data

Specifications:

- Data Fields: Fill level (%), compaction status, bin temperature, lid events, contamination flag.
- Source: Smart waste bins (ultrasonic/optical sensors, onboard controllers)
- Transmission: Event-based on thresholds; periodic heartbeat (5–15 min)

Water Metering & Leak Event Data

Specifications:

- Data Fields: Flow rate, cumulative consumption, pressure, backflow, anomaly/leak alarms
- Source: Ultrasonic/electromagnetic meters; inline pressure/flow sensors; leak probes
- Transmission: Near real-time (30–60 sec) with instant event push on anomalies

Valve Control & Actuation Logs

Specifications:

- Data Fields: Valve open/close state, command source (auto/manual), timestamp, failure codes

- Source: Smart motorized valves/actuators and local controllers
- Transmission: Event-based on state change; periodic status sync (5–10 min)

Alerts, Notifications & Escalation Workflow Data

Specifications:

- Data Fields: Alert type/severity, impacted zone, SLA timer, escalation steps, resolution notes
- Source: Waste/Water rules engine, anomaly detection service, operator inputs
- Transmission: Real-time push (SMS/email/app) with SLA-driven reminders

7.2.8.4 Air Quality & Noise Monitoring

The Air Quality & Noise Monitoring initiative enhances environmental management by deploying a network of smart sensors that continuously measure air pollutants, temperature, humidity, and noise levels across airport zones. Data from these sensors is analysed in real time to assess environmental performance, ensure compliance with regulatory standards, and maintain passenger and staff comfort. Insights generated from the system enable timely interventions, such as optimizing ventilation systems, adjusting operational activities, or alerting relevant teams when thresholds are exceeded.

Objectives:

- Monitor air quality and noise levels continuously to ensure a healthy and compliant environment
- Provide real-time data to support proactive operational and environmental decisions
- Enable long-term sustainability tracking and regulatory reporting through digital dashboards
- Enhance comfort and wellbeing for passengers and staff through data-informed control actions

This use case supports the vision of establishing a safe, healthy, and environmentally responsible operational environment through smart monitoring and responsive management systems.

7.2.8.4.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Air Quality Sensors:**
  Wall-mounted or pole-mounted sensor units positioned across terminal interiors, parking areas, and airside zones at heights between 2–3 meters for optimal air sampling. Enclosures rated IP65 or higher for dust and moisture protection.
- **Noise Monitoring Stations:**
  Pole-mounted or rooftop acoustic sensors housed in weatherproof, vibration-isolated casings to ensure accurate sound readings. Installed near runways, taxiways, and terminal façades to capture representative data.
- **Calibration Points:**
  Designated access points at each monitoring station for sensor maintenance and calibration in compliance with environmental monitoring standards.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Air quality and noise monitoring units powered from the airport's low-voltage network through weatherproof distribution boxes and circuit protection devices.

- **Solar-Powered Units:**
  Select outdoor sensors (particularly in remote airside areas) equipped with integrated solar panels and rechargeable batteries to ensure autonomous operation.
- **Backup Power:**
  UPS (500 VA) or internal battery modules providing 24–48 hours of backup during power interruptions.
- **Energy Management:**
  Smart controllers enabling automatic power optimization and low-power operation during off-peak monitoring hours.

Communication Network Infrastructure

Specifications:

- **Network Connectivity:**
  Combination of wired Ethernet (Cat6A) for fixed indoor units and wireless (LoRaWAN or 4G/5G) for remote outdoor sensors.
- **Data Transmission:**
  Continuous data flow to the central environmental management system via secure APIs, enabling real-time dashboards and alert notifications.
- **System Integration:**
  Bidirectional communication with the Building Management System (BMS) and sustainability analytics platform for automated air quality control (e.g., triggering HVAC adjustments).
- **Data Security:**
  Encrypted communication (TLS 1.3) and device-level authentication to ensure data integrity and prevent unauthorized access.

7.2.8.4.2 Technology Requirements

Air Quality Monitoring Sensors

Smart air quality sensors continuously measure pollutants across indoor and outdoor zones. These multi-parameter sensors transmit real-time data to the environmental management system to maintain optimal air conditions and regulatory compliance. Integrated temperature and humidity sensors improve environmental accuracy and HVAC coordination.

Specifications:

- Measured Parameters: CO_2, NO_2, PM2.5/PM10, VOCs, temperature, humidity
- Accuracy: ±2% for particulate matter, ±3% for gas concentrations
- Connectivity: LoRaWAN, Wi-Fi, or Ethernet depending on location
- Power: 24V DC or solar powered for outdoor units

Noise Monitoring Stations

Noise monitoring units measure ambient sound levels across the airfield, terminal façades, and passenger areas. They help identify noise hotspots, correlate acoustic data with flight operations.

Specifications:

- Measurement Range: 30–130 dB(A)
- Accuracy: ±1 dB
- Power: AC 230V or solar-powered with 48-hour battery backup
- Connectivity: 4G/LTE or LoRaWAN for continuous data transmission

Edge Data Gateways

IoT gateways aggregate data from multiple environmental sensors, process it locally for anomaly detection, and securely transmit it to the cloud. These devices ensure efficient communication and minimize latency, while maintaining continuous operation during connectivity loss through local data buffering.

Specifications:

- Connectivity: Dual Ethernet, Wi-Fi 6, and cellular (4G/5G) backup
- Data Handling: Local buffering; automatic sync upon reconnection
- Security: AES-256 encryption and device-level authentication
- Integration Points: Cloud-based Environmental Monitoring Platform, BMS

7.2.8.4.3 Implementation Requirements

The Air Quality & Noise Monitoring system ensures a healthy and compliant airport environment by continuously tracking air pollutants, temperature, humidity, and acoustic levels across terminals and airside zones. The system combines distributed environmental sensors, weather integration, and centralized analytics to detect deviations from regulatory thresholds. Data insights support proactive HVAC adjustments, noise mitigation measures, and sustainability reporting aligned with international aviation and environmental standards.

Table 7.13: Air Quality & Noise Monitoring Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Air Quality Monitoring Sensors (PM2.5, CO_2, NOx)	Terminal Halls, Airside Aprons, Parking Zones	Measure and report real-time air quality parameters for comfort and compliance	1 sensor per 500–1,000 m² indoor zone / per apron sector outdoors
Acoustic & Noise Level Sensors	Runways, Taxiways, and Perimeter Fences	Capture continuous noise data to assess impact of aircraft operations and support mitigation strategies	1 sensor per 300–500 m along perimeter or runway axis
Weather & Climate Integration Node	Rooftop or External Environmental Stations	Collect meteorological data (wind, humidity, temperature) to correlate with air/noise trends	1 node per terminal cluster
Edge Processing Units	Facility Control Rooms / Utility Buildings	Process sensor data locally for anomaly detection and reduce cloud dependency	1 unit per terminal or monitoring cluster
Environmental Performance Dashboard	Airport Operations & Sustainability Control Center	Visualize data, generate reports, and trigger alerts for air or noise threshold exceedance	1 centrally managed instance

7.2.8.4.4 Main Data Requirements

The Air Quality & Noise Monitoring system depends on continuous environmental data collection across indoor and outdoor zones. Real-time integration of air pollutant levels, acoustic measurements, and meteorological conditions enables compliance tracking, comfort optimization, and early detection of environmental risks. The data also supports operational decisions, such as HVAC control adjustments and flight scheduling in sensitive zones.

Air Quality Sensor Data

Specifications:

- Data Fields: Concentrations of $PM_{2.5}$, PM_{10}, CO_2, NOx, SO_2, O_3, temperature, humidity
- Source: Fixed and portable air quality sensors deployed across terminals, aprons, and parking areas
- Transmission: Continuous streaming (every 30–60 seconds)

Acoustic & Noise Monitoring Data

Specifications:

- Data Fields: Sound pressure levels (dB), frequency spectrum, event type (aircraft/vehicle/ambient)
- Source: Acoustic sensors and microphone arrays along runways, taxiways, and terminal perimeters
- Transmission: Continuous feed with event tagging (10–30 sec intervals)

Location & Zone Mapping Data

Specifications:

- Data Fields: Valve open/close state, command source (auto/manual), timestamp, failure codes
- Source: Smart motorized valves/actuators and local controllers
- Transmission: Event-based on state change; periodic status sync (5–10 min)

Threshold, Compliance & Alert Data

Specifications:

- Data Fields: Sensor geolocation, zone boundaries, exposure maps
- Source: GIS/BIM environment and facilities mapping systems
- Transmission: Periodic updates (daily or on asset relocation)

7.2.8.5 Dynamic Energy Zoning System

The Dynamic Energy Zoning System initiative optimizes energy consumption across terminal spaces by automatically regulating lighting, HVAC, and ventilation systems based on real-time occupancy, daylight availability, and environmental conditions. Using motion and thermal sensors, the system dynamically adjusts energy delivery to match usage patterns, ensuring comfort while minimizing waste. A centralized dashboard allows facility managers to monitor performance, override settings when necessary, and analyse consumption trends to identify further efficiency opportunities.

Objectives:

- Reduce energy waste by aligning system operation with real-time occupancy and environmental conditions
- Enhance passenger comfort through automated environmental control and intelligent zoning
- Empower facility teams with data-driven insights for efficient energy management
- Support sustainability targets by lowering carbon emissions and overall energy consumption

This use case supports the vision of achieving operational efficiency and sustainability through intelligent, responsive energy management and smart infrastructure control.

7.2.8.5.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Occupancy & Thermal Sensors:**
  Ceiling-mounted sensors positioned at key terminal areas such as gates, lounges, and corridors, using concealed brackets or modular ceiling tiles for easy access and maintenance.
- **Lighting & HVAC Controllers:**
  Wall-mounted or rack-mounted control modules integrated within existing electrical and mechanical rooms, equipped with lockable enclosures for security and environmental protection.
- **Smart Actuators & Valves:**
  Installed within air-handling units, diffusers, and ventilation ducts to enable zonal air distribution control; equipped with vibration-resistant mounting.
- **Environmental Sensors:**
  Mounted at representative points across zones (approximately every 100–150 m^2) to provide accurate temperature, humidity, and light-level feedback to the control system.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied through terminal's low-voltage network with individual circuit breakers for lighting controllers, HVAC zones, and actuators.
- **Low-Voltage (DC 12–24V):**
  Used for distributed environmental and occupancy sensors connected through structured cabling or PoE (Power over Ethernet) for simplified installation.
- **Backup Power:**
  UPS (1–2 kVA) systems supporting central controllers and BMS gateways to maintain zone control during short power outages.

Communication Network Infrastructure

Specifications:

- **Network Backbone:**
  Wired Ethernet (Cat6A or fiber) connecting zone controllers, environmental sensors, and lighting control modules to the central Building Management System (BMS).
- **Wireless Connectivity:**
  Zigbee for low-power sensor networks or BACnet/IP over Wi-Fi for control devices in areas where wired connections are not feasible.
- **Integration Interfaces:**
  Open-protocol communication with BMS and Energy Management Systems (EMS) for real-time monitoring, automation, and reporting.

7.2.8.5.2 Technology Requirements

Occupancy & Environmental Sensors

IoT-based sensors detect occupancy, motion, temperature, humidity, and light levels to enable dynamic adjustment of HVAC and lighting systems within each airport zone. These sensors form the backbone of energy zoning logic, feeding continuous environmental data into the Building Management System (BMS) for real-time optimization.

Specifications:

- Sensing Capabilities: Occupancy, thermal, CO_2, and ambient light detection

- Coverage: 10–15 m radius per sensor (indoor use)
- Power Supply: 24V DC or PoE-enabled for low-voltage operation
- Connectivity: Combination of IP-based (BACnet/IP over Ethernet or Wi-Fi 6) and non-IP (Zigbee) networks, selected based on device type and location

Smart Lighting Controllers

Programmable lighting control modules adjust brightness levels based on occupancy, daylight availability, and terminal activity. Integrated dimming and scheduling functions reduce energy consumption and extend fixture lifespan. Lighting controllers interface with BMS and can be remotely configured for maintenance or zoning reallocation.

Specifications:

- Control Type: DALI-2 / KNX-compatible dimming modules
- Response Time: <1 second for sensor-triggered adjustments
- Power Input: 230V AC, with surge protection and isolation transformers
- Features: Time-based scheduling, daylight harvesting, remote overrides

Smart HVAC Zone Controllers

Intelligent controllers manage airflow and temperature setpoints dynamically, based on real-time occupancy and comfort parameters. These units adjust damper positions, fan speeds, and cooling loads to balance efficiency with comfort, ensuring that underutilized areas consume minimal energy.

Specifications:

- Control Logic: PID adaptive algorithms for predictive airflow management
- Connectivity: BACnet/IP or Modbus TCP for integration with central HVAC systems
- Power: 24V DC
- Safety Features: Manual override and auto-fail safe mode

Zonal Energy Analytics Platform

This analytics layer consolidates energy data from sensors, HVAC, and lighting controllers to visualize performance by terminal area. It applies machine learning to detect inefficiencies and generate actionable recommendations for load balancing and demand reduction.

Specifications:

- Functions: Data aggregation, anomaly detection, performance benchmarking
- Data Analytics: AI/ML models for predictive energy management
- Interface: Web-based dashboard with real-time visualizations and KPIs
- Security: Encrypted data channels (TLS 1.3), role-based access control

7.2.8.5.3 Implementation Requirements

The Dynamic Energy Zoning System optimizes energy consumption across the airport by intelligently controlling HVAC, lighting, and ventilation based on real-time occupancy, environmental conditions, and operational schedules. The system integrates IoT sensors, smart controllers, and AI algorithms to dynamically adjust settings per zone, ensuring comfort, efficiency, and reduced peak energy demand. Each deployment location is selected to provide optimal coverage of passenger areas, technical spaces, and high-energy-use zones.

Table 7.14: Dynamic Energy Zoning System Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Occupancy & Thermal Sensors	Passenger Terminals, Lounges, and Offices	Detect presence, temperature, and motion to optimize HVAC and lighting usage	1 sensor per 50–100 m² depending on area function
Smart Lighting Controllers (DALI / PoE)	Public Areas, Gates, Corridors	Adjust lighting intensity based on occupancy, daylight levels, and schedule	1 controller per lighting zone or cluster (approx. 100–200 m²)
HVAC Zonal Controllers	Technical Rooms, Ceiling Panels	Regulate air distribution and temperature settings dynamically across terminal zones	1 unit per HVAC zone (avg. 200–300 m²)
Environmental Gateways	Electrical or Mechanical Rooms	Aggregate sensor data and execute control commands across systems	1 node per 5–10 controlled zones
Energy Management Dashboard	Airport Operations Control Centre (AOCC) or Facility Control Room	Provide real-time visibility and control over zonal energy usage, trends, and savings	1 centralized instance with multi-user access

7.2.8.5.4 Main Data Requirements

The Dynamic Energy Zoning System relies on continuous multi-source data from occupancy sensors, HVAC units, lighting controllers, and environmental sensors to intelligently regulate energy use by zone. These integrated data streams enable automated optimization of temperature, airflow, and lighting levels based on real-time occupancy and climate conditions, ensuring both comfort and energy efficiency.

Occupancy & Motion Sensor Data

Specifications:

- Data Fields: Occupancy status, motion detection, zone ID, timestamp
- Source: PIR, thermal, or ultrasonic sensors installed in terminal and office zones
- Transmission: Event-based upon occupancy change, with 15–30 sec status updates

Environmental & Climate Data

Specifications:

- Data Fields: Temperature, humidity, CO_2 levels, external weather data
- Source: Indoor environmental sensors and external weather stations
- Transmission: Continuous streaming (30–60 sec)

HVAC & Lighting Control Data

Specifications:

- Data Fields: Airflow rate, fan speed, damper position, lighting level, power consumption
- Source: Zonal HVAC controllers, lighting dimmers, and smart relays
- Transmission: Continuous or event-based per control action

Zone Mapping & Energy Profiling Data

Specifications:

- Data Fields: Zone ID, function type (lounge, gate, retail), equipment list, energy consumption baseline

- Source: Digital twin model, facility management database
- Transmission: Periodic sync (daily) with updates upon zone reconfiguration

7.2.8.6 Airfield Ground Lighting

The Airfield Ground Lighting initiative enhances airfield safety and operational efficiency through an intelligent, sensor-based lighting system that automatically adjusts runway and taxiway illumination according to visibility, occupancy, and aircraft proximity. Integrated with air traffic control and ground movement systems, the lighting network improves situational awareness for pilots and ground crews while minimizing energy consumption through adaptive dimming and LED technology. Predictive diagnostics continuously monitor system health, alerting maintenance teams to potential faults before they impact operations.

Objectives:

- Improve runway and taxiway visibility to enhance aircraft safety in all weather and lighting conditions
- Reduce energy consumption through adaptive brightness control and efficient LED systems
- Enable predictive maintenance to minimize downtime and prevent lighting failures
- Strengthen coordination between airfield lighting, ATC, and ground operations systems

This use case supports the vision of ensuring safe, efficient, and sustainable airfield operations through advanced automation and intelligent lighting control.

7.2.8.6.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Runway and Taxiway Lighting Fixtures:**
  Inset LED luminaires embedded within pavement fittings. Fixtures are anchored in corrosion-resistant aluminum bases, sealed with watertight gaskets.
- **Edge and Guidance Lighting:**
  Elevated fittings on galvanized steel or aluminum frangible mounts positioned along taxiway and runway edges. Height and alignment designed to withstand jet blast while maintaining visibility.
- **Control and Monitoring Cabinets:**
  Ground-mounted weatherproof (IP66) enclosures for lighting regulators and circuit control units located in airfield electrical substations.
- **Sensor Integration:**
  Light sensors, occupancy detectors, and environmental probes installed along runways for adaptive illumination control based on visibility and movement detection.

Power Supply Infrastructure

Specifications:

- **Primary Power Supply (AC 400V / 50Hz):**
  Distributed through airfield lighting constant current regulators (CCR) and field circuits, ensuring stable power delivery to all AGL circuits.
- **Low-Voltage Conversion:**
  Step-down transformers integrated within the CCR system for control electronics, communication modules, and sensor power.
- **Backup Power:**
  Centralized backup generator systems and UPS units (10–20 kVA) providing emergency lighting power for critical airfield zones during outages.

Communication Network Infrastructure

Specifications:

- **Network Architecture:**
  Fiber-optic backbone linking the AGL control room, CCRs, and distributed lighting circuits, enabling real-time control and feedback.
- **Control Protocol:**
  Use of standardized communication interfaces (e.g., ALCMS/IEC 61850 or Modbus TCP) for data exchange between lighting control systems and ATC.
- **Security and Reliability:**
  Redundant fiber paths with automatic failover; encrypted data transmission between field controllers and the central lighting management server.

7.2.8.6.2 Technology Requirements

LED Airfield Lighting Fixtures

High-efficiency LED runway and taxiway lights provide uniform illumination while reducing energy consumption and maintenance needs. Each fixture integrates built-in temperature and current sensors for real-time health monitoring.

Specifications:

- Type: Inset and elevated LED lights (runway edge, centreline, and taxiway guidance)
- Power: 6.6A series circuit (via CCR), 230V AC for control units
- Lifespan: ≥60,000 operational hours
- Ingress Protection: IP68 and IK10 impact rating

Visibility & Occupancy Sensors

Integrated sensors positioned along runways and taxiways detect ambient visibility, fog density, and aircraft proximity. These inputs trigger adaptive lighting intensity to optimize safety and energy usage under varying conditions.

Specifications:

- Parameters: RVR (Runway Visual Range), ambient luminance, occupancy detection
- Response Time: <1 second for dynamic dimming
- Connectivity: LoRaWAN for low-bandwidth or fiber connection for high-speed control communication
- Environmental Protection: IP66 housing with anti-condensation systems

Airfield Lighting Control & Monitoring System (ALCMS)

The ALCMS is the central control platform for all AGL operations. It enables operators to monitor, configure, and adjust lighting intensity levels based on operational conditions and visibility. It provides automated switching between operational modes (day/night/low visibility) and issues alerts for lamp failures or abnormal voltage levels.

Specifications:

- Functions: Real-time lighting control, system diagnostics, alarm management
- Interface: Graphical HMI with GIS-based runway/taxiway visualization
- Redundancy: Dual-server configuration with hot-swappable components
- Security: Encrypted control communication, user access management

7.2.8.6.3 Implementation Requirements

The Airfield Ground Lighting (AGL) system enhances aircraft safety and operational efficiency by providing adaptive, sensor-integrated lighting control across runways, taxiways, and aprons. The system dynamically adjusts brightness and colour according to aircraft position, weather, and visibility conditions. Smart controllers and LED fixtures communicate with Air Traffic Control (ATC) and maintenance systems for seamless operation, real-time fault detection, and optimized power use.

Table 7.15Airfield Ground Lighting Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
LED Runway and Taxiway Lights (with Embedded Sensors)	Runways, Taxiways, Aprons	Provide adaptive illumination based on aircraft movement and weather visibility	As per ICAO spacing standards (15–60 m intervals depending on category)
Smart Lighting Control Units (ILCMS)	Airfield Lighting Control Rooms, Electrical Substations	Manage dimming, sequencing, and synchronization across lighting circuits	1 unit per runway/taxiway lighting circuit
Occupancy and Proximity Sensors	Taxiway Intersections, Apron Entry Points	Detect aircraft presence to trigger localized lighting activation	1 sensor per intersection or entry node
AGL Monitoring & Maintenance Dashboard	Airfield Control Tower / Maintenance Operations Centre	Visualize lighting system status, detect faults, and perform predictive maintenance	1 centralized instance per airfield

7.2.8.6.4 Main Data Requirements

The Airfield Ground Lighting (AGL) system relies on continuous and highly reliable data exchange between lighting circuits, sensors, controllers, and the Air Traffic Control (ATC) systems. These data flows enable adaptive lighting control, predictive maintenance, safety compliance, and efficient energy management. The system must ensure low-latency communication and redundancy to maintain operational integrity under all weather and visibility conditions.

Lighting Circuit & Fixture Status Data

Specifications:

- Data Fields: On/off status, brightness level, circuit ID, voltage/current, fault flags
- Source: LED lighting fixtures, constant current regulators (CCRs), smart controllers
- Transmission: Continuous telemetry (1–5 sec intervals)
- Ingestion Method: Fieldbus (CANbus/Modbus RTU) → AGL Control Network → Central AGL System

Visibility & Weather Condition Data

Specifications:

- Data Fields: Runway visual range (RVR), wind speed, fog density, precipitation, temperature
- Source: Airfield weather sensors and meteorological stations
- Transmission: Continuous updates every 30–60 seconds

Aircraft & Airfield Occupancy Data

Specifications:

- Data Fields: Aircraft position, taxiway/runway occupancy, gate allocation, movement clearance
- Source: Surface movement radar (SMR), ADS-B sensors, ATC flight movement database
- Transmission: Real-time (sub-second updates for aircraft movement)

Fault Detection & Maintenance Data

Specifications:

- Data Fields: Lamp failures, cable faults, circuit overloads, maintenance logs, MTBF metrics
- Source: Smart lighting controllers, diagnostic modules, maintenance database
- Transmission: Event-based on fault detection; periodic batch updates for trend analysis

7.2.8.7 Real-Time Asset Tracking & Optimization

The Real-Time Asset Tracking & Optimization initiative improves operational efficiency by enabling continuous visibility and management of airport assets such as baggage tugs, carts, and ground support equipment. Using IoT and RFID tracking technologies, assets are monitored for location, utilization, and condition across airside and landside zones. Data is visualized through a centralized dashboard that supports dynamic allocation, dispatch, and maintenance scheduling. This ensures equipment availability where and when needed, reducing delays, idle time, and operational inefficiencies.

Objectives:

- Enable real-time location tracking and utilization monitoring of critical assets
- Improve operational coordination through dynamic asset allocation and dispatch
- Reduce downtime and asset loss by enabling continuous visibility and performance tracking
- Support data-driven decision-making to optimize resource use and maintenance planning

This use case supports the vision of enhancing operational efficiency and reliability through intelligent asset management and connected digital infrastructure.

7.2.8.7.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **IoT / RFID Tag Installation:**
  Compact, vibration-resistant tags mounted directly on mobile equipment (e.g., baggage tugs, fuel trucks, wheelchairs, carts) using magnetic or adhesive brackets. Weatherproof enclosures (IP67) for outdoor and airside durability.
- **Fixed Tracking Beacons & Gateways:**
  Ceiling- or wall-mounted LoRa/BLE beacons and gateways positioned throughout terminals, aprons, and logistics areas to enable seamless coverage and triangulation.
- **Asset Management Terminals:**
  Wall-mounted touchscreen interfaces at operational control centers and maintenance bays for local asset registration and tracking visualization.

Power Supply Infrastructure

Specifications:

- **Battery-Powered Tags:**
  Long-life lithium batteries (3–5 years average lifespan) integrated into tracking tags with low-battery alerts and energy-saving sleep modes.
- **Gateway Power (AC 230V):**
  Fixed gateways and readers powered via low-voltage circuits with surge protection and miniature circuit breakers (MCBs).
- **PoE (Power over Ethernet):**
  Used for indoor gateways and beacons to simplify cabling and ensure uninterrupted power.

- **Backup Power:**
  UPS systems (500–1000 VA) supporting core gateway clusters and asset tracking servers for continuity during power loss.

Communication Network Infrastructure

Specifications:

- **Wireless Connectivity:**
  Combination of BLE, LoRaWAN, and Wi-Fi 6 for asset tag data transmission, depending on range and density of coverage areas.
- **Network Backbone:**
  Ethernet and fiber links connecting gateways to the airport's central Asset Management System and AOCC.
- **System Integration:**
  Secure APIs for data sharing with maintenance, logistics, and operations systems to support real-time decision-making.
- **Data Security:**
  Encrypted communication protocols (AES-256 or TLS 1.3) and device authentication for data integrity.

7.2.8.7.2 Technology Requirements

IoT & RFID Asset Tags

Durable IoT-enabled RFID tags are mounted on mobile and fixed airport assets such as baggage tugs, service carts, and GSE (Ground Support Equipment) to transmit real-time data on their location, movement, and operational status. These tags operate under harsh airside conditions and provide continuous visibility through low-power communication.

Specifications:

- Type: Passive and active RFID / BLE tags with integrated accelerometers
- Transmission Range: Up to 200 meters (BLE), 30 meters (RFID passive)
- Battery Life: 3–5 years (replaceable lithium cells)
- Protection: IP67-rated enclosures, vibration- and heat-resistant

Fixed Tracking Beacons & Gateways

Tracking beacons and gateways collect signals from asset tags and transmit them to the central system for localization. Gateways are strategically installed across terminals, aprons, and service roads to ensure full coverage and redundancy. They perform edge processing to filter redundant data and reduce latency.

Specifications:

- Communication: BLE, LoRaWAN, or UWB-based triangulation
- Range: Up to 500 meters (LoRa) or 150 meters (BLE)
- Power Supply: PoE-enabled or AC 230V with UPS backup
- Data Processing: Edge analytics for position accuracy and movement patterns

Central Asset Intelligence Platform

The central platform aggregates data from IoT tags, beacons, and operational systems to visualize asset locations, usage rates, and availability in real time. It uses AI-based optimization to recommend asset redeployment and prevent equipment bottlenecks during peak periods.

Specifications:

- Functions: Real-time mapping, usage analytics, and route optimization
- Interface: Web-based dashboard with role-based user control
- Data Storage: Cloud or hybrid setup with historical trend tracking

- Security: AES-256 encryption and multi-level user authentication

Geo-Fencing & Alert System

This module enables real-time monitoring of asset movement within predefined operational zones. When assets enter or exit restricted or critical areas, alerts are automatically sent to operations control, improving asset accountability and compliance with airside safety protocols.

Specifications:

- Functions: Dynamic zone creation, asset movement alerts, access violation logging
- Accuracy: ±2 meters (BLE/UWB hybrid tracking
- Notification: Real-time SMS/email/app alerts to AOCC teams
- Security: Encrypted communication with audit trails

7.2.8.7.3 Implementation Requirements

The Real-Time Asset Tracking & Optimization deployment ensures continuous visibility and faster dispatch of critical assets (e.g., tugs, carts, GSE, wheelchairs) across airside and landside zones. The rollout combines rugged IoT/RFID tags, fixed gateways/anchors, and a central asset intelligence platform, with geo-fencing at operational boundaries to improve availability, reduce idle time, and prevent loss or misallocation during peaks.

Table 7.16: Real-Time Asset Tracking & Optimization Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
IoT/RFID/BLE Asset Tags (ruggedized)	On tugs, GPUs, belt loaders, catering trucks, wheelchairs, carts	Transmit live location, motion, and utilization; enable asset check-in/out	**1 tag per asset**
Fixed Tracking Gateways (BLE/LoRa/UWB)	Terminal ceilings, piers, baggage halls, GSE yards, apron edges	Collect tag signals, triangulate position, relay to platform	**1 gateway per 800–1,500 m² indoors**; **1 per 3,000–5,000 m² airside**
Geo-Fence Beacons / Virtual Boundaries	Airside/landside boundaries, fuel farm, maintenance bays	Trigger alerts on zone entry/exit, enforce area compliance	**Perimeter beacons every 50–100 m** or **virtual fences per zone**
Vehicle Telematics Units (CAN/GPS)	On powered GSE (tugs, loaders, buses)	Report engine hours, routes, dwell; prevent misuse	**1 unit per powered GSE**

7.2.8.7.4 Main Data Requirements

The Real-Time Asset Tracking & Optimization system depends on continuous data streams from IoT tags, telematics devices, and operational platforms to maintain full visibility of all airport assets, including ground support equipment (GSE), baggage carts, tugs, and wheelchairs. These data flows enable live location tracking, performance optimization, predictive utilization analysis, and streamlined dispatching to reduce idle time and improve operational efficiency.

<u>Asset Location & Movement Data</u>

Specifications:

- Data Fields: GPS coordinates, zone ID, velocity, heading, timestamp
- Source: IoT/RFID/BLE asset tags, vehicle telematics units, fixed location anchors
- Transmission: Continuous or periodic (every 5–10 seconds for mobile assets)

Asset Utilization & Availability Data

Specifications:

- Data Fields: Usage time, idle status, assignment records, operational cycles
- Source: IoT asset tags, operator mobile app, dispatch management system
- Transmission: Event-based (on assignment or completion) and periodic sync (every 15 min)

Telemetry & Condition Monitoring Data

Specifications:

- Data Fields: Engine hours, fuel/battery level, vibration, temperature, operational anomalies
- Source: Vehicle telematics units, embedded sensors in powered GSE
- Transmission: Continuous telemetry (10–30 sec intervals); event-based on fault

Zone & Geo-Fence Event Data

Specifications:

- Data Fields: Zone entry/exit events, geo-fence ID, time stamp, boundary violations
- Source: Fixed anchors, GPS-based asset positioning
- Transmission: Event-based upon boundary crossing

7.2.8.8 Automated Fault Detection & Diagnostics

The Automated Fault Detection & Diagnostics initiative strengthens operational reliability by enabling real-time monitoring, detection, and analysis of faults across critical airport systems, including power, baggage handling, lighting, and HVAC networks. Through edge-computing devices and smart controllers, the system continuously compares operational data against defined performance thresholds to identify anomalies as they occur. Once a fault is detected, automated diagnostics isolate the cause, classify the issue, and notify maintenance teams with recommended corrective actions. Integration with digital twin platforms allows operators to visualize affected areas and assess potential operational impacts before intervention.

Objectives:

- Identify and classify system faults in real time to prevent service disruptions
- Reduce troubleshooting time and improve maintenance response through automated diagnostics
- Enhance system visibility and decision-making using data analytics and predictive insights
- Support proactive maintenance planning and reduce operational downtime

This use case supports the vision of achieving resilient, data-driven airport operations through automation, predictive intelligence, and integrated system monitoring.

7.2.8.8.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Edge Controllers & Smart Sensors:**
  Wall- or rack-mounted edge controllers installed in technical rooms or control cabinets to collect data from electrical, HVAC, baggage handling, and lighting systems.
  Smart sensors (temperature, vibration, current, and voltage) mounted on key equipment such as air handling units, conveyor motors, and power panels using magnetic or clamp-on fixtures.

- **Diagnostic Panels:**
  Touchscreen or rack-mounted panels within maintenance control rooms for live system monitoring and diagnostics display.

- **Sensor Enclosures:**
  IP65-rated casings for all exposed airside or mechanical room installations to protect against humidity, dust, and vibration.
- **Integration Hubs:**
  Mounted in equipment rooms with structured cable routing to ensure modular expansion and easy maintenance access.

<u>Power Supply Infrastructure</u>

Specifications:

- **Primary Power (AC 230V):**
  Supplied via local power distribution boards to support controllers, communication modules, and monitoring equipment.
- **Low-Voltage Power (DC 24V):**
  Used for distributed sensors and transducers, powered through centralized control panels or PoE connections.
- **Backup Power:**
  UPS (1–2 kVA) units deployed at control rooms and server racks to maintain system visibility during grid interruptions.
- **Power Protection:**
  Surge suppressors, overcurrent protection, and grounding systems for all sensitive electronics connected to field equipment.

<u>Communication Network Infrastructure</u>

Specifications:

- **Data Network Backbone:**
  Ethernet (Cat6A) and fiber-optic cabling connecting smart sensors, PLCs, and controllers to the airport's central maintenance servers and digital twin environment.
- **Field Communication Protocols:**
  Modbus TCP/IP, BACnet/IP, or OPC-UA for interoperability between HVAC, electrical, and mechanical systems.
- **Wireless Connectivity:**
  Secure Wi-Fi or private LTE for transmitting data from mobile diagnostic devices or remote equipment zones.
- **Integration Architecture:**
  Real-time data streaming to predictive analytics platforms and AOCC dashboards via secured APIs and MQTT message brokers.

7.2.8.8.2 Technology Requirements

Edge Fault Detection Controllers

Edge-based controllers collect real-time performance data from HVAC systems, baggage conveyors, power panels, and lighting grids. These intelligent devices continuously compare sensor readings against pre-set thresholds to detect anomalies locally, ensuring immediate alerts without relying on cloud latency.

Specifications:

- Processor: Industrial-grade ARM or x86 edge controller with AI inference support
- Input Types: Analog (0–10V, 4–20mA), digital, and Modbus-compatible sensor inputs
- Response Time: <1 second for fault detection and classification
- Connectivity: Dual Ethernet and Wi-Fi 6 for redundant communication

Smart Sensors & Diagnostic Modules

Smart vibration, current, temperature, and voltage sensors are deployed on key equipment such as pumps, motors, baggage belts, and power units to capture continuous performance data. These sensors use embedded analytics to detect irregular patterns indicative of mechanical or electrical failure.

Specifications:

- Sensor Types: Vibration (triaxial), temperature, current, and power quality sensors
- Accuracy: ±1% for electrical, ±0.5°C for thermal reading
- Mounting: Magnetic or adhesive for non-intrusive installation
- Power: 24V DC or battery-operated for remote equipment

Fault Analytics & Classification Engine

An AI-powered software module processes incoming data from sensors and controllers to identify fault causes, severity levels, and probable system impacts. The engine uses historical and real-time data to classify faults as electrical, mechanical, or software-related and provides recommended corrective actions.

Specifications:

- Model Type: AI/ML-based predictive and prescriptive fault detection models
- Data Inputs: Time-series data from sensors and equipment logs
- Output: Fault type classification, root-cause analysis, and resolution suggestions
- Interface: Web-based or integrated within AOCC dashboard

Central Diagnostics Dashboard

A web-based dashboard consolidates all fault alerts, system health metrics, and maintenance workflows. It provides real-time visualization of equipment status and allows operators to prioritize issues based on severity, location, and operational impact.

Specifications:

- Interface: Multi-layer map view with color-coded asset status
- Functions: Fault logs, maintenance history, and automated work order creation
- Accessibility: Secure browser access with role-based permissions
- Security: TLS 1.3 encryption and multifactor operator authentication

7.2.8.8.3 Implementation Requirements

The Automated Fault Detection & Diagnostics system is deployed to ensure real-time monitoring, detection, and resolution of faults across key airport infrastructure such as baggage systems, HVAC, lighting grids, and power networks. Through distributed edge controllers, smart sensors, and diagnostic software, the system continuously analyses performance data to identify anomalies, classify faults, and alert maintenance teams.

Table 7.17: Real-Time Asset Tracking & Optimization Proposed Technology Location and Quantity Strategy

Technology Enabler	Proposed Location	Functional Role	Recommended Density
Edge Fault Detection Controllers	Technical Rooms, Power Distribution Panels, HVAC Units	Collect and process real-time data from connected sensors to identify abnormal conditions	1 controller per major subsystem (HVAC, baggage, lighting, power)
Smart Vibration, Temperature & Voltage Sensors	Motors, Pumps, Conveyor Belts, Electrical Panels	Measure operational parameters to detect mechanical or electrical faults early	2–4 sensors per equipment unit

Technology Enabler	Proposed Location	Functional Role	Recommended Density
			depending on size and complexity
Diagnostic Gateways / Edge Data Nodes	Service Corridors, Equipment Rooms	Aggregate sensor data and transmit alerts to central analytics engine	1 gateway per equipment cluster or terminal zone
Central Fault Analytics Platform	AOCC / Maintenance Control Room	Analyze, classify, and visualize system faults; issue alerts and suggest corrective actions	1 centralized instance integrated with BMS

7.2.8.8.4 Main Data Requirements

The Automated Fault Detection & Diagnostics system depends on high-frequency data streams from edge controllers, smart sensors, and equipment monitoring interfaces. These inputs allow continuous performance comparison against operational thresholds, real-time fault classification, and automated alerts to maintenance teams. Data integration across systems such as HVAC, power, baggage handling, and lighting ensures proactive fault identification and rapid response coordination.

Equipment Performance & Sensor Data

Specifications:

- Data Fields: Vibration, temperature, current, voltage, airflow, system pressure, fault flags
- Source: Smart vibration/temperature sensors, power meters, HVAC sensors, conveyor monitoring units
- Transmission: Continuous (1–10 sec intervals) or event-based upon deviation from normal thresholds

Edge Diagnostics & Anomaly Detection Data

Specifications:

- Data Fields: Diagnostic logs, pattern deviation metrics, fault classification (mechanical/electrical/software)
- Source: Edge fault detection controllers and embedded analytics processors
- Transmission: Real-time processing at edge; periodic sync to central system (every 5–10 min)

Fault Alerts & Event Notifications

Specifications:

- Data Fields: Fault ID, timestamp, severity, equipment type, location, recommended action
- Source: Fault analytics engine, automated rule-based alerts, AI diagnostic module
- Transmission: Event-based at detection; instant push to maintenance dashboard and mobile app

Maintenance & Resolution Data

Specifications:

- Data Fields: Work order ID, assigned technician, intervention report, resolution time, replaced components
- Source: CMMS, technician mobile app, maintenance planning system
- Transmission: Event-based on work order update; nightly batch sync for reporting

Should-Have & Could-Have Use Cases

7.2.8.9 Personalized Passenger Information System

The Personalized Passenger Information System enhances the airport journey by providing real-time, context-aware updates tailored to each traveller. By integrating indoor positioning, AI-driven recommendation engines, and live operational data, the system delivers dynamic information on gates, wait times, walking routes, baggage claim areas, and service availability through mobile apps and digital terminal displays. Passengers receive notifications customized to their current location, flight status, and preferences, reducing confusion, improving flow efficiency, and enhancing overall travel comfort.

Objectives:

- Deliver timely, personalized flight and wayfinding information through digital channels
- Improve terminal efficiency and passenger distribution via real-time data insights
- Reduce missed flights and congestion through predictive, location-based communication
- Support inclusivity with multilingual and accessible information delivery

This use case reinforces the airport's vision of a digitally connected, user-centric environment that improves situational awareness and passenger satisfaction.

7.2.8.9.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Digital Signage & Display Units:**
  Ceiling-mounted or wall-integrated LED/LCD displays in gate lounges, check-in areas, and arrival halls; anti-glare, vandal-resistant enclosures rated to IP54.
- **Beacon Nodes / Wi-Fi Access Points:**
  Mounted discreetly on ceilings or columns every 10–20 meters to ensure accurate indoor positioning coverage.
- **Interactive Kiosks:**
  Freestanding or wall-mounted touchscreen kiosks positioned at key circulation nodes with ergonomic height and accessibility compliance.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Dedicated circuits for signage, kiosks, and Wi-Fi access points via centralized electrical panels; surge-protected and stabilized.
- **Low-Voltage Power (DC 12-24V):**
  Power over Ethernet (PoE+) for beacons, IoT sensors, and low-consumption devices.
- **Backup Power:**
  UPS systems (1–2 kVA) for digital signage clusters and network switches, ensuring 30–60 minutes of runtime during power outages.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  High-speed Ethernet (Cat6A or fiber optic) connecting signage, kiosks, and IoT devices to the airport ICT backbone.
- **Wireless Coverage:**
  BLE beacons and Wi-Fi 6 access points for accurate passenger localization (±3–5 meters accuracy).
- **Integration Architecture:**
  APIs linking indoor positioning data, FIDS/AODB (Flight Information Display / Airport Operational Database), and mobile app notification servers.

- **Network Security:**
  Dual-path connectivity for display controllers and kiosks to prevent downtime during maintenance or switch failure.

7.2.8.10 Multilingual Virtual Concierge

The Multilingual Virtual Concierge initiative enhances passenger engagement by offering real-time, AI-powered assistance through mobile apps, kiosks, and interactive digital terminals. Using natural language processing (NLP), speech recognition, and multilingual databases, the system provides passengers with instant answers, wayfinding support, service recommendations, and flight information in their preferred language. It can proactively guide users to amenities such as lounges, restrooms, restaurants, or boarding gates based on their current location, flight time, and accessibility needs. This digital concierge reduces the dependence on staff, minimizes confusion for international travellers, and ensures inclusive, on-demand support across all airport zones.

Objectives:

- Provide passengers with real-time, multilingual assistance through AI chat and voice interfaces
- Reduce staff load and enhance service availability during peak periods
- Improve accessibility and inclusivity for non-native and special-needs passengers
- Integrate location-based and flight data to offer context-aware recommendations

This use case supports the vision of a digitally intelligent airport focused on inclusivity, automation, and effortless passenger interaction.

7.2.8.10.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Interactive Kiosk Units:**
  Freestanding or wall-mounted digital concierge kiosks installed in terminals, check-in halls, and transfer zones; equipped with microphones, cameras, and touchscreens (minimum 21-inch, anti-glare, IP54-rated).
- **Ceiling or Wall-Mounted Speakers & Microphones:**
  Mounted discreetly on ceilings or columns every 10–20 meters to ensure accurate indoor positioning coverage.
- **Server Racks & AI Processing Nodes:**
  Rack-mounted servers in ICT rooms or micro-data centres for local NLP model caching and edge processing.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Dedicated circuits from nearby electrical panels to support kiosks, display screens, and sensors.
- **Low-Voltage Power (DC 12-24V):**
  Power via PoE for microphones, cameras, and IoT peripheral devices.
- **Backup Power:**
  Local UPS (1 kVA) for each kiosk and central 2–3 kVA UPS for AI servers to ensure uninterrupted operation during outages.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  Ethernet (Cat6A) or fiber connections from kiosks and devices to the airport's ICT network.
- **Wireless Coverage:**
  Wi-Fi 6 or private LTE connection for mobile concierge features and cloud synchronization.
- **Integration Architecture:**
  APIs linking the AI engine with airport systems (AODB, FIDS, and CRM) to access live operational data.
- **Security & Data Privacy:**
  End-to-end encrypted data exchange (TLS 1.3) with anonymization of user voice/text inputs in compliance with data protection standards.

7.2.8.11 Dynamic Queue & Flow Management System

The Dynamic Queue & Flow Management **System** optimizes passenger movement across terminals by using real-time data from sensors, cameras, and AI analytics to detect congestion, predict crowding, and dynamically adjust passenger routing. Overhead computer vision units and footfall sensors continuously monitor queue lengths, processing times, and space occupancy, while AI algorithms generate predictive insights for staff allocation and wayfinding adjustments. Digital signage and mobile alerts guide passengers toward alternative routes or less congested checkpoints, improving comfort, throughput, and safety.

Objectives:

- Monitor and predict passenger congestion in real time using AI analytics
- Improve service allocation by adjusting queue distribution dynamically
- Enhance passenger experience and reduce perceived wait times through responsive communication
- Support operational planning and crowd management during peak hours or disruptions

This use case reinforces the vision of a smart, adaptive airport environment capable of maintaining smooth passenger circulation through data-driven intelligence.

7.2.8.11.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Overhead Cameras & Footfall Sensors:**
  Ceiling-mounted 3D depth cameras and LiDAR-based counters at key choke points (security, check-in, immigration, boarding gates) with vibration-resistant brackets.
- **Display Screens & Digital Signage:**
  Wall-mounted or suspended displays positioned at entrances and intersections to provide dynamic queue directions and estimated wait times.
- **Processing Units:**
  IP65-rated casings for all airside and public-zone sensors to protect against humidity, dust, and tampering.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied from nearby distribution panels to camera networks, signage, and edge gateways.
- **Low-Voltage Power (DC 24V):**
  For sensor arrays and control modules, distributed via PoE (Power over Ethernet) or dedicated converters.

- **Backup Power:**
  Localized UPS (1–2 kVA) for edge processing units and network switches to sustain system uptime during short power outages.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  High-speed Ethernet (Cat6A) connecting cameras, sensors, and signage to the airport's ICT backbone.
- **Wireless Coverage:**
  Wi-Fi 6 for staff handhelds and portable monitoring tablets.
- **Integration Architecture:**
  Real-time data integration with AOCC and Passenger Flow Dashboard via secure APIs.
- **Field Communication Protocols:**
  RTSP for video streams, MQTT for sensor telemetry, and HTTPS APIs for system control and dashboard updates.
- **Security & Data Privacy:**
  TLS 1.3 encryption for all data streams, VLAN segmentation between camera and analytics networks, and redundant uplinks to prevent loss of coverage.

7.2.8.12 Energy Demand Forecasting System

The Energy Demand Forecasting System leverages AI-driven analytics to predict short- and medium-term energy demand across airport facilities. By analysing historical consumption data, weather forecasts, flight schedules, and passenger volume projections, the system identifies patterns and anticipates load variations. These forecasts enable proactive energy management, optimizing HVAC performance, lighting schedules, and generator or renewable energy utilization. Integration with solar PV and battery storage systems supports grid balancing, reduces peak load dependency, and ensures energy resilience.

Objectives:

- Predict future energy demand to optimize consumption and reduce peak loads
- Integrate renewable energy generation and storage systems for efficient utilization
- Support proactive HVAC and lighting adjustments based on real-time condition
- Enhance sustainability by minimizing grid reliance and improving energy resilience

This use case reinforces the vision of a data-driven, energy-efficient airport committed to operational sustainability and carbon neutrality.

7.2.8.12.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Energy Monitoring Meters & Sensors:**
  Panel-mounted or DIN-rail energy meters installed in main electrical distribution boards (MDBs), substations, and terminal control rooms to capture load profiles and voltage data.
- **Weather and Environmental Sensors:**
  Roof- or mast-mounted meteorological units (solar radiation, temperature, humidity, wind) installed near renewable energy sites or terminal rooftops.
- **Server & Edge Processing Units:**
  Rack-mounted data acquisition servers housed in electrical rooms or energy management centres, with proper ventilation and climate control.

- **Smart Controllers:**
  Mounted adjacent to HVAC, lighting, and generator systems for load control and data synchronization.
- **Solar PV & Battery Integration Panels:**
  Wall- or rack-mounted control cabinets linking renewable energy systems with the monitoring platform.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied from existing power panels to meters, sensors, and smart controllers; fitted with overcurrent and surge protection.
- **Low-Voltage Power (DC 24V):**
  Distributed to IoT sensors and control modules via local converters or PoE interfaces.
- **Backup Power:**
  UPS units (2–3 kVA) installed in control centres and substation racks to maintain uninterrupted data logging during outages.
- **Power Conditioning:**
  Voltage stabilizers and isolators for sensitive metering and AI processing equipment.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  Fiber-optic or Cat6A Ethernet network linking energy meters, controllers, and edge processors to the central Energy Management Platform.
- **Field Communication Protocols:**
  Modbus TCP/IP, BACnet/IP, or OPC-UA for interoperability with BMS, HVAC, and renewable systems.
- **Wireless Connectivity:**
  Secure Wi-Fi or private LTE network for remote sensors and outdoor monitoring stations.
- **Integration Architecture:**
  APIs for real-time data exchange between the Energy Forecasting Platform, BMS, and AOCC.
- **Cybersecurity & Redundancy:**
  TLS 1.3 encryption, firewall segmentation between OT and IT networks, and dual uplinks for continuous data availability.

7.2.8.13 Wildlife Predictive Model

The Wildlife Predictive Model enhances airfield safety and environmental management by using AI and sensor technologies to monitor, predict, and mitigate bird and wildlife activity around the airport. By combining radar, acoustic, and optical data with ecological and climatic information, the system forecasts wildlife movement patterns that may pose risks to aircraft operations. Predictive alerts enable timely activation of deterrent measures such as ultrasonic emitters, lighting adjustments, or targeted habitat management.

Objectives:

- Predict and detect bird and wildlife presence near runways and taxiways in real time
- Reduce wildlife-related safety incidents through proactive intervention
- Support sustainable co-existence with surrounding ecosystems
- Integrate environmental and operational data to inform long-term wildlife management

This use case reinforces the goal of a safe, environmentally responsive airport ecosystem that leverages intelligent monitoring to balance safety and sustainability.

7.2.8.13.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Wildlife Detection Radars:**
  Ground-mounted short- to medium-range radar units installed at airfield perimeters or elevated poles (height 4–6 m) with 360° scanning capability.
- **Acoustic & Optical Sensors:**
  Mast-mounted directional microphones and camera systems positioned along runways, taxiways, and near water bodies for audio-visual wildlife tracking.
- **Environmental Monitoring Stations:**
  Pole-mounted or rooftop sensors for recording wind, temperature, and vegetation data in strategic ecological zones.
- **Control & Processing Cabinets:**
  Weatherproof (IP66-rated) enclosures near detection sites containing local data acquisition and power modules.
- **Solar PV & Battery Integration Panels:**
  Wall- or rack-mounted control cabinets linking renewable energy systems with the monitoring platform.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied from local airfield distribution panels to radar and camera systems with surge and lightning protection.
- **Low-Voltage Power (DC 24V):**
  Distributed to IoT sensors, acoustic detectors, and control circuits using regulated power converters or PoE-enabled network lines.
- **Backup Power:**
  Localized UPS (1–2 kVA) in control cabinets and central systems to sustain monitoring and data capture during power interruptions.
- **Renewable / Hybrid Power:**
  Optional solar panels with battery storage for remote or off-grid detection sites to ensure continuous monitoring.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  Fiber or long-range Ethernet connections from radar units and sensors to local control cabinets, with uplinks to the AOCC network.
- **Field Communication Protocols:**
  MQTT or OPC-UA for event-driven telemetry between detection systems and central analytics.
- **Wireless Connectivity:**
  Private LTE or radio frequency mesh network (2.4/5 GHz) for remote sensors beyond fiber reach.
- **Integration Architecture:**
  APIs connecting the Wildlife Model to the Airfield Management System (AMS), ATC interface, and AOCC dashboards for risk alerts.
- **Cybersecurity & Redundancy:**
  Encrypted data channels (TLS 1.3), device authentication, redundant network paths, and edge data buffering for resilience during network downtime.

7.2.8.14 AI-Powered Surveillance

The AI-Powered Surveillance initiative enhances airport safety and situational awareness by integrating intelligent video analytics with the existing CCTV infrastructure. Using deep learning algorithms, the system automatically detects unusual activities such as unattended baggage, unauthorized access, perimeter breaches, or crowd anomalies. Real-time alerts are sent to security teams through an integrated dashboard, enabling rapid response and evidence-based decision-making. Advanced image processing and thermal analytics allow continuous operation under various lighting and weather conditions.

Objectives:

- Automate detection of security threats and anomalies through AI-enabled video analytics
- Improve response times by providing real-time alerts and visual context to security operators
- Enhance perimeter surveillance and reduce dependence on manual monitoring
- Integrate analytics data into the Security Operations Centre (SOC) for coordinated incident response

This use case supports the airport's vision of a secure, intelligent, and resilient environment built on automation and real-time data-driven insights.

7.2.8.14.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Surveillance Cameras:**
  Fixed, PTZ (pan-tilt-zoom), and thermal cameras installed on poles, ceilings, and building facades covering terminals, runways, and perimeter fences; equipped with anti-vibration mounts and weatherproof housings (minimum IP66).
- **Edge Processing Units:**
  Pole-mounted or wall-mounted AI-enabled edge devices located near camera clusters for on-site analytics to reduce network load.
- **Network Video Recorders (NVRs):**
  Rack-mounted within local security or telecom rooms, connected to the central SOC for continuous video archiving.
- **Display Panels & Operator Consoles:**
  Wall-mounted or rack-integrated in the Security Operations Centre for live feeds and incident dashboards.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied from airside and terminal electrical panels with separate circuits for cameras, edge processors, and control units; includes surge suppression and lightning protection.
- **Low-Voltage Power (DC 12-24V):**
  Distributed through PoE+ (Power over Ethernet) for cameras and sensors, reducing cable clutter and enabling centralized power control.
- **Backup Power:**
  UPS units (2–3 kVA) installed at camera hubs and security rooms to maintain 1–2 hours of continuous surveillance during outages.

Communication Network Infrastructure

Specifications:

- **Data Backbone:**
  Fiber-optic or Cat6A Ethernet network connecting cameras, edge processors, and NVRs to the airport's ICT backbone.
- **Field Communication Protocols:**
  RTSP (Real-Time Streaming Protocol) for video feeds and MQTT/HTTPS for alarm and analytics data transmission.
- **Wireless Connectivity:**
  Secure Wi-Fi 6 or private LTE connections for temporary or mobile surveillance units.
- **Integration Architecture:**
  APIs connecting AI analytics platforms with SOC dashboards, access control systems, and AOCC emergency modules for coordinated response.
- **Cybersecurity & Redundancy:**
  Encrypted data streams (TLS 1.3), network segmentation for video and control traffic, device authentication, and redundant NVR storage for failover recording.

7.2.8.15 Drone Surveillance & Response

The Drone Surveillance & Response system enhances airside and perimeter monitoring by deploying autonomous or semi-autonomous drones equipped with high-resolution, thermal, and infrared imaging capabilities. These drones perform scheduled patrols, rapid-response missions, and visual inspections during incidents such as perimeter breaches, fires, or equipment failures. Integrated with the airport's Security Operations Center (SOC), the system streams live footage and event data to operators in real time. AI-assisted navigation and obstacle avoidance enable safe flight paths even in low visibility, while geofencing ensures compliance with restricted airspace.

Objectives:

- Expand surveillance coverage through autonomous airside and perimeter patrols
- Enhance emergency response capability with real-time aerial intelligence
- Reduce human resource demands and increase monitoring efficiency
- Integrate drone operations with SOC systems for coordinated incident response

This use case supports the airport's ambition to achieve proactive, technology-driven security operations that combine automation, safety, and rapid response.

7.2.8.15.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Drone Hangars / Docking Stations:**
  Ground-mounted or rooftop drone nests for automated take off, landing, charging, and data offloading; weatherproof and equipped with automatic doors (IP66-rated).
- **Launch & Recovery Pads:**
  Flat-surfaced, non-reflective helipads positioned along the airside perimeter and near maintenance hangars for manual or emergency operations.
- **Control & Communication Antennas:**
  Mast-mounted antennas placed at elevated points (10–15 m height) for uninterrupted drone connectivity; lightning-protected.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Provided to drone docking stations, communication modules, and control centres via local power panels with surge and overcurrent protection.
- **Low-Voltage Power (DC 12-48V):**
  Used for battery charging units and embedded drone components (controllers, sensors, cameras).
- **Backup Power:**
  Localized UPS (1–2 kVA) for control systems and docking stations to ensure mission continuity during outages.

Communication Network Infrastructure

Specifications:

- **Drone Communication Links:**
  Dual redundant radio-frequency (RF) and LTE/5G connectivity for command, control, and video streaming; AES-256 encryption for all transmissions.
- **Data Network Backbone:**
  Fiber or Ethernet connection between drone control centres, docking stations, and the SOC.
- **Wireless Connectivity:**
  Private LTE network for extended coverage and low-latency video transfer during patrol operations.
- **Integration Architecture:**
  APIs linking drone management software with AI analytics platforms, the Security Operations Centre, and the AOCC for situational updates.

7.2.8.16 Smart Access Control Systems

The Smart Access Control Systems initiative strengthens airport security by managing and monitoring staff, vehicle, and equipment access to restricted zones using biometric, RFID, and digital credential technologies. Integrated across terminals, airside gates, and service areas, the system authenticates personnel through facial recognition, fingerprint scans, or RFID badges while dynamically adjusting access privileges based on user roles, time schedules, and location. AI-based analytics detect irregularities such as tailgating or repeated unauthorized attempts and trigger automatic alerts.

Objectives:

- Enhance perimeter and internal access security through biometric and RFID-based authentication
- Streamline staff and vehicle movement with automated credential management
- Detect and prevent unauthorized access through AI-driven anomaly detection
- Integrate access control data with surveillance and HR systems for complete oversight

This use case aligns with the goal of a secure, automated, and accountable airport environment that leverages intelligent access management to protect assets and personnel.

7.2.8.16.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Access Terminals & Biometric Readers:**
  Wall-mounted or pedestal units installed at entry points, gates, and restricted areas; IP65-rated for durability in both indoor and outdoor conditions.

- **RFID Antennas & Vehicle Gate Controllers:**
  Mounted on gantries or barriers at vehicle entry lanes and airside access roads for automated credential scanning.
- **Server Racks & Controller Panels:**
  Housed in secure communication rooms, managing all reader inputs and relay outputs for physical locks or actuators.
- **CCTV Integration Points:**
  Ceiling or wall-mounted cameras near access points for event correlation and verification.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Dedicated circuits for biometric readers, access controllers, and gate motors, routed from local distribution panels with surge protection.
- **Low-Voltage Power (DC 12-24V):**
  Power supply for RFID modules, sensors, and control logic boards; distributed via PoE (Power over Ethernet) for flexibility and lower installation costs.
- **Backup Power:**
  UPS units (1–2 kVA) for each access control cabinet to maintain operation during outages and ensure emergency unlock capability.

Communication Network Infrastructure

Specifications:

- **Data Network Backbone:**
  Ethernet (Cat6A) connecting access terminals, biometric readers, and control panels to the central access management server.
- **Protocols & Encryption:**
  OSDP (Open Supervised Device Protocol) for reader-controller communication; TLS 1.3 encryption for data transmission.
- **Wireless Connectivity:**
  Secure Wi-Fi or private LTE for mobile credentials, handheld verification devices, or temporary access zones.
- **Integration Architecture:**
  APIs and secure data links to connect the Access Control Management System (ACMS) with the SOC, HR, and Visitor Management platforms.

7.2.8.17 Unified Incident Command System

The Unified Incident Command System (UICS) centralizes emergency coordination across airport departments, including fire, medical, police, security, and operations, under a single integrated digital platform. The system consolidates data feeds from sensors, alarms, surveillance, access control, and communication systems, providing a unified operational picture during both routine operations and crisis scenarios. When an incident occurs, automated alerts trigger predefined workflows, mobilizing the appropriate response teams based on location, severity, and incident type.

Objectives:

- Establish a unified command platform integrating all emergency response and monitoring systems
- Enable real-time situational awareness through live data visualization and automated workflows
- Improve interdepartmental coordination between airport security, emergency, and operations teams
- Reduce response times and improve incident documentation for post-event analysis

This use case reinforces the vision of a **resilient, responsive, and interconnected airport ecosystem**, where emergencies are managed through data-driven collaboration and automation.

7.2.8.17.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Command Centre Consoles:**
  Ergonomically designed, wall-mounted or desk-based control consoles installed in the Airport Operations Control Centre (AOCC) and Security Operations Centre (SOC) for 24/7 incident management.
- **Large Display Walls:**
  Multi-screen video walls (LED/LCD) for GIS-based mapping, live video feeds, and system dashboards.
- **Server Racks & Integration Cabinets:**
  Rack-mounted servers, integration gateways, and middleware units housed in dedicated data rooms adjacent to the AOCC for redundancy and network efficiency.
- **Field Sensor Nodes & Alarm Interfaces:**
  Panel-mounted interface units for integrating alarms from fire detection, HVAC, access control, and utility systems.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Dedicated electrical supply for AOCC and SOC control systems, including command consoles, communication devices, and display units, with centralized grounding and surge protection.
- **Low-Voltage Power (DC 24V):**
  Powering integration gateways, PLCs, and communication relays for sensor interfaces.
- **Backup Power:**
  UPS systems (3–5 kVA) ensuring continuous operation of all command centre components during power interruptions; supplemented by generator backup for long-duration outages.

Communication Network Infrastructure

Specifications:

- **Data Network Backbone:**
  Fiber-optic network connecting all safety, security, and operational systems (CCTV, HVAC, access control, fire alarms) to the UICS platform within the AOCC.
- **Protocols & Middleware:**
  Integration via OPC-UA, BACnet/IP, and REST APIs for interoperability between legacy and new subsystems.
- **Wireless Connectivity:**
  Secure Wi-Fi and private LTE network for mobile responders' tablets, handheld radios, and incident-reporting devices.
- **Integration Architecture:**
  The UICS connects through an API gateway to external entities such as emergency services (police, fire, medical), enabling two-way data sharing and automated incident reporting.
- **Cybersecurity & Redundancy:**
  Encrypted VPN tunnels, segmented VLANs for incident traffic, dual redundant servers, and failover routing to ensure continuous system availability and data protection.

7.2.8.18 Digital Twin for Operations

The Digital Twin for Operations initiative creates a real-time, data-driven 3D replica of the airport's infrastructure, assets, and operational processes. By integrating data from systems such as HVAC, baggage handling, energy management, and flight operations, the digital twin provides a dynamic operational view of terminal and airside activities. The system allows operators to visualize asset performance, simulate operational scenarios, and predict bottlenecks before they occur. During disruptions, it helps coordinate recovery by assessing the cascading impact of changes (e.g., gate reassignments or equipment failures) across dependent systems. The twin also supports predictive maintenance and long-term planning by analysing historical and real-time data trends.

Objectives:

- Centralize all operational data into a unified, real-time visualization platform
- Predict and mitigate disruptions through scenario-based simulations
- Improve cross-departmental coordination and asset management
- Support long-term operational planning and infrastructure optimization

This use case reinforces the vision of a resilient, responsive, and interconnected airport ecosystem, where emergencies are managed through data-driven collaboration and automation.

7.2.8.18.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Operations Control Consoles:**
  Multi-monitor workstations within the Airport Operations Control Centre (AOCC) for visualization, simulation, and control of digital twin environments.
- **Server & Data Processing Racks:**
  Rack-mounted servers installed in secure data centers to handle real-time 3D rendering, analytics, and model updates.
- **Sensor Integration Points:**
  Ceiling or wall-mounted IoT sensors across terminals and airside (temperature, vibration, occupancy, energy flow) feeding live data into the twin.
- **VR/AR Interface Stations:**
  Dedicated operator stations for immersive inspection and simulation using augmented or virtual reality for training and planning.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Dedicated supply for AOCC visualization consoles, servers, and processing equipment; equipped with overvoltage and surge protection.
- **Low-Voltage Power (DC 12–48V):**
  Powering IoT sensors, gateways, and edge controllers distributed throughout terminal and airside areas.
- **Backup Power:**
  UPS (3–5 kVA) and generator systems for the AOCC to maintain continuous digital twin operations and data integrity during outages.

Communication Network Infrastructure

Specifications:

- **Data Network Backbone:**
  High-speed fiber-optic network connecting IoT sensors, BMS, SCADA, baggage handling, and HVAC systems to the digital twin data servers.
- **Edge Connectivity:**
  Local edge computing gateways for preprocessing sensor data and minimizing latency.
- **Communication Protocols:**
  Middleware supporting BACnet/IP, Modbus TCP, OPC-UA, and REST APIs for interoperability across all systems.
- **Cloud Synchronization:**
  Secure cloud interface for data storage, AI model training, and remote operational analytics.
- **Cybersecurity & Redundancy:**
  Encrypted data exchange (TLS 1.3), segmented VLANs for system data flow, redundant network paths, and continuous failover synchronization.

7.2.8.19 IoT-Enabled Predictive Maintenance System

The IoT-Enabled Predictive Maintenance System enables continuous, data-driven monitoring of critical airport assets such as HVAC systems, baggage conveyors, elevators, lighting infrastructure, and power distribution units. By deploying embedded IoT sensors and AI analytics, the system measures key performance parameter, such as vibration, temperature, current, and operating hours, to forecast equipment degradation and predict failures before they occur. When anomalies are detected, predictive algorithms assess the severity, estimate the remaining useful life (RUL) of components, and automatically generate maintenance work orders. Maintenance teams receive alerts via mobile dashboards, allowing planned intervention without operational disruption.

Objectives:

- Predict and prevent equipment failures through continuous sensor-based condition monitoring
- Reduce unplanned downtime and optimize maintenance scheduling and resource use
- Extend asset lifespan and improve spare part management through accurate health forecasting
- Support data-driven maintenance planning integrated with airport operations

This use case supports the airport's vision for intelligent, proactive infrastructure management that combines automation, analytics, and reliability engineering for operational excellence.

7.2.8.19.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Sensor Deployment:**
  Clamp-on vibration, thermal, and current sensors installed directly on rotating or electrical equipment such as motors, pumps, and fans.
- **Condition Monitoring Units:**
  Compact, panel-mounted monitoring devices in equipment rooms or control cabinets collecting data from multiple sensors via wired or wireless interfaces.
- **Edge Gateways:**
  Wall- or rack-mounted data aggregation units positioned in mechanical and electrical rooms to pre-process sensor data before transmission to the cloud.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Supplied from local panels to edge gateways, condition monitoring units, and control servers.
- **Low-Voltage Power (DC 12-24V):**
  Used for IoT sensors and transducers, powered through PoE (Power over Ethernet) or DC loops.
- **Backup Power:**
  UPS units (1–2 kVA) in control and server rooms to maintain data continuity and alert generation during power interruptions.

Communication Network Infrastructure

Specifications:

- **Data Network Backbone:**
  Ethernet (Cat6A) and fiber-optic cabling interconnecting sensors, gateways, and predictive maintenance servers.
- **Field Communication Protocols:**
  OPC-UA, Modbus TCP/IP, or BACnet/IP ensuring compatibility with building and maintenance management systems.
- **Wireless Connectivity:**
  LoRaWAN or Wi-Fi 6 networks for low-power, wide-range sensor communication in hard-to-reach operational areas.
- **Integration Architecture:**
  APIs and MQTT message brokers transmitting real-time data to the Maintenance Management System (MMS), AOCC dashboards, and the digital twin.

7.2.8.20 Smart Cleaning System

The Smart Cleaning System initiative modernizes airport facility management by automating and optimizing cleaning operations based on real-time occupancy, usage, and environmental data. Using a network of IoT sensors installed in restrooms, lounges, and terminal areas, the system monitors parameters such as footfall, waste bin levels, humidity, and air quality to dynamically adjust cleaning schedules. Cleaning teams receive real-time task notifications through a mobile app, allowing prioritized dispatch to high-traffic or complaint-prone areas. Passenger feedback interfaces, such as touch panels or QR codes, allow users to report cleanliness issues, feeding data directly into the central dashboard.

Objectives:

- Automate and optimize cleaning schedules based on real-time usage and sensor data
- Improve cleanliness standards through data-driven dispatch and feedback integration
- Enhance operational efficiency and resource allocation for janitorial teams
- Support sustainability goals by reducing chemical and water use through targeted cleaning

This use case reinforces the vision of a resilient, responsive, and interconnected airport ecosystem, where emergencies are managed through data-driven collaboration and automation.

7.2.8.20.1 Primary Infrastructure Requirements

Mounting & Structural Support

Specifications:

- **Smart Waste Bins & Fill-Level Sensors:**
  Wall- or floor-mounted bins with ultrasonic or infrared fill sensors in high-traffic areas (restrooms, lounges, check-in halls).

- **Environmental & Occupancy Sensors:**
  Ceiling-mounted motion, CO_2, humidity, and ammonia detectors in restrooms and public areas to assess usage and cleanliness levels.
- **Feedback Panels & QR Tags:**
  Wall-mounted or pedestal touchscreen panels and QR codes near exits and facilities for passenger feedback collection.
- **Maintenance Control Panels:**
  Rack-mounted servers or gateways in facility management rooms to centralize sensor data collection and routing.

Power Supply Infrastructure

Specifications:

- **Primary Power (AC 230V):**
  Used for gateway hubs, control panels, and network routers within janitorial and maintenance areas.
- **Low-Voltage Power (DC 12–24V):**
  Deployed for environmental sensors, fill-level detectors, and occupancy modules; supplied via PoE (Power over Ethernet) or battery where wiring is impractical.
- **Backup Power:**
  UPS units (1–2 kVA) installed in maintenance rooms to ensure continuous monitoring during outages.

Communication Network Infrastructure

Specifications:

- **Data Network Backbone:**
  Ethernet (Cat6A) and Wi-Fi 6 connectivity linking sensors, mobile apps, and facility dashboards to the airport's maintenance management system.
- **Integration Architecture:**
  APIs connecting the cleaning management system to the central Facility Management and AOCC platforms for data visualization and reporting.
- **Wireless Connectivity:**
  Zigbee, LoRaWAN, or BLE protocols for low-power IoT communication across wide terminal zones.
- **Cloud Synchronization:**
  Cloud-based analytics for trend detection, task optimization, and predictive scheduling.
- **Cybersecurity & Redundancy:**
  Encrypted data exchange (TLS 1.3), segmented VLANs for system data flow, redundant network paths, and continuous failover synchronization.

7.2.9 SMART INFRASTRUCTURE & DATA STRATEGY

To design the smart infrastructure, we target an integrated digital platform. This approach ensures the airport operates cohesively unlocking real-time insights and adaptive capabilities for improved performance and user satisfaction ultimately helping the airport meet its objectives. We follow these data integration steps to ensure seamless flow and functionality. We begin by identifying all relevant data sources, including physical assets, digital systems, and external third-party feeds that contribute to smart operations. Once sources are mapped, data collection mechanisms are established to securely capture real-time information from sensors, controllers, enterprise platforms, and external APIs such as weather or traffic systems. Collected data is then ingested and integrated into a centralized data repository or lakehouse, where it is standardized, validated, and enriched for interoperability. This unified dataset supports advanced analytics and machine learning models that uncover insights into performance, efficiency, and anomalies. The results are visualized through dashboards and reporting interfaces, enabling data-driven decision-making and continuous optimization.

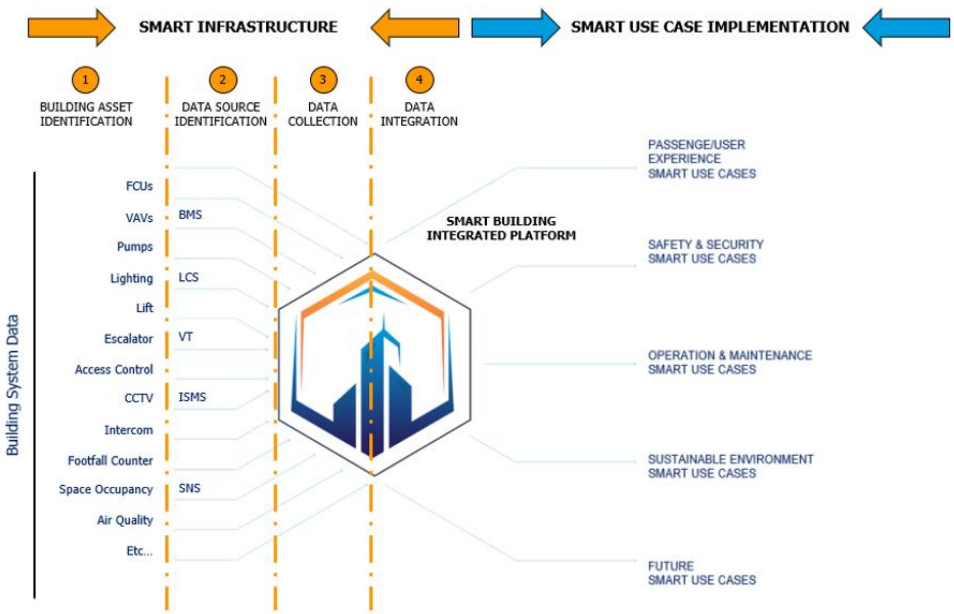


Figure 7.10: SMART Infrastructure Strategy Example

High-Level Network Architecture

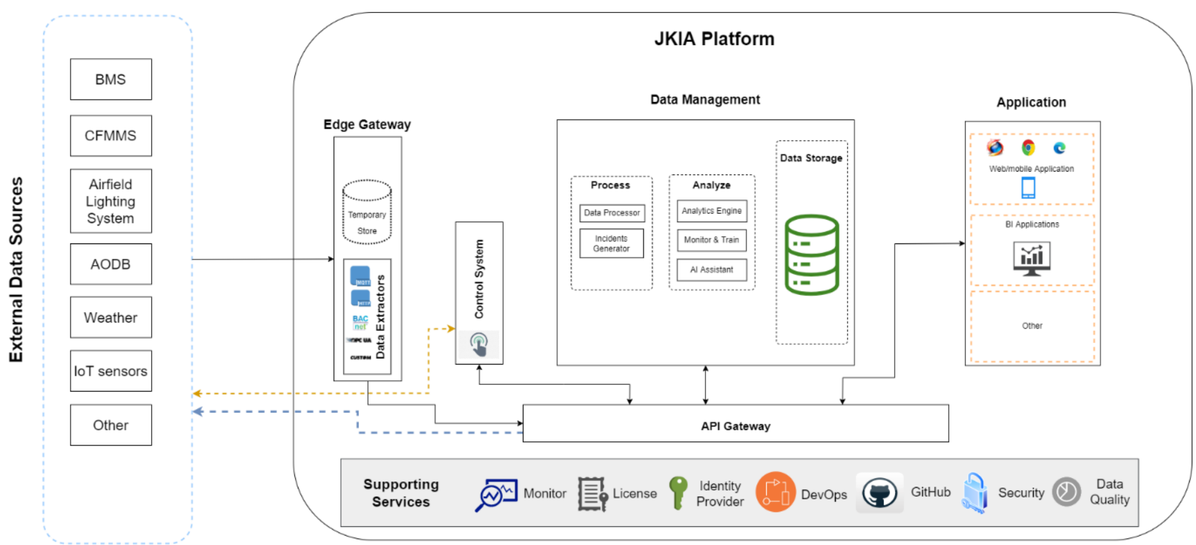


Figure 7.11: High-Level Network Architecture Example

The JKIA platform architecture shall be designed to include the needed architectural blocks leveraging cutting-edge technologies to deliver the intended use cases. In this section, we will be elaborating more on the components of the JKIA platform.

Basically, the JKIA platform shall be composed of a set of components handling the different states of the data whereby it is collected from other systems, stored, processed, analyzed, and visualized by the given applications consuming this data. The platform offers many features to target audiences, allowing them to monitor and control available entities and systems. It also exposes data to other systems allowing bi-directional communication via an API gateway.

As designated above, the components are as follows:

A. External Data Sources:
    a. Not a component of the JKIA Platform itself.
    b. Include all systems, applications, devices, or any other entity that serves as a source of data and exposes this data via an industry standard protocol (MQTT, OPC-UA, HTTP, etc.) or API. Some data sources might require custom data extractors that don’t use industry standard protocols to collect data. In this case, specific components would be built to serve this purpose.
B. Edge Gateway:
    a. Serves as a protocol translator among various industrial and IoT standards (such as Modbus, CAN, MQTT, OPC UA), facilitating smooth communication between diverse devices and the JKIA platform.
    b. Gathers data from multiple systems through built-in data extractors that communicate over specific protocols. When needed, the edge gateway can also consolidate and filter critical information before transmitting it to JKIA platform, thereby minimizing data overload and reducing network congestion.
    c. Ensures continuous operation by maintaining core functions and temporarily storing data during cloud connectivity outages, guaranteeing uninterrupted system performance.
C. Control System:
    a. This component is responsible for sending commands from the platform to the corresponding systems or equipment to be controlled.
    b. The system makes sure to properly handle such commands as these are considered as critical actions.
    c. It can control devices or systems depending on the available actions via the given protocols or APIs.
    d. Feedback is always returned based on the executed commands to detect success or failure.
D. Data Management:
    a. This includes storing, processing, & analyzing data.
    b. Prepares the data to be consumable by other components.
    c. The collected data is pushed to the data store in a normalized schema. ETL (Extract Transform Load) tools, platforms, or methods are usually implemented to allow for extracting data from heterogenous systems, transforming the different formats into a normalized schema, & loading this data into a common centralized data store.
    d. Stores different types of data in various data stores depending on the nature of the data whether time-series data or configuration data or graph-like, transactional, etc. This is served within the context of a data lakehouse architecture. The data lakehouse architecture is a modern data architecture that combines the scalability and flexibility of a data lake with the structured data management and performance features of a data warehouse. It allows storing all types of data—structured, semi-structured, and unstructured—in a unified platform, while supporting high-performance analytics, business intelligence, and machine learning workloads. A commonly used design pattern in data lakehouse environments is the medallion architecture which is a layered design pattern allowing the organization of data into progressive quality tiers—Bronze, Silver, and Gold—to support scalable, reliable, and high-performance analytics.
    e. Historical records for different data especially time-series data can be handled and maintained. Of course, specifically for time-series data storage, there is no one-size-fits-all and different factors like data frequency, retention policies, and other criteria need to be considered.
    f. Anonymization of certain types of data is applied as well to ensure data privacy is respected. This is essential in airport systems to protect passenger and staff privacy while ensuring compliance with data protection regulations like GDPR or local aviation data protection laws.
    g. Processing the data at hand can be executed using configurable systems that allow for running different types of workflows and formulas to generate calculations or aggregations. Of course, such algorithms can be customized as needed depending on the use cases at hand.

h. The Analyze component includes the needed components that utilize AI/ML models to process real-time and historical data and produce the needed outcomes serving the corresponding use cases. The sub-components included here are:
    i. **Analytics Engine:** The Analytics Engine is responsible for transforming raw operational data into actionable insights. It ingests real-time and historical inputs, applies statistical models and machine learning algorithms, and delivers outputs such as predictions, forecasts, anomaly detection, optimization recommendations and computer vision. These outputs could support a variety of AI use cases for airport operations. The flow of operations in this engine includes pre-processing of data, model inference, and post-processing.
    ii. **Monitor and Train:** Effective AI systems require a structured model lifecycle encompassing training, deployment, monitoring, and retraining. This lifecycle is depicted in MLOps principles that bring DevOps to ML systems.
        1. Monitor: Once deployed, monitoring becomes essential to ensure reliability and compliance. Model registries maintain versioning and lineage, enabling reproducibility and rollback. Drift detection pipelines monitor shifts in input data or prediction behaviour, triggering retraining if thresholds are breached. Explainability frameworks offer insights into feature contributions, while audit logging ensures traceability by capturing all inference details. This monitoring infrastructure enables continuous learning cycles and maintains model integrity over time.
        2. Train: In the training phase, data is pre-processed and engineered to create meaningful features, followed by batch or online model training depending on the application. Evaluation leverages cross-validation, time-aware techniques, and metrics. Tools could be employed for model selection, often within a champion/challenger framework to continuously promote the best-performing models.
    iii. **AI Assistant:** The AI assistant operates on a multi-agent conversational framework where domain-specific agents manage tasks such as data retrieval, analytics, and system control. A coordination layer orchestrates these agents to ensure context-aware and goal-driven responses. Natural language understanding interprets user intent, while routing logic assigns tasks to the appropriate agents. The platform is built on scalable microservices with asynchronous processing, reinforced by data governance, audit logging, and adaptive learning for continuous improvement and secure operation.

E. API Gateway:
    a. This component acts as the single-entry point for all client interactions with the platform's backend services and data.
    b. It is responsible for routing requests & aggregating responses, handling cross-cutting concerns such as authentication, rate limiting, logging, and request/response transformation.
    c. Simplifies client-side logic by abstracting service complexity.
    d. Provides bi-directional secured interaction with components within Digital Twin platform and outside.
    e. Provides interactive API documentation through Swagger UI
    f. Compliant with OpenAPI standards, ensuring standardization and compatibility with industry tools.
    g. Authenticates requests using JWT tokens in compliance with the OAuth 2.0 standard, ensuring secure and stateless access control.

F. Application:
    a. This component reflects on the applications that consume the data available.
    b. The applications can be web or mobile applications, BI platforms, or any other visualization platform that can integrate with the existing data via the available API gateway.
    c. The application component allows end-users to visualize data and control entities as needed resembling a cognitive digital twin of the airport
    d. Different types of visualizations are available to end-users including but not limited to: real-time cards, historic trend lines, gauges, alerts, 3D models (BIM, GIS, etc.), log tables, documents, etc.
    e. The 3D model is interactive and seamlessly integrated with live data, offering immersive experiences such as spatial navigation, real-time data visualization for each asset, entity tracking, and dynamic

heatmaps across zones. Users can engage with the digital twin environment intuitively, enhancing situational awareness and decision-making through a visually rich and immersive interface.

f. Different dashboard views each with certain objective to be available based on the needed requirements.

G. Supporting Services:

a. This component encapsulates many important components of the platform that are required to allow for it to be secure, configurable, deployable, manageable, highly available, licensed, & properly authenticated.

b. Data quality service is responsible to ensure and maintain the quality of data throughout its lifetime and use in the system.

c. Monitoring is essential to ensure the uptime of services and alert concerned parties as needed to take the necessary action.

d. Ensuring proper licensing of the deployed platform to prevent unauthorized versions.

e. Centralized authentication & authorization provided service to service and user to service via the deployed Identity Provider component along with other features as needed like MFA, integrated active directory authentication, etc.

f. Enhance collaboration, automate workflows, and accelerate the software development and deployment process using DevOps implemented methods.

g. Version control and code collaboration using GitHub. This will allow for better management of release versions.

h. Communication between components is secured to ensure data protection both in transit and at rest and respecting the compliance with needed security standards. Cybersecurity section below reflects on the requirements in this domain.

H. Cybersecurity

a. The platform shall be delivered as a secure by design product and the security framework befitting of the solution shall conform to the principles and requirements developed by the nationally and globally recognized standards including but not limited to:

i. ISO 27001 and 27002 Code of Practice defining the requirements for establishing, implementing, and maintaining an Information Security Management System (ISMS).

ii. ISO/IEC 62443 defining the technical security requirements for Industrial Automation and Control Systems (IACS) components, ISO/IEC 27400 for IoT security and privacy, which provides consensus on fundamental security concepts and requirements related to security for IoT.

b. The security framework for the solution shall fulfill the below security objectives:

i. Manage security risks across the platform's ecosystem.

ii. Achieve cyber resilience of critical operations.

iii. Detect proactively information security events across different assets.

iv. Respond promptly to information security incidents impacting the solution.

c. The security services shall apply across the different technological layers and shall include but not limited to:

i. Asset Management shall document and classify data sources in information asset registers, to keep track of how data is being used and where it is located and provide the needed protection throughout the data lifecycle. Personal and sensitive data (e.g., passenger flight details, operational logs) shall be handled with utmost confidentiality and managed in accordance with applicable data protection and cybersecurity regulations. Information owners and custodians shall be trained to apply security handling requirements and comply with data retention policies.

ii. Platform security shall establish baseline security requirements for the platform's software services such as configuring security settings, disabling weak protocols, changing default passwords, enforcing minimum strength criteria of password, installing software and system updates, employing redundant HW/SW (Hardware/Software) components to ensure high availability, maintaining contingency planning to provide the resilience needed to respond to technical disruptions, etc.

iii. Network security shall safeguard connected IoT devices, gateways, and networks, and protecting the integrity, confidentiality, and accessibility of critical networks and data in the event of loss of connectivity to the Central Data Store. A secure network architecture is maintained through logical and physical segregation, redundancies, service level agreements, traffic filtering, firewall access control lists, security device deployment (WAF, firewall, IPS), and secure remote access. This includes but not limited to segregating airside control networks (e.g., VDGS, FIDS, AODB) from public Wi-Fi and guest networks, and ensuring compliance with GCAA network segmentation guidelines.
iv. Application security shall encompass software assurance techniques and processes involved in securing the application throughout the Software Development Lifecycle (SDLC). This ensures that all microservices, APIs and interfaces used to ingest, process and visualize airport data are subject to code reviews, static/dynamic analysis and secure-coding standards.
v. Data security and privacy shall protect structured and unstructured data from unauthorized access, tampering and/or data loss, according to the sensitivity and business value of the information. This control encompasses data analysis and classification, secure data handling, availability, and access monitoring and auditing.
vi. Cryptography shall identify strong and industry approved standard algorithms applied to the data in motion and at rest to preserve their confidentiality, integrity, and authenticity. The implementation of encryption on transmitted data is kept current with new threats and methods, and the cryptographic keys are unique, randomly generated, and securely stored and managed.
vii. Identity management & access control shall span several security techniques to ensure that access to the platform's services, information, administration and configuration portals are based on the principles of need-to-have and need-to-know, least privilege, and segregation of duties. This capability involves password security for authentication, authorization, and privilege assignment.

The above stated multi-layered security approach, also known as Defense in Depth, employs a holistic security taking into consideration interconnections and dependencies, and providing effective layers of protection based on the business's exposure to cybersecurity risks. These services shall be adaptive, agile, and regularly tuned to maintain a resilient security immune system that can defend against any possible attack or threat on the ever-widening landscape. It remains paramount that a set of security services defined hereunder are maintained for continuously securing the operations of the information and information resources to provide a complex barrier to any malicious entry, increase the likelihood of detection, and decrease the likelihood of a successful compromise.

d. The SOC services shall be deployed to ensure integration with the airport's existing SOC where applicable. in alignment with the Employer requirements and the platform's deployment model.
    i. Security monitoring shall collect security events across information systems to monitor status of its connected devices and equipment periodically, detect attempts of attacks, and break the attack chain before attackers attain their objectives to maintain healthy, secure and available IT systems across the operational environment.
    ii. Technical vulnerability management & security testing shall include regular vulnerability scanning, penetration testing exercises, and technical assessments of the underlying systems and applications. Deduced vulnerabilities and weaknesses are properly mitigated and remediated (patching, security configuration, software update releases, etc.) within timeframes commensurate with the risk.
    iii. Security incident management shall provide a framework to detect, contain, notify, respond and recover from security incidents affecting the system or its airport data integrations. If a security incident impacts critical airport data, appropriate stakeholders shall be notified within an agreed timeframe and a status report provided to the Client.

Data Strategy

Data Strategy shall be executed with compliance to available standards. Within such complex and interconnected data representations, the following are aimed for:

- The schema (data model) shall be built in the most scalable and optimized structure to store ontology as well as time-series data. Ontology is a model that lists the types of objects found within the building, the relationships that connect them, and constraints on the ways that objects and relationships can be combined. Standards like Brick or Haystack can be used for ontology and semantic tagging whereby the tagging standards are followed for building up the needed ontology as well as the metadata required by every entity. Of course, this shall entail naming convention standards to be applied at the data level. Moreover, migration and maintenance of the data model should be simple and fault tolerant. The data model must be able to evolve over time whilst maintaining the integrity of the data.
- Data and state can be further classified by the nature of the information stored - either original or derivative information. A clear segregation of information to identify the original separately from that which is derivative should be done – original data must be protected against data loss and corruption whereas derivative data can be reconstituted if necessary. Original information must guarantee that in the event of system failure the data will not be lost or lose synchronicity via backup and replication mechanisms. Derivative information does not have to guarantee these criteria, though they can be beneficial, so long as the process involved in deriving the data is repeatable within an acceptable period. In all cases, data and state should maximize the following criteria:
    - Security of data
    - Read and write performance
    - Schema evolution and maintainability
    - Size efficiency

  The recording and monitoring of system and building performance requires the ability to store and recall wide spans of data over history for both comparison and future trend analysis. Time-series data is a specialist type of data that represents the change of values over time and is used to store such types of data. Recent data points are typically inspected in more detail however long tails of historical data allow the analysis to glean insight from slowly changing patterns. A data store for time-series data must be able to:

    - Recall at least 1 year of historical data
    - Supply data in a format that can be easily analysed, combined and compared

- Management of data to be as automatic as possible – manual manipulation of data must be minimized as far as possible. Also, data shall be stored across local area controller storage, to local disks attached to the edge layer and replicated to cloud services as required. Encrypted backups of data storage should be taken regularly, preferably to an offsite location.

7.2.10 PRELIMINARY PROCUREMENT STRATEGY

SMART Services Proposed Procurement Strategy

We recommend considering a Master System Integrator (MSI) for this project. The MSI should create a centralized data repository to aggregate information from various systems like BMI, access controls, and security systems, ensuring interoperability and ease of access for analytics. Collaborating with extra low-voltage subcontractors is vital for integrating IoT sensors and smart devices into this repository, supported by regular coordination meetings. A robust vendor management strategy is necessary to evaluate and select technology providers that align with project goals, while establishing interoperability standards will prevent vendor lock-in. The system must be designed for scalability and futureproofing, accommodating upgrades and new technologies. Additionally, data security and compliance should be prioritized from the outset, alongside ongoing training and support for staff to facilitate smooth system adoption.

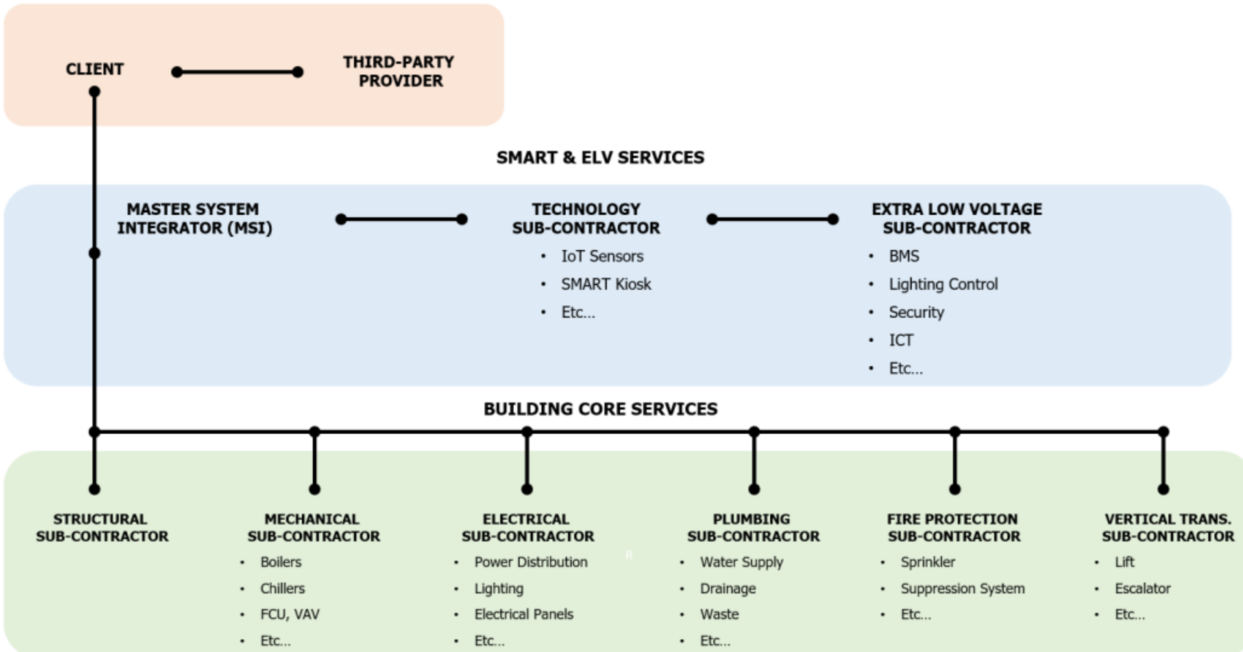


Figure 7.12: SMART Procurement Approach

8 ENVIRONMENTAL ASSESSMENT

8.1 PURPOSE AND SCOPE OF THE ENVIRONMENTAL ASSESSMENT

This section outlines key environmental considerations designed to guide the Integrated Master Plan from the outset. The goal is to anticipate and address environmental risks, opportunities, and constraints early in the process to avoid expensive redesigns, regulatory issues, or stakeholder pushback during implementation.

The environmental assessment follows the Strategic Environmental and Social Assessment (SESA) approach developed for the Master Plan. The SESA scoping framework helps set thematic, geographic, and time-related boundaries, identifies critical issues for further analysis, and lays the groundwork for evaluating alternatives, applying mitigation measures, and setting up monitoring systems.

8.2 APPLICABLE STANDARDS AND GUIDING FRAMEWORK

The SESA scoping aligns with Kenya's SEA and EIA regulations and incorporates global best practices, such as the World Bank's Environmental and Social Framework (ESF), the IFC Performance Standards (PS1–PS8), UNEP guidance on strategic assessments, and ICAO's environmental guidelines for airports.

As such, this chapter:

- Identifies major environmental constraints and sensitive areas;
- Highlights key impact pathways from the proposed master plan elements; and
- Lays out the future environmental work needed to support approvals and detailed implementation through SESA and follow-up assessments.

8.3 ENVIRONMENTAL BASELINE CONTEXT AND SENSITIVE RECEPTORS

According to SESA scoping, the area influenced by the master plan includes both airport sites and their surrounding regions. It identifies environmentally and socially sensitive locations that require early attention in the planning process.

Notable sensitive areas include Nairobi National Park, Ngong Road Forest, nearby wetlands, and densely populated urban communities.

Implications for the master plan:

- Land use planning and zoning must consider and respect these sensitive areas.
- Early evaluation of development options—like where to place runways, terminals, roads, and commercial areas—should aim to avoid or minimize impacts, with mitigation measures applied when avoidance isn't possible.

8.4 KEY ENVIRONMENTAL RISKS AND OPPORTUNITIES ASSOCIATED WITH THE MASTER PLAN

The SESA scoping reveals that the planned developments could bring both benefits and challenges. Potential gains include economic growth, better transport links, and improved safety and security. However, several environmental risks are also noted:

- Noise and Vibration
  - More aircraft and expanded airport infrastructure could increase noise pollution in nearby communities, making it essential to have noise management and monitoring plans.
- Air Quality and Emissions
  - Air and road traffic, along with construction activity, could worsen local air quality and increase greenhouse gas emissions. This will require thoughtful design, operational controls, and evidence-based monitoring.
- Biodiversity and Habitat Sensitivity
  - Given the proximity to ecologically important areas like Nairobi National Park and wetlands, protecting biodiversity and maintaining ecological connections is critical. Wildlife hazard management will also be needed during planning and operation.
- Land Take, Land Degradation, and Soil Risks
  - Building new infrastructure could degrade land and soil, or introduce contamination from materials like fuel and chemicals. These risks demand careful early design and strong construction management.
- Waste Management and Pollution Control
  - As the project grows, so will waste—both solid and hazardous. This could strain current systems, making it necessary to improve waste planning and ensure safe handling and disposal.
- Climate Resilience and Vulnerability
  - Climate change poses risks such as flooding, heat stress, and service interruptions. Infrastructure planning must account for these threats by incorporating resilient design features.
- Construction-Phase Nuisance and Disruption
  - Temporary disruptions such as dust, noise, traffic delays, and utility issues are common during construction. To manage this, environmental planning and clear communication with stakeholders are essential.

8.5 STRATEGIC MITIGATION DIRECTIONS TO BE EMBEDDED IN THE MASTER PLAN

At this stage, mitigation is framed as high-level design and planning guidance, to be expanded upon in the SESA and later Environmental and Social Impact Assessments (ESIAs). The use of the mitigation hierarchy—avoid, minimize, restore, offset—is recommended, backed by an Environmental and Social Management Plan (ESMP) with clear monitoring indicators.

Key strategic directions to integrate into the master plan include:

1. Avoidance and Spatial Safeguarding: Screen development options early to avoid protected areas, wetlands, forests, and dense neighbourhoods. Document decisions using an alternatives analysis aligned with the SESA.
2. Impact Management Through Design: Design airport layouts and operations to reduce noise and air pollution and support these decisions with monitoring systems and data-driven planning.
3. Pollution Prevention and Waste Management: Build infrastructure that supports waste segregation, safe storage, collection, and compliant disposal, with capacity to handle future growth and unexpected events.
4. Biodiversity and Wildlife Risk Management: Incorporate planning that is sensitive to biodiversity and introduces stronger controls for managing wildlife-related risks, based on identified sensitive areas.
5. Climate Resilience Integration: Design essential infrastructure and services to withstand climate challenges, using criteria identified during SESA scoping.

8.6 FORWARD ENVIRONMENTAL WORKSTREAM AND DELIVERABLES

The next steps in the SESA process include:

- Conducting detailed environmental, social, and economic baseline studies;
- Evaluating strategic alternatives and potential cumulative impacts;
- Developing a comprehensive mitigation plan and monitoring framework (ESMP), and
- Submitting the final SESA report to NEMA for approval.

For each specific component of the master plan (like expanding runways or terminals), further environmental assessments will be required, in line with Kenyan regulations and any international lender requirements. The SESA will serve as the guiding framework for these follow-up studies.

9 SECURITY PLANNING

The following section provides high-level security planning assumptions and general site-level guidelines to guide the infrastructure and building designers. These inputs are intended to serve solely as strategic direction and do not constitute detailed design requirements. They should be further elaborated, refined, and validated during subsequent design phases.

The airside area of an airport is called the Critical Part Security Restricted Area (CPSRA) meaning that everything inside its boundary should be controlled at all items with all persons, items and vehicles passing into this area being screened for prohibited items and then protected as sterile from unauthorized interference.

It is therefore important that airside areas are monitored and kept under surveillance. Patrolling, along with video surveillance (VSS), will aid airport operators in the monitoring of these areas. Patrols should not be undertaken in a predictable pattern such that a hostile can predict where a patrol will be at any given time. Any breaches need to be reported and rectified promptly.

9.1 REVIEW OF THE COLLECTED DATA RELATED TO SITE SECURITY SYSTEMS

Screening Checkpoints

The image below illustrates the Master plan layout of JKIA airport, indicating the locations of the existing security screening points and existing airside/landside fence, which is outlined in red.

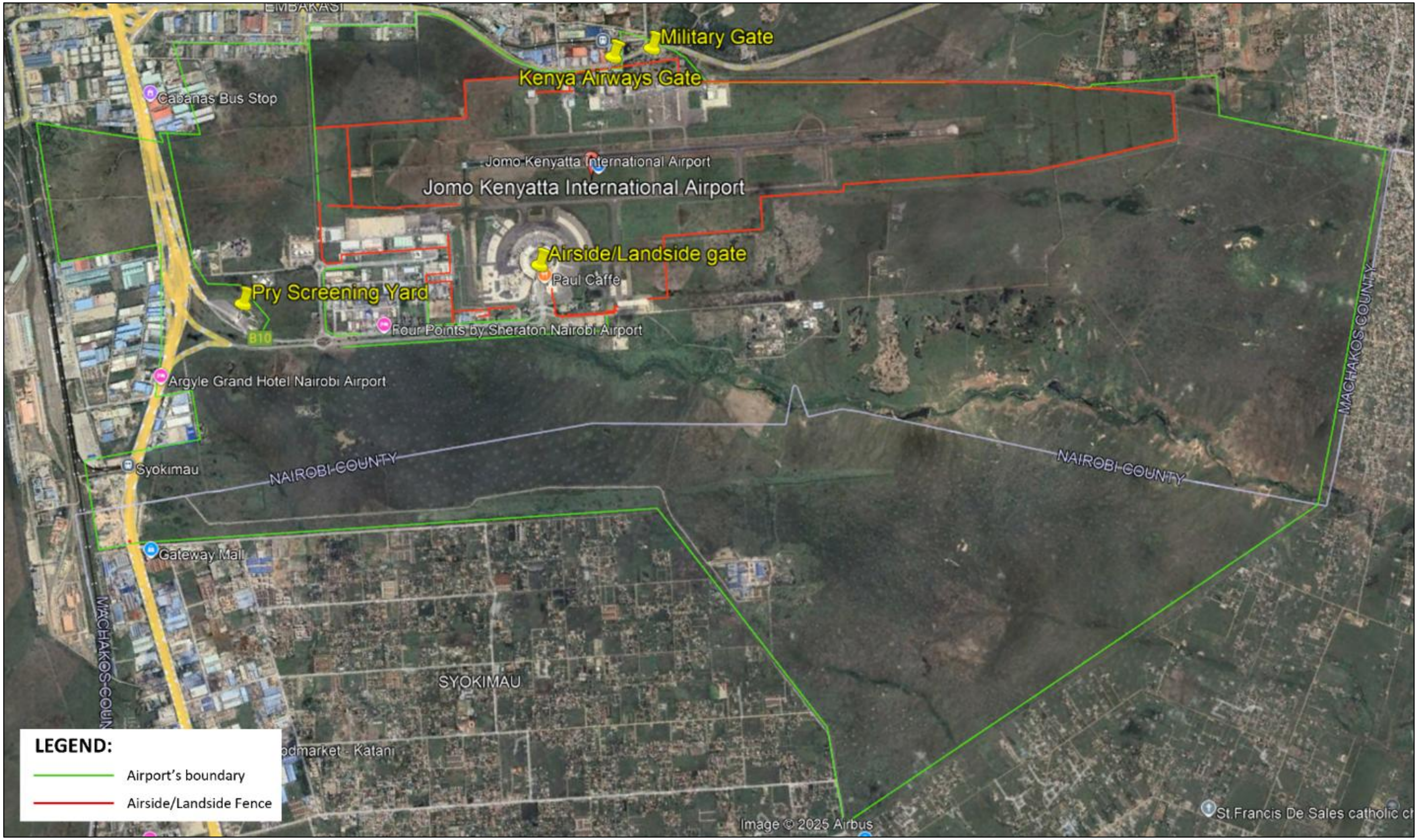


Figure 9.1: Master plan layout showing the locations of the existing security screening points and the existing airside/landside fence (outlined in red) within JKIA airport

The image above reflects the location of the existing security checkpoints within JKIA airport. As indicated in the image above, we have the following security checkpoints:

- Pry Screening Yard
- Kenya Airways gate
- Military gate

Single Access Vehicle Screening Point

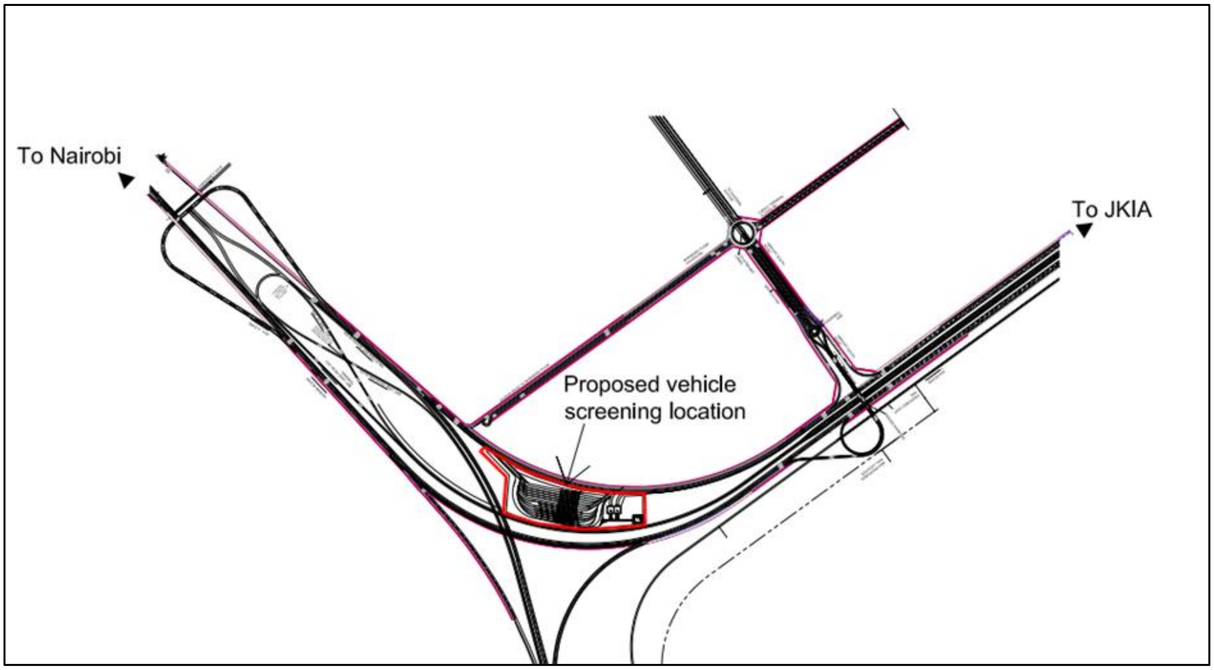


Figure 9.2: Existing Vehicle Screening Location, extracted from Report No. "SINGLE ACCESS VEHICLE SCRENING POINT"

Based on the provided images and the received data, it has been observed that the existing vehicle screening point is comprised of 16 lanes, distributed as follows:

- 13 dedicated lanes for Trucks/Cars/Buses
- 3 dedicated for VVIPS

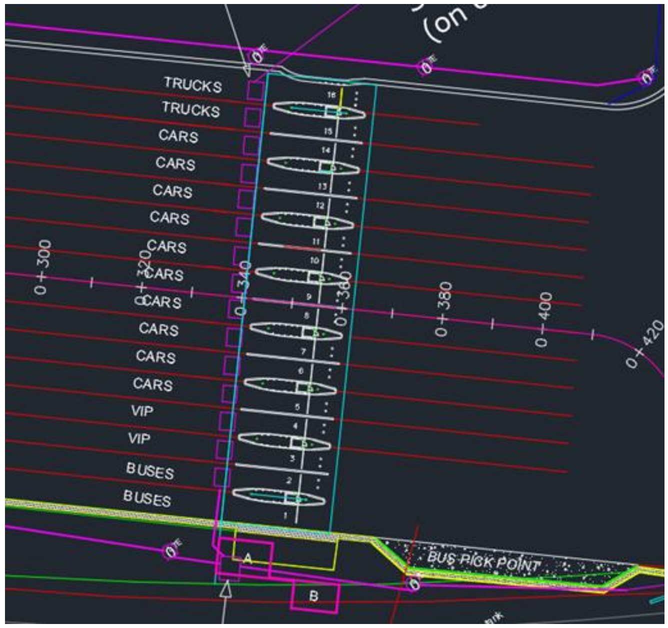


Figure 9.3: Existing Vehicle screening bays' details

In addition, the equipment that has been observed available at the vehicle screening point are the following:

- CCTV camera
- ANPR camera
- UVSS

As per document no. "EXISTING FACILITIES ASSESSMENT AND INCEPTION REPORT, 2017", it has been mentioned that:

- KAA provides AVSEC services.
- All vehicles entering the premises are inspected at the airport screening yard. Although bags are not screened, vehicles are visually checked and undercarriage scanning via UVSS.

Pedestrian Screening

- Passengers and staff are also screened, though not in line with AVSEC criteria.
- Upon entering the Passenger Terminal Building (PTB), all passengers, staff are screened. Bags are also screened, this is additional to in-line screening within the BHS area.
- After check-in (and immigration for international flights), passengers are screened again prior to entering the airside area. The procedures are in line with AVSEC criteria.
- Certain flights undergo a secondary screening at the gate. This is common practice for certain airlines (e.g British Airways) or certain destinations (e.g. UK, US).

Waste Management Trucks Screening

As per the received document no." EXISTING FACILITIES ASSESSMENT AND INCEPTION REPORT, 2017", the waste management trucks are crossing from Landside to Airside with solid waste. While the truck is inspected, the waste is not screened.

9.2 APPLICABLE CODES AND STANDARDS

The below represents the list of security related regulations that will serve as the basis for our master planning process.

- ICAO – International Civil Aviation Organization, Aviation Security Manual (doc. 8973 – reserved),
- NSSA – National Safe Skies Alliance, Guidelines for protection of boundaries of airports
- ICT Security Standard- 2023
- CIVIL AVIATION (SECURITY) REGULATIONS, 2024
- RIA for Civil Aviation (SECURITY) Regulations 2024
- TSA – Transportation Security Administration

9.3 DEFINING AIRSIDE AREAS

Airside areas are any areas within the restricted part of the airfield. No access is granted to these areas without passing through screening. Included in these areas are the aircraft stands, air traffic control facilities, aircraft maintenance areas, etc.

Security measures should be in place to ensure that these areas cannot be used by unauthorized persons to gain access to aircraft and that the design of these areas does not present a risk to persons or aircraft operating within the CPSRA.

Where general aviation operations are taking place, these should be contained within a 'Demarcated Area' which should be kept separate from the CPSRA.

Facilities which have loading bays in landside public areas and a landside / airside boundary running through the center, or leading from the building, present particular vulnerabilities which need to be addressed as far as practicable in the design. Measures should be in place to prevent unauthorized access to airside areas and to detect an unauthorized person immediately if such measures fail.

Airports should have oversight arrangements in place to monitor and evidence the effectiveness of measures applied. Consideration needs to be given as to how this is to be achieved in tenanted or leased property which may not be owned by the airport operator.

Critical infrastructure is any facility on or connected to an airport that, if damaged or destroyed, would seriously impair operations. This can include air traffic control towers, communication facilities, radio navigation aids, fuel installations / fuel farms, power transformers and primary and secondary power supplies, water supplies, operationally critical areas such as snow clearance routes.

Such infrastructure should be afforded an appropriately high level of security even if located with the CPSRA. This should include means to detect unauthorized access or unlawful interference and to respond accordingly.

Appropriate physical security measures should be applied to facilities outside the CPSRA (whether airside or landside) that might be used as a means to undermine the security integrity of the CPSRA.

Areas and facilities used for the handling and storage of screened hold baggage and in-flight supplies should be designed to limit opportunities for unauthorized access and to facilitate supervision and monitoring of staff, for example through VSS and clear lines of sight.

Inflight Supplies and Catering

All catering, stores and supplies intended for carriage on passenger commercial flights are subjected to appropriate security controls and subsequent protection until loaded onto the aircraft.

In-flight supplies are perceived to be a vulnerable point in overall aviation security due to the very large numbers of sub-contractors and suppliers required to fully equip and cater a modern passenger aircraft. For a wide-bodied long-haul aircraft, the quantity of supplies runs into the many thousands of individual items per flight.

Catering can be considered a particularly vulnerable target due to the volume of supplies taken onto aircraft, the widespread knowledge of the catering operation and the ability to target specific flights through catering consignments.

All in-flight stores, therefore, must be subjected to some form of security control which starts with the supplier and ends when the cabin crew on-board an aircraft sign the relevant documentation accepting the stores.

Airlines usually manage and contract their own in-flight supplies, but sufficient space and facility must be made available for the screening of such.

Inflight stores are handled, screened, protected, sealed and securely transported onto aircraft in a similar manner to cargo

9.4 SITE PERIMETER

The role of the site perimeter is to delineate the boundary between landside and the CPSRA while also providing a physical security boundary to prevent unauthorized personnel and vehicles, along with prohibited items, from gaining access into the CPSRA.

A secondary role of the perimeter is to project a sufficiently hostile view of perimeter security to a potential intruder so that a deliberate attempt to gain unauthorized access to the airside area of the airport is considered difficult with the likelihood of failure or capture appearing high.

It also offers the capability for airport staff to be aware of any hostile reconnaissance activity and/or any other activity occurring in the airport's landside area that may be a precursor to an attempted breach of perimeter security.

Thoughts must be given to protecting airside assets that are located close to the perimeter and considered at risk while having systems in place to have the capability to detect inadvertent or deliberate perimeter breaches and respond appropriately.

It is recommended that fencing installed on the CPSRA external boundary should meet at least the minimum requirements as per regulatory recommendations from ICAO:

a) Frequency and means of application of surveillance and patrolling of the security restricted area, the perimeter fence and the surrounding areas by the appropriate security service
b) The frequency and means of exercising surveillance and patrolling of the public area to exclude the possibility of leaving objects that may pose a potential danger to the safety of persons and property; provides:
c) maintaining in good condition the fences around the aerodrome and other technical barriers that separate airside, airside security restricted area, and the critical part of security restricted area,
d) protecting passageways from the public area to the security restricted area from unauthorized access and the intrusion of objects that may pose a threat to air transport,
e) patrolling the security restricted area and controlling the common area,
f) the possibility of limiting access to a public area on an ad hoc and rapid basis.

In order to achieve the above and to meet international best practice, the following advice should be followed:

There should be a 3-metre clear zone to both sides of the perimeter fence. Where this is not possible a higher standard of fencing may be considered as an alternative, but it is essential that the fence is suitably topped or is at least 1.5 meters higher than the highest item likely to be placed against it. Where security fences are required, then information on suitable fences and their ability to resist manual attack or to support intruder detection systems can be obtained from government security specialist. Typically, a weld mesh construction, of minimum 2.4m height with appropriate security topping.

Hostile Vehicle Mitigation (HVM) can be incorporated into perimeter fencing either separately alongside or as part of the fence or as a base to the fence itself. This is a way of preventing hostile incursion of a vehicle into the airfield or onto taxiways that run close to the perimeter fence and can be determined through vehicle dynamic analysis conducted by security specialist.

Care should be taken to ensure that structures, including HVM, are not able to be used as climbing aids and if located near the perimeter. If installed near the perimeter, this must be done only where increased fence height is possible. Similarly, walls used as (or near) the perimeter should be a minimum of 3 meters high and combined with a topping that makes climbing more difficult. CCTV should always be installed, along with adequate lighting, near walls as they can be areas that prevent natural surveillance.

The landside / airside perimeter should be clearly marked at regular intervals and at all entry points to notify persons that the airside area is restricted to authorized persons only.

A perimeter road should be designed in within the boundary line to facilitate inspection of and maintenance to the fence and security patrols.

Options include a dual fence line or a single fence line - a dual fence is preferred, and if used, a single fence should be of higher security standard. As per Stakeholders requirements, KCAA requested perimeter intrusion detection system to cover the airside/landside fence.

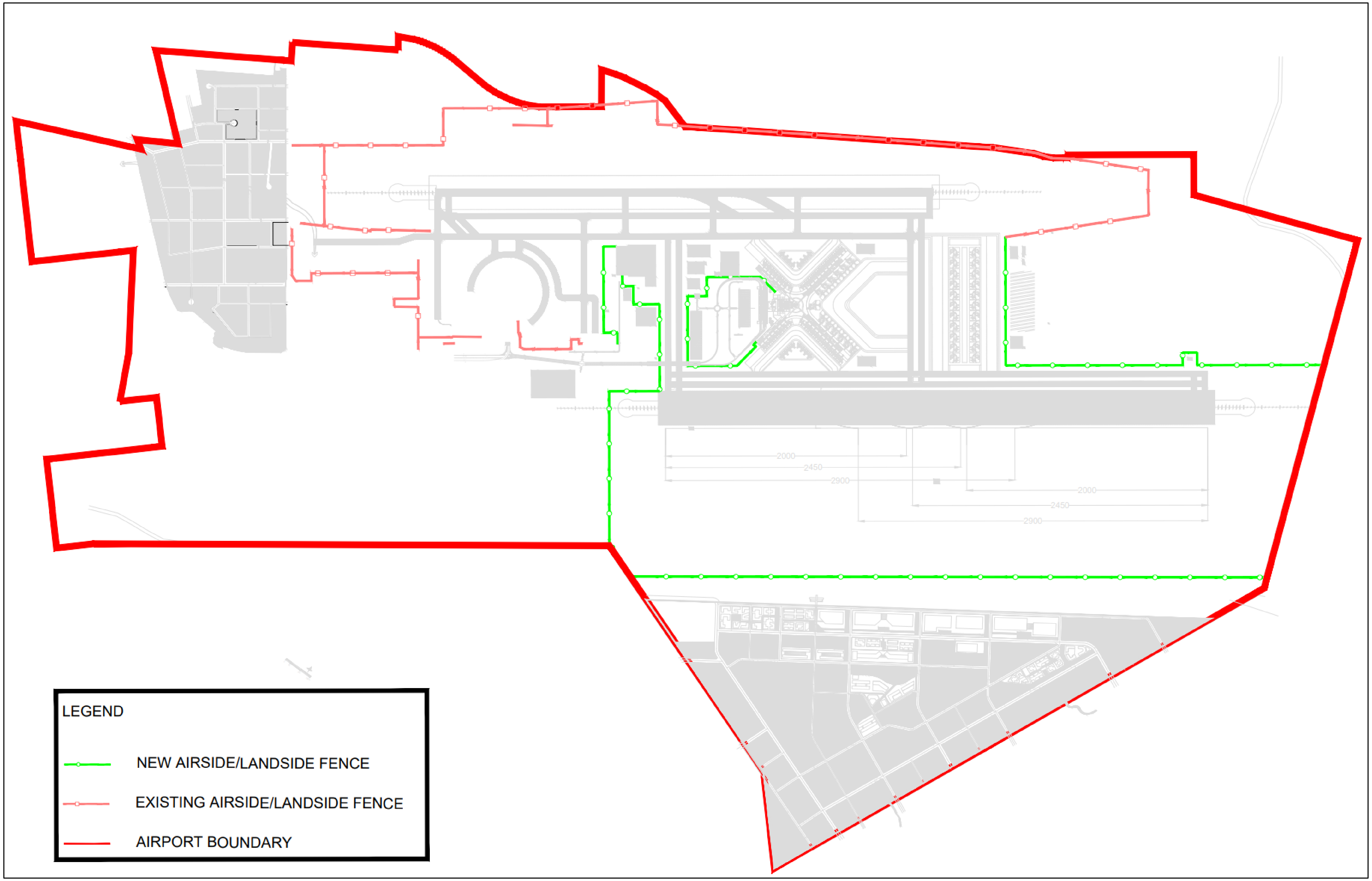


Figure 9.4: Layout showing the Airport Boundary, Old and New Airside/Landside Fence

PIDS Field Equipment and DETECTION Technologies

This section provides a selection of products currently available in the market.

The following list is not meant to be exhaustive, but rather highlights the most potential common detection equipment. The selection of the technology shall be developed at later design stages:

- Video Surveillance System
  - Video Motion Detection
  - Thermal imaging
  - Intelligent Video Analytics
  - Video Based Tracking
- Fence and Wall Mounted Sensor Systems
  - Coaxial Cable Technology
  - Fiber Optic Cable
  - Taut Wire
  - 3D LiDAR Sensors
- Ground-Mounted/Waterside Sensor Systems
  - Buried Pressure Line Sensor
  - Ported Coax Buried Cable
  - Pulse Infrared System (Exterior)
- Microwave Sensors
  - Mon-static Microwave
  - Bi-static Microwave
  - Electric Field or Capacitance
- Radar Based Sensor Systems
  - Radar Systems
  - LADAR Systems
- Access Control Systems
- Other Detection Technologies
  - Mechanical Switches
  - Magnetic Switches
  - Balanced Magnetic Switches
  - Glass Break
  - Photo Electric Beam
  - Wall Vibration
  - Audio Sensors
  - Passive Ultrasonic
  - Active Ultrasonic
  - Electric Field
  - Capacitance
  - Strain Sensitive Cable
  - Buried Geophone

9.5 SECURITY SCREENING

Of primary concern in any forward-looking commercial airport security enhancement program is the need to assess the efficacy of the front-line passenger and baggage screening processes, which in turn, are only as good as the technology which supports them and the people who operate them.

Passenger and baggage screening is the most visible security process, receiving constant high-level attention from the traveling public, governmental entities, and the international aviation community, all of which recognize the need for an Integrated national plan to move forward.

Table 9.1: General Recommendations for Security Enhancements at airports, extracted from NPISPA

These general recommendations for security enhancements at airports of all sizes and complexity are all very similar; all should be adjusted and re-sized according to the size, complexity, threat-risk profile, and local operational characteristics of each individual airport.	
Location	Recommendations
Passenger Checkpoint Screening	1. Provide all checkpoints w/Tip Ready X-ray 2. Explosives Trace Detection at each lane 3. Reconfigure for positive passenger control 4. Whole body imaging- for non-metallic Items
Hold Baggage Screening	Establish Multi-stage screening process Step 1. EDS or X-ray detection Step 2. Extensive OSR training Step 3. Physical or ETD trace exam

9.5.1 CONTROL POSTS

Control post serves as point of crossing airside / landside boundary for all staff and vehicles. They serve as airside gatehouses for all staff and vehicles going on to the airside or leaving it.

To provide that functionality they should be equipped with personal security screening with queueing for staff. Social areas for security staff are also necessary.

Facility for vehicle inspection should be provided under the roof. Limited parking spaces for security screening company are to be provided on airside, including the charging points for electric vehicles.

To prevent a Vehicle Borne Improvised Explosive Device (VBIED) from passing airside area, Vehicle Control Posts are used. A Vehicle Control Post is designed to provide a controllable area in which security staff can identify and screen vehicles, their contents and occupants before granting access into an airside area. Security staff need to be satisfied that no prohibited items pass through.

Number of security lines and exact space requirements are to be developed within the detailed design stage, on basis of data coming from each operator intended to serve at the airport.

Additionally, provisions for large vehicle inspection facility shall be considered to inspect all large truck traffic intending to pass through the gate. It is envisioned that once a vehicle is inspected and authorized to access the installation, the vehicle may be tracked and monitored until it enters and exits the installation.

The inspection equipment may be a mobile or fixed installation. It should be noted that some detection equipment is built-in to a large, drive-through structure.

Potential Vehicular Screening Equipment include the following:

- Most vehicle inspections are conducted with manual procedures using tools or hand-held detectors
- CCTV Under Vehicle Search Systems (UVSS)
- Mobile Vehicle Inspection Systems (Imaging)
    - X-ray and Gamma ray Inspection Systems
- Fixed / Portable Vehicle X-ray Inspection Systems (Imaging)

As with all other assets to be secured, the Vehicle Control Posts will have a number of stakeholders who each require input into the design of each post according to its location and function. General considerations should include:

- Sufficient entry lanes to accommodate vehicles at peak times without causing queuing that blocks through roads. Clear signage and road markings will aid drivers with guiding them to the correct point and will reduce confusion and guard force workload.
- Secure protection for security staff from the elements and in the event of an attack – this facility will probably also contain the controls for security systems and HVM barriers.
- Clear line of sight of the entire control post free from obstruction is important for security staff. Consider adequate lighting for dark hours and for CCTV coverage – staff need to be able to identify individuals and vehicles accurately, not have just general visibility.
- Vehicle restraint measures need to be employed to stop vehicles at the checkpoint. An 'airlock' system is the most secure – the outer barrier opens to allow access into the 'airlock' while the inner barrier remains closed. Once the vehicle is searched and passed, the inner barrier then opens to allow the vehicle through, but the outer barrier is then closed to prevent tailgating. Rated HVM barriers that will prevent forced access should be installed.
- All search and waiting areas need to be outside the secure perimeter and HVM rated barriers. Ensure that no climbing aids are in the vicinity so that when the checkpoint is closed, the perimeter is completely secure.
- Vehicle search facilities need to be included to ensure that there are no concealed prohibitive items. This might include under-vehicle screening or identification systems; explosive trace detection and potentially x-ray to scan the contents of the vehicle.
- There needs to be a mechanism designed in to reject a vehicle that fails inspection, without it having to proceed through into the secure area to turn around.
- Control posts must have an emergency lane kept clear at all times to allow for emergency vehicles to access and egress the landside / airside boundary. There must also be sufficient room airside for an emergency vehicle holding point, where these vehicles wait for airside escort vehicles.
- Systems need to be in place for the reliable identification of vehicles, for example CCTV and Automatic Number Plate Recognition (ANPR) but design teams should be aware of the susceptibility of some systems to deception, especially ANPR and so should seek further guidance on this. Consider lighting requirements and adequate data connectivity.
- The screening facility for individuals needs to cater for the new Computerized Tomography (CT) and body scanner equipment.
- A method to prevent cross-contamination of screened and unscreened individuals moving to and from vehicles needs to be considered.
- A separate lane for pedestrian only traffic will minimize confusion and also the chance for cross-contamination between groups of people.
- Emergency access control needs to be considered at all times and a route kept free for this. Additionally, egress from airside through the control post also needs to be considered.
- Locations and numbers of crash gates need to be considered – as to whether control posts will be used for this purpose. If so, appropriate rated barriers need to be installed to prevent unauthorized access and these should be selected according to the results of a Vehicle Dynamics Assessment.

Location

It is anticipated that a single Control Post will be needed for PAL1 as well as PAL2, with this facility developed in line with the airport's anticipated growth phases. The location of this Control Post is indicated in the below layout as follows:

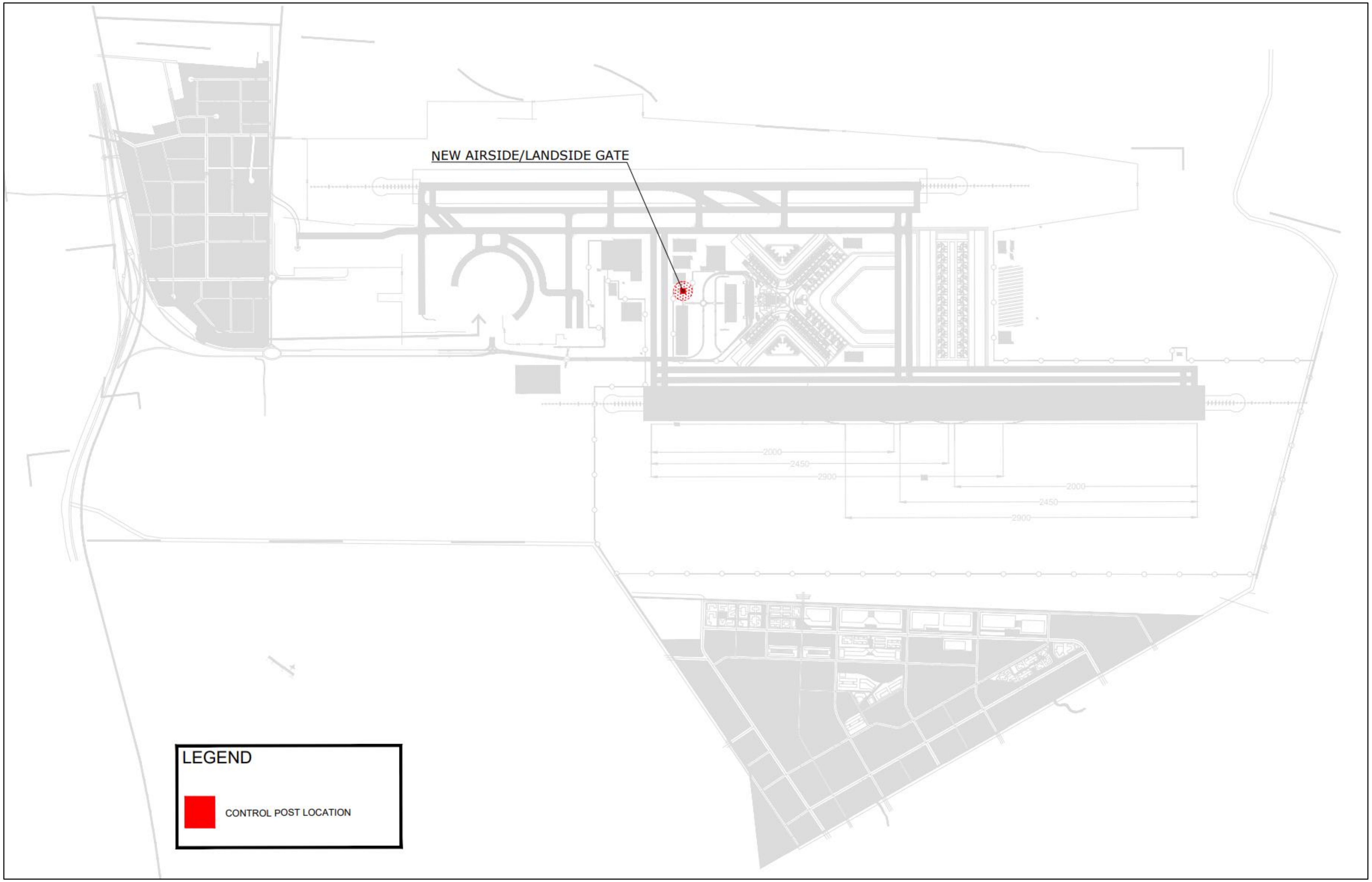


Figure 9.5: Proposed Location of the new Airside/Landside Gate

9.5.2 PASSENGER AND HOLD BAGGAGE SCREENING

Often referred to as the "first line of defense", passenger and baggage screening consists of the proper coordination of the people, equipment, and procedures necessary to achieve the highest possible level of confidence in preventing the Introduction of weapons or dangerous goods aboard an aircraft.

The consequences for performance that does not meet that standard could be catastrophic and, due to the complex interconnectivity of the global aviation system, there must be no weak link anywhere in that system.

At its most basic level, the checkpoint must channel passengers into a queue that will allow for individual screening, prevent any opportunity to bypass the checkpoint, and provide for additional screening of passengers or baggage if the need arises. The configuration of the Individual checkpoint must consider the peak passenger throughput, the special needs of persons with disabilities or other factors such as VIP screening, seasonal and regional differences in the nature of the dress, carry-on items, to name a few.

A typical security checkpoint layout is presented below. Although not identified as such in the graphic, areas marked "J" on either side of the checkpoint can be easily modified to perform private screening of Individuals.

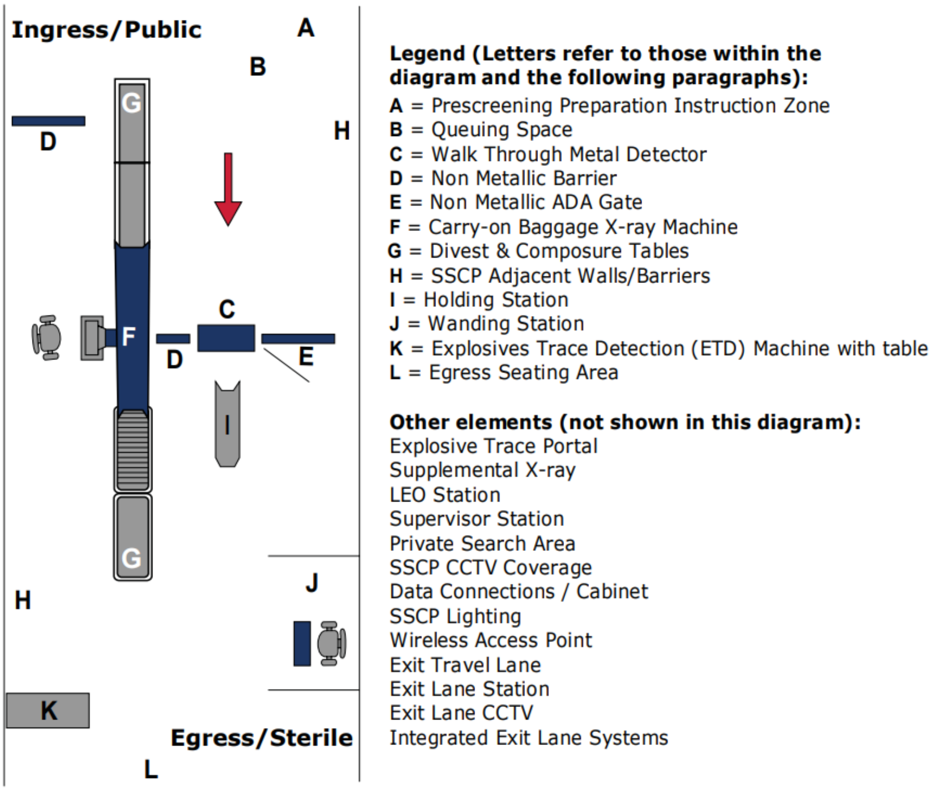


Figure 9.6: Typical Security Screening Checkpoint Layout and Elements, extracted from TSA

9.5.2.1 Passenger screening – Terminal

Centralized screening within the PTB shall be based on the below passenger screening assumptions; However, it shall be validated and detailed by the PTB designer at later design stages in coordination with the relevant stakeholders.

- Centralized passenger security search
- Throughput: 200 pax/hour/lane
- Assumed working hours: 16 hours
- Lane dimensions: 40m x 5.8m
- Potential Equipment:
  - Walk-through metal detector (WTMD) or magnetometer
  - Hand held metal detectors (HHMD)
  - Millimeter wave Imaging and backscatter x-ray transmission
  - 100% security scanner

- Capability to multi-plex and have remote screening room
- Automated Tray Return System (ATRS)
- Optimized team size (capabilities and number, 7-12 screeners/lane) and performance

Passenger screening should also include the use of physical search and Explosive Trace Detection (ETD). Current regulations require:

- Liquid explosive detection
- when using x-ray equipment for passenger cabin baggage screening, the minimum number of staff in the security lane is three per passenger

Based on the above throughput and lane dimensions assumptions, the following estimations can be derived:

Table 9.2: Estimations for the required number of screening units

	PAL1	PAL2
MAP within the newly proposed PTB	10	15
Estimated Passengers per Hour	1,713	2,569
Estimated Required Passenger Screening Equipment	1,713÷200 ≈ 8.6 → therefore, 9 screening units are required	2,569÷200 ≈ 12.9 → therefore, 13 screening units are required
Estimated Required Lane area	40m x 5.8m x 9 = 2088 m^2	40m x 5.8m x 13 = 3016 m^2

Based on the above assumptions, nine screening units will be required for PAL1, and thirteen screening units will be required for PAL2.

The following is a list of general guidelines:

- Access and facilities for passengers with restricted mobility. This may be in the form of a specifically designed lane and/or dedicated lane and equipment
- Facilities to conduct private physical screening (on request by passenger)
- Facilities for the storage of confiscated, including prohibited items. Facilities for the latter may require specific design e.g., liquid storage, lockable
- CT machines produce heat, and most screening equipment has temperature and humidity tolerances. HVAC system design should take this into account
- Screening equipment including tray return systems can produce a lot of noise which increases stress for passengers and can be dangerous to screening staff. The acoustics design should take this into account
- Lighting is critical to the accurate assessment of images. Consideration should also be given to glare from screens and equipment. Additionally, lighting can have a positive or negative influence on experience and passenger stress. The lighting design should take this into account
- The structural design should take load bearing needs into account e.g., CT machines weight 1-2 tons compared to x-ray at about 350kg
- Staff screening team effectiveness is vital to achieving throughput objectives. Competence contributes to this through operational means including procurement models (outsource vs employees), performance management models, quality control policy and procedures and training should be used to address this. The physical design of the screening checkpoint should also take into account staff needs, human to machine interface, ergonomics etc. Human factors specialist advice should be sought
- Subject to the terminal's architectural objectives architectural advice may be needed to customize elements of the screening checkpoint e.g., design of redress tables
- User experience and performance requirements for passengers and staff should be taken into account when development specification and procurement non-regulated equipment e.g., tray return system
- The ICT design should take account of power and data requirements of the screening checkpoint
- Preventing items or persons bypassing the screening process
- As the screening checkpoint is the likely boundary of the CPSRA it should be designed so as to prevent unauthorized access into the CPSRA during operational and non-operational hours
- Screening checkpoints should incorporate elements that reduce the opportunity for observing the search operations from public areas
- Provision of support facilities for personnel, including rest areas, interview areas (which will have specific design requirements e.g., one way glazing), observation room or platforms.

9.5.2.2 Hold Baggage Screening

Like passenger screening, the choice of options to screen hold baggage is determined by considering the following criteria:

- The effectiveness of the screening equipment
- The efficiency of the screening process and its effect on passenger flow
- Cost effectiveness
- Consistency with the concept of operations for specific applications
- Bag time in system, to allow for all processing and distribution

Potential Hold Baggage Screening Equipment:

- Computed Tomography x-ray devices (CTX)
- Explosive Trace Detection (ETD) units

Based on the assumption of utilizing the Smiths CTX 9800 system, the following estimations can be derived:

- According to its datasheet, the system can handle a dimensional throughput of 1,000 bags/hour
- Assumed Working hours: 16 hours
- An average of 1.5 checked bags per passenger:
- 1,000 bags/hr ÷ 1.5 bags/pax ≈ 667 passengers per hour

Table 9.3: Estimations for the required number of screening units

	PAL1	PAL2
MAP within the newly proposed PTB	10	15
Estimated Passengers per Hour	1,713	2,569
Estimated Required Baggage Screening Equipment	1,713÷667 ≈ 2.57 → therefore, 3 screening units are required	2,569÷667 ≈ 3.9 → therefore, 4 screening units are required

Based on the above assumptions, three screening units will be required for PAL1, with one additional unit for redundancy, resulting in a total of four units. Similarly, four screening units will be required for PAL2, with one additional unit for redundancy, resulting in a total of five units.

Effectiveness and efficiency are often the trade-off in the selection of a hold baggage screening process.

The location of the hold baggage screening equipment, whether stand alone or in-line, must ensure compliance with the standard set forth by the International Civil Aviation Organization (ICAO) that requires hold baggage be protected from unauthorized interference after it has been screened.

As mentioned at the start of the section, this information is provided as high-level security planning assumptions to guide the PTB designer. They should be further refined and validated during subsequent design phases in coordination with the relevant stakeholders and based on the approved material.

9.5.3 STAFF SCREENING

Staff screening should achieve the same screening outcome as that for passengers i.e., prevent prohibited items entering security restricted areas and on-board aircraft, taking account of the application of tools of trade policies. This does not mean the same equipment is required, only that the same security outcome is achieved.

Equipment used to screen staff should be compliant with regulations.

Screening checkpoint layout, equipment and resourcing should take account of throughput needs as is the case for passenger screening. Whilst ‘experience’ may not be considered as critical for staff as for passengers, staff screening should not unduly delay personnel reaching their work site.

Staff screening is ideally located separately to passenger screening, even if co-located.

The amount/quantity and location of screening for staff should take account of:

- staff movement needs because of ways of working e.g., needing to move between Landside and CPSRA in a cargo to undertake their job
- relative location of staff transport to place of work e.g., commuting by train to work in the baggage makeup area
- airline crew requirements for briefing and efficient access to aircraft
- rest facilities and provisions e.g., location of staff rest areas in CPSRA to avoid the need to pass through screening when returning from breaks
- the security objective that the number of access points into the CPSRA is minimized
- resilience should another staff screening checkpoint (SCP) become unavailable e.g., equipment failure, insufficient staff

Some airlines may choose to process and screen crew off-site then buss them to airside in 'secure' buses. This reduces the need for processing and screening facilities at the airport but will entail additional buses on the roads and through the control posts.

Many of the considerations that are relevant to passenger screening checkpoint design are relevant to staff screening e.g., lighting, acoustics, human factors. See Passenger Screening.

9.5.4 ARRIVALS SCREENING

Provision must be made for some capacity to do on-arrival screening as an Additional Security Measure. Provision should include space and the Information and Communications Technology (ICT) to deploy equipment (equivalent to departure screening). The location should be located as close to the arrival gate as possible to prevent the dwelling of the unscreened passengers in the terminal and/or mixing with other people (screened or unscreened).

9.6 VIDEO SURVEILLANCE SYSTEM (VSS)

The VSS is typically comprised of Closed-Circuit Television (CCTV) cameras as well as the servers and storage that allow for live viewing as well as recording of video for forensic purposes. It is common that the CCTV cameras are used in conjunction with the ACS, allowing for security operators to assess alarms, determine the required response, and direct security personnel during a response to a possible event. Video analytics can also be considered to provide alarms to operators for possible events or activity adjacent to critical facilities.

As of a master planning perspective, Video Surveillance cameras shall be mainly deployed in the following locations:

- Perimeter fencing and boundaries
- All vehicular and pedestrian gates
- Security checkpoints
- Roads and circulation areas
- Entire exterior of critical buildings, such as ATC

The head-end equipment and VSS storage shall be housed within the Data Centers. The monitoring of the cameras feeds shall be done in the Security Operations Center within the newly proposed PTB.

9.7 SECURITY OPERATIONS CENTER

Security Operations Center to monitor the airport's cameras will need to be provided for this task.

The SOC will be required to be provided with appropriate equipment, consoles, and operators to allow for all alarms and events to be assessed and responded to in a timely manner and in accordance with ICAO requirements.

The SOC should be in a location that provides adequate protection from disruption from events that may occur on the site and should not be readily accessible to the public or traveling public. It is important to consider the types of events that may occur and unsure that the SOC would not need to be evacuated or otherwise be impaired due to an event on the site.

The SOC should be located so that access is possible from both the landside and the airside to allow for security and operational personnel to move quickly between the various zones. As a potential suitable location, the SOC could be located in the new PTB.

Regardless of the location chosen, the SOC should be provided with the following capabilities at a minimum:

- The SOC should have ready access for airside and landside personnel.
- The SOC should have redundant data feeds so that loss of a single fiber connection, data center, or major telecom does not impact the SOC operation.
- The SOC should have UPS and generator backup to allow for the SOC to remain operational should power fail.
- The SOC should be secured by Access Control and in a hardened area that would provide shelter in the event of a threat to the airport, be it a man-made event or a natural event related to weather.
- The SOC should be provided with separate HVAC, plumbing, water supply, and other critical utilities so that a failure in the overall facility systems does not impact the SOC

11 APPENDIX

11.1 APPENDIX A – JKIA AIRFIELD LAYOUT - EXISTING

11.2 APPENDIX B – JKIA AIRFIELD LAYOUT – PHASE 1 (EXISTING RUNWAY UPGRADE)

11.3 APPENDIX C – JKIA AIRFIELD LAYOUT – PHASE 2 (DEPENDENT RUNWAY)

11.4 APPENDIX D – JKIA AIRFIELD LAYOUT – PHASE 2 (INDEPENDENT RUNWAY – THRESHOLD ALIGNED SPACE RESERVATION FOR 3RD RUNWAY)

11.5 APPENDIX E – JKIA AIRFIELD LAYOUT – PHASE 2 (INDEPENDENT RUNWAY – THRESHOLD STAGGERED & SPACE RESERVATION FOR 3RD RUNWAY)

11.6 APPENDIX F – JKIA AIRFIELD LAYOUT – PHASE 2 (INDEPENDENT RUNWAY – THRESHOLD ALIGNED – ULTIMATE PHASE LAYOUT)

11.7 APPENDIX G – JKIA AIRFIELD LAYOUT – THIRD RUNWAY & TAXIWAY SYSTEM – SPACE RESERVATION

11.8 APPENDIX H – JKIA LAYOUT – SPACE RESERVATION FOR TERMINAL BEYOND 2045 – OPTION 2

11.9 APPENDIX I – JKIA LAND USE PLAN

11.10 APPENDIX J – JKIA TERMINAL BUILDING