Ahmedabad
Sardar Vallabhbhai Patel
International Airport

Ahmedabad Airport Master Plan NATS Review

Version 1.1 (Final)

NATS Private – Commercial in Confidence

Prepared By: NATS Consultancy

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Record of Changes

A record of changes made to the document will be recorded in the following table:

Version Number	Date	Comments
0.1	02/08/2022	Draft
1.0	26/08/2022	Final – Comments added as per commentary log: "Client Comments Log Responses - AMD Master Plan Review"
1.1	14/09/2022	Updated: • Table 1 – 2026 Taxiway Infrastructure Commentary: "Runway 23 operations will be challenging as demand increases between 2026 and 2030" • Table 12 – 2026 Taxiway Infrastructure Commentary: "Runway 23 operations will be challenging as demand increases between 2026 and 2030" • Section 4.6 Conclusions – Taxiways – 2026 Taxiway Infrastructure Commentary: "Runway 23 operations will be challenging as demand increases between 2026 and 2030" • Recommendation 1 - Code E Parallel Taxiway, suggested timeframe updated to "2030"

Executive Summary

This study was commissioned by Adani to provide an independent high-level review of the infrastructure and forecast demand contained in the Ahmedabad Airport Master Plan.

The airport master plan sets out ambitious targets to grow to 18M passengers annually in 2026 (Master Plan Phase 1), 28M passengers annually in 2030 (Master Plan Phase 2) and 40M passengers annually in 2040.

Desktop analysis was carried out to review the runway, stand, taxiway, and airspace infrastructure provided by the Master Plan phases and compare against forecast demand.

The main findings are summarised in the table below:

	Phase 1 - 2026	Phase 2 - 2030	2040
Adani Forecast demand, annual passengers	18M	28M	42M
Adani Forecast demand, annual movements	123k	184k	318k
Runway capacity			Limited to 36 movements per hour unless A-D-A separations are reduced
Stand capacity		Demand for overnight stands is likely to approach capacity	Demand for overnight stands is likely to exceed capacity
Taxiway infrastructure	Runway 23 operations will be challenging as demand increases between 2026 and 2030		The taxiway infrastructure is likely to become constrained as traffic levels increase
Airspace infrastructure		5NM minimum radar separation may limit airspace capacity	5NM minimum radar separation may limit airspace capacity

Table 1: Summary of Airport Capacity

The table below provides a qualitative estimate of peak theoretical capacity based on analysis in this report and benchmarking with other busy single runway airports.

	Annual Passengers	Annual Movements	Average Daily Demand	Peak Hourly Demand
Ahmedabad (Theoretical Peak Capacity)	34M	220K	603	36

Table 2: Ahmedabad Theoretical Peak Capacity

This study makes several recommendations to support the enhancement of the airport's capacity.

Table of Recommendations

Glossary

Acronym	Description
AA	Arrival-Arrival (Sequence)
ACE	Airport Capacity Enhancement
ADA	Arrival-Departure-Arrival (Sequence)
AODB	Airport Operations Data Base
ASMGCS	Advanced Surface Movement and Ground Control System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Movement; Air Traffic Management; Air Traffic Monitor
AROT	Arrival Runway Occupancy Time
ATOT	Actual Take-Off Time
ATS	Air Traffic Service
COTS	Commercial Off The Shelf
DD	Departure-Departure (Sequence)
DEP	Departure Enhancement Programme
DROT	Departure Runway Occupancy Time
EFPS	Electronic Flight Progress Strips
ICAO	International Civil Aviation Organisation
IMC	Instrument Meteorological Conditions
LUT	Line-Up Time
MARS	Multi Aircraft Ramp System
MATS	Manual of Air Traffic Services
NM	Nautical Mile
PBN	Performance Based Navigation
RECAT-EU	Re-Categorisation [of wake vortex separation standards] for Europe
RET	Rapid Exit Taxiway
RNAV	Area Navigation
RSVA	Reduced Separation in the Vicinity of the Aerodrome
RUIG	Runway Utilisation Improvement Group
SID	Standard Instrument Departure
SMR	Surface Movement Radar
SSR	Secondary Surveillance Radar
TMA	Terminal Manoeuvring Area

Table 3: Acronyms and Descriptions

Table of Contents

1. Introduction and Background

This study was commissioned by Adani to provide an independent high-level review of the infrastructure and forecast demand contained in the Ahmedabad Airport Master Plan.

Traffic at Sardar Vallabhbhai Patel International Airport has grown rapidly and the airport is currently the 7th busiest in India (FY2020/21), handling over 11M passengers per year pre-COVID.

The airport master plan sets out ambitious targets to grow to 18M passengers annually in 2026 (Master Plan Phase 1), 28M passengers annually in 2030 (Master Plan Phase 2) and 40M passengers annually by 2040.

This study reviews the two Master Plan phases above with respect to the following areas of airside capacity:

1. Runway Capacity
2. Stand Capacity
3. Taxiway Infrastructure
4. Airspace Infrastructure

1.1 Methodology

To carry out the study, NATS reviewed the following documents:

1. Master Plan airside layouts for phases 1 and 2
2. Master Plan – airside capacity
3. Master Plan – airport forecasts
4. The current airport Aeronautical Information Publication (AIP)

Desktop analysis was carried out to review the runway, stand, taxiway, and airspace infrastructure provided by the Master Plan phases and compare against forecast demand.

Detailed analysis (for example Fast-Time Simulation) was not carried out. However, this approach is recommended in future to provide more precise capacity assessments to support the phasing of Master Plan developments.

1.2 Current Layout

The airport has a single runway. The runway is operated in both directions; however, the Runway 23 operation is preferred and according to the Master Plan document is used 71% of the time, compared to 29% for Runway 05.

The airport is considered fair-weather with minimal impacts from weather-based disruption.

Figure 1: Current Layout, 2022

1.3 Phase 1 Layout - 2026

Phase 1 of the airport Master Plan includes the following airside developments:

- Addition of new terminal phase 1 with L, M, N and N1 taxiways for access
- Addition of R Code C parallel taxiway
- Addition of R5 RET on Runway 23
- Addition of R3 RET on Runway 05
- Addition of R4 and R1 runway access taxiways

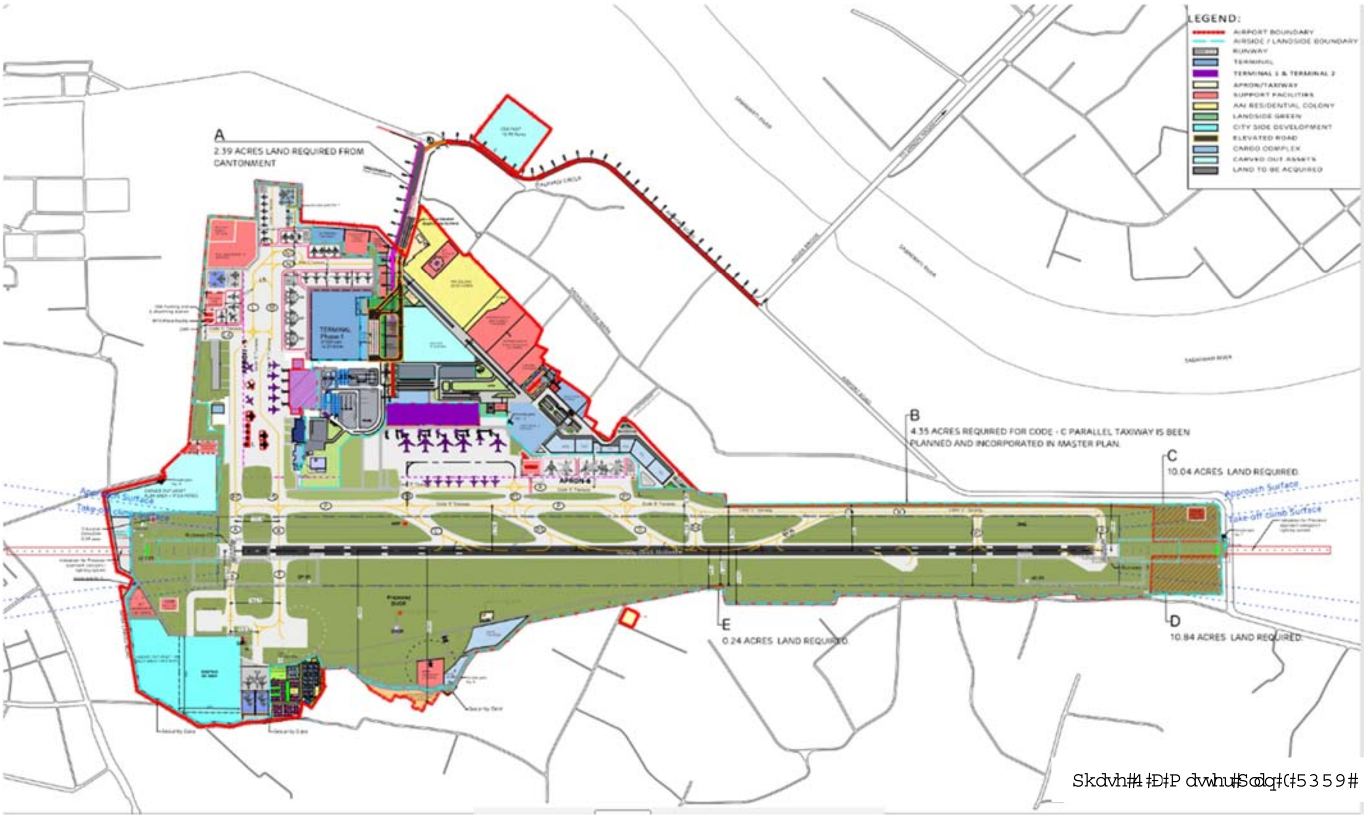

Figure 2: Phase 1 Layout, 2026

1.4 Phase 2 Layout – 2030

Phase 2 of the airport Master Plan includes the following airside developments:

- Addition of new terminal phase 2
- Addition of new remote aprons with L1 and L3 access taxiways
- Addition of R taxiway alongside the southern apron areas
- Realignment of stands in Apron 2

Figure 3: Phase 2 Layout, 2030

2. Runway Capacity

2.1 Runway Capacity Definition

Runway capacity is usually one of the more constraining aspects of an airport's capacity. Assessing runway capacity can be complicated as it can depend on many related parameters:

- Mode of operation: How the runways are operated, dependencies between runways.
- Separations: The time or distance-based separation applied for varying sequences of aircraft:
    - Arrival following Arrival (A-A),
    - Departure following Departure (D-D),
    - Arrival, Departure, Arrival (A-D-A).
- Wake mix / speed constraints
- Infrastructure: Constraints such as:
    - Entry placement – runway entry points to deliver optimised departure sequencing.
    - Exit placement – to minimise the time spent on the runway after arrival, Arrival Runway Occupancy Time (AROT).
    - Parallel taxiways and the need to backtrack on departure/arrival.

Typically, runway capacity is determined as an hourly service rate: the number of arrivals and departures an airport can service through the runway infrastructure as constrained by the parameters above. This hourly service rate can inform annual passenger capacity as constrained by the runways when combined with assumptions on daily schedule profile, fleet mix, and passenger loads.

This section reviews runway capacity figures developed in the Master Plan and provides recommendations for tools and supporting infrastructure.

2.2 Master Plan Report Validation

2.2.1 Overview and Assumptions

The "AMD Master Plan Report R6" Master Plan document focusses on Runway 23 capacity from 2020 through to 2068. The methodology and outputs were reviewed to validate the Master Plan figures.

It should be noted that according to the Master Plan, Runway 05 is used 29% of the time. Due to the single RET in this direction, this mode of operations may provide less capacity. This is discussed further in section 2.4.1.

The initial assumptions made in the Master Plan are that separations are limited by ATS surveillance to 5NM with a 0.5NM Buffer and a 5s response time. These assumptions lead to a capacity curve displayed in Figure 4.

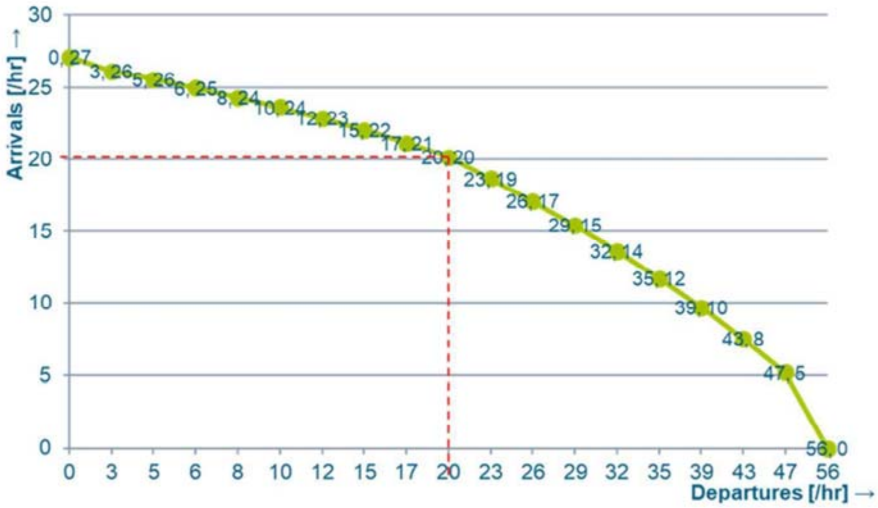

Figure 4: Theoretical Runway Capacity (RWY 23) [1]

The capacity values in Figure 4 are derived from expected separation values as discussed below:

2.2.1.1 Arrival-Arrival Separations (A-A)

The peak capacity of 27 arrivals and 0 departures suggests an A-A separation of 138s.

$$\frac{3600s}{(27-1)} = 138s$$

The denominator in the above equation is the number of A-A separations minus the first arrival at 0s. This aligns with the anticipated 5.5NM separation if 1NM is approximated to 25s at 140kt approach speed.

This arrival separation is a reasonable estimate of performance when constrained by a 5NM radar separation.

2.2.1.2 Departure-Departure Separations (D-D)

The peak capacity of 56 departures and 0 arrivals suggests a D-D separation of 65s.

$$\frac{3600s}{(56-1)} = 65s$$

The denominator in the above equation is the number of D-D separations minus the first departure at 0s. The 65s D-D separation relies on perfect departure sequencing and supporting airspace infrastructure to allow for divergent splits throughout the hour.

Considerations that impact departure sequencing include:

- Wake mix
    - This is unlikely to be a significant constraint given the predominant Code C aircraft.

- Speed Group

[1] Source: Figure 5-2 page 74 AMD Master Plan Report

    - Similarly unlikely to be a significant constraint given the predominant Code C aircraft.

- SID Sequencing
    - Given a radar minimum of 5NM it is likely that the most efficient means of maximising runway capacity is to separate departures structurally using SIDs. This would lead to a minimum departure separation of 60s; however, this would rely on a perfect mix of diverging SID demand to destinations.
    - Figure 5 displays the 2022 scheduled origin and destination directional balance for Ahmedabad. This suggests that there is a good balance of northerly and southerly demand to create an efficient sequence, so long as bunched demand for a particular direction does not occur and sufficient sequencing tools are available to controllers.

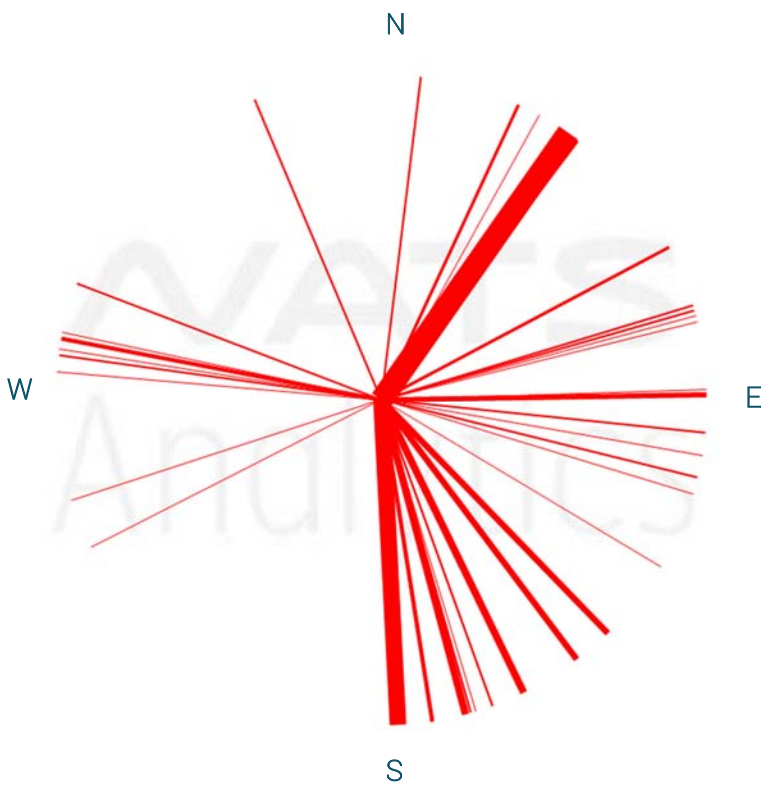

Figure 5: Directional Analysis of Ahmedabad Airport Scheduled Origins/Destinations

In practice it is likely that average achieved departure separations will be considerably higher than the 65s required to deliver 56 departures per hour. This is because throughput at this level requires an optimal sequence, necessitating a constant, even split of SID use.

Table 4 shows the maximum hourly departure capacity declared by airports with throughput levels similar to those aspired to by Ahmedabad airport:

Airport	Annual passengers	Annual movements	Maximum declared hourly departure capacity
London Gatwick (2019)	46.5M	283k	37 (Summer 2022)
London Stansted (2019)	28.1M	183k	35 (Summer 2022)

Table 4: Maximum Declared Hourly Departure Capacity at Similar Airports

2.2.1.3 Arrival-Departure-Arrival Separations (A-D-A)

The peak capacity of 20 arrivals and 20 departures suggests an A-D-A separation of 180s.

$$\frac{3600s}{(20)} = 180s$$

The 180s A-D-A separation is a reasonable estimate of likely performance, corresponding to 7.2NM with 1NM equal to 25s at 140kt approach speeds.

2.2.1.4 Impact of Code D/E Aircraft

The impact of Code D/E aircraft is important because the parallel Taxiway R can only be used by Code C aircraft.

In 2030, the expected demand of Code E aircraft is ~10% of flights, it is expected that this will also incorporate future Code D demand. This means that for a balanced demand of 20 arrivals and 20 departures, it would be expected that at least 2 flights would require backtracking on either arrival or departure (dependent on the runway in operation).

As a result, separations would be increased to incorporate the time required to backtrack as follows:

- Runway 23 – A-D-A and D-D extended separations.
- Runway 05 – A-D-A and A-A extended separations.

The impact on the operation would depend on the runway direction being used and the potential demand expected during the period.

Each Code E aircraft requires an approximate 360s/14NM separation to accommodate the backtrack. This is derived from the data in the Master Plan document:

- Peak balanced capacity is 20/20 utilising A-D-A separations for all flights with 180s separations.
- Hourly capacity reduces to 36 when 2 Code E aircraft are required to backtrack.
- 34 Normal A-D-A separations = 3600 – (16*180) = 720
- 2 Code E backtracks = 720/2 = 360s per backtrack.

These figures are also aligned to those in the AIP, which suggests backtracking separations of between 12-22 NM depending on the operation.

For each additional Code E aircraft:

- ~2 A-D-A separations are replaced.
- ~2.5 A-A separations are replaced.
- ~5.5 D-D separations are replaced

Recommendation 1: Code E Parallel Taxiway

Code E Parallel Taxiway

The airport should consider expanding the current planned parallel taxiway to be Code E compliant. It is understood that there are limitations to the implementation of the parallel taxiway, the expansion to Code E compliance would increase the runway capacity by 2-5 movements per hour.

Benefits: Increased runway capacity in all modes, decrease in complexity of operation due to removal of backtracking.

Suggested timeframe: 2030

2.2.1.5 Other Considerations

The following caveats should be considered when reviewing the capacity figures above:

- The separations and capacity curve are theoretical maxima achieved by delivering perfect sequences.
- In practice, demand tends to be mixed and less predictable. The more that the infrastructure aides in optimising the runway sequence, the more closely theoretical capacity will match actual capacity.
- Limitations on the day are managed tactically and not declared as part of capacity declarations.

2.2.2 Runway Capacity and Demand

The runway capacity for peak Arrival, Departure and balanced demand hours outlined in the prior section is compared to the peak demand derived from the "AMD Master Plan Report R6" as shown in Table 5.

Peak Hour Aircraft Movements	2020	2030	2040	2050	2060	2068
Arrival	12	21	23	24	25	25
Departure	13	23	25	25	25	25
2-way	22	38	41	41	41	41

Table 5: Peak Hourly Runway Demand

2.2.2.1 Arrival Peak Capacity and Demand

Peak arrival demand is forecast to be 21 in 2030, increasing to 23 in 2040.

Achieving 21 arrival movements at 5.5NM will allow for 17 departure movements in the hour. (17 A-D-A separations and 4 A-A separations). Increasing arrival movements above this becomes progressively more prohibitive to the number of acceptable departure movements. Depending on schedule shape and demand, the arrival peak hour could be declared at closer to 23 arrivals and 12 departures, or 24 arrivals and 10 departures. Many other high intensity and high demand airports utilise more complex Performance Based Capacity Declarations, where the capacity is declared dependent on the outcome of demand in terms of resulting delays. This allows for more control over where and how peak demand vs firebreaks occur. This is discussed in more detail in section 2.5 below.

For Runway 05, peak arrival capacity is further constrained when there is demand for Code E aircraft. Any Arrival-Arrival separations involving Code E aircraft require additional separation for the arrival backtrack.

Recommendation 2: Reduce Minimum Radar Separation

Technology enhancements to reduce the minimum radar separation.

The airport should consider technology enhancements to reduce the minimum radar separation from 5NM to 3NM.

Benefits: Increase capacity and resilience.

Timeframe: From Phase 1 (2026)

2.2.2.2 Departure Peak Capacity and Demand

Peak departure demand is forecast to be 23 in 2030 and 25 in 2040.

With 23 departure movements planned, capacity allows for 19 arrival movements in the hour. Depending on schedule shape and demand, departure peak hours could be declared at closer to 17 arrivals and 26 departures or 15 arrivals and 29 departures.

Runway 23 peak departure capacity is further constrained when there is demand for Code E aircraft. Any Departure-Departure separations involving Code E aircraft require additional separation for the departure to backtrack.

2.2.2.3 Balanced Demand Peak Capacity and Demand

Peak balanced demand is forecast to be 38 and 41 in 2030 and 2040 respectively.

In either runway operation, the balanced capacity is limited to 36 movements (when considering impact of Code E aircraft on the operation).

This means that to provide the runway capacity to service expected balanced demand hours from 2030 onwards, A-D-A separations must be reduced.

2.2.2.4 Impact of Reduced A-D-A Separations

Reducing A-D-A to 6NM (150s) in hours with balanced demand could increase capacity to 38-40 movements per hour, assuming:

- ~14NM (360s) A-D-A for backtracking Code E aircraft.
- ~2 Code E backtracking aircraft in the demand hour.

Number of seconds in an hour

Two backtracking Code E separations.

$$\frac{(3600s - 720s)}{150s} = 19$$

6NM A-D-A Separation

Number of remaining A-D-A separations

Recommendation 3: Reduced A-D-A Separation

Reduced A-D-A Separation
Benefits: A reduced A-D-A separation of 6NM would provide a higher runway capacity in periods of balanced demand. Suggested timeframe: Phase 2 - 2030

2.3 Master Plan Forecast Daily and Annual Movements

Table 6 shows the breakdown of the total forecast annual passenger numbers and commercial movements as shown in the master plan document "*AMD Master Plan Report_R6*". The figures in bold represent calculated daily figures assuming even demand across the year. The average hourly demand can then be compared to the previously validated hourly capacity figures.

Forecast	2030	2040
Annual Passengers	28,012,485	42,262,706
Annual Movements	184,254	318,491
Average Daily Movements (365d)	505	873
Average Hourly Demand (24h)	21	36
Average Code C Passenger Load (90% of traffic)	135	118
Average Code E Passenger Load (10% of traffic)	304	265
Average Passenger Load per flight (all traffic)	152	133

Table 6 – Summary of Demand Required to Service Forecast Annual Passengers

The forecast scaling of annual movements to annual passengers aligns well with expected passenger loads based on the assumed split of 10% Code E and 90% Code C aircraft. The average passenger loads are calculated as the number of annual movements multiplied by 90% or 10% then divided by the number of annual passengers multiplied by 80% or 20%.

The analysis shows that the forecast number of passengers increases at a lower rate than the number of movements, meaning that passenger loads are forecast to reduce significantly from 2030 to 2040. It is noted that as airports become capacity constrained the opposite trend is often observed: Airlines deploy larger aircraft and passenger loads increase. Assuming the same forecast passenger loads as 2030 would allow 42 million passengers to be delivered by only 280k movements in 2040.

2.3.1 Gap Analysis

The table below shows the forecast demand and available runway capacity for 2030 and 2040:

		2030 – 28 million passengers	2040 – 40 million passengers
*Average Hourly ATM Demand**		21	36
Hourly Capacity	Arrival Peak**	21 arrivals / 17 departures = 38 total	
	Departure Peak**	19 arrivals / 23 departures = 42 total	
	Balanced	18 arrivals /18 departures = 36 total	

Table 7: Gap Analysis of Hourly Demand Required to Service Forecast Annual Passengers vs Runway Capacity

*The average hourly demand assumes average daily movements split equally across a 24-hour operation.
**These figures do not incorporate Code E impact that reduces capacity for arrivals and departures dependent on runway operation.

Peak arrival and departure demand periods have capacities close to or higher than the average demand required to service 40 million passengers per year. However, depending on the runway direction in use, this capacity will be constrained by the Code E demand. It's likely that peak arrival or departure periods will see demand more than the average of 36 flights per hour, if this occurs when the runway in operation is constrained by Code E aircraft, the demand will become challenging to service.

The balanced capacity assumes 10% Code E operations and can service 36 arrivals and departures per hour. To accommodate 40 million passengers per year, the average hourly demand is 36. It is likely that there will be many periods of demand lower than 36 per hour, and these will need to be balanced with periods of demand higher than 36. If this demand is equally split between arrivals and departures, the runway capacity is not sufficient to service the demand.

To illustrate this point, Figure 6 shows the average schedule demand for June 2022. There are clear peaks in demand in the morning (departures, followed by arrivals) and evening (broadly balanced arrivals and departures). Demand is lower overnight and through the middle of the day. Total demand is 202 movements per day.

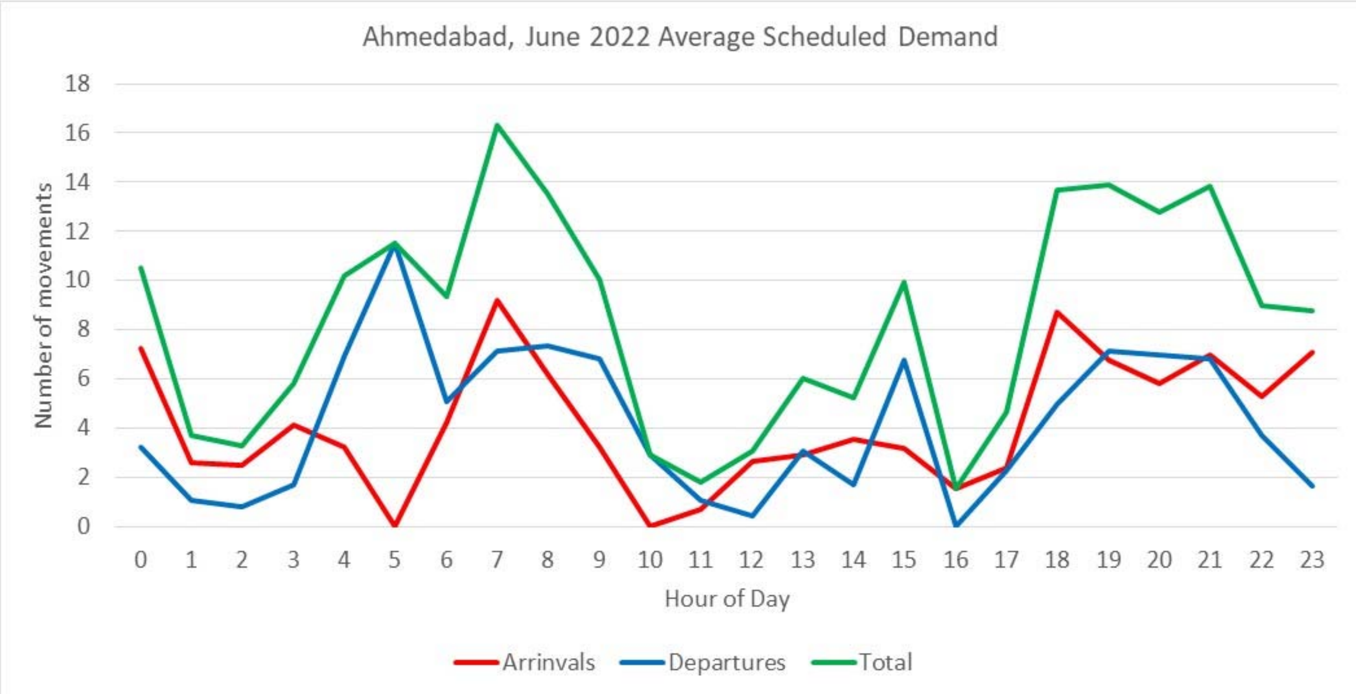

Figure 6: June 2022 average schedule demand

Figure 7 shows an example of what a grown scheduled demand profile with peaks of 36 movements per hour could look like.

The morning and evening peaks have been grown to 36 movements per hour, spreading the morning peak. The remainder of the profile has been grown by the same proportion (roughly x2.5) and the trough between the morning and evening peaks has been further increased to a minimum of 20 movements per hour. The resulting profile has 596 daily movements, which would meet demand for 2030, but would fail to meet demand for 2040 by a considerable margin.

Averaging 596 movements per day would equate to approximately 28.9 to 33.1 million passengers per year, depending on the assumed passenger loads.

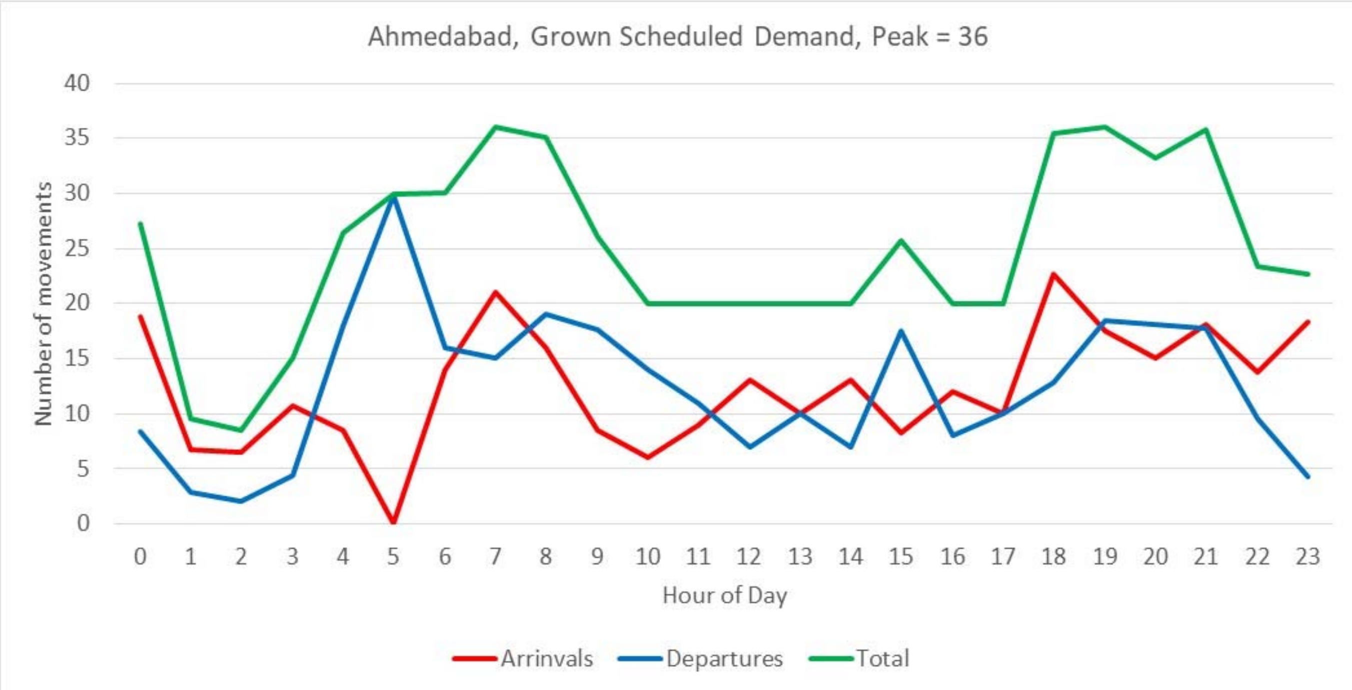

Figure 7: Grown scheduled demand profile with peaks of 36 movements per hour

2.3.2 Impact of Reduced A-D-A Separations on Daily Movements

Assuming the implementation of reduced A-D-A separations to 6NM, Figure 8 shows an example of what a grown scheduled demand profile with peaks of 40 movements per hour could look like.

The morning and evening peaks have been grown to 40 movements per hour, spreading the morning peak. The remainder of the profile has been grown by the same proportion (roughly x2.9) and the trough between the morning and evening peaks has been further increased to a minimum of 24 movements per hour. The resulting profile has 675 daily movements, which would meet demand for 2030, but would fail to meet demand for 2040 by around 200 movements per day.

Averaging 675 movements per day would equate to approximately 32.7 to 37.5 million passengers per year, depending on the assumed passenger loads.

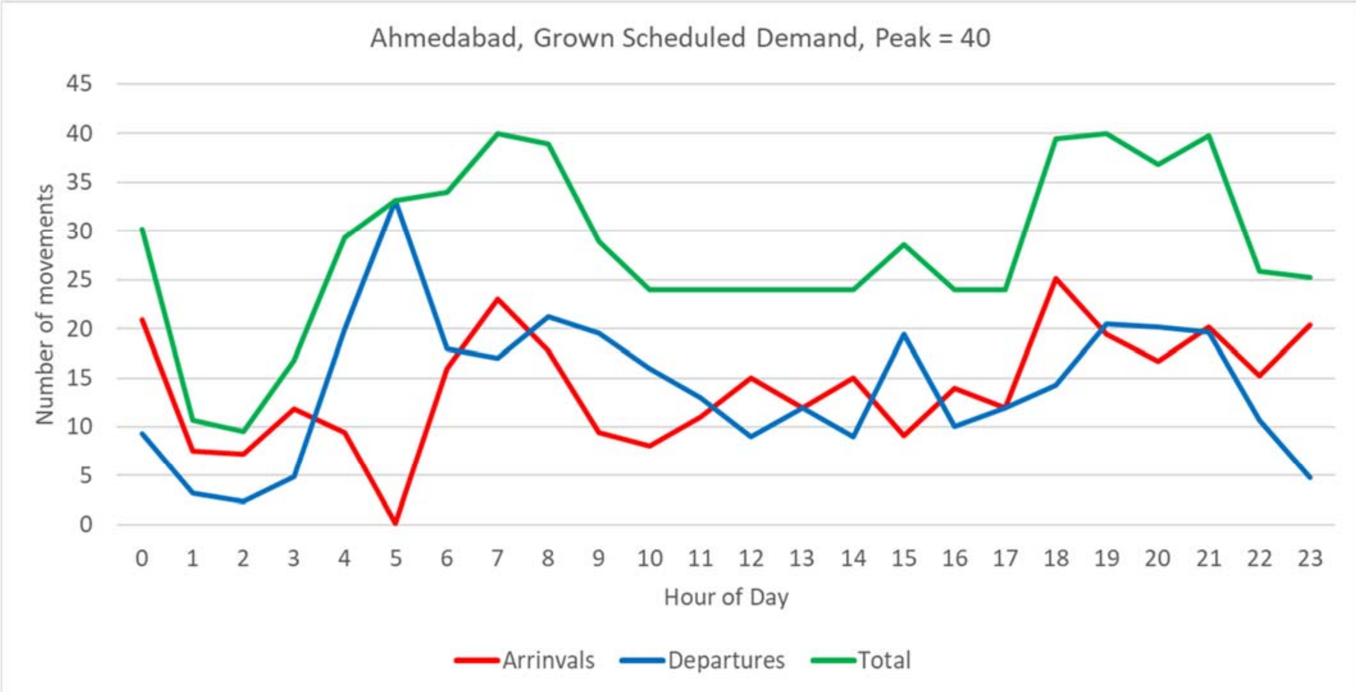

Figure 8: Grown scheduled demand profile with peaks of 40 movements per hour

2.4 Runway Infrastructure Constraints

2.4.1 Rapid Exit Taxiways

The use of Rapid Exit Taxiways can reduce the runway occupancy times and improve runway capacity.

When RETs are added as shown at the top of Table 8, the expected AROTs will allow for sufficient margin to incorporate the events necessary to make up a 180 second A-D-A sequence. This is illustrated in detail in section 7.1.

The additional RETs proposed (Delta, Romeo 5, Charlie, and Romeo 3) are positioned at similar distances from the runway thresholds as those at other high intensity single runway airports and are therefore not expected to constrain capacity.

Airport	Runway	Exit	Distance to Threshold (m)[2]	Design Exit Speed (kts)	Expected use	Expected AROT (s)
Ahmedabad	23	Delta	1557	50	~50% of narrowbody aircraft	50-55
	23	Romeo 5	1960	50	~50% of narrowbody aircraft	55-65
	23	Charlie	2397	50	Most code D/E aircraft	> 65
	05	Romeo 3	1960	50	All narrowbody aircraft	55-60
London Gatwick	26L	E	1323	38	~40-45% of traffic	40-50
	26L	FR	1773	52	~55-60% of traffic	50-60
	26L	GR	2069	49	<5% of traffic	> 60
	08R	D	1318	38	~25-30% of traffic	50-55
	08R	CR	1739	49	~55-60% of traffic	50-55
	08R	BR	2194	52	~5-10% of traffic	60-65
London Stansted	22	NR	1276	52	~45-50% of traffic	40-45
	22	LR	1891	52	~40-45% of traffic, most code D/E	50-60
	04	PR	1566	52	~40-45% of traffic	50-55
	04	QR	1844	52	~45-50% of traffic, most code D/E	55-60
Mumbai	27	N7	1574	50	~5% of traffic	55
	27	N8	1878	50	~90% of traffic	55-60
	27	N9	2150	50	~5% of traffic	60

Table 8: Benchmarking RETs

[2] Source: AMD Master Plan Report / London Gatwick and Stansted AIP documents

Table 8 benchmarks the proposed RET locations in Ahmedabad's Master Plan against other high performance single runway airports.

There is a risk that Runway 05 AROTs could be extended if Code C aircraft are not able exit at Romeo 3. At the other airports above, almost all traffic is expected to vacate at or before RETs positioned 1800-2100m from the threshold, therefore it is reasonable to assume that this risk is low. However, a more detailed study is recommended to assess the need for an additional RET for Runway 05.

If the A-D-A separation is reduced to 6NM or lower, the margin to incorporate the DROT, buffer and landing clearance reduces. In this case, ensuring that DROT and Line-Up Times are minimised will be important. This is illustrated in detail in the diagram in section 7.1.

Recommendation 4: ACE - Performance Monitoring

Airport Capacity Enhancement (ACE) - Performance Monitoring

The airport should consider undertaking an Operational Performance Summary (OPS) to determine key metrics that may constrain operations in the future:

- Arrival Runway Occupancy Times
- Departure Runway Occupancy Times
- Line-Up Times
- Separations (AA / DD / ADA)
- Backtracking performance for departures on Runway 23 and arrivals on Runway 05

Ideally, performance monitoring should be carried out regularly, and also after the new infrastructure is built.

Benefits: Understand performance and ensure the benefits from the new infrastructure are being realised.

Suggested timeframe: 2023 onwards

Recommendation 5: RET Lighting

Runway Exit Taxiway Lighting

The Master Plan does not provide details of Rapid Exit Taxiway Lighting or Rapid Exit Taxiway Indicator Lights (RETILS) which support planning from a flight deck perspective and help to increase capacity.

The airport should consider the use of Rapid Exit Taxiway Lighting and RETILS on all RETs to provide flight deck crews with 300m, 200m and 100m indicators to the next Rapid Exit Taxiway. The RETILS can be used in day and night-time settings.

> Benefits: Reduce runway occupancy times, improve consistency of performance and help to make this element of the operation more predictable.
>
> Suggested timeframe: Phase 1 (2026) onwards

2.5 Tools and Enhancement Opportunities

Recommendation 6: Performance Based Capacity Declaration

Performance Based Capacity Declaration

Performance Based Capacity Declaration (PBCD) is a process whereby runway capacity is declared based upon the expected operational outcomes of the airport, typically the expected levels of airborne and departure delay.

By employing a Fast-Time Simulation (FTS) model to predict the level of delay associated with a given schedule, it is possible to objectively assess the likely operational impact of adding additional movements, or re-timing existing movements. Proposed changes to the scheduled movements can then be approved or rejected based upon an evaluation of their acceptability, for example by comparing the predicted delay to an agreed delay threshold. This approach is in contrast to declaring capacity as a figure limiting hourly movements in terms of arrivals, departures or balanced, whereby the actual capacity based on wake mix, SID mix and arrival/departure balance and impact of low-demand delay recovery periods is not included.

Strategic Airport Capacity Manager

NATS has provided a PBCD process at multiple capacity constrained airports worldwide over many years, including the London airports (Heathrow, Gatwick, and Stansted), Hong Kong, and Delhi IGIA. This method of declaring capacity has enabled these airports to maximise the use of the limited capacity they have available by taking advantage of the accessible intelligence about their future schedules.

NATS uses the Strategic Airport Capacity Manager (S-ACM) simulation tool for this purpose, which was developed and introduced in 2013 specifically for the capacity declaration process at London Heathrow Airport.

Benefits: Greater flexibility to match capacity with airline demand, leading to a higher overall daily capacity.

Suggested timeframe: 2023 onwards

Recommendation 7: AMAN / DMAN

Recommendation – AMAN / DMAN

Implement Arrival Manager and Departure Manager (AMAN/DMAN) ATC decision support tools to support arrival and departure sequencing and metering. DMAN ideally would also include a Target Start-up Approval Time (TSAT) system (that gives the time an aircraft can expect a start-up approval from ATC). This would help manage the number of aircraft taxiing and queuing on the airfield.

Benefits: Improve arrival and departure sequencing and metering capability.

Suggested timeframe: Phase 2 (2030) onwards

Recommendation 8: Demand-Capacity Balancing (DCB)

Demand-Capacity Balancing (DCB)

Demand-Capacity Balancing (DCB) is the process of comparing traffic demand and available capacity in a defined timeframe, determining bottlenecks, and assessing mitigation measures in order to find the optimum result in terms of minimising delays and costs.

Conceptually the DCB process can be applied to any node within the network (airport, waypoint, sector, TMA, FIR, etc.); however, through extensive experience in developing such concepts in support of operational trials in SESAR PJ24, NATS considers that the Airport DCB process is particularly important.

To support London Heathrow Airport, NATS has implemented a DCB tool to provide more accurate predictions of in and off block times together with the operational performance metrics up to 10 days ahead of operation. It is also used to monitor and intervene during the day of operation itself and to feed other airport systems (e.g. A-CDM and the RMS) to improve airport-wide planning.

The system uses en-route global wind data, local weather forecasts, schedules, and flight data, together with machine learning and simulation techniques to make flight time predictions and test alternative operational strategies (e.g. runway inspection timing) before they are implemented. The tool was first deployed at Heathrow in April 2017 and was subsequently integrated with NMOC to issue Target Time of Arrival (TTA) messages as part of the SESAR PJ24 operational trials. Through these trials it was demonstrated that TTA regulations resulted in 26-40% less ATFM delay than would have been required if applying traditional processes.

The Heathrow DCB system is deployed within the Airport Operating Centre (APOC) and our en-route ATC centre and is used by both Airport and ATC staff. NATS provide specialist staff to the APOC called "Heathrow Traffic Coordinators" these positions are non-operational and can be undertaken by non-licenced staff. Their role is to proactively optimise the operational plan in response to evolving conditions and to co-ordinate between airport, local ATC, and ATFM to generate a jointly aligned daily strategy.

> Benefits: Greater tactical control of the airport and awareness of current and near future demand allows for better decision making, reduced delays and improved passenger experience.
>
> Suggested timeframe: Phase 1 (2026) onwards

Recommendation 9: Intelligent Approach / Time-based Separation

Intelligent Approach / Time-based Separation

To assist in the consistent delivery of arrival spacing Heathrow and Toronto (with Amsterdam Schiphol and Gatwick also soon to adopt the technology) uses the Intelligent Approach™ (IA) tool to support the use of Time Based Spacing (TBS). This assists controllers by providing visual markers which adjust for the spacing between consecutive arrivals given the real-time wind conditions. This helps increase the consistency of delivery and can also improve the runway throughput during periods of stronger winds as spacing can be reduced due to the acceleration of wake dispersion in strong wind conditions.

> Benefits: Improved consistency of delivered separations and increased resilience to headwind conditions.
>
> Suggested timeframe: Phase 1 (2026) onwards

Recommendation 10: Runway Sequence Optimisation

Runway Sequence Optimisation

Runway sequence optimisation or “pack and gap” is a dynamic final approach spacing regime that reflects the balance of arrivals and departures at any given time. It provides the opportunity to avoid capacity loss in the system and generate greater flexibility in the scheduling limits.

Recommendation

It is recommended that a controller support tool such as IA is evaluated to provide safety assured separation markers directly on to the radar display. This will support all ATCOs in delivering reduced final approach spacing with greater consistency. DGCA approval may be required prior to the operational use of any such tools by AAI.

> Benefits: Optimise runway capacity in response to peaks in arrival and departure demand.
>
> Suggested timeframe: Phase 1 (2026) onwards

Recommendation 11: Airline Pilot Performance and Engagement

Airline Pilot Performance and Engagement

It is recommended that the airport considers establishing a Runway Utilisation Improvement Group (RUIG) which would include representatives from the airport, AAI, and the major airlines. This group would meet regularly to discuss topics such as runway exit utilisation and runway occupancy times. Experience at other airports has shown that these forums can contribute to significantly improved performance.

Benefits: Improve runway performance and consistency.

Suggested timeframe: 2023 onwards

2.6 Conclusions – Runway Capacity

Reduced A-D-A separations will be required by 2040 to meet the balanced demand for the runway.

	Phase 1 - 2026	Phase 2 - 2030	2040
Target Capacity, Annual Passengers	18M	28M	42M
Target Capacity, Annual Movements	123k	184k	318k
Runway capacity			Limited to 36 movements per hour unless A-D-A separations are reduced

3. Stand Capacity

In this section, the stand capacity of Ahmedabad for each phase of the Master Plan is assessed, with consideration out to 2040 and servicing 40 million passengers per year. A benchmarking exercise was also undertaken with airports that are comparable to Ahmedabad's growth aspirations.

3.1 Assumptions and Master Plan Validation

The stand capacity of an airport is driven by many factors, including:

- Number of stands
- Size of available stands
- Airline / category preferences
- Stand occupancy times
- Schedule / demand shape
- Quantity of overnight based aircraft

The airport Master Plan provides information about the planned number of stands:

3.1.1 Number of Stands and Sizes

3.1.1.1 Phase 1 - 2026

Stand Size	Number of stands available	Purpose / notes
Code A	4	4 stands for GA
Code B	20	16 stands for GA, 4 for commercial
Code C	27	18 remote stands, 9 contact stands
Code D	5	5 cargo stands
Code E	3	1 remote stand, 2 contact stands
MARS	5	3 in the new Terminal, 2 in Terminal 2
Total	64-69, of which 40-45 Code C and above	

Table 9: Phase 1 – 2026 – Number of Stands

3.1.1.2 Phase 2 – 2030

Stand Size	Number of stands available	Purpose / notes
Code A	0	-
Code B	16	16 stands for GA
Code C	48	40 remote Stands, 8 contact stands
Code D	5	5 cargo stands
Code E	0	-
MARS	11	11 in the new Terminal
Total	80-91, of which 64-75 Code C and above	

Table 10: Phase 2 – 2030 – Number of Stands

3.1.2 Stand Occupancy Times

Stand occupancy times (turnaround times) are a significant constraining factor to the stand plan and stand capacity. The longer aircraft occupy stands for; the fewer stands are available for inbound flights.

Airports with high levels of low-cost airlines tend to have lower stand occupancy times and more opportunity for higher traffic levels.

The airport master plan states that average occupancy times are:

- 96 minutes for Code C
- 140 minutes for Code E

The Code C occupancy time assumed above appears high for low-cost airlines comparing against similar operations at similar airports. Whilst these values may be indicative of current operations, it is likely that occupancy times would reduce as demand increases. IndiGo and SpiceJet, for example, both target turnaround times of 25 minutes or less.

The airport also discussed the use of split occupancy times for Code C Domestic (45 minutes) and Code C International (60 minutes) flights. These times are in line with average stand occupancy times at similar airports; for low-cost airlines, future stand occupancy times may still be reduced below this.

3.1.3 Schedule/Demand Shape and Overnight Parking

The schedule and demand shape are the driving factor behind when aircraft will require stands. It is challenging to develop accurate indications of stand capacity using only runway-capacity figures. It is therefore recommended that more detailed fast-time simulation is used to determine stand capacity with forecast schedules. This is because periods of high arrival demand without departure relief can quickly overcome stand capacity, even if balanced demand implies stand capacity is available.

The current stand occupancy profile (using 2022 schedules) indicates a stand constraint primarily overnight, with unconstrained operations through the day. This is in line with similar airports with significant volumes of low-cost airline operations. Low-cost airline business models frequently require based aircraft stationed overnight with large first-wave departure demand between 06:00-08:00. Generally, these flights operate three or four rotations and return to base between 21:00-23:00 in the evening. This pattern creates the overnight peak for stand demand which is seen in Ahmedabad. If the airport is saturated overnight, the airport must ensure high levels of early morning departures prior to any inbound wave.

It is therefore likely that Ahmedabad will be limited by overnight stand capacity (45-75 stands 2026-2030).

Recommendation 12: ACE - Stand Capacity Simulation

ACE - Stand Capacity Simulation

It is recommended that the airport considers utilising Fast-Time Simulation (FTS) to determine stand capacity with the constraints examined in this section. A forecast future schedule will more accurately indicate levels of stand occupancy and when potential stand constraints might occur.

In practice, estimating stand capacity is complex and many variables influence the level of stand capacity available. One of the major factors is the schedule used and the linking between arrivals and departures.

To provide a more detailed view of the stand capacity in 2026 and 2030, it is recommended that a detailed stand capacity assessment is carried out, using forecast linked schedules for the target years.

Benefits: Obtain a more detailed view of future stand capacity and constraints.

Suggested timeframe: 2022 onwards.

3.1.4 On-Pier Service

It was noted that the Phase 1 layout has 18 remote Code C stands, whilst the Phase 2 layout has 40. These figures are likely to make the airport's target of 90% pier service impossible to achieve. This is especially challenging as turnaround times are likely to reduce to 25 minutes or less for the majority of Code C low-cost airline flights.

Pier service is a metric that could be generated by the stand capacity modelling recommended above. This activity could help to devise a strategy to improve on-pier service to meet the target.

3.2 Benchmarking

3.2.1 Stand Counts

Table 11 shows how the Master Plan stand provision compares to airports that handled annual passenger demand similar to that forecast for Ahmedabad.

Phase 1 – 2026

The main comparison is with London Luton. Both airports achieve/aim for 18M passenger per year with 123k to 142k annual movements. The mix of traffic is similar, and the number of stands is also similar. It is therefore assumed that Phase 1 will not be constrained by the stand operation, but careful attention must be applied to the number of aircraft parked overnight.

Phase 2 – 2030

The main comparison is with London Stansted. Both airports achieve/aim for 28M passengers per year with 180k annual movements. The mix of traffic is similar. In this case, London Stansted operates with 50% more available stands. London Stansted operates 24/7 but is restricted in the number of flights it can operate per season between 23:00 and 07:00. If Ahmedabad operates more frequently overnight, the demand for overnight stands may be reduced.

2040

Comparisons are made with London Gatwick and Mumbai, with all three airports targeting over 40M passengers per year and over 280k annual movements. Both Gatwick and Mumbai benefit from significantly more stands than are expected to be provided at Ahmedabad, suggesting that supporting these levels of traffic will be challenging.

Airport	Year	Annual passengers	Annual movements	Average daily movements	Code D-F : Code A-C proportions	Number of stands
London Luton	2019	18.0M	142k	389	2% : 98%	~42 code C
London Stansted	2019	28.1M	183k	501	5% : 95%	~110, with ~160 centrelines
Mumbai	2019	45.8M	304k	833	14% : 86%	~105 with ~150 centrelines
London Gatwick	2019	46.5M	283k	775	11% : 89%	~119, with ~186 centrelines
Ahmedabad	2026	18.0M	123k	337	5% : 95%	~45 with ~50 centrelines
	2030	28.0M	184k	504	10% : 90%	~91 with ~103 centrelines
	2040	42.3M	318k	871	10% : 90%	~91 with ~103 centrelines

Table 11: Benchmarking of Available Stands

Note that Multi Aircraft Ramp System (MARS) stands in Table 11 are considered as 2 stands with 3 centrelines.

3.2.2 Stand Use Profiles

To reinforce the points made above, Figure 9 and Figure 10 below show simulated stand use profiles (the number of stands occupied by time of day) for London Stansted and London Gatwick airports. The traffic levels handled by these airports correspond well to the forecast demand levels for Ahmedabad in 2030 and 2040 respectively.

Phase 2 – 2030

Figure 9 shows peak stand demand at London Stansted reaching 77 stands overnight, which would be close to the limit of the available Ahmedabad Phase 2 stand infrastructure.

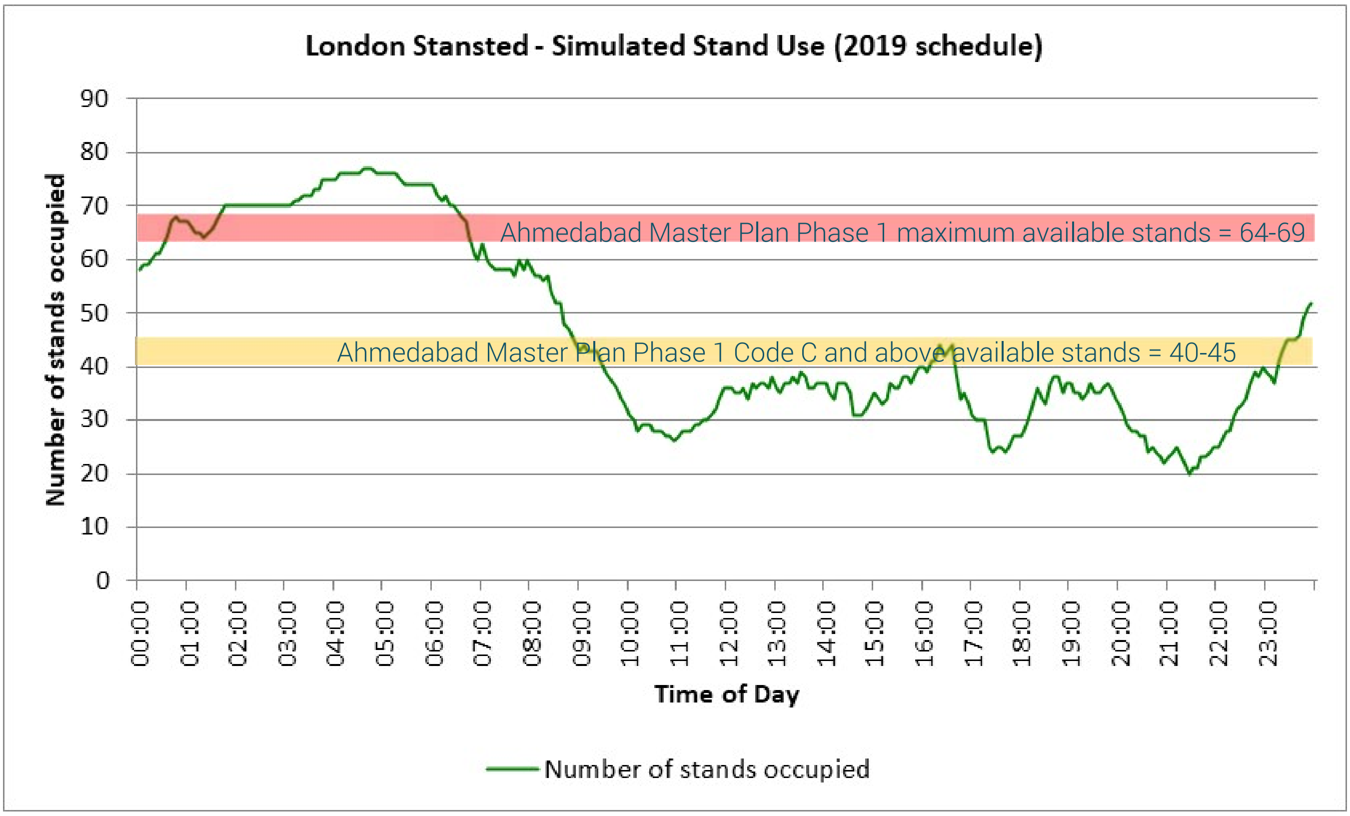

Figure 9: London Stansted simulated stand use by hour of day

2040

Figure 10 shows peak stand demand at London Gatwick reaching 119 stands overnight, which would exceed the Ahmedabad Phase 2 stand capacity by a considerable margin.

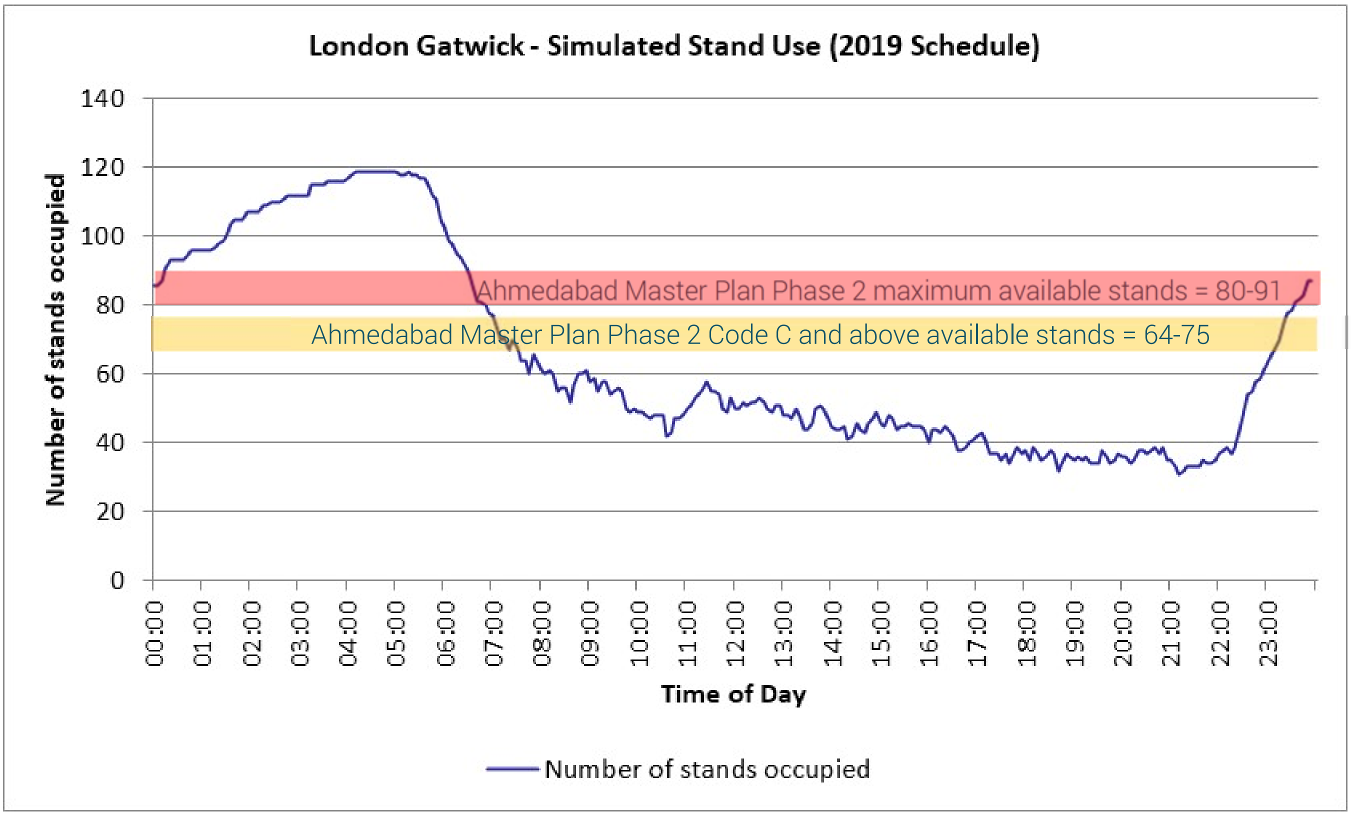

Figure 10: London Gatwick – Simulated Stand Use by hour of day

3.3 Other Considerations

3.3.1 Use of Multiple Aircraft Ramp System (MARS) stands

The proposed apron layout provides opportunity to maximise the space available for parking of different aircraft types especially with the use of MARS stands adjacent to the terminal complex.

Recommendation 13: MARS Utilisation

MARS Utilisation

The airport should consider how best to use MARS stands. In the Master Plan there are 12 MARS stands that can either accommodate 12 wide bodied aircraft or 24 narrow bodied aircraft. Experience operating at other airports where these concepts are frequently used suggests that careful planning is required for the provision of Ground Servicing Equipment, including staging areas for cargo that is flown as belly freight. This is in addition to ensuring there is sufficient space on the ground,

There also needs to be careful stand planning to ensure that there are no simultaneous pushbacks on adjacent stands or from the left and right of a MARS stand.

Benefits: Optimised MARS usage will ensure maximised stand capacity

Suggested timeframe: Phase 2 (2030) onwards.

3.3.2 Role as a Diversion Airport

Note that Ahmedabad's long runway and favourable weather conditions make it a preferred airport for handling diversions from other airports. A sufficient stand capacity buffer should therefore be allowed for this.

3.4 Tools and Recommendations

Recommendation 14: Use of a Stand Allocation Tool

Use of a Stand Allocation Tool

The airport should consider the use of a stand planning tool to optimise stand allocation. Ideally, the tool should automatically and optimally allocate aircraft to stands to maximise availability and pier service, considering the constraints of each stand and airline preferences. The tool should respond to changes in flight times, for example early or late arrivals and delays to turnarounds. In addition, the tool should manage the towing of aircraft to and from remote stands.

Benefits: Optimise stand allocation to maximise availability and pier service

Suggested timeframe: Phase 1 (2026) onwards.

Recommendation 15: Options for Additional Stand Capacity

Options for Additional Stand Capacity

The airport should consider options to provide additional stand capacity, for example:

- Use of additional remote parking, for example on certain designated taxiways, particularly during the overnight period.
- Options to construct additional stands south of the runway. It is noted that the DVOR and ASR navaids are located in this area and therefore implementation may be challenging. A feasibility and cost-benefit analysis should be undertaken for the additional infrastructure.

Benefits: Additional stand capacity will maximise the capacity of the airport as a whole.

Suggested timeframe: Phase 1 (2026) onwards.

3.5 Conclusions – Stand Capacity

Demand for overnight stands is likely to approach capacity by 2030 and to exceed it by 2040.

	Phase 1 - 2026	Phase 2 - 2030	2040
Target Capacity, Annual Passengers	18M	28M	42M
Target Capacity, Annual Movements	123k	184k	318k
Stand capacity		Demand for overnight stands is likely to approach capacity	Demand for overnight stands is likely to exceed capacity

4. Taxiway Infrastructure

4.1 Proposed Taxiways, Flows and Hotspots

This section analyses the proposed taxiway infrastructure, potential flows around the airfield and resulting potential hotspots on the airfield. Increased numbers of hotspots and magnitude of impact from hotspots results in increased delays for aircraft on the ground and increased complexity for controllers.

4.2 Phase 1 – 2026

4.2.1 Runway 23 Operations

Figure 11 shows the potential flows and hotspots when using Runway 23 with the infrastructure present in Phase 1 – 2026.

The comments below correspond to numbered areas highlighted in Figure 11:

1. The taxiways servicing the main Apron area appear to be workable with potential flows on both parallel taxiways limiting contraflow. Main stands pushing back directly on to the taxiways may cause some limited congestion, however arriving aircraft waiting for stand can utilise the vacant parallel taxiway to wait.
2. This area is one of the key hotspots for the operation. Arriving and Departing aircraft to the main Aprons must cross at this intersection. Since all aircraft must route via Taxiway Papa in both directions, it's likely that preference would be given to arriving traffic. During periods of high arrival demand or bunched arrival demand, these taxiways could become congested. At ~20kts it would take 90s for an arrival to leave the RET, taxi to the crossing point and a further 90s for a departing aircraft taxi to the RET. This means that if the A-A separation is <180s then the departure will not get to the RET before the proceeding arrival needs its use, this means that in periods of high arrival demand, departures may be stuck at the intersection waiting for a gap in arrival demand.
3. Having the arrival flow utilising the RETs onto the only available taxiway for departures introduces potential contraflow hotspots. The departure will likely have to wait at "Point 2" or taxi via the apron to route around incoming arrivals.
4. The Code E holding area for departure backtrack will likely cause some delay. Any Code C departures would need to queue behind it, with little to no ability to re-sequence the departure queue. Only one aircraft can hold here at a time without blocking the RET.

The taxiways between numbered areas 2 and 4 are likely to become increasingly challenging to operate as forecast demand increases to 38 movements per hour in 2030.

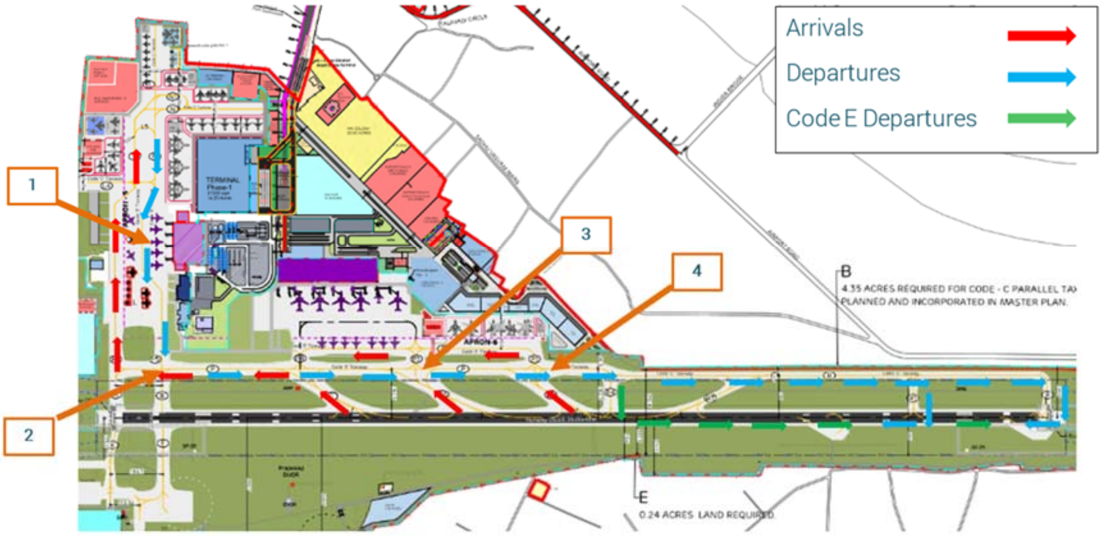

Figure 11: Phase 1 – 2026 - Runway 23 Potential Flows and Hotspots

Recommendation 16: Review Parallel Taxiway Phase 2 Timing

Review Parallel Taxiway Phase 2 Timing

The airport should consider when the parallel taxiway will be delivered as part of Phase 2. The Runway 23 operations will likely become constraining as demand grows, balancing that demand increase against the phased development could alleviate congestion and provide sustained consistent growth.

Benefits: Sustained growth, minimising constraints brought about by a single taxiway.

Suggested timeframe: Phase 1 (2026) onwards.

Recommendation 17: Consider area south of runway for additional RET and Taxiway Infrastructure

Consider area south of runway for additional RET and Taxiway Infrastructure

The airport should consider using the area south of the runway for an additional southerly RET. This could deconflict the arriving and departing traffic during Runway 23 operations.

It is noted that the DVOR and ASR navaids are located in this area and therefore implementation may be challenging. A feasibility and cost-benefit analysis should be undertaken for the additional infrastructure

Benefits: Deconflict the arrivals and departures, provide relief to main parallel taxiway system as demand increases. Note the potential complexity of crossing the traffic over the runway.

Suggested timeframe: Phase 1 (2026) onwards.

4.2.2 Runway 05 Operations

Figure 12 shows the potential flows and hotspots when operating using Runway 05 with the infrastructure present in Phase 1 – 2026.

The comments below correspond to numbered areas highlighted in Figure 12:

1. Access to multiple runway line-up points could help improve departure sequencing in periods of high departure demand. However, the second line-up point is also where arrivals taxi to enter the main apron areas.
2. Contrary to Runway 23 operations, all flights are taxiing westerly along the parallel taxiways and through the aprons. This will likely result in less taxiway congestion and delay.

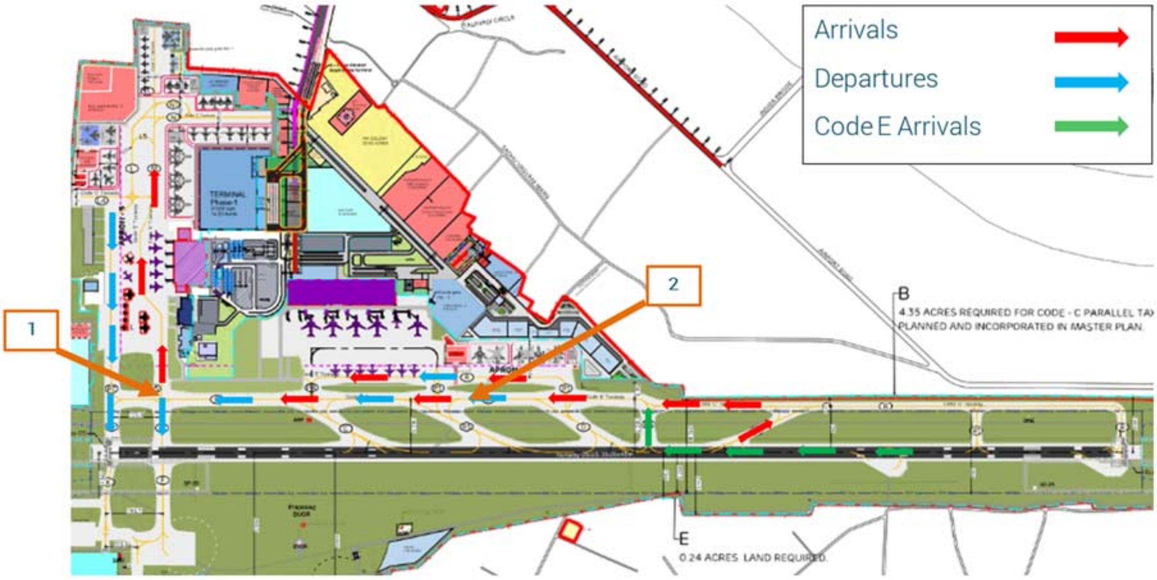

Figure 12: Phase 1 – 2026 - Runway 05 Potential Flows and Hotspots

4.3 Phase 2 – 2030

4.3.1 Runway 23 Operations

Figure 13 shows the potential flows and hotspots when operating using Runway 23 with the infrastructure present in Phase 2 – 2030.

The comments below correspond to numbered areas highlighted in Figure 13:

1. The main apron stands push back on to one of the key taxiways parallel to the aprons. This is normal for many high intensity airports and is unlikely to constrain flows. However, this could be challenging in hours with high, mixed demand.
2. The crossing taxiways between the two parallel taxiways are only planned to be rated to Code C. To ensure good flows for arrivals and departures on each individual taxiway (both of which are Code E rated), it would be advisable to also ensure the connecting taxiways can accommodate Code E's that need to cross. While Code E demand is expected to be low the impact on the operation can be large, Code Es take up valuable room on taxiways so ensuring they have good manoeuvrability in Aprons will ease congestion.
3. Many of the remote stands are in cul-de-sacs. Some of these stands may require pushing back out of the cul-de-sac, requiring high levels of taxiway holding. Similarly, bussing operations to these cul-de-sacs may require crossing busy taxiways.
4. The key hotspot from the 2026 infrastructure is resolved with the additional parallel taxiway. The arrival and departure flows are no longer required to cross each other. The extensive perpendicular crossing points between taxiways will also help reduce taxi-times.
5. The inner apron taxiways will help limit arrivals and departures in contraflow. As turnaround times for low-cost Code C airlines reduce and demand increases, this area could become congested. The prominent Runway 23 RET has direct access to the eastern entry to the Apron allowing for very short arrival taxi times.
6. As demand increases, each Code E departure will become constraining as holding here prevents Code C departures from taxiing to the holding area.

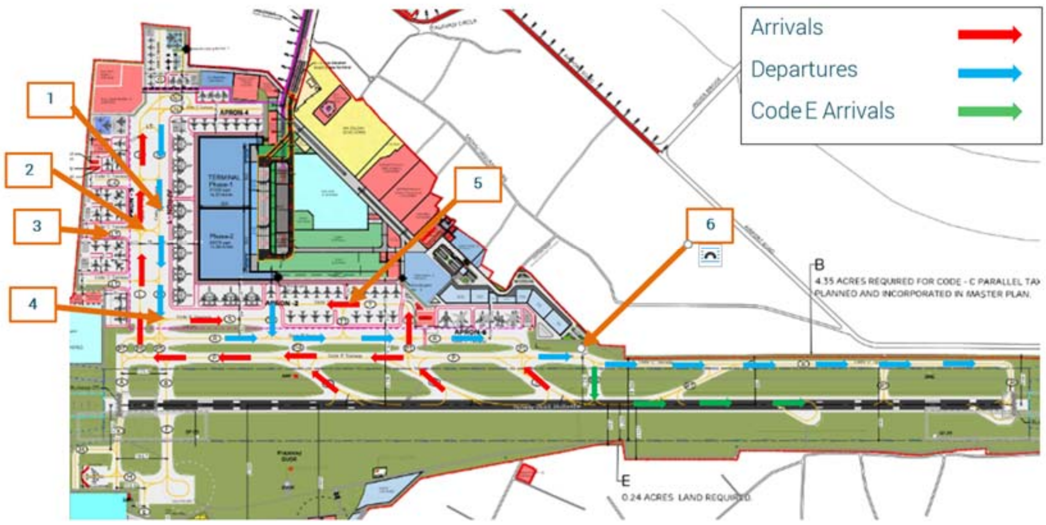

Figure 13: Phase 2 – 2030 - Runway 23 Potential Flows and Hotspots

4.3.2 Runway 05 Operations

Figure 14 shows the potential flows and hotspots when operating using Runway 05 with the infrastructure present in Phase 2 – 2030.

The comments below correspond to numbered areas highlighted in Figure 14:

1. The main apron stands push back on to one of the key taxiways parallel to the aprons. This is normal for many high intensity airports and is unlikely to constrain flows. However, this could be challenging in hours with high, mixed demand.
2. The crossing taxiways between the two parallel taxiways are only planned to be rated to Code C. To ensure good flows for arrivals and departures on each individual taxiway (both of which are Code E rated), it would be advisable to also ensure the connecting taxiways can accommodate Code E's that need to cross. While Code E demand is expected to be minimal, the impact on the operation can be large, Code Es take up valuable room on taxiways so ensuring they have good manoeuvrability in Aprons will ease congestion.
3. Having multiple line-up points offers significantly increased capacity to sequence departures effectively. It's likely that the runway hold area for Runway 05 will become congested as demand starts increasing, it's usual to have up to 5 or 6 aircraft queuing in peak departure periods. There is a risk that this queue will interact with arriving aircraft, however the multiple parallel taxiways and apron taxiways offer ways to minimise this congestion.
4. The flows here are all in a single direction, combined with the multiple taxiways this area will flow well even with high levels of demand. The Apron has many Code C stands and remote stands that could cause congestion as demand increases, however having multiple ways in and out of the Apron will generate the flexibility to operate with minimal interactions.

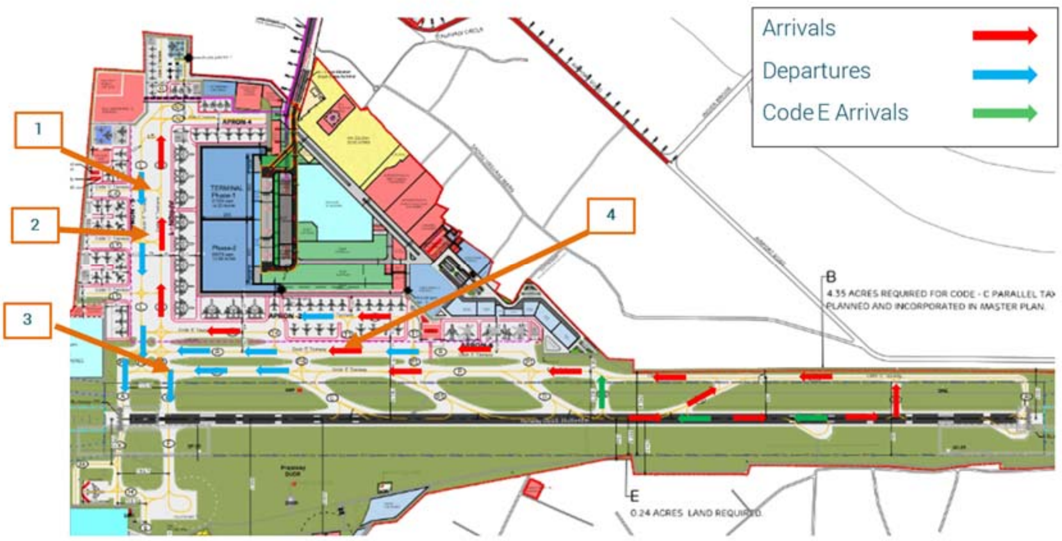

Figure 14: Phase 2 – 2030 - Runway 05 Potential Flows and Hotspots

4.4 Taxiway and Aerodrome Lighting and markings.

Recommendation 18: Taxiway Centreline Markings

Taxiway Centreline Markings

The existing airfield markings are CAT I, which includes taxiway centrelines, CAT I runway points, intermediate holding points and taxiway edge lighting. It could not be determined if the runway holding points had a co-located stop-bar or only the painted holding point markings with guard lights.

The taxiways are a mixture of concrete and tarmac finish. The yellow markings applied directly to a concrete finish can be difficult to see in certain weather conditions or when faded. The clarity difference between the markings on the tarmac portions as opposed to the concrete areas is clearly visible.

Recommendations for centreline markings are outlined below:

1. A full audit/survey is undertaken to assess that both the taxiway markings and signage are fully compliant with the latest CAT I regulatory requirements. Also, to assess the physical condition of the markings and signage to determine if repainting, new signage facias etc. are required.
2. Markings on the concrete surfaces to have the yellow markings applied on a black background.
3. To add enhanced taxiway centreline markings and/or painted runway hold position signs at each runway holding point. Enhanced markings and surface markings could also be considered at intermediate holding points, particularly if designated as a hotspot.
   The enhanced taxiway centre line markings are an extension of the hold position markings and designed to denote the proximity of a runway holding position. Painted surface markings are used where standard signage cannot be physically installed or to enhance the minimum signage requirements. Painted surface signage is often used at runway holding points to emphasise the proximity of a runway. Both enhanced taxiway centreline markings and painted surface markings can be used as part of an aerodrome's runway incursion prevention measures.

   Benefits: Improved accessibility and clarity for flight crews

   Suggested timeframe: Phase 1 (2026)

Recommendation 19: Taxiway Edge Lighting

Taxiway Edge Lighting

At present Ahmedabad uses a mix of centreline markings and blue edge lights. The masterplan does not show any enhancement to the taxiway lighting system using taxiway centreline green lights and the use of taxiway stop-bars or Intermediate Holding Positions.

The use of taxiway edge blues only could result in confusing mass of blue lights commonly referred to as “Sea of Blue”. This can result in flight deck crew finding it difficult to navigate the airfield and correctly identify taxiway boundaries especially at intersections and where a complex taxiway system has several small radius curves.

Benefits: Improved accessibility and clarity for flight crews

Suggested timeframe: Phase 1 (2026)

Recommendation 20: Taxiway Centreline Lighting

Taxiway Centreline Lighting

The most positive means of providing taxiway guidance is the provision of green taxiway centreline lights. If these lights can also be selectively operated, this will ensure that there is positive control to guide the aircraft to its final parking stand or runway holding point.

Whilst the airport is not a CATIII Runway, use of taxiway centreline lighting can be effective in daytime (subject to correct intensity settings), nighttime, and during periods of reduced visibility to maintain safe and effective CAT I operations. The installation of taxiway centreline lights eliminates the need for so many blue edge lights. The airport could then leave taxiway edge lights at intersections and curves only.

Benefits: Improved accessibility and clarity for flight crews

Suggested timeframe: Phase 1 (2026)

Recommendation 21: Stop-bars and Intermediate Holding Positions

Stop-bars and Intermediate Holding Positions

Taxiway stop-bars and Intermediate Holding Positions provide an effective means to controlling ground movements of aircraft and vehicles. The use of stop-bars could be effective in sequencing aircraft to the runway holding points.

With the proposed growth at Ahmedabad, the use of selectable taxiway centreline lights and some taxiway stop-bars will provide a safe, effective and efficient method of operation to support the airport's growth expectations. Examples of this lighting can be seen at many airports where there is one runway in operation, mainly smaller airports but also at large single runway airports i.e., London Gatwick.

Benefits: Improved accessibility and clarity for flight crews

Suggested timeframe: Phase 1 (2026)

4.5 Tools and Enhancement Opportunities

Recommendation 22: ACE - Ground Modelling – Fast Time Simulation

ACE - Ground Modelling – Fast Time Simulation

Given the complex dynamics of arrival and departure flows at the airport, it is recommended that the airport considers Fast-Time Simulation (FTS) modelling of taxiway network for the Phase 1 and Phase 2 Master Plan scenarios to check that the layouts will work efficiently with the proposed traffic levels and identify possible bottlenecks that may need to be addressed.

Benefits: Confirm that the layouts will work efficiently for both Runway 23 and 05 operations. Identify and address possible bottlenecks.

Suggested timeframe: 2023

Recommendation 23: EFPS System

EFPS System

The airport should consider the introduction of an Electronic Flight Progress Strip (EFPS) system. Over time, this system should become the default method of operating with paper strips only used as a back-up. This supports standardised operating practices, enhances safety, and provides a rich source of data for other airport systems.

Benefits: Increase operational efficiency, enhance safety

Suggested timeframe: Phase 1 (2026)

Recommendation 24: Airside Road Holding Positions

Airside Road Holding Positions

When considering the airside road layout in the Master Plan, all roads appear to avoid the manoeuvring area. However, if the airport is considering using service roads to cross the Code E Taxiways perpendicular to the runway, the use of Road Holding Positions should be considered to reduce the possibility of vehicles crossing active taxiways in front of aircraft.

Road Holding positions can be incorporated into the overall AGL system with the use of signs and lights. Road Holding Positions are used at many airports, including those that NATS operates i.e. London Heathrow, London Gatwick, and those that NATS has also provided consultancy services to, including Singapore Changi and Abu Dhabi International.

Benefits: Safe transit/bussing for remote operations opposite the main terminal.

Suggested timeframe: Phase 2 (2030) onwards.

Recommendation 25: Remote Apron Control Tower

Remote Apron Control Tower

The airport should consider whether a physical Apron Control Tower is needed given that the technology is available to do this remotely.

Options are available to provide a remote ATC service away from the airfield, such as the method of operation now used for ATC at London City Airport, or from a dedicated facility located within the airport

The space occupied by the proposed Apron Control Tower is valuable and if needed could potentially provide an additional aircraft parking stand adjacent to the proposed cargo stands.

Benefits: Increased ATC flexibility and control whilst releasing valuable space.

Suggested timeframe: Phase 2 (2030) onwards.

4.6 Conclusions – Taxiways

Phase 1 - 2026

- The taxiway infrastructure is congested and has notable hotspots. The area of single taxiway parallel to the runway is likely to become increasingly challenging to operate as forecast demand increases to 38 movements per hour in 2030.

Phase 2 – 2030

- The taxiway infrastructure enhancements alleviate most hotspots and constraints, allowing the airport to grow in demand without expectation of taxiway congestion.

2040

- The apron, cul-de-sac, remote operations, and pushback constraints will likely start to become a concern as daily movements increase to accommodate 42M passengers per year.

	Phase 1 - 2026	Phase 2 - 2030	2040
Target Capacity, Annual Passengers	18M	28M	42M
Target Capacity, Annual Movements	123k	184k	318k
Taxiway infrastructure	Runway 23 operations will be challenging as demand increases between 2026 and 2030		The taxiway infrastructure is likely to become constrained as traffic levels increase

5. Airspace Infrastructure

It was noted that airspace infrastructure is not covered by the current Master Plan document.

Recommendation 26: Airspace Development Plan

Airspace Development Plan

The airport should consider creating an airspace development plan to ensure that sufficient airspace infrastructure is in place to support the Master Plan growth targets.

Benefits: Ensure that the development of the airport does not become constrained by the airspace infrastructure.

Timeframe: From 2023

5.1 Current Airspace Infrastructure

The airport has a control zone (CTR) with a 30NM radius, extending vertically to FL70.

5.1.1 SIDs and STARs

The airport has six RNAV1 STARs and six RNAV1 SIDs for each runway direction.

The waypoints BODAR, QQZ, RKT and UUD are the start or end points for both STARs and SIDs. This means that as traffic increases, more arrivals and departures will be routed through these points, leading to possible congestion and potential conflicts.

5.2 Enhancement Opportunities

Reducing Minimum RADAR Separation

As discussed on page 17 :

Recommendation 2: Reduce Minimum Radar Separation.

Recommendation 27: ILS for Runway 05

ILS for Runway 05

The airport should consider the addition of ILS for Runway 05. Whilst Runway 23 has an ILS approach, Runway 05 currently does not. This could potentially reduce capacity for Runway 05 operations.

Benefits: Ensure that the capacity and resilience is not lost when operations switch to Runway 05.

Timeframe: From Phase 1 (2026)

Recommendation 28: General Airspace Capacity Enhancement Opportunities

Airspace Capacity Enhancement Opportunities

1. High Intensity Runway Operations (HIRO) training for Air Traffic Controllers to maximise the use of available runway capacity.

2. Fast-Time Simulation to model the airport and surrounding airspace with 2026, 2030 and 2040 traffic levels to identify potential bottlenecks and remedial actions.

3. Consideration of PBN SIDs with reduced angles of divergence to increase departure throughput at peak times if traffic demand requires it.

4. Consideration of offload SIDs to handle increased demand for departures in particular directions (e.g. North and South) if traffic patterns require it.

5. Review of the strategy for absorbing arrival delay: Consider the advantages and airspace, technology, and staff requirements for:
    a. Holding
    b. Point Merge
    c. Vectoring
    d. Speed control

6. Development of a plan for airspace operations to include the proposed new greenfield airport at Ahmedabad Dholera.

5.3 Conclusions – Airspace

As traffic continues to grow, it is likely that the airspace infrastructure will come under increasing pressure. It is therefore essential for the airport to have a plan in place to increase airspace capacity in line with increases on the ground.

	Phase 1 - 2026	Phase 2 - 2030	2040
Target Capacity, Annual Passengers	18M	28M	42M
Target Capacity, Annual Movements	123k	184k	318k
Airspace infrastructure		5NM minimum radar separation may limit airspace capacity	5NM minimum radar separation may limit airspace capacity

6. Conclusions

The runway, stand, taxiway and airspace capacity constraints at Ahmedabad airport are summarised in the table below:

	Phase 1 - 2026	Phase 2 - 2030	2040
Adani Forecast demand, annual passengers	18M	28M	42M
Adani Forecast demand, annual movements	123k	184k	318k
Runway capacity			Limited to 36 movements per hour unless A-D-A separations are reduced
Stand capacity		Demand for overnight stands is likely to approach capacity	Demand for overnight stands is likely to exceed capacity
Taxiway infrastructure	Runway 23 operations will be challenging as demand increases between 2026 and 2030		The taxiway infrastructure is likely to become constrained as traffic levels increase
Airspace infrastructure		5NM minimum radar separation may limit airspace capacity	5NM minimum radar separation may limit airspace capacity

Table 12: Summary of Airport Capacity

The table below shows the constraints above and compares Ahmedabad Airport to the busiest single runway airports around the world (2019 figures, unless otherwise stated):

	Annual Passengers	Annual Movements	Area	Stands	Comments
Gatwick	46.5M	283K	1670 acres	119	Single runway operation
Mumbai	45.8M	304K	1850 acres	105	Predominantly a single runway operation
Istanbul SAW	35M	220K	1845 acres		2nd runway under construction
Lisbon	31.2M	217K	928 acres	82	Has two runways, but only one used at any one time. Significant use of double stand

					/ taxiway aircraft holding.
HK Kai Tak (1996)	29.5M	158K	800 acres		
Stansted	28.1M	183k	908 acres	110	
Lima	25.4M	200K			2nd runway under construction
San Diego	25M	231K	663 acres		
Ahmedabad (2040)	42.3M	318k	1124 acres	91	

Table 13: Comparison of Single Runway Airports

The figures in Table 13 suggest that Ahmedabad with a single runway, 1124 acres of space and 91 planned stands, will likely be constrained to similar levels of demand as Lisbon Airport, limited by the number of stands available overnight.

This means that between 2030 and 2040, the forecast demand of 30M to 40M passengers per year will be constrained. Fast-Time Simulation is recommended to determine the magnitude of the stand constraint.

The table below provides a qualitative estimate of peak theoretical capacity based on analysis in this report and benchmarking with other busy single runway airports.

	Annual Passengers	Annual Movements	Average Daily Demand	Peak Hourly Demand
Ahmedabad (Theoretical Peak Capacity)	34M	220K	603	36

Table 14: Ahmedabad Theoretical Peak Capacity

The figures in Table 14 are derived as follows:

1. The limit of Peak Hourly Demand on page 20. A peak hourly demand of 36 leads to a peak daily capacity of 596 movements. With Performance Based Capacity Declarations (Recommendation 5) it's likely that an additional 7 movements per day can be accommodated.
2. The average passenger load per aircraft as outlined in section 2.3 page 18. The average passenger loads are: Code C – 137, Code E – 309. Assuming 10% of demand is Code E, supporting 20% of annual passengers.
3. The limit to the number of overnight stands and area compared to Stansted in section 3.2.1 page 34. Fast-Time Simulation is recommended to determine the demand on the stand infrastructure with various schedules.
4. The taxiway infrastructure will likely not constrain demand at this level. However, Fast Time Simulation is recommended to confirm the impact on the airfield.

7. APPENDIX

7.1 A-D-A Process

Figure 15 provides a breakdown of the activities that occur on the runway during an ADA sequence.

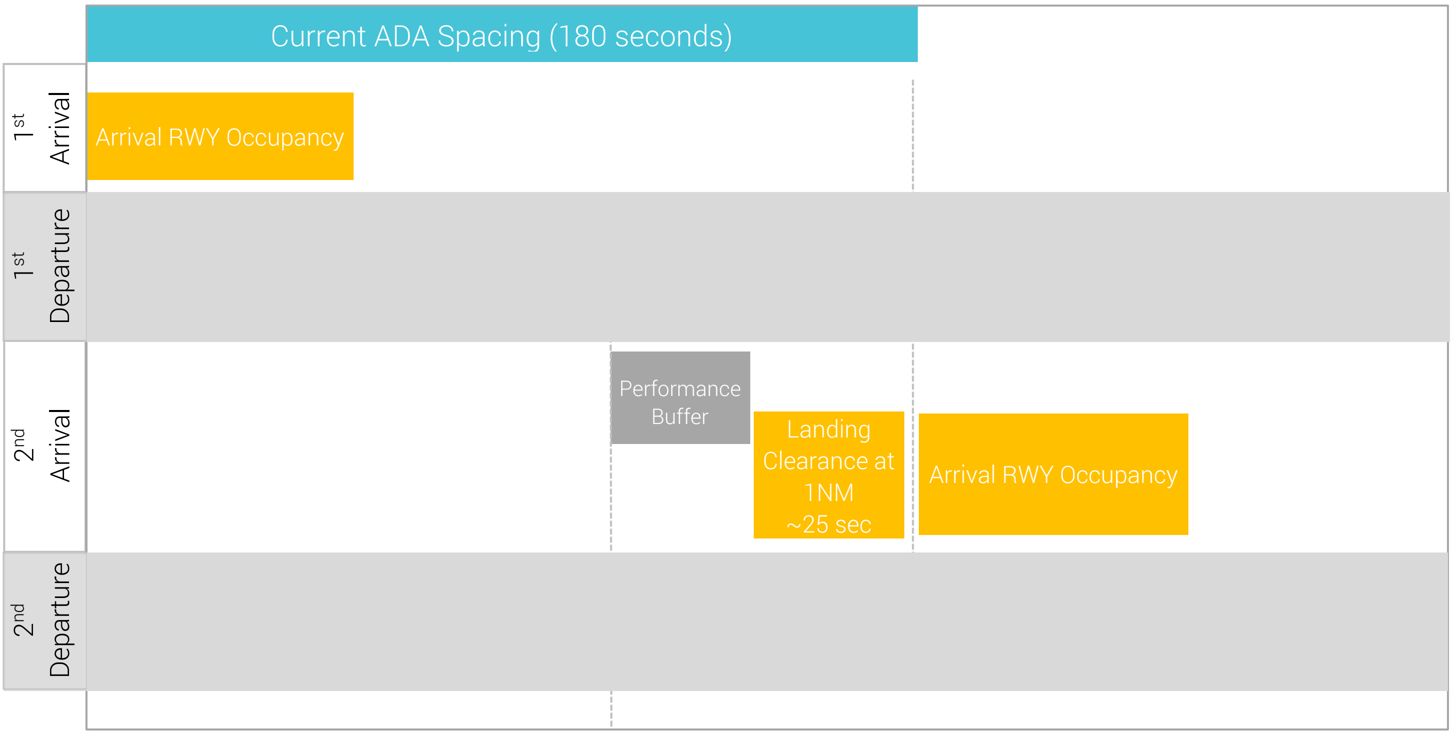

Figure 15: Critical path actions in an Arrival-Departure-Arrival runway sequence

The sequence occurs as follows:

1. The 1st arrival touches down, rolls out, and vacates the runway, the time it takes to do this is the "Arrival Runway Occupancy Time" *AROT*. During that time the 1st departure will have been cleared to enter and line up on the runway.
2. As soon as the arrival has vacated the runway, the departure is cleared to take off and will lift off. The time it takes to do this is the "Departure Runway Occupancy Time", *DROT*.
3. The runway occupancy times cannot be easily predicted by the controller issuing clearance; therefore, the A-D-A sequence contains a small amount of inefficiency between the anticipated runway occupancy time and the time at which landing or departure clearance is granted. This inefficiency is captured in the diagram as "Performance Buffer".
4. Ideally the landing clearance for the 2nd arrival will be issued when it is around 1NM from touchdown. At normal final approach speeds this is equivalent to 25 seconds prior to touchdown.
5. Repeat from Step 1 for the 2nd arrival and departure.

If this sequence of events is less than the A-D-A separation, the system is not constrained by the runway occupancies.

i.e.: *AROT + DROT + Performance Buffer + Landing Clearance < A-D-A separation*