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Airport Runway System Performance Capacity Assessment: The Case Study
for Addis Ababa Bole International Airport Runway System

By

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A Thesis Submitted to the School of Graduate Studies In partial fulfillment
of the requirements for the degree of Master of Science

In

Road and Transport Engineering

Advisor

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The undersigned have examined the thesis entitled “**Airport Runway System Performance Capacity Assessment: The Case Study for Addis Ababa Bole International Airport Runway System**” presented by **Alemu W/Mariam** , a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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ABSTRACT

The airfield's capacity is a crucial aspect vital to airport transportation services, with the runway serving as a pivotal component influencing the airport's overall capacity. This study focuses on analyzing the capacity and demand of the airfield particularly the runway at Addis Ababa Bole International Airport (AABIA).

Flight data, encompassing daily operations on various sampled dates under different weather conditions, aircraft compositions, seasonal variations, across multiple years, and, during peak and non-peak hours has been meticulously sampled, modeled, analyzed, and filtered to identify the maximum hourly capacity and the potential capacity constraints factors.

Two method of capacity analysis have been used. The first method is Federal Aviation Administration (FAA) Advisory Circular AC 150/5060-5¹. Using this method, 40, 50, and 60 Percent Arrival capacity was calculated and this capacity figure identified the general status of the capacity compared to the current demand and deep understanding achieved. In the Second method (ICAO), aircraft separation rules for arriving and departing aircraft were taken into account. Based on the nature of the aircraft fleet mix statistical analysis Poisson Joint cumulative Distribution for leading and following aircraft was computed for all possibilities. After getting the capacity at four points of arrival departure combinations joining those four points on the arrival vs departure graph serves as the capacity curve or capacity envelope. By inserting the actual current arrival vs departure data in the same graph of the capacity envelope, the current demand compared to the capacity is identified.

Conversely, the impact of runway occupancy time and actual runway demand on departure delays has been evaluated using linear regression. The study results indicate that actual demand has no effect on departure delays. However, the duration of runway occupancy has a slight influence on delays, suggesting that the current demand has not yet reached the runway system's capacity. Therefore, the delays are caused by the factors which are not related to the runway system.

The general conclusion is reached that the capacity of the runway system is higher than the current demand indicating that at this point the Runway system is not a major factor in any current delays in aircraft operations. In other terms, the findings reveal that the current runway capacity can sufficiently meet the current demand. Despite the capacity of the runway system exceeding demand during peak hours, the study indicates that the average runway occupancy time is higher compared to similar hub airports such as London Gatwick and Mumbai airports which are busier airports that have a similar runway system and handles a mix of Heavy and Medium aircraft similarly, indicating that proactive measures is required to enhance the capacity of the runway system to ensure that the runway system will accommodate the future demand without causing excess delays.

Key words: AABIA, Capacity, DOCT, delay, departure and Arrival rate.

¹ https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22824

Contents

1	INTRODUCTION.....	5
1.1	Background	5
1.2	Problem Statement.....	7
1.3	Research Questions.....	7
1.4	Objective	8
1.4.1.	General Objective	8
1.4.2.	Specific Objective	8
1.5	Scope and Limitations	8
1.5.1	Scope	8
1.5.2.	Limitation	9
1.6	Significance of the Study	9
1.7.	Structure of Thesis	10
2	LITERATURE REVIEW	13
2.1	Introduction	13
2.2	Air Transport System and the Development of AABIA	13
2.3	The Airport and Its Components.....	14
2.3.1	Runway System	15
2.3.2	Taxiway	15
2.3.3	Apron-Gate System.....	16
2.4	Airfield Capacity and Delay	17
2.4.1	Airfield Capacity.....	17
2.4.2	Delay	19
2.5	Aircraft Operations and Procedure.....	22
2.6	Method of Capacity and Demand Analysis.....	24
2.6.1.	FAA Capacity AC Guideline (Advisory Circular AC 150/5060-5)	24
2.6.2.	ICAO Aircraft Separation Rules.....	25
2.6.3	Linear Regression	27
2.7	Conclusion.....	28
3	RESEARCH METHODOLOGY	28
3.1	Introduction	30
3.2	Study Area.....	30
3.3	Ethiopian Air Line Fleet Information.....	31
3.4	Sample size determination	33
3.5	Data Collection method and procedure	33
3.6	Data Analysis Method	38
3.6.1.	FAA Capacity AC Guideline (Advisory Circular AC 150/5060-5).....	38
3.6.2.	ICAO Aircraft Separation Rules.....	39
3.6.3.	AABIA Current Demand.....	41
3.6.4	Regression Analysis	42
4	RESULT AND DISCUSSION	43
4.1	Introduction	43

4.2	Capacity and Demand of Addis Ababa Bole International Airport	43
	Figure 13 Hourly arrival and departure capacity envelope	48
4.2.2.	Demand and Capacity comparison of AABIA with London Gatwick and Mumbai	48
	Chatrapati Shivaji International Airport	48
4.3.	The Effect of runway occupancy time on the delay of flight at AABIA	53
4.3.1	Descriptive statistics	53
5	CONCLUSION AND RECOMMENDATION	58

List of Figures

Figure 1	Organization Structure of the Paper.....	12
Figure 2	Destination number and annual passenger and load factor growth rate of AABIA	14
Figure 3	Airport and its components (Source:civilplanets.com)	14
Figure 4	Aircraft operations and procedure(source:ACDM@FRA version 5.1).....	23
Figure 5	Gate to gate operations management (Source: Stuart Ratcliffe, 2015)	23
Figure 6	FAA Runway capacity guideline table and chart (Source: AC 150/5060-5 FAA Circular)	25
Figure 7	Aerial Image of AABIA taken from Google Map.....	31
Figure 8	The data feature from the data provide (flightradar24) website.....	36
Figure 9	Flight track record sample for an airplane departing from AABIA converted from CSV data using Google Earth..	36
Figure 10	Hourly operation capacity based on flight Mix Index and runway-use configuration.....	38
Figure 11	AABIA Hourly demand for randomly taken three days (arrival and departure).....	41
Figure 12	Hourly capacity base for 40, 50 and 60 PA, Touch and go factor and Exit facto FAA chart	44
Figure 13	Hourly capacity envelDLocAABIA HOURLY AIRCRAFT OPERATIONS SCHEDULE	48
Figure 14	AABIA Hourly arrival vs departure demand scatter points and capacity envelop line	49
Figure 15	London Gatwick Airport arrival vs departure scatter points	49
Figure 16	Mumbai Airport hourly arrival vs departure scatter points	49
Figure 17	AABIA Hourly aircraft operation demand schedule	50
Figure 18	London Gatwick Airport Hourly Operations	50
Figure 19	Mumbai Airport hourly operations	51
Figure 20	Box plot of Hourly operations for three airport having similar runway system	52
Figure 21	Box plot for Departure Runway Occupancy Time (Sec) for similar runway systems	53
Figure 22	The histogram delays distribution graph.....	55

List of Tables

Table 1	AABIA Basic Information	30
Table 2	AABIA Runway Basic Information	30
Table 3	Ethiopian Airline fleet as of December 2022	32
Table 4	Sample of Daily Departure matrices	35
Table 5	Flight history for any selected flight (ET959) of one-year data availed view	35
Table 6	Sampled extracted CSV format data	37
Table 7	The joint cumulative probabily distribution for Leading-Following aircraft arrival operation	40
Table 8	ICAO Wake turbulance catagories and separation minima	45
Table 9	Theoretical hourly arrival vs departure capacity of AABIA	48
Table 10	Sammary of quantitative Variables data	53
Table 11	Summary of Weight Category Data	53
Table 12	Summary of Nominal Variable Data.....	54
Table 13	Multicollinearity analysis result	54
Table 14	ANOVA result	55
Table 15	Linear regression table	56

Acronym and Abbreviations

AABIA:	Addis Ababa Bole International Airport
FAA:	Federal Aviation Administration
ICAO:	International Civil Aviation Organization
IATA:	International Air Transport Association
ATC:	Air Traffic Control
ATFM:	Air Traffic Flow Management
AOBT:	Actual Off-Block Time (time when an aircraft departs its parking position)
ATD:	Actual Time of Departure
STD:	Scheduled Time of Departure
ACDM:	Airport Collaborative Decision Making
ROT:	Runway Occupancy Time
TSAT:	Target Start-up Approval Time (time at which an aircraft can expect start-up approval)
ATOT:	Actual Take-Off Time
CDM:	Collaborative Decision Making
ELDT:	Estimated Landing Time
EIBT:	Estimated In-Block Time
TOBT:	Target Off-Block Time
TTOT:	Target Take-Off Time
VMC/IMC:	Visual Meteorological Conditions / Instrument Meteorological Conditions
IFR/VFR:	Instrument Flight Rules / Visual Flight Rules
WSG:	Worldwide Slot Guidelines (IATA standard for airport slots)
PA:	Percent of Arrival
TOFT:	Take-Off Forecast Time

1 INTRODUCTION

1.1 Background

An airport is one of the most significant components of a country to play a significant role economically, socially, politically, etc. Being one of the gateways to the country and one of the big hubs for the air transportation system of Africa, the Middle East and the world at large, AABIA is the backbone of the aviation industry of Ethiopia and beyond (*Ethiopia NASP 2023-2025*, 2022).

Addis Ababa Bole International Airport (IATA: ADD, ICAO: HAAB) serves as a pivotal international gateway for Addis Ababa, Ethiopia, located within the Bole district approximately 6 km (3.7 mi) southeast of the city center and 65 km (40 mi) north of Bishoftu (*Ethiopia NASP 2023-2025*, 2022). Formerly recognized as Haile Selassie I International Airport, it stands as the primary hub for Ethiopian Airlines, the country's flagship carrier, facilitating connections across Ethiopia, Africa, Asia, Europe, North America, and South America. Additionally, the airport houses the Ethiopian Aviation Academy (DeArmon et al., 2016).

The establishment history of AABIA dates back to 1960 when Ethiopian Airlines encountered the issue of Lidetta's runway being too short to accommodate its new jet aircraft, the Boeing 720. Consequently, a decision was made to construct a new airport at Bole. Ethiopian Airlines, which handles 95% of the airport's operations, has been consistently growing, as demonstrated by the increasing the number of passengers accommodated and new destinations achieved.

By December 1962, the new runway and control tower became operational. In 1997, an expansion project was announced for the airport, which unfolded in three distinct phases:

Phase one involved the addition of a parallel runway and the expansion of the existing runway. Phase Two encompassed the construction of a brand-new terminal featuring a spacious parking area, a complex of shops, and dining establishments. Phase three saw the erection of a 38-meter-tall (125 ft) control tower, double the height of its predecessor, along with the installation of advanced electrical and fire-fighting equipment.

From time to time, the passenger of Ethiopian airline increase dramatically since it is the bestairline in the history of Africa. The number of destinations has also increased drastically according to the recent source. Therefore to increase its competitiveness throughout the world, it is necessary to

study the capacity, efficiency and quality of the service by considering international aviation standard.

It is well known that the airport has two major components, namely airside and landside. Runway, Taxiway and Apron system which comprise the arrival and departure process from the gate to the local airside zone and vice versa are the major physical parts of airside air transport system that affect the overall delay of any flight(Poldy, 1982), (Lei et al., 2020) , (Zhang & Wang, 2017),(DeArmon et al., 2016) and(Fisher et al., 2012a).Runway is the first and the major system of airport that affect the capacity and demand of air flight.

Runway capacity is the maximum number of aircraft movements that a runway system in an airport can operate in a given time period under a given set of operational factors(K. Chen et al., n.d.)and (Mitsokapas et al., 2021). Based on several studies, runway capacity depends on the operational factors that include the characteristics of the physical infrastructure (for instance, the number of runways and runway layout) as well as time varying factors (such as weather conditions, fleet mix and air traffic control regulations among others(Lei et al., 2020),(Bubalo & Daduna, 2011),(Mascio et al., 2020) and (Ashford et al., 2011). These factors together make runway service capacity to be highly dynamic in nature. Runway service capacity supports airport and air traffic managers and Engineers in various strategic and engineering decisions related to airport planning and operations such as distributing the daily runway demand over the available capacity of the runway system (TransSolutions et al., 2014) appraising investments in runway service capacity expansion and used to modelling and managing airport delay or even delay propagation within the airport network.

Airport delay is the main problem of most airports which affect the service quality of airport not only economically but also affect the trip purpose of passengers. Based on several studies delay depends on the demand and capacity of runway¹ which intern depends on departure runway occupancy time, direction of flight(Fisher et al., 2012b), type and weight of aircraft (Lei et al., 2020) and arrival rate of flight (Zhang & Wang, 2017)by keeping the significant impact of weather on space as it is.

This paper has focused on analyzing the capacity and demand of runway system of airport as well as the delay and departure run-way occupancy time also. This study delves into the fundamental elements and operations of the airfield with a specific focus on assessing runway capacity in relation to current demand. It aims to pinpoint potential factors influencing both the runway

and overall airfield capacity. In order to achieve the overall objective of the study, the data have been collected from website of international flight package (FlightRadar24) by placing gold level subscription.

The capacity and the actual demand of runway capacity has been determined by using departure and arrival-based capacity whereas factors influencing departure delay have been identified using linear regression after extracting all necessary independent variable. Additionally, a rigorous comparative analysis has been conducted with other international airports that boast similar runway systems but achieve higher aircraft operation volumes. This comparison aimed to identify specific factors, of varying natures, which could potentially serve as bottlenecks enhancement for accommodating the growing demand at AABIA.

1.2 Problem Statement

The capacity of an airport's airfield is a fundamental determinant of its ability to meet increasing demand, ensuring operational efficiency and minimizing delays. However, a significant knowledge gap exists in understanding how existing airfield limitations contribute to delays and operational inefficiencies, particularly at rapidly growing airports like Addis Ababa Bole International Airport. As demand continues to surge without corresponding enhancements in capacity, delays will escalate beyond acceptable thresholds, disrupting the flow of air traffic and negatively impacting the airport's overall performance.

Despite the critical importance of aligning capacity with demand, there is a lack of focused research addressing the evaluation and enhancement of airfield capacity as a strategic solution to mitigate delays. This gap is further amplified by limited exploration of how specific operational inefficiencies within the airfield influence flight delays and cancellations. These disruptions not only impose economic and social costs but also threaten the airport's ability to sustain and attract future demand, making this an urgent area of inquiry.

This study seeks to bridge this knowledge gap by conducting a comprehensive assessment of the airfield's current capacity relative to existing and projected demand. By identifying the factors impeding the smooth and timely movement of air traffic and proposing practical, cost-effective solutions, this research aims to provide a framework for enhancing airfield capacity. Ultimately, the study underscores the need for strategic, evidence-based interventions to optimize the

operational efficiency of the airfield and, by extension, the airport as a whole, ensuring its ability to meet present and future demands effectively.

1.3 Research Questions

- 1 What is the capacity and demand of the Addis Ababa Bole International Airport runway system?
- 2 What is the effect of the runway occupancy time on the delay of the Aircraft departure?
- 3 What are the possible developments to increase the efficiency of the runway?

1.4 Objective

1.4.1. General Objective

The general objective of this study is to assess the capacity performance of the Addis Ababa Bole International Airport Runway system.

1.4.2. Specific Objective

- I) To know the capacity and demand of Addis Ababa Bole International Airport Runway system
- II) To know the effect of the runway occupancy time on the delay of aircraft operations
- III) To know the possible efficiency enhancement measures to the runway capacity

1.5 Scope and Limitations

1.5.1 Scope

The scope of this paper is limited to assessing the airside aspect of the airport, primarily focusing on the runway, excluding terminal buildings and other landside facilities and infrastructures.

1.5.2. Limitation

The data utilized in this study were sourced from third parties and detailed on-time performance data. The data that is crucial for identifying specific causes of delays throughout aircraft operations was unavailable. The data such as Actual off Block Time (AOBT) when the pilot requests the ATC for departure Clearance and the Actual Departure Clearance Time given by the ATC is not specifically known. The Push Back Time is also not available. Consequently, secondary findings serve as indicators of potential constraints rather than definitive conclusions. The economic aspect of capacity like cost of delays are not part of this research. It is clear that for any delays there is a consecutive cost implication and the magnitude needs its own analysis which is beyond the scope of this research

1.6 Significance of the Study

This study will be used as initial insight for airport managers and engineers in various strategic and engineering decisions related to airport planning and operations such as distributing the daily runway demand over the available capacity of the runway, appraising investments in runway service capacity expansion and used to modelling and managing airport delay and delay propagation within the airport network if it is feasible. In addition, it also serves as an initial point of reference for similar research endeavors aimed at enhancing the airfield capacity and overall airport efficiency of AABIA.

1.7. Structure of Thesis

The diagram below follows a logical sequence from identifying a problem, reviewing existing knowledge, detailing methodologies, analyzing findings, and concluding with actionable insights. Each section feeds into the next, culminating in a comprehensive research framework.

Introduction

The top-level represents the Introduction, which serves as the starting point of the research process. This section typically provides an overview of the topic, background information, and the research objectives.

Statement of the Problem

The second level represent different aspects of the Statement of the Problem. This section defines the issues or gaps in knowledge the research seeks to address. The different shades (gray and black) may symbolize varying dimensions or perspectives of the problem.

Literature Review

The third level consolidates the information, indicating the Literature Review. This step involves gathering and synthesizing existing knowledge to provide context for the study and highlight why the research is necessary.

Methods

The fourth level represents the Methods section. This block spans multiple processes, emphasizing the comprehensive and central role of methodology in the research process. It details how the research is conducted.

Subsections within Methods:

Description of Study Area:

Likely one of the smaller green blocks in the next level, specifying where the research is carried out.

Sample Size and Data Collection Method:

Two additional blocks that outline the sample population size and the techniques for gathering data (e.g., surveys, interviews, experiments).

Data Analysis Method:

Another block, detailing how the collected data is processed and analyzed (e.g., statistical methods, qualitative analysis).

Result and Discussion

The two large green blocks in the sixth level represent the Result and Discussion section. This section interprets the findings, compares them with existing knowledge, and evaluates their implications. The convergence of inputs suggests combining data analysis outcomes and insights for discussion.

Conclusion and Recommendation

The final green block at the bottom represents the Conclusion and Recommendation section. It summarizes the research findings, draws conclusions, and provides actionable recommendations based on the study.

The flowchart in the diagram visually represents the structure of the research process

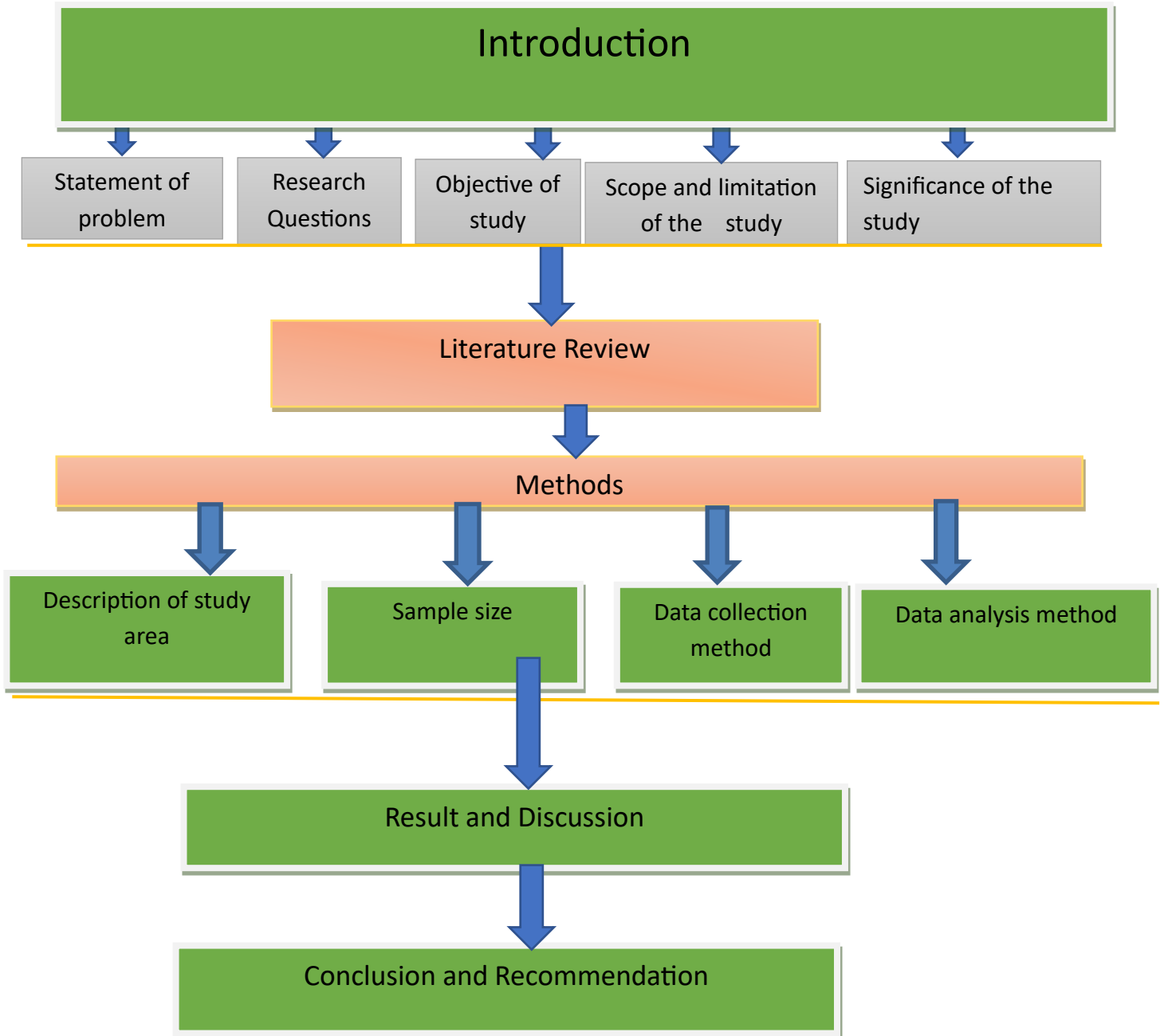


Figure 1 Organization Structure of the Paper

2 LITERATURE REVIEW

2.1 Introduction

In this part, airport transportation system, the development of bole international airport, the major component of airport system such as taxiway, runway and apron system, demand and capacity of airport, factors affecting efficiency of runway, method of determining demand and capacity of runway have been addressed using several international reports and articles.

2.2 Air Transport System and the Development of AABIA

One of the most significant parts of the global transportation network is air travel. It not only offers the primary means of long-distance transportation worldwide, but it also has a significant economic influence on both national and global economies. Additionally, air transportation is crucial to efforts to enhance environmental quality and advance sustainable development because of the very nature of aviation infrastructure (such as airports) and modern flight technology (such as jet engines that burn fuel and emit air pollutants) (*Ethiopia NASP 2023-2025, 2022*). Airports, air traffic control systems, planes, and airlines are the main elements of the air transportation network². Modifications to just one of these elements will have a significant impact on the aviation sector's future.

Ethiopia's Addis Ababa Bole International Airport (ICAO: HAAB, IATA: ADD) is an international airport. Situated 65 kilometers (40 mi) north of Bishoftu and 6 km (3.7 mi) southeast of the city center, it is situated in the Bole district. Haile Selassie I International Airport was the previous name of the airport (*Ethiopia NASP 2023-2025, 2022*) It serves as the principal hub for Ethiopian Airlines, the national carrier with links to Asia, Europe, North America, and South America, as well as locations within Ethiopia and across the African continent. The Ethiopian Aviation Academy is based out of the airport as well (*Ethiopia NASP 2023-2025, 2022*) The airport handled around 580 flights a day as of June 2024.

² <https://flynashville.com/wp-content/uploads/2020/02/BNA-MPU-AIRPORT-PLANS>

The Addis Ababa Bole international airport increases its development dramatically not only in number of destination but also million passengers have been accommodated every year and there was also cargo service especially during the time of Covid19.

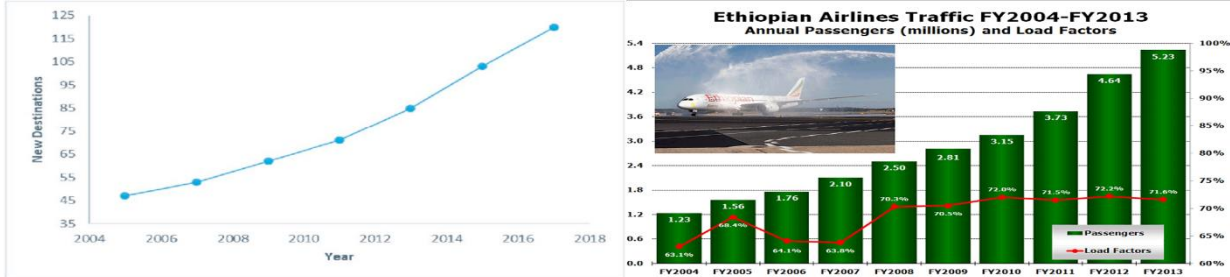


Figure 2 Destination number and annual passenger and load factor growth rate of AABIA

2.3 The Airport and Its Components

An airport encompasses many features that allow aircraft to take off and land and allow pilots and passengers to access facilities on the ground. Typically, an airport’s facilities are divided into three components: airside, terminal, and landside (Bubalo & Daduna, 2011) and (Fisher et al., 2012b).

The **airfield** is defined as a system of components (i.e., runways, taxiways, and apron•gate areas) on which aircraft operate (Lei et al., 2020), (150-5060-5part1¹), and (Wang & Zhang, 2021)

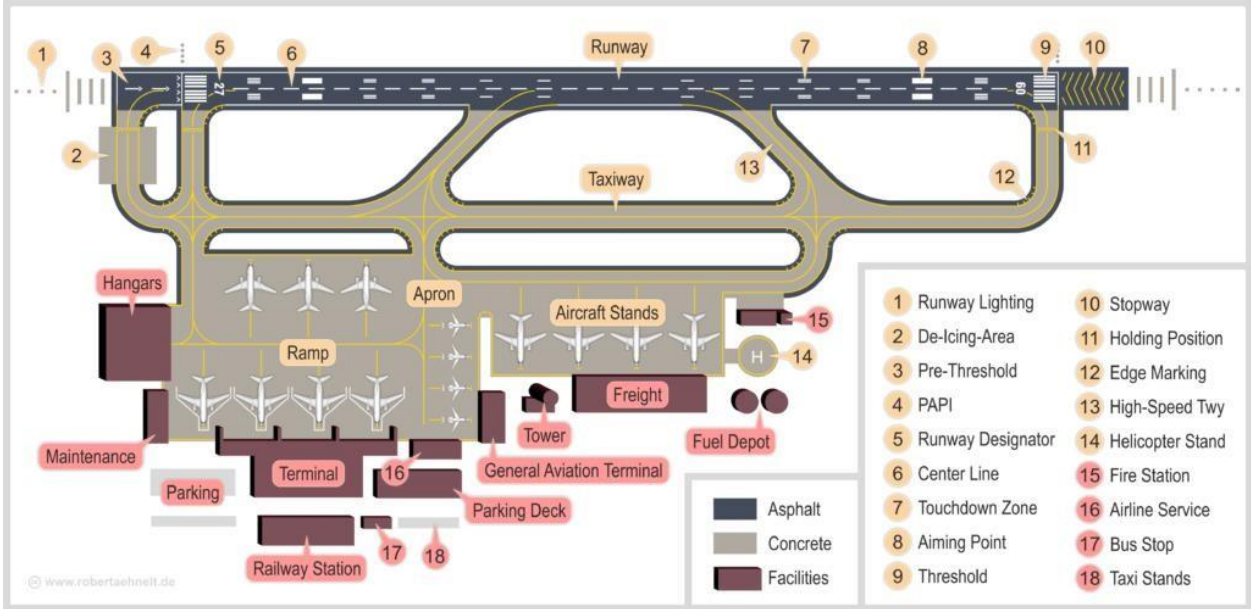


Figure 3 Airport and its components (Source:civilplanets.com)

2.3.1 Runway System

Runway Component. Air traffic control procedures (including those reflecting the effects of wake vortices) are major factors that influence runway component capacity and delay(Zhang & Wang, 2017) and (Dray, 2020); therefore, the runway component encompasses the common approach and departure paths to and from the runways. A **runway** is a strip of hard or paved level ground on which aircraft take off and land (Janić, 2017). A runway's surface typically is hard and can be made of concrete or asphalt as well as grass/turf, dirt, or gravel. In Airports that are used mostly by commercial and larger general aviation aircraft, a concrete or asphalt runway is a standard. Airports can have a single runway or multiple runways that may or may not be operated simultaneously. The number of runways and the way the runways are operated can have a substantial effect on airfield capacity(Wang & Zhang, 2021),(Zografos et al., 1997) and (Lei et al., 2020). Runway length, width, pavement strength, and orientation determine whether a runway is usable by a particular aircraft type for landing or takeoff. The runway must be long enough for an aircraft to accelerate to takeoff speed or slow down sufficiently to exit the runway. The runway must be wide enough to accommodate the width of the landing gear and provide wingtip clearance to adjacent buildings and aircraft. Runways are generally oriented in the direction of the prevailing winds; aircraft operate best with a headwind, and most aircraft have limited ability to fly with strong cross winds or tailwinds. Pavement must be strong enough to support the design aircraft (i.e., the largest aircraft regularly operating at the airport) without structural damage to the aircraft or pavement.

2.3.2 Taxiway

A taxiway is a hard or paved strip of level ground along which aircraft taxi from the runway to a parking position (and vice versa) or from one part of the airport to another. The capacity of the taxiway component usually is much greater than the capacities of the runway or apron-gate components, with one exception--taxiways crossing an active runway (Clare & Richards, 2011) and (Salihu et al., 2021).Taxiways can be used to temporarily hold aircraft waiting to take off or waiting for a gate, but it is best to hold aircraft on an apron.

There are three major types of taxiways (Clare & Richards, 2011) and (Salihu et al., 2021):

1. **Parallel (full or partial) taxiways**, which generally provide a route for aircraft to reach the runway end or to use after exiting the runway

2. **Entrance/exit taxiways**, which connect runways to parallel taxiways or some other type of taxiway, and which provide a path for aircraft to enter the runway for departure or exit the runway after landing

3. **Access (or circulation) taxiways**, which provide paths for aircraft to move between the various airside components of the airport (and which include bypass and crossover or transverse taxiways, including those that cross active runways, and apron-edge taxiways)

The number, location, and layout of taxiways can significantly affect airfield capacity. Taxiways provide space for the temporary staging and sequencing of aircraft prior to takeoff and after landing. Such taxiway use frees the runways to be used efficiently for takeoffs and landings. The combination of runways and taxiways is generally referred to as the *movement area*.

2.3.3 Apron-Gate System

Holding Bays located near the ends of runways or near the terminal building, holding bays (or hold pads) are intended to provide an area off the taxiway system for aircraft that must wait until ready to take off or until a gate is ready since aviation aircraft do not operate on a fixed schedule, the aircraft parking time in the apron area fluctuate widely. Typical holding bay locations and geometries are shown on Figure 2-4. Holding bays can affect capacity if sufficient space does not exist for aircraft to wait without occupying a needed gate or blocking a taxiway (Lai et al., 2015) and (Pyrgiotis et al., 2013).

Hold pads are provided primarily at busy commercial airports to stage and store aircraft awaiting departure so air traffic controllers can properly sequence them. Deicing pads are a special category of hold pads that are especially needed and important to airport operations during snow and ice conditions. Holding bays are useful, and in many situations necessary, near departure runway ends to allow aircraft to be bypassed for takeoff. Without this bypass capability, an aircraft holding for ATC clearance or because of inclement weather at its destination could unduly delay other departures attempting to use the same runway.

Holding bays also are necessary when, for a variety of reasons, a gate may not be immediately available for arriving aircraft. This type of holding bay should be located near the terminal complex to allow easy access to the gate area when a gate becomes available.

Aprons typically are defined areas of land intended to accommodate parked aircraft for purposes of fueling, maintenance, or loading or unloading passengers, mail, or cargo (Pyrgiotis et al., 2013).

Aprons typically surround buildings, such as terminals and hangars, but also can be designed specifically to store aircraft out in the open using tiedowns. Large aprons can include taxi lanes, which are areas identified to provide access between taxiways and aircraft parking positions. The combination of the apron and taxi lanes is generally referred to as the non-movement area. At certain busy air carrier airports, spots are established as points on the apron where aircraft leaving a non-movement area are expected to contact ground control for taxi clearance. Sometimes also referred to as the ramp, aprons at small general aviation airports are widely accessible, and both aircraft and automobiles may park on its surface.

Gates are the access points between the aircraft and the terminal at which passengers typically embark or disembark the aircraft (Dray, 2020). An airport can have one or more gates, and these gates may be at ground level or on an upper level, for which a loading bridge is provided to connect the aircraft to the door of the terminal building. At general aviation airports terminal entrance points are not typically called gates; this term is typically used at commercial service airports. Gates are designed to accommodate different types of aircraft and can affect capacity if the number of gates provided is inadequate to accommodate arriving or departing aircraft, or if the layout of gates impedes taxiing aircraft from reaching the runway ends in a safe and efficient manner.

2.4 Airfield Capacity and Delay

2.4.1 Airfield Capacity

Definitions of airfield capacity vary depending on the source or audience. The Airfield Capacity is defined as a measure of “the maximum number of aircraft operations which can be accommodated on the airport or airport component in an hour(Barrer et al., 2005),(Newell, 1979),(Ignaccolo, 2003) and(Pyrgiotis et al., 2013).” In the original research that led to the development of AC 150/5060-5, considerable effort was expended on reaching a single concept of capacity. In practice, however, at least two definitions of capacity remain widely used: (1) a measure of maximum sustainable throughput similar to the definition in the AC (Newell, 1979) and (2) a measure of practical capacity defined as the number of aircraft operations that result in a specified maximum average delay (Poldy, 1982). Both of these definitions have validity and are intended to answer different questions.

- **Maximum sustainable throughput** (Newell, 1979) answers the question, “How many aircraft operations can an airfield reasonably accommodate in a given period of time when there is a continuous demand for service during that period?”
 - **Practical capacity (service volume)** (Cavusoglu & Macário, 2021) **and** (Pyrgiotis et al., 2013) answers the question, “How many aircraft operations can an airfield accommodate at a specified level of service?” Level of service typically is defined in terms of a threshold level of average annual aircraft delay (e.g., 7 minutes per aircraft operation).

FAA also has defined capacity in terms of specific time intervals (Cornman et al., n.d.). The two most commonly used time intervals are hourly and annual (Cornman et al., n.d.). Hourly airfield capacities can be calculated using the AC for different runway configurations and weather conditions in terms of cloud ceilings and visibilities at the airport. Annual airfield capacity—referred to in the AC as annual service volume (ASV)—is an estimate of how many aircraft operations an airport can accommodate in a year, and can also be calculated using the methods in the AC. (ACRP Report 79, 2012) ICAO generally defines capacity as the number of movements per unit of time that can be accepted during different meteorological conditions (Cornman et al., n.d.). However, ICAO identifies that there are a number of variables in this definition that give rise to key performance capacity indicators such as:

A- Maximum hourly number of movements possible during visual or low visibility meteorological conditions (VMC/IMC).

B- Maximum daily number of movements possible between the core hours during visual or low visibility meteorological conditions (VMC/IMC).

C- Average daily airport capacity measured as a moving average; and so on.

Many other variables also exist that are not mentioned by ICAO such as wind conditions, aircraft mix, systems capability and staffing. As such the definition should not be constrained to meteorological condition variations. Airport Council International defines capacity as “Maximum aircraft movements per hour assuming average delay of no more than four minutes, or such other number of delay minutes as the airport may set”.

In a broader sense ACAM Manual (2016) defined capacity as the maximum number of sustained movements per unit of time that can be accepted during different local capacity factors (Newell, 1979) and (Cavusoglu & Macário, 2021). Therefore, capacity of an airfield is the maximum number of flight operations per unit time per given condition or combination of conditions.

2.4.2 Delay

The term delay is quite simple and generally applied when an event occurs later than it was planned, scheduled, or expected to happen. It is a common term used in everyday conversation, not a term that is unique to aviation. However, delay is used or interpreted differently by various stakeholders involved in airport planning studies, airline operational on time performance analyses, and the public. In general, delays in aviation may describe one of two following situations based on different international studies (Pyrgiotis et al., 2013), (Z. Chen & Wang, 2019), (Xu et al., n.d.) and (Anderson et al., 2019):

- Actual operational or real-time delay events, often compared to flight schedule. For actual flights—current or historical—delays are often measured as the actual times compared to the planned or scheduled times. Schedule may refer to times filed in a flight plan or a published airline schedule.
- Mathematical or calculated estimates (using analytical or simulation models) for planning, often compared to unimpeded, nominal, or optimal travel time. Analysts often use computer simulation (Janić, 2017) and (Rebollo & Balakrishnan, 2014) tools or other analytical procedures to evaluate delays and delay savings. These tools and methods typically calculate a nominal or unimpeded time, then measure any additional time as delay.

Delay is the most important element of airfield capacity assessment and it is one of the main variables to be analyzed. Delays are versatile in nature and type depending the who is dealing with it. Passengers (end users), aircraft operators, air traffic controllers, airport managers, airlines etc. have their own perspective on delay. Delays happen due to many reasons and at different point in time of aircraft operations. Delays can happen due to weather condition (Z. Chen & Wang, 2019), volume of traffic(Pyrgiotis et al., 2013), equipment used in traffic control, runway geometry (Cavusoglu & Macário, 2021)etc. and also delays can happen at any point in time and space such as enroute, nearby airspace of the airport , on the runway, on taxiway, on apron or at the gate and beyond(Clare & Richards, 2011).

FAA's Airport Master Plan AC 150/5070-6B with Change 1 (May 2007) “Delay is typically expressed in minutes per aircraft operation, which can be translated into hours of annual delay and

easily converted into dollar estimates to be used as a basis for comparison (DeArmon et al., 2016). Traditionally, 4 to 6 minutes of average delay per aircraft operation is used in annual service volume (ASV) calculation (TransSolutions et al., 2014). When the average annual delays per aircraft operation reaches 4 to 6 minutes, the airport is approaching its practical capacity and is generally considered congested.”

“Airports experiencing severe delay due to congestion will not be able to accommodate rising demand for air service. Average delay per operation of 10 minutes or more may be considered severe. At 20 minutes of average delay (approximately the highest recorded average delay per operation known to FAA at an airport in the United States), growth in operations at the airport largely will cease (Pyrgiotis et al., 2013). Prior to reaching these levels, airlines would begin to use larger aircraft, adjust schedules, and cancel or consolidate flights during peak delay periods. Passengers would make use of alternative airports, seek other means of transportation (e.g., automobile or train), or simply avoid making some trips (Poldy, 1982). Airports typically focus both on throughput and average delay. In general, an airport measures its impact on delay based on the overall ability to stay below maximum airport capacity. If the airport’s operations were under their maximum capacity all day, from the airport’s point of view, there were no airport-caused delays, regardless of when a particular aircraft was scheduled to depart versus when it actually departed. Those airports that have significant delays recognize that this affects their ability to compete for air service with other airports. International operations can have a big impact on, and be greatly affected by, delays. In some cases, if a flight misses its assigned slot time, the flight has to be cancelled and therefore process exceptions are made to make sure international departures are not delayed.

At many airports today, traffic demand is well below capacity. Where the demand is below VMC capacity, delays are small such that delay analyses, much less airline scheduling practices, are not of great concern. Other airports believe that most of these delays could be avoided by the airline scheduling additional time between flights. Most airlines take their own gate capacity at each airport into account when developing their schedules, but do not necessarily consider runway capacity. This results in schedules being developed that can be maintained during VMC capacity, but these same schedules far exceed IMC capacity. Airports with similar VMC and IMC capacities tend to have somewhat reasonable delays during IMC. Also, airports that only encounter IMC a small amount of time can tolerate much higher IMC delays. However, airports with huge

differences between VMC and IMC capacities that experience IFR (Instrument Flight Rule) conditions somewhat regularly experience significant delays

Data commonly used for evaluating aircraft travel times and delays at an airport is the out-off-on-in (OOOI) data. Many airlines use onboard systems, such as the Aircraft Communications Addressing and Reporting System (ACARS) to automatically record these times, which are defined as follows based on the international standard (TransSolutions et al., 2014) and (Pyrgiotis et al., 2013):

- Wheels “out” of the gate/parking position is the time an aircraft departed from the gate, typically measured when the parking brake is released. Also called the actual time of departure (ATD), which can be compared to the STD.
- Wheels “off” the runway is the time an aircraft departed from the runway.
- Wheels “on” the runway is the actual time an aircraft landed on the runway.
- Wheels “in” the gate or parking position is the time an aircraft arrived at the gate, typically measured when the parking brake is set. Also called the actual time of arrival (ATA), which can be compared to the scheduled time of arrival (STA).

Analysis of taxi times at an airport use “out-to-off” times for taxi-out or departure taxi time, and “on-to-in” times for taxi-in or arrival taxi time. Similarly, “out-to-in” times would require the entire time from one airport gate to another, which can be compared to the scheduled block time.

The published STD and STA are the only parts of the airline schedule development that are publicly available. The duration from the STD to STA is the scheduled block time. Airlines include in the block time the expected taxi-out time, expected en route time, and expected taxi-in time at the destination airport. It is important for the scheduled block times to be accurate, but there are competing forces for setting the block times, as follows:

- Passengers purchase tickets or flights based on the STA and/or STD. These times need to be both realistic and convenient in order to meet passenger expectations.
- An airline’s planning and staffing are based on scheduled times. For every minute in the block time, the crew and aircraft are not available to be scheduled for another flight/ trip. Each minute in the block time is equivalent to millions of dollars.
- U.S.DOT rankings are based on percent on-time compared to the STA and STD.
- Turnaround times at gates and minimum connection times for passengers are based on the block times

Airlines add time to their block time schedules to accommodate for historical actual times, which include some delay resulting from flight restrictions, congestion, and a variety of other factors. Although there is concern that airlines “pad” (Rebollo & Balakrishnan, 2014) the block times to artificially improve their on-time performance, it is a costly endeavor to add minutes to the block time. Each carrier must make a decision as to what is the most realistic block time to apply to a given flight.

If airlines use the average block time, then they are guaranteed to be underestimating actual times for a large number of flights. If they use a larger number for the block time, their on-time performance will improve, but it will be quite costly because that aircraft, crew, etc., cannot be available for another scheduled flight. In this example, the airline could schedule to a block time of 135 minutes and 8.5% of the flights would have experienced a block time of 135 minutes or less, showing that smaller amount of block time is achievable, but not consistently since over 90% of the flights took more time than that. Even if airlines publish a schedule with the average block time of 147 minutes, 44% of the flights would experience a block time longer than that. Since the published time is used by passengers in anticipating not only their airport arrival, but their subsequent arrival at their ultimate destination, passengers prefer to have a scheduled arrival time that is reliable (ACRP Report 104, 2014)

Analysis of causes of delays is a bit complicated as there are cases where multiple factors can cause a single operational delay. Gate departure delay can be caused (Pyrgiotis et al., 2013), for instance, by delay of baggage loading delay (Cavusoglu & Macário, 2021), start boarding delay (Lai et al., 2015), start-up approval delay etc. at a time.

2.5 Aircraft Operations and Procedure

An airport flight operation procedure starts from time of ATC (Air Traffic Control) flight plan activation until take off according to ACDM

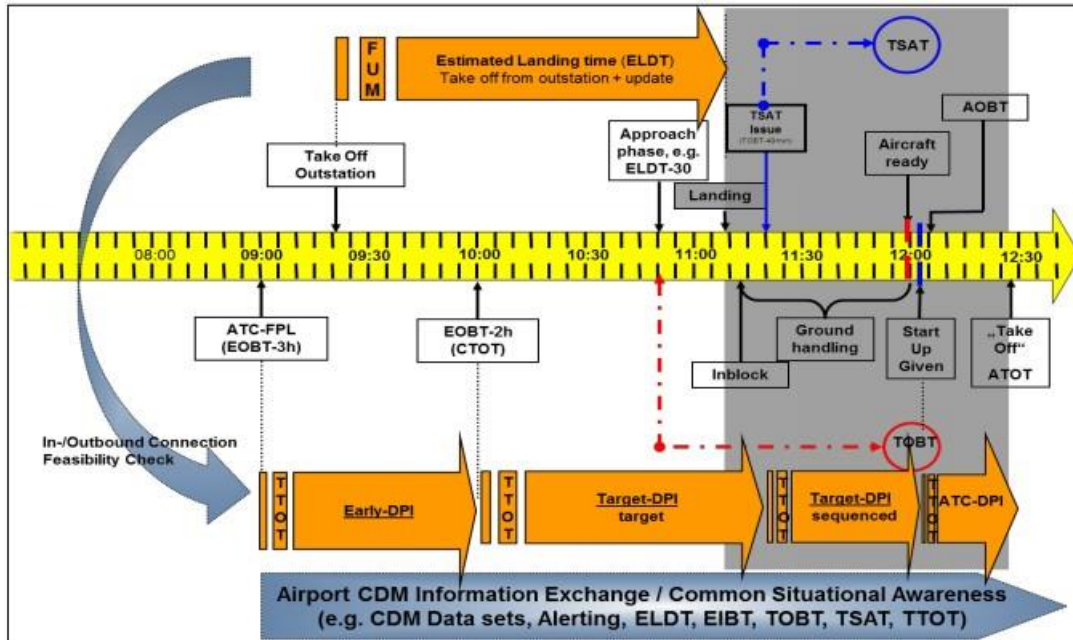


Figure 4 Aircraft operations and procedure (Source: ACDM@FRA version 5.1)



Figure 5 Gate to gate operations management (Source: Stuart Ratcliffe, 2015)

Air Traffic Flow Management (ATFM) (Lai et al., 2015) is an Air traffic Management service established with the objective of contributing to a safe, orderly and expeditious flow of air traffic by ensuring that an Air Traffic Control (ATC) service is provided in an environment where system capacity (airports and airspace) is optimized and the demand is balanced against that system capacity.

Collaborative decision-making (CDM) (Anderson et al., 2019) is defined as a process focused on how to decide on a course of action articulated between two or more community members. Through this process, ATM community members share information related to that decision and agree on and apply the decision-making approach and principles. The overall objective of the process is to improve the performance of the ATM system as a whole while balancing the needs of individual ATM community members.” – ICAO

Airport Slot (Dray, 2020)-Is mandatory at coordinated airports for each movement (arrival and departure) and is valid for a specific time at a specific weekday and for a specific period applied for. The airport slot is used to plan the airspace, runway and terminal building capacity and/or other capacity constraints for a whole season to minimize airport congestion and potential delays. (Worldwide Slot Guidelines, 2020)

Air Traffic Control (ATC) slot(Dray, 2020)- is needed by each regulated/controlled departing or arriving flight on the actual day of operation to manage traffic flows through congested resources (airport/airspace). This slot is only valid for a specific flight and for a specific departure time window. An **ATC slot** always has precedence over an **Airport Slot**.

Airport coordination is a means of managing airport capacity through the application of a set of rules contained in these Worldwide Slot Guidelines (WSG).

2.6 Method of Capacity and Demand Analysis

2.6.1. FAA Capacity AC Guideline (Advisory Circular AC 150/5060-5)

(K. Chen et al., n.d.)

Look up tables and analytical models including tables and graphs can be used to compute the capacity of a runway system based on specific Fleet Mix Index, Touch and go operation numbers, weather condition and rapid taxi position, the hourly capacity at 50, 40and 60 percent Arrivals(Lei et al., 2020). As the first step, it helped to get the hourly capacity estimate. Based on the historical data, the average percentage of Class A, B, C, and D aircraft for daily operations have been identified using the following table and chart.

Table 1-1. Aircraft classifications

Aircraft Class	Max. Cert. T.O. Weight (lbs)	Number Engines	Wake Turbulence Classification
A	12,500 or less	Single	Small (S)
B		Multi	
C	12,500 - 300,000	Multi	Large (L)
D	over 300,000	Multi	Heavy (H)

No.	Runway-use Configuration	Mix Index % (C+3D)	Hourly Capacity Ops/Hr		Annual Service Volume Ops/Yr
			VPR	IFR	
1.	[Diagram of runway configuration]	0 to 20	98	59	230,000
		21 to 50	74	57	195,000
		51 to 80	63	56	205,000
		81 to 120	55	53	210,000
		121 to 180	51	50	240,000

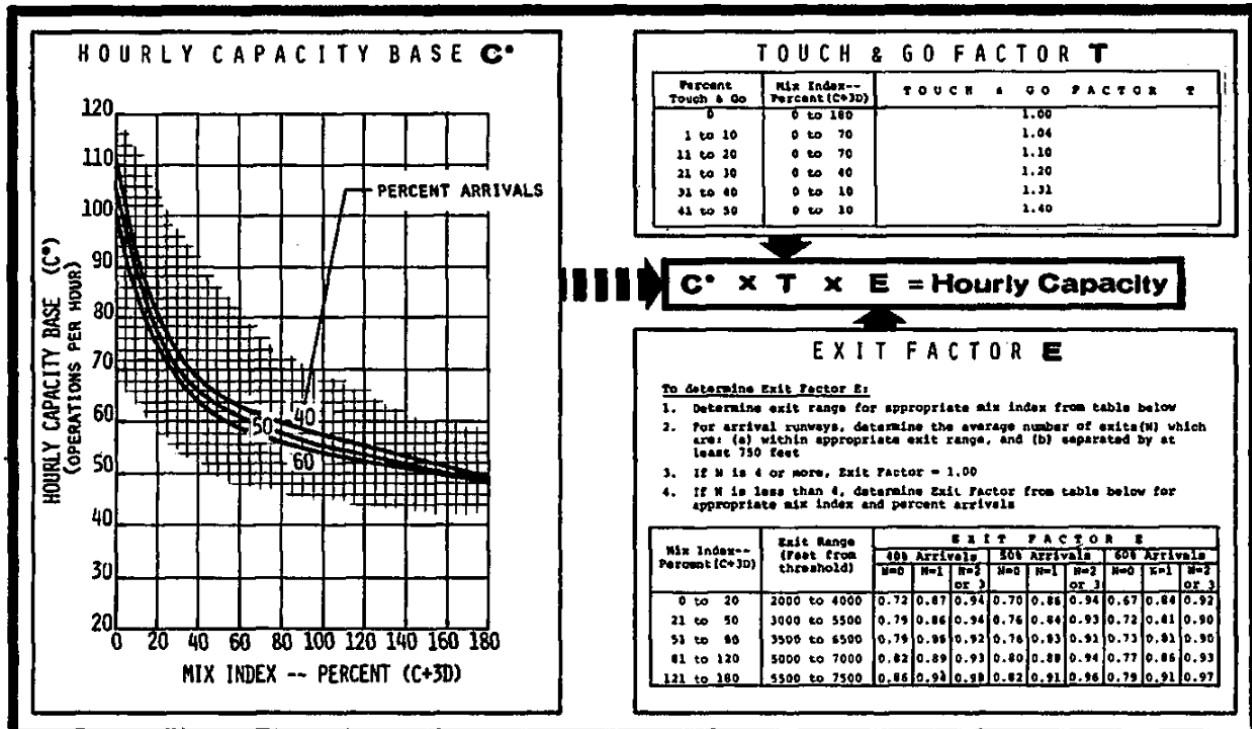


Figure 6 FAA Runway capacity guideline table and chart (Source: AC 150/5060-5 FAA Circular)

2.6.2. ICAO Aircraft Separation Rules

2.6.2.1. Arrival Based Capacity (Arrival-Arrival Capacity (100% PA))

To calculate the A-A capacity the following assumptions are made (Lei et al., 2020) and (Ignaccolo, 2003)

- There are only arrival aircraft that have continuous demand throughout the peak hour
- General aviation rules of separation are applied

- No noise abatement restriction is imposed
- The fleet mix is the assumed expected mean value and remains the same throughout the peak hours.
- There is no constraint due to ATC equipment and operations, terminal gate, apron, and taxiway that could affect the runway capacity
- No political constraint on movement rate
- No constrain of airspace acceptance and delivery rate
- Favorable weather condition is considered since the effect of weather as a hub airport having Heavy and Medium class aircraft is minimal and also 90% of the flights are Marginal VMF
- Runway Occupancy Time during landing is taken into consideration to determine the governing factor in comparison with separation rules.
- The sequence of arriving aircraft during peak hours is taken from the total average daily arriving aircraft data. The probability of different sequential arrangements as leading and following aircraft are computed and tabulated.

For a given leading and following operation condition the capacity is

$C_i = 1/T_i$, Where C_i is the capacity for the runway(operation per given time) whereas T_i is the time required for a single operation.

The probability of two independent variables in our case Leading aircraft and Following Aircraft is $P_{ij} = P_i * P_j$ Where P_i is the probability Of leading aircraft P_j is the probability of trailing (following) aircraft. After all the joint cumulative probability distribution have been determined using the under bellowed formula. The joint cumulative probability distribution function is

$$F(x, y) = \sum_i \sum_j P_{ij}$$

2.6.2.2. *Departure Based Capacity (Departure-Departure capacity (0%PA)*

Here, the same assumptions as that of the Arrival based is taken in to account except that all operations are continuous departures(Clare & Richards, 2011) and(Fisher et al., 2012b).

2.6.2.3. *Arrival-Departure-Arrival Capacity*

This case is when mixed operation of Arrival and Departure are along the same direction: the following two conditions are taken into account.

- 1) When arriving aircraft are Heavy aircraft leading Medium condition where the capacity found to be 1/125 Sec or **28.8** Arrival Per hour 23% of the time (Lei et al., 2020) and(Fisher et al., 2012b).
- 2) It was also identified that an additional 28.8 Departures per hour can be involved between arriving aircraft(Barrer et al., 2005). The probability of such an event is 23% while the remaining 77% are governed by a Runway Occupancy Time of 60 Sec which means 60 Operations per hour.

2.6.3 Linear Regression

In some studies linear regression has been employed to know the effect of departure occupancy time on the delay departure in runway operation(Abdel-Aty et al., 2007) and (Clewlow et al., 2010). The model developed by this method will have implication of managing the delay by coordinating with runway occupancy time, type of aircraft and flight (national or international). In order to further examine the effect of arrival rate, departure rate, runway occupancy time and type of aircraft and flight on delay of departure flight, some studies conduct regression analysis using the time of delay of departure as dependent variable (Clewlow et al., 2010). There was also a research conducted with an improved regression model for taxi-out times would that include both the number of departures and the number of arrivals with better degree of determination.

2.7 Conclusion

Based on the literature review, it is evident that demand, capacity, and delay are the main parameters that affect not only the performance and quality of transport but also the economic feasibility and profitability of airports. Various studies have been conducted on these topics, primarily focusing on airports in Western countries. These studies underscore the necessity of having versatile and well-organized data to perform high-level and accurate research. The computational approaches for determining capacity range from simple numerical manipulations to sophisticated simulation modeling software applications, depending on the study's objectives.

Moreover, it is understood from the literature that there is no universally agreed-upon method for measuring airfield capacity. Guidelines such as the FAA Capacity AC Guideline and ICAO Aircraft Separation Rules offer frameworks, but they lack a standardized approach. Similarly, methods for analyzing delays range from simple linear regression models to more complex non-linear regression techniques. Periodic assessments of demand and capacity are crucial since these factors are time-dependent and influenced by seasonal variations and regional economic development.

However, a significant gap exists in the research concerning Addis Ababa Bole International Airport (AABIA). While demand and capacity assessments are well-documented for airports in other regions, studies specific to AABIA are notably scarce. This scarcity can be attributed to the lack of readily available, well-detailed, and organized data, as well as the high costs associated with obtaining such information. These challenges highlight the importance of this study, which aims to assess the demand and capacity of AABIA and model departure delays. The findings are expected to provide valuable insights for airport managers, engineers, and researchers, aiding in strategic, engineering, and scientific decision-making.

Addis Ababa Bole International Airport presents unique opportunities and challenges for this research. On the positive side, the airport's single runway, parallel taxiway, and straightforward taxi-in and taxi-out layouts simplify capacity and delay computations compared to more complex airports. Additionally, consistent wind directions and distinct seasonal weather conditions further facilitate the analysis. On the downside, the absence of well-organized and detailed data limits the ability to conduct comprehensive analyses that yield high-profile results and conclusions. Furthermore, delays caused by airport management activities, such as ticketing and check-in processes, are not included in this study due to the unavailability of data and because they fall beyond the study's scope.

In summary, this study addresses critical gaps in the current literature by focusing on demand and capacity assessments specific to AABIA. It emphasizes the need for detailed and organized data to enable comprehensive analyses and highlights the significance of aligning the study objectives with these research gaps. By doing so, this research not only contributes to the academic field but also provides practical insights for enhancing airport operations and management.

3 RESEARCH METHODOLOGY

3.1 Introduction

As mentioned in part one, the main objective of the study is assessing demand and capacity of AABIA and identifying runway factors affecting departure delay. Therefore, in order to achieve the general objective of the study, sample size, data collection method and employed analysis method have been presented as follows.

3.2 Study Area

The study area (Addis Ababa Bole International Airport) has a characteristics which is presented by the information as shown in table below.

Table 1 AABIA Basic Information

<i>Description</i>	<i>Data</i>
<i>Country</i>	<i>Ethiopia</i>
<i>Province or District</i>	<i>Addis Ababa</i>
<i>Nearest Town or City with Distance from Airport</i>	<i>Southeast of the Centre of Addis Ababa (6 km)</i>
<i>Airport's Complete Name</i>	<i>Addis Ababa Bole International Airport</i>
<i>Latitude</i>	<i>8.983225</i>
<i>Longitude</i>	<i>38.795754</i>
<i>Elevation (m)</i>	<i>2333 m</i>
<i>IATA Code</i>	<i>ADD</i>
<i>ICAO Code</i>	<i>HAAB</i>
<i>Managing Company or Airport Authority</i>	<i>Ethiopian Airlines</i>

Table 2 AABIA Runway Basic Information

<i>Description</i>	<i>Data</i>	<i>Remark</i>
<i>Runway 1 Dimensions</i>	<i>3700 m X 45 m</i>	<i>Mainly serves as a taxiway</i>
<i>Runway 2 Dimensions</i>	<i>3800 m X 45 m</i>	<i>Mainly serves as a Runway</i>
<i>Orientation</i>	<i>07L / 25R</i>	<i>True Alignment is 73.7 degrees from the magnetic north</i>
	<i>07R / 25L</i>	<i>True Alignment is 253.7 degrees from the magnetic north</i>
<i>Surface</i>	<i>Asphalt concrete</i>	
<i>Taxi Way</i>	<i>5 taxiways, 23m wide each</i>	



Figure 7 Aerial Image of AABIA taken from Google Map

3.3 Ethiopian Air Line Fleet Information.

Ethiopian airline is the most well known in the world since it accommodates not only millions of passenger per year but also it gives better cargo service in Africa. Even if it is international airport, 95% of the fleet using the airport is Ethiopian. The main users of the airport is Ethiopian Air Line which has the following information as presented in table below.

Table 3 Ethiopian Airline fleet as of December 2022

Aircraft	In service	Orders	Passenger fleet			Notes
			Passengers			
			B	E	Total	
Airbus A350-900	20	—	30	318	348	
Airbus A350-1000	—	4	TBA			Orders converted from Airbus A350-900.
Boeing 737-700	9	—	16	102	118	Order includes 15 options. To be converted into freighter.
Boeing 737-800	17	4	16	138	154	
			12	156	168	
Boeing 737 MAX 8	11	21	16	144	160	
Boeing 767-300ER	1	—	24	208	232	
				211	235	
Boeing 777-200LR	6	—	34	287	321	
Boeing 777-300ER	4	—	34	365	399	
Boeing 787-8	19	—	24	246	270	
Boeing 787-9	10	—	30	285	315 ^[6]	
De Havilland Dash 8-400	32	—	7	64	71	
			—	78	78	
Cargo fleet						
Boeing 737-800BCF	4	—	Cargo			
Boeing 767-300BCF	—	3	Cargo			Delivery begins in 2023.
Boeing 767-300BDSF	2	1	Cargo			Converted from passenger aircraft.
Boeing 777F	9	5	Cargo			
Total	144	38				

3.4 Sample size determination

The study population is the number of flights served in year 2023 and 2024 and using AABIA runway. Therefore, the number of study population (AABIA flights) is infinite as can be exemplified by the number of flight in the month of May which is more than 39000 flight. Therefore, Cochran's formula have been employed in this study for infinite population as follows:

The sample size for an infinite population, (Number of flight= N)= $[Z^2 * p (1 - p)] / e^2$

Where:

N=minimum number of sampled flight

Z=the score of confidence level (1.96 for 95% confidence level)

P= percentage of succeeded population=0.5 to get maximum number of sample

e= precision =0.05 for 95% confidence

Therefore, N= $[(1.96^2 * 0.5 * (1-0.5)) / 0.05^2] = 385$ minimum number of flight are required to conducted sample representative study. Moreover, the repetitive nature of the data would also make such number of sample sufficient for the data analysis. Accordingly, in this paper a total of 433 flight information's have been used for the analysis that have full scanned information.

3.5 Data Collection method and procedure

Upon review of the literature and other similar research to adapt and target the method of approaches, the following procedure have been implemented for the data collection.

Accordingly, the first step was to see how detailed and what sort of data were available. A couple of websites having flight data were assessed and mainly two websites were selected namely "Flightradar24 (<https://www.flightradar24.com>)" and "Airportia (<https://www.airportia.com>)" to acquire the necessary detailed data. Both websites have their advantage and disadvantages one over the other. The former website has more accurate tracking detail data available while the later website provides data more friendly to copy and analyze. Since more accurate detail is a priority, subscription was made as a 'Golden member' on a monthly payment basis to get one-year of data while from the later website one week data could be acquired any given time without any specific subscription.

For comparison purpose, other airports having similar runway system and have achieved higher capacity (higher demand) were targeted for data collection. London Gatwick International airport, Mumbai Chhatrapati Shivaji Airport and San Diego International Airports were targeted for data

collection and preliminary assessments were made on the data and nature of the airports and the aircraft operation on the runway system. In the process of acquiring yearly data and preliminary analysis, it was learned that the pattern of aircraft operations has a strong similarity and repetitive nature every week. AABIA has additionally significant similarities even daily. As a result, sampling of the data taken from the randomly selected weeks of recent years like 2023 and 2024 can serve reasonably for the analysis of peak hours demand and capacity and for detailed studies of departure delays and runway occupancy time which were very essential data that play major roles in identification of possible enhancement areas to improve the capacity of the runway system, the airfield and the airport at large.

Flight data such as flight date and number, flight destination, flight schedule of departure and arrival and flight actual departure and arrival, status of arrival, aircraft type used, and detailed track record of any given flight with detailed coordinates of latitude and longitude, speed, elevation and direction data in few second intervals could also be acquired for each tracked flight.

As a preliminary study weekly data for a randomly selected month of the year 2023 is taken and it was observed that at any given day of the week, the flight operations pattern is similar to any other same day of the week. Moreover, the similarity of the pattern of daily operations is also more similar to AABIA than others specifically London Gatwick Airport. From, the weekly data, peak hours were selected. Here, the selection of peak hours was a little bit tricky and needed a proper understanding of the dynamics. The actual peak hours and the scheduled peak hours are different not only in magnitude but also in range of hours. Due to delays, the actual real pattern of peaking hours is different from the scheduled peak hours. The arrival schedule between 7 AM and 8 AM, for instance, is less than the actual, while between 6 AM and & 7 AM is the reverse due to significant flights scheduled to arrive between 7 and 8 AM arriving in advance between 6 and 7 AM. The arrival schedule between 7 AM and 8 AM on the date of 22 June 2023 was 21 arrivals while the actual arrival was 8 and while the arrival schedule between 6 AM and 7 AM was 10 and the actual arrival was 16 and very similar patterns were observed for other days of the week. Other airports like London Gatwick Airport have such discrepancies but to a small extent compared to AABIA.

Therefore, the actual arrival and departure are taken for peak hour data analysis. AABIA has a smaller percentage of tracked data compared to other similar airports. 76% of data was tracked and available for AABIA compared to 98% of actual data for London Gatwick Airport. On the other hand, all tracked data are not relevant to this research, most aircrafts have the tracked records in the

vicinity of AABIA specifically those local flights have tracked data only while they are departing and arriving which is an advantage for this research. There are also very few flights that never have any record data. Such absence of actual tracked data can affect the accuracy of the analysis of the data to a very small extent. The overall data, however, represent the actual operation dynamics on the runway system and serves satisfactorily for this research scope.

Table 4 Sample of Daily Departure matrices

TIME	FLIGHT	TO	AIRLINE	AIRCRAFT		STATUS
Sunday, Apr 14						
10:00 AM	ET841	Kinshasa (FIH)	Ethiopian Airlines	A359 (ET-AVD)		Departed 10:27 AM
10:00 AM	ET959	Bangui (BGF)	Ethiopian Airlines	B38M (ET-AVI)		Departed 10:22 AM
10:05 AM	ET290	Shire (SHC)	Ethiopian Airlines	DH8D (ET-AYH)		Departed 10:10 AM
10:05 AM	ET939	N'Djamena (NDJ)	Ethiopian Airlines	B38M (ET-AWI)		Departed 10:31 AM
10:10 AM	ET173	Jimma (JIM)	Ethiopian Airlines	B38M (ET-BAL)		Departed 10:35 AM
10:15 AM	ET102	Mekele (MQX)	Ethiopian Airlines	DH8D (ET-AVR)		Departed 10:33 AM

Table 5 Flight history for any selected flight (ET959) of one-year data availed view

DATE	FROM	TO	AIRCRAFT	FLIGHT TIME	STD	ATD	STA		STATUS	
22-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	7M8	—	10:00 AM	—	11:40 AM		Scheduled	Play
21-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	7M8	—	10:00 AM	—	11:40 AM		Scheduled	Play
19-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	7M8	—	10:00 AM	—	11:40 AM		Scheduled	Play
17-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	7M8	—	10:00 AM	—	11:40 AM		Scheduled	Play
15-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-AWF)	3:07	10:00 AM	10:44 AM	11:40 AM		Landed 11:51 AM	KML CSV Play
14-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-AVI)	3:05	10:00 AM	10:22 AM	11:40 AM		Landed 11:27 AM	KML CSV Play
12-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-BAN)	3:06	10:00 AM	10:36 AM	11:40 AM		Landed 11:41 AM	KML CSV Play
10-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-AVL)	2:58	10:00 AM	10:25 AM	11:40 AM		Landed 11:23 AM	KML CSV Play
7-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-AWJ)	3:03	10:00 AM	10:41 AM	11:40 AM		Landed 11:44 AM	KML CSV Play
5-Apr-24	Addis Ababa (ADD)	Bangui (BGF)	B38M (ET-AZA)	3:18	10:00 AM	10:20 AM	11:40 AM		Landed 11:39 AM	KML CSV Play

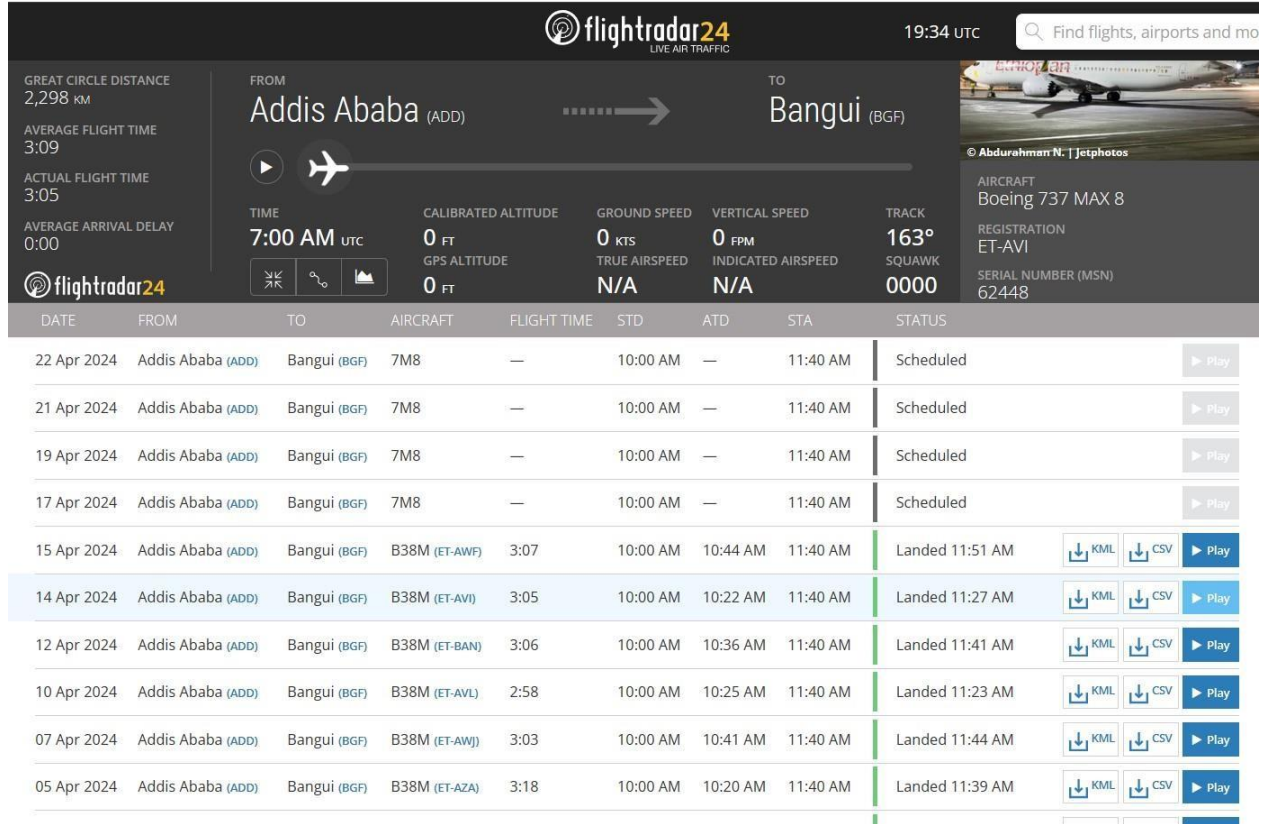


Figure 8 The data feature from the data provide (flightradar24) website

A selected CSV data imported in the Google Maps Pro application shows the detailed position, speed, altitude and direction from the start of departure to the end of arrival.



Figure 9 Flight track record sample for an airplane departing from AABIA converted from CSV data using Google Earth

Sample CSV data matrix for a given departure (ETH959 Addis Ababa to Bangui) on the date of April 04, 2024, Scheduled Time of Arrival 10:00 AM local time (7:00 UTC) and Actual Time of Departure (ADT) 10:22 AM local time (07:22 UTC).

Table 6 Sampled extracted CSV format data

Timestamp	UTC	Callsign	Position	Altitude	Speed	Direction
1713079256	2024-04-14T07:20:56Z	ETH959	8.97242,38.783867	0	5	78
1713079337	2024-04-14T07:22:17Z	ETH959	8.972534,38.784206	0	15	73
1713079344	2024-04-14T07:22:24Z	ETH959	8.972786,38.78508	0	42	73
1713079351	2024-04-14T07:22:31Z	ETH959	8.973386,38.78709	0	72	73
1713079361	2024-04-14T07:22:41Z	ETH959	8.974686,38.791561	7275	112	73
1713079374	2024-04-14T07:22:54Z	ETH959	8.976948,38.799309	7275	159	73
1713079387	2024-04-14T07:23:07Z	ETH959	8.980299,38.810768	7275	183	73
1713079401	2024-04-14T07:23:21Z	ETH959	8.983932,38.823681	7675	208	74
1713079415	2024-04-14T07:23:35Z	ETH959	8.987375,38.836197	8425	199	74
1713079428	2024-04-14T07:23:48Z	ETH959	8.990681,38.847515	8775	203	73
1713079441	2024-04-14T07:24:01Z	ETH959	8.994265,38.859734	9000	209	73
1713079455	2024-04-14T07:24:15Z	ETH959	8.998123,38.872841	9275	214	74
1713079467	2024-04-14T07:24:27Z	ETH959	9.001465,38.884758	9500	218	74
1713079483	2024-04-14T07:24:43Z	ETH959	9.006089,38.900883	9800	229	74
1713079495	2024-04-14T07:24:55Z	ETH959	9.009888,38.914272	10000	236	73

AABIA's recent average daily operation per day is 392 tracked by flight radar 24.com such that for tracked arrival and departure operation detailed data for runway occupancy time, actual departure and arrival taxing time, arrival-departure schedule data including type of aircraft is availed for all flights. Then, calculations for fleet mix, and percent of arrival are done on a full data basis. Cross check was undertaken on the CSV data acquired from Flightradar24 with the actual flight operation and it was observed that the CSV data started from the aircraft engine start time while the actual aircraft movement starts from the pushback where the aircraft pushed by the pushback truck up to the position of ready to engine start. Sometimes the engine start time aligns with the aircraft movement start time when the aircraft is already in ready-to-start position mostly when it is located outside of the terminal gate. In this case, the CSV data and the actual aircraft movement data are the same. The pushback time is learned to be a couple of minutes and can be estimated for the overall taxing time estimation.

3.6 Data Analysis Method

In this paper, both “FAA Capacity AC Guideline” and “ICAO Aircraft Separation Rules” have been employed to determine the demand and capacity of AABIA. Multiple linear regressions have been also employed to estimate the Departure Runway Occupancy Time, number of hourly departures and other factor influence on the delay of departure on the runway system. The detail of each method have been shown as follow below.

3.6.1. FAA Capacity AC Guideline (Advisory Circular AC 150/5060-5)

In this method the capacity of runway system is analyzed by considering the proportion of fleet mix, touch and go operation numbers, weather condition and rapid taxi exit position and the hourly capacity at 50, 40and 60 percent Arrival have been identified. As the first step, it helped to get the hourly capacity estimate. Based on the historical data, the average percentage of Class A, B, C, and D aircraft for daily operations is identified to compute the fleet Mix Index.

Aircraft Classifications

Aircraft Class	Max. Certified Take-Off Weight (lbs)	Number of Engines	Wake Turbulence Classification
A	12,500 or less	Single	Small (S)
B	12,500 or less	Multi	Small (S)
C	12,500 – 300,000	Multi	Large (L)
D	Over 300,000	Multi	Heavy (H)

Runway-Use Configuration and Capacity (Single Runway)



Mix Index (C + 3D)	VFR Hourly Capacity (Ops/Hr)	IFR Hourly Capacity (Ops/Hr)	Annual Service Volume (Ops/Yr)
0 to 20	98	59	230,000
21 to 50	74	57	195,000
51 to 80	63	56	205,000
81 to 120	55	53	210,000
121 to 130	51	50	240,000

Figure 10 Hourly operation capacity based on flight Mix Index and runway-use configuration (Source: FAA Circular)

As the airport is the hub for Ethiopian Airlines, the majority of the aircraft operation on the runway is Ethiopian Airlines. Out of 140 aircraft at service, Boeing 737 and DHC-8 Dash8 are class C (Medium Wake turbulence category) aircraft while all others are classified as class D aircraft. Out of the total aircraft operations, Ethiopian Airlines comprises 95% while other Airlines such as Kenya Airways, Emirates, Egypt Air, Turkish Airlines, Fly Dubai, and others all combined comprise only 5 % of the total operations. Almost all of those Airlines use aircraft class C and D as well.

The aircraft using the runway is more of class C and D such that the Mix Index % (C+3D) is close to the maximum value with the average operation of 65% of class C and 35% of class D aircraft. Roughly, 51 operations per hour can be considered the approximate theoretical base capacity for 50% of arrival (PA). For the capacity calculations, the touch and go factor and exit factors are taken into consideration. The touch-and-go factor (T) is considered 1 as the percent during peak hour was learned to be nil. The taxi exit factor depends on the number of exits available between 5500 ft (1675 m) and 7500 ft (2285 m) from the threshold for a Mix Index of 121 to 180 which is the AABIA runway case. From those tables and graphs, the hourly capacity of the runway for 40, 50, and 60 percent Arrival (PA) is identified and this figure helps to briefly understand the capacity estimate by considering the current peak hour demand.

3.6.2. ICAO Aircraft Separation Rules

3.6.2.1. Arrival Based Capacity (Arrival-Arrival Capacity (100% PA))

To calculate the A-A capacity the following assumptions are made:

- There are only arrival aircraft that have continuous demand throughout the peak hour
- General aviation rules of separation are applied
- No noise abatement restriction is imposed
- The fleet mix is the assumed expected mean value and remains the same throughout the peak hours.
- There is no constraint due to ATC equipment and operations, terminal gate, apron, and taxiway that could affect the runway capacity
- No political constraint on movement rate

- No constrain of airspace acceptance and delivery rate
- Favorable weather condition is considered since the effect of weather as a hub airport having heavy and medium class aircraft is minimal and also 90% of the flights are marginal VMF
- Runway Occupancy Time during landing is taken into consideration to determine the governing factor in comparison with separation rules. The actual aircraft arriving runway occupancy time was checked from the CSV data of the flight track record and visual observation also was undertaken on a virtual online live flight track. Global runway occupancy time for arrival and departure was taken in addition.
- The sequence of arriving aircraft during peak hours is taken from the total average daily arriving aircraft data. The probability of different sequential arrangements as leading and following aircraft are computed and tabulated as the table below. Out of 198 average daily arriving aircraft, 65% are class C while the remaining 35% are class D.

Table 7 The joint cumulative probably distribution for Leading-Following aircraft arrival operation

Leading Aircraft Class	Following Aircraft Class			
	Super Heavy	Heavy	Medium	Light
Super Heavy	-	-	-	-
Heavy	-	0.12	0.23	-
Medium	-	0.23	0.42	-
Light	-	-	-	-

The jointly distributed random discrete variables used to identify the sum of all probabilities all leading and following aircraft $P(X=x_i, Y=y_j)$ is 100% or 1 for any given ‘ x_i ’ the leading aircraft and ‘ y_j ’ the following aircraft.

3.6.2.2. Departure Based Capacity (Departure-Departure capacity (0%PA)

Here, the same assumption is made as Arrival based except that all operations are continuous departures. The fleet mix is also the same, i.e. 65% of Medium aircraft while 35% is Heavy Aircraft categories. According to ICAO, if immediate divergence is possible for the following aircraft, a minimum separation time of 60 Sec applies and 120 Sec applies otherwise.

3.6.2.3. Arrival-Departure-Arrival Capacity

In this case, mixed operation of Arrival and Departure along the same direction is taken. However, considering the following two conditions is mandatory.

- When arriving aircraft are Heavy aircraft leading Medium condition where the capacity found to be 1/125 Sec or **28.8** Arrival Per hour 23% of the time.
- It was also identified that an additional 28.8 Departures per hour can be involved between arriving aircraft. The probability of such an event is 23% while the remaining 77% are governed by a Runway Occupancy Time of 60 Sec which means 60 Operations per hour.

3.6.3. AABIA Current Demand

The current demand for the aircraft operation is the maximum demand ever. The demand is smoothly increasing from year to year. The hourly demand which has been taken randomly for some days in 2023 and 2024 as shown in the graph below is the actual operation of arrival and departure taking place in 24 hours of the day.

This demand data that is depicted in the capacity envelope graph clearly shows the current demand status as compared to the theoretical capacity. For the study of capacity, the actual arrival and departure data was taken as opposed to the scheduled data to filter the peak hours for further detailed study. A Sample of Hourly Arrival-Departure for a random Monday (M -A-D), Saturday(S-A-D) and Wednesday (W A-D) have been shown in the bar graph below.

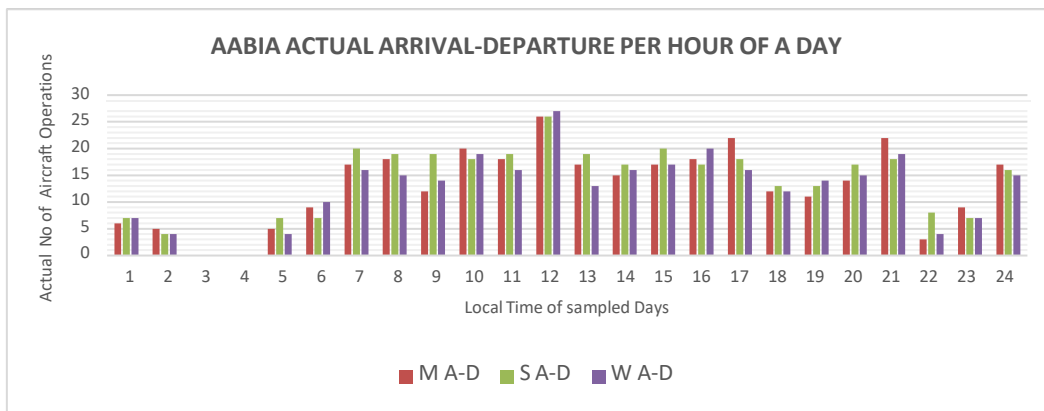


Figure 11 AABIA Hourly demand for randomly taken three days (arrival and departure)

From the above graph, the single primary peak hour operation is at 12 Hr (Between 11 Hr and 12 Hr) and there are several secondary peak hours such as 7Hr, 8Hr, 10Hr, 11Hr, 15Hr, 16Hr, 17Hr, and 21Hr. Demand data for other international airports are also taken for comparison and analysis of the detail for the hourly arrival and departure patterns.

3.6.4 Regression Analysis

In this analysis, multiple linear regression analysis have been employed to predict the departure delay related to the runway system. Therefore, the variable is departure delay which is the difference of actual departure and schedule departure time. Departure delay is measured in minute which is continuous dependent variable. Hence, multiple linear regression have been employed. Departure runway occupancy time (DOCT), arrival rate (AR), departure rate (DR), weight of aircraft(W), type of flight (national or international), and time of flight (day time or night time) are the independent variables.

$$\text{Departure Delay} = a + b \cdot \text{DOCT} + c \cdot \text{AR} + d \cdot \text{DR} + e \cdot \text{W} + f \cdot \text{N/I} + g \cdot \text{D/N}$$

Where: a, is a constant and b, c, d, e and f, are the coefficient of independent variable

DOCT=departure occupancy time

AR= Arrival Rate

DR=Departure Rate

W=weight of aircraft

N/I= National/International flight

D/N=day time flight/Night time flight

4 RESULT AND DISCUSSION

4.1 Introduction

As stated above, the main objective of this paper is assessing the capacity and demand of Bole international airport runway system and identifying factors that have been found to influence the delay of flights in the system of runway. The capacity of runway have been identified using ICAO Aircraft Separation Rules and FAA method whereas the actual demand of runway system have been determined using the flight data from the database of flight radar 24 after identifying peak hour data. Runway operating parameters affecting the delay of flight have been also determined using linear regression analysis method. The detail of result of analysis have been presented as follows in their respective order.

4.2 Capacity and Demand of Addis Ababa Bole International Airport

4.2.1 Theoretical Capacity of Addis Ababa Bole International Airport

The capacity of Addis Ababa Bole International airport have been determined using ICAO Aircraft Separation Rules, Departure Based Capacity and Arrival-Departure-Arrival Capacity method.

Before going to the detail analysis, it is necessary to show the real ground condition of runway and assumptions considered for the capacity analysis. The actual rapid exits are located about 2250 m and 2800 m from the threshold, the first one is located between the given ranges such that the number of exits is assumed one. From the chart, shown in figure 12 below, the exit factors for 40, 50, and 60 Percent of Arrivals are 0.94, 0.91, and 0.91 respectively (red circles) which suggest capacities of 48, 46, and 46 operations per hour respectively. Here it is also learned from the chart that as the Mix index increases the exit factor reduces and as the percent of arrival increases the exit factor decreases. As the number of exits increases from one to two, the factor increases from 0.91 to 0.97 which indicates that one more rapid exist, which is geometrically feasible, can increase the capacity by 6%. From ICAO Aerodrome Design Manual requirement for class C and D aircraft, for minimum of two rapid exits required, it states that there may be a need to provide additional exit, especially at long runways (the case of Bole) after the main rapid exits depending upon local conditions and requirements. An

interval of about 450 m is recommended within 600 m of the end of the runway. Accordingly, the addition of one more rapid exit between 1675 m and 1800 m (2250-450) from the threshold in both directions can improve 6% of the runway capacity when the demand approaches the maximum capacity of the runway.

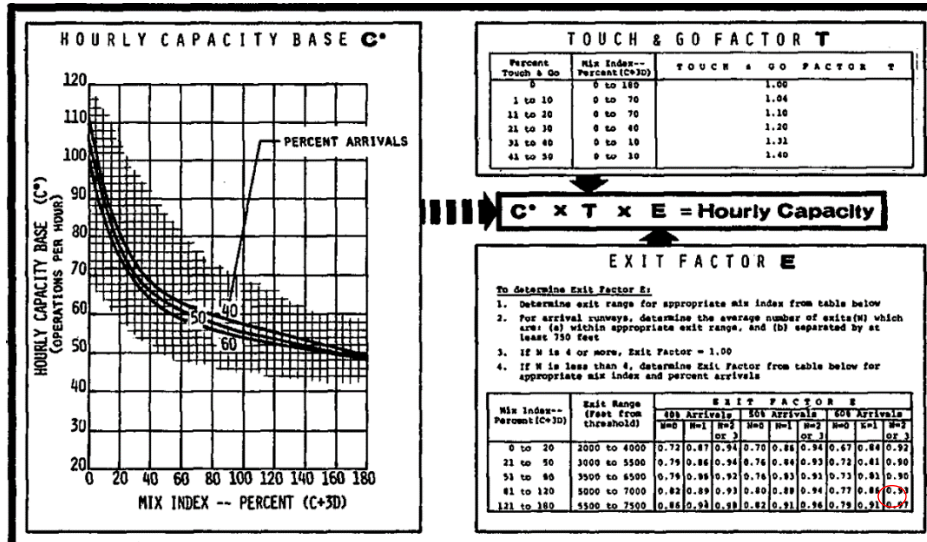


Figure 12 Hourly capacity base for 40, 50 and 60 PA, Touch and go factor and Exit factor FAA chart

From the above FAA circular data, the following observations are made.

The fleet Mix Index is the most important factor in determining the capacity of a single runway system. In VFR (Visual Flight Rule) condition, the smallest Mix index can have a capacity of up to 98 operations per hour while the highest Mix Index can have a capacity base of 51 Operations per hour which shows the smallest index can accommodate double the highest index.

The smaller the Mix Index the higher the effect of the weather in IFR condition. In IFR condition the capacity of the smallest index is reduced from 98 op/hr. to 59 Op/hr. While the highest operation is almost the same for VFR and IFR 51 op/hr. and 50 op/hr. respectively.

The hourly capacity of a single runway system is not affected, unlike another type of configuration by the percent of arrival. The hourly capacity at 40, 50, and 60 percent are very close to each other compared to other configurations.

The Touch and Go operations are considered nil since that operations are undertaken during nonpeak hours and do not have any impact on the peak hour operations. As the historical data indicates, AABIA has 90% Marginal VFR condition, and being a hub airport with a higher mix index concludes that the effect of weather on the hourly capacity of the runway system is minimal. Then

the hourly theoretical capacity will assume the VFR condition for capacity evaluation throughout this study.

4.2.1.1 Actual Capacity of AABIA using Arrival Biased Capacity (A-A- (100% PA))

Firstly, the aircrafts served in Addis Ababa Bole International Airport have been classified using the table and the chart. It is assured that most of the aircraft operation on the runway is Ethiopian Airlines. Out of 140 aircraft at service, Boeing 737 and DHC-8 Dash8 are class C (Medium Wake turbulence category) aircraft while all others are classified as class D aircraft. Out of the total aircraft operations, Ethiopian Airlines comprises 95% while other Airlines such as Kenya Airways, Emirates, Egypt Air, Turkish Airlines, Fly Dubai, and others all combined comprise only 5 % of the total operations. Almost all those Airlines use aircraft class C and D as well. Therefore, the capacity depends on whether the type C aircraft are leading by type D aircraft or following.

Table 8 ICAO Wake turbulence categories and separation minima

LEADER AIRCRAFT	FOLLOWER AIRCRAFT			
	SUPER HEAVY (A380)	HEAVY (>136T) (D)	MEDIUM (7.0T - 136.0T) (C)	LIGHT (< 7.0T)
SUPER HEAVY		5 nm (9.26 Km)	7 nm (13 Km)	8 nm (14.82 Km)
HEAVY(D)		4 nm (7.41 Km)	5 nm (9.26)	6 nm (11.11 Km)
MEDIUM (C)				6 nm (11.11 Km)
LIGHT				5 nm (9.25 Km)

Where blank, the minimum radar (surveillance) separation rule applies, which is 3 nm but can be 2.5 (4.63 Km) under certain conditions

1 nm (1 nautical mile) = 1.852 km, 1 Kts (Knot) =1.15 mph (mile per hour) and 1 Kts= 1.852 km/hr

The first case is, when class C aircraft leading by class D aircraft (C-D), according to the ICAO approach, speed limit for class C aircraft is 140 Kts which is 25 sec for 1nm and 125 sec for 5nm. Therefore, the capacity under this consideration is 1/125 sec that implies 28.8 arrival per hour. So the probability of P (D, C) is p (0.35, 0.65) is 23%.

The second case is, class D aircraft followed by class D aircraft: according to ICAO, the approach limit for class D is 150 Kts which is 23 for 1 nm and 93 Sec for 4 nm.

The capacity under this condition is $1/93 \text{ Sec} = 0.01075 \text{ Arrival per second}$ ($60*60*0.01075$) = 38.7 Arrival per Hour. Therefore, the probability of P (D, C) which is P (0.35, 0.35) is 12%.

The third case where the case of class C aircraft leading by class C aircraft (C-C), according to the ICAO approach, speed limit for class C aircraft is 140 Kts which is 25 Sec for 1 nm and 63 Sec for 2.5 nm assuming favorable conditions. Therefore, the capacity under this consideration is $1/63 \text{ sec}$ that implies 57.14 arrival per hour. So that, the probability of P (C, C) which is P (0.65, 0.65) is 42%.

The fourth case, there is also option of class D following class C Leading (D-C) according to the ICAO approach, speed limit for class D aircraft is 150 Kts which is 23 Sec for 1 nm and 93 Sec for 2.5 nm assuming favorable conditions. Therefore, the capacity under this condition is $1/93 \text{ Sec} = 0.01075 \text{ arrival per second}$ ($60*60*0.01075 = 38.7 \text{ arrival per hour}$). The probability of P (D, C) which is P (0.65, 0.35) is 23%.

Therefore, by considering all probabilistic cases mentioned above; the overall hourly capacity of all arrivals is $= 28.8*0.23 + 38.7*0.12 + 57.14*0.42 + 38.7*0.23 = 6.624 + 4.644 + 24.0 + 8.90 = 44 \text{ Arrival per hour}$ without any departure operation.

4.2.1.2. Departure Biased Capacity (Departure-Departure capacity (0%PA)

According to ICAO, if immediate divergence is possible for the following aircraft, a minimum separation time of 60 Sec applies and 120 Sec applies otherwise. Assuming divergence is possible, with 60 Sec separation a maximum of 60 Operations per hour. is possible. Such a possibility was confirmed by the topography counter of the vicinity technical personnel from ATC and the flight crew. In case of Departing after a larger aircraft executing a low approach, or missed approach, 2-minute separation is required. This operation has a probability of 23% and in that case the departure capacity is $1/120 \text{ operations per second}$ and 30 operations per hour. Therefore, total departure capacity = $0.23*30 + 0.77*60 = 6.9 + 46.2 = 53 \text{ Departure per hour}$ with out any arrival operations.

4.2.1.3. Arrival-Departure-Arrival Capacity

First case when there is increased departure in between A-A operations without affecting A-A capacity. According to Arrival-Arrival sequencing, 125 Sec is required for leading class D and following class C approaches. Here runway occupancy time for the arriving aircraft is the critical factor for the consideration of departure in between consecutive arrivals. The midpoint between two arriving aircraft is $125/2$ which is 62.5 Sec which means this time is higher than the minima for departure separation rule and at the same time runway occupancy time can also be less than or equal to 60 Sec which means $1/62.5$ Sec is the capacity at Heavy-Medium arrival condition which means 23% of the time.

This means 23% of the time the capacity is $1/62.5 = 0.016$ operation/Sec = 57.6 Operation/hr. implying that $0.23 * 57.6 = 13$ operations can be accommodated during Heavy aircraft leading Medium operation (D-C) which is $13 - 6.67$ which is 6 more operations can be accommodated. Then $44 + 6 = 50$ Operation (44 arrival and 6 departure) per hour is possible in ideal conditions.

Second case for 50% Arrival (Arrival-Departure-Arrival): As discussed above for 0.23% of the hour 13 operations are possible when heavy aircraft is leading the medium one. In the other 77% A-D- A operation, the Runway Occupancy time plays the governing role. It is generally assumed the ROT for a single operation is 60 Sec such that the capacity in this case is 60 Operations per hour which is 30 Arrival and 30 Departure. Therefore, the total operation of 50% Arrival = 13 operations + $0.77 * 60 = 13 + 46 = 59$ operations per hour which is 29 Arrival and 29 Departure.

As it is learned from the nature of arrival and departure capacity, there is an inverse dependency between arrival and departure. As arrival capacity increases the departure capacity decreases then, there is an optimum capacity where no improvement is made in one without reducing the other. This trade-off between arrival and departure in a given condition is referred as the Pareto frontier. Then the above calculation of the A-A, D-D, and A-D-A approach of maximum capacity of aircraft operation is illustrated as the arrival-departure capacity curve envelope.

Connecting the arrival and departure points as indicated in the table below results in the capacity envelope graph depicted here.

Table 9 Theoretical hourly arrival vs departure capacity of AABIA

ARRIVAL/HOUR	0	29	44	44
DEPARTURE/HOUR	53	29	6	0

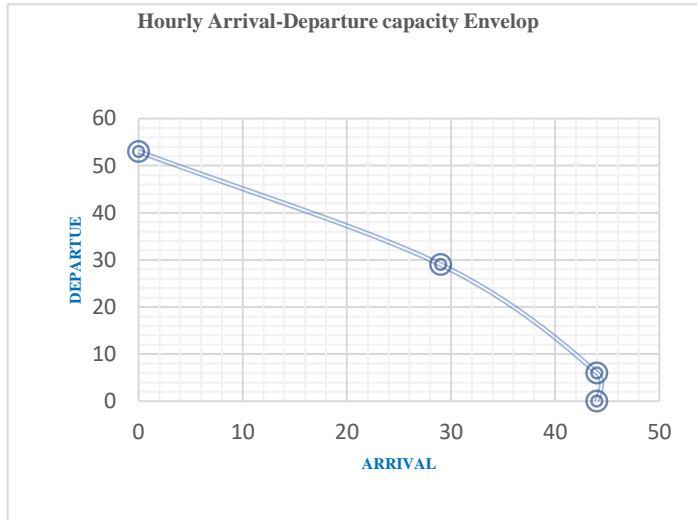


Figure 13 Hourly arrival and departure capacity envelope

4.2.2. Demand and Capacity comparison of AABIA with London Gatwick and Mumbai Chatrapati Shivaji International Airport

Upon achieving the capacity, it is crucial to analyze the demand relative to this capacity. For this analysis, London Gatwick Airport and Mumbai Chhatrapati Shivaji International Airport have also been selected. These airports were chosen primarily because their runway systems are similar to AABIA. Although Mumbai Airport has an additional crossing runway, it is not used for operations, thus maintaining the similarity. Additionally, these airports handle similar aircraft types, predominantly from the Heavy and Medium categories, due to their status as hub airports. The following graphs show the three airports' scattered arrival vs departure hourly demand and capacity envelope which is particularly computed for only AABIA and used for three of them to have better comparisons and analysis.

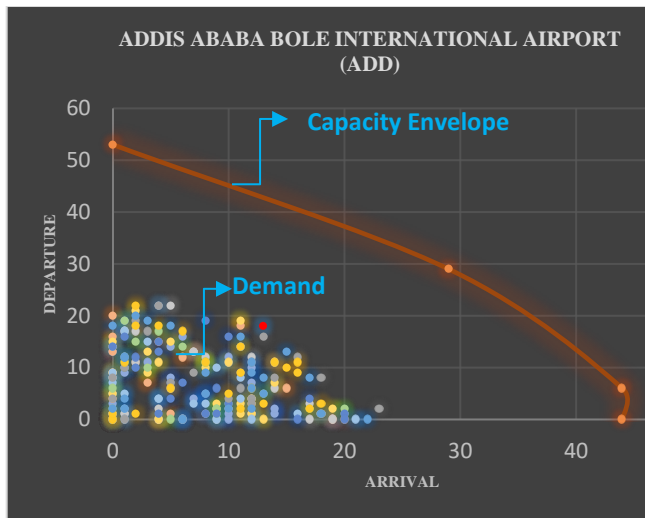


Figure 14 AABIA Hourly arrival vs departure demand scatter points and capacity envelop line

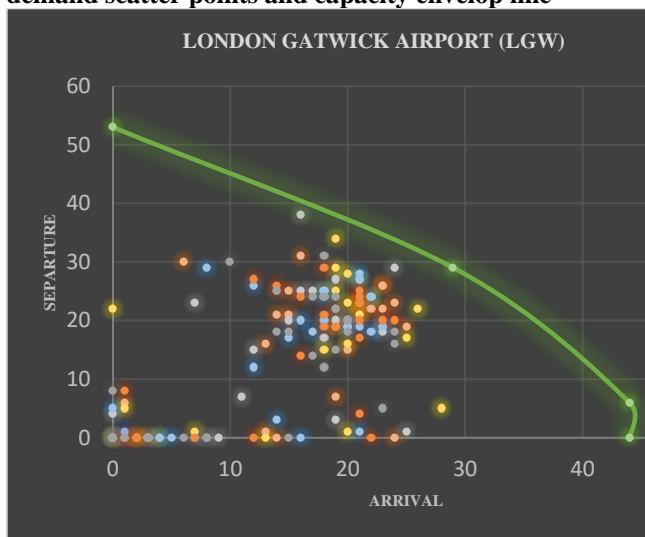


Figure 15 London Gatwick Airport arrival vs departure scatter points

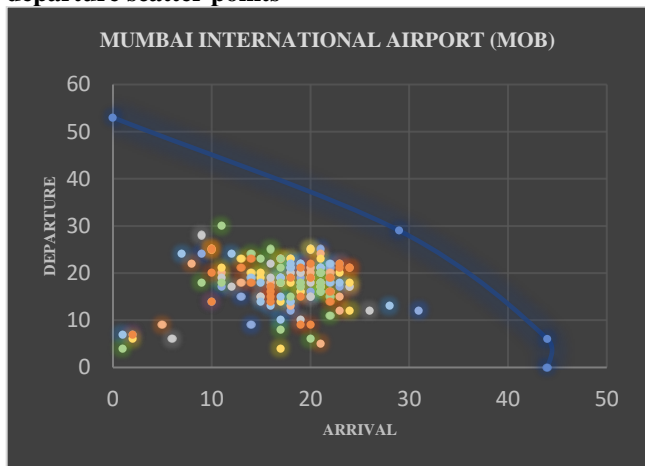


Figure 16 Mumbai Airport hourly arrival vs departure scatter points

From figure 14 graphs, it can be captured that AABIA aircraft operation capacity is higher than the demand. The difference between the capacity and the demand is also higher than in the other airports. The scatter points showing the hourly departure vs arrival, are far below the capacity envelop line. The points are also sparsely scattered showing no correlation between the arrival and departure. The scattering behavior with no correlation indicates that the flight operation schedules are not optimized rather they are random and having huge differences of number of operations from hour to hour. From 0 up to 32 operations per hour.

While London Gatwick and Mumbai Airports scattered points populated close to the maximum capacity envelop and also are not sparsely populated rather condensed around certain region of the graph where optimized number of operations achieved. In fact in case of London Gatwick there are some operations having smaller number of operation during certain period of the night due to the environmental rule and probably other social laws. Whereas Mumbai airport does not have smaller number of hourly operation as work almost all hour of the day except between 3 AM and 4 AM where they have smaller number of operations relative to the other hours of the day.

From the graphs, it can be captured that AABIA aircraft operation capacity is higher than the demand. The difference between the capacity and the demand is also higher than in the other airports. The scattering pattern clearly shows that the arrival-departure correlation for the other two airports is more than AABIA and the demand for the other two airports is closer to the capacity envelope as well. More demand can be accommodated given that the other facilities of the airport such as the terminal, the Apron, and ATC operations services sufficient enough to accommodate a similar future increase of demand.

The clustered Column graph for hourly operation against the time of the day with their respective frequency vs hourly operation probability distribution graph for the three airports is shown below

Graphs and charts (Probability distribution of hourly operations)

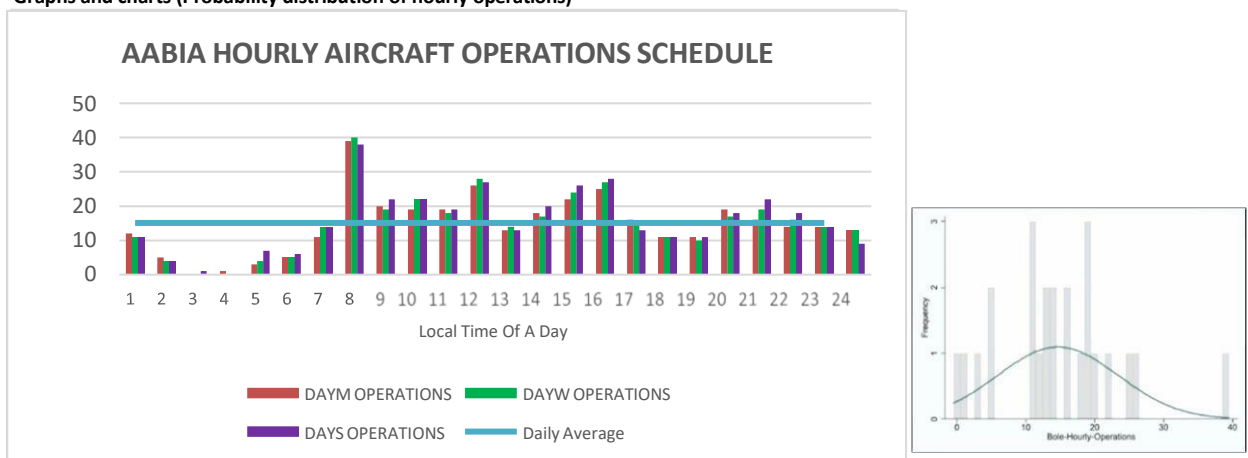


Figure 17 AABIA Hourly aircraft operation demand schedule

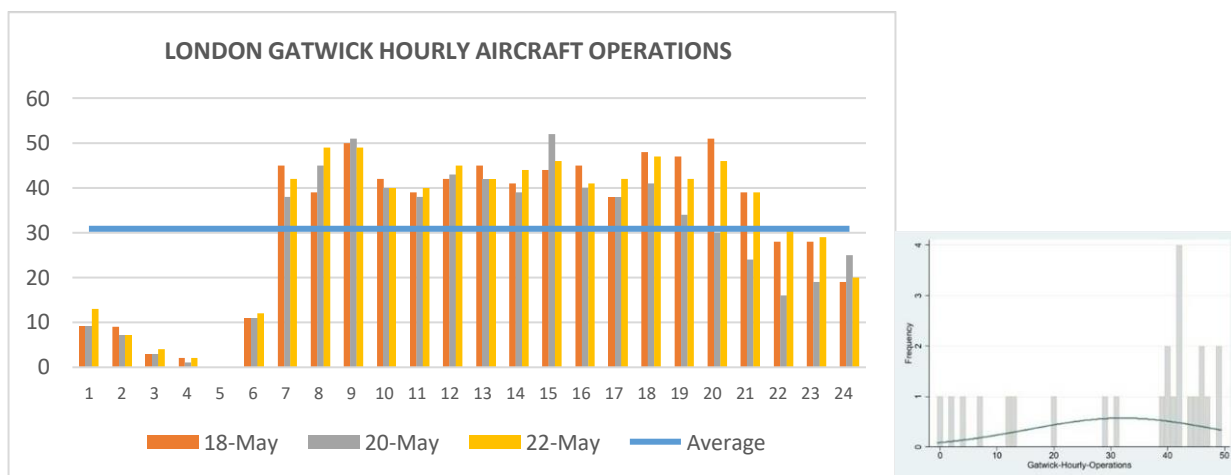


Figure 18 London Gatwick Airport Hourly Operations

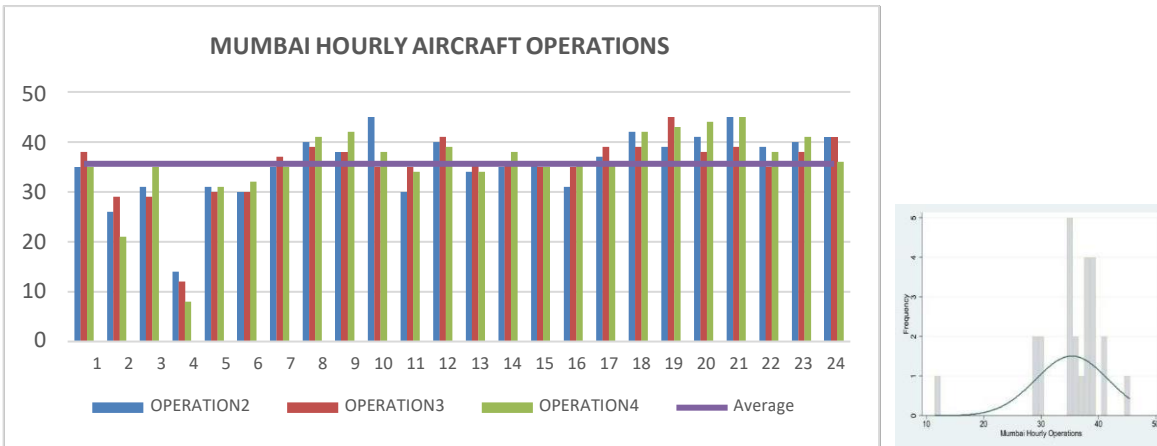


Figure 19 Mumbai Airport hourly operations

The following basic phenomenon have been observed:

- The AABIA hourly arrival and departure pattern of one day is very similar to the other random days more than the other two airports
- The hourly fluctuation or variation of the number of operations is higher for AABIA
- Most of the hourly operations are between 10 and 20 operations per hour while the other two airports are 35 to 40 operations per hour for Mumbai and 40 to 50 operations per hour for London Gatwick
- AABIA the hourly operation has left skewed kurtosis while the other two have right hand skewed Kurtosis

As the box plot graph below shown in figure 20 excludes the outliers, it depicts the nature of the operation in a better way. Accordingly, further observations are made

- Mumbai's hourly operation is more consistent than the other two. The majority of operations are between 35 and 40 operations per hour for Mumbai while between 15 and 44 for London Gatwick and between 9 and 19 for Bole airport.
- The whole operations excluding the outliers, Mumbai still has more consistency of hourly operation than the two.
- Taking the focus of the study into account, it is observed that AABIA demand is far below the other two airports.

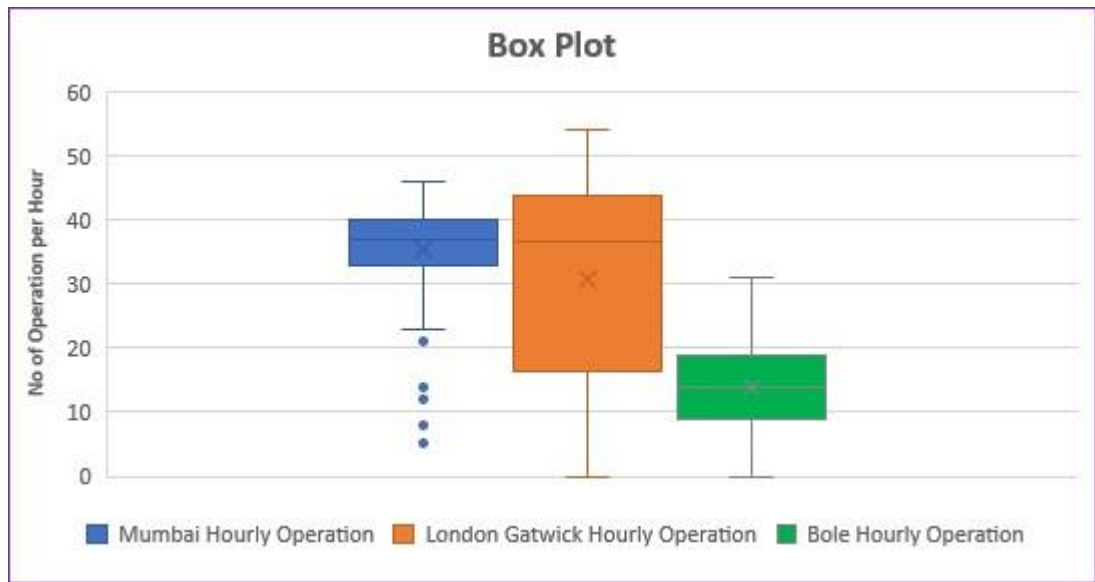


Figure 20 Box plot of Hourly operations for three airport having similar runway system

For the case of comparison and assessment of the three airport such as AABIA, GATWICK and MOB, the same one day data have been taken and comparing using delay and departure runway occupancy time as follows.

In terms of departure runway occupancy time, the average departure of runway occupancy time of AABIA, GATWICK and MOB are 91.38, 74.7 and 77.65 sec respectively. Moreover, significant portion of the aircraft for Bole occupy the runway more than the average 91.38 second up to 240 Second while the other two airports do not have any departure occupying more than 100 sec as such. This implies that, both GATWICK and MOB airport the occupancy time is critically important for mitigation of delays and congestion unlike AABIA where the runway occupancy time has little effect on mitigation of delays as the demand is much lower than the capacity of the runway.

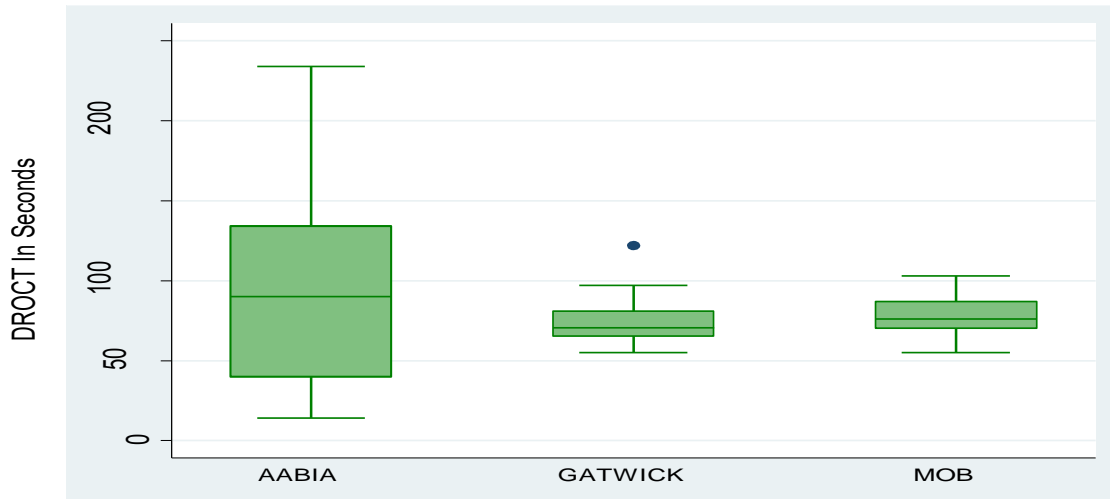


Figure 21 Box plot for Departure Runway Occupancy Time (Sec) for similar runway systems

4.3. The Effect of runway occupancy time on the delay of flight at AABIA

4.3.1 Descriptive statistics

The detail of the data used for the modeling of delay of departure have been showed as follow below.

Table 10 Summary of quantitative Variables data

Variable	Minimum	Maximum	Average
Variable	Minimum	Maximum	Average
Delay (minute)	0	118	26.72
DROT (sec)	40	586	93.16
Arrival/hr.	0	27	6.63
Departure/hr.	0	28	12.61

Table 11 Summary of Weight Category Data

Weight *1000Kg	Coding	Number of Aircraft
W1 = 28	1	62
W2 = 29	2	127
W3 = 70	3	22
W4 = 78	4	63
W5 = 85	5	18
W6 = 228	6	58
W7 = 243	7	1
W8 = 254	8	15
W9 = 283	9	25
W10 = 354	10	46

Table 12 Summary of Nominal Variable Data

Variable	Nominal Symbol	Code	Number of aircraft Sampled
International Flight	I	1	300
National Flight	N	0	133
Day Time Flight	D	0	275
Night Time Flight	N	1	158

4.3.2 Identifying multicollinearity among independent and dependent variable.

Multicollinearity is the main problem of modeling since redundant variables sharing the same information will appear in the model causing the model to Show biased information. To avoid such type of problem, multicollinearity analysis have been conducted using Pearson correlation coefficient as follows.

Table 13 Multicollinearity analysis result

Correlations								
Variables		Delay	DROT	Arrival/hr.	Departure/hr.	weight	I/N	D/N
Delay	Pearson Correlation	1	.178**	-0.034	-0.032	0.016	0.088	-.113*
	Sig. (2-tailed)		0.000	0.503	0.529	0.756	0.083	0.026
DROT	Pearson Correlation	.178**	1	-.118*	0.042	.203**	.132**	-0.045
	Sig. (2-tailed)	0.000		0.020	0.410	0.000	0.010	0.381
Arrival/hr.	Pearson Correlation	-0.034	-.118*	1	0.015	-0.008	-0.069	.154**
	Sig. (2-tailed)	0.503	0.020		0.768	0.871	0.174	0.002
Departure/hr.	Pearson Correlation	-0.032	0.042	0.015	1	-.126*	-.181**	.268**
	Sig. (2-tailed)	0.529	0.410	0.768		0.013	0.000	0.000
weight	Pearson Correlation	0.016	.203**	-0.008	-.126*	1	.400**	-.275**
	Sig. (2-tailed)	0.756	0.000	0.871	0.013		0.000	0.000
I/N	Pearson Correlation	0.088	.132**	-0.069	-.181**	.400**	1	-.402**
	Sig. (2-tailed)	0.083	0.010	0.174	0.000	0.000		0.000
D/N	Pearson Correlation	-.113*	-0.045	.154**	.268**	-.275**	-.402**	1
	Sig. (2-tailed)	0.026	0.381	0.002	0.000	0.000	0.000	

4.3.3 Multiple Linear Regression Analysis

In this model, the dependent variable is departure delay, whereas the independent variable are departure runway occupancy time, hourly arrival rate, hourly departure rate, weight of aircraft, type of flight such as national flight or international flight, day time flight or night time flight.

The normality of the dependent variable which is delay is a continuous data having the distribution histogram of the data is shown in the graph below. From the graph it is identified that the distribution graph is normal.

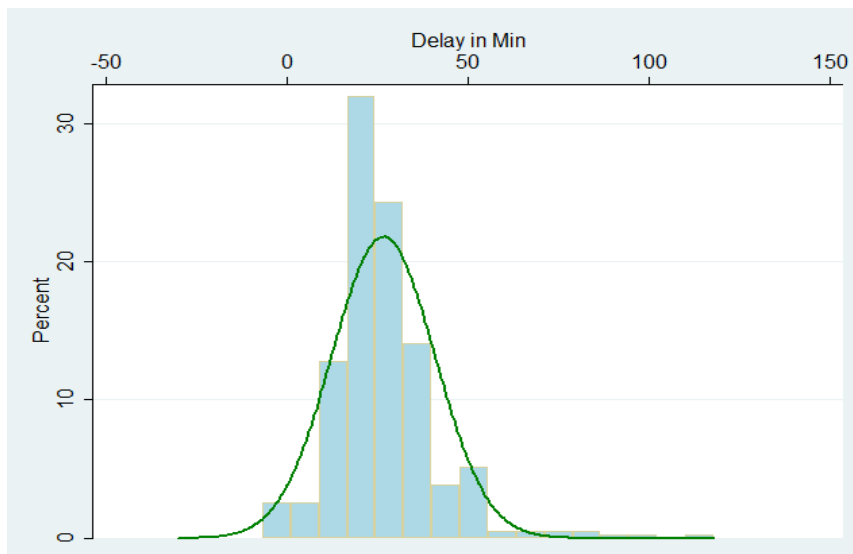


Figure 22 The histogram delays distribution graph

The summary result of the model has been showed in the tables below.

4.3.3.1 Significance of the model

The significant importance of the model have been checked by using ANOVA analysis with $p(df=6, F=3.048)=0.006$ which is less than 0.05 at 95% confidence level showing the model is good.

Table 14 ANOVA result

ANOVA result					
Model		df	Mean Square	F	Sig.
	Regression	6	584.317	3.048	0.006
	Residual	375	191.686		
	Total	381			

Table 15 Linear regression table

model	Variables	Std. Error	Beta	t	Sig.
Delay	(Constant)	2.716	24.452	9.003	0
	DROT	0.014	0.182	3.484	0.001
	Arrival/hr.	0.103	0.014	0.266	0.79
	Departure/hr.	0.11	0	0.009	0.993
	weight	0.267	-0.082	-1.457	0.146
	I/N	1.754	0.051	0.868	0.386
	D/N	1.686	-0.103	-1.796	0.073

Based on the result of analysis, the model shows that those factors initially assumed to be related to the departure delay does not have almost any relevance, since the degree of determination(R^2) is very low which is 3.1% as compared to the null model without any predictor. The only predictor variable in the model is departure runway occupancy time with coefficient of 0.182. This indicates that the main cause of the delay of departure is not on the system of runway. Which also prove that the runway system contribution to the departure delay is insignificant. Which means in another term that there is almost no delay caused by the runway capacity limit. In fact, during track record data assessment, it was observed that at the east side of the taxiway system noticed to cause long time taxing for both departing from east to west and for arrival from west to east due to some interruption probably maintenance work during sometime beginning of 2024.

From the interview data taken, the causes for the delays at the terminal gate system could be connection flight delay, security, ground operation, baggage loading, catering arrangements, weather, mechanical problems etc which are of course beyond this research scope to provide accurate figures. No significant traffic congestion or traffic queuing on the runway system, taxiway and even on the apron area were observed during live ground traffic movement assessment. From the historic data, the actual arrival and departure operations per hour are not significant enough to cause congestion in the runway system compared to the capacity of the runway system of AABIA.

4.4 Capacity Enhancement

Further study was undertaken for AABIA airport in comparison to the other airports. The Runway Occupancy Time for arrival and departure was also assessed. Higher time of Runway Occupancy time was recorded in AABIA as compared with the other airports and global standards. Even if

AABIA runway occupancy time is higher than other airports, it has no effect on the capacity of runway since the actual demand is smaller as compared to its capacity.

However, in the future the demand of flight from or to AABIA speculated to increase since the airport is the hub with increasing demand of passengers. Therefore, step by step capacity enhancement is needed to avoid excessive delays. From the historic data the first phase of enhancement could be the scheduling trend. As compared to the other high demand capacity airports, the hourly operations consistence is very low and the arrival and departure graph is highly scattered having a very low correlation. As the demand increases the variation of the hourly operation should reduce and the demand and departure balance could be rearranged better. From technical interview it was also observed that technological improved ATC system also could be the next phase of enhancement to improve the flight control communication system and efficiency. Moreover, a well-organized ATC system is also enhancing the capacity in such a way that the minimum separation rule is optimized, efficient and well controlled rapid taxi exit utilization is set. An efficient aircraft movement in general enhance the actual capacity of the runway system.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A thorough examination of air traffic patterns at AABIA during peak hours is crucial for implementing proactive measures in the event of a potential imbalance between demand and capacity. Reactive measures to enhance capacity are equally vital if such an imbalance exists. This study, conducted with meticulous attention to detailed data provided by third-party, and informed by interviews with aviation and airline personnel, serves as the foundation for determining whether AABIA's runway system can adequately accommodate current aircraft operations and if the runway system have an impact on the departure delay seen in the airport. The findings reveal that the current runway capacity can sufficiently meet the current demand. Despite the capacity of the runway system exceeding demand during peak hours, the study indicates that the average runway occupancy time is higher than compared to global standards practices and as well compared to similar hub airports such as London Gatwick Airport which is a busy airport which has a similar runway system and handles a mix of Heavy and Medium aircraft similar to AABIA. Based on the result of linear regression, the runway Occupancy time (RWOT) is found to have significant effect on the delay. However, it is seen that the model explains only 3.1% of the variation in the delay showing a need to look for variables that explain the delay better.

As Compared to London Gatwick and Mumbai Airport the following four basic specific aircraft movements of AABIA are observed which can contribute to longer Runway Occupancy Time

- During departure time, the time between crossing holding stop (ATC line-up clearance) to the start of take-off time (TOFT)
- Time between arriving touch down and the line-up clearance for departing aircraft waiting for departure.
- Time between crossing the threshold and vacating of the runway for arriving aircraft. Here, the arriving aircraft mostly exit through random taxi exits. Significant number of aircraft even use the last exit that is used for departure line-up entrance after passing the two rapid exit. It was observed this is happening due to the ATC controller does not command the exit type unlike other busier international airports.

- The separation distance or time between two arriving or departing aircraft is almost all the time higher than the IACO separation rules.
- Based on the result of linear regression, arrival and departure per hour could not be found significant effect on the delay of departure. Therefore, the main case of delay is airport management service such as checking and ticketing since the delay is maximum as compared to London Gatwick Airport.

Generally, it is learned that the above factors may not affect the overall aircraft movement at the current demand condition. However, as the demand increases and approaches the theoretical capacity, those factors are critically important such that proactive measures in improving those factors will enhance the operation standard and make it eligible for higher demand operations which could happen sooner or later and make it eligible for higher demand operations which could happen sooner or later.

5.2 Recommendation

It can also be deduced from our observation and similar researches that airport customer services detail processes at check-in counter, at security check up and at airport gate, aircraft ground operations on apron and taxi operation and Air traffic control system are area to do detailed studies to identify the factors for the delay of the airport.

Hence, in order for AABIA runway system to operate to its capacity and with minimized delay, there is a need for these elements to operate efficiently. Hence this research recommends to further studies on those aspects of the airport.

5.3 Future research directions

Based on the research undertaken the following key areas need to be looked for further research

- The effect of terminal operations on departure and arrival delay of AABIA
- Delay relations with taxiway and apron geometric characteristics
- The effect of Air-control system on delay of AABIA

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