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Improving Safe Approach and Landing System in Tribhuvan International Airport

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This study was done in order to improve safe landing procedure for approaching aircrafts at Tribhuvan International Airport; the nation's only international airport located in Kathmandu, Nepal. The airport sits in a narrow valley 1,338 meters above sea level, resulting in numerous accidents each year. The author of the thesis had himself flown in and out of the airport many times and analyzed the situation of the airport and its safety importance. The aim of the study was to find appropriate modern navigation system for Tribhuvan International Airport in order to improve airport performance and save the life of travelling passengers.

This report was a result of qualitative research using case study approach where information was collected through airport officials, newspaper reporter and analyzing of secondary data. The secondary data was collected from the published material of related authority, airport office and web pages. Research was carried out for finding the ways of improving landing performance of Tribhuvan International Airport. Three different types of modern navigation systems were introduced, compared and analyzed.

The result obtained from the research showed one proper modern navigation system for Tribhuvan International Airport. The study creates a good foundation for further research into improving safe approach and landing at the airport. The information would be useful for engineers setting up navigation systems at the airport in near future as well.

Keywords	Tribhuvan International Airport, Safety, Runway, Approach, Aircraft, Navigation

Contents

List of Abbreviations

CAAN	Civil Aviation Authority of Nepal
TIA	Tribhuvan International Airport
SSC	Significant Safety Concern
ICAO	International Civil Aviation Organization
KTM	Kathmandu
ATS	Air Traffic Service
FIR	Flight Information Region
VHF	Very High Frequency
DME	Distance Measuring Equipment
VOR	VHF Omnidirectional Range
NDB	Non-Directional Beacon
RNP	Required Navigation Performance
RNAV	aRea NAVigation
ATC	Air Traffic Controller
CIAA	Commission for the Investigation of Abuse of Authority
NAC	Nepal Airlines Corporation
ILS	Instrument Landing System
LPDME	Low Power Distance Measuring Equipment

RVR	Runway Visual Range
DH	Decision Height
UHF	Ultra High Frequency
FAA	Federal Aviation Administration
GBAS	Ground-Based Augmentation System
SBAS	Satellite-Based Augmentation System
NSP	Navigation System Panel
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GLONASS	Global Orbiting Navigation Satellite System
WAAS	Wide Area Augmentation System
GAGAN	GPS-aided GEO Augmented Navigation
MSAS	Multi-functional Satellite Augmentation System
SDCM	System for Differential Correction and Monitoring
EGNOS	European Geostationary Navigation Overlay Service
LVP	Low Visibility Procedures

1 Introduction

Safety is an essential perspective with regards to aeronautics industry. The primary target of executing safety instruments and controls in an airport is to secure travelers going back and forth through the air terminal and additionally to guarantee the security of individuals on the ground and encompassing condition too. There are numerous air terminals and aviation parts far and wide which are not ready to convey enough security to the general population. One of them is Nepal's flying segment. The country's aviation sector was recorded on the "Significant Safety Concern" (SSC) in July 2013 as indicated by International Civil Aviation Organization (ICAO). Later, the aviation sector was removed from ICAO air safety list in 2018. Moreover, as per the report issued by European Commission on 30 November 2017, none of the Nepali Airline organizations are permitted to fly in the skies of major European Countries [1]. Tribhuvan International Airport (TIA) aviation safety problem has perplexed Nepal government for many years. Although, the airport has gone through slow state of evolution throughout the years, it still lacks modern technical innovation when it comes to approach and landing. Thus, this project aims to improve the safety of Nepalese aviation based on the safe approach and landing of aircraft in Nepal’s only international airport.

The first objective of this report is to study the current situation of TIA which will cover the available infrastructures, incidents and issues regarding the renovation of the airport. The second objective is to find proper navigation system for TIA in terms of budget, terrain limitation and available resources.

Most of the information was obtained from articles published by related authority and web pages. Bibek Dubey, working as a junior technician for Yeti Airlines at TIA and Sangam Prasain, a newspaper reporter for Kathmandu Post helped to provide necessary information about the current situation of the airport via email.

This thesis covers different types of modern navigation systems used across the globe. The operating principle of different systems are described in detail, as well as their installation notes and budget. Finally, the proposed solution for Tribhuvan International Airport and the conclusion of this project are presented.

2 Tribhuvan International Airport

The Tribhuvan International Airport (TIA) is situated at the heart of Kathmandu Valley. It is located 5.5 km east of Kathmandu City Centre and in touching distance with other two ancient districts of Nepal; Bhaktapur and Lalitpur. Originally named Gaucharan Airport, it has served as an airfield since 1949, and was inaugurated and retitled Tribhuvan Airport in 1955 by King Mahendra in remembrance of his father King Tribhuvan. In 1964, the airport was entitled Tribhuvan International Airport. Later, the TIA complex was completed in 1990 and was unveiled by King Birendra. Additionally, Civil Aviation Authority of Nepal (CAAN) was founded in December 1998 under Civil Aviation Act. with the aspiration of giving wellbeing and security to TIA and other aeronautics areas of Nepal. Nepal entered in the field of aviation when a single engine aircraft Beechcraft Bonanza landed in Kathmandu in 1949 carrying the Indian Ambassador. Following, on February 1950, the first charter flight was operated connecting Kathmandu with Calcutta. Lufthansa Boeing 707 was the first jet aircraft to land at TIA in 1967. [2]

At present, TIA has one international and one domestic terminal. The international apron has nine parking sections out of which four sections can accommodate wide-body aircraft and the remaining five can adjust narrow-body aircrafts. On the other hand, domestic apron has space for 17 small aircrafts. In addition to that, there are 13 helipads within the airport. Furthermore, there is a Cargo Handling Department near the international terminal [2]. Figure 1 shows the aerial image of TIA.

Figure 1. Aerial Image of TIA displaying runway and terminal buildings [3]

Currently, around 29 international airlines and 3 TIA based airlines (Nepal airlines, Buddha Airlines and Himalayan airlines) connect Kathmandu to other parts of the world (mainly Asia and Middle East). As many Nepalese people work in countries like Qatar, United Arab Emirates, Malaysia and Saudi Arabia, most of the flights are being operated to and from TIA to these nations. Domestic flights are functioned by Buddha Air, Yeti Airlines, Nepal Airlines and other small airlines to other cities of Nepal. Tourists can also go to mountain sight-seeing flights operated by domestic airlines and helicopter operators. [2]

Other general information of TIA is presented in Table 1.

Table 1. General Information of TIA [4]

Location	Kathmandu, Nepal	Variation	0.53°E (0.05° annual change)
ICAO ID/ IATA	VNKT/ KTM	Type	Civil, International
Latitude	27° 41’ 47.70” N	Datum	WGS 1984
Longitude	085° 21’ 32.76” E	Time Zone	UTC +5:45
Elevation	4390 ft. (1338 m)	Opening hours	6:00 AM to 12:30 AM

2.1 Flights and Passengers Statistics

2.1.1 International Statistics

As per TIA statistics, global air traveler activity kept on average twofold digit development in 2017, enrolling a 10.74 percent expansion over the earlier. Record 3.88 million travelers went through TIA in 2017. International air traveler activity through TIA dove 8.37 percent to a 13-year low of 3.21 million in 2015, as explorers remained away because of the April earthquake. Be that as it may, in 2016, traveler movement swelled

9.12 percent to 3.51 million. A breakdown via aircrafts exhibits that Indian Jet Airways completed the summary of transporters with the most lifted number of passengers. It flew 469,301 people, up 40.43 percent year-on-year. Nepal Airlines slipped to second position with its explorer carriage advancement accomplishing a little 1.04 percent after the carrier put one of its two Boeing 757s available to be purchased a year back. It flew 388,329 passengers in the midst of the review time period. Qatar Airways saw its customer numbers drop 9.90 percent to 307,923 individuals. Air Arabia slipped to fifth with a negative passenger advancement of 15.44 percent. The bearer flew 287,617 travelers in 2017. India's standard transporter Air India saw a 13.81 percent advancement in passenger carriage to 208,367. Dubai-based insignificant exertion transporter Fly Dubai also watched a negative 9.16 percent advancement as it got 293,083 flyers. Himalaya Airlines bounced to the seventh spot recording a strong 421.58 percent passenger improvement a year back. It flew 179,893 explorers. China Southern recorded a strong 186.55 percent improvement pulling in 126,036 flyers. Also, Thai Airways saw its traveler carriage grow 1.01 percent to 170,365. Malaysian-based simplicity bearer Malindo posted a strong improvement of 92.90 percent. It flew 162,620 explorers every year prior. Regardless, another insignificant exertion transporter Air Asia saw its voyager numbers plunge 42.55 percent to 97,991 per year back, as per TIA estimations. [5]

As indicated by TIA, 29 aircrafts including three Nepali airlines made 33,362 flights in 2017, recording a 23 percent rise. This implies 91 universal flights by and large took off and arrived at TIA. In 2016, there were 75 departures and arrivals every day. Most of the international aircrafts flying to and from Nepal comprises B772, B752, B738, MD83, ATR72, A310, A319, A320 and A332. [5]

2.1.2 Domestic Statistics

Domestic airlines saw development of a record 2.45 million travelers in 2017, as explorers flew instead of using bone-shaking national highways. The quantity of air passengers recorded in 2017 is 693,794 more than in 2016, as per Tribhuvan International Airport (TIA). The figure incorporates 40,349 travelers flown by helicopter organizations and single-engine air ship. [6]

Buddha Air stood out in development of travelers in 2017. Buddha recorded 25.44 percent development in traveler in 2017, flying 1.26 million travelers — the most elevated number so far by an individual aircraft in Nepal's flight industry. Buddha's opponent, Yeti Airlines saw its traveler number develop by 35.73 percent to 554,745 in 2017.Tara Air, which just works on rural parts, in any case, watched a decay of 7.48 percent in traveler development. It flew 65,301 travelers in 2017. Saurya Airlines, which began its operation in November 2014, conveyed 182,014 travelers, up 101.77 percent. Nepal's biggest helicopter administrator Shree Airlines in April 2017, flew 115,600 travelers. In like manner, Nepal Airlines saw its traveler number bounce 97.63 percent to 95,100. Simrik Airlines and Summit Air likewise observed traveler development in 2017, with Simrik flying 65,322 travelers, up 33.61 percent, and Summit shipping 42,498 travelers, up 31.10 percent. Travelers flying Sita Air grew 11.96 percent to 21,640. Domestic aircraft fleet includes MI17, MI18, ATR72, ATR42, D228, DHC6, BA46, BO6, AL03, J41, B1900, Cessna, Pilatus and microlights. [6]

2.2 Infrastructures Details

2.2.1 Airport Runway

There is only one runway in TIA oriented 02/20. All the domestic and international flights are operated in this sole runway. The grass runway of TIA was paved with concrete in 1957. Approach and Runway Lights are available. [2] Table 2 below shows the information of only runway of TIA.

Table 2. Runway Information of TIA [4]

Orientation	Runway Dimensions	Surface	ILS	PCN
02/20	3050m*46m /150ft	Asphalt	No	054FAWT

Furthermore, not much of renovation has been carried out in the runway since it was paved. The runway has developed a number of cracks near the southern end between Delta and Echo marking, precisely in the area 1,600 meters north from the southern end, where the airplanes touch down while landing. Murari Bhandari, a civil engineer at TIA informed that the runway at the airport has been hazardous since 2013, the time when TIA expanded its services to a considerable number of domestic and international flights. A study report from the Ayesa Ingenieria Arquitectura of Spain and Aeroports De Paris Ingenierie of France has already revealed that the runway is not enough to handle wide-body aircraft due to its ageing asphalt foundation. Therefore, aircraft weighing more than 196 tons are not allowed to land in the six-decade old runway. While cracks and uneven surfaces can cause risky departures and arrivals, aircraft authorities have been confronting hours-long postpones pretty much consistently amid the rainy season, baffling travelers and causing monetary misery among carriers. Huge number of flights have been redirected or postponed as of late because of issues in the runway. Inconvenience for the most part happens in the rainy season. In monsoon 2018 only, the runway had created cracks more than 20 times. [7]

2.2.2 Airspace and Route Structure

Due to Nepal's topographical feature, covered with hills and mountains, it has been very difficult throughout the years to design airspace and air route efficiently. Limited airspace and increasing traffic has made TIA congested both in the air and on the ground. [8]

According to CAAN report; there are two different airspace classes in Nepal; Class C Airspace (Within Controlled Airspace) and Class G Airspace (Outside Controlled Airspace). Moreover, Kathmandu FIR is divided into two sectors divided by 83° longitude. There are 2 terminal maneuvering area and 8 Control Zones within Kathmandu FIR. [8]

These are following International ATS routes to and from Kathmandu FIR: [8]

L626: Kathmandu-**NARAN-PALPA-SUKET-MAHEN-ONISA**-Delhi

B345: Lhasa-**NONIM-TUMLI-KTM-NARAN-BWA**-Lucknow

G335: Kathmandu-**LNC-LALBA-SEETA-JALES**-Patna

R325: Kathmandu-**LNC-LALBA-SEETA-JANAK**-Patna

G348: Kathmandu-**KIMTI-TUMLI-MECHI-BBD**-Paro

G336: Patna-**BIRGA-SMR-**Kathmandu

G590: Varanasi-**OMIPA-SMR**

G598: Lucknow-**APIPU-PARSA-SMR**

R581/G463: MONDA-IPLAS-**GAURA-ROMEO-SMR**

2.2.3 Communication, Navigation and Other Infrastructures Available

Recently, new VHF Remote Control Air Ground system has been installed in Phulchowki (near Kathmandu) and Nepalgunj airport to increase VHF coverage round the country. The table 3 shows the communication frequencies and navigation aids for approaching aircraft. [8]

Table 3. Navigation aids for Approaching Aircraft towards TIA [4]

Type	ID	Name	Channel	Frequency	Distance from field	Bearing from Navaid
VOR-DME	KTM	KATHMANDU	070X	112.3	1.4NM	021.9
NDB	LNC	NALINCHOWK	-	252	6.3NM	296.1

According to ICAO; In Nepal NDB, VOR/DME and other ground-based radio navigation aids are provided by ground facilities to enhance flights safety and accessibility far and wide. VOR/DME is a combined radio navigation station which consists of two radio beacons, a VHF omnidirectional range (VOR) and distance measuring equipment (DME). They provide the two measurements needed to produce a navigational fix. This navigating technique is one of the oldest innovation in aviation industry. It was first introduced in 1950. [8] Figure 2 shows the VOR DME approach chart for aircrafts approaching TIA.

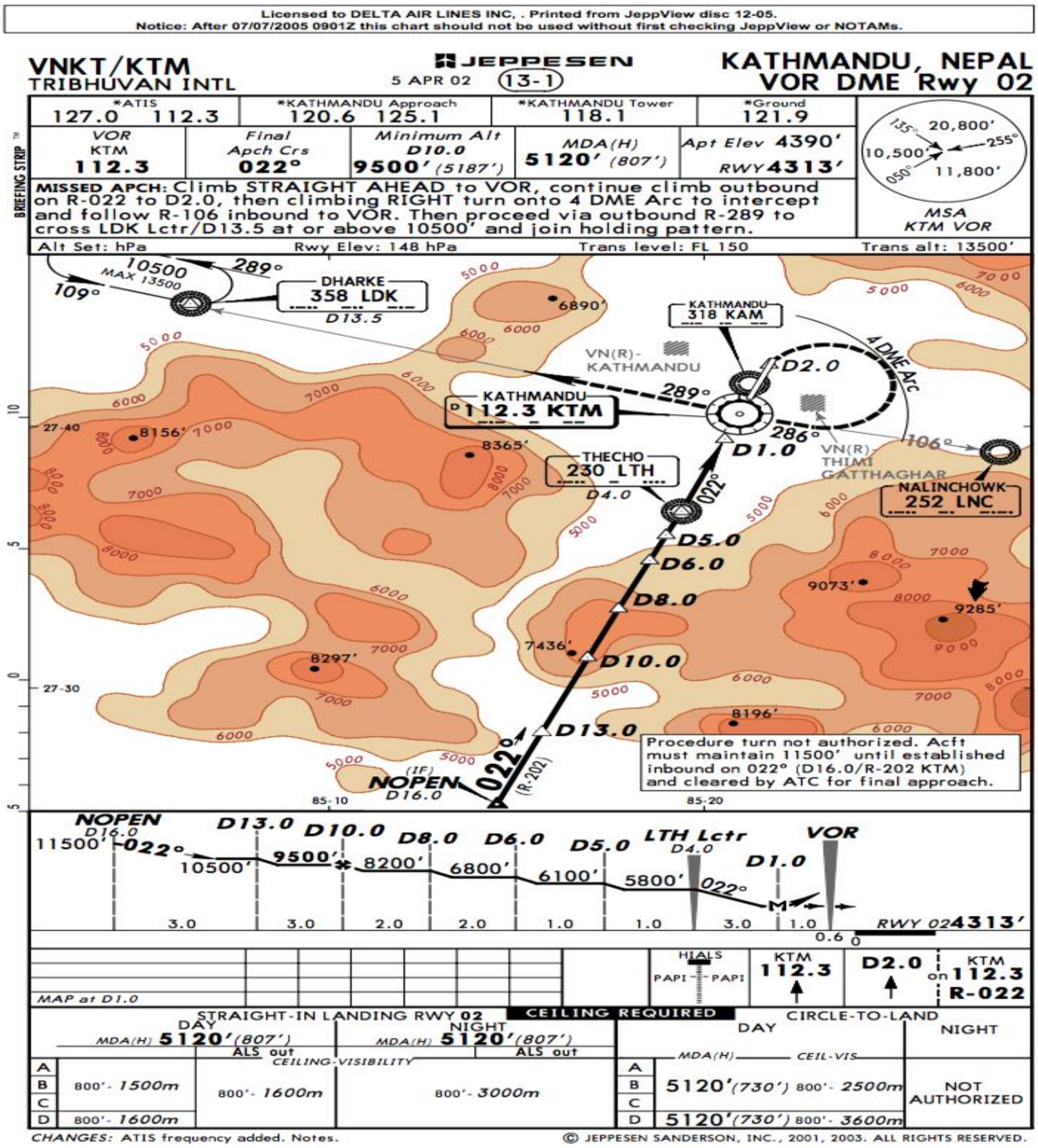

Figure 2. VOR DME Approach chart for aircrafts approaching TIA [9]

In addition to that, after the 36th session of ICAO assembly, Nepal government and TIA officials were forced to implement RNAV and RNP operations enroute to TIA as the assembly asked all the contracting state should implement vertical guidance for all instrument ends, either as primary approach or as a back-up. The project started in 2010 and most of the work has been completed. Thus, in order to land in TIA, the approaching airlines and flight crew should have RNAV authorization as TIA is one of the most difficult international airports to land on. [8] Figure 3 shows the RNAV approach chart for aircrafts approaching TIA.

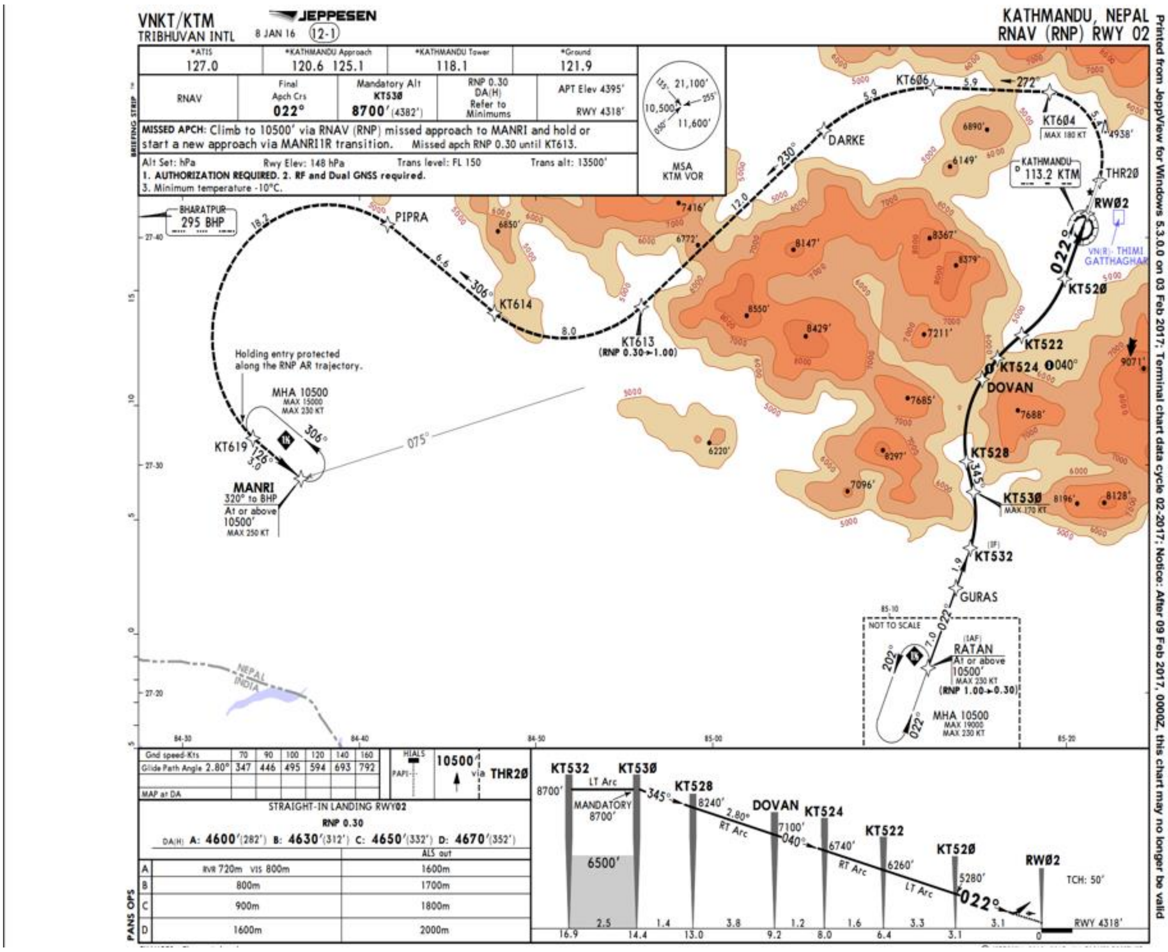

Figure 3. RNAV approach chart for aircraft approaching TIA [10]

Only few airlines are authorized to land on TIA using RNAV/RNP approach. Despite, using RNAV approach, Turkish airlines missed the runway and crashed in 2015. Furthermore, hundreds of international and domestic flights are still cancelled or delayed during bad weather. Hence, for the proper scheduling of flight round the year in any given weather, a proper modern approach and navigation system is required in TIA. Table 4 shows other infrastructures available in TIA.

Table 4. Ground Infrastructures available at TIA [11]

Customs	YES	JET A-1 fuel	YES
Immigration	YES	AVGAS 100	NO
Passenger Terminal	YES	Single point refueling	YES
Cargo Terminal	YES	Control Tower	YES
Pax transport	YES	Weather Facilities	YES
Ground handling services	YES	Airport Radar	YES
De-icing equipment	NO	Fire Fighting Facility (ICAO)	YES

2.3 Incidents

In a time where flight in numerous parts of the world is winding up even more secure, accidents in TIA keep on frequenting the headlines. Major accidents and incidents related to TIA throughout the years are listed below:

- 10 May 1972: A Thai Airways Douglas DC-8 overran the runway on arriving with 100 travelers and 10 crew members on board, there was one casualty. [2]

- 31 July 1992: A Thai Airways Airbus A310-304 crashed into a terrain while approaching TIA, all 113 people on board lost their life. [2]

- 28 September 1992: A Pakistan International Airlines Airbus A300 B4-203 crashed while approaching Kathmandu, all 167 passengers and crew members on board lost their life. [2]

- 17 January 1995: A Nepal Airlines DHC-6 Twin Otter 300 caught the airport perimeter fence during takeoff killing 1 passenger and 1 crew member on board. [2]

- 7 July 1999: A Lufthansa Cargo Airlines Boeing 727-200 crashed into terrain, five minutes after takeoff, killing all five crew members aboard. [2]

- 5 September 1999: A Necon Airlines HS 748 crashed into a communication tower of Nepal Telecom while approach, all 15 people aboard lost their life. [2]

- 26 December 1999: Indian Airlines Flight 814 enroute from Kathmandu to Delhi was hijacked. [2]

- 24 December 2008: A Nepal Airlines DHC- 6 Twin Otter 300 skidded off runway during takeoff. [2]

- 24 August 2010: An Agni Air Dornier Do 228 crashed into a hill in heavy rain after taking off from TIA towards Lukla. [2]

- 15 December 2010: A Tara Air DHC-6 Twin Otter 300 approaching TIA from Lamidanda lost signal and crashed east of Kathmandu killing all people aboard. Most of them were Bhutanese tourists. [2]

- 25 September 2011: A Buddha Air Beechcraft 1900D struck terrain approaching TIA due to poor visibility. None of the passengers and crew members on board survived. [2]

- 28 September 2012: A Sita Air Dornier Do 228 crashed after take-off after hitting a vulture. 16 passengers and 3 crew members died in the crash. [2]

- 4 March 2015: A Turkish Airlines A330-300 crash landed after attempting to land in dense fog. All 227 passengers and 11 crew members were evacuated safely. [2]

- 12 March 2018: A Malindo Air Boeing 737-900ER overran a runway after a high speed rejected takeoff compelling the airport to close 12 hours until it was removed. No casualties. [2]

- 1 September 2018: A Yeti Airlines Jetstream 41 skidded off the runway while landing in TIA. None of the passengers and crew members were hurt. [2]

Thus, there had been 15 major accidents, resulting in a total of 410 deaths. An examination of causes of air crashes showed that most of the accidents were caused while approach and landing. Furthermore, ATC errors were also seen in these incidents as this could not be unexpected as increased traffic requires improvement in traffic management, technologies and understanding. Numerous accidents have been gone before by comparative occurrences and lives and property could have been saved if the issues, adding to those accidents had been addressed when they showed themselves. Hence, a proper modern approach and landing system may have saved the lives of those innocents to some extent, had it been installed before.

2.4 Problems and Challenges behind Airport Renovation

After a decade of civil war, from 1996 to 2006 and the abolition of monarchy, the political situation in Nepal is not yet stable. Due to the tensions between the main parties (the Congress Party, the Maoist Party and the Marxist-Leninist Party), there has been difficulty of establishing an effective coalition government. There is still not confidence between public, the administration and the Armed Forces. Consequently, social unrest, street demonstrations and strikes are frequent. Nepal is also a landlocked country, with limited resources and industrial sector apart from agriculture. Hence, the economy is fragile and not much is being invested in the proper renovation of TIA. In addition to the development of the airport, renovation work on many heritage sites of Nepal which were damaged in an earthquake in April 2015 are also stalled due to political infighting.

Another major problem is corruption. According to a report published by Aviation Nepal on February 2018, the Special Court has acquitted former Director General of CAAN, Er. Ratish Chandra Lal Suman including former CEO Prachandaman Shrestha in the bill of Corruption. Commission for Investigation of Abuse of Authority (CIAA) in April 2015 had filed a corruption case against 23 high-ranking government officials, including two sitting secretaries on the charge of embezzling 3.4 million dollars. Meanwhile, the CIAA has also started investigating into the alleged irregularities during the purchase of two wide-body aircraft by Nepal Airlines Corporation (NAC). [12]

3 Modern Navigation Systems

3.1 Ground-Based Navigation-Instrument Landing System (ILS)

An Instrument Landing System, previously named Lorenz Beam was invented by C. Lorenz AG company in 1929. An ILS helps pilots to land the aircraft using an instrument approach when the weather is bad and there is no visual contact with the runway. The first fully automatic landing using ILS occurred at Bedford Airport in 1964. ITU Radio Regulations defines ILS as “A radio navigation system which provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing” [13]. The ILS has been the foundation of landing course for well over 50 years. [14]

3.1.1 Operating Principle

The ILS consists of two main components: Localizer and Glide Slop Indicator. Figure 4. Shows typical ILS installation. The Localizer creates and transmits signs to give last approach route data to landing aircraft. It provides directional guidance along the extended center line of the runway. A frequency between 108.1 and 111.95 MHz is transmitted in the VHF band with odd first decimals only. The radio signal transmitted produces two overlapping lobes. For an approaching aircraft the lobe on the left-hand side and right-hand side is modulated by a 90 Hz tone and 150 Hz tone respectively. The receiver which is located to the left of center line detects more of 90 Hz modulation and less of 150 Hz and causes the vertical indicator needle in an aircraft to indicate that a correction to the right is necessary. Equally, a receiver right of the center line receives more 150 Hz modulation than 90 Hz and hence, the needle indicates that a correction to the left is necessary. When flying along the localizer center line, there will be no deflection of the needle, signifying that the aircraft is on a right path. [14]

Likewise, the Glide Slope sends an UHF carrier signal with 40 spot frequencies from 329.15 to 335 MHz. The signal is emitted in the vertical plane in two lobes similar to the localizer. The upper and lower lobe consists 90 Hz and 150 Hz modulation respectively. The line where the two modulations are equal in depth defines the center line of the glide path. The angle is generally 3° from the horizontal but could be adjusted between 2 to 7° according to local environment. The ideal flight path on an ILS approach is where the localizer and the glide slope planes intersect. The pilot follows the ILS cockpit indications to fly the glide path. [15]

An ILS precision approach and landing requires a few parts. For legitimately ILS-prepared air ship ensured for the classification of administration used, the ground-based ILS frameworks are the electronic handling and antenna components. The runway requires proper approach lights and markings alongside a methodology lighting framework. Different parts might be required, for example, Runway Visual Range (RVR) and Marker Beacons or LPDME. Marker beacons deliver accurate range fixes along the horizontal plane. All marker beacons transmit 75 MHz frequency. A VOR or a low-powered NDB (locator) can be provided on most installations to assist in interception of the localizer and holding procedures. [14] Figure 4 shows the architecture of ILS.

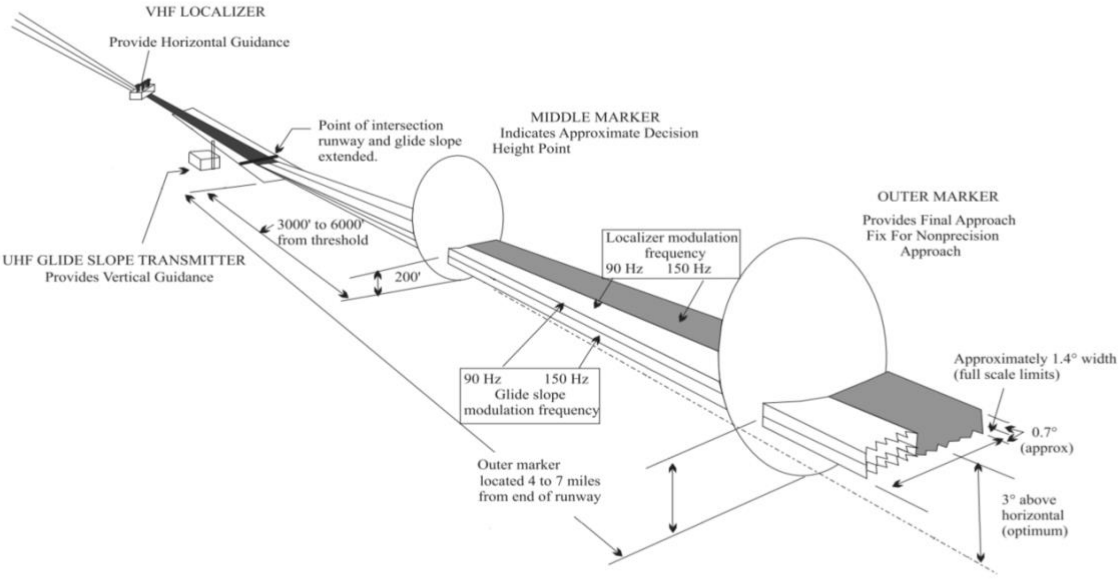

Figure 4. ILS Architecture [14]

When flying the ILS approach, the pilot descends with approach guidance to the Decision Height (DH), at which point he/she makes the final decision to land or go around. The precision approaches and landings are classified into three categories based on DH and RVR. The specification of each category is detailed below:

Category I (CAT I): Precision approaches with a DH higher than 60 meters (200 ft) and RVR more than 550 meters (1800 ft)

Category II (CAT II): Precision approaches with a DH between 30 and 60 meters (100-200 ft) and RVR more than 350 meters (1200 ft)

Category III (CAT IIIa, CAT IIIb, CAT IIIc): This navigation systems are designed for automatic landing during poor visibility (DH less than 30 meters). They are categorized into sub-classes based on the degree of fault tolerance of onboard guidance system and quality of ground equipment. [14]

3.1.2 Installation and Operational Notes

3.1.2.1 Localizer

The localizer antenna array is installed on the runway extended centerline at the opposite end to the approach end and should be at a distance (approx. 300 m) below the runway take-off obstruction clearance plane. The mostly used are the bidirectional log-periodic dipole arrays that produce a back course as well. The localizer width indicated by the needle on the aircraft cross pointer indicator from full deflection in 150 Hz modulation to full deflection in 90 Hz modulation should be normally 5° for uncategorized systems and all other systems must be adjusted to 210 meters wide at the landing threshold. The localizer electronic equipment shelter building shall be located 100-200 meters to the side of the aerial and should be within 30° of the longitudinal axes of the array. [15]

The Series 2100 Instrument Landing System, developed by Selex ES, a Finmeccanica Company, in cooperation with FAA is certified for *Category I, II* and *III* operations in the most versatile and technically advanced system in the industry today. The localizer specification is shown in Figure 5. The equipment is designed to provide a usable on-course signal at a minimum distance of 25 nautical miles from the runway and at a minimum altitude of 2,000 ft above the threshold.

Dimensions - cabinet (W x D x H)	24" x 24" x 24" 61cm x 61cm x 61cm
Environmental	
Temperature	Indoor equipment: -10°C to +55°C Outdoor: -50°C to +70°C
Relative humidity	Indoor equipment up to 90% noncondensing. Outdoor equipment up to 100%
Altitude	0 to 4573m (0 to 15,000 ft) MSL.
Duty cycle	Continuous, unattended
Wind	Up to 100mph (161km/hr), with 0.5" (12.7mm) ice
Electrical	
Primary power	90-264V AC ±15%, 47-63Hz single phase
Standby power	24V DC no-break battery back-up system, minimum 6hr operation
Frequency stability	±0.0005%
Power output	20W maximum (adjustable)
Frequency range	108 - 111.975MHz
Frequency control	Synthesizer
Modulation tones	90/150HZ navigation, 1020Hz identification
Coverage	Per ICAO Annex 10
Monitors	Dual Parallel AND/OR configuration, monitors standby transmitter and built-in test generator for monitor certification
RMM	Comprehensive; includes alarms and maintenance alerts with automatic call out to any telephone number
Antennas	
Configurations	8, 14, 16 or 20 element antenna array with integral monitoring and optional near and far field monitoring

Figure 5. Localizer Specification [16]

3.1.2.2 Glide Slope Indicator

The glide path indicator is usually installed approximately 225-380 meters from the approach end and 120-210 meters to the side of the runway centerline. The selection of antenna arrays depends on the near-field and far-field terrain characteristics. The glide path width indicated by the needle on the aircraft cross pointer indicator from a full fly-up to fly down indication varies from 1.5° to 1°. In the event of failure or malfunction, the transmitters are duplicated, with an automatic change-over facility from primary to secondary equipment [15]. The Glide Slope specification is shown in Figure 6 developed by Selex ES.

Mechanical	
Weight - cabinet	193lbs (87.5kg)
Dimensions - cabinet (W x D x H)	24” x 24” x 24” 61cm x 61cm x 61cm
Environmental	
Temperature	Indoor equipment: -10 °C to +55 °C Outdoor: -50 °C to +70 °C
Relative humidity	Indoor equipment up to 95% noncondensing. Outdoor equipment up to 100%
Altitude	0 to 4573m (0 to 15,000 ft) MSL.
Duty cycle	Continuous, unattended
Wind	Up to 100mph (161km/hr)
Electrical	
Primary power	90-264V AC ±15%, 47-63Hz, single phase
Standby power	24V DC no-break battery back-up system, minimum 6 hr. operation
Frequency stability	±0.0005%
Power output	5W maximum (adjustable)
Frequency range	328.6 - 335.4MHz
Frequency control	Synthesizer
Modulation tones	90/150Hz navigation
Glide angle	2 to 4 degrees
Coverage	Per ICAO Annex 10
Equipment	BITE with fault diagnostics to LRU capable of being performed from a remote location
Monitors	Dual parallel AND/OR configuration, monitors standby transmitter and builtin test generator for monitor certification
RMM	Comprehensive, includes alarms and maintenance alerts with automatic dial out to any telephone number
Antennas	
Configurations	Null-Reference, Side-Band Reference, Capture-Effect (M-array), and Non-Imaging (Watts End Fire)

Figure 6. Glide Slope Indicator Specification [16]

3.1.2.3 Marker Beacons

The Marker Beacons used in ILS radiate a fan shaped field pattern and are operated on a frequency of 75 MHz. There are usually two marker beacons: Outer Marker and Middle Marker. The Outer marker is installed roughly 4 nautical miles from the runway limit and is adjusted over the front light emission localizer. Its purpose is to provide height, distance and gear working checks to aircraft on final approach. It is regulated at 400-hertz and keyed to transmit dashes constantly at a rate of two every second. The middle marker is installed approximately 1050 meters from the runway threshold aligned across the front beam of the localizer. The inner marker is modulated at 1300 Hz and indicates the imminence, in low visibility conditions, of visual approach guidance. Few ILS installations utilize an inner marker beacon installed 75-450 meters from runway threshold modulated at 3000 Hz [17]. The marker beacons specification designed by Selex ES is shown in Figure 7.

Mechanical	
Weight - cabinet	50lbs (22.7kg)
Dimensions - cabinet (W x D x H)	21.25 x 10" x 28.25" 54cm x 25.4cm x 71.8cm
Environmental	
Temperature	-50°C to +70°C
Relative humidity	0 to 100%
Altitude	0 to 4573m (0 to 15,000 ft) MSL.
Duty cycle	Continuous, unattended
Wind	Up to 100mph (161km/hr)
Electrical	
Primary power	120-240V AC ±15%, 47-63Hz, single phase
Standby power	12V DC no-break battery back-up system
Operating frequency	75MHz
Frequency stability	±0.0005%
Power output	2.5W maximum (adjustable)
Built in measuring equipment	Audio Frequency Counter, Digital Voltmeter, Transmitter power meter, VSWR meter
RMM	Comprehensive data to include alarms.
Modulation capability	0% to 97% adjustable
Polarization	Horizontal
Keying for	Outer Marker Middle Marker Inner Marker Fan Marker
Coverage	Per ICAO Annex 10

Figure 7. Marker Beacons Specification [16]

The localizer, glide slope and marker beacons are monitored. The tower controller has available a continuous visual indication of the state of each component of the ILS on a monitor panel and is given warning of failure by a system of lights and audible signals.

3.1.3 ILS Implementation at TIA

As TIA is in the middle of densely populated area surrounded by high terrain on all sides, implementing ILS can be challenging. Moreover, the airport's total ground surface area is limited. Below mentioned are few details that should be kept in mind while implementing ILS in TIA:

- The localizer should be installed in the northern side of the runway (Runway 20) facing south, as all the wide body aircrafts approach the airport from south (Runway 02). However, the northern side does not have enough area to install ILS approximately 300 meters from the runway end, the runway should be extended around 200-300 meters from the southern side.

- The center of the glide slope signal must be arranged to define a glide path of approximately 5° above horizontal because of the 7456-foot-tall terrain on the approach path. This will cause the aircrafts to approach the runway steeply which is not safe, especially for wide body aircrafts carrying heavy load.

- Outer Marker can be placed at D4 (4 Nautical miles far from runway threshold) and Middle Marker at D0.5 (Around 3500 feet from the landing threshold). Nevertheless, the approach path is covered with dense population. Finding any area to install marker beacons can be challenging. Available Locator and VOR can be used instead of marker beacons.

- Papi Lights, Runway Lights (Runway end identifier lights, runway edge light systems, runway centerline lightning, touchdown zone lights and land and hold short lights) and Visual Approach Slope Indicators should be installed accordingly meeting the criteria for ILS landing.

- Air Traffic Controllers and other operators should be given proper training to use ILS approach and landing system.

3.1.4 Budget

Analyzing reports from Euro control Business Case Studies, the estimated cost of installing ILS system for 1 runway today is shown in Table 5.

Table 5. Estimated Budget to install ILS [18]

ILS Category II/III lightning system and infrastructure	€ 600 000
Installation	€ 200 000
Civil Works	€ 250 000
Calibration	€ 40 000
Operation and Certification per year	€ 125 000

Hence, the estimated installation cost is around 1.2 million euros (approx. Nepalese RS 15 Crore). The cost may go even higher when there is terrain limitation around the aerodrome.

3.2 Satellite Navigation- Ground-Based Augmentation System (GBAS)

Ground-Based Augmentation System (GBAS) is defined by European Space Agency as: “A civil aviation safety critical system that supports local augmentation at airport level of the primary GNSS constellations by providing enhanced levels of service that support all phases of approach, landing, departure and surface operations” [19]. This system was first introduced by United States. The Honeywell’s Smart Path was the first GBAS solution to receive FAA System Design Approval in 2009 and has awarded FAA Research Program for next generation air traffic management. GBAS was comprised in Annex 10, Volume 1 by Amendment 76, developed by the Global Navigation Satellite

System Panel (GNSSP) from ICAO, that later became the current Navigation Systems Panel (NSP).

3.2.1 Operating Principle

The Global Navigation Satellite System (GNSS) consists of two constellations (GPS and GLONASS). The constellations are unable to provide availability, accuracy, integrity and continuity to provide precision approach. The Ground Based Augmentation System (GBAS) is planned principally to help exactness approach tasks using the concept of differential corrections to augment satellites signal. It comprises of a GBAS Ground Subsystem and a GBAS Aircraft Subsystem. One GBAS Ground Subsystem can support a boundless number of aircraft units inside its GBAS inclusion volume. The ground subsystem furnishes the airplane with methodology way information and, for each satellite in view, corrections and integrity data. The corrections enable the air ship to decide its position with respect to the methodology way more precisely. The GBAS Signal in Space is characterized to be just the information from the ground to the airplane subsystem. The Satellite Signals in Space are a piece of the fundamental GNSS satellite heavenly bodies. Each satellite transmits two radio frequencies band, L1 and L2. The frequencies are centered 1575.42MHz and 1227.6 MHz respectively. [20]

The ground foundation for GBAS consists of two to four GNSS receivers which gather pseudo ranges for all the essential GNSS satellites in view and registers and communicates differential adjustments and uprightness related data for them dependent on its own studied position. These differential data are transmitted starting from the earliest stage by means of a Very High Frequency (VHF) Data Broadcast (VDB) transmitter. The communicated data incorporates pseudo range rectifications, integrity parameters and different locally important information. The data communicated is received via airplane in VHF inclusion that likewise gets data from the navigation satellites. At that point, it utilizes the differential corrections on the data got, specifically from the navigation satellites to figure the exact position. The exact position is utilized, alongside path points information, to supply deviation signs to drive suitable aircraft frameworks supporting accuracy approach tasks. GBAS provides several approach glide angles and displaced threshold as well as curved approaches. The lowest assignable frequency used in GBAS is 108.025 MHz and the highest is 117.950 MHz. The separation between these frequencies is 25 KHz. At a rate of 10500 symbols per second, GBAS data is transmitted as 3-bit symbols. [19] [20] Figure 8 shows the architecture of GBAS system.

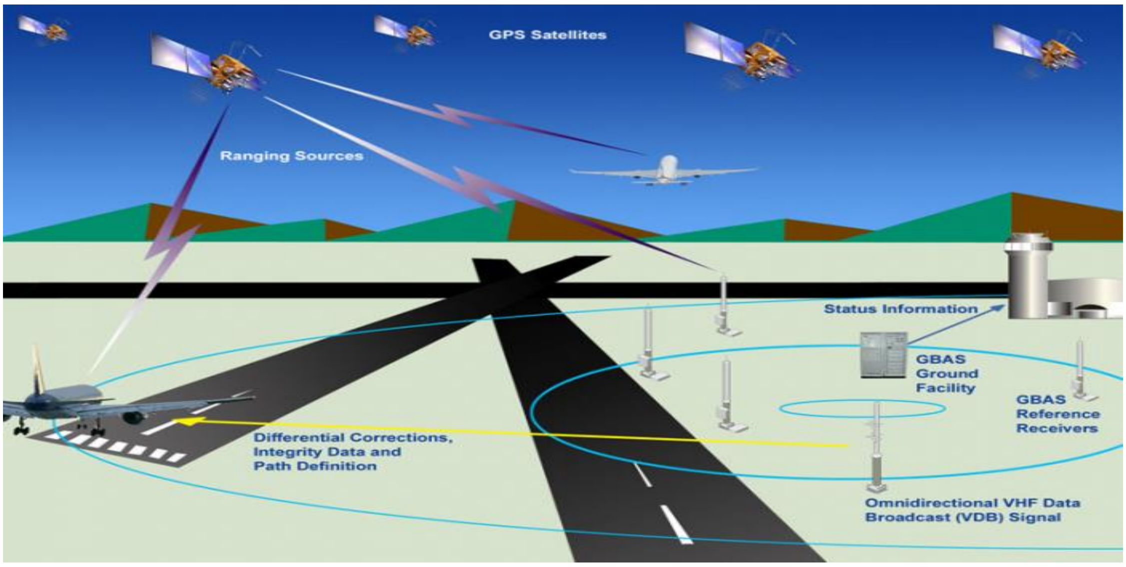

Figure 8. GBAS Architecture [19]

The current Honeywell's SmartPath SLS-4000 GBAS is certified to *Category I* precision landing with a 200 ft DH and can be upgraded to 100 ft *Category II* with real-time monitoring of ionospheric conditions, while the more precise *Category III* SLS-5000 is waiting for well-suited airliners [20]. Ground system coverage of GBAS is shown in Figure 9.

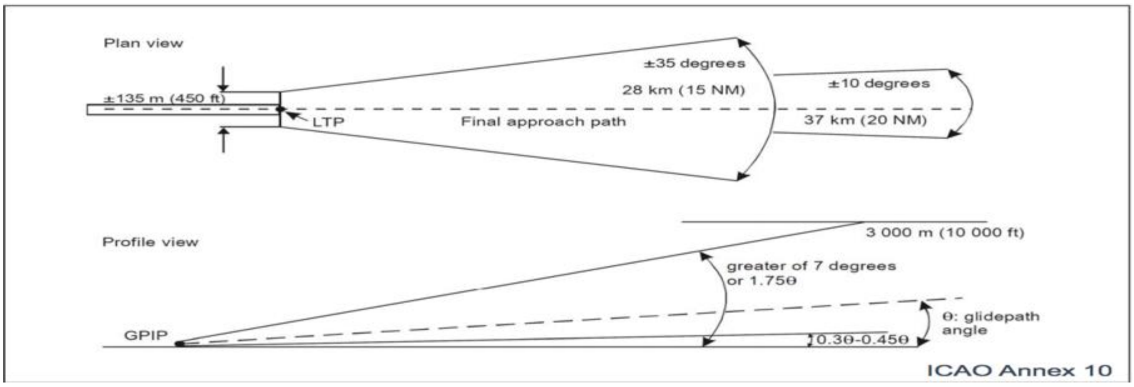

Figure 9. GBAS Coverage [21]

3.2.2 Installation and Operational Notes

The installation of a GBAS ground system comprises considerations in choosing suitable sites for the GNSS reference receivers antennas and the VDB antenna. ICAO Annex 14 obstacle limitation criteria must be met while planning the antenna installation. The site ought to be chosen in a region free of obstacles, in order to allow the gathering of satellite signs at rise edges as low as could be expected under the circumstances. All in all, anything covering GNSS satellites at rise points higher than 5 degrees will degrade framework accessibility.

3.2.2.1 GNSS Reference Receivers

GNSS reference receiver antennas should be installed in a such place where access is controlled. They should be designed and sited to limit multipath signals which interfere with the desired signal. Fixing antennas near to a ground plane reduces long-delay multipath developing from reflections below the antenna. Mounting height should be appropriate enough to avoid the antenna being covered by snow and being interfered by ground traffic. Metal structures like air vents, pipes and other antennas should be outside the near-field effects of the reference receiver antenna. Moreover, the installation of each antenna should be strong enough so that they will not flex in winds or under ice loads. [21]

3.2.2.2 VHF Data Broadcast (VDB) transmitter

The VDB antenna would be positioned so that an unhindered line-of-sight endures from the antenna to any point within the coverage volume for each supported FAS. Attention should also be given to confirming the minimum transmitter-to-receiver separation so that the maximum field strength is not surpassed, and to provide the required coverage for multiple FAS at a given airport, and so as to allow flexibility in VBD antenna positioning. The actual coverage volume around the transmitter antenna may need to be significantly larger than that required for a single FAS. The capability to deliver this coverage is determined on the VDB antenna location with respect to the runway and the height of the VDB antenna. On the whole, increased antenna height may be required to deliver sufficient signal strength to users at low altitudes but may also result in unacceptable multipath nulls within the anticipated coverage volume. An appropriate antenna height trade-off must be made based on study, to certify the signal strength requirements are met within the entire volume. Attention should also be given to the influence of terrain topographies and buildings on the multipath atmosphere. [21]

3.2.2.3 Ground Processing System

Ground Processing System consists of computers, monitors and maintenance terminal. The ground facility system monitors data from satellites, reference receivers and VDB transmitter and provides the information to ATC. They should be installed in a such a place where access is easier within the airport. Wires are to be placed underground and connect the system with reference receivers and transmitter [21]. The NORMARC 8100 model specification is shown in Figure 10 designed by Indra Navia AS.

NORMARC 8100 GROUND BASED AUGMENTATION SYSTEM (GBAS)	
TRANSMITTER	
Frequency Range	108 – 117.975 MHz
Output Power Range	20 – 80 W
Coverage:	
Laterally	28 km ± 35°, 37 km ± 10°
Vertically	0,75 – 7°
ENVIRONMENTAL CHARACTERISTICS	
Operational Temperature:	
Indoor	-10 – 50 °C
Outdoor	-40 – 55 °C
Humidity:	
Indoor	95% below 35 deg 60% above 35 deg
Outdoor	95% below 35 deg 60% above 35 deg
Rain	100 mm/h
Icing	50 mm
Wind	130 km/h
Solar radiation	1120W/m²
ACCURACY	
Range Accuracy	ED-114 GAD C
Position Accuracy	ICAO Annex 10 (16m horizontally and 4 m vertically 95%)
BATTERY BACKUP	
Battery Operation	3 – 30 h depending on # of transmitters, output power and duty cycle
PHYSICAL CHARACTERISTICS	
Power Consumption	400-2000 W depending on # of transmitters, output power and duty cycle
Dimensions (HxWxD)	1020x600x550
Weight	100-110 kg depending on configuration, excluding battery bank and antennas
REMOTE CONTROL	
Data transmission medium	2-wire lined, 600 ohm, FSK or RS-232
MAINTENANCE & MONITORING	
PC-based over Ethernet local or remote, for configuration, alarm log, diagnostics, validation	
RECORDING	
In-rack one week of legal recording	

Figure 10. GBAS Control System Specification [22]

3.2.3 GBAS Implementation at TIA

Below are some details which should be kept in mind while installing GBAS in TIA:

- Ionosphere is a challenge for GBAS implementation. Hence, it is necessary to identify the occurrence of significant ionosphere event before installing GBAS system at TIA. Then, the velocity of the wave fronts and the gradients is calculated using the data of ionosphere event. Finally, the calculated points must be entered into the threat model, allowing the evaluation of the applicability of the model.

- Installation of three reference receivers might be enough for the single runway at TIA. The location of the reference receivers should be free of obstacles from 5 degrees elevation. The reference receivers should be at distance of 200 m from each other and maximum 1300 m away from the ground control facility. Data should be collected periodically from the receivers and stored.

- VDB transmitter can be installed near the runway end (Runway 02) no more than 200 m away from the ground control facility.

- ATC and other ground staffs should be given proper training to use GBAS system.

3.2.4 Budget

Analyzing the reports from Honeywell and Euro Control database, the estimated cost of GBAS System is shown in table 6.

Table 6. Estimated budget to install GBAS [18]

GBAS lightning system and infrastructure	€ 1 500 000
Installation	€ 200 000

Civil Works	€ 300 000
Ionosphere Measurement and Approach Design	€ 500 000
Operation and Certification per year	€ 80 000

Hence, the estimated cost is around 2.5 million euros (approx. Nepalese RS 30 Crore) to install GBAS system in one airport.

3.3 Satellite Navigation- Satellite-Based Augmentation System (SBAS)

European Space Agency defines SBAS as “A civil aviation safety-critical system that supports wide-area or regional augmentation- even continental scale through the use of geostationary satellites which broadcast the augmentation information” [23]. The main objective of SBAS is to provide accuracy, integrity and availability. The system was first introduced by the US Department of Transportation with the helping hands of Federal Aviation Administration in 1994. It is intended to allow aircraft to rely on GPS for all phase of flight including safe approach to any airport within the coverage area.

3.3.1 Operating Principle

In general, SBAS is composed of three main components; space segment, ground segment, and the user segment. Figure 11 shows the architecture of SBAS system.

- Space segment: The SBAS space segment consists of multiple communication satellites in charge of broadcasting, over the service area, the SBAS navigation message. They also broadcast the same type of range information as normal GPS/GNSS satellites that retransmits to the users the navigation message generated on ground. [23]

- Ground Segment: The ground segment is composed of multiple reference stations. These ground stations monitor and collect information on the GPS signals and then sent the data to master stations using a terrestrial communication network. The reference stations also monitor signals from geostationary satellites, providing integrity information regarding them as well. The master stations in the ground process all the data and estimate the satellite corrections, ionospheric model and error variance terms. They also perform a dedicated integrity assessment on the information and format the outputs according to the SBAS standards to the users. The output signal is then transmitted to SBAS satellite. [23]

- User Segment: This segment comprises all the equipment that makes use of the SBAS signal from SBAS satellite, for example GPS receiver in the aircraft. The receiver helps to determine the exact location and time of the aircraft using normal GPS calculations. Hence, in this way the system helps in navigation and approach towards the designated airport. This system provides 95 percentage of horizontal and vertical accuracy. [23]

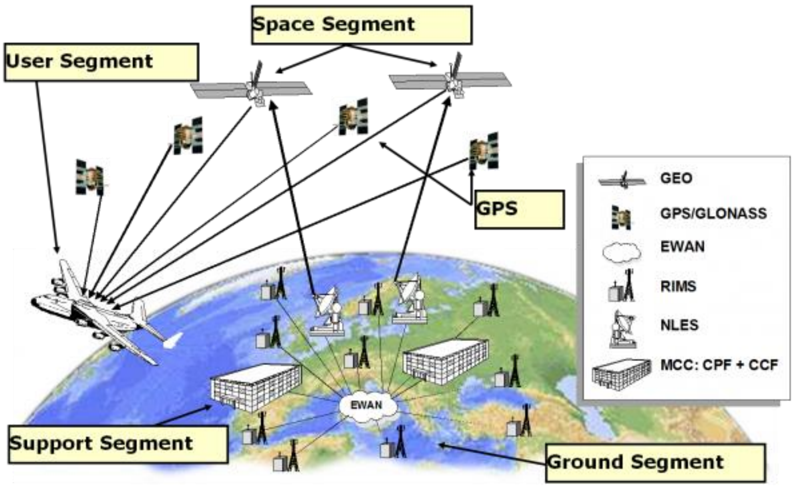

Figure 11. SBAS Architecture [23]

3.3.2 Uses Around the World

The major SBAS implemented are mentioned below and illustrated in Figure 12.

- The Wide Area Augmentation System (WAAS) operated by United States

- The European Geostationary Navigation Overlay Service (EGNOS) operated by ESSP on behalf of EU.
- The Multi-functional Satellite Augmentation System (MSAS) operated by Japan
- The GPS Aided Geo Augmented Navigation (GAGAN) operated by India
- The System for Differential Corrections and Monitoring (SDCM) deployed in the Russian Federation.

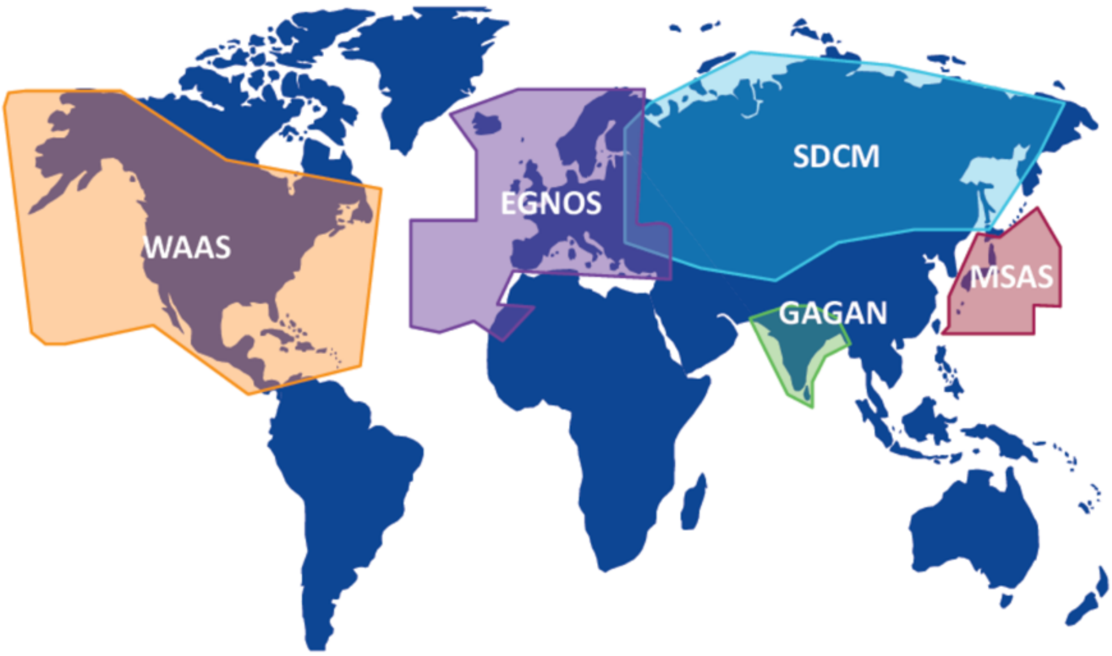

Figure 12. SBAS Implemented around the world [24]

3.3.3 Limitations and Budget

Every man-made satellites are subject to space weather and debris threats which could disable the elements of the system. In addition to that, aircraft conducting SBAS approach must have certified GPS receivers, which are much more expensive than non-certified units. SBAS is also not a sole-solution for approach, as it is not capable of the accuracies required for category II or III approaches. Hence, the runway should be equipped either with ILS or a new system should be executed.

The total project cost is estimated 100 to 110 million dollars as of now and can be used for thousands of airports. The system can also be used in various purposes other than aviation. Once the satellites and ground stations are installed; a total cost of publishing a runway's SBAS approach is approximately 50 thousand dollars only and can save maintenance cost as well. [18]

When it comes to TIA and Nepal, this budget might be too much for a nation consisting of only one international airport. In addition to that, TIA does not have ILS installed in its runway. Nevertheless, Nepal may have an agreement with India to use their satellites and ground stations as implementing the approach system in TIA won't cost much.

4 Approach Technology Comparison (ILS vs GBAS vs SBAS)

Different navigation systems have been considered as possible sensors: ILS, GBAS and SBAS. The research has been focused on the accuracy and has been chosen as the comparison parameter among different systems. The longitudinal and lateral positioning errors for the proposed navigation systems are shown in Figures 13 and 14, respectively. [25]

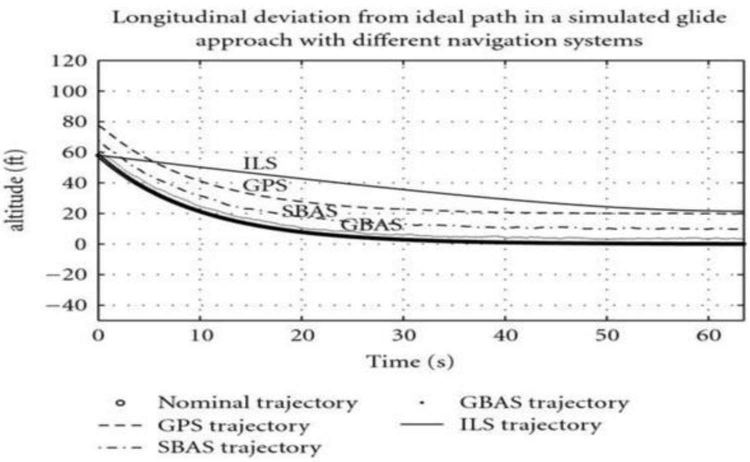

Figure 13. Longitudinal deviation [25]

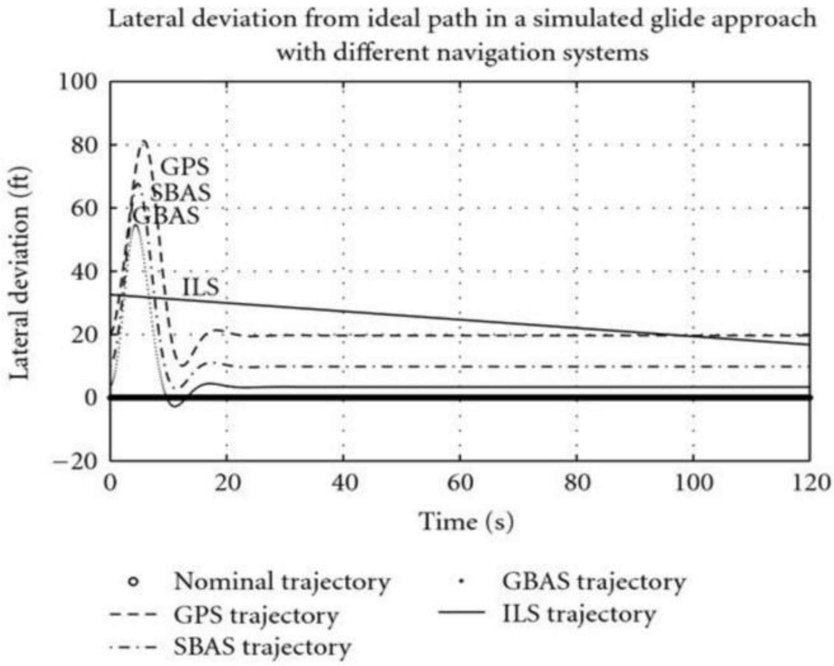

Figure 14. Lateral deviation [25]

Figure 13 demonstrates the longitudinal deviation from the ideal path acquired with an aircraft approaching with the considered, different sensors. It shows that GBAS system provides the best accuracy performance whereas ILS marks the poorest. The graph shows that at the final approach (around 3.8 NM from the runway threshold), the lateral deviation passes from almost four feet for GBAS to more than 20 feet for ILS. [25]

Figure 14 shows the lateral deviation of the same aircraft under identical flight conditions and control settings. The utilization of a GBAS sensor grants to accomplish a lateral error, that is, the separation between the ideal and the actually flown paths, superior to anything an ILS approach as far back as 5.7 NM from the runway threshold. [25]

Thus, Figures 13 and 14 obviously demonstrate how every considered navigation system can satisfy CAT I prerequisites. Increased GPS, that is, SBAS and GBAS, are likewise ready to fulfill CAT II necessities.

5 Analysis

ILS is moderately costly to purchase and deploy and its expense of possession is additionally significant, not minimum in view of the need to fly ordinary adjustment flights looking at the framework consistently. Another weakness is that when the climate truly strikes in and CAT II/III landing tasks are in advancement, departing aircraft need to hold moderately a long way from the runway to stay away from impedance with the radio signs. This has a stamped negative impact on the flight rate of an air terminal. At long last, however not unimportantly, different ILS establishment is required for every runway end to be served.

SBAS, invented primarily for aviation use, is of course the solution par excellence for general GPS usage since it does provide the necessary corrections everywhere these are needed. Regarding cost, obviously the requirement for a satellite constellation notwithstanding GPS adds a significant add up to the amount to the funds expected to set up a SBAS system.

On the other hand, a noteworthy advantage of GBAS system is the possibility of defining curved approach paths which help in avoiding noise sensitive areas. Additionally, GBAS also provides final approach segment data, describing approaches for each of the runway ends being served. A single installation can serve the whole airport covering all runways. It is also possible to define approaches to a grass landing strip or a helicopter landing area. This concluding will be of special interest once helicopters get up to speed with satellite-based landing aids. The expense of ownership of a GBAS installation is very low related to ILS. There is generally no need for regular calibration flights and the equipment itself is also much simpler. Once approaches centered on GBAS are available to *CAT II* minima and ILS is not used, aircraft will be able to hold at the usual *CAT I* holding positions even when low visibility procedures (LVP) are in use. This eradicates one of the important sources of reduced throughput during LVP (the need to hold further from the runway to avoid interference with the ILS signals).

6 Proposed Solution for Tribhuvan International Airport

The aim of this project was to propose a suitable approach and landing system for Tribhuvan International Airport by comparing different modern navigation systems. After analyzing all the navigation systems in terms of terrain limitation, error sources, budget and available ground resources, the proposed navigation system is GBAS System.

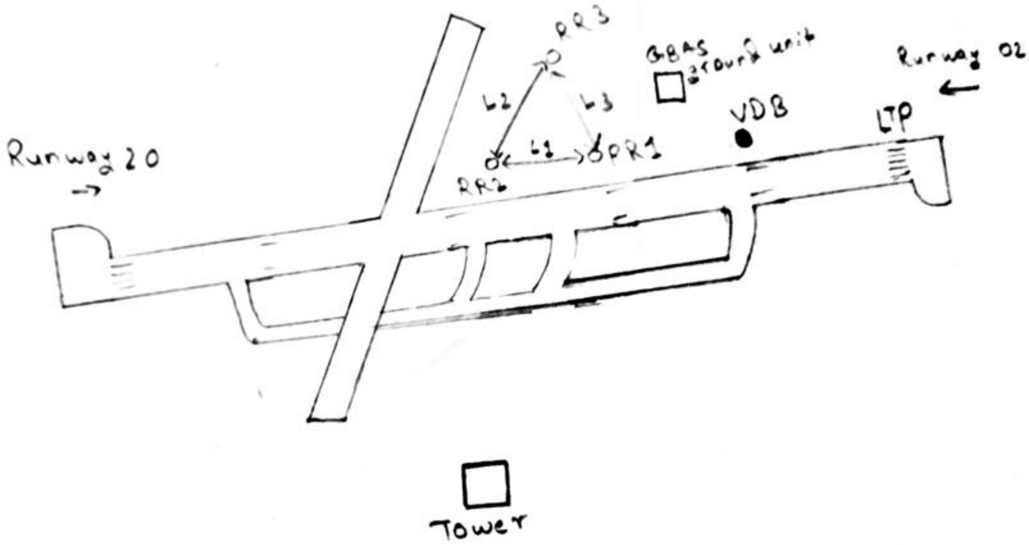

Figure 15. Proposed locations of Reference Receivers (RR1, RR2, RR3), VDB transmitter and GBAS Ground Unit at TIA

The proposed GBAS system consists of three GPS reference receivers with antennas, a VDB transmitter and a GBAS ground unit inside the TIA premises. As TIA has limited ground space, the available best area to install GBAS system is shown in Figure 15. The receivers and transmitters should be installed in accurately surveyed positions meeting the criteria of ICAO.

GBAS potentially supports all-type of precision approaches. One ground unit will be sufficient to provide approaches to two runway ends of TIA. The highly reliable positioning service of GBAS enables to increase the capacity of TIA, as well as avoid obstacles and congested airspace of Nepal. Curved approach paths provided by GBAS helps to avoid noise sensitive areas around Kathmandu Valley as well. Additionally, the system improves terminal area surveillance, reduces flight inspection costs and requires less maintenance than other navigation system.

Moreover, the airlines flying in and out of TIA can also benefit from the system. The system offers reduced track miles and schedule reliability. Other benefits include increased signal stability, no on-board procedure database and improved surface movements. The aircrafts can also takeoff during low visibility.

As indicated in Figure 16, the performance requirements of GBAS system are expressed in terms of four quantitative concepts: Accuracy, Integrity, Continuity and Availability making GBAS the suitable navigation system for Tribhuvan International Airport.

Typical Operation	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	Integrity	Time-To-Alert (TTA)	Continuity	Availability
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220m (720ft)	N/A	$1–1\times10^{-7}$/h	10s	$1–1\times10^{-4}$/h to $1–1\times10^{-8}$/h	0.99 to 0.99999
Non Precision Approach with vertical guidance (NPV-I)	220m (720ft)	20m (66ft)	$1–2\times10^{-7}$ per approach	10s	$1–8\times10^{-6}$ in any 15s	0.99 to 0.99999
Non Precision Approach with vertical guidance (NPV-II)	16m (52ft)	8m (26ft)	$1–2\times10^{-7}$ per approach	6s	$1–8\times10^{-6}$ in any 15s	0.99 to 0.99999
Category I (CAT-I) Precision Approach	16m (52ft)	6.0m to 4.0m (20ft to 13ft)	$1–2\times10^{-7}$ per approach	6s	$1–8\times10^{-6}$ in any 15s	0.99 to 0.99999

Figure 16. Static GBAS performance [19]

7 Conclusion

The conclusion that has to be drawn is that the main objectives of the project was achieved. The first objective which was to study the current situation of Tribhuvan International Airport was completed. The available infrastructures of the airport were discussed and the reasons behind airport's need for a new modern navigation system was explained as well.

Considering the second objective of research, GBAS system was proposed as a suitable navigation system for Tribhuvan International Airport. The document that fully describes Ground-Based Augmentation Systems operating principle, installation notes and budget shall be used in the evolution of the TIA landing activities.

GBAS frameworks are being tested and implemented everywhere throughout the world. With results appearing, GBAS Precision Approach benefit effortlessly meets the execution necessities for CAT-I operations. The GBAS Positioning service will be an additional preferred standpoint of GBAS frameworks, fit for giving GNSS increase to different tasks, as Landing, Departure and Surface movements.

8 Future Work

There are few guidelines mentioned below to be followed, in order to complete the process of implementing GBAS system in TIA:

- To find out the exact location to deploy Reference Receivers to collect GNSS data and generate GBAS messages corrections in a continuous basis
- To calculate all the GBAS related data needed to accurately process the GBAS system at TIA
- To execute flights tests for dynamic performance evaluation.

Firstly, GBAS ground station and a multi-mode receiver should be installed to acquire GBAS Precision Approach service.

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