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Concept of Operations for NextGen Alternative Positioning, Navigation, and Timing (APNT)

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Table of Contents

Tables and Figures

Executive Summary

The Next Generation Air Transportation System (NextGen) is the United States' initiative to modernize the nation's air traffic control system. Its design will maintain safety while supporting an estimated two-fold increase in air traffic by 2025. Many of the foundational elements that will be required to meet the predicted capacity and efficiency improvements rely on widespread use of precision Positioning, Navigation, and Timing (PNT) services provided by the Global Positioning System (GPS). GPS sourced PNT services are the primary enablers of performance-based navigation (PBN) and Automatic Dependent Surveillance – Broadcast (ADS-B) services that, in turn, enable Trajectory-Based Operations (TBO), area navigation (RNAV), Required Navigation Performance (RNP), precision approach, Closely Spaced Parallel Operations (CSPO), and other plan operational improvements for the NextGen environment.

In accordance with U.S. National Policy[1], the FAA needs to ensure a sufficient backup PNT capability is present to mitigate risks to aviation users if the PNT services provided by GPS become unavailable. The FAA's NextGen Alternate PNT (APNT) program ensures that alternate PNT services will be available to support flight operations, maintain safety, minimize economic impacts from GPS outages within the National Airspace System (NAS), and support air transportation's timing needs.

Homeland Security Presidential Directive HSPD-7, Critical Infrastructure Identification, Prioritization, and Protection identifies the NAS as critical infrastructure and requires protection against terrorist acts (in this case intentional interference with PNT) that could:

> "(a) Cause catastrophic health effects or mass casualties comparable to those from the use of a weapon of mass destruction;
> (b) Impair Federal departments and agencies' abilities to perform essential missions, or to ensure the public's health and safety;
> (c) Undermine State and local government capacities to maintain order and to deliver minimum essential public services;
> (d) Damage the private sector's capability to ensure the orderly functioning of the economy and delivery of essential services;
> (e) Have a negative effect on the economy through the cascading disruption of other critical infrastructure and key resources; or
> (f) Undermine the public's morale and confidence in our national economic and political institutions."

Further, under National Security Presidential Directive 39, U.S. Space-Based Position, Navigation, and Timing Policy, requires the Secretary of Transportation to:

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[1]DOT 22-02, March 7, 2002, DOT Action Plan for Transportation Infrastructure Relying on GPS, Homeland Security Presidential Directive-5, Office of the Press Secretary, The White House, February
28, 2003 and Homeland Security Presidential Directive-7, Office of the Press Secretary, The White House, December 17, 2003

> “In coordination with the Secretary of Homeland Security, develop, acquire, operate, and maintain backup position, navigation, and timing capabilities that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the United States, in the event of a disruption of the Global Positioning System or other space-based positioning, navigation, and timing services, consistent with Homeland Security Presidential Directive-7, Critical Infrastructure Identification, Prioritization, and Protection, dated December 17, 2003.”

PNT services in 2011, consisting of legacy navigation and surveillance systems are not capable of providing the PNT performance necessary to support NextGen and provide an RNAV backup to the RNAV capabilities required in NextGen. The current system of ground-based navigation aids is based on a routing structure that is detrimental to the growth in demand. Precision navigation and surveillance are necessary to realize increased use of three-nautical mile separation with surveillance-based conformance monitoring for TBO as part of the NextGen. Therefore, the FAA must identify strategies that will provide the necessary APNT-supported aircraft operations conducted under Instrument Flight Rules (IFR) in the NextGen operating environment. The APNT strategy is consistent with the NextGen Implementation Plan and FAA Strategic Goals 1 and 2 for increased safety and capacity, respectfully.

With both navigation and surveillance through ADS-B being derived from GPS, an opportunity for common mode failure is created. An aircraft can lose navigation and the FAA can lose surveillance that would normally compensate for loss of navigation. The ability to disrupt air transportation by interfering with GPS becomes more likely as aviation grows more dependent on GPS as its major source of flight information.

As NextGen modernization and implementation progresses, dependence on GPS services increases, requiring appropriate mitigations for the vulnerability of GPS to radio frequency interference (RFI) and other potential outages where necessary. The FAA must continue to ensure safety of the NAS and to provide for continued en route and terminal flight operations in the presence of GPS interference or other loss of service where economically feasible.

By 2025, the FAA will need an alternative PNT service that reduces this vulnerability, provides an RNAV backup to the GPS RNAV capability and supports timing for navigation and possibly other uses on the ground and in the air. The concept of operations for APNT is built on 4 pillars:

- Safe recovery (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under Instrument Flight Rule (IFR) operations,
- Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area,
- Continued dispatch of air carrier operations to deny an economic target for an intentional jammer, and

- Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event.

Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event. The focus on APNT research is to extend coverage of distance measuring equipment (DME) that can be used to provide most commercial aircraft with an RNAV capability independent of GPS, define a minimum operating network of ground-based navigation aids to safely recover aircraft in the presence of interference, and examine the feasibility of being able to derive position based on the use of precision timing, independent of the GPS performance.

Precision time and frequency stability are critical to navigation and positioning and is the basis for how GPS works. Precision time from GPS is used extensively in transportation and other segments of critical infrastructure for purposes beyond navigation and positioning. As the FAA looks to the future, alternative timing sources will be required for not only navigation and positioning, but for networking, efficient use of spectrum, and improvements in automation. For APNT, the requirements for time and frequency stability are driven by the navigation alternatives being considered and the system and node synchronization required maintaining precise Coordinated Universal Time (UTC).

1. Introduction/Scope

This concept of operations (CONOPS) supports the development of operational and technical requirements for an alternative means of providing a Next Generation Air Transportation System (NextGen) Alternative Positioning, Navigation and Timing (APNT) service to support the safe, secure, and efficient operations of the United States' National Airspace System (NAS). The CONOPS uses current procedures as well as anticipates procedures that would exist in the future when NextGen is operational (2025).

This APNT CONOPS builds upon the JPDO NextGen CONOPS that supports precision area navigation, high-density airspace operations, flexible use of the airspace, and trajectory-based operations (TBO), where there is a four-dimensional trajectory that will be used for flight planning, strategic management of operations, aircraft sequencing, spacing and separation. Precision positioning, navigation and timing are key enablers necessary to deliver the precision performance of TBO and its ability to provide increased capacity and efficiency, especially in high-density airspace, to meet growth in air transportation demand. The Federal Aviation Administration's NextGen Mid-Term NextGen CONOPS does not address far-term capabilities that would require APNT for continuity of services.

The APNT CONOPS serves as a bridge between today's procedures and procedures that will be enabled within a precision navigation/TBO environment in the future as the NAS evolves to NextGen.

A key element to precision area navigation and provision of positioning information is the use of satellite-based navigation and surveillance in the form of the Global Positioning System (GPS). GPS is used for navigation and for Automatic Dependent Surveillance – Broadcast, or ADS-B[2]. While the aircraft position is derived from GPS, it is subsequently reported by ADS-B. Both navigation and position reporting (used for surveillance) are supported by the same information derived from the satellite constellation. This is a significant departure from pre-GPS operations, where navigation and surveillance had separate sources and an independence that supported safe operations through communications, navigation and surveillance, each being independent of each other and each capable of supporting separation.

The position calculated by the GPS receiver is dependent on precision time, the third element in PNT. This calculation of position requires the current time, the position of the satellite and the measured delay of the received signal (time of arrival). The position accuracy is primarily a function of satellite position and this measured time delay. The GPS delivers position accuracy of 3 meters, or 30 nanoseconds of time (each nanosecond of error represents 0.299 meters of precision).

The APNT CONOPS addresses two representative GPS interference events, 1) a wide area event where a fixed high-power interference source creates an impact area with a

[2] Reference DO-260B Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Services-Broadcast (TIS-B), December 2009, RTCA, Inc.

radius of 300 nautical miles (nm) and 2) a smaller, localized recurring event of 60-80 nautical miles but with an unpredictable, intermittent, and highly mobile ground-based interference source. To represent the procedures and consequences of interference, en route, arrival, terminal and surface operations are considered for two airports. The first is Hailey, Idaho (FMA), an airport tucked within a deep canyon with mountains on three sides, and where there is no alternative means for a precision landing aid other than area navigation (RNAV) using required navigation performance (RNP). The other is Miami International Airport in Florida, where an intermittent GPS interference source is constantly present. Miami was selected as a representative air carrier operation location and is common to prior work done on integrated communications, navigation and surveillance (I-CNS) for the Joint Planning and Development Office (JPDO).

While the APNT CONOPS principally focuses on operations relating to positioning and navigation, that position information supports surveillance with ADS-B. Precision time is also required in several alternatives selected for investigation. The APNT solution(s) may require time synchronization and stable frequencies between the ground sites. This is the case for APNT alternatives using multilateration and pseudolites. Where multiple ground sites are needed and networked together, this timing is called APNT node synchronization. Representative time and frequency values can be found in Appendix I.

Since APNT is researching feasible alternatives, APNT node synchronization would only be required if it were needed to synchronize the multiple ground stations of multilateration or pseudolite alternatives so that receivers on the ground or in the air could measure the time of arrival of a signal. This time accuracy would need to be somewhere between 10 and 100 nanoseconds and possess Stratum 1 frequency stabilization of 1×10^{-11} Hertz (Hz) per hour.

1.1 Background

The FAA is in the process of transforming its National Airspace System (NAS) into the Next Generation Air Transportation System (NextGen). The transformation from an air traffic control system to an air traffic management system is designed to support a predicted increase in air traffic by a factor of two times by 2025. As described in the FAA Flight Plan, the NextGen Implementation Plan (NGIP), and the JPDO NextGen Concept of Operations (CONOPS), the air traffic system of the future will be much more dependent on positioning, navigation and timing (PNT) from Global Positioning System (GPS). In fact, PNT is one of the foundational aspects of NextGen. This strategic goal will not be achievable without a NextGen Alternate PNT (APNT) solution that can provide the required PNT services in the event of a GPS loss of service.

The concept of operations for APNT is built on 4 pillars:

- Safe recovery (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under Instrument Flight Rule (IFR) operations,
- Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area,

- Continued dispatch of air carrier operations to deny an economic target for an intentional jammer, and
- Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event.

NextGen APNT services will fill the performance gap that would otherwise impact operations, e.g., increased fuel usage /carbon footprint, delayed flight time, increases in pilot and controller workload, and other inefficiencies. These inefficiencies would result in economic impacts and become increasingly costly to air traffic operations and impact passenger-value-of-time. While the current legacy navigation and surveillance infrastructure cannot accommodate growing demands for 2025 and beyond, NextGen APNT will ensure adequate PNT services supporting safety, environmental and economic demands.

1.2 Problem Statement

GPS-derived PNT is vulnerable to interference. The signals emanating from satellites in medium earth orbit (MEO), 11,500 miles above the Earth are extremely weak and are highly susceptible to interference. Interference can be intentional or unintentional, natural or man-made. As GPS use continues to grow across a broad spectrum of users (well beyond aviation, maritime and other transportation applications), the likelihood of interference events increases. The consequences and risks of an interference event also grow. There are two types of risks, safety and economic. The safety risks relate to the ability to maintain safe separation in all situations and during transitions – especially where the independence of navigation and surveillance services is lost and common mode failures can occur. The economic risks relate to losses in capacity and efficiency during an interference event because of the inability to utilize precision performance procedures.

An interference event can, in some cases, be compared to a snowstorm or other severe weather event where airport throughput becomes limited and en route aircraft need to be re-routed. The difference is that the onset of interference is instantaneous and can occur without warning. Aircraft in flight caught inside an interference airspace volume must have the capability to maintain navigation via non-GPS means, obtain assistance from ATC in order to recover navigation, or be provided radar vectors. The workload in dealing with an interference event rapidly rises without warning and there is a period of time where changes in separation, sequencing and spacing add to the workload. As the interference event progresses, demand is restricted and the NAS reaches a new steady-state condition with less capacity and efficiency. It is the transition from one state of GPS operations to a lower state of performance without GPS that creates the safety risk. The extent to which the APNT solution(s) maintains the capabilities of GPS-based PNT describes the extent to which the alternative serves as a redundant solution and maintains safety while minimizing economic risk.

National policy requires a back-up capability for PNT in the event of loss of GPS. The existing legacy navigation and surveillance infrastructure, i.e., VHF Omni-Range (VOR), Distance Measuring Equipment (DME), Non-Directional Beacon (NDB) and secondary radar, may not achieve the desired level of performance for NextGen operational improvements. In order to sustain performance-based operations in the NextGen environment, NextGen APNT services will likely be needed to support continuous operations during a GPS outage.

When the NextGen is fully deployed the primary enabler of PNT services will be GPS. GPS-based PNT will support planned NextGen operational improvements (OI) that include Area Navigation (RNAV), Required Navigation Performance (RNP) and Trajectory Based Operations (TBO). NextGen will rely on surveillance services enabled by Automatic Dependent Surveillance-Broadcast (ADS-B), which are also dependent on GPS. The NextGen environment will significantly increase airspace capacity, efficiency, and safety in accordance with FAA Strategic Goals.

In the 2025 operational environment, many NextGen enabled capabilities and OIs that are focused on capacity and efficiency would be lost in the event of a GPS outage. In addition, there are safety issues relating to the transition from the start of the interference event to establishing a new steady state operation at reduced demand levels. A summary of OIs impacted by GPS interference is provided in Appendix H. With the loss of GPS capabilities, current legacy infrastructure will not fully support NextGen operational goals. Reduced operational efficiency and possible disruption to air traffic operations would occur in the transition from performance-based navigation back to conventional, non-RNAV, Very High Frequency Omni-directional Range (VOR)-based navigation. Following this transition, operational efficiency and capacity would remain limited until the source of the GPS outage is located and eliminated. Without an RNAV/RNP-capable alternative PNT, GPS becomes a much more significant critical infrastructure target for disruption.

The anticipated shortfall is addressed by enabling a seamless transition to APNT based operation upon the loss of GPS to maintain performance-based operations. This will allow the national airspace system to operate at acceptable NextGen performance levels. Air traffic controllers will be able to provide optimum spacing without an increase in workload during GPS outage. Pilots will continue operations in high-density airspace with little or no impact.

1.3 Identification

The concepts for APNT are derived from the JPDO NextGen Concept of Operations and flow to selected functional areas relating to satellite-based navigation and surveillance, performance-based operations and the use of this performance for a combination of navigation, surveillance and trajectory-based operations, both in the air and on the surface. The purpose of this section of the Concept of Operations is to tie APNT to other related concepts and functional areas. Because there is yet to be an FAA developed far-term concept for NextGen and TBO, and APNT has concepts for both the current operating environment and the NextGen target environment, APNT is identified against the JPDO NextGen Concept of Operations and the functional areas impacted by a GPS Interference event. The functional areas of the JPDO Concept of Operations are listed as Level 1 concepts in Figure 1.1.

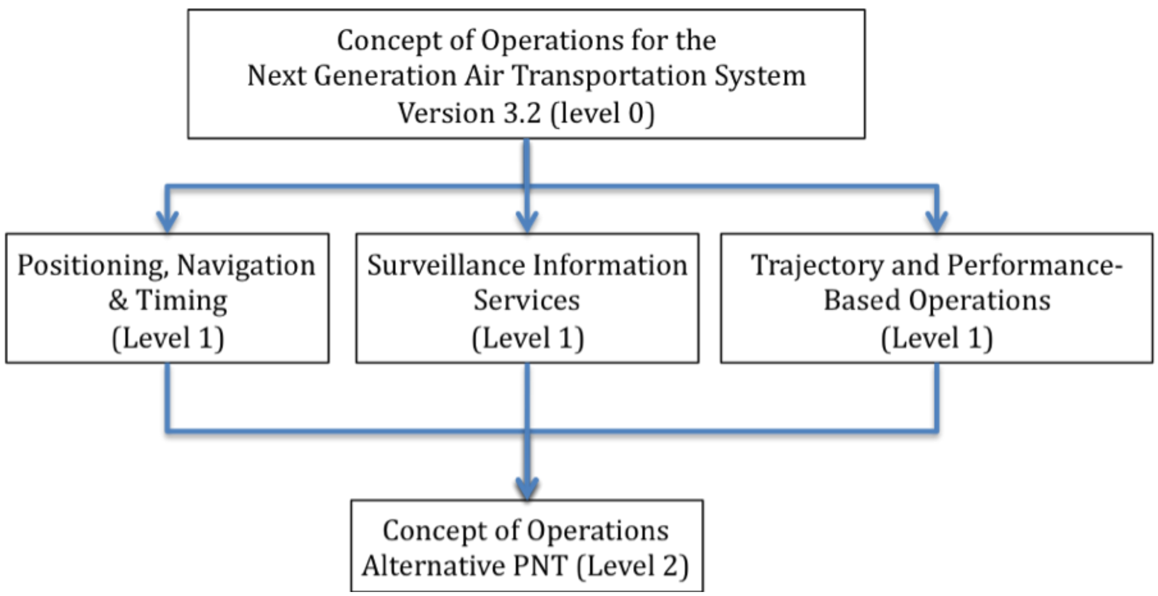


Figure 1.1: **Concept Position within Hierarchy**

1.4 Concept Overview

The NextGen APNT operational concept is to provide position, navigation, and timing services that will seamlessly allow aircraft to continue flight operations with acceptable levels of impact, in the event of GPS outage. APNT will ensure operational safety while maintaining levels of efficiency and capacity enabled by the NextGen capabilities against a significantly greater level of demand than present today. APNT services will support the development of procedures fully enabled by RNAV/RNP, ADS-B, TBO, and Four Dimensional Trajectory (4DT) operations. APNT will allow the use of these services during the loss of GPS.

Pilots, dispatchers, and controllers will all benefit from the availability of APNT services. Specifically, pilots will be able to utilize the availability of aircraft position, navigation, and timing services during GPS outage and continue to use RNAV/RNP. This will avoid inefficiencies for the pilot by eliminating an operational transition from performance-based to conventional VOR-based navigation. Furthermore, aircraft dispatchers will gain the ability to continue to schedule operations and to choose preferred trajectories during a GPS outage. Controllers will be able to manage separation services and continue performance-based operations during the loss of GPS. Current legacy PNT services cannot adequately support NAS operations within the NextGen environment since a significant element of en route and terminal operations would be impacted through reversion to present-day system performance and would require replacement/retention of the VOR infrastructure.

2. Current Operations and Capabilities

Several legacy ground-based systems are used to provide alternative PNT services today. These systems allow aircraft relying on GPS for navigation to transition to an alternate means of navigation when GPS is unavailable. However, these systems do not allow for seamless transition to alternative PNT operations. Furthermore, FAA plans to eliminate a portion of these aging legacy systems.

DME - During a GPS outage the DME/DME-derived position allows the aircraft position to be known, and navigation to continue, at reduced levels of performance. Aircraft position bias is calculated between DME/DME and GPS ensuring that aircraft position is not lost.

VOR / NDB – Before flight crews can rely on the VOR or NDB for Legacy APNT; they must tune and confirm reception of the desired VOR or NDB. However, VOR and NDB cannot support RNAV or RNP operations, which prevent them from being a viable option for a NextGen operating environment.

Radar - For aircraft not capable of utilizing the Legacy APNT system but are within radar coverage, air traffic controllers can utilize secondary surveillance radar and provide radar vectoring and altitude assignments in the presence of interference.

ADS-B – During a GPS outage, ADS-B in inoperative, since position is derived from GPS. ADS-B is being used today to substitute for radar coverage. In the absence of ADS-B and outside the coverage of existing radar, controllers will need to revert back to procedural separation.

Legacy navigational aids are based on pre-defined route structures that drive coverage by line-of-sight. In NextGen, performance-based navigation, positioning and surveillance from satellites are used to open up the airspace by removing flight track constraints and allows aircraft to operate off these constraining airways. This freedom to operate off the route structures adds capacity and efficiency in the system and provides users with more options in selecting flight tracks.

ILS – The Instrument Landing System (ILS) is retained in the APNT concept of operations to provide the ability to recover aircraft in the presence of weather and GPS interference.

2.1 Definitions

The following definitions are unique to TBO and are evolving as more detailed concepts of operations are developed. Each definition is derived from the JPDO work on TBO and early FAA concepts in the mid-term for the use of trajectory information in traffic management.

- **Trajectory Operations** – The concept of an Air Traffic Management (ATM) system in which every aircraft that is operating in or managed by the system is represented by a 4-D trajectory (4DT). Every managed aircraft known to the system has a 4DT either provided by the user or derived from a flight plan or type of operation. Trajectory operations represent a mid-term implementation strategy to gain capacity and efficiency. In this mid-term, automation provides decision support tools that enable controllers to handle more traffic oriented toward user-preferred routings. These tools take a significant step toward automated separation by providing conflict detection, resolution of conflicts, rank ordering of actions to be taken, and provides the controller with the ability to manage flows.

- **Trajectory-Based Operations** – Extends trajectory operations and provides separation, sequencing, and merging and spacing of flights based on a combination of their current and future positions. TBO operates gate-to-gate, extending benefits to all phases of flight operations. TBO uses the 4DT to both strategically manage and tactically control surface and airborne operations. Aircraft are handled by their trajectory and ANSP automation provides TBO. Concepts for TBO have yet to be fully defined.

- **4DT** – Defined laterally and longitudinally by latitude and longitude, vertically by altitude and with time. Surface movement is a 3DT – lateral, longitudinal, and time.

- **Closed Trajectory** – The ANSP automation, the controller, and the aircraft automation have the same view of what the aircraft is doing. There is agreement between automation on the ground and in the air, and actions are synchronized.

- **Open Trajectory** – The aircraft is no longer flying to an agreement with the automation. The aircraft and the ground are not in synchrony and the aircraft is flying off the agreed-upon trajectory for operational reasons like weather avoidance, a vector for sequencing or spacing, and/or a speed adjustment that will impact timing.

- **Conformance Monitoring** – Monitoring of the aircraft's position, altitude, and time performance against the agreed-upon 4DT. Monitoring is against performance requirements for the flight maneuver or surface movement. Monitoring occurs both in the air and within ground automation.

- **Conformance Alerting** – Alerts are generated if the aircraft is not meeting its 4DT performance. These alerts occur both in the aircraft and with the ANSP.
- **Control-by-Exception** – Is an action where the controller intercedes to correct or re-sequence an aircraft not meeting its trajectory.

- **Self-Separation** – Delegation of separation responsibility to the flight crew for specific maneuvers or operations in designated airspace.

- **Flight Object** – An extensible and dynamic collection of data elements that describes an individual flight. It is the single common reference for all system information about that flight. Authorized system stakeholders and the ANSP may electronically access consistent flight data that is tailored to their specific need and use. The flight object facilitates the sharing of common flight information between systems and enables collaboration using a common reference framework.

- **Intent** – What the aircraft is planning to do. Intent is provided by ADS-B for air-to-air and air-to-ground surveillance. This is ADS-B intent. The flight object also carries intent information and it is the intent sent by data link between the aircraft and the ANSP that represents the confirmation of intent, execution of the 4DT, and forms the basis for conformance monitoring. As the aircraft progresses in the flight, supplemental intent messages are sent to the ANSP to provide updates of progress and changes in 4DT performance.

- **Independent Navigation Systems** – mean that position and course guidance are derived from different sources.

- **Aircraft State** – the position of an aircraft at the moment of detection of an interference event.

2.2 Description of Current Operations

Today's NAS and its airspace structure are built on ground-based navigation aids to create aircraft routings, arrival and departure paths. The aircraft's flight trajectory is restricted to the service volumes of the navigational aids. To operate off airways requires area navigation, where the aircraft derives its position. RNAV is based on a network of DMEs or use of GPS.

The VOR network defines the route structure for both high altitude (Jet Routes) and low altitude (Victor Airways) "highways in the sky." These route structures extend to fixes near the airport for arrivals and departures. The VOR network also supports non-precision approaches at airports that today are redundant to GPS approaches.

Because most of the traffic is routed onto an airway, sectors of airspace are defined for en route air traffic control based on these routes. RNAV is changing this picture, as more aircraft begin to use GPS or DME-DME to navigate off airways, opening up airspace utilization and providing efficiencies in the operations by flying more direct routing.

In the terminal airspace, aircraft are routed along VOR routes, pre-defined Standard Terminal Arrival Routes (STAR). These STARs transition the aircraft to an instrument approach that includes non-precision VOR approaches or precision ILS or GPS procedures. Departures are managed through Standard Instrument Departures (SID) at most major airports.

Current operations for navigation are shifting to greater reliance on GPS for RNAV and RNP, creating new opportunities for greater efficiency and precision in navigation. This precision positioning is then broadcast as ADS-B for use in both air-to-air and air-to-ground surveillance. It should be noted that a DME-DME derived position cannot be substituted with a GPS position in ADS-B, making ADS-B totally dependent on GPS (as augmented by satellite-based or ground-based augmentation systems).

On the airport surface, aircraft are routed using visual navigation aids (signs, marking and lighting) and that is not likely to change. In the NextGen Mid-term Concept of Operations, positioning and position reporting with ADS-B and/or multilateration are expected capabilities for the airport surface movement. However, the addition of cockpit moving maps, provision of information through ADS-B, and the use of enhanced vision systems for surface movement may lead to new concepts in surface navigation based on improved information in the cockpit.

2.3 Current Supporting Infrastructure

The FAA sustains over 12,000 facilities dedicated to supporting navigation. This supporting infrastructure is made up of a mix of the following equipment:

Table 2-1 Existing Aids to Navigation

Aid Type	Use	Number[3]
VOR/VORTAC	Defines Victor Airways and Jet Routes; supports feeder fixes for arrivals; provides non-precision approaches; defines departure paths. A VORTAC combines VOR and TACAN	1050
TACAN (Tactical Navigation)	Defines Victor Airways and Jet Routes; supports feeder fixes for arrivals; provides non-precision approaches; defines departure paths; combines course with ranging information through DME	130 stand-alone units
DME	Slant-range distance measuring capability used for RNAV and for defining points on approach and departure paths	1,300
NDB	Provides airway structure in remote locations, supports elements of instrument approaches	1,300, of which 300 are federal
ILS Category I	Precision approach capability	1,000
ILS Category II/III	Precision approach capability	130
GPS	En route, terminal navigation with precision approach and departure capabilities	1

[3]Source: 2010 Federal Radionavigation Plan

3. Justification and Description of Changes

Current operations in all flight domains and surface movement are not fully dependent on the use of performance-based operations and the future use of trajectory-based operations for navigation (4-D operations) and positioning. As the NAS transitions to NextGen, flight tracks in the airspace will no longer be dependent upon published routes. Instead, a trajectory will be negotiated, approved and then flown nearly independent of ground-based navigation aids or surveillance coverage by radar. The ubiquitous dependency on GPS (and the Global Navigation Satellite Systems (GNSS) globally) makes use of satellites for navigation, positioning and timing. A GPS failure due to interference becomes a common mode failure for both navigation and positioning (ADS-B position reporting) and may impact timing in surveillance systems and networking.

APNT is based on a mission need to support national policy by providing a backup to GPS as a critical infrastructure and sustain operations in a manner that preserves RNAV and RNP, rather than operating by falling back to VOR-defined route or radar vectors. APNT provides an alternative means of safely recovering aircraft in a GPS interference area and allows for continued dispatch of equipped aircraft that are able to launch and use alternative means of navigation until clear of the interference area. APNT reduces the risk of intentional and unintentional interference (natural or manmade) by allowing aircraft operations to continue.

4. APNT Concept of Operations

As U.S. aviation transitions to NextGen with increased emphasis on precision navigation and TBO, RNAV/RNP will become the norm for operations and using airways and arrival and departure procedures designed around the limitations of a ground-based infrastructure will no longer be beneficial or efficient for the traffic volume anticipated. Growth in air traffic drives increased precision in navigation with airspace being used more efficiently and capacity gained, especially in high-density airspace.

The concept of operations for APNT is built on 4 pillars:

- Safe recovery (landing) of aircraft flying in IMC under IFR operations,
- Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area,
- Continued dispatch of air carrier operations to deny an economic target for an intentional jammer, and
- Flight operations continue without a significant increase in workload for either the pilot or the ANSP during an interference event.

This APNT concept uses existing procedures and new concepts derived from the TBO Study Team Report prepared for the JPDO by the TBO Study Team[4] that describes operational scenarios for operating within NextGen. To bridge between the current

[4] TBO Study Team, Trajectory-Based Operations (TBO) Operational Scenarios for NextGen, version 1.9.2, September 2010.

operations and the JPDO NextGen, the FAA mid-term NextGen CONOPS was used.[5] Two interference conditions were then added and discussions held on operational concepts. Both interference conditions result in making GPS inoperative in the cockpit. Depending on where the aircraft is, and what its capabilities are, actions are then taken to mitigate the impact of the event. From the information derived, the APNT CONOPS was developed.

The APNT CONOPS is neutral to technical solutions, except to using existing aircraft avionics configurations to compare and contrast the impacts of the outages. Three groups of aircraft are used. The first is an aircraft having a flight management system (FMS) with an inertial reference unit (IRU) and a scanning DME transponder (DME-DME). This is a DDI-aircraft. The second group of aircraft has an FMS and DME-DME, but no IRU. This aircraft is referred to as a DD-aircraft. The third group has no FMS or DME-DME and is equipped with GPS as a primary source of positioning and navigation (GPS-only aircraft). In general, the last group is not equipped with any type of DME because the FAA currently permits GPS to be used in lieu of DME by policy.

All groups of aircraft are equipped with GPS, with some augmented by satellite-based augmentation system (SBAS) and some with a ground-based augmentation system (GBAS)[6]. All aircraft also have ADS-B as mandatory equipage to receive IFR services from the ANSP by 2020. The most likely combination in the United States is GPS/SBAS supplying positioning information to ADS-B. A NextGen aircraft will need RNAV and ADS-B to participate and RNP will be necessary in high-density airspace.

One element of an APNT strategy is the retention of a selected number of instrument landing systems that would provide precision guidance for landing. Not all current ILSs would need to be retained as their purpose shifts from the primary means of aircraft approach guidance and landing to an alternative means, where RNAV/RNP approaches with vertical guidance support normal operations and the ILS provides a means of recovering aircraft in weather in the event of interference. Either a DDI or a DD-aircraft can navigate to an ILS localizer intercept and execute an approach. A GPS-only aircraft would require vectors to the ILS or use a VOR to fly a course to an ILS intercept.

In the current NAS, the RNAV and RNP capabilities enabled by GPS are another layer of positioning and navigation and users are rapidly shifting away from a dependence on ground-based navigational aids. While the need for DME and the ILS to continue is widely accepted as part of the alternative PNT, VOR is a different story.
VORs are beyond or are approaching the end of service life and are not suitable for area navigation. While NextGen calls for precision navigation, VORs only support non-precision approach procedures. Retention of VORs in NextGen is unlikely. A transition strategy calls for a minimum operating network (MON) that retains a limited number of VORs for use as a backup. Any decision on retention of VOR would also require

[5] FAA Air Traffic Organization NextGen & Operations Planning, NextGen Mid-Term Concept of Operations for the National Airspace System, Releasable Version 2.1, September 2010.
[6] As of the publication of this APNT Concept of Operations, the GBAS system is not scheduled for deployment. Additional research is required to support low-visibility approach procedures.

replacement of the aging infrastructure. The purpose of the MON is to preserve the ability to navigate and land in the presence of interference during a transition period until APNT can be researched and developed to mitigate the risk of GPS interference.

For the purpose of the concept of operations for APNT, a VOR MON is used that provides three services: 1) The ability to procedurally climb to 5,000 feet above ground level (AGL) and receive a VOR, proceed direct and depart the VOR to land at an airport using an ILS, 2) retention of VOR-defined routes in mountainous terrain where vectors from the ANSP could not be provided in the presence of interference, and 3) use in providing course guidance and an aid to fly to and receive ANSP vectors to in the absence of ADS-B performance. The decrease in the number of VORs and ultimately their elimination does not consider continued use in Alaska and Hawaii. The VOR is retained during transition because general aviation has equipage for IFR operations. In developing the APNT concept of operations, a MON is assumed.

The APNT CONOPS considers surveillance coverage for separation by the Air Navigation Service Provider (ANSP). In today's NAS, surveillance is evolving from secondary surveillance radar (SSR), backed up by primary radar to a fused product that includes position information from ADS-B. For IFR operations, there are three types of operations: 1) procedural, where there is no surveillance coverage and position reports are used for separation, 2) radar coverage (SSR or Primary) that may include fused positions from both radar and ADS-B, and 3) ADS-B-only surveillance coverage, where ADS-B is dependent on GPS for the position information. This ADS-B-only operation becomes procedural separation at the time of GPS failure. In every case where GPS is providing the position source for ADS-B and fails, there is a need to re-establish the separation distances for the means used. In the case of ADS-B using 3-nm separation the aircraft must be increased in separation to 5-nm separation beyond 40 nm from the SSR site. Likewise, radar-like separation services using ADS-B in airspace with no radar coverage must revert to procedural separation procedures.

In the case where ADS-B provides the only means of surveillance and instrument services are required. GPS interference would represent a common mode failure, where both navigation and surveillance are lost. This is primarily a mountainous terrain problem created by the lack of SSR radar line of sight coverage and offshore, as in the Gulf of Mexico. One possible way around this problem is wide-area multilateration, where position is derived from time of arrival of transponder interrogations. Since multilateration is one of the possible APNT alternatives, it is not considered to be present and part of the NAS in the APNT CONOPS.

4.1 APNT CONOPS Narrative

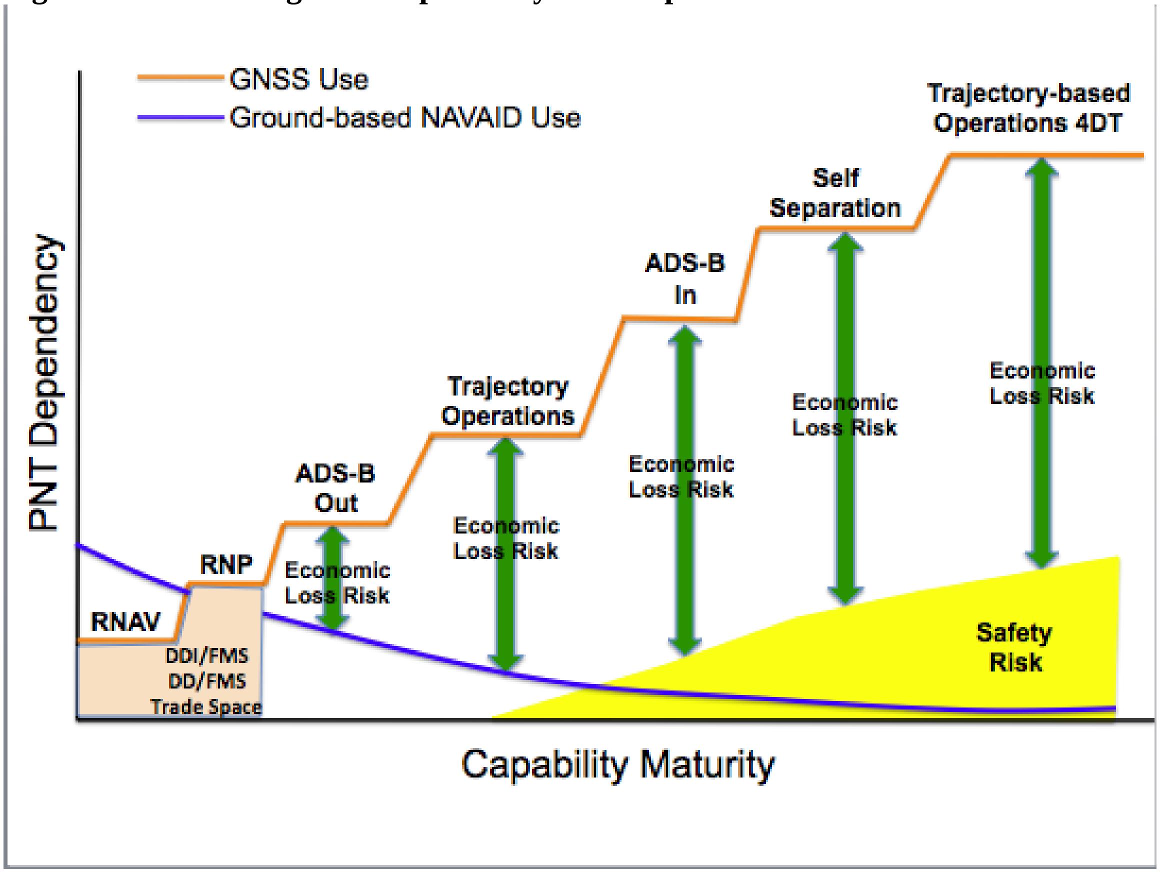
The majority of risk associated with a GPS outage is economic, principally capacity and efficiency losses, as delays are incurred. However, there is also a safety risk element that must be addressed. This safety risk element is tied to two functions. The risks associated with the transition from one aircraft state to another, and the risk associated with changing aircraft separation spacing, discontinuing paired flight activities, the delegation of separation, and self-separation.

This stepped transition to the NextGen Target Environment for PNT is illustrated in Figure 4.1. As NextGen capabilities mature, dependency on precision PNT to support these capabilities will increase. The use of ground-based navigation aids (especially VOR) decline as aviation shifts to full RNAV operations and RNP where beneficial.

Transition to NextGen, from an aircraft equipage standpoint, is in its infancy. While there is greater use of RNAV and RNP through a combination of GPS, DDI and DD with an FMS for aircraft equipage, a trade space exists for operators on what avionics to carry. As the mandate for ADS-B approaches, equipage with GPS will be required. Whether the operator chooses to augment GPS with SBAS or GBAS depends on their respective business cases and the timing for availability of GBAS. Since ADS-B is fully dependent on GPS as its positioning source for automatic position reporting, the ADS-B mandate by 2020 represents the transition point to the Target Environment. It is at that point the avionics mix will certainly change.

Air carriers will have GPS with augmentation as one independent navigation system, legacy DDI or DD with FMS as the other system for en route and terminal arrival and departure, and ILS for precision landing. The least equipped IFR general aviation aircraft should have GPS with augmentation in support of the ADS-B mandate and would likely retain their ILS receiver for precision landing.

Figure 4.1. Increasing PNT Dependency with Capabilities



The economic loss risk associated with a GPS interference event increases with each new set of NextGen capabilities. As such, the value of APNT as an insurance policy against adverse economic impacts and protector of safety increases over time.

4.1.1 Current Environment APNT Concepts

APNT is a program that must provide a backup strategy in the Current Environment because both intentional and unintentional GPS interference happens today. In the current environment, some aircraft can continue to operate along RNAV routes; others who do not have DME-DME will need to rely on published Victor Airways and Jet Routes. For this reason, the APNT Concepts address both the Current and NextGen Target Environment.

4.1.1.1 Non-DME/DME aircraft operators

For the many regional and general aviation aircraft operators that do not have DME/DME equipped aircraft, the current APNT solution is a combination of VOR and ILS. At the moment of interference, their aircraft must transition from RNAV to the use of VOR for departure, climb along a route defined by VOR, and cruise. Their arrival path to perform a non-precision approach would use a VOR or the VOR for course guidance to intercept an ILS to conduct a precision approach. The transition from RNAV to VOR for each aircraft state is provided in Table 4-1. In this case, RNAV is the principal means of navigation at the start of the interference event using GPS augmented by SBAS.

Table 4-1 Summary of Actions at Time of Interference – Non-DME/DME– Current Environment

Aircraft State	At Time of Interference	New State	Notes
01-Parked	Requires new clearance and flight plan to start taxi-out whether in interference service volume or requiring a flight through a service volume of interference.	01-Parked	If in interference area, aircraft needs new routing. If flying to an interference area, aircraft may not depart without ability to navigate at destination if that destination is in interference service volume.
02-Taxi-out	A taxi-out aircraft would receive instructions to return to the ramp until a new flight plan could be attained.	01-Parked	The workload to provide each departing GA aircraft with a new clearance would be an excessive burden for the ANSP within the interference service volume and the extent of the interference would not be immediately known.
03-Takeoff Position	Instructions to taxi back to the ramp until a new flight plan could be attained. At a non-towered airport the aircraft could depart Visual Flight Rules (VFR) and remain VFR until a new IFR clearance is received.	01-Parked	The aircraft would have been planned for an RNAV departure and requires re-planning.
04-Takeoff	Takeoff would proceed and pilot would require radar vectors on course to a VOR-based route structure until clear of the interference. In the absence of radar, pilot would be cleared to climb and proceed to nearest VOR, expect further clearance at arrival.	05-Initial Climb	Trapped in the air at the time of interference or on takeoff roll requires intervention by the ANSP and provides the pilot time to reconfigure navigation. In airspace where ADS-B is the only surveillance source, radar services would also be unavailable, and the ANSP would need to revert to procedural separation. It is more of a safety consequence to stop a takeoff roll than provide new clearances once airborne.
05-Initial Climb	Continue climb with radar vectors or clearance to proceed to a VOR and expect clearance based on VOR infrastructure until out of the interference service volume.	06-Climb	In non-radar environments where surveillance is provided by ADS-B, a VOR within range of the airport would be necessary to provide positive course guidance, especially in mountainous terrain.

Table 4-1 Summary of Actions at Time of Interference – Non-DME/DME– Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
06-Climb	If established on an RNAV departure path, the aircraft would be cleared to transition to a VOR path or be given radar vectors if beyond the range of a VOR.	06-Climb	This climb case is predicated either on being in reception distance of a VOR or radar vectors. In a non-radar environment, the pilot would need to shift to VOR, find a nearby station and provide a radial to report a position for procedural separation to be applied until in radar contact or reporting an actual fix along that radial.
07-Cruise	In interference, the aircraft would maintain heading and altitude until a new clearance is provided by the ANSP. This clearance would direct the aircraft to an airway intercept at an intersection or at the navigational aid to continue the flight. Upon clearing the interference area, RNAV could be resumed at the request of the pilot and with an amended clearance. Radar vectors could be used to get the pilot toward an intercept.	07-Cruise	In cruise below radar coverage and using ADS-B for surveillance, the aircraft would need to determine its position from VOR radials and use position reporting for separation until established in radar contact. This becomes a safety issue in mountainous terrain.[7]
08-Top of Descent Approaching Interference Area	Adequate time exists for the aircraft to either receive a descent with radar vectors to a VOR-defined terminal arrival or transition to a VOR airway or arrival segment.	09-Initial Descent	Depending on the weather and the airport of destination, the pilot may be routed to a different airport that can support an instrument approach and relieve demand on the primary airport. Prior to top of descent there are options for reducing demand at congested airports.
08-Top of Descent in Interference Area, airport not in interference	Radar vectors to a terminal arrival defined by VOR or radar vectors to clear interference; report when GPS operative, or continue VOR arrival path.	09-Initial Descent	In a non-radar environment, with ADS-B also failed, navigation must come from VOR until clear of interference as aircraft moves lower in altitude. Position reporting would be needed within the clearance to descend.

[7] Masking from the terrain diminishes the likelihood of being exposed to interference at lower altitudes in mountainous terrain. The ANSP could retain airways through mountain passes using VORs during the RNAV transition, in which case, the general aviation pilot concerned about GPS being inoperative could fly such a route through the mountainous area and monitor VORs.

Table 4-1 Summary of Actions at Time of Interference – Non-DME/DME– Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
09-Initial Descent	Whether approaching or within interference airspace, the aircraft would transition to using the VOR for course guidance. Depending on workload, radar vectors may be applied if in radar coverage.	10-Arrival	In busy metroplex airspace, the workload to provide radar vectors at current traffic volume is not significant since most aircraft receive vector direction today to join the ILS approach for landing. Outside of radar coverage, this workload increases in a GPS failure, due to terrain clearance needs and position reporting against VOR radials.
10-Arrival	The arrival segment is either radar vectors at the time of interference leading to a standard terminal arrival path or vectors to intercept the ILS. This maneuver may not be at the destination of choice in congested airspace.	11-Approach	In a non-radar environment, the aircraft must transition to a VOR and hold; then proceed outbound to an ILS intercept. This concept eliminates the need to know how to fly a non-precision VOR approach.
11-Approach approaching the initial approach fix (IAF) when interference encountered	If approaching the IAF, the aircraft can transition to ground-based navigation aids.	11-Approach	There is a mix of non-directional beacon (NDB), DME required, VOR to an ILS transition, and radar required locations to get to the ILS. The NDB will not be in the Target Environment and any APNT procedure should not rely on DME for recovery of general aviation aircraft.
11-Approach inside the IAF	Once starting an instrument approach using RNAV, a missed approach is appropriate at time of failure to allow a transition to an ILS. If the IAF is defined by VOR, or the aircraft is already on an intercept angle to reach the localizer prior to the final approach fix (FAF), the aircraft could continue if the ILS was also being monitored at the time of interference.	12-Approach	In absence of surveillance, no vectors would be available and the pilot could not use RNAV to reach the missed approach point. Pilot must transition to ILS non-radar missed and transition to a VOR for holding until cleared for another approach. In interference, there is no holding possible with GPS alone.

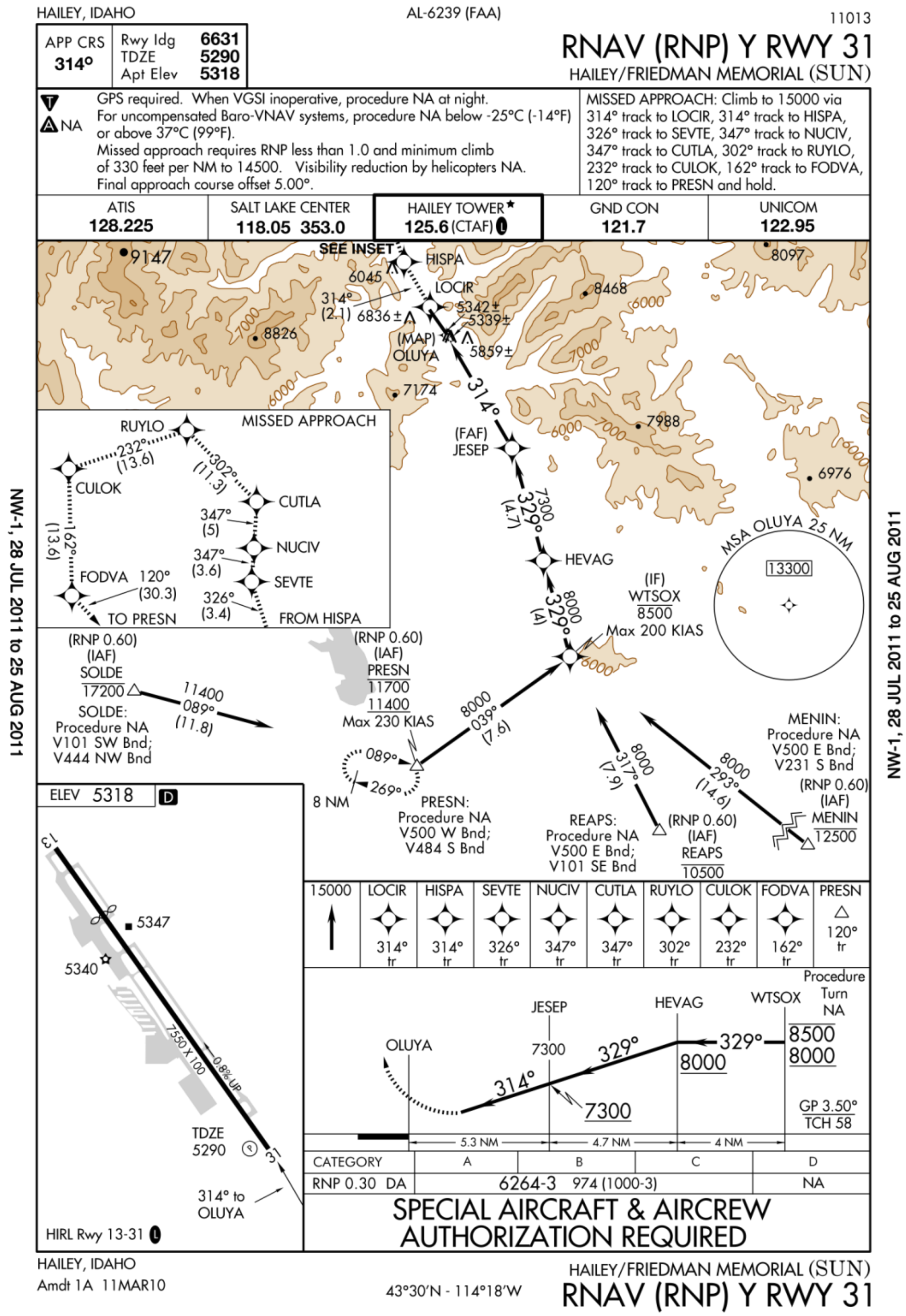
Table 4-1 Summary of Actions at Time of Interference – Non-DME/DME– Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
12-Approach	Once inside the FAF, the pilot has little choice but to execute a missed approach if GPS is lost. Many RNAV approaches use RNAV procedures and precision for the missed approach. This guidance would not be available in the presence of interference. A procedural missed approach made up of headings and climb rates would be needed in the absence of radar.	13-Missed Approach	In a non-radar environment, the aircraft must avoid terrain based on being able to receive a VOR and would need to either reach radar coverage, fly out of the interference area, or be able to fly to an alternate using VOR. Returning to fly the ILS is not viable without a VOR feeder radial to the ILS intercept in the absence of surveillance coverage.
14-Landing	If at or beyond decision altitude, the choice is to land or go missed approach. A GPS failure impacts the missed approach but does not impact landing	15-Landing Rollout	
15-Landing Rollout	Not impacted by GPS failure except for loss of cockpit moving map functions.	16-Taxi-in	Landing rollout guidance and taxi guidance can be impacted in low-visibility operations.
16- Taxi-in	Not impacted by GPS failure except for loss of cockpit moving map functions.	01-Parked	

As can be seen from Table 4-1, in those cases where the aircraft is operating outside of radar coverage and surveillance is provided solely by ADS-B, the loss of ADS-B along with GPS can place the lower end general aircraft in a position of not knowing its position and having no way of navigating without VOR. Missed approach procedures in non-radar airspace must consider a procedural missed approach for when there is a GPS interference event.

The worst case approach is shown in Figure 4.2 and has been selected to address APNT concept safety points. GPS is required to execute this approach, including the missed approach segment. The approach has been designed for GPS-based access to the airport. However, the airport is not served by radar, and ADS-B extends surveillance coverage to operate as if radar were present. The net effect is that radar vectors cannot serve as a solution in dealing with aircraft separation and the provision of vectors for course guidance. If the aircraft is inside of the final approach fix at JESEP and suffers a GPS outage, and does not have course guidance the aircraft would be forced to break out with a climbing left turn to avoid terrain, continue to climb to the south until at or above the 13,300-foot minimum safe altitude. The turn would be needed because the pilot could not judge a missed approach path without navigation. Public use of GPS-based RNP becomes commonplace as NextGen matures. In an APNT concept, this approach will have a procedural missed approach as a backup, and will be heading driven, until the flight crew could climb into APNT service coverage. An alternative at many airports will be for the flight crews to monitor an ILS back-course. However, since this airport does not have an ILS, this option does not exist. Any aircraft outside of the Final Approach Fix (FAF) and out of radar coverage at the time of interference would be obligated to proceed to an alternate for landing.

Figure 4.2. RNAV (RNP) Y Runway 31 Approach at Friedman Memorial



For an aircraft operating in the Current Environment that is GPS equipped, with VOR and an ILS as their alternate source of navigation and landing, the pilot would observe the GPS INOP, would receive an aural alert and know that at least the aircraft had lost navigation. If ADS-B equipped, there would be a similar ADS-B INOP and aural alert. The pilot would only know if the failure is an interference event if the pilot was using ADS-B In, because other aircraft in the vicinity would lose their ADS-B Out position reporting. The pilot would likely make a radio call to report the outage. The workload of the ANSP controller would go up as radio calls cloud the airwaves.

Pilots are expected to fly their clearance and continue until the clearance is modified. A pilot approaching a turning waypoint would not know position and time of arrival if RNAV were not available. The ANSP would need to provide a radar vector on course and direct the aircraft until established on a VOR-based routing, an ILS intercept for landing, or flight out of the interference service volume.

In non-radar environments there are no radar vectors. In this case, the pilot must establish position from VOR radials, report position, and receive a new clearance, most likely to proceed to that VOR from the reported position. This gives the ANSP controller and pilot time to re-plan the route of flight and possibly change the destination. In the concept of the VOR minimum operating network, the pilot would climb to a designated altitude, receive the VOR signal and proceed along that radial to the VOR.

A prudent pilot would have pre-selected the nearest VOR as the pilot flies the trajectory, especially in a climate of interference events elsewhere in the NAS. Likewise, before starting an RNAV approach into an airport that also has an ILS on that runway, the ILS would be tuned, identified, and be ready to use if necessary.

4.1.1.2 DME/DME Aircraft Operations

For air carrier operations there are more options because of current equipage. In the mix of avionics are added aircraft that can use DME-DME to update their inertial and the aircraft have flight management systems, or some aircraft that do not have inertial use DME-DME to update position within the FMS. These aircraft (DDI-aircraft and DD-aircraft) are capable of supporting departure climbs, en route cruise, descents and arrivals without dependence on GPS. DDI and DD aircraft are not able to fly RNAV RNP approaches but can use their capabilities in the presence of interference to fly an intercept to the ILS. For these aircraft, the alternative navigation to GPS is a combination of DME-DME position updates and ILS for landing.

Table 4-2 provides the summary of actions at the time of interference for the Current Environment for air carrier aircraft and higher end general aviation aircraft equipped with either DDI or DD. Note that 14 CFR 121.349 requires two independent means of navigation and for the existing fleet this would be RNAV from GPS and DME-DME with ILS serving as the other independent means for approach and landing. Note that DD aircraft must be within coverage of multiple DMEs to perform all the actions described in Table 4-2.

Table 4-2 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial Aircraft - Current Environment

Aircraft State	At Time of Interference	New State	Notes
01-Parked	Requires new clearance and flight plan to start taxi-out whether in interference service volume or requiring a flight through a service volume of interference. Will likely experience a gate hold while changes are being made.	01-Parked	If in interference area, aircraft needs new routing. If flying to an interference area, aircraft may not depart without ability to navigate at destination if that destination is in interference service volume. If the aircraft is fueled, alternates are already defined.
02-Taxi-out	A taxi-out aircraft would receive instructions to continue. DDI aircraft would have received an IRU update from GPS prior to the interference event. In low-visibility, cockpit-moving maps would not function. Aircraft dependent on synthetic vision where current position from GPS is needed to drive the database would not be available for low-visibility operations. Since Airport Surface Detection Equipment, Model X (ASDE-X) would be available and operating from the aircraft's transponder, a failure of GPS and ADS-B would not adversely impact surface movement tracking by the ANSP.	02-Taxi-out	The workload to provide each departing aircraft with a new clearance would be an excessive burden for the ANSP within the interference service volume at major airports and the extent of the interference being immediately known. This mapping of interference is a critical element of the Future Environment, but for now, DDI and DD aircraft can depart all high-density airports because it is assumed that DME coverage is sufficient under APNT to receive updates within a minute of receipt of a position solution. Some delays may be experienced at high-density locations to regulate demand in the airspace if there are a number of aircraft incapable of self-navigation and requiring radar vectors for arrival.
03-Takeoff Position	Aircraft would be cleared for takeoff to follow an RNAV departure path using DDI and DD.	04-Takeoff	Within one minute of a DME-DME solution, the aircraft would be capable of position update. Surface movement detection on ASDE-X airports would provide controllers with aircraft position in low visibility.

Table 4-2 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial Aircraft - Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
04-Takeoff	Takeoff would proceed and pilot would use DDI/DD until clear of the interference. In the absence of radar, pilot would be cleared to climb and proceed on course.	05-Initial Climb	In non-radar airspace, surveillance provided by ADS-B would also be lost, so in non-radar airspace ANSP would need to revert to procedural separation. This requires the pilot to report positions and the controller and pilot can expect an increased communications workload during initial climb.
05-Initial Climb	Continue climb with DDI/DD RNAV until out of the interference service volume.	06-Climb	In non-radar environments where surveillance is provided by ADS-B, position reporting would be used.
06-Climb	If established on an RNAV departure path, the aircraft would continue an RNAV departure.	06-Climb	This climb case is predicated either on being in reception service volume for multiple DME with the correct geometry to resolve positions for both departing and arriving aircraft. In a non-radar environment, the pilot would fly the RNAV procedure. An aircraft with an IRU has the ability to coast. For DD aircraft lacking an IRU, they would need to be in reception range of multiple DME.
07-Cruise	In interference, the aircraft would continue using DDI or DD. Upon clearing the interference area, RNAV could be resumed using GPS and RNP precision would improve. Support from the ANSP would not be needed and there would be minimal increase in workload, both in the cockpit and for the ANSP in dealing with DDI and DD aircraft.	07-Cruise	In cruise below radar coverage and using ADS-B for surveillance, the aircraft would need to use position reporting for separation until established in radar contact. Minimum safe altitudes for terrain avoidance would be necessary.[8] Aircraft with synthetic vision would be unable to use the capability without the GPS position. Terrain avoidance capabilities tied to the FMS would continue to receive position information and function.

[8] Except for arrival and departure to mountainous airports, en route air carrier operations are at sufficient altitude to receive valid DME-DME position solutions.

Table 4-2 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial Aircraft - Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
08-Top of Descent Approaching Interference Area	Aircraft with DDI and DD can expect to continue to Top of Descent and use RNAV to reach an intercept to an ILS.	09-Initial Descent	Depending on the weather and the airport of destination, the pilot may be routed to a different approach path to balance workload by the ANSP. Prior to top of descent there are options for reducing demand at congested airports.
08-Top of Descent in Interference Area, airport not in interference	RNAV using DDI and DD; report when GPS operative for RNAV RNP approach and landing.	09-Initial Descent	In a non-radar environment, with ADS-B also failed, Position reporting would be needed within the clearance to descend.
08-Top of Descent in Interference Area, airport in interference	Adequate time exists for the aircraft to continue the RNAV descent and expect radar vectors to execute an ILS approach. Many airports today use ILS procedures where radar vectors are required for sequencing aircraft. DDI and DD aircraft do not require as much service from the ANSP during interference because they can sustain RNAV arrivals.	09-Initial Descent	DDI and DD aircraft should only be limited by needed reductions in demand due to ANSP workload. In non-radar ADS-B airspace, where ADS-B is lost, leader-follower relationships would also be lost using ADS-B In applications.
09-Initial Descent	Whether approaching or within interference airspace, the aircraft would continue the RNAV arrival path. Depending on workload, radar vectors may be applied if in radar coverage.	10-Arrival	In busy metroplex airspace, the workload to provide radar vectors at current traffic volume is not significant since most aircraft receive vector direction today to join the ILS approach for landing. Outside of radar coverage, this workload increases in a GPS failure, due to terrain clearance needs and position reporting to support separation.
10-Arrival	The arrival segment is either continuation of DDI and DD RNAV or radar vectors at the time of interference leading to a standard terminal arrival path or vectors to intercept the ILS.	11-Approach	In a non-radar environment, the aircraft may need to hold; then proceed to an ILS intercept. Aircraft capable of holding would do so while the ANSP deals with aircraft having no capability for course guidance or for those transitioning to VOR.

Table 4-2 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial Aircraft - Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
11-Approach approaching the initial approach fix (IAF) when interference encountered	If approaching the IAF for an RNAV RNP procedure, the aircraft can transition to ILS before the IAF if available for the runway or use RNAV to reposition for a different runway with an ILS. In most cases, the aircraft would receive radar vectors to an ILS intercept or a radius to fix turn to an ILS localizer.	11-Approach	In the transition from the Current Environment to the Target Environment, the number of ILS's would be reduced, since the ILS in the Target Environment serves as an alternative navigation source and RNAV/RNP is primary. The targeted ILS's to retain are the CAT II/III units and CAT I where needed to recover aircraft in the presence of interference.
11-Approach inside the IAF	Once starting an instrument approach using RNAV, a missed approach is appropriate at time of failure to allow a transition to an ILS. If the IAF is defined by RNAV, or the aircraft is already on an intercept angle to reach the localizer prior to the final approach fix (FAF) the aircraft could continue if the ILS was also being monitored at the time of interference.	12-Approach	In absence of surveillance due to ADS-B failure, the pilot could not rely on radar vectors to the ILS or for the missed approach. DDI and DD aircraft would be capable of flying an intercept and a missed approach at most airports supported by positioning from DME-DME.
12-Approach	Once inside the FAF, the pilot has little choice but to execute a missed approach if GPS is lost. Many RNAV approaches use RNAV procedures and precision guidance with RNP for the missed approach. This precision may not be available for DME-DME without upgrade to the ground infrastructure. A procedural missed approach made up of headings and climb rates would be needed in the absence of radar coverage for vectors, where there is poor DME geometry or DME service volume coverage is inadequate for the missed approach.	13-Missed Approach	In a non-radar environment, the aircraft must avoid terrain based on positive course guidance from DDI or DD. Returning to fly the ILS at that same airport and runway is only viable if the missed approach provides a path for a subsequent ILS intercept in the absence of surveillance coverage and radar vectors.

Table 4-2 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial Aircraft - Current Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
14-Landing	If at or beyond decision altitude, the choice is to land or go missed approach. A GPS failure impacts the missed approach but does not impact landing	15-Landing Rollout	
15-Landing Rollout	Not impacted by GPS failure except for loss of cockpit moving map functions.	16-Taxi-in	Landing rollout guidance and taxi guidance can be impacted in low-visibility operations.
16- Taxi-in	Not impacted by GPS failure except for loss of cockpit moving map functions.	01-Parked	

The DDI and DD avionics equipage works to provide an APNT that reduces ANSP and pilot workload in interference. This is especially true at high-density airports. The ability to continue to dispatch and continued support of arrivals meets the APNT pillar that supports continued operations to deny the interferer an economic target.

From the pilot's perspective in the Current Environment, GPS interference would appear as a GPS INOP on the primary flight display and an alert. Since the aircraft is also monitoring RNP performance, RNP will degrade and may produce an alert depending on the avionics setup. An initial workload burden will occur as pilots report and controllers acknowledge multiple outages of GPS.

In the interference scenarios used at Miami, the interference is intermittent, meaning that both the ANSP and the aircraft pilot/operator can expect an interference event at any time in the future. With enough regularity such interference is more than a nuisance. When interference is expected, the aircraft operator would plan for such an event. In the Current Environment, the impact is small, since most approach procedures at Miami International Airport require radar for sequencing. However, depending on the periodicity of interference events, operators would begin to plan to not use RNAV and RNAV/RNP procedures. This would limit approach and departure options and impact airport throughput.

4.1.2 Target Environment APNT Concepts

In the Target Environment, APNT is supporting key capabilities of the NextGen CONOPS, including:

- Network-centric operations – where information is shared with stakeholders in near-real time, providing common situational awareness and greater strategic planning,
- Collaborative Air Traffic Management (CATM) – where information collected and shared is used to guide decisions on flows and system performance,

- Precision Navigation and Surveillance – where precision use of RNAV with RNP becomes a matter of routine so as to open up more airspace trajectories and support increased arrival and departure rates in high-density airspace and airport operations, and
- Trajectory-based Operations – where the 4 D trajectory is used by automation (both on the aircraft and at the ANSP) to merge, sequence and separate aircraft.

The NextGen CONOPS calls for aircraft to be separated by automation due to the density of traffic that would exceed the capabilities for the air traffic controller to handle. Rather, the air traffic controller would handle "control-by-exception," where the controller deals with aircraft that are approaching or are outside of their 4 D trajectory and require correction. The problem arises when the number of aircraft that must be handled by exception exceeds the ability of the controller to handle that traffic. This would be the case if GPS failed in the airspace under TBO operations without an alternative PNT.

Under TBO automation, looks ahead along the trajectory, assessing conformance with the agreed-upon trajectory, and comparing one aircraft against all other aircraft in the vicinity. Automation then provides actions for the controller to select for implementation, keeping the controller's situational awareness with tools designed to strategically and tactically deal with flows of traffic and actual separation.

TBO functions gate-to-gate, with surface and airborne functions built around the 4 D trajectory and a common set of shared information. Key to the automation processes is the sharing of aircraft preferences, equipage and capabilities carried in what is called the flight object. Think of the flight object as a flight plan with extensions that contain information about the flight, including its agreed-to 4 D trajectory. There is a contract formed between the pilot/operator and the ANSP that is tied to this 4 D trajectory. The expectation on both sides of the operation is that the trajectory will be flown as accepted and approved.

The ANSP will update the 4 D trajectory as the flight progresses and the operator/pilot may request changes in the trajectory. Most changes are handled strategically, meaning that the action would occur further out in time than 20-30 minutes. Inside this time window, changes in trajectory are considered to be tactical changes. This concept is important to the APNT concept because strategic actions reduce demand approaching the interference area and tactical actions deal with delivering changes to trajectories necessary to sustain separation and recover aircraft caught in the interference area.

Today, pilots and controllers have a clear understanding of performance in the other three dimensions - lateral, longitudinal and vertical. The fourth element of the trajectory is time. It is time of a current and future position that provides automated separation. It is time that is used to sequence and merge aircraft. Time use requires a common time (and performance standard) to be used by all aircraft and ATC automation. Precision is measured in seconds. The parameter tolerances are not known at this time and require research; however, the value is expected to have variability between aircraft and automation in the range of 3 to 5 seconds.

The JPDO TBO Study Team has introduced a concept of required time performance, or RTP. RTP is the time equivalent to RNP and serves the same purpose, setting a tolerance on performance. In some airspace, RTP is measured in minutes; in more dense traffic it is measured in seconds. RTP is used by automation to plan and execute separation, using conformance monitoring to assess the progress of the flights, define takeoff times, and reduce variability in the system to gain efficiency and capacity.

Representative RTP values for high-density airspace operations include:

- Takeoff time for taxi-out ± 1 minute
- Climb ± 12-18 seconds
- Top of Climb ± 1-3 minutes
- Cruise ± 1-3 minutes
- Top of descent ± 1 minute
- Metering fix on arrival ± 12-18 seconds
- Final approach fix ± 3-4 seconds
- Runway threshold ± 3-4 seconds

In low-density traffic, RTP has greater tolerance, approaching the performance of today's estimated time of arrival. The precision is driven by traffic volume and airspace configuration and considers the capabilities of the aircraft, as identified from the flight plan and flight object. These representative RTP values are subject to evaluation by research as the TBO concepts are developed.

Required navigation performance also changes in the Target Environment, becoming more precise in order to support 3-nm separation and to increase the options for arrival and departure paths. Representative RNP values expected in the Target Environment include:

- Climb – RNP 0.3 – supporting additional departure paths until (diverging likely below 12,000 to 15,000 feet)
- Climb – RNP 1.0 – above 12,000 to 15,000 feet to top of climb
- Cruise – RNP 1.0 to 2.0 depending on flight track
- Top of Descent – RNP 1.0
- Descent – transition from RNP 1.0 to RNP 0.3 for converging segments of the arrival
- Arrival – RNP 0.3
- Approach –RNP 0.1 or less

An alternative PNT system would need to support at least RNP 0.3 to sustain departure and arrival paths at high-density airports and support navigation to an ILS intercept for aircraft recovery in the presence of interference. RNP 0.3 is needed in the terminal airspace to increase the number of arrival and departure paths available to manage the density of traffic.

The risk of GPS failure by interference is a common mode failure, losing both positioning, navigation and position reporting through ADS-B. A significant number of ADS-B In capacity and efficiency enhancements will be lost. Surveillance coverage based on ADS-B only will lead to loss of surveillance and therefore, the loss of the use of radar vectors to help recover aircraft. Fortunately, most major airports have secondary surveillance coverage and the impact is limited to airspace that has low-density traffic.

However, most of the anticipated ADS-B In applications for leader-follower maneuvering will not be available during interference. This will shut down paired approaches to closely spaced parallel runways and limited self-separation for passing, merging and spacing maneuvers. Not being able to "see" the other aircraft electronically as a follower aircraft limits efficiency and capacity in the NextGen Target Environment.

In developing the operations concept, the role of aircraft and ANSP automation must be factored in. On the aircraft, a DDI aircraft can continue to operate and sustain TBO and precision navigation; provided it can deliver RNP 0.3. ADS-B. RNP 0.3 in the terminal area is planned for locations where economically beneficial or required by safety. The inertial system can also coast the aircraft and provide a time period where no changes are needed from the ANSP; this includes the ability to locate a waypoint and change direction consistent with the 4 D trajectory. DD aircraft with an FMS can also continue, provided the aircraft is within the service volume of multiple DME. An aircraft without DME must rely on radar vectors and must be in coverage of that radar. If outside of secondary surveillance coverage, the aircraft has no positioning, navigation or reporting through

The ADS-B specifications do not allow the use of position determination from sources other than GPS, so even the DDI and DD aircraft would not report positions automatically through ADS-B in the presence of interference.

A GPS-only aircraft may not have VOR available in the Target Environment. VOR is planned to first decrease to a minimum operating network and then to be shut down fully some time after 2020. The FAA is currently defining the structure of the MON and work is needed on further reduction below this MON level of service. The reduction in VOR service is not planned for Alaska or Hawaii and a limited number of VORs may also need to be retained in mountainous terrain.

Appendix B provides a graphical representation of the NextGen automation functional areas. Two elements of automation, the Strategic TBO Evaluation and the Conformance Monitoring functions play key roles in APNT and send corrective actions to other elements and distribute information across the network-centric operations for common situational awareness.

The APNT CONOPS for the NextGen Target Environment logically starts with the detection and determination of the extent of the interference event. While the pilot will know that her/his aircraft cannot use GPS due to cockpit alerts, the ANSP's automation needs to know the service volume of the interference and provide the controller with the necessary corrections.
As the surveillance data network detects the loss of ADS-B NIC-NAC-SIL performance, the aircraft is flagged as ADS-B inoperative. At the loss of ADS-B due to the loss of GPS, the position and altitude and time for the aircraft is known and transferred through the surveillance network. This information arrives at the Strategic TBO Evaluation function that compares aircraft capabilities and selects a pre-defined set of options based on aircraft equipage, position relative to the service volume mapping. The evaluation function receives information from the Conformance Monitoring function as to the progress being made on the 4 D trajectory.

Knowing the position of the aircraft in the interference service volume, the capabilities of the aircraft from the flight object, and the progress along the 4 D trajectory, the Strategic TBO Evaluation function publishes to the tactical controller a time-sequenced list of corrective actions. These actions will have the aircraft either continue based on DDI and DD capabilities, provide changes in altitude or heading to attain changes in the 4 D trajectory necessary for separation, or use control-by-exception for those aircraft without a DDI/DD capability. The tactical controller can send, via data link, a batch of these changes or use voice to deal with the changes in a time-based priority order. The same set of changes flow to Conformance Monitoring to modify trajectories and define new alert parameters for the controller. The Conformance Monitoring function carries the current position information, the old trajectory and the changes ordered in time priority.

Trajectory changes also flow to the strategic controller, who deals with aircraft that are more than 20 to 30 minutes away from a needed change in trajectory. This might include aircraft in the interference volume that are just minutes away from a needed change in trajectory. The strategic controller may also provide alternative trajectories for aircraft approaching the interference area. A DDI aircraft can continue at high-density airports all the way to the intercept of the ILS for landing consistent with the 4 D trajectory and not contribute to the controller or pilot workload.

At the same time that the Strategic TBO Evaluation function publishes the immediate tactical and strategic changes within the volume of the interference area, the location of the interference area is posted through network-centric operations. This posting includes actions to re-route aircraft approaching the interference area that are en route through the interference area, and not able to navigate in the interference area based on information contained in their flight object. DDI/DD can continue into the interference area because they are capable of their own navigation in the presence of interference.

If demand must be reduced within the interference service volume, aircraft approaching the area are re-routed. If an aircraft is not able to navigate in interference, radar vectors are provided for landing outside of the interference area, diverting these aircraft while still in surveillance coverage. Some of these aircraft traveling to a destination outside of the interference would be given an altered 4 D trajectory taking the aircraft around the interference. Only aircraft capable of self-navigation and under surveillance would continue to destination. An aircraft not in radar coverage but capable of navigation would revert to position reporting until radar contact is established.

Automation's role is to not only provide the controller with a priority list of actions, but to examine aircraft scheduled to enter the interference area and make decision recommendations to manage demand and optimize a new steady-state for the airspace. Information is provided for Strategic Resource Planning and a game plan activated that provides information for trial planning for flights that have not yet departed. The advantage of network-centric operations is that common situational awareness is provided to those that need the information to make decisions.

This rapid mapping of the interference area (a matter of seconds) also flows to national operations centers for use in narrowing the search for the source(s) of interference. By using a line-of-sight calculation from each aircraft, the area on the ground to search for the interference source is reduced.

The pre-planned actions taken in response to an interference event are dependent upon where aircraft are in the system at the time of interference and the density of the traffic. The options available are dependent upon aircraft capabilities and the position of the aircraft relative to other aircraft. An aircraft in surveillance coverage independent of ADS-B is handled differently from one that is not. An aircraft on approach to a runway in weather and not able to land because of visibility that must execute a missed approach is treated first as a control-by-exception action by the tactical controller, as dictated by the urgency of the action. In non-radar environments where IFR services have been extended by ADS-B and where the aircraft is unable to follow an alternative PNT guidance, the aircraft will execute a procedural missed approach with heading and climb performance specified with the procedure.

4.1.2.1 Pre-Planned actions by Low-End General Aviation

For the low-end general aviation aircraft, under the NextGen Target Environment, the VOR may no longer present. This means that if operating in a non-radar environment, there are no options for continuing navigation in the presence of interference without APNT being carried on the aircraft. This is one of the factors that must be considered in further reduction of VORs below the level of the VOR MON. However, the vast majority of low-end IFR general aviation aircraft fly in a radar environment. It is only in the mountainous west where radar coverage is not available at the lower altitudes to provide radar vectors in the presence of interference.

Table 4-3 Summary of Actions at Time of Interference – Non-DME/DME and non-DME/DME Inertial Aircraft – NextGen Targeted Environment

Aircraft State	At Time of Interference	New State	Notes
01-Parked	Requires new clearance and flight plan to start taxi-out whether in interference service volume or requiring a flight through a service volume of interference.	01-Parked	If in interference area, aircraft needs new routing. It may depart and remain VFR. If flying IFR to an interference area, aircraft may not depart without ability to navigate at destination if that destination is in interference service volume.
02-Taxi-out	A taxi-out aircraft would receive instructions to return to the ramp until a new flight plan could be attained.	01-Parked	The workload to provide each departing GA aircraft with a new clearance would be an excessive burden for the ANSP within the interference service volume and the extent of the lower altitude interference may not be fully known because of the lack of aircraft reporting. As a result, the ANSP automation would assume that the interference extends to the ground.
03-Takeoff Position	Instructions to taxi back to the ramp until a new flight plan could be attained. At a non-towered airport the aircraft could depart VFR and remain VFR until a new IFR clearance is received.	01-Parked	The aircraft would have been planned for an RNAV IFR departure and requires re-planning.
04-Takeoff	Takeoff would proceed and pilot would require a procedural runway heading and climb rate until in radar contact or the aircraft is clear of the interference. In mountainous terrain, this climb-out may be a standard rate continuous turn until clear of terrain and in radar contact. If the airport is VMC, the pilot would be advised to return and land.	05-Initial Climb	Trapped in the air at the time of interference or on takeoff roll requires intervention by the ANSP and provides the pilot time to reconfigure navigation. In non-radar airspace, ADS-B would also be lost and ANSP would need to revert to procedural separation. It is more of a safety consequence to stop a takeoff roll than provide new clearances once airborne.

Table 4-3 Summary of Actions at Time of Interference – Non-DME/DME and non-DME/DME Inertial Aircraft – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
05-Initial Climb	Continue climb with radar vectors until out of the interference service volume.	06-Climb	In non-radar environments where surveillance is provided by ADS-B and in IMC, little choice exists but to provide a climb procedure based on spiraling up until clear of terrain and reaching radar contact. This is an unacceptable procedure if icing is forecasted and requires a climb through icing.
06-Climb	If established on an RNAV departure path, the aircraft would be cleared to continue climb and given a time to assume a new heading that would approximate climb performance from information derived from the flight object.	06-Climb	This climb case is predicated on the expectation of when the aircraft would clear the interference area and a calculated heading, speed and altitude solution provided by automation and capable of being executed by the pilot to first clear terrain; then clear other traffic; then reach radar coverage. This is an emergency application of expected trajectory progress until established in radar coverage.
07-Cruise	In interference, the aircraft would maintain heading and altitude until a new clearance is provided by the ANSP. This clearance would consider the aircraft capabilities, weather conditions, and traffic density. Vectors may be provided to remove the aircraft from the area through diversion to an airport outside of the interference area. Upon clearing the interference area, RNAV could be resumed at the request of the pilot and with an amended clearance. Radar vectors could be used to get the pilot toward an intercept to an RNAV path en route to destination.	07-Cruise	In cruise below radar coverage and using ADS-B for surveillance, the aircraft would need to determine its position from ground reference if available and use position reporting for separation until established in radar contact. This becomes a safety issue in mountainous terrain.[9]

[9] Masking from the terrain diminishes the likelihood of being exposed to interference at lower altitudes in mountainous terrain. However, positive course guidance through mountainous terrain may not be available, forcing the aircraft to reverse course to remain in GPS coverage.

Table 4-3 Summary of Actions at Time of Interference – Non-DME/DME and non-DME/DME Inertial Aircraft – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
08-Top of Descent Approaching Interference Area	Adequate time exists for the aircraft to descend with radar vectors to an ILS runway for landing.	09-Initial Descent	Depending on the weather and the airport of destination, the pilot may be routed to a different airport that can support an instrument approach and relieve demand on the primary airport. Prior to top of descent there are options for reducing demand at congested airports.
08-Top of Descent in Interference Area, airport not in interference	Radar vectors to a terminal arrival or radar vectors to clear interference; report when GPS operative.	09-Initial Descent	In a non-radar environment, with ADS-B also failed, the aircraft should be given an altitude change to clear terrain, report altitude as necessary for separation, and place the aircraft on a heading, based on last known position to fly out of the interference area.
08-Top of Descent in Interference Area, airport in interference	Adequate time exists for the aircraft to descend with radar vectors to an ILS runway for landing. This arrival may not be to the airport of choice as the automation begins to reduce demand within the impacted area.	09-Initial Descent	In a non-radar coverage area with the failure of ADS-B, the options become climbing into radar coverage on a heading, leveling off and be given a heading to fly that clears terrain, and takes the aircraft out of the interference area.
09-Initial Descent	Whether approaching or within interference airspace, the aircraft would require radar vectors to continue.	10-Arrival	In busy metroplex airspace, the workload to provide radar vectors is determined by traffic volume with the objective to join the ILS approach for landing. Outside of radar coverage, the descent would need to be terminated in favor of terrain clearance.
10-Arrival	The arrival segment includes radar vectors at the time of interference leading to an ILS. This maneuver may not be at the destination of choice in congested airspace.	11-Approach	In a non-radar environment, the aircraft would not be able to continue, being given an altitude and direction to climb to avoid terrain.

Table 4-3 Summary of Actions at Time of Interference – Non-DME/DME and non-DME/DME Inertial Aircraft – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
11-Approach approaching the initial approach fix (IAF)	If approaching the IAF, the aircraft can receive vectors to the ILS.	11-Approach	If the aircraft is outside the coverage of radar surveillance and not already established on an intercept to an ILS, the aircraft would need to climb on a heading that avoids terrain and continue the climb until either in radar contact, depart the interference area, or reach VFR conditions. The controller will have been provided with local weather information, the floor of the radar coverage, and distance to clearing the interference as part of network-centric operations.
11-Approach inside the IAF	Once starting an instrument approach using RNAV, a missed approach is appropriate at time of failure. Radar vectors would guide the missed approach and return for an ILS or routing to another nearby airport outside of the interference area.	12-Approach	In absence of surveillance, no vectors would be available and the pilot could not use RNAV to reach the missed approach point. Headings and rates of climb to avoid terrain associated with the approach would be needed.
12-Approach	Once inside the FAF, the pilot has little choice but to execute a missed approach. Many RNAV approaches use RNAV procedures and precision for the missed approach. This guidance would not be available in the presence of interference. A procedural missed approach made up of headings and climb rates would be needed in the absence of radar coverage.	13-Missed Approach	In a non-radar environment, the aircraft must avoid terrain and would need to either reach radar coverage, fly out of the interference or seek VMC conditions.
14-Landing	If at or beyond decision altitude, the choice is to land or go missed approach. A GPS failure impacts the missed approach but does not impact landing	15-Landing Rollout	
15-Landing Rollout	Not impacted by GPS failure except for loss of cockpit moving map functions.	16-Taxi-in	Landing rollout guidance and taxi guidance can be impacted in low-visibility operations.
16- Taxi-in	Not impacted by GPS failure except for loss of cockpit moving map functions.	01-Parked	

In the absence of radar coverage with both GPS and ADS-B inoperative and no other means of surveillance, an aircraft that lacks an APNT is limited to headings and rate climbs to clear terrain. Separation between aircraft becomes a major workload if actually in IMC conditions or at night. For arrivals at airports with mountainous terrain, a GPS-out procedure is needed or an alternative to radar coverage such as multilateration must serve as the surveillance gap filler. The tradeoff between carrying an APNT and providing an alternative to radar coverage is dependent on traffic volume and the risk of interference impacting the area. This is not an issue in high-density airspace since there is adequate radar coverage retained to support radar vectors for those few aircraft that do not have a requirement for alternate PNT.

One function possible in the ANSP automation that would combine flight object information with terrain data and the last known position of the aircraft would be a series of time-based heading and altitude changes built around a confirmed airspeed. This would provide the ANSP with the equivalent of a pre-calculated dead reckoning capability within the automation to first clear the aircraft to a minimum safe altitude or radar coverage, whichever occurs first. This concept of ANSP dead reckoning is feasible. Likewise, in the Target Environment, the aircraft may have a "pilot assistant" as introduced by the TBO Study Team, where aircraft automation is continually calculating position and performance. The concept of automated dead reckoning requires concept development and research and is not part of the scope of APNT.

4.1.2.2 Pre-Planned actions by Airlines

For Miami, the interference scenario used to develop the APNT CONOPS involves an intermittent interferer who impacts the airport for a range of approximately 60 miles. The NextGen Future Environment is using precision navigation and TBO for arrivals and departures at Miami International Airport. At the moment of interference, the service volume is mapped. Due to the traffic density, measures are put into place to reduce demand within the airspace by taking strategic actions to re-route some traffic, divert some to locations outside of the interference area, and allow certain aircraft with APNT to continue. Initially, throughput is degraded, not unlike a snow or thunderstorm event at the airport. As demand stabilizes, the airport is able to continue landing and departing aircraft.

The problem with an intermittent interferer is that it will be difficult to locate this mobile interferer and shut the perpetrator down. The ANSP and the airlines will revert to procedures based on radar vectors to ILS approaches and reduce the overall efficiency of the arrival airspace. Departures will also be reduced because not all aircraft would be capable of departing in IMC without radar vectors. The DDI/DD capable aircraft require an initial climb to receive an updated position from DME-DME, so radar departures would be used. Departures from airports not covered by surveillance could not be supporting in IMC. Table 4-4 summarizes the actions at the moment of interference based on aircraft state. Note that DD aircraft must be within coverage of multiple DMEs to perform all the actions described in Table 4-4.

Table 4-4 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial – NextGen Targeted Environment

Aircraft State	At Time of Interference	New State	Notes
01-Parked	Requires new clearance and flight plan to start taxi-out whether in interference service volume or requiring a flight through a service volume of interference. Will likely experience a gate hold while changes are being made.	01-Parked	If in interference area, aircraft needs new routing. If flying to an interference area, aircraft may not depart without ability to navigate at destination if that destination is in interference service volume. If the aircraft is fueled, alternates are already defined.
02-Taxi-out	A taxi-out aircraft would receive instructions to continue. DDI aircraft would have received an IRU update from GPS prior to the interference event. In low-visibility, cockpit-moving maps would not function. Aircraft dependent on synthetic vision where current position from GPS is needed to drive the database would not be available for low-visibility operations. Since ASDE-X would be available and operating from the aircraft's transponder, a failure of GPS and ADS-B would not adversely impact surface movement tracking by the ANSP.	02-Taxi-out	The workload to provide each departing aircraft with a new clearance would be an excessive burden for the ANSP, and taxiing and gate-holding aircraft represent the quickest way to limit demand on the airspace. This mapping of interference by the automation is a critical element of the Future Environment, creating common situational awareness and making decisions to let certain equipped aircraft continue to taxi for departure. DDI and DD aircraft can depart all high-density airports because DME coverage is sufficient under APNT to receive updates within a minute of receipt of a position solution when airborne, and surface movement automation can function using ASDE-X independent of ADS-B. Some delays may be experienced at high-density locations to regulate demand in the airspace if there are a number of aircraft incapable of self-navigation and requiring radar vectors for arrival.

Table 4-4 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
03-Takeoff Position	Aircraft would be cleared for takeoff to follow an RNAV departure path using DDI and DD.	04-Takeoff	Within one minute of a DME-DME solution, the aircraft would be capable of position update for on-course guidance and at most air carrier airports would be under surveillance. Surface movement detection on ASDE-X airports would provide controllers with aircraft position in low visibility.
04-Takeoff	Takeoff would proceed and pilot would use DDI/DD until clear of the interference.	05-Initial Climb	In non-radar airspace, ADS-B would also be lost and ANSP would need to revert to procedural separation. This requires the pilot to report positions and the controller and pilot can expect an increased communications workload during initial climb.
05-Initial Climb	Continue climb with DDI/DD RNAV until out of the interference service volume.	06-Climb	In non-radar environments where surveillance is provided by ADS-B, position reporting would be used.
06-Climb	If established on an RNAV departure path, the aircraft would continue an RNAV departure.	06-Climb	This climb case is predicated on being in reception service volume for multiple DME with the correct geometry to resolve positions for both departing and arriving aircraft. In a non-radar environment, the pilot would fly the RNAV procedure. An aircraft with an IRU has the ability to coast. For DD aircraft lacking an IRU, they would need to be in reception range of multiple DME. If the aircraft were not able to sustain RNP 0.3, the ANSP would need to shut down certain departure paths enabled by precision navigation, impacting capacity and efficiency.

Table 4-4 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
07-Cruise	In interference, the aircraft would continue using DDI or DD. Upon clearing the interference area, RNAV could be resumed using GPS and RNP precision would improve. Support from the ANSP would not be needed and there would be minimal increase in workload, both in the cockpit and for the ANSP in dealing with DDI and DD aircraft.	07-Cruise	In cruise below radar coverage and using ADS-B for surveillance, the aircraft would need to use position reporting for separation until established in radar contact. Minimum safe altitudes for terrain avoidance would be necessary.[10] Aircraft with synthetic vision would be unable to use the capability without the GPS position. Terrain avoidance capabilities tied to the FMS would continue to receive position information and function.
08-Top of Descent Approaching Interference Area	Aircraft with DDI and DD can expect to continue to Top of Descent and use RNAV to reach an intercept to an ILS.	09-Initial Descent	Depending on the weather and the airport of destination, the pilot may be routed to a different approach path to balance workload by the ANSP. Prior to top of descent there are options for reducing demand at congested airports ranging from slowing arrivals, to re-routing, to diversion.
08-Top of Descent in Interference Area, airport not in interference	RNAV using DDI and DD; report when GPS operative for RNAV RNP approach and landing.	09-Initial Descent	In a non-radar environment, with ADS-B also failed, position reporting would be needed within the clearance to descend.
08-Top of Descent in Interference Area, airport in interference	Adequate time exists for the aircraft to continue the RNAV descent and expect radar vectors to execute an ILS approach. Many airports today use ILS procedures where radar vectors are required for sequencing aircraft. DDI and DD aircraft do not require as much service from the ANSP during interference because they can sustain RNAV arrivals.	09-Initial Descent	DDI and DD aircraft should only be limited by needed reductions in demand due to ANSP workload. In non-radar ADS-B airspace, where ADS-B is lost, leader-follower relationships would also be lost using ADS-B In applications.

[10] Except for arrival and departure to mountainous airports, en route air carrier operations are at sufficient altitude to receive valid DME-DME position solutions.

Table 4-4 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
09-Initial Descent	Whether approaching or within interference airspace, the aircraft would continue the RNAV arrival path. Depending on workload, radar vectors may be applied if in radar coverage.	10-Arrival	In busy metroplex airspace, the workload to provide radar vectors at current traffic volume is not significant since most aircraft receive vector direction today to join the ILS approach for landing. At the Future Environment demand level, automation would continue to use conformance monitoring and handle separation activities. Outside of radar coverage, this workload increases in a GPS failure, due to terrain clearance needs and position reporting to support separation.
10-Arrival	The arrival segment is either continuation of DDI and DD RNAV or radar vectors at the time of interference leading to a standard terminal arrival path or vectors to intercept the ILS.	11-Approach	In a non-radar environment, the aircraft may need to hold; then proceed to an ILS intercept. Aircraft capable of holding would do so while the ANSP deals with aircraft having no capability for course guidance or for those transitioning to VOR.
11-Approach approaching the initial approach fix (IAF)	If approaching the IAF for an RNAV RNP procedure, the aircraft can transition to ILS before the IAF if available for the runway or use RNAV from DDI/DD to reposition for a different runway with an ILS. In most cases, the aircraft would receive radar vectors to an ILS intercept or a radius to fix turn to an ILS localizer.	11-Approach	In the transition from the Current Environment to the Target Environment, the number of ILS's would be reduced, since the ILS in the Target Environment serves as an alternative navigation source and RNAV/RNP is primary. The targeted ILS's to retain are the CAT II/III units and CAT I where needed to recover aircraft in the presence of interference. With fewer ILS runways, the efficiency of the airport is reduced during an interference event if in actual IMC conditions.

Table 4-4 Summary of Actions at Time of Interference – DME/DME and DME/DME Inertial – NextGen Targeted Environment (Continued)

Aircraft State	At Time of Interference	New State	Notes
11-Approach inside the IAF	Once starting an instrument approach using RNAV, a missed approach is appropriate at time of failure to allow a transition to an ILS. If the IAF is defined by RNAV, or the aircraft is already on an intercept angle to reach the localizer prior to the final approach fix (FAF), the aircraft could continue if the ILS was also being monitored at the time of interference.	12-Approach	In absence of surveillance due to ADS-B failure, the pilot could not rely on radar vectors to the ILS or for the missed approach. DDI and DD aircraft would be capable of flying an intercept and a missed approach at most airports supported by positioning from DME-DME.
12-Approach	Once inside the FAF, the pilot has little choice but to execute a missed approach if GPS is lost. Many RNAV approaches use RNAV procedures and precision guidance with RNP for the missed approach. This precision may not be available for DME-DME without upgrade to the ground infrastructure. A procedural missed approach made up of headings and climb rates would be needed in the absence of radar coverage for vectors, where there is poor DME geometry or DME service volume coverage is inadequate for the missed approach.	13-Missed Approach	In a non-radar environment, the aircraft must avoid terrain based on positive course guidance from DDI or DD. Returning to fly the ILS at that same airport and runway is only viable if the missed approach provides a path for a subsequent ILS intercept in the absence of surveillance coverage and radar vectors.
14-Landing	If at or beyond decision altitude, the choice is to land or go missed approach. A GPS failure impacts the missed approach but does not impact landing	15-Landing Rollout	
15-Landing Rollout	Not impacted by GPS failure except for loss of cockpit moving map functions.	16-Taxi-in	Landing rollout guidance and taxi guidance can be impacted in low-visibility operations.
16- Taxi-in	Not impacted by GPS failure except for loss of cockpit moving map functions.	01-Parked	

For domestic US airspace, the APNT for NextGen needs to deliver the performance necessary to sustain continuing operations. While there may be some legacy aircraft that will not be able to continue to operate in weather, they can be successfully guided with radar vectors or routed away from or out of the interference airspace. If aircraft can continue to dispatch, then the value of aviation as a target for interference is diminished. Central to continued dispatch is the ability to take off using vectors until the aircraft is at sufficient altitude to be within the range of DME.

Sustaining the ability to fly optimized profile descents and to transition from RNP 1.0 to RNP 0.3 for maneuvering in the airport airspace will sustain the variety of arrival and approach paths necessary to handle the density of traffic. At locations with low-density traffic, RNP 1.0 will be adequate for arrivals and departures.

Offshore and oceanic operations pose a different challenge. Within the Future Environment of NextGen, ADS-B In applications would be used for merging and spacing along RNAV 4 D trajectories. Interference could be encountered offshore in the form of both unintentional and intentional interference. Aircraft may be operating on an RNP 4 or RNP 10 lateral performance. Aircraft may be accomplishing passing maneuvers using ADS-B In. The concept requires the development of 4 D trajectory-based operations that factor in the possibility of interference and drift of inertial reference units. Assuming a 300 nm interference area, aircraft would need to coast through the interference using their IRU for navigation for up to an hour. The lateral and longitudinal spacing of aircraft would consider the loss of GPS when assigning the trajectory.

4.2 Assumptions and Constraints

This concept of operations addresses operations of civil aircraft operating in the NAS with procedures of today and within NextGen under trajectory-based operations. It covers instrument flight operations in both instrument and visual meteorological conditions (IMC and VMC).

- Aircraft operating under visual flight rules (VFR) are not covered. In the event of a GPS outage, these aircraft can continue using visual reference (pilotage) and land visually. Likewise, a VFR aircraft is not receiving services from the ANSP.
- Unmanned aerial systems (UAS) are not addressed. This class of aircraft that is flying under instrument flight rules (IFR) may need a redundant navigation capability.
- Military aircraft are not addressed since they have use of additional codes and tactical air navigation (TACAN) capabilities are retained.
- Operations in Alaska and Hawaii are not considered. This is because a transitional strategy for navigation has not been defined for these locations.
- For air carrier operations in IFR, two independent navigation systems are required by
  14 CFR 121.349. Since the DME-DME system cannot provide precision approaches, the ILS serves as one of these independent systems for approach and landing along with RNAV/RNP as the primary. For en route navigation, RNAV/RNP represents one method of independent navigation and DME-DME or VOR the other.

- VOR is phased out since it cannot support RNAV operations and has limited utility with GPS equipage to support the mandated ADS-B equipage by 2020.
- TBO is dependent on time, and this time must be the same in automation, both in the air and on the ground. At a minimum, aircraft clocks must be synchronized and set to a common time standard time (such as UTC) to the nearest second before taxi out. Time can be derived from GPS, uplinked as part of a broadcast message, or set manually using an approved source of time. This synchronization is verified by the transmission of onboard time in data link messages. While the time precision of flight performance is greater than a single second, seconds of precision are specified for certain airspace and traffic density.
- TBO introduces a concept of required time performance (RTP) that varies with the flight operation and the density of traffic. Representative time performance considers significant reductions in variability over the current NAS that, by itself, will gain capacity and efficiency.
- ANSP automation develops the TBO trajectory and provides separation.
- Backup to GPS is needed now and provided by DME, VOR and ILS, but for introduction of many operational improvements dependent on performance-based navigation and TBO, the introduction of APNT concepts and solution set research and development must be completed well before mandatory equipage of ADS-B in 2020, so that equipage decisions in advance of 2020 can consider backup strategies. The long lead times for development of standards for avionics requires resolution of issues regarding APNT early enough to influence the mandatory equipage in the marketplace.

4.3 Operational Environment

The operating environment description provides an opportunity to compare existing NAS operations with future operations using RNAV/RNP for precision navigation and trajectory-based operations with 4-D trajectories in a target future environment. To aid in understanding the transition, a Reference Environment is used. The Reference Environment provides a representative set of characteristics, performances and capabilities that are described and are necessary to support a comparison between the Current Environment and the Target Environment. A simple example is today's NAS provides services on a first-called, first-served basis. NextGen services will be provided in the order needed to initiate and maintain an agreed-upon trajectory. This trajectory considers not only position in the airspace or on the airport surface, but also the time progression of a flight in relationship to other flights it may interact with during the execution of that 4-D trajectory. Table 4-5 is an example of the environment for two capabilities, 5-mile separation (lateral and longitudinal) and 3-mile separation. Appendix A provides the details for a set of capabilities for the three environments relating to positioning, navigation and time.

Table 4-5 Operational Environment Description

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
5-nautical mile lateral and longitudinal separation distance	Minimum separation en route in radar coverage	Based on radar performance and distance from the radar site	3-mile lateral and longitudinal separation distance based on ADS-B performance
3-nautical mile lateral and longitudinal separation distance	Minimum en route and terminal separation distances within 40 nm of radar coverage	Based on radar performance and distance from the radar site	3-mile lateral and longitudinal separation distance based on ADS-B performance

In Table 4-5's example, aircraft separation, as administered by the ANSP, is governed by the performance of the radar and its coverage service volume. If the aircraft target is beyond 40 nm from the radar site, separation must be at 5 nm or greater. If within 40 nm of the radar site, then that spacing can be reduced to 3 nm. In the Target Environment, the precision of GPS is used by ADS-B to provide surveillance that does not suffer from radar's rho-theta method of measuring position and separation uncertainty so that separation can be reduced. In the Target Environment, it is envisioned that 3 nm separation standards would apply to high-density airspace. It is unlikely that 3 nm separations would be needed throughout the entire NAS.

Airspace, density of traffic, capabilities of the ANSP, and capabilities of the aircraft drive the operational environment. The difference between the Current Environment and the Target Environment is a change in procedures and different aircraft equipage that enables the new procedures and lead to precision navigation and positioning, along with trajectory-based operations. Within the Current Environment, APNT is dependent on aircraft equipage with an instrument landing system for precision landing; VOR navigation for en route use of Jet Routes and Victor Airways as well as standard arrivals, departures and non-precision approaches; and distance measuring equipment to determine slant range distance to a DME station and scanning multiple DMEs (referred to as DME-DME) to update position for inertial reference units.

Overlaying the current navigation infrastructure of the United States is the use of RNAV derived from either DME-DME or GPS with its augmentations. RNAV/RNP rapidly emerging as a standard operating method, where on-board monitoring and alerting exists and GPS is used to increase precision. RNP has a lateral containment for precision. In the Current Environment, RNAV is evolving to be the standard for navigation throughout the NAS, and RNP where operationally beneficial, leaving other legacy infrastructure to serve as an alternative PNT source.

The Reference Environment is a combination of the mix between satellite-based positioning and navigation and ground-based navigational aid support for positioning and navigation. The Reference Environment's purpose is to support a NAS in transition, where aircraft are equipping to perform precision navigation and ANSP tools are emerging to introduce trajectory operations for collaborative air traffic management.

The Target Environment relies on GPS and there is a diminution of ground-based navigation aids, reliance on ADS-B for surveillance (including in areas not presently covered by radar), RNAV throughout the NAS, RNP where beneficial, and retention of only those ground-based navigation aids necessary to serve as an alternative PNT source to support aviation during interference events. The Target Environment is NextGen PNT.

4.4 Operations

The Operations section describes the operational procedures and concepts that APNT will support.

4.4.1 Principles for Presentation of Information

Aviation is transitioning to precision navigation that requires monitoring of performance in the cockpit. When combined with trajectory-based operations in the Target Environment, a 4-D path must be depicted in the sky and conformance to performance requirements needs to be presented to the pilot. The controller needs automated tools that also monitor conformance to the 4-D flight path. Both the pilot and the ANSP need to be able to assess progress in meeting the cleared trajectory.

Performance monitoring must include information on position, progress toward meeting the trajectory and the status of GPS that is contributing the information needed. Whether on the flight deck or at the air traffic controller position, the moment of failure of GPS must be clearly presented to both parties. Likewise, both parties must know the extent of the outage service volume. This is because the options in dealing with the interference that is causing the outage are predicated on the remaining capabilities of the aircraft, the position of the aircraft in the airspace relative to the interference volume, the instrument procedures being executed, and the density of traffic. In the Target Environment, the ANSP automation must collect last known position information and offer the controller a time-based sequence of actions to deal with the different capabilities of the aircraft involved.

4.4.1.1 Flight Deck

Notice of an outage (whether from interference or any other means) should appear on the primary flight display (PFD). The reason for this is that it is in the forward field of view and is most likely the instrument in use to fly an approach or missed approach procedure. The pilot needs to know when a failure occurs. Information needed must be in direct view of the pilot and tied to aircraft attitude. Likewise, alerts and annunciations are needed with respect to the navigation display and the FMS.

The APNT must also provide the pilot information. First, that the navigation system in use is no longer using the GPS, and then provide the information needed to support performance with the 4-D trajectory and precision navigation. When GPS fails and the FMS reverts to the IRU, conformance and alerting for RNP must continue in the Target Environment in order to support the density of aircraft operations.

More precision associated with RNP will require changing scales of information being presented on the PFD. Performance limits for the airspace must be known to the pilot as performance degrades.

4.4.1.2 ANSP

When the GPS goes inoperative on the aircraft, ADS-B is no longer able to broadcast the aircraft position. The first indication of an interference event in the Current Environment will appear as a change in surveillance source from ADS-B to SSR, or the loss of aircraft from the display in a non-radar environment. The controller will realize that there is an interference problem as multiple aircraft exhibit the same behavior. With the Current Environment, the ADS-B degraded performance will be detected by changes in the Navigation Integrity Category (NIC), the Navigation Accuracy Category for position (NAC) and the Surveillance Integrity Level (SIL), commonly referred to as NIC-NAC-SIL. The dropping of multiple ADS-B aircraft positions in the surveillance data network will cause alerts at the receiving site and the outage will be reported to the national operations center and a notice to airmen will be issued. The controller will receive numerous voice radio calls regarding loss of navigation.

These information paths in the Current Environment exist because ADS-B is in its infancy as a source of surveillance. However, in the Target Environment of NextGen precision navigation and trajectory-based operations, the ANSP automation and the air traffic controller must know the extent of the disruption throughout the service volume. The automation must use the aircraft position, its equipage and capabilities in terms of APNT, and the intent from the 4 D trajectory to build a course of action relative to all other aircraft in the impacted airspace. The automation must also examine the aircraft position and capabilities of aircraft approaching the area of interference so that strategic redirection of selected aircraft can occur.

The information needed is a 3-D mapping of the impacted airspace volume that can be generated by the ADS-B ground infrastructure and provided to the ANSP automation. This is referred to in the APNT CONOPS as the interference service volume. The controller receives the boundaries of the interference within seconds of the event occurring. Within a minute, the automation has prioritized actions to be taken based on the capabilities and positions of aircraft. These actions are explained in the narrative description of the APNT CONOPS.

The creation of the interference service volume from surveillance and the strategic re-direction of aircraft approaching an interference area through the TBO ANSP automation represent new functional requirements that do not exist today. These requirements are designed to contain air traffic controller workload and allow decision support tools to assist the controller in managing the onset of the interference event.

4.4.1.3 Secondary Users of Information

In the Current Environment, most secondary users would be informed of a GPS outage event through a notice to airmen. In addition, as capacity would be reduced, demand must be reduced and the FAA's Command Center would begin to constrain demand and re-route traffic as needed.

In the Target Environment of NextGen, information would flow through network-centric operations, providing the service volume impacted and the tactical corrective actions being taken. Strategic actions would begin to route around the interference areas, introduce delays to regulate demand, and change the acceptance rates at impacted airports.

4.4.2 Aircraft States

Because GPS interference can occur at any time, the impact to pilot/operators of the aircraft and the ANSP are based on the position and flight phase of the aircraft at the moment of interference. The APNT CONOPS must accommodate position-based scenarios. For this reason, aircraft states are used. A state is a particular condition that an aircraft is in at the time of the event. This state is influenced by both navigation and surveillance using ADS-B. ADS-B has multiple functions from surveillance to situational awareness. ADS-B Out is the broadcast function from the aircraft that is used by the ANSP for surveillance and by other aircraft that receive automatic position reports from aircraft and display aircraft positions as ADS-B In. ADS-B In supports a series of applications, where aircraft can "see" the position of other aircraft and can perform such maneuvers as spacing, sequencing and merging, performing maneuvers in a leader-follower relationship, and using information from ADS-B from other aircraft to plan and execute a maneuver by the pilot.

In discussing the relationships between aircraft, the JPDO NextGen CONOPS uses a leader-follower construct, where one aircraft is leading and another is following. An example would be paired approaches. To help understand the information presentation, another relationship for information is the use of "ownship" and "othership." This refers to the aircraft you are piloting and the other aircraft involved in a space and/or time relationship. Generally, leader-follower relationships must be terminated at the time of the outage and activities like self-separation end. The follower would be given a diverging course or slowed down to increase separation. Table 4-6 characterizes the different aircraft states used in the APNT CONOPS:

Table 4-6 Aircraft States

Aircraft State Number	Aircraft State Name	Description
01	Parked	The aircraft is parked at the gate or on the ramp and the starting/ending point for flight
02	Taxi-Out	The aircraft has started taxiing to the assigned runway for takeoff
03	Takeoff Position	The aircraft is in position on the runway and ready to start the takeoff roll
04	Takeoff Roll	The aircraft is advancing down the runway and lifts off
05	Initial Climb	This is the segment where gear are retracted, power is reduced for climb and the aircraft begins to follow the flight path for departure
06	Climb	The aircraft is climbing along a prescribed path following a departure procedure and there may be level-offs during the climb for other traffic
07	Cruise	This is the en route phase of flight
08	Top of Descent	A point in space and time where the aircraft will start a descent toward the destination
09	Initial Descent	The segment of the descent that begins at the end of cruise and continues until the aircraft has begun an arrival to an airport
10	Arrival	The segment flown on a path leading to the start of an approach procedure; in the Current Environment a standard terminal arrival route
11	Initial Approach	Approaching on an intercept to a final approach path segment in the Current Environment and any segment that leads to a turn to final approach in the target environment
12	Approach	The segment between the final approach fix and decision height
13	Missed Approach	The path flown that begins at a point inside the final approach fix and continues to the missed approach waypoint.
14	Landing	From decision height to touchdown
15	Landing Rollout	The segment on the runway where the aircraft is decelerating and exiting the runway
16	Taxi-in	The segment where the aircraft is proceeding to the gate or ramp
17	Leader Aircraft	The aircraft is leading along a trajectory where another aircraft is following and maintaining spacing off of the leader
18	Follower Aircraft	The follower is using ADS-B-In information to station keep on the leader

The aircraft state is used as a descriptor to define current state, a change caused at the time of the interference event, and then a new condition within an existing state or a change in states. As an example, assume that an aircraft is in the cruise state and receiving updated position information from DME-DME as well as GPS. The IRU is updated by the GPS position report. Should the GPS be inoperative due to interference, the state does not change, but there is a new condition within that state whereby the IRU now receives updates from DME-DME and the flight management system uses this new information to guide the aircraft. However, if the aircraft is in the approach state and GPS is lost, the aircraft must transition to the missed approach state, or rely on the NextGen APNT for course guidance.

Changing a navigation source within a state does not represent a safety or workload risk. However, when the state itself must be changed, there is an increased safety and workload risk associated with the maneuver. A simple example is a failure of GPS during initial climb. Here the aircraft can be below the floor of the DME-DME coverage and would go through a period of no navigation signal, requiring radar vectors to climb on course. Both the pilot and controller workloads are increased until position updates can be derived from a DME-DME calculation.

4.4.3 GPS Interference Alerts

Cockpit alerts to GPS failure would be both visual and optionally aural. This is because of precision performance needed during an approach and the likelihood that a missed approach must be accomplished inside the final approach fix. With an APNT, hazardous or misleading information that GPS is inoperative and that an alternative navigation method is now in use must be contained within the design of the avionics. The pilot must know the performance of this alternative navigation method at the time of transition from GPS to APNT. If flying using RNP, the performance may be impacted by the shift from GPS to APNT. How well the aircraft is contained within the lateral and vertical limits required for the 4 D trajectory must be known to both the pilot and the controller and if out of tolerance, alerted.

This need to integrate GPS outage information with APNT and other functions of NextGen is why the APNT concepts and solution sets be developed starting in 2012. On average, it takes 16 years to go from requirements to approved avionics. This involves standards committees, performance assessments, and decisions to require or not require equipage to take advantage of APNT.

For the ANSP, the conformance monitoring automation in the Target Environment is tracking the tolerances of performance. Upon an alert to the service volume impacted by the GPS outage, the air traffic controller is alerted to changes in parameters for conformance monitoring, to a pre-defined configuration for GPS outages. This reset of the parameters changes alert and alarm functions and provides a period of time for transition from the failure moment to a new steady state with separation and performance.

4.4.4 Interference Events

For the purposes of developing the concepts for APNT, two types of interference are used. The first is a relatively high-powered intentional interference with an effective range of 300 nm radius measured at Flight Level (FL) 40,000 feet (400). The interference source operates continuously and radiates from the ground. The interference event from onset is expected to last a day or more and cannot be immediately located and shut down. Airspace being impacted is in the mountainous west. The airport used in this interference example is Friedman Memorial Airport at Hailey, Idaho.

The airport uses an RNAV RNP approach to Runway 31. This approach was selected because there is no ILS at the airport and there is a requirement for RNP for the missed approach due to terrain. If failure occurs inside the final approach fix, an aircraft must execute a missed approach and an RNP value of less than 1.0 must be sustained. This approach requires special aircraft and aircrew authorization (SAAAR) and is currently flown today. It represents a future for precision navigation where SAAAR transitions to normal public use in the Future Environment of NextGen. The Friedman Memorial Airport is a worse- case situation that tests the APNT CONOPS for all-weather operations. *There is no answer in the APNT CONOPS for an aircraft that only has GPS as its means of navigation and no other alternative for positioning.*

The second interference event(s) is low-power, mobile, intermittent, and deliberate attempt to jam GPS. The perpetrator(s) are traveling around Miami, Florida operating one or more jammers and have received enough notoriety that they are lead stories on local news. At the start of the interference event(s) it began near the airport and our scenario for the APNT CONOPS starts with this first event. As time progresses, the ANSP and the airlines must assume that an interference event will happen, but for the first time, it was a surprise to aviation and marine operations.

The SSCOT ONE Arrival (Figure 7.1) was used in the concept development because it supports RNAV with either GPS aircraft or DDI aircraft.

Approaches to the parallel Runway 08L and 08R are used. The Airport Layout is Figure 7.2. Both runways have an ILS and one has a SAAAR RNAV/RNP approach. In the Target Environment, these parallels (separated by 750 feet) represent a candidate for paired approaches, using a leader-follower relationship. The RNAV (RNP) Y RWY 8R approach has both an RNP 0.11 decision altitude and an RNP 0.3 decision altitude.

Figure 4.3 SSCOT ONE Arrival

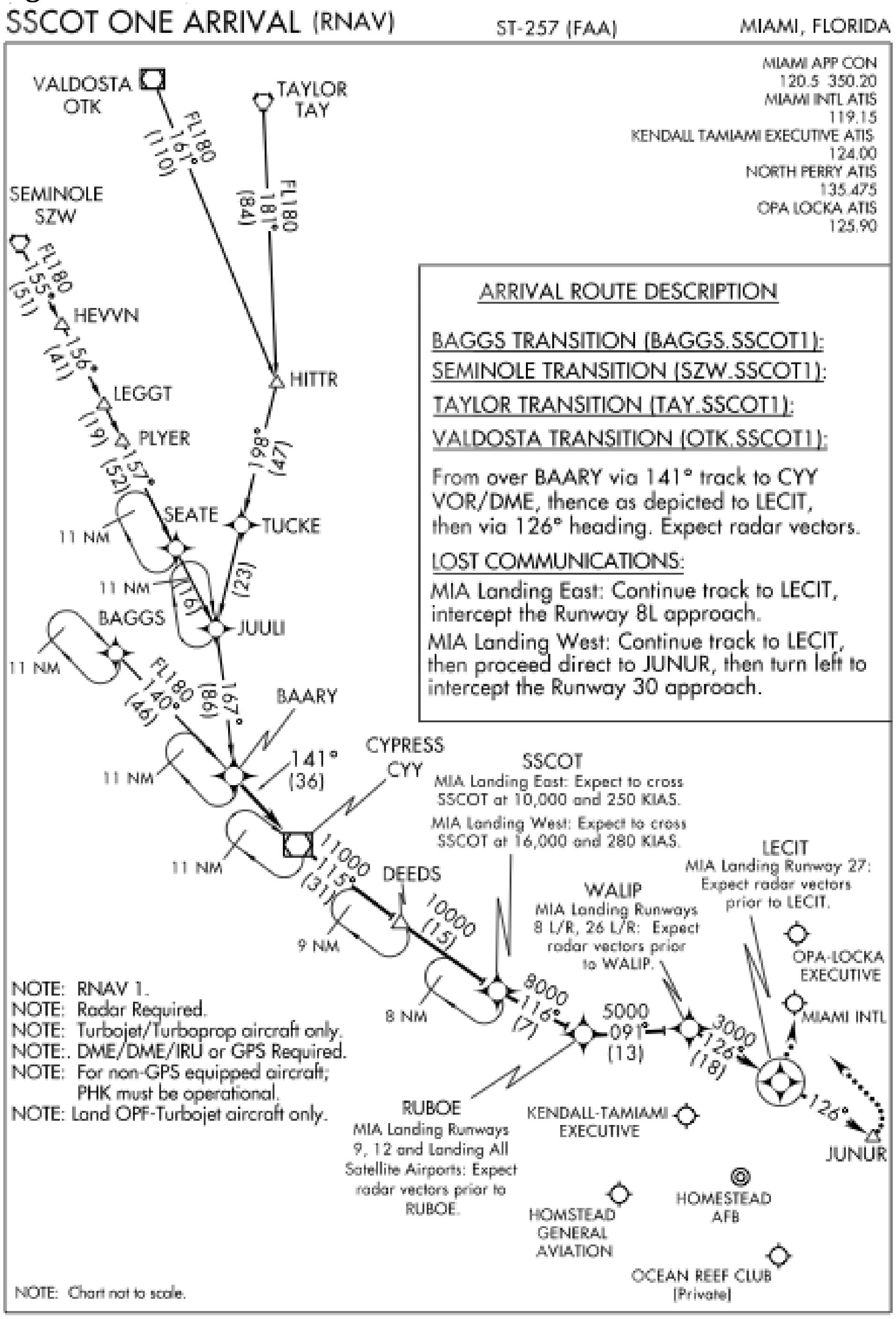
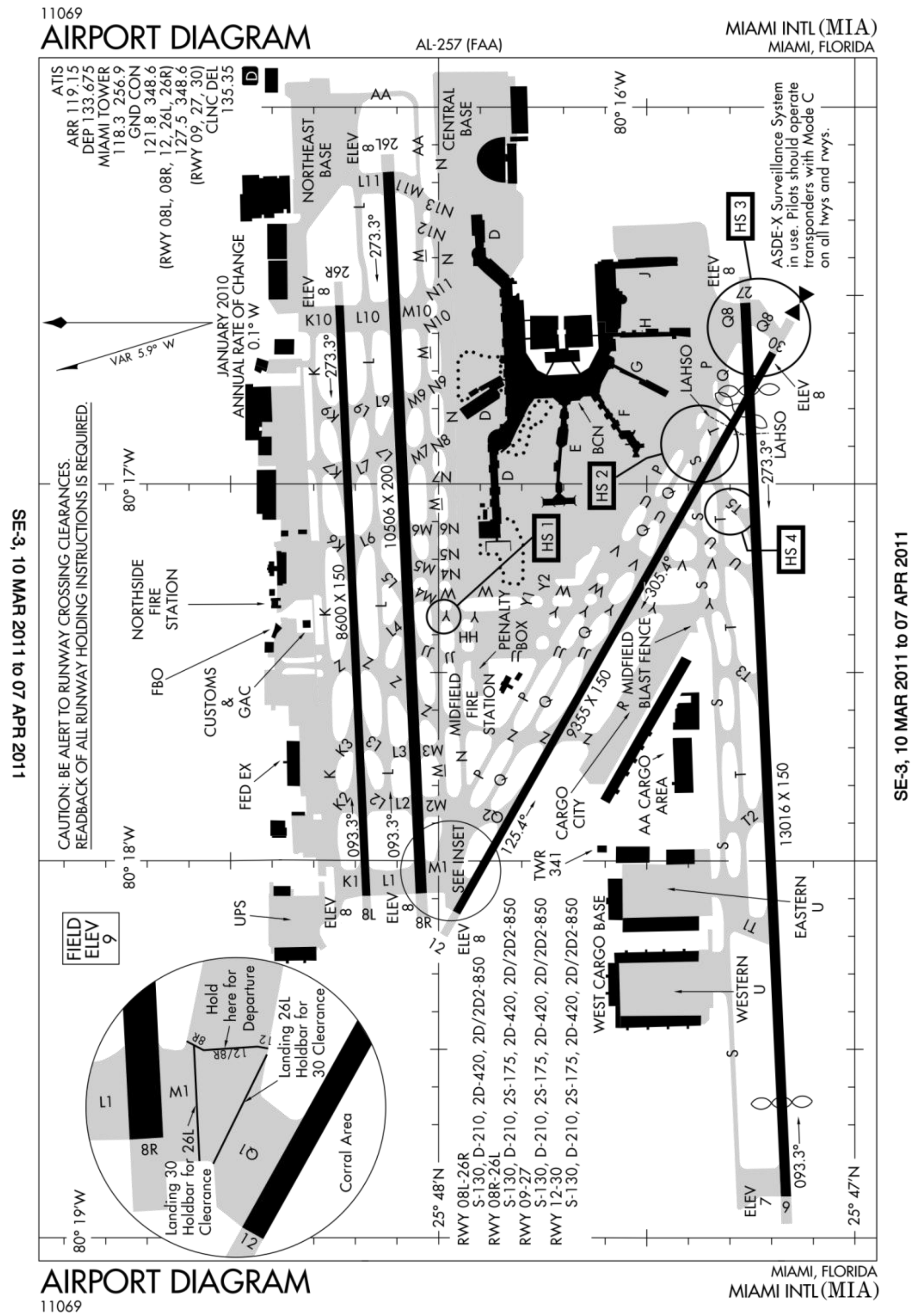


Figure 4.4 Miami Runway Layout



4.5 Benefits to be Realized

The purpose of the FAA's APNT program is to determine how the alternative method of positioning and navigation can be implemented at the lowest possible cost. APNT represents an insurance policy against an interference event, assuring safety of operations, recovering aircraft, allowing for continued flight operations and not requiring an excessive workload on either the pilot or controller.

Direct user benefits relate to sustaining operations and the safe recovery of aircraft in the presence of interference. By using APNT, cost avoidance benefits can accrue to the FAA by transitioning to an all RNAV NextGen operating environment, making VORs and the route structures they support obsolete. By not replacing these VORs, an estimated $1 Billion recapitalization can be avoided. Cost avoidance benefits also exist for a reduction in the number of Category I ILS systems that would be duplicative of GPS precision approaches. This reduction in the number of ILS units includes where there are multiple Category I ILS units at an airport. Only one unit may need to be recapitalized to provide precision landing performance in the presence of GPS interference, as opposed to all Category I ILS units.

By attaining the navigation goal of RNAV everywhere and RNAV/RNP where beneficial, dependency on ground-based navigation aids shifts from a principal means of navigation to a scaled back number of ground-based navigational aids as alternative means of navigation during the transition to NextGen. If multilateration or pseudolites prove to be cost beneficial and perform as planned, then nearly all VORs can be eliminated in the contiguous United States except those required by international agreement.

The ability to use APNT makes deliberate interference of GPS targeted at aviation less likely. This is because the impact of an interfering event does not cause severe disruption to the air transportation system, making aviation less of a target.

The economic impact of avoided events can be characterized as today's weather events. A snowstorm disrupts air transportation at a cost. Whether or not GPS will be interfered with is not the question, it is one of when and how often. The greater dependence the Nation has on this technology, the richer the target. The disruption created by one or two interfering events in a major metropolitan area, forcing demand to be reduced so as to return to today's capacities can be determined and costs can be associated with such an event. The challenge will be in estimating the likelihood and duration of an interference event in a 2025 timeframe.

Loss of GNSS puts the entire NextGen Concept of Operations at risk, especially at high activity airports and in super-density airspace. As a minimum, an alternative PNT source that backs up GNSS must:

- Be capable of safely recovering airborne aircraft to their destination or a suitable alternate.
- Be able to provide the positioning and navigation functions to other integrated ICNS functions to sustain NextGen operations, specifically TBO.

- Deliver position information sufficient to provide separation services.
- Continue to allow the dispatch of aircraft, reducing the impact of GNSS performance problems on the economy.
- Prevent excessive pilot and controller workload during the absence of GNSS.
- Provide an alternative means of positioning and navigation supporting the broadest segment of aviation at the lowest possible equipage cost.
- Supply an alternative path for delivery of timing information for uses that go beyond just aviation.

In the absence of an alternative PNT source for positioning and navigation, the following impacts can be expected:

- **Surface Movement**
    - Loss of moving maps and taxi guidance/clearances in the cockpit
    - Increased controller workload
    - Limitations in taxiing in low-visibility operations
    - Taxi out efficiencies and automated sequencing lost
    - Lower arrival and departure rate even in clear weather will lead to gate holds
- **Takeoff/Climb**
    - Reduction in departure capacity to favor arrivals for recovery
    - Loss of RNP 0.3 departures, reducing departure paths to manage demand
    - TBO departures abandoned, placing aircraft on open trajectories with radar vectors in instrument conditions
    - Significant control-by-exception workload at high traffic loads
    - Aircraft leaving interference area require new 4 DT negotiation and clearance
    - Separation distances increased
    - Demand reduced and capacity lost
- **Cruise**
    - 3-mile separation lost in the area of interference
    - Loss of flow corridors
    - Increased separation workload while reconfiguring to TBO with greater separation distances
    - Some aircraft totally dependent on radar vectors (control-by-exception)
    - Self-separation will not be authorized during GNSS interference
    - Those aircraft self-separating will need to seek vertical separation and gain a 4DT with reversion of separation to the ANSP
    - Oceanic airspace operations with interference will require development of safety procedures that consider IRU performance
    - Loss of off-shore/oceanic TBO requires procedural flight tracks in absence of GNSS with the problem of going from precise positioning and navigation to procedural separation
- **Arrival/Approach and Landing**
    - Significant transitional workload at time of interference
    - Missed approaches must be accommodated

- Separation distances must be increased
- Closely-spaced parallel operations are terminated below 3,400 feet separation
- TBO techniques like merging and spacing, limited self-separation, paired approaches, etc. are terminated
- Departures are delayed to accommodate recovery of aircraft
- Ground stops and holding of aircraft capable of doing so is used to balance demand and get demand below the level of automated separation to a manageable level of control by exception
- For repeated intermittent interference, fuel loading for contingencies is increased
- TBO using 4DT must be recalculated for some aircraft and open trajectories (vectors) used extensively
- Some aircraft are dependent on radar vectors to an ILS final

Loss or diminished performance across surface movement and the flight segments will have a safety impact during transition to greater separation distances and will require a significant increase in workload at the ANSP controlling facility. Once a new steady-state condition can be established through reducing demand, NextGen functions like TBO can provide increases in performance, but not to the previous level of demand. While the safety impact is in the transition, the economic impact is in regulating demand to sustain a safe operating level.

In order to sustain the traffic load, support NextGen TBO and provide for continued operations in the presence of interference, an alternative APNT must be capable of supporting RNP 0.3 for terminal airspace where economically beneficial or required for safety, RNP 1.0 for 3 miles separation en route, and deliver a position solution for surveillance, either from a transponder or use of other sources of navigation to generate the ADS-B message.

5. Operational Scenarios

In developing the operational scenarios, scenarios developed for NASA and the JPDO were re-used. City-pairs were selected that test the consequences of loss of GPS. In developing the APNT concept of operations, a flight from Phoenix to Miami and a flight from Phoenix to Bozeman, Montana (BZN) were used. During that process, a flight into Hailey, Idaho was also considered, providing more difficult terrain and RNAV/RNP performance. The Hailey, Idaho investigation provides the basis for worse case information. The Phoenix to Miami and Phoenix to Bozeman have alternative integrated CNS architectures developed for the JPDO by the Raytheon team. Use cases exist for these flight segments that challenge the robustness of the NextGen Enterprise Architecture.

The JPDO’s TBO Study Team also used the Phoenix to Miami in developing the concepts for TBO. This re-use of flight segments has made it possible to add more detail to both TBO and APNT.

There is not an operational scenario specifically developed for Time. As part of the research, the timing capability evaluation may include GPS time transfer aided by other radio frequency and terrestrial communications sources or other suitable technologies. Time performance for navigation and positioning is driven by the positional accuracy required. The first priority is to provide sufficient APNT node synchronicity to support RNAV/RNP and TBO. Secondarily, benefits may result with a capability of providing GPS independent time to other non-PNT applications across the NAS, namely as an alternative timing service. Providing a comprehensive, independent NAS time service is not part of the scope of the APNT program.

5.1 Overview

Unlike today where navigation and surveillance are separate, by 2025 the FAA and the users of NextGen will be relying on heavily integrated use of the Global Navigation Satellite Services (GNSS) for both navigation and surveillance. The failure of GNSS now impacts positioning, navigation and surveillance.

NextGen addresses airspace use through increased aircraft position precision and reduced separation distances so as to fit more aircraft into the airspace. The concept of trajectory-based operations (TBO) is one of the capabilities upon which the concept of operations is built. TBO provides a different way to offer safety assurance in separation while enabling operational improvements to meet demand through increasing capacity and efficiency. TBO separates aircraft based on a combination of current position and knowing where the aircraft will be at times in the future. Between present and future is conformance monitoring of the 4-dimensional trajectory (4DT).

The traffic levels in 2025 exceed the ability of controllers to manage and separate traffic and require automation to assist in separation. Controllers manage flows and handle a subset of aircraft that are not able to meet their 4DT. This concept of control is known as control-by-exception. Because automated separation assistance will handle most of the traffic load, the system must be designed to not fail, must deal with off-nominal operations, and provide options to the pilot and controller to resolve downstream conflicts and manage flow contingencies. If automation were to fail, the controller would not be able to handle the increased level of traffic.

5.2 GNSS Service Disruptions

For the 2025 operational scenarios, sets of representative GNSS disruptions are used. Each event is described in terms of its impact, location, extent of disruption and most likely cause. The disruptions do not consider GNSS system failures. However, system failures can come from command and control disruptions. The possibility also exists that systemic performance failures of newer satellites being placed in service, where multiple satellites will experience the same performance problems, taking the number of functioning satellites in the constellation below the number needed for reliable navigation. Solar storm impacts could exceed tolerances. There could be a direct attack on either the satellites or the command and control infrastructure.

These systemic failures would be quite disruptive but each represents an action for the Department of Defense and solutions lie outside of aviation's direct control. Systemic failure mode risks are low enough that, by themselves, would not drive a broad segment of users to a backup decision for GNSS. External actions by third parties to jam or spoof represent a larger risk.

Spoofing would likely follow a short duration interference event, followed by walking off the navigation solution that may not be detectible by the aircraft. Spoofing may also not require the alteration of the navigation solution, but instead, the generation of multiple virtual ADS-B returns that would appear as aircraft, which are not really there, and create the equivalent of a denial of service attack. This risk is reduced by the presence of secondary surveillance radar (SSR) backup to GPS. The SSR can verify valid targets where SSR coverage exists. The fact that surveillance is also dependent on GNSS for ADS-B provides an integrated risk; two capabilities are impacted with one action.

For an analysis of potential alternative PNT requirements, the most likely risk is unintentional or intentional interference with GNSS across a geographical area. For the scenarios, four different types of interference events are considered. These include a localized, short-range interference, two different large area interference events, and a deliberate, mobile and intermittent transmission designed to disrupt flight operations at a major airport. The two large area interference events are based on interference area coverage provided in Notices to Airmen for military exercises and testing, with radius of coverage on the order of 300 nm from the center at FL 250.

5.2.1 Localized Interference

This event is limited in range and is characteristic of an unintentional signal generation. This interference is from an engineering test bed or avionics repair station, where the test equipment malfunctions or is not used with proper shielding. For this scenario, the emitter source is on or very near the airport and has an effective interfering range of 60 nautical miles. The signal generator has been left on at the close of business and is detected when the technician disables the necessary shielding device but fails to shut down the signal generator and leaves for the day.

5.2.2 Wide-area Interference

These events include two varieties. One is used in the Bozeman, Montana area and impacts airspace with a radius of 300 nm. The second is a similar area event emanating from a surface vessel in the Gulf of Mexico that is beyond the range of the ANSP SSR coverage. Both of these events use more powerful emitters and are intentional interference events.

5.2.3 Mobile Intermittent Interference

This event relies on an intentional attempt to interfere with aviation as a national terrorist or economic target to disrupt operations at Miami International Airport. The approach that is being used is a mobile van driving roadways in the greater Miami area and intermittently turning on the jammer and then turning it off. This event has been going on for days and law enforcement is unable to locate the mobile source. Interference is on the range of 60 to 80 nm. The consequence is to disrupt air traffic control by denying use of approach procedures and impacting throughput of the operation. But aviation may not be the target, rather it is an attempt to impact as many vehicles that use GPS maps as possible to frustrate motorists. This is one of the consequences of the ubiquitous nature of GPS. The press is having a field day on the disruptions and has dubbed the individual the Roadway Jammer. They have picked up on a theme of how unsafe the condition is; yet the aircraft are still flying at a reduced rate of throughput at Miami. This media attention is feeding the terrorist's desires to sustain the operation.

A variation on this mobile intermittent interference scheme is a more troublesome multiple, coordinated interference operation.

5.3 Scenario Approach

The scenarios use a primary aircraft and numerous secondary aircraft showing the interaction between aircraft and services provided by the air navigation service provider, which in this case is the FAA. Each scenario represents one or more flight legs using a mix of air carriers, general aviation, and military operations to exercise the breadth of capabilities that are scheduled to exist in 2025. In order to develop the scenarios, flight procedures have been described that represent the most likely way that certain operational capabilities could be implemented under NextGen. In some cases, it was necessary to speculate on how possible interactions between aircraft with varying degrees of avionics functions, how performance would be affected, and how ANSP automation and air traffic controllers would handle a particular situation.
Following discussion of the nominal operation under NextGen in the 2025 time frame, a block of text follows, identifying the issues created by the interference event, the operational impact, and variations based on aircraft equipage, avionics configuration, flight procedures, weather, etc. For example, an aircraft that uses a GNSS position solution and places it on a navigation bus can still generate ADS-B messages based on other sources of navigation that also reside on the navigation bus. However, an aircraft that relies on just GNSS for positioning will no longer be able to transmit position via ADS-B.

The scenario format is set up so that use cases can be developed from the narratives. A use case is a chronological listing of events that include a description of the action, action taken, what information passes between initiator and receiver, and how the receiver uses the information. While the scenarios represent the first step in this process, the use cases act as a translation step between operations and architectures. The information flows help construct architectures and can subsequently be used to evaluate redundancies, availability and create representative performance requirements.

All of the flights occur on Thursday, March 20, 2025. Just as today, there will be a mix of equipage and aircraft capabilities. This requires certain accommodations in the provision of services and limits the access at certain airports at certain times. While a level of equipage is assumed based on the 2018 baseline of what would be expected that aircraft would need to have, some of the secondary aircraft used in these scenarios are less capable, in order to show the interaction between the best equipped and the least equipped operating in the airspace. The baseline 2018 assumptions are consistent with the JPDO *Avionics Roadmap V1.0* which was prepared to describe the near and midterm avionics capabilities. In 2025 it can be expected that improved information sharing, more highly integrated functions, modular avionics, and integrated systems performance that is aligned with the ground will be available for use.

Areas of emphasis in the scenarios include:

- Collaborative Capacity Management – the process of negotiating between users and the ANSP to deal with available capacity in NextGen
- Collaborative Flow Contingency Management – advising and negotiating down-stream options to deal with traffic flows
- Trajectory Management – the process of defining and flying a four-dimensional (4D) trajectory that considers capacity, flow contingencies and many other performance-based factors, known as TBO
- Separation Management – the processes and procedures used to safely separate aircraft both on the airport surface and in the air
- Information Sharing Environment – where common information sharing increases situational awareness for stakeholders participating in the scenarios
- Flexible Airports and Surface Operations – where procedures and tools are available to improve throughput, surface movement, and environmental performance.
- Network Enabled Operations – where information flows to assist in both the tactical and strategic air traffic control and management functions.

By 2025, a significant change exists over today's operations, whereby the 4D trajectory guides the path of aircraft controlled by the ANSP. The trajectory-based operation includes flight planning, surface movement and all phases of flight. Separation, sequencing, merging and spacing of aircraft are based on the expected future position of all aircraft (Point B) as opposed to current position (Point A). A distinction is also made here when discussing controller actions. There are strategic controllers who are typically working 20 to 30 minutes ahead of the aircraft's position, and tactical controllers who are managing current flight operations and separation. The tactical controller principally has the safety role and the strategic controller is more focused on flows. The pilot can communicate with both, but the principal contact is with the tactical controller.

Figure 5.1 is a graphical representation of the city pairs used in the scenarios. Each airport and route has been selected to demonstrate the capabilities and off-nominal conditions in 2025. The scenarios follow a primary aircraft from Sunset Airlines on a gate-to gate flight to emphasize the information sharing and coordination. Starting in Phoenix, the aircraft flies to Miami. This city-pair was selected to explain a combination of over-land operations, where air-ground surveillance is available and offshore over the Gulf of Mexico, outside of ANSP ground-based surveillance coverage.

Along each of the flight segments, interactions between our primary aircraft and other aircraft, weather, and airspace uses are described to help understand how operations may occur in 2025.

The flight from Phoenix to Bozeman is used to describe general aviation operations and to use an airport that is a likely candidate for a virtual tower. There is no terminal radar control facility (TRACON) for Bozeman, providing an opportunity to describe the impact of interference on flight operations in the absence of surveillance from SSR or radar.

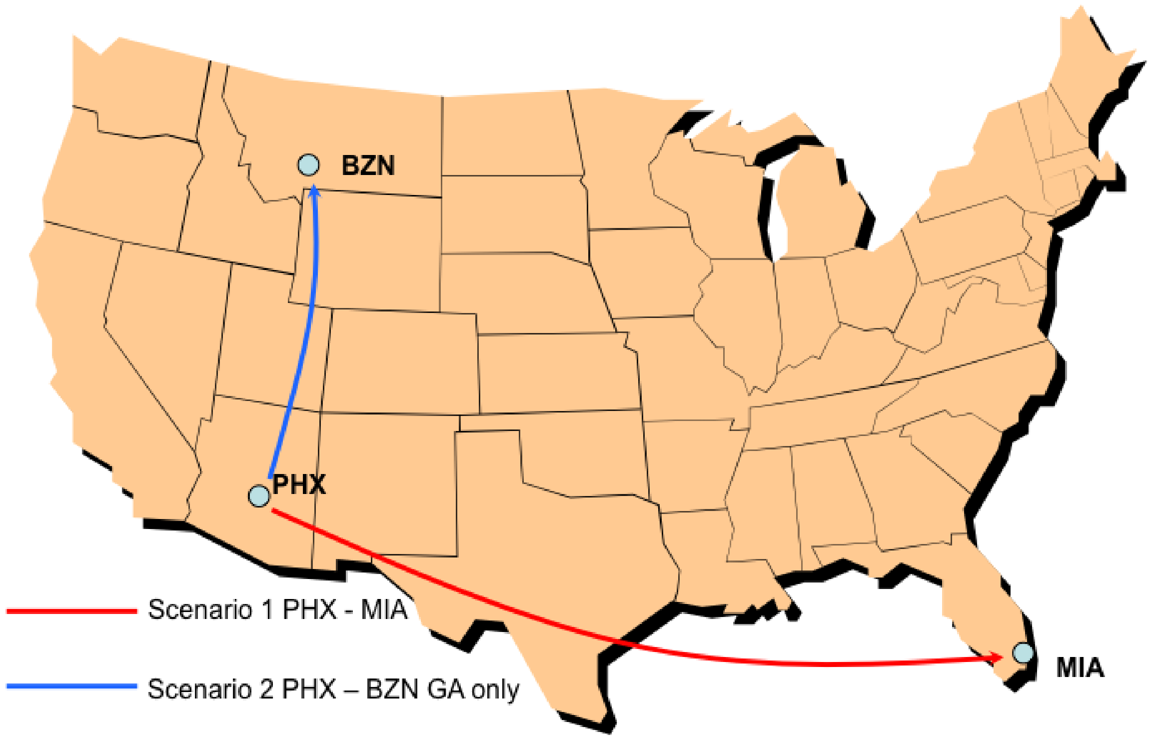


Figure 5.1. City-Pair Operational Scenarios

The offshore flight segment in the Gulf of Mexico places the aircraft outside of the range of ANSP surveillance and terrestrial data communications coverage. In the future, this gap may be closed by using offshore oil platforms as exploration is extended outward and ADS-B ground stations populate a larger area of the Gulf.

This report is organized around operational scenarios. It starts with definition of special terms used, followed by a generic description of the pre-flight planning activities that would be common to each scenario for air carrier operators. Within each scenario, assumptions are listed in tabular form at the start of the scenario. The scenarios will introduce the individual participating aircraft whose full equipage can be found in Appendix D. Appendix F is a list of operational improvements and enabling technologies that become part of NextGen in the 2018 to 2025 timeframe. Readers should refer to the FAA's online Operational Improvement Portal/Browser https://nasea.faa.gov/products/oi/main for the operational improvements planned to be in place by 2018. Appendix H condenses the operational improvements to a subset that would be directly impacted if GPS interference occurred.

5.4 Terms Used in Scenario Development

Many aeronautical terms can be used in describing operational concepts, procedures and scenarios. Each will be defined as used. However, there are sets of unique terms that will be used that need greater definition. This section provides background on the terms unique to NextGen discussions.

Business Trajectory – This is a flight profile and operational scenario that best fits the designed purpose of the aircraft or vehicle. It is what the customer is seeking when they invest in the aircraft or vehicle. In the case of Sunset Airlines, the business objective is to operate as a low-cost carrier to capture passengers on price point and service. It prides itself on on-time performance and has built a reputation for operating the most environmentally friendly airline in the nation. The business trajectory must allow on-time operations in NextGen for the aircraft to be competitive over other low-cost carriers and price competitive over other air carriers. The Business Trajectory is gate-to-gate and includes ground handling, surface movement and the airborne trajectory.

Login – A security process used to connect the aircraft to network-centric operations. This concept is used to access the network for pre-flight planning by the pilot or dispatch and by the pilot in the aircraft to enroll the aircraft in the network. As part of the 4D trajectory-based clearance, a coded message is received from the FAA or any ANSP. This coded message is unique for the flight and is used as part of the login for authentication.

Biometric Authentication – A security and information configuration tool that uses pilot physical information for access. Examples are fingerprints and/or retinal scanning. In addition to security access, there is an information profile that the pilot has created and can modify that filters and formats information the pilot needs to conduct flight. This is done to reduce information overload created by network-enabled access.

Optimum Profile Climb (OPC) – A performance-based climb profile that best aligns with the business trajectory. In the case of Sunset Airlines, this profile is used to define the departure 4D trajectory and represents a fuel-efficient climb to the initial level-off, pending aircraft weight changes that would allow cruise climb.

Cruise Climb – A simple, continuous gradual climb from initial to final cruise altitude to increase efficient use of fuel as weight changes through fuel burn. Cruise climb is a gradual change in altitude as opposed to flight at fixed cardinal altitudes.

Required Navigation Performance (RNP) – is used initially to manage complexity of operations and gain capacity. RNP involves precision positioning, navigation and timing (PNT) that have monitoring and alerting capabilities in the aircraft that tells the crew how well and whether the aircraft is within tolerances for lateral navigation. For purposes of the development of operational scenarios, RNP will be combined with barometric information and time to explain the concepts whose foundation is today's precision navigation operation and end up as the 4D trajectory. RNP is expressed in terms of lateral displacement in nautical miles. An RNP 4.0 means that the aircraft is expected to stay within 4 nm of a prescribed trajectory or ground track. This is 4 miles either side of centerline. An RNP 0.1 is one-tenth of a nautical mile, or

607.5 feet. Two times the RNP tolerance represents the safe containment area.

Optimum Profile Descent (OPD) – This is a generic term describing energy managed descent profiles that includes the Continuous Descent Arrival (CDA) and tailored arrivals (TA) that may include intermediate level-offs during the descent profile. The arrival starts from a point in space called the top-of-descent and allows for low-power, continuous descent to airport arrival. This method of operation is designed to save fuel (and therefore reduce emissions) and reduce noise impacts. The OPD is predicated on a flight path with no intermediate level-offs, requiring the aircraft to power up to maintain level flight. By 2025, the OPD will be modified to include metering and a contracted time of arrival at top of descent and at landing. The flight track may be lengthened or shortened to meet the time of arrival. The ideal CDA is an idle power continuous descent to a 4-mile stabilized final approach segment.

Controlled Time of Arrival (CTA) – The CTA is the basis for trajectory-based operations. In an individual flight there may be multiple CTAs designed to support strategic aircraft separation and flow contingencies downstream. No two aircraft can be at the same point in space at the same CTA without causing a near-miss or collision. It is the conformance to the flight track, CTA, and elevation (altitude) that define four-dimensional air traffic management, or 4D trajectory-based operations. An aircraft may have a CTA for a metering fix on departure, another CTA for a significant route change of direction, a CTA for top of descent to start an OPD, and a CTA for crossing the runway threshold for landing.

Require Time of Arrival (RTA) - RTA and CTA are different. CTA is a matter of conformance and RTA is a function of the FMS. Pilots flying to an RTA may not be flying with trajectory-based operations but must reach a point where a transition occurs to 4D contracted operations. RTAs are used routinely to describe waypoints with time for flight planning but do not have the added element of a "contracted" arrival.

Required Time of Performance (RTP) – This is time's equivalent to RNP and is expressed in either seconds or minutes. It represents the time variability for a given point along the 4D trajectory. There may be an RTP requirement for top-of-climb, arrival at top-of-descent, reaching a metering fix, etc. RTP provides the level of time performance required and is executed in the flight management system as an RTA. RTP is a new concept being explored by RTCA and the JPDO TBO Study Team in developing the concept of use for TBO. RTP is envisioned as having a performance range or tolerance governed by the airspace configuration and the density of traffic.

Required time(s) of merge (RTM) – required time(s) of merge represents that point on the arrival (or departure) where the aircraft is expected to merge into a landing sequence or a departure fix crossing sequence in the 4D trajectory. There may be merge points on OPDs where aircraft with different top-of-descent points merge into a single arrival stream. An RTM may exist on a climb to merge an aircraft into an overhead stream of traffic. On departure, this RTM can be used to set up multiple aircraft flows for en route operations. An RTM is the point where merging ends and spacing begins or where the aircraft is now in position for a paired approach. RTM is expressed as a CTA.

Paired Approach – A paired approach is where one aircraft is paired with another and maintains spacing and separation on the aircraft it is following. In a paired approach, the aircraft may land on the same runway or another closely spaced parallel runway.

Touchdown point – a point on the runway where the aircraft is expected to touch down based on a variable glide slope as a technique to avoid wake turbulence and its associated separation distances or to reduce taxi time for long runways.

Trajectory-based Operations (TBO) – TBO is a new concept for the National Airspace System. A major transformation in NextGen is the use of TBO as the main mechanism for managing traffic in high–density or high-complexity airspace. Early implementation of trajectory operations includes 2D and 3D trajectories in airspace operations that migrate to 4D from gate-to-gate. Within trajectory-based, NextGen airspace, all traffic management functions across all time horizons are based on the aircraft's 4D trajectory. Data communication, surveillance, ground-based and airborne automation and flight planning tools are used to create, exchange, and execute trajectories are prerequisites for TBO. The use of precise 4D trajectories dramatically reduces the uncertainty of an aircraft's future flight path, in terms of predicted spatial position (latitude, longitude, and altitude) and time along points in its path. This enables airspace to be used much more effectively than is possible today to safely accommodate high levels of demand and maximize the use of capacity-limited airspace and airport resources. TBO and super-density arrival/departure operations are likely to be used during peak periods at the busiest metropolitan areas. High-altitude en route and oceanic airspace, and areas where major flows occur will use TBO.

In trajectory-based airspace, differing types of operations are conducted, distinguished by the manner in which procedures are selected and clearances are initiated, transmitted, negotiated, monitored, and revised. Performance-based services are applied based on the anticipated traffic characteristics; minimum requirements for operations and procedures to be used are selected to achieve the necessary level of capacity. Overall, preferences for all users are accommodated to the greatest extent possible, and trajectories are constrained only to the extent required to accommodate demand or other national concerns, such as security, safety, or environmental concerns. The 4D trajectory flown by the aircraft is the result of the application of the business objectives and constraints on the business trajectory. With TBO, the ANSP provides services to aircraft of differing capability in proximity to each other. Operators that equip their fleets to conduct TBO receive services from the ANSP that allow them to achieve operating benefits. A major element of TBO is trajectory-based separation management, which uses automation and shared trajectory information to better manage separation among aircraft, airspace, hazards such as weather, and terrain. Trajectory-based separation management also includes delegation of separation tasks to the flight crew. In 2025, ground automation and flight automation exchange information to define issue and accept changes in the trajectory.

Closed and Open Trajectories – TBO is based on a concept that, if there is a 4DT accepted by the operator, then this 4DT represents a "contract" where the aircraft's performance is expected to meet that flight path and time. The characteristics of the trajectory are being driven by the flight deck automation and the trajectory is synchronized with ground automation. Both the air and ground performance monitoring are working to deliver the defined future aircraft position that is being used for separation, sequencing, merging, and spacing. If the trajectory is closed, conformance monitoring can occur. If there is a change, without negotiation and acceptance of a new 4DT (say on a vector from the controller for reasons of separation), the trajectory becomes open. One or both sides of the automation now have an inconsistency in the trajectory. Open trajectories are allowable and may be used to maneuver in the airspace to avoid weather or during periods of self-separation. However, the objective is to return to a closed trajectory as much as possible.

Control by Exception[11] – Aircraft are expected to fly a 4D trajectory that meets necessary performance for the airspace. In the event that an aircraft cannot meet this "contract" the controller will intercede and control this aircraft outside of the unfulfilled 4D performance. This means that an aircraft not able to meet the required performance takes an efficiency penalty and is sequenced in traffic gaps to preserve the integrity of those aircraft meeting their contract.

Guidance Display – this is a display in the primary forward field of view that serves as an interface where traffic is displayed from ADS-B (and TIS-B in transition) and where tools are provided for merging, spacing, separation and pairing for flight maneuvers. The guidance display uses conflict detection and resolution (CDR) tools to support separation and sequencing.

Digital Communications - data link communications are used for negotiation of flight trajectories with the ANSP and the aircraft can participate in trajectory-based operations and airspace. 4D trajectory clearances travel over a critical link, but other paths for information are available to the aircraft, including broadband performance delivering essential, advisory and supplemental information supporting aircraft connectivity to network-centric operations. Commercial communications paths are the norm. Because most of the changes to a trajectory are made strategically, the required communication performance emphasis is on integrity more than availability.

5.5 Operational Procedures

These scenarios introduce new concepts that have yet to be defined in terms of operational procedures. This section defines a limited concept of use so the reader understands the intent of these new procedures.

Merging and Spacing – a cockpit toolset that allows one aircraft to plan to merge on another so as to roll out behind the leader at a specified distance or time. Typically used in the approach phase, it also has applications en route to set the landing sequence, to follow another aircraft through weather, or provide a method of maintaining spacing in-trail or laterally with another aircraft during maneuvering.

Station Keeping – a procedure that maintains a fixed distance (or time) from another aircraft that is detected and monitored electronically in the cockpit. Station keeping may be the appropriate method for electronic VFR, where aircraft are detected on a common situational awareness display and followed or where a specified distance is used to pass well clear.

[11] From a perspective of control by exception, what information does the ANSP need and when do you need it from the aircraft in terms of performance tolerance? This is a rich area requiring early definition.

Paired Approach – a procedure where two aircraft are paired up for an approach to a single runway or closely-spaced parallel runways and the follower is required to maintain spacing, either longitudinal or offset, or both.
Wake Vortex Departure Winds – departures are delayed 2 minutes behind a departing heavy aircraft and 3 minutes for a super-heavy. In this case, there are wind detectors along the runway that monitor vortex drift. As crosswinds blow the vortices out of harm's way, the minutes of delay can be reduced and the following aircraft can be released.

Wake Vortex High and Long – when a following aircraft's glide path is above the leader and it touches down on the runway at a point beyond where the lead aircraft touches down, wake vortices can be avoided.

5.6 Scenario Assumptions

Table 5-1 summarizes the general assumptions associated with an alternative PNT capability to GNSS. Table 5-2 provides assumptions for aircraft performance in 2025. Specific performance information is tied to the segments of the scenarios. The impact of a GNSS outage focuses on an assumption that an alternative PNT service does not exist in the scenarios to identify problem areas within NextGen.

Table 5-1 General Assumptions Relating to GNSS Interference (APNT)

By 2025:	Notes
There will be "RNAV everywhere and RNP where beneficial." It is recognized that there will likely be many different variants of use of RNAV and RNP that are yet to be defined.	In ANSP managed airspace where TBO is used, RNP is required whenever a 4DT is provided as the means of separation.
Alternative PNT (APNT) is a means to continue RNAV and RNP operations to a safe landing during periods when it is discovered that GNSS services are unavailable due to interference.	APNT is a concept that compensates for GNSS interference, but for which the operator must make a business decision whether or not to take advantage of the concept.
Users equipped for APNT will be able to continue conducting RNAV and RNP operations (dispatch, departure, cruise, arrival) during the GNSS outage after the transition to APNT.	A continued operation in the presence of interference reduces the desirability of wanting to interfere with GNSS on a deliberate basis.
Users not equipped for APNT may not be able to continue RNAV and RNP operations (dispatch, departure, cruise, arrival) in areas where GNSS is required during the GNSS outage. Aircraft not equipped with APNT will be assisted by ATC to a safe landing.	This landing may not be at the airport of choice by the operator, but one of convenience to clear the aircraft from the air.
APNT must provide RNAV or RNP 2 en route, between RNAV or RNP 1.0 to 0.3 for terminal Class B and C airspace, LNAV or RNP 0.3 for approaches, and RNAV or RNP 1 for missed approach, where economically beneficial or required for safety.	Airspace classifications will likely change by 2025, but to help understand where and how operations would be affected; the current classification scheme is used.
APNT service volume consists of the conterminous 48 states. Altitude of coverage includes FL 600 down to 5,000 feet AGL, and sufficient coverage to support RNP-0.3 approaches wherever required for safety or economically beneficial.	The 5,000-foot AGL floor is set to provide APNT support even below the SSR backup to ADS-B.
By 2020, ADS-B Out will be mandated anywhere a transponder is required today.	While ADS-B is dependent on GNSS, this does not mean that operations are halted in the presence of interference. Either alternate means of position reporting are used, or surveillance is supported by airport terminal SSR.

By 2025:	Notes
APNT services will provide backup positioning to support 3nm separation in terminal area operations for dependent surveillance, wherever required for safety or economically beneficial.	This is necessary to sustain airport throughput.
APNT will provide backup timing services for navigation and positioning and possibly other aviation applications.	These timing services relate to time transfer using Stratum 1 frequency performance.
APNT will ensure backward compatibility for existing DME and DME/DME users.	Current aircraft FMS capabilities include use of slant-range distance and direction from multiple DME to derive position.
APNT service performance may not be equivalent to GPS performance (coverage, accuracy, integrity, availability, continuity).	
At least one Instrument Landing System (ILS) will be retained at airports wherever required for safety or economically justified.	
APNT supports position reporting for conformance monitoring for safety and security.	

A significant number of the APNT assumptions are predicated on "wherever required for safety or economically justified." This assumes that either there is traffic volume where the APNT capability is necessary, where terrain is a problem for navigation and/or recovery of aircraft, and/or there is a need to support separation of aircraft beyond coverage of SSR. The economic justification is more difficult, since the number of interference events is expected to be small. Therefore, the economic justification is geared more toward preventing loss of existing economic activity in the presence of interference.

GNSS interference can be viewed like a weather event. It is important for some aircraft to continue to operate, but many general aviation aircraft can wait out the storm and fly later in the day or the next day. For air carriers, maintaining schedule and aircraft positioning is much more important. The difference is one of scale of disruption to air transportation. The loss of a few flights at smaller airports may be acceptable, but the loss of operations over 4 to 5 hours or longer at a hub operation may disrupt scheduled service for days.

Table 5-2 NextGen Concept of Operations Assumptions for 2025

By 2025, Most Aircraft Can Support:	Notes
Lateral Precision – aircraft in high-density operations have the necessary navigation precision to support RNP 0.1 and higher.	RNP 0.3 represents the most common airport arrival and departure performance requirement.
Separation Responsibility – The tactical controller is responsible for separation of operations under ANSP control. The pilot is responsible for separation in designated self-separation airspace and is delegated separation responsibility by the controller	In addition, there are selected, pre-defined delegated separation maneuvers like pair-wise approaches, procedures to closely-spaced parallel runways, and surface movement.
Curved Approach Paths – radius to fix at RNP 0.3 and higher	
Arrivals and Departures – RNP 0.3 to RNP 1.0 in congested airspace or at super-density airports	RNP 1.0 or RNP 2.0 or just RNAV in less dense operations
GNSS for Approach – equivalent to today's ILS CAT I and eventually achieving performance equivalent to ILS CAT II & III with augmentation (SBAS for CAT I/GBAS for CATII & III)	This GNSS in 2025 uses dual frequencies (L1, L5) but some aircraft are not equipped with L5.
GLS – vertically guided approach services to 100 feet ceiling and 1,200 feet Ruway Visual Range (RVR) using GBAS and enhanced vision	As GBAS matures GNSS Landing System capabilities migrate to providing equivalent of ILS CAT II & III
LPV – vertically guided approach services down to 200 feet with SBAS	
ILS – CAT II and III retained on runways where installed	

Table 5-2 NextGen Concept of Operations Assumptions for 2025 (Continued)

By 2025, Most Aircraft Can Support:	Notes
ILS – CAT I retained on at least one runway where economically feasible as backup	
RNAV/RNP Approach – 0.3 to 0.1 RNP value with equivalent missed approach performance	In some cases, the approach minima are driven by the missed approach. By using RNP on the missed approach, lower minima can be sustained.
DME – DME exists to support DME-DME positioning	
Inertial Reference Unit (IRU) drift rates of 2 nm/15 min for single IRU, 2 nm/SQRT(2)/15 min for dual IRUs; 2 nm/SQRT(3) /15 min for triple IRUs	FAA Advisory Circular 90-100A, U.S. Terminal and En Route Area Navigation (RNAV) Operations requires for RNAV 1 and 2 Routes of less than 2 nm per 15 minutes with total system error of less than or equal to 1 nm throughout the route and flight technical error of 0.5 nm for D/D/I aircraft in terminal procedures.
Electronic Flight Bag (EFB) – integrated into the cockpit guidance display in the forward field of view if used for self-separation or complex approaches.	Numerous options exist today for the position of the EFB.
Analog Voice – used to sustain the party line and for emergency transmissions. Clearances for takeoffs and landings travel by voice	This is an operational policy issue that goes to making sure that others operating on the airport know when an aircraft is cleared to take off or land.
Aircraft Node on the Net – the aircraft is connected with broadband from commercial service providers for exchange of strategic information and with the ANSP for clearances and intent reporting	
Connection Security – Aircraft uses a login procedure with authentication to connect to net centric operations	
ADS-B Rule – All aircraft using the services of the ANSP in designated airspace have ADS-B Out	• Today’s Class A, B and C airspace • At and above 10,000 feet MSL in 48 contiguous states and the District of Columbia • Within 30 nm of airports listed in 14 CFR 91.225 from surface to 10,000 feet • Class E airspace over the Gulf of Mexico from the coastline out to 12 nm at and above 3,000 feet MSL

Table 5-2 NextGen Concept of Operations Assumptions for 2025 (Continued)

By 2025, Most Aircraft Can Support:	Notes
ADS-B In on some aircraft with cockpit display of traffic information	Forward field of view
Cockpit display of traffic information – within CDTI, tools are available for airborne conflict management that includes conflict detection and resolution; tools available for merging and spacing (station keeping)	In 2025, toolsets enable assisted visual separation using ADS-B In
Traffic Collision Avoidance System (TCAS) – still in use.	In 2025, TCAS is still used as the last line of defense in preventing mid-air collisions
Secondary Surveillance Radar still operational en route and at most major airports with a primary radar element for non-cooperative targets	NAS architecture calls for limited replacements until multifunction phased-array radar is in place starting deployment in 2023.
Primary Radar – exists in terminal airspace and en route, principally used for weather and detecting non-cooperative targets for security	FAA currently doing technology assessments for a multi-purpose phased array radar (MPAR) for service decision in 2017 and operational by 2023
Critical Data Communications includes clearance delivery, frequency changes, ATIS, transfer of control, traffic management information, taxi out and in clearances, FMS loadable information and the start of machine-to-machine issuance and acceptance of 4DT clearances	Negotiation of TBO likely to travel on other networked links.
Broadcast Services include ATIS, FIS-B, TIS-B and ADS-R (rebroadcast of surveillance position information from the ANSP)	ADS-R compensates for two different ADS-B architectures in UAT and 1090 ES
Commercial Data Communications has grown to provide value-added services that can also carry weather, planning, advisory and strategic flow information useful to the flight crew	Mostly broadband system capabilities
Multilateration exists for airport surface movement and terminal applications for larger airports	Operates passively from transponder or ADS-B emissions or through active interrogation of transponder
ASDE primary surface radar is decommissioned	ADS-B required and used for surface movement

Table 5-2 NextGen Concept of Operations Assumptions for 2025 (Continued)

By 2025, Most Aircraft Can Support:	Notes
FMS is migrating to support not only path management, but performance management. FMS generated performance reporting can be down-linked to provide intent and conformance reports.	In 2025, there is a considerable legacy mix of FMS systems, but the FMS is evolving to be a mission computer capable of supporting TBO
RNP Values for scenarios: Oceanic airspace outside of ANSP surveillance – RNP 4.0 Off-shore (Gulf of Mexico) RNP 1.0 for self-separation and RNP 2.0 for procedural separation En Route Under ANSP surveillance with 3 mile separation – RNP 0.3 and with 5 mile separation RNP 1.0 to RNP 2.0 Terminal maneuvering - RNP 0.3 Final Approach segment – RNP 0.3 to RNP 0.1	
Optimized Profile Descent (OPD) is preferred method of arrival with a closed trajectory linking from top of descent to runway threshold	This is a significant fuel saving measure
Optimized Profile Climb (OPC) is used to provide the best business trajectory for departures with the path and vertical component build on the aircraft's performance	This is a significant fuel saving measure
Cruise-Climb – represents a shallow climb in airspace as fuel is burned to reach a more efficient altitude for fuel efficiency	Likely to be delivered under trajectory operations as a block of vertical airspace. Climb rate is typically less than 200 feet per minute.
Low-visibility Operations – landing to zero-zero, taxi-out and takeoff to an equivalent visibility of 300 RVR (may be lower with enhanced vision)	Taxi-in from zero-zero dependent on moving map performance of 1-3 meters
Surface movement precision for low visibility – positioning in the range of 1 to 3 meters.	
En Route Separation is 3 nm lateral, 1-minute longitudinal and 1,000 feet vertical under the control of the ANSP and 5 nm lateral, 5 nm longitudinal, and 1,000 feet vertical for self-separation.	Self-separation is just beginning to be used beyond paired approaches in the en route environment.

Table 5-2 NextGen Concept of Operations Assumptions for 2025 (Continued)

By 2025, Most Aircraft Can Support:	Notes
250 knot Restriction – eliminated in 2025 in favor of best Lift to Drag for the configuration.	Current restriction is a maximum speed of 250 knots below 10,000 feet
Required Time Performance (RTP) – is expressed in terms of the precision required to arrive at a point in space at a prescribed time consistent with and agreed upon 4DT.	RTP is a new concept being introduced in TBO Scenarios by the JPDO and as a candidate to explain the allowable variability in timing for different flight maneuvers. Variability narrows as the need for precision rises with traffic density.
Require Time of Arrival (RTA) – is the time function of the FMS for aircraft with FMS coupled throttles	RTA is used to execute RTP requirements
Controlled Time of Arrival (CTA) – represents the ANSP's time that needs to be met in a 4DT	CTA represents the contracted time of arrival at a point along the trajectory
Estimated Time of Arrival (ETA) – The predicted time of reaching a destination or waypoint in space.	ETA is an estimate that may fall outside the bounds of required time performance and is used to show an increase in time variability

5.7 System Planning

A key element of the NextGen concept of operations is the flight object, a 4D description of the flight plan.[12] In the majority of the cases, the desired flight trajectory is provided to the ANSP well in advance of the actual flight, so as to compare its business trajectory against all other flights. This 4D trajectory considers the business trajectory; environmental factors, weather, most efficient flight profiles, and cruise climb segments. The ANSP may come back to the pilot or dispatcher with recommended modifications that can then be negotiated or accepted for the flight. It is in this pre-flight phase that information is collected on surface movement, takeoff time, the route of flight (defined by waypoints and time) the point in space where self-separation operations will be authorized, any required time performance for start or end of a particular flight activity, the location for top of descent, the flight track for the descent and approach, and the landing runway. Times are expressed in hours, minutes and seconds UTC. Compliance with the take-off time is aided by providing the flight crew with a countdown timer

[12] Flight plan or flight object? By 2025, it is expected that the notion of a flight plan is replaced with a flight object. The flight object contains more information than is needed for automation to construct an initial trajectory, and is updated throughout the flight with each transaction between the ANSP and the aircraft. How the automation, the controller, the pilot, and the dispatcher use the flight object needs definition. For now, the flight plan represents a hybrid of the flight object.

display[13] that is initiated at brake release for taxi. Actual times (UTC) are used at liftoff and on to touchdown at destination.

There are four phases to trajectory operations and for the flight-planning segment, the first three are accomplished before arriving at the aircraft:

5.7.1 Pre-negotiation

Pre-negotiation starts with flight planning and includes access to all known or projected constraints available through network-centric information systems. The operator defines the trajectory objectives (the business trajectory). Where does the operator want to fly, when, and how does the operator want to get there. The operator considers known and projected constraints and also provides the ANSP with operator constraints that will affect the 4DT. These operator constraints may be related to crew qualifications, aircraft capabilities and limitations at dispatch, and any special conditions relating to the flight. The dispatcher may, because of expected constraints at the departure or arrival airport add constraints on the subsequent flight of this aircraft.

5.7.2 Negotiation

During the negotiation phase, the operator negotiates with the ANSP to determine if the business trajectory can be met considering all other traffic and system constraints. If the desired trajectory can be supported, then the operator and the ANSP move to the agreement phase. If not, then the ANSP provides options for the operator to select from. Once constraints are dealt with, this phase moves to approval.
In the air, the negotiation phase is not unlike in-flight requests today that reflect necessary changes. Negotiation leads to a change that maintains the closed trajectory.

5.7.3 Agreement

The agreement is quick. It involves the final request, acceptance by the ANSP, and assignment and acceptance of a 4D trajectory clearance. The clearance represents a “contract” to be executed. This clearance may be for the entire flight or a segment that is not unlike a clearance limit today. Both the operator and the ANSP are committed to execute the 4DT using TBO.

5.7.4 Execution

During the execution phase, the aircraft maintains the trajectory within the window defined in the clearance, with performance that satisfies the agreement. The aircraft and the ANSP monitor compliance with the agreement through conformance monitoring. If the operator is unable to meet the agreement, then negotiations start again to change the closed trajectory, or the controller may intercede and provide a route or time change, creating an open trajectory while the automation on the ground works a new 4DT. Throughout the execution phase, the pilot knows best how well the aircraft is performing.

[13] Certain ramp operations may impact the time included in the countdown timer. Activities such as de-icing, etc., will be included.

Updates are provided to the ANSP as the flight progresses. These updates are used by the ANSP for conformance monitoring.

The ANSP role will evolve from flow management and control to include capacity and flow contingency management for high performance airspace and high-density operations. The goal is to negotiate a de-conflicted schedule of daily operations that accommodate the business trajectory requests for the airspace user. The de-conflicted plan will be based on execution of an established 4D trajectory referenced system for nominal operations. This allows the resources to focus on non-routine operations as exceptions to the planned flows.

The pilot or dispatcher has access to information that is rich in probabilistic treatment of past performance. Airlines have used data mining of their own performance as well as that of the ANSP to help characterize the probability of even the slightest changes in the system. For example, dynamic special use airspace (SUA)[14], temporary flight restrictions (TFRs) and throughput with different runway configurations at airports can be called up out of databases extracted through network-centric operations. Knowing the previous history of SUA use can identify how to time passage through frequently used airspace. If the weather information is leading to a runway swap for winds at an airport, the speed of that transition is known, the capacity impact is known, and can be counted on to improve the predictability of the proposed 4D trajectory.

Dispatchers and general aviation owner/operators can provide multiple options for a given flight at both the pre-negotiation and negotiation phases of flight planning for the 4DT. The ANSP then knows acceptable alternatives as the ANSP integrates the information for all flights under its control.

In addition, information from the same city pairs and the same aircraft can be called up and compared to the proposed flight. These data mining tools allow the pilot or dispatcher to review previous nominal performance, identify off-nominal events that have caused delays or flow constraints, and modify their own proposed new 4D trajectories. This type of optimization is commonplace in 2025 and is driven by the richness of information available and the existence of actual flight tracks captured from ADS-B. Whether you are in the cockpit in flight or sitting in a dispatch suite, you can track the progress of the aircraft – today's, yesterday's or last year's flights are all available through network-enabled operations.

The information rich planning and operating environment will eliminate the need for rigid, fixed playbook operations and will allow more dynamic operations based on the ability to retrieve other optimized solutions to support the non-routine requirements.

[14] Special Use Airspace, or SUA is changing to Special Activity Airspace (SAA), a term that is emerging to demonstrate the flexibility of dynamically assigning airspace, not just to the military for designated use. The term "SUA" is retained in the operational scenario descriptions, because the operational user understands SUA. As SAA and dynamic airspace concepts are developed and understood, SAA will become the appropriate term of reference.

For Sunset Air, the dispatcher is working an entire day's schedule for the individual aircraft. Tomorrow it will depart Phoenix and go to Miami. It will leave Miami for New York with a new flight crew that will then fly the aircraft on to Houston. The aircraft will return to Phoenix using an expected crew arriving on another flight from Chicago.

For flight planning, the flight from New York to Houston appears to be most problematic. There is a massive cold front moving across the area during the day that will impact flights and will likely leave Houston in a low-visibility condition. While the visibility is not a flight problem for Sunset Air because all of its Boeing 737/1000's carry the latest technology, including enhanced vision, the volume of traffic going into Houston at the time will generate delays, even for the most capable aircraft. The dispatcher begins to figure possible multiple 4D trajectories for that flight segment based on the known optimized performance envelope of the aircraft and environmental requirements, knowing full well that dynamic conditions may warrant changes. However, the overall airline operations are based on the execution of the business trajectory including the 4D "agreement." Each flight segment for the day represents a balance between Sunset Air's business model and its resulting trajectory and constraints known to exist in the aviation system. New York to Houston will impact the planning for the flight from Phoenix to Miami.

Sunset Air Flight Operations is a node on the network that supports flight planning, collaborative decision-making and provides access to near-real time surveillance information on their aircraft. Weather information is available. Expected airport configurations for the day are available. Any existing or planned flow contingencies are a valuable source for flight planning. Airline dispatch knows of expected military needs for dynamically assigned special use airspace and for two flight segments this may be an issue. Aircraft information, including performance data for the expected winds and temperatures is called up from airline databases and the dispatcher starts the flight plan and builds both the 4D trajectory request and the flight object.[15]

Sunset Air knows that there is a current problem with an intermittent jammer operating in the Miami area. While the dispatcher will plan for normal use of GNSS, the dispatch will load additional fuel to be carried in case it is needed supporting holding or vectoring as opposed to their normally planned optimized profile descent. If interference occurs during the arrival in Miami, Sunset Air will lose the fuel saving benefits of the OPD and will have had to carry extra weight for the added reserve fuel.

The dispatcher, using biometrics for login, connects to the portion of the aeronautical network operated by the FAA and transmits the day's flight information for use by the FAA in defining the necessary trajectories. The FAA already has on file information from previous flights and it too has spent some time optimizing for that day. The FAA now compares this proposed trajectory and notes that there are some flow contingencies for

[15] What fate flight plan? By 2025, the flight plan should be fully replaced by the flight object, but there is not an elegant way to handle such a transition with the workforce. A more detailed definition of the flight object and its uses would be appropriate as a JPDO follow-on work effort.

both the flight leg going into New York and Houston. The FAA sends to the dispatcher some different options that include a later arrival time at New York and Houston. Since it will be the same aircraft, this lateness can be accommodated. The dispatcher selects the preferred option and adds to the flight object crew information that will later be used to authenticate the crew when they login to the network-centric operations.

While the dispatcher for Sunset Air is developing their daily operation plan, the ANSP is collecting the requests from all other airspace operations including planned military flights and unscheduled operators and integrating them into an overall capacity-based system plan. Conflicts during this planning phase are negotiated between those filing the request and system capacity management tools. These plans are based on improved weather prediction capabilities and create the nominal operating plan for the day.
The FAA then sends to the dispatcher the 4D negotiated flight profile for agreement between Sunset Air dispatch and the FAA. This segment includes the necessary information for the flight from Phoenix to Miami. This agreement also contains an imbedded security code that will be used when the aircraft logs in. The dispatcher then prepares the information needed for the first flight segment for upload to the aircraft. While the aircraft is en route to Miami from Phoenix, the second leg will be prepared and will contain updated information as the day progresses.

Sunset Air also has information available for the pilots, who have digital access to flight planning information from anywhere. This capability is external to the FAA's network-centric aeronautical system and contains company information. The pilot can review that day's flight(s), review expected weather conditions, and can set their preferred information profiles. These information profiles help to manage against information overload in the cockpit. While there is a minimum set of information pilots must review and use, the balance of the information is available on demand from a combination of on-board information storage and linking between the aircraft and the aeronautical network. The pilot can change the individual information profile at any time. When the flight crew arrives at the aircraft, both the captain and first officer use biometric authentication to power up the aircraft and log into the available networks. This login then sets the information profile, downloads the flight information for that leg (or multiple legs) and verifies that the 4D trajectory is as planned. At this point, the crew has all the information needed to accomplish the flight gate-to-gate.

GNSS Interference

In flight planning, known or potential areas of GNSS interference would be carried in NOTAMS available through network-enabled operations. In the case of this flight, there is a NOTAM on intermittent interference in the Miami area. Both the dispatcher and the pilots know about this interference. Graphical representation of the interference area has been created from recorded ADS-B information from aircraft during previous events.

This shows 3D volumes where valid ADS-B position reporting was occurring and where it was blocked by interference.[16]

The mapping capability was created to reduce controller workload at the moment of interference so that trajectory and separation changes could be made. The map supports the automation that manages and de-conflicts trajectories. The source of information is the ADS-B ground station network that detects loss of ADS-B by aircraft being tracked and provides position and altitude to create the 3D volume of affected airspace.

This boundary line for interference is overlaid on the Miami airspace. The dispatcher reviews this information and concludes that if interference occurs on this flight that the aircraft will likely be interrupted in its OPD and be given holding or vectors to landing. This will affect aircraft fuel loading. Most importantly, since this same aircraft is expected to go on to JFK, any delay must be factored in for subsequent flight segments.

This tool used to map areas of interference operates in near-real time from surveillance information and is accessible by strategic and tactical controllers and can also be viewed in the cockpit during flight as a deliverable just like weather graphics. The tool's output reduces the communications workload between the tactical controller and the pilot during an interference event, provides the pilot and controller with information on when the aircraft will leave the area of interference, and supports the flight planning of interference events just as if it were a weather event.

Factors for dispatchers to consider include the impact of interference on the minimum equipment list, crew training, alternates (in the absence of suitable backup for landing), flight time and fuel loading, alternative flight paths to provide full TBO, and impact on the narrowing of choices for descent and arrivals or loss of possible departure paths. Because the flight goes on to JFK, the dispatcher must also consider the departure requirements out of MIA before even dispatching from PHX.

5.8 Scenario Description – Phoenix to Miami

Operational Objective:
The following scenario addresses the activities conducted by Sunset Air flight 42 to provide on time service from Phoenix to Miami. To meet this primary objective the Sunset Air operational team (flight crew and Airline Operations Center (AOC)) will utilize their 2025 avionics, automation and decision support tools to collaborate with the equally well equipped ANSP to plan, fly and respond to varying conditions during the 4-hour flight. Specific issues addressed include route alterations due to changing weather conditions, avoidance maneuvers in the face of an errant UAS flight, and dynamic Special Use Airspace (SUA). In addition, the Sunset 42 will alter its approach to accommodate turbulence and will accept last minute gate changes.

[16] The ability to rapidly map areas of interference from surveillance lack of an ADS-B report is a new recommended capability to reduce controller workload and aid in dealing with interference events.

Throughout this nominal 2025 NextGen scenario, there will be breaks in the story line to address impacts of GNSS interference.

Sunset Air Flight 42 is a regularly scheduled, Federal Aviation Regulation Part 121 air carrier flight of a hypothetical Boeing 737-1000 aircraft operating from Phoenix Sky Harbor International Airport to Miami International Airport in Florida. The Boeing 737-1000 is the latest derivative of the now 55 year old, basic single aisle "tube and wing" twin jet transport. This version carries 165 passengers and a crew of two pilots and four flight attendants. The new wing and engine combinations enable an en route cruise speed of Mach 0.82 and a ceiling of 45,000 feet. It meets stage 4^+ criteria for both take-off and landing noise.

The pilots for this flight are based in Phoenix and have reviewed the preliminary flight plan before leaving home for the airport. The flight will be full, as usual, since the revenue generation software has been perfected to see that all seats are sold at some price. The prevailing westerly winds are stronger than average today and so the flight is planned at long range cruise to save fuel but may still arrive early, even with a slight re-route around convective weather anticipated over the Gulf of Mexico. Miami weather will be basic VFR with low altitude cumulus and visibility around six miles in haze. No alternate is required for Miami but some contingency fuel is planned for possible en route weather deviations over the Gulf and the continuing disruptions from a GNSS interferer operating as a mobile jammer around Greater Miami.

Upon arrival in the flight office, the captain is informed that her aircraft has just pulled into the gate and that the APU would not start. Maintenance wants to defer it to Miami for repair. As this will leave only the engine driven generators, the Captain reviews the forecast for Miami more carefully as an engine failure before arrival would mean a one-generator approach. Auto-land and Category 2 or below visibility would not be permitted. But as the forecast is good, the crew accepts the deferred item.
Sunset Air's operational control and dispatch function has used its new 4D flight planning software, fed by the most recent atmospheric forecast information including winds, temperatures, turbulence and expected convective activity to arrive at a flight trajectory that best matches the business case. The use of a single authoritative source for weather through the 4D Weather Cube is a tool available through network-enabled operations and connectivity with the ANSP. For Flight 42 today, because of the strong tailwinds, fuel savings is the primary driver. The captain voices her concern about having to carry additional fuel and its weight penalty just because the mobile jammer has not been apprehended yet. The 4D trajectory from flight planning is sent to the ANSP for approval.

The planned trajectory anticipates a departure to the west and a close in, RNP 0.3 departure turn around to the east. The climb is steeper than normal to the initial cruise altitude because of the wind gradient. The radius to fix maneuver must consider the stronger tailwinds at higher altitude so the climb is planned to reach altitude as quickly as possible. The route is planned to skirt the northern edge of the forecast convective weather area over the Gulf, as this route has fewer wind miles to destination. Also, with the APU out, suitable alternates are much closer than the longer over-water path in the event a diversion became necessary.

The ANSP response came right back with two alternatives only slightly altering the plan sent from the airline operations center (AOC). Because the Gulf of Mexico traffic is all compressing to the north, for potential congestion in this area they have offered an earlier crossing time of an en-route waypoint over the Gulf, or altitude either 1,000 feet higher or 1,000 feet lower at that point. The Captain and dispatcher review these options and pick the 1,000-foot higher altitude. Speeding up to arrive earlier would negate the possible fuel savings and even though 1,000 feet higher is slightly above the optimum cruise altitude, it is more likely to clear the building convective activity in the area. This option is selected, sent back to the ANSP, and serves as the basis for the fuel load actually put on the airplane.

The Captain and her first officer then go to the airplane parked on the north finger of Terminal 3. They board about 10 minutes prior to passenger boarding and perform their system tests, safety checks and cockpit setup. Flight 42 is logged into the ATC system and digital ATIS is displayed to the pilots on their EFB's in response. Flight 42's departure occurs during a heavy arrival period at the airport and both RWY 25L and RWY 26 will be taking arrivals simultaneously. Runway 25R will be used for departure, even though RWY 26 would have permitted a shorter taxi. The taxi route is also displayed on the EFB airport map from the gate, via the ramp, to taxiways Tango and Echo, then to runway 25R.[17] PHX has ASDE-X multilateration capabilities that can track aircraft from ADS-B or from the aircraft's transponder, so aircraft on Tango that were previously not visible to the tower are clearly tracked and automatically monitored for ground conflicts at all points on the movement area.

By 2025, the distinction between the movement areas and the non-movement areas are an artifact of controller procedures. There is now one common picture and the line delineating roles and responsibilities is defined by the implementation strategy for surface movement automation and use of data link to convey information.

All passengers, fuel, catering, baggage, and cargo are loaded by the scheduled departure time and the doors are all closed.

[17] Throughout these scenarios, Sunset Air uses an event timer or countdown timer to track pushback, taxi, takeoff, time to a CTA, etc. The time value is set by the pilot and used as an aid to monitoring progress. On taxi-out the time is known between the gate and the selected runway from data mining of similar flights from ADS-B information.

But since the APU is inoperative, the engines must be started at the gate prior to push back. This process is accomplished and what would have been a departure two minutes prior to schedule is now two minutes after.

Pushback clearance is requested and granted through the data link with ramp control.[18] After disconnect from the tug, the First Officer pushes another button and requests taxi clearance and the response from automated ground control shows the route from their present position to RWY 25R in graphical form on the EFB. This taxi map can be displayed either on the EFB or linked to the field of view guidance display. At the intersection of Tango and Echo the aircraft they are to follow on Echo begins flashing on the EFB and is accompanied by a chime when the sequence is first assigned by ATC. It is a Boeing 777, and Sunset 42 falls in behind it when it passes. Another button push by the First Officer brings up the Wake Vortex Avoidance System display for PHX. It shows RWY 25R to be in

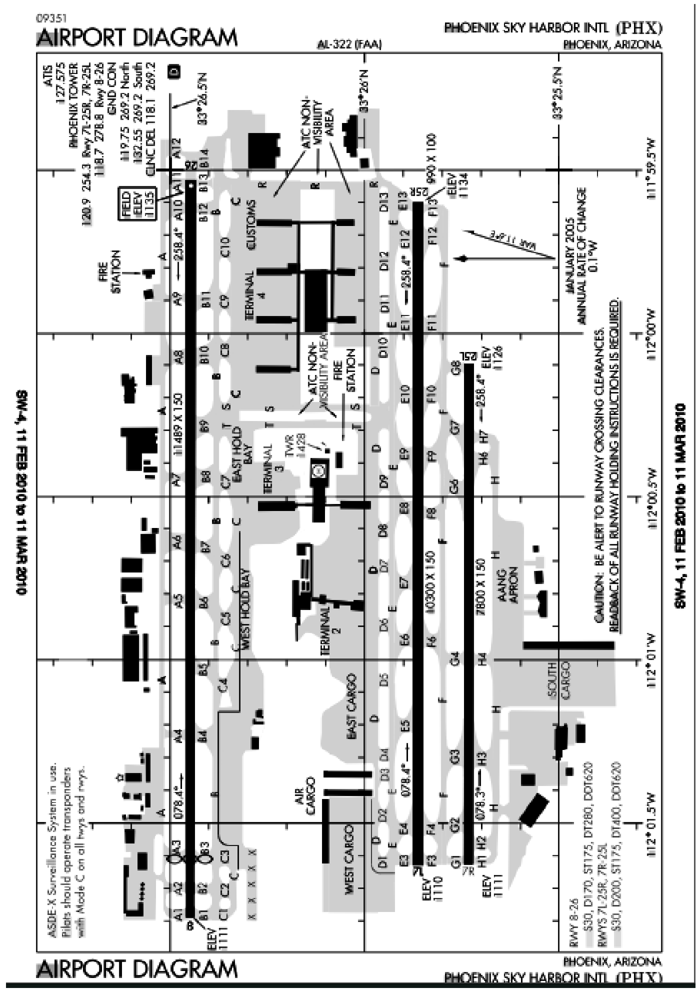


Figure 5.2 Phoenix Airport Layout

green status, meaning that the crosswind component on the runway is currently strong enough that no additional spacing will be required behind the Boeing 777 on takeoff.

Along the taxi route, information is displayed as to how well Sunset 42 is meeting its taxi-out times. Since Sunset 42 is following the B-777, the flight crew notices it is accelerating its taxi to make up time and so does Sunset 42. Sunset 42 also knows that because the wake vortex avoidance system has the runway in the green, they will save approximately one-minute and end up making up the two minutes that they were delayed in getting off the gate.

[18] In a data link rich environment where there is a 3D trajectory for surface movement, radio transmissions for approvals for push-back and taxi are likely not necessary. Whether voice is used for clearance to takeoff needs to be assessed. All the commands can be explicit in the graphical representation of surface movement on the EFB or guidance display.

GNSS Interference

Had an interference event been detected at PHX while Sunset 42 is taxiing, it would have been detected through the ADS-B multilateration capability. This does not prevent numerous voice calls from aircraft alerting the tower to loss of GNSS navigation and the tower notices alerts to the loss of ADS-B information on their surface situational displays. The aircraft can be tracked using multilateration, but they must now revert to text delivery of taxi routes or by voice, depending on the aircraft EFB configurations. The loss of GNSS impacts cockpit-moving maps by not showing own-ship position or the position of others. The automated taxi clearance and guidance has now failed and controllers must set the sequence and increase voice communications.

The TRACON has advised of the extent of the interference, including a graphical representation of the area. The TRACON's strategic controller has begun reducing the number of departure routes available for use and will begin reworking the 4D trajectories of departures, based on the need to create 1) a path for vector departures, 2) use of RNAV standard instrument departures with lower performance, and 3) to manage arrivals, some of which have executed missed approaches due to loss of navigation or loss of navigation precision.

Sunset 42 is departing on RWY 25R, but priority will be given to landing aircraft through the interference. Sunset 42 may be delayed so that the runway can be used for recovery. The strategic controller, in reviewing the flight object for Sunset 42 finds that an early maneuver will be a radius to fix turn using RNP 0.3 to get Sunset heading to the east. The need to alter just this one maneuver will affect timing downstream and will cause further revisions of the TBO 4D contract. The controller knows that departing aircraft will be able to continue to take off and fly out of the interference area, but will require special handling to move them out of the area of interference. Aircraft on arrival with IRUs and FMSs will be able to update position from DME and still use RNAV procedures. Aircraft on the ground can update their position at the end of the runway before departure and use some RNAV procedures, but not RNP 0.3 departures. Aircraft lacking the ability to update their position can depart and receive vectors from the ANSP using multilateration or secondary surveillance radar until clear of the interference area. In the immediate terminal area, 3-mile separation can continue to be used, but separation distances will need to be increased as the aircraft leaves the 40 nm coverage diameter of secondary surveillance.

Airport Performance Impacts:

- **Loss of moving maps and taxi guidance/clearances in the cockpit**
- **Reduction in departure capacity to favor arrivals for recovery**
- **Increased controller workload**
- **Loss of RNP 0.3 departures, reducing departure options**
- **Limitations in taxiing in low-vis operations**
- **Missed approaches must be handled with radar or MLAT vectors**
- **Taxi out efficiencies and automated sequencing lost**
- **Lower arrival and departure rate even in clear weather**

Had the interference event occurred in low-visibility conditions, the ANSP's first concern would be recovery of aircraft and departures would be held until the airspace use is re-stabilized. In visibility conditions at or above 600 feet RVR, surface operations would continue using visual navigation aids[19]. Aircraft with enhanced vision could continue to operate, but a significant segment of aircraft would be limited in taxiing below 600 RVR. Progressive taxi instructions off of the ASDE-X multilateration functions could provide guidance and separation on the surface with an increased workload. Low visibility departures are conducted today down to 300 feet RVR with heads-up displays and runway course guidance from either GPS or the back course from a Category II ILS. Special low-visibility procedures for taxi and takeoff could be created for GNSS disruption, but the capacity penalty in low visibility would be significant, compared to low-visibility taxi guidance from moving maps, GNSS augmented by GBAS takeoff procedures for centerline guidance, and the ability to see other traffic electronically.

Nominal Scenario Resumes

The pre-takeoff checklist is accomplished during taxi. As soon as the B-777 lifts off the runway, takeoff clearance is given to Sunset 42. This is indicated by the extinguishing of the runway hold lights across the taxiway and the blue course line on the cockpit moving map guidance display turning magenta[20]. On Sunset's newly delivered 1,000's, the ADS-B "In" targets of other aircraft have both the aircraft and its predicted wake location show as a single display object. As the Boeing 777 lifts off, its symbol on Sunset's guidance display begins to leave a trail behind it that indicates an approximation of the wake location. With LNAV and VNAV engaged, the auto-throttles are engaged and Sunset 42 rolls down the runway. The Boeing 777 wake is seen to drift off the downwind side of the runway as predicted, away from Sunset 42's track. The RNP 0.3 departure procedure accomplishes two things, avoidance of the most noise sensitive areas southwest of the airport and an expeditious radius turn for course reversal to an east-southeast heading toward Miami. The radius to fix turn means that Sunset 42 can leave the standard instrument departure procedure as soon as possible and gets going on track for the 4 D trajectory. As this airplane beats Stage 4 noise rules and is precisely navigated along the path of least disturbance, people on the ground don't even notice Sunset Air 42 against the normal background of urban noise.

No climb restrictions had been issued at the time of takeoff, but about five miles southeast of the airport, a potential conflict is shown on the guidance display with an inbound flight that will cross right to left, about six miles ahead. The ANSP gives a reduction in climb rate to Sunset 42 by voice, in order to be 1,000 feet below the altitude

[19] A significant system cost is visual aids, including marking, signs and lighting. These costs can be reduced on most airports as the use of moving maps increases. Centerline taxiway lighting would likely still exist at large airports for low-visibility operations.

[20] While "cleared for takeoff" can be as simple as changing lighting settings or imaging on the surface movement map use of data link or voice is also possible and used at other airports where moving maps are not provided.

of the conflicting flight where their paths will cross.[21] The crew acknowledges and the altitude window on the glare shield now shows the crossing altitude instead of initial cruise altitude. Immediately after this crossing, the altitude window reverts to the desired initial cruise altitude of FL 370 again and the crew begins an optimized profile climb that reflects weight, wind and aircraft performance and is built into the 4D trajectory.

The controller's imposition of a climb restriction does not affect the 4DT under TBO. Vertical climb performance is the greatest variable and there is a vertical range defined between the engine-out climb performance, and best climb performance based on the aircraft's performance capabilities. When the altitude restriction was given, the tactical controller entered the new altitude variable and the ground automation updated the conformance monitoring parameters. This allows the ground automation to continue monitoring compliance with the 4DT. The aircraft will also send changes in performance and climb as detected by the FMS that will further refine the 4DT performance.

GNSS Interference

A GNSS interference event at PHX detected before takeoff, and known to be of limited range (in this case approximately 60 miles), Sunset 42 would set the aircraft position in the inertial for the runway end for departure. The IRU would then be capable of guiding the aircraft on the departure. RNAV/RNP would degrade at approximately 2 nm per 15 minute interval. However, as Sunset 42 climbs through 4,000 to 5,000 feet, the aircraft will begin receiving DME-DME updates so that climb can continue. It is unlikely that the early turn (RNP 0.3 radius to fix) to head east-southeast will require more airspace and would be approved by a clearance to reverse direction and then rejoin the 4DT flight path. This becomes an open trajectory that affects conformance monitoring. The tactical or strategic controller can identify the turn from wide-area multilateration close in to PHX and provide an update for conformance monitoring. Sunset 42 is well equipped to continue dispatch. Surveillance from ADS-B is backed up by wide area multilateration. Navigation is provided by the IRU and FMS provides conformity to the 4D trajectory. Position is updated from DME-DME, and since Sunset 42 has an architecture that uses a navigation bus, the DME-DME derived position is used for ADS-B[22].

Sunset 42 can see the B-777 and selected other aircraft, but with the GNSS interference, they know that some aircraft will disappear from the display, unless Sunset 42 is capable of receiving ADS-R, a rebroadcast of whatever the TRACON is seeing through a combination of SSR, multilateration, and ADS-B from aircraft with a navigation bus.

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[21] This same message could have traveled via data link, but here the voice command also alerts the crossing traffic that the situation is well in hand. The tradeoff between data and voice is dependent on the value of the "party line."

[22] At present, if interference occurs, the ADS-B function would not send misleading information, opting to not broadcast GNSS position in error. The provision of alternative position information taken from a navigation bus would need to be developed, including information about source, accuracy and integrity.

Airport Departure Impacts:

- **TBO departures abandoned, placing aircraft on open trajectories with radar vectors in instrument conditions**
- **Significant control-by-exception workload at high traffic loads**
- **Aircraft leaving interference area require new 4 DT negotiation and clearance**
- **Separation distances increased**

After approximately 15 minutes, Sunset 42 begins to receive intermittent GNSS coverage, and within 20 minutes, the aircraft is clear of the interference area.

While Sunset 42 is capable of dealing with the GNSS localized interference, other aircraft are not. The weather at PHX is sufficient to allow visual flight rules (VFR) departures and aircraft heading west can maintain VFR until clear of the interference. Any aircraft with a DME-DME can establish its position above approximately 4,000 feet, but the precision of departure paths using RNP are impacted, so there are fewer departure paths, reducing capacity. Aircraft that only have RNAV and ADS-B driven by GNSS would not be able to depart in weather unless the ANSP is willing to use vectors for departures to clear of the interference. This could be a significant workload at some airports. Choosing to rely on air traffic control in a TBO operation puts every aircraft unable to maintain RNAV procedures in a control-by-exception category, at a time where the strategic and tactical controllers are dealing with recovery of aircraft, who on arrival, are unable to rely on RNAV and RNAV RNP arrivals. Some, but not all aircraft could continue their departures by departing VFR and picking up an IFR clearance, others could rely on standard instrument departures built on existing ground-based navigation aids. The retention of these ground-based navigation aids is a significant cost element just to support departure throughput.

In absence of an alternative PNT source, TBO departures would be abandoned, requiring considerable downstream workload to re-enroll all IFR aircraft into a TBO structure. All of the departures would be considered open trajectories, meaning that conformance monitoring tools would be out of sync with aircraft intent. Aircraft intent from the aircraft would be limited to a clearance limit and most of the advantages of automation-to-automation interaction between the air and the ground would be lost. Separation distances would likely be increased until demand is reduced.

The concept for TBO is built around a closed trajectory, where the aircraft and the ground automation are in sync with each other. Ground automation tracks conformance with the 4D trajectory and look downstream for conflicts and flow contingencies.[23]
In summary, demand must be controlled as RNP departure options are reduced. Separation would likely change due to the lack of GNSS and heavier reliance on terminal SSR or wide-area multilateration to provide coverage for the loss of ADS-B. The added

[23] A fundamental issue is whether tactical air traffic controllers can even manage the volume of traffic in the airspace when automation is not performing its role of conformance monitoring. Aircraft on a SID would help reduce the work burden, but there is a net loss in capacity with an interference event, throttling back demand to stabilize workload.

separation distances are driven by the loss of positioning precision and the need to work to close open trajectories and get aircraft back into a TBO 4D trajectory environment. This task would be especially difficult for airports like Detroit, where departing aircraft must be inserted into overhead streams. Controller workload in dealing with a high number of control-by-exception events will rise.

Nominal Scenario Resumes

Just after reaching cruise altitude at FL 370, the pilots notice a UAS on the traffic display climbing toward their route ahead over southern New Mexico. It appears to be coming from the border area with Mexico, probably returning to base after a surveillance patrol. As the scenario develops, it is apparent that the ANSP has intervened with the UAS controller by stopping its climb at FL 360. The lateral positions of Sunset 42 and the UAS are nearly coincident at the crossing and “do not descend” is displayed by TCAS to the Sunset crew as it passes overhead. The UAS either overshot its altitude slightly or approached FL 360 at an excessive rate, leading to the preventive resolution advisory (RA) being issued even with nominally legal separation. The advantage here is that the UAS was identified well in advance by the use of ADS-B and Sunset Air could deduce the potential conflict through the richness of information provided.

GNSS Interference

For reasons of weight, it is unlikely that a military UAS would carry a backup PNT capability and would be using military GPS coding. On the high-end military UAS aircraft, ADS-B would be activated and deactivated by the controller, depending on the mission. On the civil (commercial) side of UAS, GNSS would be used without advantage of military coding and would be subject to interference. Civil UAS would be required to carry and use ADS-B. The loss of positioning would leave the ground controller flying the UAS without full guidance information, but may still have telemetry on other UAS performance parameters. In autonomy mode, the UAS would need to rely on inertial navigation, drop to dead reckoning, possibly enter an orbit, and would not be detectable from the ground unless also carrying a transponder and within the coverage of SSR. This area of APNT for commercial UAS operations needs to be further investigated from a failure modes and effects perspective.

The UAS represents an aircraft with no legacy avionics and a significant payload concern over adding weight for redundancy. Navigation is highly dependent on functioning GNSS for all but the largest military UAS aircraft. The loss of GNSS and ADS-B eliminates navigation and may seriously impact remotely piloted units. Autonomous units will lose precision.

Nominal Scenario Resumes

The flight is routine over southwest Texas following the 4D trajectory generated in Sunset Air’s flight planning computer and accepted by the ANSP. The latest update on the weather situation over the Gulf is received by the crew through the 4D weather SAS, showing the convective activity to be strongest at and south of the currently planned route. No tops are yet above FL 350 but that can change as the day progresses. The crew discusses the possible need for lateral deviations and notes that they will likely be to the north, if necessary. Just then, an airspace alert is received showing turbulence in the flight path. Sunset 42 sends a request for cruise climb to FL 410, to fly above the turbulence. The strategic controller handles the request and uses tools to provide a vertical band of airspace for the cruise climb and provides the trajectory information that ground automation provides and hands off the 4DT to the tactical controller who then sends it to Sunset 42. The response approving the request is almost immediate, and the crew activates the trajectory change in the FMS.

In this latest version of the FMS, the cruise climb function determines the optimum altitude not only based on the present aircraft weight and outside temperature, but also the current wind at the present altitude and for several thousand feet above or below the present altitude. While climbing 1,000 feet may make sense in a calm wind situation, the wind gradient at the moment might make that less economical than staying put for a while. Today, however, the tailwind component continues to increase with altitude up to the tropopause which is at FL 410 in this area, so the cruise climb guidance keeps Sunset 42 a little above the “no wind” optimum altitude, very slowly climbing (less than 100 feet per minute) as fuel is burned off and the airplane gets lighter.

When Sunset 42 gets to the San Antonio area, an amended 4D trajectory request comes in from the ANSP. Due to traffic out of Houston, the ANSP is requesting a hard altitude be used until entry into the designated self-separation airspace.[24] This will facilitate their manual separation of other less capable aircraft in the area. Sunset 42’s crew responds they will maintain FL 390, and descends 100 feet to that altitude. The ANSP has used its optimization tools to generate the request and accommodate the Houston traffic. Sunset 42 could have declined and the ANSP would re-plan; however, the level of collaboration in NextGen also demands a commensurate level of cooperation.

When they reach a point about 20 miles off the Texas coast, they enter self-separation airspace and the ANSP drops all conformance requirements to the 4D trajectory while the aircraft is in the self-separation segment. The voice guard frequency goes to a designated air-to-air contingency frequency. The required contact information to be used when leaving this airspace on the Miami end is also received and acknowledged by the crew as a 4D ETA. This ETA is also the basis for the expected arrival in the event of lost communications.

Sunset 42 now resumes its cruise-climb to FL 410 and the crew turns their attention to the developing weather ahead. The broadcast compilation of ground-based radars compiled by the 4D weather SAS is not the best in this area due to the distance off shore, but some of the measured tops are now poking through 40,000 feet. There is a complete undercast

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[24] Transition to self-separation will likely be at a prescribed 4DT point where the closed trajectory will be opened for maneuvering so as to effect positive transfer of control of separation responsibility. In this case, it is a geographically defined volume of airspace that is dynamically assigned. The JPDO TBO Study Team is considering entry and exit points for self-separation as occurring with the change to and from a closed trajectory.

of cirrostratus now with its top at 40,000 feet. As Sunset 42 was at 40,200 in the cruise climb, the crew hurries the climb slightly to FL 410 to stay in the clear and have a better visual picture of the isolated higher tops poking through the stratus layer. The airborne weather radar is showing returns, including Doppler returns from the more active cells. Lightning detection equipment also shows the areas of greatest storm intensity. Flight 42 turns 10^0 right to increase the distance from a building cell 50 miles ahead. To the right of this cell is a 40-mile wide area of lower tops, with a very extensive building area south of that. The crew decides to go through the break in the line above all clouds at 41,000 feet.

About that time another flight begins to converge from the left. It is Westair 134, a Dallas to Miami 737-800 also flying at FL 410. The Sunset 42 crew detects Westair 134 on their guidance display. The crew has already activated features in the conflict detection and resolution (CDR) toolset to establish a track on Westair. It appears to be using the same break in the weather and has come south of its great circle track from DFW to MIA to stay in the clear. Both aircraft are equipped for self-separation and as the ADS-B information is swapped, the aircrafts' computers use CDR to minimize the individual disruption caused by the two aircrafts' proximity. Sunset Air is a 737-1000, which is about 10 knots faster at this altitude than the Westair Boeing 737-800. So as the aircraft slowly converge abeam each other, the software provides guidance to shift to RNP 0.3 performance and both crews are to fly parallel courses separated by a 1.2 nautical miles while Sunset 42 slowly pulls ahead. Using voice the Sunset 42 and Westair 134 crews exchange intent and the parallel maneuver is executed. Both crew could have set a wider parallel path but since both were visual on top, they selected the 1.2 nm option. 18 minutes later, when Sunset is ahead by 3 miles, the restriction is dropped in both aircraft and they again proceed according to their own optimization and hazard avoidance plans. Had Sunset 42 disappeared into the clouds, turbulence information would have been shared and Westair 134 may have opted to follow Sunset 42 with the knowledge that their separation distances will be increasing. As Sunset 42 picks through the tops of the thunderstorms, the track is visible on Westair's displays.

Picking their way between the tops with the aid of information from both satellite-based and airborne advanced weather sensors augment the visual scene, making it as easy as looking at the map and sticking as close to the storms as will allow for the optimized trajectory.

GNSS Interference

Westair 134 and Sunset 42 are using the precision provided by GNSS, shared air-to-air ADS-B and coupled with inter-aircraft communications on an open voice channel to maneuver safely in self-separation airspace. Other aircraft may be on procedural separation outside of the range of SSR and air-ground ADS-B; however, Westair and Sunset can see other aircraft that are transmitting their position from ADS-B. This would be a common situation for any aircraft that is authorized self-separation. Some of the aircraft in the airspace are not self-separating and may only have ADS-B out (no cockpit display of traffic). The use of a common guard frequency allows Sunset 42 to contact these other aircraft by call sign and inform them that Sunset 42 is self-separating. A call is made when Sunset 42 is no longer a traffic factor.

Within this context of 2025 maneuvering, Sunset 42 and Westair 134 detect an interference event. It manifests itself as a receiver off (or unable) alert. Both aircraft have a navigation bus, but are outside of the range of DME-DME for update, so their last valid position before the alert is the last update to their IRU. These IRUs begin to lose precision at about 2 nm every 15 minutes[25]. If the aircraft were within the performance of RNP 1.0 at the time of outage, RNP would increase due to loss of precision at a rate of adding 2 miles every 15 minutes. The aircraft has just entered the interference area but has no way of knowing at that time how large the area is. They may be just skirting the edge or faced with flying through the entire diameter of the cone of interference.

For aircraft receiving air traffic control services in the offshore airspace and relying on DME-DME but out of range to update the FMS they can continue to coast. But if equipped and authorized with dual GNSS equipped without an FMS, these aircraft are now without navigation. For aircraft on procedural separation, they would most likely be flying a pre-defined track separated longitudinally by Mach number and laterally by distances that would provide safe separation for sufficient duration to fly out of the interference area.

However, to build these tracks based on a contingency of a GNSS outage is inefficient and loses capacity. In offshore operations, outside of the range of a navigation backup, procedures could be developed to compensate for GNSS interference that is emanating from the surface.

In the case of self-separating aircraft, they would have knowledge of aircraft that are within approximately 70-90 miles of their own position at the time of start of interference. But aircraft being detected from ADS-B would just disappear. This is an unacceptable condition. Procedures would need to be developed to handle re-establishment of vertical separation in the surrounding airspace. The cockpit conflict detection and resolution tools would need to provide a summary of position, identify an altitude to attain vertical separation, and resolve potential conflicts. The pilots would then need to

Self-separation Impact:

- **Self-separation will not be authorized during GNSS interference**
- **Those aircraft self-separating will need to seek vertical separation and gain a 4DT with reversion of separation to the ANSP**
- **Oceanic airspace operations with interference will require development of safety procedures that consider IRU performance**
- **Loss of off-shore/oceanic TBO requires procedural flight tracks in absence of GNSS with the problem of going from precise positioning and navigation to procedural separation**

[25] To get position from an inertial system, two integrations are needed to go from acceleration to velocity to distance. As a result, linear drift rates in the inertial results in exponential error growth in the position error/bias. Some manufacturers are supporting next-generation inertial systems that can coast with no GNSS and sustain RNP 1.0 for 2.23 hours.

use voice communications to self-organize the vertical separation.

The question becomes how long of an exposure to the interference could an aircraft expect? As a rough measure, assume that the aircraft is just entering the cone of interference from the ground along a flight path that represents the diameter of the cone's slice at the aircraft's altitude. If the diameter were 350 nm, then the aircraft would be exposed to the interference at Mach 0.8 for approximately an hour. The military is reporting planned interference areas with a radius of 350 nm. In that time, the IRU would only degrade in an hour by 8 miles. Without an IRU, aircraft flying nearly an hour without navigation and positioning harkens back to the 1930's and dead reckoning.

Just as with lost communications, procedures will be needed for en route lost positioning and navigation to fly out of the interference area.

Nominal Scenario Resumes

As Sunset 42 flies eastward, nearing the end of the weather area, another dynamic SUA in the eastern Gulf pops up "active" with the desired route of flight crossing its southwestern corner. This SUA has an unlimited top, and as Sunset 42 will want to begin its descent soon, a deviation to the right begins immediately to just miss the edge of the SUA. The sudden presence of the dynamic SUA is also received in the AOC office of Sunset Air. The forward flight-planning algorithm takes this into account as well as expected turbulence during the initial portion of the descent. A new recommended 4D trajectory is sent to the flight deck and to the ANSP. Because a reduced speed will be used in the turbulence area, an adjustment is made to the expected arrival time at the runway. This is noted in the ANSP automation and the ETA is modified for flight following purposes. The new trajectory also includes the descent profile starting shortly after the flight begins to diverge from the SUA. The optimized profile descent is calculated by the aircraft based on weight and expected winds and designed as a power off descent to the merge point on approach. The track is not charted as a standard terminal arrival route (STAR) but is unique to each flight capable of performing this operation.

The computed speed, altitude profile, and track over the ground optimize the descent of the flight. As these parameters are also transmitted to the ANSP, this 4D trajectory arrival procedure can be accommodated because the time of arrival at the merge point is a controlled time of arrival with required time performance. While some AOC's provide the desired profile as calculated from the aircraft, others depend on the ANSP to assign the descent maneuver. Instead of trying to fit all arrivals along the same path, the use of OPDs built on tailored 4D trajectories opens up options to provide more aircraft with this most fuel efficient and environmentally friendly approach. The option to self-define is a function of airspace density. For example, going into super-density airports like JFK, Sunset Air will receive both the OPD profile as a 4D trajectory and winds derived or reported from other flights in the same airspace accomplishing similar maneuvers. The aircraft would then determine the top of descent and return a proposed vertical trajectory along the pre-defined track. The larger the traffic volume, the less the number of tailored options available, but the better the time performance because the ANSP software is learning from each preceding flight and using surveillance information to capture variations. These OPDs can take the aircraft to the runway end with a seamless flight track to a final approach segment, or drop the aircraft on a downwind for a radius to fix turn to final.

Sunset Air 42's crew puts on the seatbelt sign for the expected turbulence and everyone is buckled up as they begin the descent to Miami. The speed is reduced so that the turbulence, downwind of the convective weather area, is experienced as a light and steady chop. Halfway through the descent the air becomes smooth; the seatbelt switch is turned off for any last minute trips to the lavatory before being switched on again for the duration of the flight. The crew would have sped up in the smooth air but a message from the ANSP now says 18 seconds will need to be lost before the merge point. This merge point is a firm CTA, meaning that there can be other adjustments but it is expected to be hit with ± 4 seconds precision. The first officer makes this amendment in the FMS and the speed guidance returns to the turbulence penetration speed, but this time it's to meet a new CTA.

Approaching the Miami terminal area, it is not necessary to slow to 250 knots because ADS-B "Out" is required in the airspace so there are no legal "unknowns" that was part of the basis for the 250 knot restriction when originally conceived. However, Ariba Air 151, an Airbus A-320 "semi-classic" is arriving from the south and incapable of flying to a prescribed 4D trajectory containing a CTA. The ANSP calls on voice and clears Sunset Air 42 to merge behind Ariba 151 and follow that flight to the runway with a 70-second spacing. Sunset 42 selects Ariba 151 and sets the 70-second spacing requirement and the merging and spacing tools onboard the aircraft acquires Ariba 151 on the traffic display. The crew then follows the speed and heading commands to fall in behind Ariba and finds itself on final to RWY 9 with 65 seconds spacing and the speed guidance calling for a further reduction. The flaps are extended a little earlier than planned and a reduced speed is maintained until the 70-second interval is achieved.

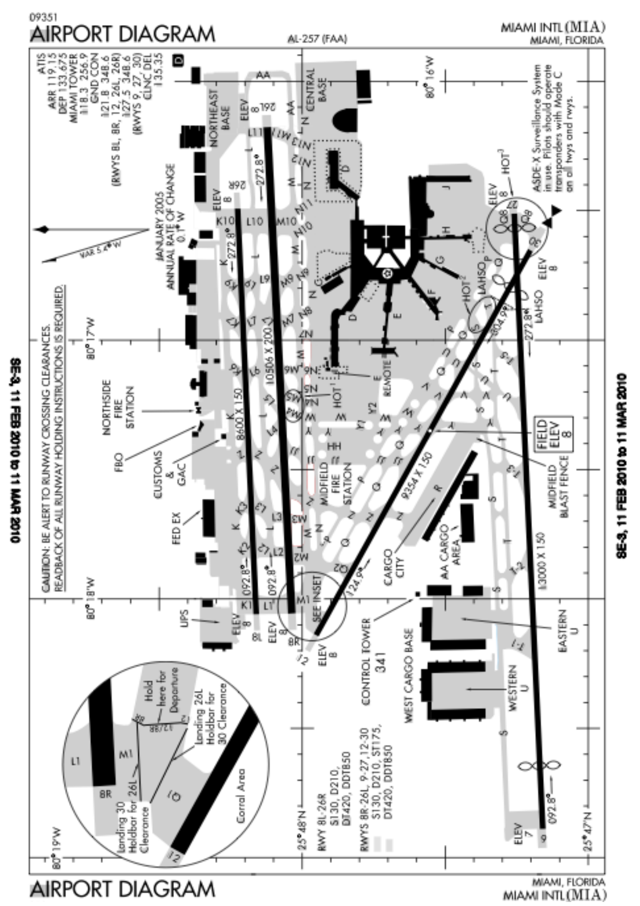

Figure 5.3. Miami International Airport Layout

The weather is visual but the approach is a GLS to RWY 9 with lateral and vertical guidance both on the panel and on the HUD in front of each pilot. The Captain follows the guidance “heads up” keeping a visual watch for birds or anything else in the airspace while she manually flies the approach and landing to maintain her proficiency. Sunset 42 touches down 71 seconds behind Ariba 151. A normal gentle deceleration makes the T-3 turn off appropriate and the crew begins the after landing “cleanup.” The Miami airport map is showing on the guidance display with a green cleared route to the gate. The airline’s gate control determined which gate Sunset 42 would use days in advance according to the strategic plan for optimizing ramp

resources, but two prior irregular operations necessitated a change for Sunset 42 to use a gate, two spots closer to the end of the D Concourse.

This change was sent to both the flight and to Miami Ground Control as a data message when it was determined a change would be necessary to avoid a gate hold. The ground control automation calculated and sent the cleared taxi route to flight 42 as soon as the “on the ground” message from the ADS-B was received. It showed taxiway Sierra and Yankee, Yankee 2 into the ramp of the D Concourse and to hold short of RWY 30. However, as Sunset 42 approached the RWY 30 on Yankee, the red hold short bar disappeared from the display and the lights across the taxiway were extinguished. “Cleared to cross 30” was the voice annunciation accompanying the data link message displaying the same words.

Sunset 42 didn’t even slow and continued an uneventful taxi to the gate. As the brakes were set, the arrival message sent to the company showed two minutes early (helped by the straight-in landing to the east) and the fuel burn was 400 pounds less than plan. The passengers all made their connections and took for granted all the things that went into making this a successful flight.

In 2025, this arrival will be fairly typical, where an OPD is interrupted to follow another aircraft. Because of the mixed equipage and differing degrees of performance among aircraft, most will be able to use OPDs to touchdown and the ANSP software will set the landing sequence based on 4D trajectory information. This sequence may be set well before top of descent. The software will then manage merge points for multiple aircraft, set up paired approaches, and provide options to the controllers for insertion of less equipped aircraft. While the ideal situation is an OPD that takes you to final approach, the reality is that in accommodating other aircraft, it may be necessary to have the OPD take the aircraft to a position and path downwind to the runway. While this is slightly less efficient than an OPD, it allows the air traffic controller to manage compression and support arrivals from all directions to the active runway. Under this concept, an arriving aircraft is positioned on the downwind and then drives to pre-defined fixes along the downwind path. Each fix is set up to provide a starting point for a radius to fix turn to final approach.

A significant element of successful merging and spacing will be the tools on the aircraft. This software capability is driven from known aircraft positions that rely on GNSS and allow an aircraft with ADS-B In to merge on a lesser-equipped ADS-B Out aircraft. Cockpit display of traffic information allows those who are equipped with merging and spacing capabilities to follow another aircraft, whether through a cloud layer or on final approach. In essence, the capability can work as an equivalent to electronic visual flight rules and increase capacity over instrument separations. In more sophisticated applications, a following aircraft can set up the vertical separation to avoid wake vortices, use the tools for operations to closely-spaced parallel approaches as a paired approach, or support landing two aircraft on the runway at the same time with sufficient touchdown spacing to safely decelerate and exit the runway.

GNSS Interference

In no other area of flight operations is the dependency on GNSS more important than in the arrivals and approach to landing at airports. In order to handle the expected future traffic demand at many metropolitan airports, the precision of position and the necessity to meet timed performance is the greatest. The NextGen concept of operations is based on the ability to support increasing demand and shift more workload to automation, both on the ground and in the air. Reductions in separation, pairing of approaches, the use of OPDs to gain efficiencies, surface movement automation, traffic sequencing, and the entire 4D trajectory-based operations are predicated on GNSS being operational. Efficiency and capacities at airports is critical to handling the traffic load without overpowering the capabilities of the flight crews and controllers to safely perform their duties. While safety can be sustained by reducing demand, this is exactly what any deliberate attempt to interfere is going after. It is what makes GNSS a target in the first place, either to elicit fear or create an economic burden on aviation.

To be able to continue dispatching and recovering aircraft at capacities that meet demand levels during a GNSS interference event, denies the benefit of intentional interference. But aviation will not be the only target of interference. As use of GPS becomes increasingly ubiquitous, without alternatives to provide the same capabilities, the jammer of the future may very well be targeting intelligent highways, maps in vehicles, or

Terminal Impacts:

- **Significant transitional workload at time of interference**
- **Missed approaches must be accommodated**
- **Separation distances must be increased**
- **Closely-spaced parallel operations are terminated below 3,400 feet separation**
- **TBO techniques like merging and spacing, limited self-separation, paired approaches, etc. are terminated**
- **Departures are delayed to accommodate recovery of aircraft**
- **Ground stops and holding of aircraft capable of doing so is used to balance demand and get demand below the level of automated separation to a manageable level of control by exception**
- **For repeated intermittent interference, fuel loading for contingencies is increased**
- **TBO using 4DT must be recalculated for some aircraft and open trajectories (vectors) used extensively**

anything else to gain attention through disruption. For this reason, the interference scenario for arrivals into Miami uses an intermittent, mobile jammer. This is someone who continues interference events for short durations, is mobile, and relishes in the reports of the havoc being caused.

After several repeat interference events, the ANSP cannot count on using 4D arrivals. The airline AOC must plan for the contingency with additional fuel loads and meet minimum equipment list requirements. The crews know that their planned flight path can be interrupted at any time. Workload goes up and the disruption takes hours to recover, only to be hit again by another interference event. As a precaution, strategic flows are constrained to reduce demand and provide for buffers in anticipation of the next event. Without some alternative PNT, the Miami operations will look like wave after wave of thunderstorm events.

Sunset 42 detects the unreliability of GNSS while on the OPD, having already left top of descent over the eastern Gulf of Mexico. Because Sunset 42 is within range of DME on land, the aircraft is able to continue the arrival path assigned and meet their CTAs. Miami controllers are aware of the interference event and the volume of interference coverage from a map generated from the surveillance data network that tracks loss of ADS-B position reports based on GNSS. The automation tied to the network is comparing blank ADS-B reports with SSR and multilateration reports and generating information for use by the controllers. The map is also broadcast to the cockpit of any aircraft capable of receiving graphical weather. This information is rapidly distributed as a flash message throughout the network-enabled operations system used by the ANSP and shared with the users.

The ANSP has not lost surveillance coverage, since the surveillance data network delivers a fused surveillance product to the ANSP automation. There is a loss of precision, there may be a need to increase separation; there will be a need to modify arrivals. The number of options open for OPDs will close down and aircraft will need to be routed onto a set of published STARs that are based on retained ground navigation aids since some aircraft will not have IRUs. GLS approaches are lost for use and the ANSP will need to vector aircraft for an intercept with the ILS localizer. Fortunately, some of the OPDs are designed to position the aircraft (by RNAV) on final approach. Flight routes will be extended to allow for merging and intercept of the localizer. Less equipped aircraft will need vectors, significantly increasing controller workload. The best equipped will experience holding (because they can) in order to recover the less-capable aircraft.

The advantage goes to the least equipped aircraft in the presence of interference because they are the least able to continue operations in the absence of navigation and require the highest workload to recover safely. These aircraft will be recovered to the first available airport, vectored out of the interference area, or handled by extended vectoring until they can be integrated to land, likely not at the airport of choice. Some will be told they are not allowed to enter the interference airspace so as to relieve demand.

ADS-B applications will be disabled. Since most of these applications are designed to increase capacity and efficiency, this loss is an economic impact. The safety impact is the need to go from TBO separation standards to SSR standards. This transition from steady-state TBO operations to off-nominal operations carries with it a need to deal, in priority sequence, with the most critically impacted aircraft first and attempt to reach a reduction in demand to the point where the controller can sort out and recover aircraft. The problem here is that at the time of interference, automation is separating more aircraft than the controller can handle under TBO in control by exception.

Closely spaced parallel runway operations will be suspended for runways below 3,400 feet separation. This is because the RNAV flight path at lower altitudes will be disabled because of the lack of low-altitude DME-DME updates. In 2025, paired approaches down to runway separations as low as 750 feet can be expected but will not be possible. Basically, only approaches that can be flown today to closely-spaced parallel runways that are not dependent on GPS can be flown.

The intermittent nature of the interference does not mean that when there is no interference that the storm has passed. Just as with severe weather, there is a period of recovery needed, where runway throughput is lower. Transitioning back to GNSS and ADS-B operations may be delayed because of implementation of contingency plans and procedures to balance workloads. Removing restrictions will be difficult in anticipation of another intermittent interference event.

Without an APNT to at least sustain an RNP 0.3 capability, the airspace at large airports cannot support the traffic volume in 2025. This is not to say that many airports across the nation also need RNP 0.3. If you are not capacity constrained, larger lateral distances are perfectly acceptable. It is likely that the top 50 airports by operations will need an extended backup strategy to provide for arrivals and continued dispatch.
TBO, the basic tenet of the NextGen concept of operations, is highly dependent on precision and predictability, where automation assists in separation. Automation understands 0 and 1, yes and no, on and off. It is not capable of handling grey areas of uncertainty. GNSS creates this uncertainty.

5.9 Scenario Description – Phoenix to Bozeman

Operational Objective:
The following scenario addresses the activities conducted by a general aviation turboprop aircraft. N72MD is faced with a complex workload as a single pilot operation in a relatively high performance aircraft. The pilot is aided by automation. The ANSP operates an un-staffed NextGen virtual tower at Bozeman, Montana that uses local ground surveillance, communications and navigation equipage linked to controllers via network centric infrastructure located at the Colorado Springs FAA facility. The primary focus of the scenario is to illustrate the operations of aircraft with mixed avionics equipage at a remotely staffed airport.

N72MD is a single engine corporate turboprop Socata TBM 850 en route to Bozeman at FL 210. The aircraft’s single pilot crew is transporting five senior managers of the

Wyoming State Bank from their meeting in Phoenix to a business meeting with town leaders in Bozeman over investing in a corporate industrial park. The pilot does not know exactly when the meeting will end and the flight will depart. Using his tablet computer, he has logged into a commercial service provider who has applications for planning the flight. Just like his air carrier counterparts, he has connectivity through this service provider to the ANSP.

General aviation users can use flight-planning software similar to airlines that plot out the best or optimum 4D trajectory and then propose and negotiate with the ANSP digitally. They can also be equipped with sophisticated weather receiving and 4D trajectory analysis systems, called here the virtual pilot assistant, that monitors the latest updates from the 4-D Weather SAS for changes that will require changes to the trajectory. The pilot assistant provides options to the single pilot of N72MD.

For N72MD, the flight-planning tool would take the departure point and destination point and using knowledge of wind and temperature profiles and the forecast for convection, select the most efficient RNAV trajectory. Altitude recommendations are made – even considering the final portion of the flight at BZN. The virtual pilot assistant can be set to avoid weather that the pilot is not comfortable flying in or that meets ride comfort preferences. This information is provided to the flight planning software. If the software uses the latest forecast information from the 4-D weather SAS, it will ensure common weather picture (including forecasts) collaboration with the ANSP. Use of other weather information (e.g., private vendor) will not and this will add an additional level of flight management if the weather impacts are different.

The flight planning capability the pilot has on the ground or in the air overlays all of the tolerances pertaining to the flight at the point in time the flight is planning to pass to create one out-of-tolerance field. In essence, this is the airspace where the flight planner has told the flight-planning program “I can’t fly there.” or “I don’t want to fly there.” The flight planning software considers the convection, winds, temperatures, airspace restrictions, and other weather restrictions (legal restrictions and personal preference) at the time of the flight, and determines the optimal 4D trajectory.

During the flight, N72MD can automatically monitor the updates to the 4-D weather SAS for changes that affect the planned trajectory. As the aircraft approaches the halfway point, the area of out-of-tolerance weather, characterized as turbulence moves farther east across the planned trajectory.

While flight planning, he learns that there is clear air turbulence en route, that snow squalls are possible at and around Bozeman with poor visibility at the expected time of his arrival, a radical change from the incredible weather here in Phoenix. He decides to file a couple of options, with varying time windows. He will file with an alternate because of the uncertainty of weather at BZN. Weight and balance and fuel loading options are available on his tablet and the tablet has an interface that will allow the download of information on the tablet directly into the aircraft’s automation. He can plan and upload multiple options. As he finishes his session with the flight planning service provider, he has seven time options with defined 4DT flight planning and flight objects. Each of these options has been negotiated with the ANSP and once the decision to go is made, the option closest to when the passengers will be ready to depart will be used. The ANSP will then delete all other options.

Having the aircraft as a node on the network tied to the ANSP aids single pilot operations. N72MD has a pilot assistant, a set of computer applications that work in the background throughout the flight to assist the pilot. This assistance can range from conformance monitoring of clearances, to monitoring information on the network regarding reports on turbulence, changes in weather conditions at destination, and a host of other conditions that can be selected by the pilot.

Computers on N72MD continuously track many safety aspects of the flight and the aircraft is designed to provide the pilot with the information needed at the best opportunity in order to ensure pilot workload remains manageable. The onboard system provides enhanced “master caution” functionality by not only alerting of a mechanical or other unsafe condition but it also automatically packages the information in a way that permits the pilot to confirm the indicators and take the correct action quickly.

The passengers arrive at the fixed base operator (FBO) passenger lounge and the pilot quickly selects the time window flight object and downloads the latest information. The aircraft is fueled and ready. The FBO provides transport to the aircraft and the pilot gets his passengers loaded. The pilot then powers up the aircraft, transfers data from his tablet to the onboard computers and contacts the ANSP. In that transaction via voice, he uses a pass phrase for authentication that was part of his transaction with the flight planning service provider and provided by the ANSP. Had this been a data link message, the same authentication would be used.

The pilot receives and accepts the 3D trajectory for surface movement and will be departing behind a Boeing 737 (Sunset 42) with a turn to the north over Phoenix, then an optimized climb to altitude. While the pilot has a moving map display that identifies own ship as well as other aircraft, it does not have the sophistication to automatically show ANSP generated routes and clearances. Instead, he receives a text version of the taxi route that he can then enter into his map and follow along. His pilot assistant automation does conformance monitoring and will alert to a wrong turn and will verify runway traffic if crossing as well as other runway incursion alerting.

Once in line in the taxiway queue, the pilot finishes his takeoff checklist and focuses on the RNP 0.3 noise abatement departure off of RWY 25R. The noise abatement departure requires a precise flight path adherence as well as a power reduction after liftoff with a higher climb gradient to 4,000 feet. If N72MD follows the TBO 4D trajectory, he will meet the noise abatement procedural requirements.

Takeoff has been delayed by about 3 minutes due to departing traffic and the pilot expects that after airborne, he will receive an updated 4DT. During the turn to the north, a text data link message chime is received and he selects the synthetic voice option to hear the change. He acknowledges receipt and can replay this message as needed to set up his navigation and climb performance. He suspects the reason for the change is a 4-ship F-35 departure eastbound out of Luke AFB. Within a minute he is watching a four-ship rejoin on the ADS-B traffic display. Because of the 4DT change, his climb is shallower than he would like, but will not require a level off. After N72MD crosses the path of the F-35s, he resumes his original climb profile.

GNSS Interference

This low-power interference event occurs while N72MD is waiting in the departure queue. He detects the interference through GNSS unable alerts, his pilot assistant alerts to the chatter on the network, a display of the coverage area is detected and he calls it up on one of his displays. He can see it is centered at PHX itself. The weather is VFR so he elects to do a visual departure, reduce his altitude on climb and fly out of the interference zone. He shifts his cockpit map display to a terrain version and his proposed flight track is overlaid on the map.

If it had not been good weather, he did not have another navigation option since the FAA had previously removed the VORs, even though he still carries the dual combined VOR/ILS receivers.

His only options in interference in the weather is to taxi back and wait it out or possibly get a vector off of the SSR or multilateration capability. He would likely receive this service because it is less work to vector the aircraft off of PHX than to coordinate a taxi-back. Had the aircraft been elsewhere on the airport, the ANSP would likely request the aircraft to delay its departure until after arrivals could be handled.

General Aviation Impact:
- **Limited to VFR departures only**
- **Avoid flying in interference area**
- **In IMC, dependent on traffic density to depart by vectors**

On departure, he would have no navigation, his ADS-B would not be broadcasting a position and he would not receive ADS-R information. He would still receive the traffic information service (TIS-B) off of the SSR or as a function of multilateration. N72MD would then fly by ANSP vectors until he reported a valid GNSS reception.

Nominal Scenario Resumes

The aircraft automation is tracking terrain, weather and traffic information in real-time. On this flight, the pilot assistant system has alerted the pilot that an approaching narrow band of precipitation (snow in this case) that may be impacting operations at BZN at about the same time as the flight’s ETA. Recognizing the pilot is receiving instructions from ANSP, the aircraft computer temporarily delays the notification until it senses that no internal (cabin) or external (ATC) communications are occurring. The pilot assistant computer can also ensure that the pilot is not on task configuring the flight navigation system, or other critical functions. At the same time that the pilot is alerted to the potential weather, the onboard displays toggle to a graphical forecast, which show the squall line's current position as well as forecast movement and position at the ETA. The computer recommends a plan of action, which in this case is to increase speed by 12 knots. The computer also provides the pilot with revised estimates for fuel remaining and automatically presents the pilot with pilot reports (PIREPS) indicating smooth air in advance of the snow. The pilot accepts the recommendations from the computerized pilot assistant, and increases power accordingly. Because the speed change is less than 10 percent, the pilot does not notify the ANSP. Had it been greater than 10 percent, the pilot assistant would advise that a notification is required.

The ANSP knows of the speed change from ADS-B and the conformance monitor updates the information automatically. This ground-based conformance monitor will make changes based on surveillance and intent information automatically and show the changes to the strategic and tactical controllers. If the conformance monitor believes that a change is heading, course, altitude, or speed will put the aircraft outside of the pre-set conformance bounds, then the monitor will alert to the controller.

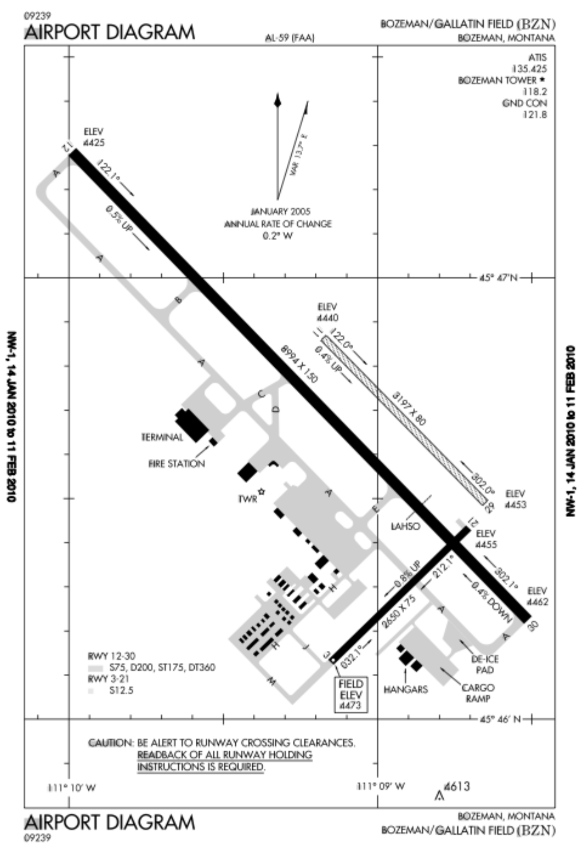

Figure 5.4. Gallatin Field Bozeman, Montana

N72MD continues to follow the 4DT, still based on an ETA so the required time of performance is a wide window due to lack of traffic downstream between the present position, and where top of descent is intended. At FL 210, there is little traffic to content with. Because N72MD is a node on the aviation network, he has access to considerable flight planning and advisory information. The pilot has configured his pilot assistant to watch for PIREPs, changes in weather, and anything on the network relating to airports and weather along the route of flight. The pilot uses this connectivity to review the position of the squall line and expects he will be through it before it hits the airport itself.

Just prior to the top of descent, N72MD is cleared direct to the initial approach fix, descend with pilot discretion to the minimum descent altitude at that fix. Passing through 15,000 feet, the aircraft descends out of radar coverage but controllers continue to track the aircraft progress via ADS-B. Controllers request that the pilot maintain 196 knots in the descent. Air traffic controllers, who are responsible to assign aircraft their sequence for arrival, select the speed. The system they use understands the aircrafts' performance capabilities and selects the best time slot for the aircraft, further reducing chances for potential delay. N72MD can receive this clearance either by voice or data link. Generally, in areas of low traffic density, voice is used more frequently.

N72MD sees Sunset Air 20, a Boeing 737-1000 descending as well and expects to be sequenced in front of the air carrier.

N72MD and Sunset Air pilots have reviewed Automated Terminal Information Service (ATIS) on forward facing flight displays. Pilots note the weather, active runway and also note that the parallel taxiway is closed. Landing is expected to Runway 12 at Gallatin Field. Taxiway Echo is closed and there may be a land and hold short restriction at the intersection with Runway 3/21. The pilot of N72MD updates his airport graphic to show the closed taxiway.

This is done so that the pilot assistant can track conformance. Pilots obtain the ATIS information via a broadcast data link, continuously transmitted to all aircraft within range. Pilots can also view weather data (graphical METAR) for nearby airports, in color-coded depictions, on the en route moving map.

Both aircraft descend from cruise to 12,000 feet in IMC. Passing through 11,000 feet, they emerge from the clouds into VMC. The pilots rely on traffic monitoring and alerting systems to supplement their see-and avoid-procedures. Even though the merge could happen anywhere, the ANSP has planned the merge in VMC conditions but sequencing was set up before top-of-descent for both aircraft by the strategic controller.

Numerous VFR aircraft are operating underneath the cloud base. Sightseeing rotorcraft, flight training, and small aircraft arriving for the weekend all use the airport, since the next closest airport is many miles away. On average, two-thirds of the traffic operating VFR is equipped with an ADS-B transmitter (ADS-B out). Many of the aircraft also receive traffic, weather and other information via the ADS-B data link. The ADS-B out signals from the VFR aircraft is received by Sunset Air 20 and N72MD directly via air-to-air, because they are equipped with dual-receive ADS-B-In avionics.[26]

Bozeman has become a virtual tower, meaning that VFR traffic not equipped with ADS-B are not allowed within 3 miles of the airport. While there are non-equipped aircraft in the vicinity, none are expected in the traffic pattern. This was the tradeoff made by the community to provide better ANSP services.[27]

[26] Dual receive avionics imply both a 1090 and a UAT receiving hybrid, allowing the 1090 aircraft to receive TIS-B and FIS-B functionality and the UAT to receive direct 1090 reports, an important element in classic airspace where TIS-B coverage may not be adequate. This is a step on a path for a unified ADS-B system with sufficient future capacity to handle 3X traffic.

[27] There are cost and policy implications that the FAA has yet to address. In order to provide the equivalent of tower services, clearances for takeoff and landing must be provided. This leads to the need for some visual coverage, likely by cameras. Excluding non-ADS-B aircraft from the airspace may prove to be difficult. A compromise exists in the virtual tower concept of operations. It could be that the service is a virtual terminal, whereby control in VMC is to 1,000

GNSS Interference

The concept of virtual towers to either replace existing staffed towers or provide new services to airports that do not currently have tower and TRACON services is totally dependent on ADS-B and accurate positioning using GNSS. The multiple ground station infrastructures required for multilateration of the surface and surrounding airspace could be an option at some larger airports, but for an airport like Bozeman, a dual redundant ADS-B ground receiver site is adequate. Since GNSS is critical to most low-end ADS-B-Out avionics configurations, the loss of ADS-B is the equivalent to the loss of surveillance, especially in mountainous terrain where SSR backup coverage is non-existent. GNSS opens a significant number of instrument operations possibilities at mountainous airports. This includes complex RNAV and RNAV/RNP approaches and the surveillance that ADS-B brings.

A virtual tower operation is dependent on surveillance. Interference in the absence of an alternative PNT source that can be carried by aircraft using the airport means that in the event of an interference event, the virtual tower capabilities will need to be terminated for the duration of the interference event. While the national capacity will not be impacted and ripple back through the system (since these airports have lower levels of operations), safety services will.

Nominal Scenario Resumes

Controllers broadcast on party line voice the arrival routes of both the Sunset Air and N72MD flights to provide situational awareness for all aircraft in the virtual terminal airspace. A visual scan of the airport surface and airspace using remote camera sensors by the controller indicates no problems for the planned approach and contact both aircraft via voice to inform the pilots of other traffic in the area.

Shortly after the broadcast, the ANSP’s conflict detection tool predicts a possible separation violation between Sunset 20 and a sightseeing aircraft not equipped for self-separation operation. The controller alerts Sunset 20 via voice and provides an alternate 4DT via data link to set the landing sequence and maintain 3-mile spacing on arrival.

Sunset 20 reviews the alternate 4DT and accepts the alteration, continuing its descent on the new final approach. Both Sunset Air and N72MD monitor the airspace using their cockpit displays and visual scans.

N73984 is a 2008 Garmin G1000 all-glass Cessna 172 that has not been upgraded significantly since new. The student pilot and flight instructor onboard the aircraft have been practicing basic flight procedures in the flight school’s practice area. The

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feet. In weather, non-ADS-B aircraft would be required to call their position. This would limit FAA investment to a communications and ADS-B receiver link that covers the surface so that ADS-B aircraft can be seen and sport aviation could use the radio channel.

approaching line of snow has shortened their training so they are returning to BZN for a full-stop landing. The student pilot and flight instructor listen to the ATIS and contact the tower. They are instructed to plan for a straight-in approach and landing, and report a two-mile final to the airport's single runway. They make an uneventful landing and taxi to the flight school ramp.[28] The ANSP uses local video sensors to confirm the arrival and taxi of N73984 clearing the runway.

Sunset Air is now 20 miles from BZN. The ANSP uses the flight sequencing functionality to confirm the landing sequence, and instructs Sunset Air to follow N72MD for landing. Onboard the aircraft, the Sunset Air pilots use CDTI to select N72MD as the aircraft they will be spacing against on final approach. The OPD procedure is designed to allow the aircraft to arrive at the initial approach fix on the proper glide path angle required for the approach. Because the pilots have selected an aircraft to follow, the integrated aircraft system can now determine what speed changes will be necessary to arrive at the fix at the correct speed to ensure proper, but not excessive, separation all the way to landing. This station keeping function is enabled as part of the avionics conflict detection and resolution software.

The ANSP contacts both N72MD and Sunset 20 to call out balloon traffic in the vicinity of BZN, as shown on its video feed, but no action is required by either plane as the balloon does not impact their arrival.

N72MD is 10 miles from BZN and is the first aircraft cleared to land in several minutes. A helicopter contacts BZN air traffic control and reports they are dispatching from the Bozeman Deaconess Hospital to pick up a patient at a traffic accident scene northwest of the airport on I 90 and return to Bozeman Deaconess Hospital in downtown Bozeman (southeast of the airport). The controllers easily identify the ADS-B equipped aircraft on the traffic display on the virtual tower work suite and approve the transition through the airspace. Because the helicopter is flying parallel to the runway following I 90 and headed to the northwest near the approach path, controllers advise the pilot of N72MD to be aware of the helicopter one thousand feet below and paralleling the freeway. The pilot in N72MD uses the onboard CDTI to assist in the visual acquisition of the helicopter. N72MD acquires the traffic while descending to the downwind for Runway 12.

The snow shower has yet to reach the airport. However, an operations vehicle equipped with ADS-B is currently inspecting runway surface conditions. The pilot assistant alerts the pilot that the runway is in use and the moving map depicts a vehicle on the runway's surface and the pilot can see from the display that the vehicle is still on the runway. Three miles from the runway on a visual approach, the pilot of N72MD lowers the landing gear.

[28] The ANSP provides the equivalent of tower services at a tower suite located at another facility. The tower suite uses ADS-B and visual and infrared cameras to monitor the airport and communications is provided through transceivers on site. Aircraft not equipped with ADS-B are not allowed to conduct flight operations at the airport. This includes sport aviation. The airspace out to 3 miles is sterilized and requires ADS-B equipage. Before a virtual tower can be commissioned, ground vehicles must also have an equivalent ADS-B capability. Video is used to deal with deer, birds, and an occasional errant vehicle.

The pilot contacts air traffic control regarding the vehicles and is advised that the vehicles are clearing the runway.

At one-mile on final, the pilot assistant alerts to runway incursion, the pilot confirms the vehicle is still on the runway, and initiates a go-around. The dynamics of the go-around maneuver are recognized by the Surveillance Information Services automation that alerts the controllers who subsequently assign left hand traffic, to follow Sunset Air, now on a 4-mile final.

The merging and spacing system on board the Sunset Air has brought the aircraft to within three miles of N72MD on final approach, as instructed by the ANSP. Taking into account the slower final approach speed of the TBM 850, Sunset Air has compensated for the difference in speed by arriving at target approach speed at the calculated time necessary to avoid getting too close. With snow on the ground, the flight crew has difficulty visually acquiring the small TBM, but because they are approved to rely on air-to-air ADS-B in lieu of visual acquisition in the terminal area, the crew continues with the final approach. Shortly after the pilots see the acceleration of the lead aircraft and hear that the TBM has initiated a go-around due to a vehicle on the runway, Sunset Air receives their clearance to land. When two miles from the touchdown zone, the aircraft's moving map depicts the runway status as green because the vehicle is now safely clear of the runway.

Now on the downwind, N72MD is cleared to land behind the Sunset Air Boeing 737. Now conscious of the potential for wake turbulence, the pilot of N72MD activates the aircraft's wake turbulence advisory system.[29] Because the aircraft avionics are monitoring all ADS-B aircraft, the pilot simply selects the Sunset Air flight and the wake turbulence advisory system integrates all data onboard the aircraft (winds, temperature, ATIS info, ADS-B data from Sunset Air) in order to graphically present and estimate the zone where there is highest risk of vortex rotation. The pilot observes the touchdown point where Sunset Air lands, and uses the wind shear advisory system to conduct a smooth final approach and safe landing.

Sunset 20 touches down and must exit at the runway end because Taxiway Echo is closed. Sunset knows that there is an aircraft turning base behind him and keeps up his speed on the runway. The surface moving map shows no other traffic on or landing on the crossing runway. Sunset 20 exits the runway at taxiway Alpha and taxis to the terminal.

N72MD touches down abeam Taxiway Bravo, landing beyond the touchdown point of Sunset 20 with plenty of stopping distance since land and hold short of Runway 3/21 is

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[29] Elementary airborne wind shear and wake vortex avoidance is just being introduced in 2025. It is based on a geographical mapping of areas and likely intensities. For vortices, it is the equivalent of station keeping but allows for maintaining an approach slope above and touchdown beyond the lead aircraft. For wind shear, it creates an alert zone where the pilot can set the altitude for activation and monitors elevation changes of leading aircraft using ADS-B derived information.

not required. N72MD requests to taxi down Runway 21. The ANSP approves after scanning the runway to verify it is vacant. Once clear of the runway, the pilot completes the brief taxi to the fixed base operator.

GNSS Interference

The interference scenario for the flight from Phoenix to Bozeman is a 350-mile radius interference area over land where there is only partial surveillance backup from SSR. The airport is small, relative to a metroplex area, and it is unlikely that additional surveillance would be added. Today, operations are conducted under IFR to airports that do not have surveillance, using procedural separation. It is unlikely that this area of the country would be deliberately targeted, but Bozeman sits near several military installations of possible interest. High terrain around Bozeman offers an opportunity to deploy a jammer at a higher elevation to increase the range of interference.

This scenario was written around good weather at Bozeman. Had the weather been IMC, most of the low-end general aviation would not likely be flying. However, this scenario has six main stories: 1) N72MD, a business aircraft, 2) Sunset 20, a fully capable B 737, 3) N73984, a low-end general aviation aircraft, 4) a balloon, 5) a medevac helicopter, and 6) a virtual tower operation providing the equivalent level of service as a tower/TRACON combination.

General Aviation Impact:

- **At smaller airports in mountainous terrain, where surveillance becomes dependent on GNSS through ADS-B, services must revert to procedural separation**
- **Aircraft that are minimally equipped with GNSS and ADS-B in IMC are not able to navigate during an interference event and may not be under surveillance coverage for backup**
- **Safety implications of interference are significant in IMC**

As the interference unfolds, the virtual tower would receive mapping information from aircraft through the surveillance data network. At first, the mapping would be incomplete because of the low density of aircraft in the airspace. Depending on the position of the jammer, terrain may mask some of the interference. Since the virtual tower is a physical position in Colorado Springs, coordination of flights with the center would be occurring.

The balloon should not be flying in IMC and is not a factor in the presence of interference. Likewise aircraft operating under the exception to the ADS-B-Out rule would remain away from the airport and maintain VFR.

N72MD and Sunset 20 would know of the interference from cockpit alerts. It is unlikely that N73984 or the medevac helicopter would respond to an alert with a radio call since both are operating VFR, but would detect the failure or be told by the ANSP. The impact to the helicopter would be minimal unless the visibility is poor. The medevac helicopter is on an “I follow roads” mission out I 90 and would descend to a lower altitude to maintain visual on the highway.

In weather, N73984 could not get vectors to the ILS for Runway 12, unless multilateration was in place at the airport. The aircraft is below the SSR coverage. The ANSP could not use ADS-B and the aircraft is not carrying an alternative means of positioning and navigation. N73984 would only be detectable to Sunset 20 by TCAS and N72MD by traffic advisory system (TAS). This leaves N73984 in the difficult position of dead reckoning in weather. If west of the airport, he could set up a maneuver to cross through the ILS and turn to intercept. Most likely, Sunset 20 would help to track the aircraft using TCAS and orbit over the airport. N73984 cannot go to the north or east due to terrain. The retention of a VOR in this area would have provided N73984 with some safe options and connection to an ILS for landing.

Most of the 4DT TBO functionality would be lost for N72MD and Sunset 20. Their arrivals using an OPD would need to be modified. Since Sunset 20 is capable of using the navigation bus and using a different source (DME-DME and IRU) for the ADS-B position content, he would remain visible to the ANSP through both SSR coverage and ADS-B and could continue the OPD. More likely, Sunset 20 would be put in a holding pattern under ANSP surveillance, until other aircraft could be cleared out by recovery at Bozeman.

N72MD now lacks GNSS navigation and would still be under SSR surveillance during the OPD down to the floor of the SSR coverage. The pilot’s assistant would automatically alert to the interference and pull up possible options for the pilot to consider as part of a prepared application. One of those options would be to discontinue the current descent and request vectors to the ILS from the ANSP. The ANSP would need to hold the aircraft at altitude where SSR coverage was possible and set the pilot up with a descent out of SSR surveillance on an intercept to a procedural arrival, with associated minimum vectoring altitudes. Backup surveillance coverage dictates the airspace that can be used to recover the aircraft.

5.10 Conclusion

Each of our nation’s non-hub airports represent unique issues for surveillance coverage that can best be solved by an alternative PNT. The need is to support surveillance to the start of the backup landing approach that then carries the aircraft to the surface. For these airports, especially in the west, surveillance becomes a larger issue as aviation migrates to an all GNSS world. Aircraft that routinely fly in IMC can weigh the benefits of equipage with an alternative PNT. The four pillars of the APNT approach support the benefits that can be realized:

- Safe recovery (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under Instrument Flight Rule (IFR) operations,
- Strategic modification of flight trajectories to avoid areas of interference and manage demand within the interference area,

- Continued dispatch of air carrier operations to deny an economic target for an intentional jammer, and
- Flight operations continue without a significant increase in workload for either the pilot or the Air Navigation Service Provider (ANSP) during an interference event.

For hub airports, and especially metroplex super-density airports, the need for an alternative PNT is four-fold: 1) the need to sustain PNT, 2) provide a continuing dispatch capability, 3) ultimately support TBO and 4) reduce GNSS as a target for interference through sustained continuing operations.

For airline operations, the answer will be dispatch reliability. The ability to continue to dispatch and fly out of the interference area is essential to economic operations. While TBO can operate with any separation and any value of RNP, it must do so in a steady state way, meaning that in the presence of an intermittent jammer, the demand and separation must be set for the jamming event, not nominal operations. At the instant of interference, there is a period where aircraft can coast. Newer inertial systems will help to extend this coasting performance. The challenge will be the workload and delay measures needed to reduce demand to the point where a steady state can be realized once again.

For the general aviation business pilot, the benefit of an alternative PNT will be in the continuity of services and not requiring delays in departure due to interference events. For sport aviation and lower-end instrument general aviation, the need for a backup PNT may not exist, provided they are flying in areas with robust surveillance from sources other than ADS-B and the ANSP is providing their safety net for recovery, possibly not at the airport of choice. Their investment in ADS-B is driven by rule and access to airports and airspace, but many operators will not require an alternative PNT.

The loss of GNSS in absence of an alternative PNT capability represents the equivalent of a major weather event. It will pass, but demand will not be met, delays will grow and it may take days for the air transportation to reach normal capacity in the presence of a sustained, wide area interference event. The transition from loss of ADS-B from 3-mile separation to 5 miles of separation will create a safety risk until steady state is reached. Our ability to continue to dispatch aircraft prevents this loss in efficiency and deters interferers specifically targeting aviation.

Since the early 1990's the FAA has maintained a strategic vision to transition the NAS from a ground-based ATC system to a satellite based ATC system. Following HSPD-7 policy, the FAA should maintain adequate redundancy in capability to ensure that during a GPS outage, operations could safely and efficiently continue. As the FAA moves towards the NextGen environment, need for an APNT solution becomes increasingly critical to satisfy policy, operational improvement, and technical requirements.

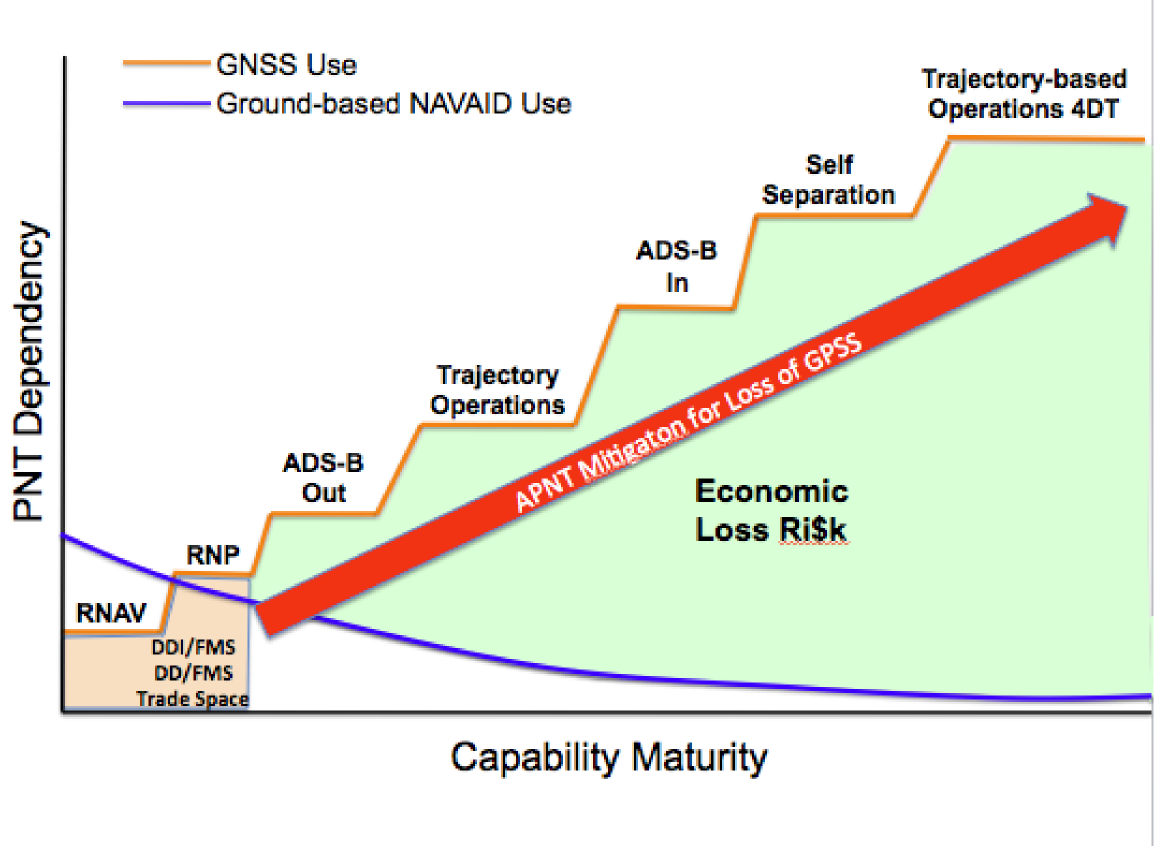

Figure 5.5 Capability Maturity

As the figure shows, aviation is transforming along a trajectory where reliance on GNSS and the use of ADS-B are an essential element of NextGen. The consequence of satellite based PNT and surveillance is the possibility of interference. In an environment without APNT, there is the potential for significant impact to operations from a GNSS outage due to interference. Most of these impacts are economic, created through disruptions in operations. In the absence of an APNT strategy the economic impacts can be significant, especially for the case where there is a deliberate attack on the availability of GNSS. This threat is not limited to aviation. Other transportation segments and the American public in general are becoming increasingly dependent on satellite-based PNT.

6. Summary of Impacts

This section is dependent on the research to reach a technically sound alternative PNT approach and deliver a service. The impact on key performance areas (KPA) will mature as research is conducted. A key impact will be the cost of equipage, either for the aircraft, the FAA, or both. To begin this process, the following matrices cover the operator/user and the FAA potential impacts. This information will allow the affected organizations to add to the potential impacts and begin planning for their portions of APNT implementation. Since APNT is starting with a research initiative to consider what can be done to support an alternative PNT, the impacts are expected to grow with coordination of the APNT CONOPS.

Table 6.1 Summary of Impacts - Aircraft Operator

KPA	Air Carrier	Regional Carrier	General Aviation	Military
Safety	Position uncertainty increases workload until new steady state is reached through APNT. Risk of navigation errors. Risk of communication errors rise as volume of communications increases.	Position uncertainty increases workload until new steady state is reached through APNT. Risk of navigation errors. Risk of communication errors rise as volume of communications increases.	Position uncertainty increases workload until new steady state is reached through APNT. Reliance on vectors or use of VOR increases workload. Risk of navigation errors. Risk of communication errors rise as volume of communications increases.	Military capable of operating in the presence of interference as an RNAV aircraft.
Security	May impact certain geo-positioning methods of authentication or encryption used in air-ground communications.	May impact certain geo-positioning methods of authentication or encryption used in air-ground communications.	May impact certain geo-positioning methods of authentication or encryption used in air-ground communications.	May impact certain geo-positioning methods of authentication or encryption used in air-ground communications.
Capacity	IFR departures impacted under interference conditions without APNT, leading to loss of operations. Likely loss of dependent parallel arrival streams at large airports. Arrival options become limited to ILS.	IFR departures impacted under interference conditions without APNT, leading to loss of operations. Likely loss of dependent parallel arrival streams at large airports. Arrival options become limited to ILS.	Low-end GA vectored to nearest available airport runway with ILS to land or by use of VOR to an ILS transition. IFR GA grounded without APNT capability.	Some loss of capacity at joint civil-military airports where civilian traffic must be handled in presence of interference.

Table 6.1 Summary of Impacts - Aircraft Operator (Continued)

KPA	Air Carrier	Regional Carrier	General Aviation	Military
Efficiency	Initial loss of efficiency at onset of interference event due to need to accommodate non-DDI and DD aircraft. Loss of certain ADS-B-In applications. APNT preserves RNAV efficiencies with interference.	Initial loss of efficiency at onset of interference event due to need to accommodate non-DDI and DD aircraft. Loss of certain ADS-B-In applications.	IFR aircraft must use minimum operating network, abandoning RNAV or avoid the interference area completely, causing re-routes, no IFR departures in interference and possible recovery at other than the airport of choice.	Military capable of operating in the presence of interference as an RNAV aircraft.
Environment	Some loss of fuel-efficient flight procedures relating to ADS-B In applications within the interference event impacted airspace.	As efficiency goes down, fuel consumption goes up. During airport interference event, taxi delays will increase emissions.	Rerouting around interference area increases emissions for the flight that is partially offset by holding departures.	No impact.
Global Interoperability	APNT is proposed as a U.S. solution with legacy compatibility to support RNAV globally.	Regionals lacking DD or DDI who enter the country will require radar vectors to ILS for landing in interference. No APNT service outside of CONUS.	Lower-end general aviation impacted if not carrying APNT capability in presence of interference, requiring landing if IFR at an airport capable of supporting such recovery.	Military capable of operating in the presence of interference as an RNAV aircraft.
Access and Equity	DD and DDI aircraft continue operations as planned. Non-DME solutions may lead to an equipage requirement for access at larger, metroplex areas.	DD and DDI aircraft continue operations as planned.	DD and DDI aircraft continue operations as planned.	Military capable of operating in the presence of interference as an RNAV aircraft.
Reliability	Reliability of use of RNAV increases with APNT.	Reliability of use of RNAV increases with APNT.	Non-DD and DDI aircraft would need to retain VOR.	No Impact.
Availability	APNT limited to CONUS. Depending on the solution, not all served airports will be covered, leading to limited schedule adjustments in the presence of interference.	Some served airports may not have coverage by APNT.	Non-equipped aircraft may not be able to land IFR at some airports, due either to surveillance coverage for vectors or a suitable ILS.	No Impact.

Table 6.1 Summary of Impacts - Aircraft Operator (Continued)

KPA	Air Carrier	Regional Carrier	General Aviation	Military
Maintainability	No expected impact.	No expected impact.	No expected impact. VOR would need to be retained and maintained.	No expected impact.
Staffing	No expected staffing impacts.	No expected staffing impacts.	No expected staffing impacts.	No expected staffing impacts.
Training	With APNT, no additional training required since APNT is an RNAV/RNP solution.	Aircraft operators without DME-based solution would need to continue to train on use of VOR and ILS and likely requirement to demonstrate proficiency.	Aircraft operators without DME-based solution would need to continue to train on use of VOR and ILS and likely requirement to demonstrate proficiency.	No expected training impacts.

Table 6.2 Summary of Impacts – Federal Aviation Administration

KPA	Controllers	Technical Ops	Aviation Safety	Acquisition
Safety	Transitional workload increases at start of interference as separation is adjusted, sequencing changed to manage different aircraft capabilities as the controller deals with aircraft not capable of using APNT solutions. Until a new state with demand adjusted downward, workload can be high for all controller positions – Tower, Terminal and En Route.	An APNT solution will likely drive as high an availability as the VOR and DME of today, requiring similar performance for restoral of services. Flight checks will likely be required.	The APNT will require operational approvals with any limitations based on coverage and performance. Approach procedures, especially the missed approach segment, may need to be modified to reflect a GPS out procedure to be used when interference occurs.	The APNT solution will need to be integrated with navigational aid sustainment programs through 2025. If DME is the solution, but modified to support APNT, backward compatibility will be required to sustain existing safety services.
Capacity	Aircraft equipped with APNT can continue to operate in an interference area, but demand will initially be reduced until non-equipped aircraft can be handled with radar vectors, since both aircraft navigation and ADS-B will be lost in interference areas.	NAS Capacity impacted by interference may lead to requirements to assist in locating the sources of interference and assessing the area of interference.	ADS-B In applications may need to consider interference mitigations.	Tools may be needed to identify the interference airspace volume to aid controllers in managing flights.
Security	To be determined.	To be determined.	To be determined.	Security risk analyses required for the APNT solution leading to security certification.

Table 6.2 Summary of Impacts – Federal Aviation Administration (Continued)

KPA	Controllers	Technical Ops	Aviation Safety	Acquisition
Efficiency	Loss of RNAV/RNP capabilities for aircraft not equipped with APNT solution, decreasing efficiency of airspace use.	APNT is established where economically feasible and may not cover all airspace. If interference occurs in a non-covered airspace.	No Impact.	No Impact.
Environment	APNT supports RNAV and RNP so impacts of extended flight tracks with vectoring are reduced.	Site clean-up issues for navigation aids that can be eliminated with APNT in place.	No Impact.	Site clean-up issues for navigation aids that can be eliminated with APNT in place.
Global Interoperability	International carriers may not have the same APNT solution, requiring priority handling.	Unknown Impact.	It will be necessary to develop the concepts and international standards for backup to GNSS.	It will be necessary to develop the concepts and international standards for backup to GNSS.
Access and Equity	In the presence of interference, after managing flights incapable of continued dispatch would be denied access to the airspace. Some aircraft en route to an interference area may be re-routed while others with APNT continue.	No Impact.	Requirements for operations specifications and possible rules regarding operating in interference may be necessary so that access and equity issues can be resolved.	During an interference event, the controller may need a tool to prioritize the handling of traffic, manage demand, and support access requirements.

Table 6.2 Summary of Impacts – Federal Aviation Administration (Continued)

KPA	Controllers	Technical Ops	Aviation Safety	Acquisition
Reliability	APNT reliability must be able to mirror the performance of RNAV/RNP from GPS, support ADS-B and trajectory-based operations, being nearly transparent to the aircraft operator.	Reliability equivalent to current ground-based navigational aids.	To be determined.	To be determined.
Availability	To be determined.	To be determined.	To be determined.	To be determined.
Maintainability	To be determined.	To be determined.	To be determined.	To be determined.
Staffing	To be determined.	Ground-based navigation (VOR) decommissioning teams needed to expedite cost avoidance.	To be determined.	To be determined.
Training	Development of procedures and specialized training in dealing with intentional interference events.	Development of maintenance and logistics training for new system elements of APNT.	Development of procedures for loss of navigation and ADS-B. Training on procedural development for personnel.	Equipment repair and maintenance training materials need development along with the APNT solution development.

Cause and effect relationships between the APNT CONOPS and the mid-term NextGen CONOPS will need to be defined. Because the APNT capability is targeted for the 2025 timeframe of NextGen and involves the elimination of VORs, a transition strategy tied to a minimum operating network is needed and being developed.

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Homeland Security Presidential Directive 7: Critical Infrastructure Identification, Prioritization and Protection, Department of Homeland Security, December 17, 2003.

DO-260B Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Sercices-Broadcast (TIS-B), December 2009, RTCA, Inc.

8. Appendices

Appendix A – Operational Environment Description

This table includes operational capabilities and airspace uses that are impacted by GPS interference. The Current environment describes the current NAS. The Reference environment represents the bridge to NextGen in terms of PNT and the Target Environment represents the NextGen use of precision navigation and trajectory-based operations. This environment description is incomplete due to the fact that work is just starting on the performance requirements of TBO.

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Surface Navigation	Visual navigation using signs, lighting and marking	Increased use of cockpit moving maps as an aid to positioning	Integration of surveillance, conformance monitoring and provision of time progression graphically in the cockpit to provide taxi routes
Surface Positioning	Visual identification of the aircraft by the ground or local controller	Use of ASDE-X for identification and tracking as a supplement to visual	Full integration of surveillance with automation to deliver an aircraft from the gate/ramp to the runway end based on a 3D trajectory
Surface Surveillance	Visual or with position reporting in low visibility	ASDE-X surface surveillance	ADS-B surface surveillance
Surface Timing	No requirement for synchronized time	Evolution from no requirement for time in surface movement to starting to use time strategically for surface operations	Time measured in single-second intervals to set the takeoff time with a maximum variability from start of taxi to takeoff of ± one minute

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Takeoff	Visual guidance using lighting and marking for the takeoff roll	Use of GPS for centerline guidance for low-visibility performance down to 300 RVR or use of synthetic/enhanced vision[30]	Widespread use of takeoff roll guidance from GPS and the use of synthetic/enhanced vision. RTP of ± 1 minute
Initial Climb	Visual or instrument reference to maintain runway heading until gear is retracted and aircraft proceeds on course. In low visibility, uses the back course ILS for centerline guidance or the FMS	Visual or instrument reference to maintain runway heading while cleaning up the aircraft and accelerating and using GPS for course guidance through the FMS	Visual or instrument reference using RNP 0.3
Climb Navigation	Following a flight path defined in a standard instrument departure using VOR or RNAV overlay	Using RNAV with RNP 1.0 that is not an overlay of existing capabilities	RNAV/RNP O.3 for high-density operations and RNAV/RNP 1.0 for medium density operations. Low-density operations not requiring terrain avoidance can use RNAV. TBO used for all aircraft using ANSP services
Climb Positioning	Derived on the aircraft from DME-DME or from GPS	Derived on the aircraft from DME-DME or from GPS	Derived from GPS with DME-DME as a backup

[30] Synthetic vision uses a geo-reference database and present position to depict a graphical representation of the environment around the aircraft. Enhanced vision uses sensors to produce a visual representation of the environment to supplement visual queues.

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Climb Surveillance	Radar-based with 3 nm separation within 40 miles of the radar site	Mix of ADS-B in non-radar and SSR in the radar environment with 3 or 5 nm separation distances depending on the source of surveillance and traffic density	Fused positioning information that includes ADS-B and SSR with 3 nm separation continuing beyond 40 nm using ADS-B. ADS-B only surveillance in non-radar environments using 5 nm performance equivalent to SSR only.
Climb Timing	No requirement	No requirement	RTP of + 12 to 18 seconds at fixes along the climb trajectory
Cruise Navigation	Airways or Jet Routes based on ground-based navigation aids, with limited "Q" and "T" routes based on GPS and/or DME-DME	Lateral performance of 4 to 8 miles, leading to the use of RNP 2.0 in some airspace and a transition to RNAV	Full RNAV with RNP 2.0 and 1.0 in most airspace depending on traffic density. RNP 1.0 is most common.
Cruise Positioning	Dependent on radar or procedural separation	Use of fused radar and ADS-B or ADS-B only in non-radar environments	Use of fused radar and ADS-B or ADS-B only in non-radar environments
Cruise Timing	No requirement	No requirement	RTP of 1-3 minutes for medium and high-density airspace.
Top of Descent	Requested by the pilot or directed by the controller	Pre-determined by the pilot and provided in advance of reaching top of descent to fly an optimized profile descent.	Calculated as part of the TBO 4 D trajectory with an RTP value of ± 1 minute

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Initial Descent	RNAV, radar vector or VOR-based navigation to join a standard terminal arrival route (STAR)	Extends STAR further out from the airport to eliminate open trajectories	RNAV/RNP path described as 4 D trajectory from top of descent to final approach with RNP 1.0
Initial Descent Timing	No requirement	No requirement	RTP variability decreases from ± 1 minute at top of descent to a precision of ± 12 to 18 seconds at metering fixes.
Descent Positioning	Radar with 5 nm separation distances	ADS-B/Radar fused position reports	ADS-B/Radar fused position reports with 3 nm separation in high-density airspace
Arrival Navigation	VOR or RNAV overlays of existing STARs	STARs with a mix of VOR and more efficient paths using RNAV RNP 1.0	RNAV RNP 1.0 paths defined as 4 D trajectories that transition to RNP 0.3 as the aircraft get closer to the airport (notionally at 12,000 to 15,000 feet)
Arrival Positioning	5 nm beyond 40 miles of the surveillance radar and 3 nm within 40 miles	5 nm beyond 40 miles of the surveillance radar and 3 nm within 40 miles	3 nm using ADS-B in high-density airspace
Arrival Timing	± 15 minutes estimated time of arrival	± 5 minutes estimated time of arrival	RTP of ± 12 to 18 seconds, decreasing to a precision of ± 3-5 seconds on approach
Approach Navigation	VOR, ILS and RNAV as overlays	RNAV/RNP LPV approaches and ILS	RNAV/RNP LPV with RNP values lower than RNP 0.1

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Approach Positioning	Radar	ADS-B Out and radar mixed surveillance operations to the same standard as SSR	ADS-B Out for the ANSP and ADS-B In for leader-follower paired approaches, merging and spacing
Approach Timing	No Requirement	No Requirement	RTP ± 3-5 seconds precision
Missed Approach Navigation	Heading and climb rate, back-course localizer guided, VOR radials, RNAV and RNAV RNP (usually for SAAAR approaches)	Reduction in the number of missed approach options and an increased use of RNAV/RNP missed approaches	RNAV and RNAV/RNP missed approaches with procedural backups in the presence of interference
Missed Approach Positioning	Radar surveillance or position reporting	ADS-B surveillance	ADS-B surveillance and fused surveillance where radar is available
Landing Navigation	Visual reference from signs, marking and lighting	Visual reference from signs, marking and lighting	Visual, synthetic and enhanced vision with GPS
Rollout	Visual reference from signs, marking and lighting	Visual reference from signs, marking and lighting	Visual, synthetic and enhanced vision with GPS with deceleration aids in the cockpit and moving map integration
Taxi-in	Visual reference from signs, marking and lighting	Visual reference from signs, marking and lighting and use of cockpit moving maps	Visual reference from signs, marking and lighting plus graphical route delivery and presentation on moving maps and the use of synthetic and enhanced vision in low visibilities.
Leader-follower merging	No Requirement	ADS-B In application	ADS-B In application

Operational and Airspace Capability	Current Environment	Reference Environment	Target Environment
Leader-follower spacing	Visual	Visual	ADS-B In application
Leader-follower passing maneuver	No Requirement	No Requirement	Uses ADS-B In to maintain separation on the aircraft being passed, then swap leader and follower
Leader-follower Paired Approach	No Requirement	No Requirement	ADS-B In application to pair aircraft for closely-spaced parallel runway operations where the follower uses information from the leader’s ADS-B Out to station-keep with the correct spacing

Appendix B. Trajectory-based Operations Automation Functional Flow Diagrams

The automation functions for TBO are yet to be developed. The TBO Study Team used generic descriptions of these functions to support TBO scenario development. Within APNT, the ANSP's automation plays a role in 1) defining the service volume impacted by the GPS interference event(s) and 2) providing the resolution of the trajectory to deal with the interference based on the position of the aircraft, its capabilities, the density of the traffic and the relationship between the aircraft and other aircraft in the vicinity. It is the automation that is responsible for separation. Key to APNT is the functional role of the Strategic TBO Evaluation Service and Conformance Monitoring. The resolution of the interference event is a pre-planned response that is activated by detecting the presence of interference (multiple aircraft in the airspace with common failures). The automation functions are first described generically as to their function, then in terms of how they work together as a system and then information inputs and outputs are provided. Readers are advised that TBO is very much in its infancy and the Joint Planning and Development Office is just beginning work on the safety case for TBO. Key to this safety case is whether or not automation will be capable of performing the separation functions. If not, a new NextGen Concept of Operations will be needed. From an APNT perspective, if the controller must provide the separation function, the workload of a GPS outage will be significantly greater.

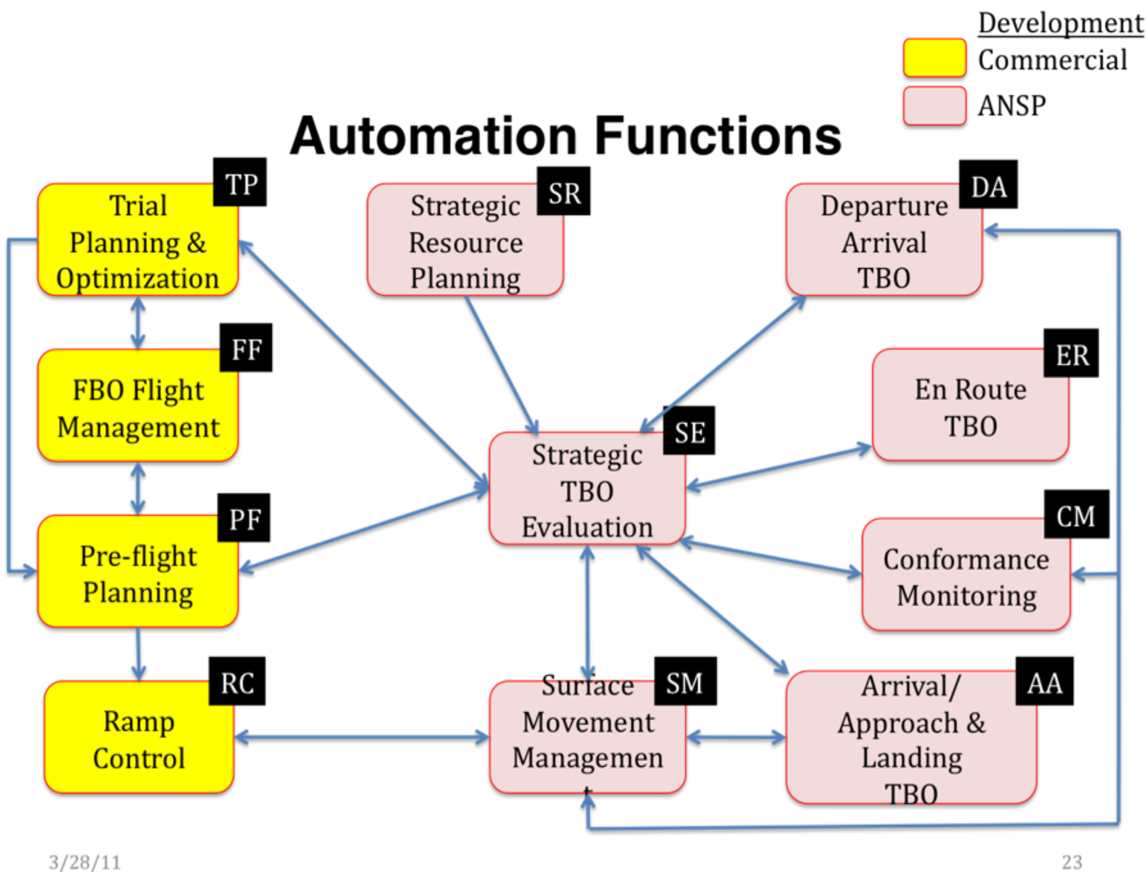
TBO Functional Toolsets

- *Strategic Resource Planning* – allocates resources against workload and demand, replays past performance, plans for tomorrow, next week, next month
- *Trial Planning and Optimization* – the ability to evaluate options well before negotiating a flight plan
- *Pre-flight Planning* – building the flight object and providing essential flight information to the ANSP
- *ANSP Strategic TBO Evaluation* – compares choices and sets the 4DT for all served flights
- *Ramp Control* – tools for management of preparing an aircraft for flight and handling arrivals
- *FBO Flight Management* – FBO connectivity tools bridging between the pilot and the ANSP – kiosk or cockpit connectivity
- *ANSP Surface Movement Management* – tools for sequencing and managing surface movement for departures and arrivals

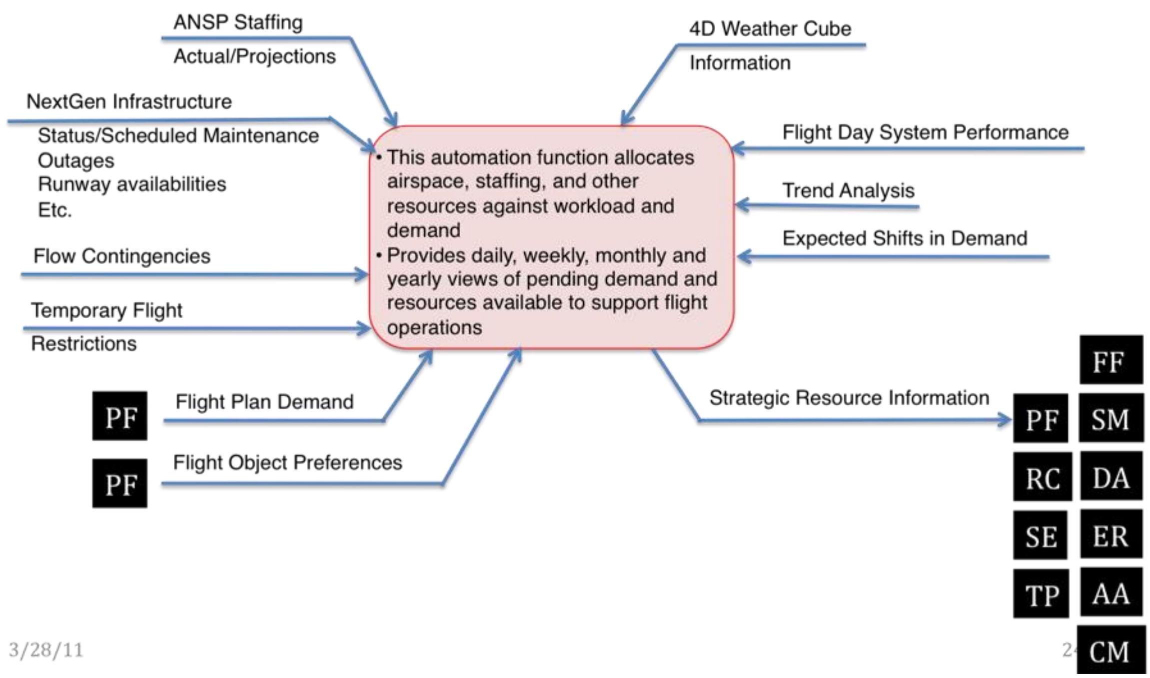
3/28/11 18

TBO Functional Toolsets (Con't)

- *Departure/Arrival TBO Automation* – matches trajectories with airspace and procedures and supports sequencing, spacing and separation – links to TBO Strategic Evaluation Services
- *En Route TBO Automation* – provides 4DT TBO services – links to TBO Strategic Evaluation Services
- *Arrival/Approach and Landing TBO Automation* – provides 4DT sequencing, spacing, separation, and descent profiles for arriving aircraft – links to TBO Strategic Evaluation Services

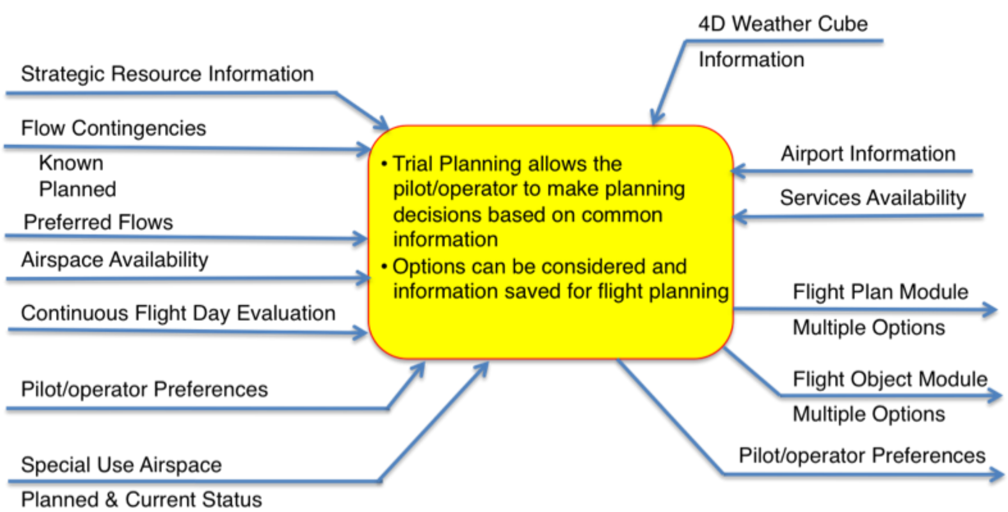

Development
Commercial
ANSP
Automation Functions
TP
Trial Planning & Optimization
FF
FBO Flight Management
PF
Pre-flight Planning
RC
Ramp Control
SR
Strategic Resource Planning
SE
Strategic TBO Evaluation
SM
Surface Movement Managemen
DA
Departure Arrival TBO
ER
En Route TBO
CM
Conformance Monitoring
AA
Arrival/ Approach & Landing TBO
3/28/11
23

Strategic Resource Planning Automation Functions



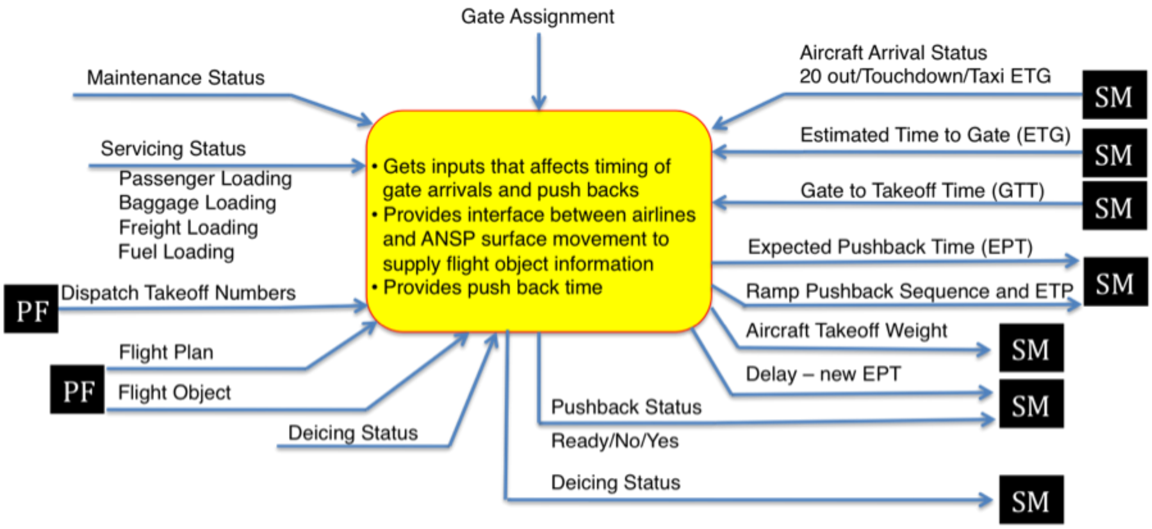
3/28/11 2

Trial Planning and Optimization Automation Functions

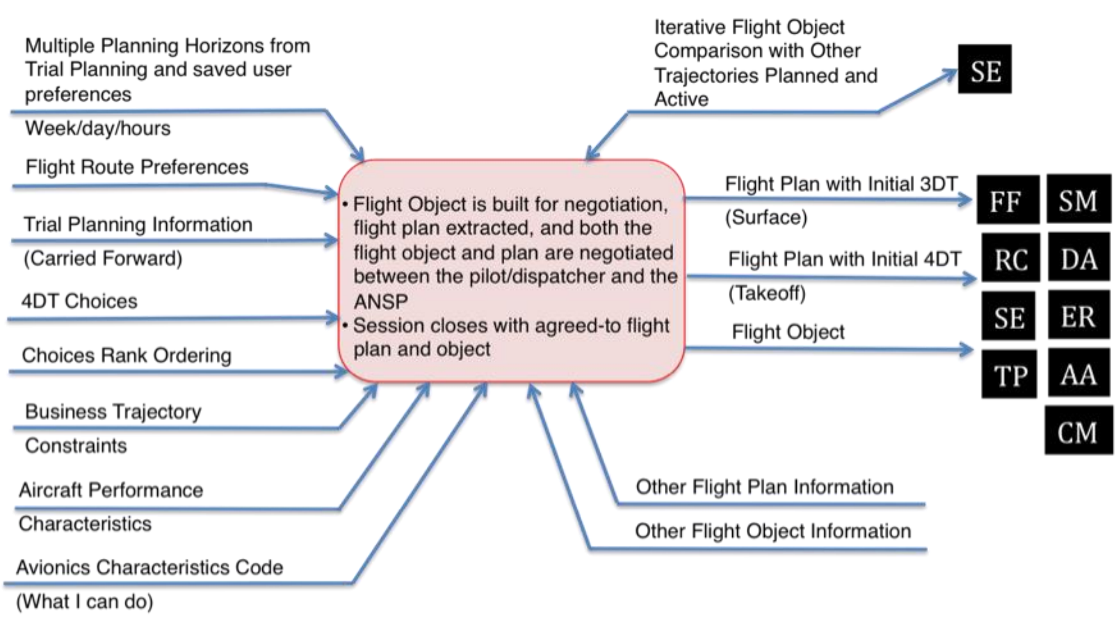


3/28/11 25

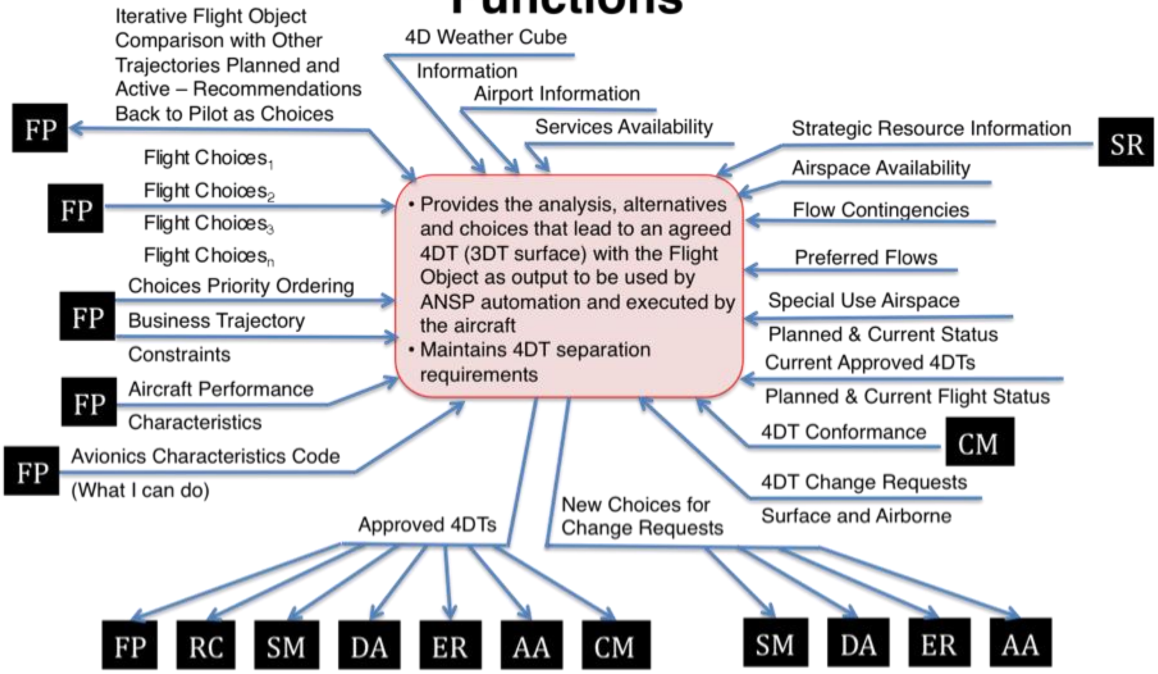
Ramp Control Automation Functions



Pre-flight Planning Automation Functions



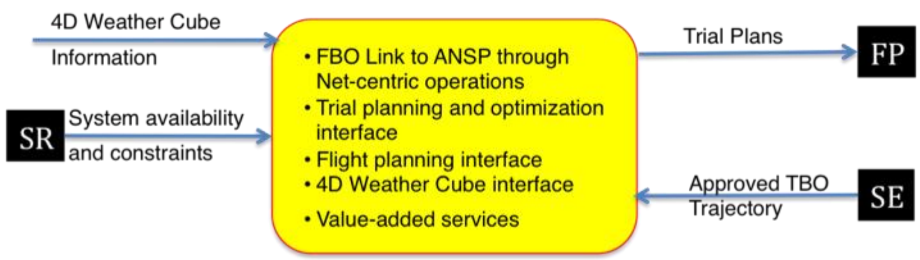
ANSP Strategic TBO Evaluation Automation Functions



3/28/11 28

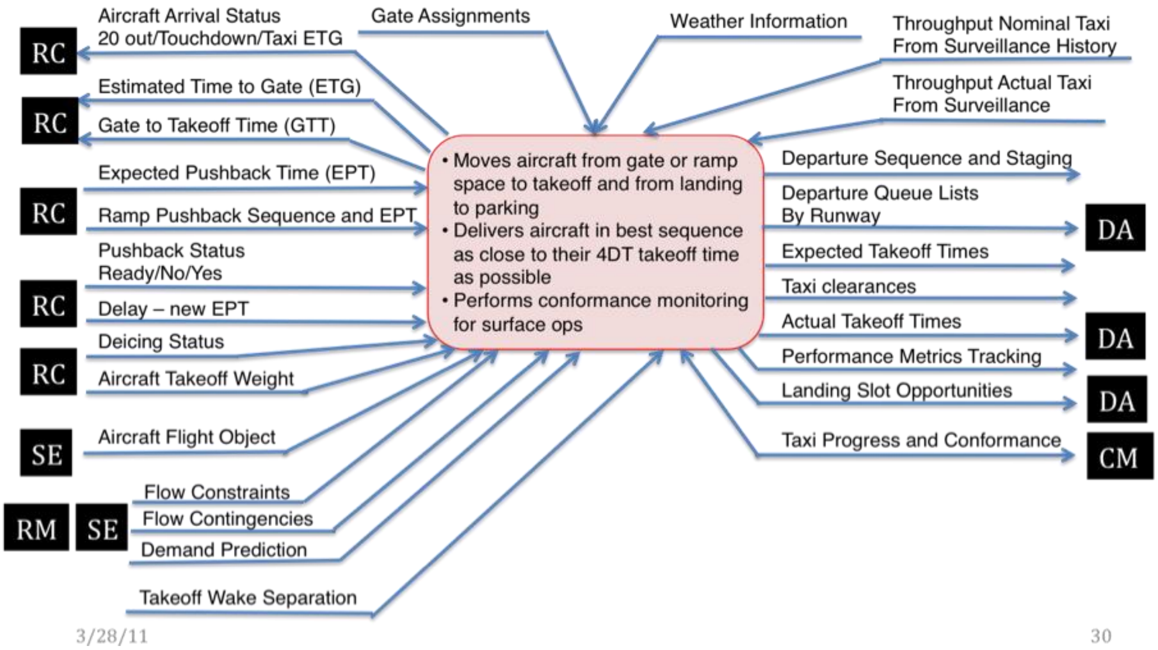
FBO Flight Management Functions

This module provides an interface to the ANSP automation to support flight planning and development of the TBO 4 D trajectory

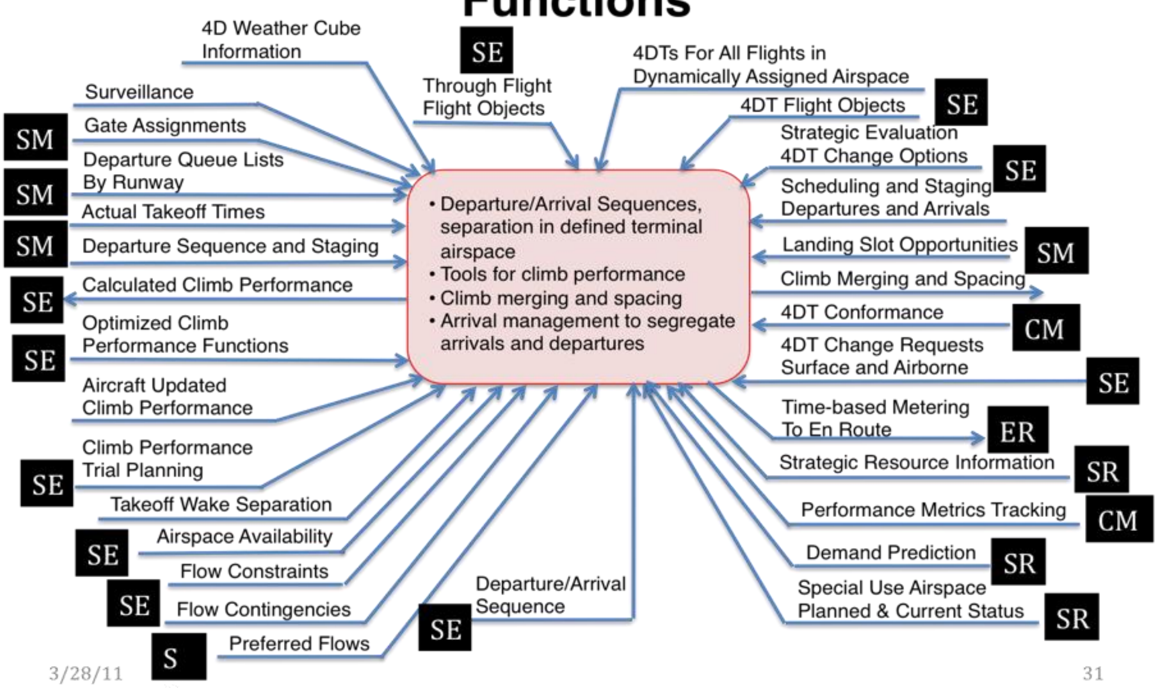


3/28/11 29

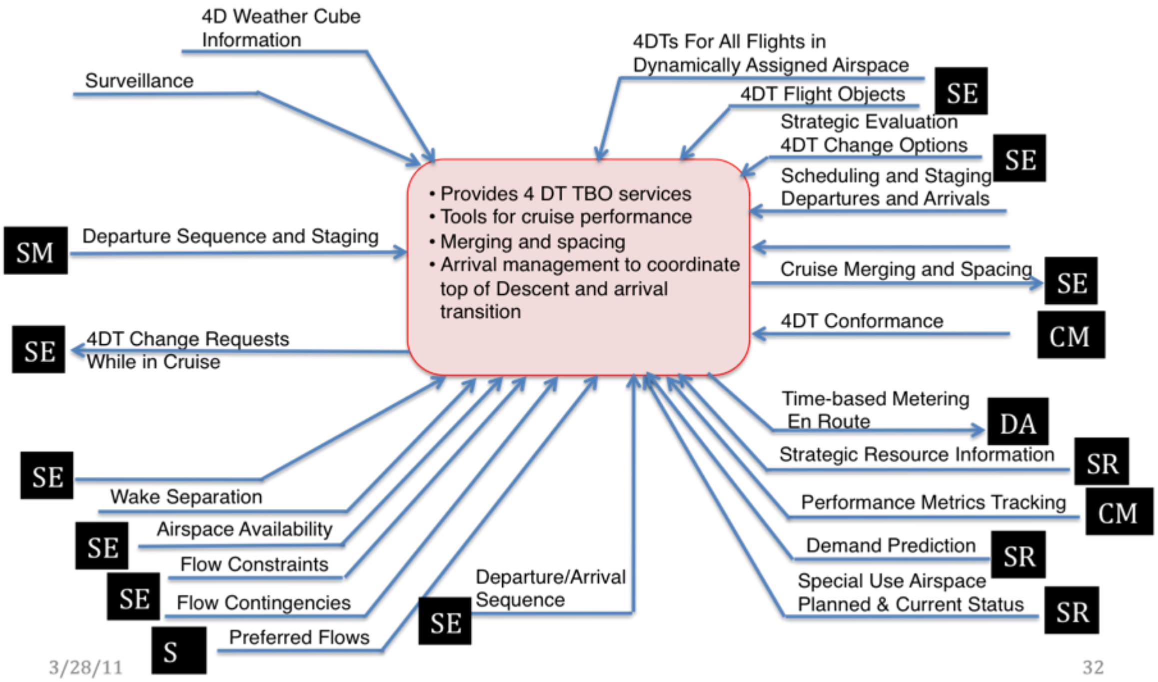
ANSP Surface Movement Management Automation Functions



ANSP Departure/Arrival TBO Automation Functions



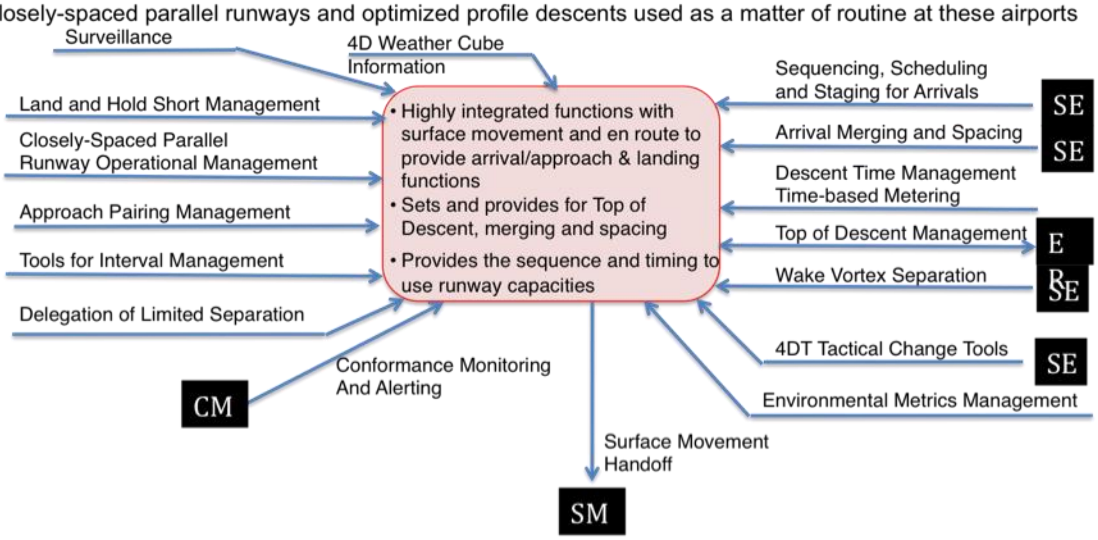
ANSP En Route Automation Functions



3/28/11 32

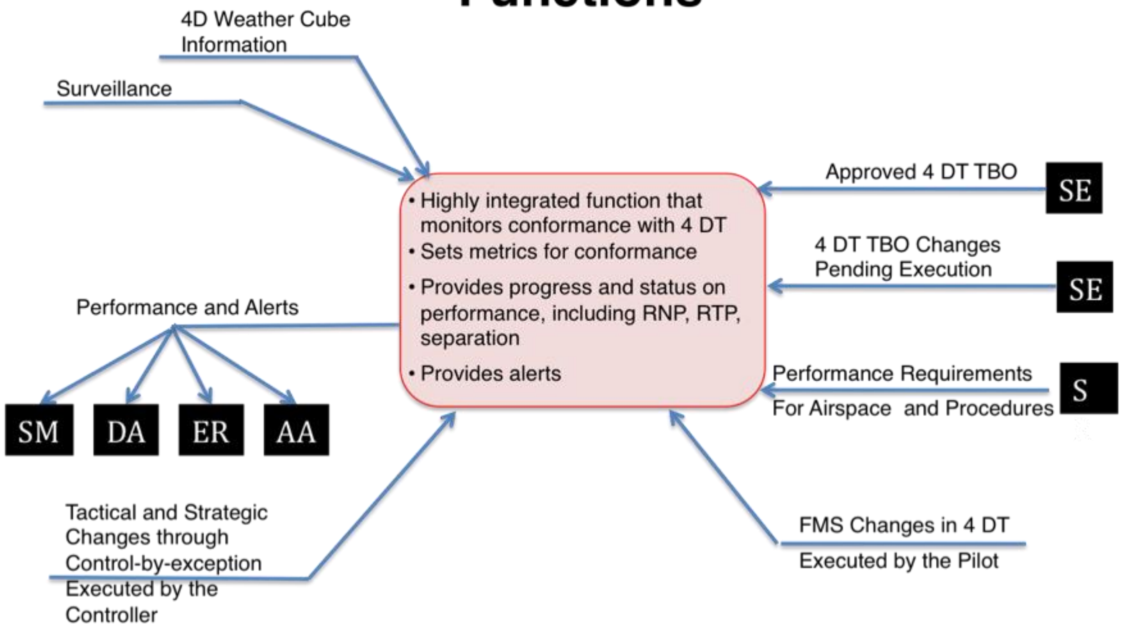
ANSP Arrival/Approach/Landing TBO Automation Functions

Arrival/Approach/Landing has all the functions found in Departure/Arrival plus tools necessary for high-density and selected other airports for handling complex arrival procedures, including paired approaches, closely-spaced parallel runways and optimized profile descents used as a matter of routine at these airports



3/28/11 33

ANSP Conformance Monitoring Automation Functions



3/28/11 34

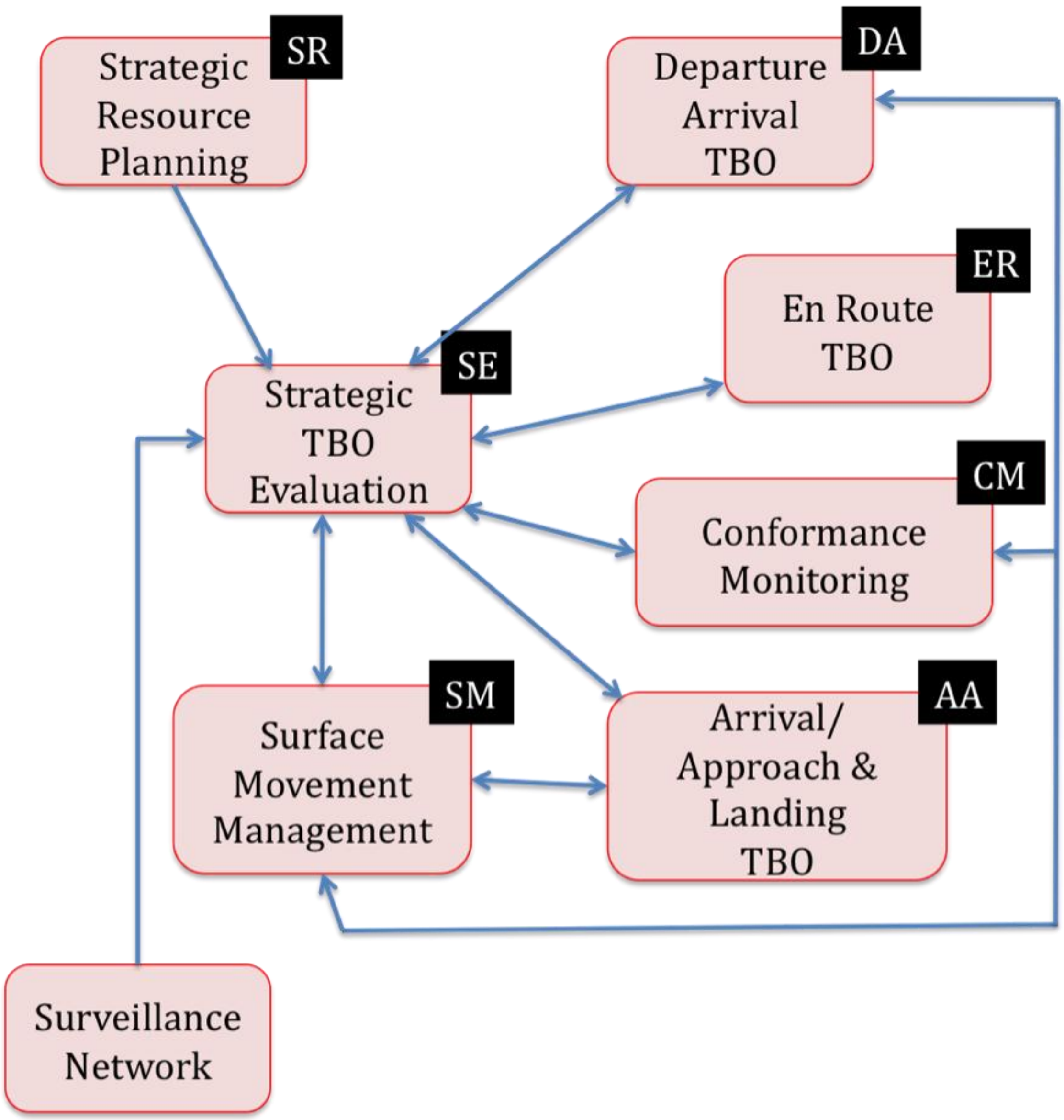
Appendix C. GPS Operational Concept Informational Flow Diagrams

The following diagrams illustrate the decision processes used to generate actions at the point of loss of GPS based on the phase of the flight and equipage. In NextGen, the Strategic TBO Evaluation Service is the central automation element responsible for trajectories and separation of aircraft. In the event of a GPS interference event, a new trajectory must be generated. The following charts show the processes used to derive corrective actions. Note that in the case of the GPS-only equipped aircraft operating in IMC conditions and where surveillance is provided to the ANSP by only ADS-B, there is little support that can be provided.

Diagramming Overview

- Information flows are defined by the position and capability of the aircraft at the onset of the interference event
- Traffic volume in high-density airspace exceeds the ability of the controller to step in and control all aircraft by using “control by exception”
- Automation plays a vital role in defining the impacted airspace volume and providing the controller with actions
- The pilot still relies on cockpit alerting and procedures (to be defined)
- The structure of the information flows allows for later definition of modeling and simulation and is used in both the operations concept and the Operational Services and Environment Description (OSED)
- Alternative PNT exists today using DME and inertial reference systems
- The FAA has committed to retaining ILS on at least one runway at most airports as a landing aid backup to GNSS
- Development of a minimum VOR network is not considered here since the FAA has not committed to recapitalization of a limited set of VOR units

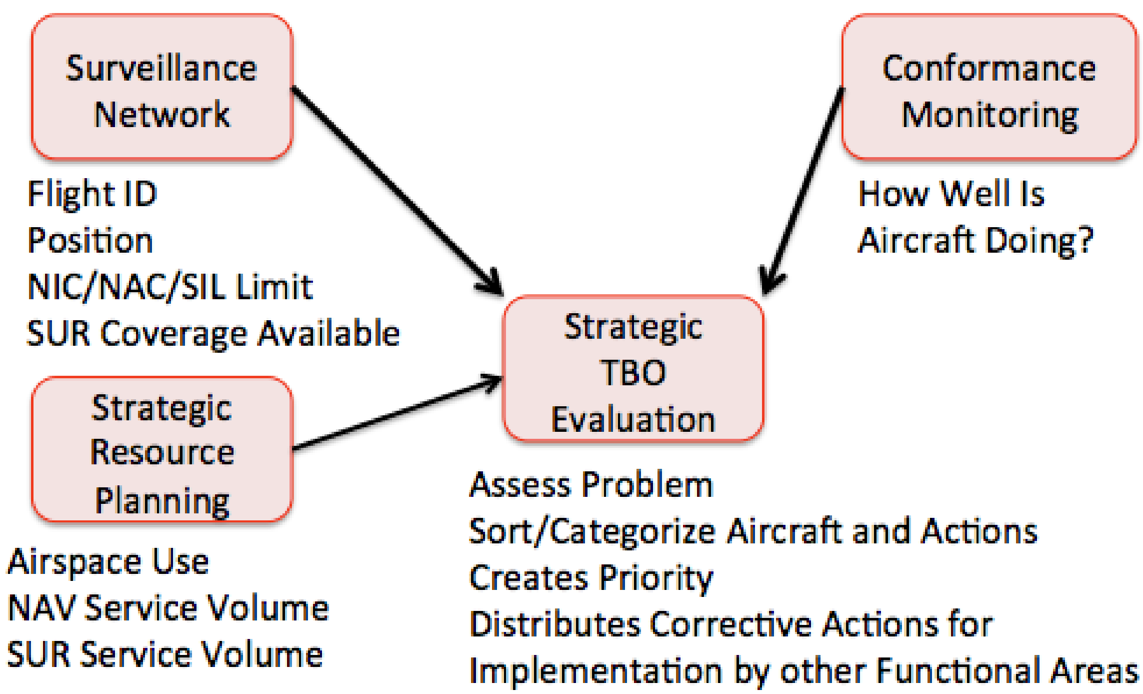
ANSP Automation Functional Areas

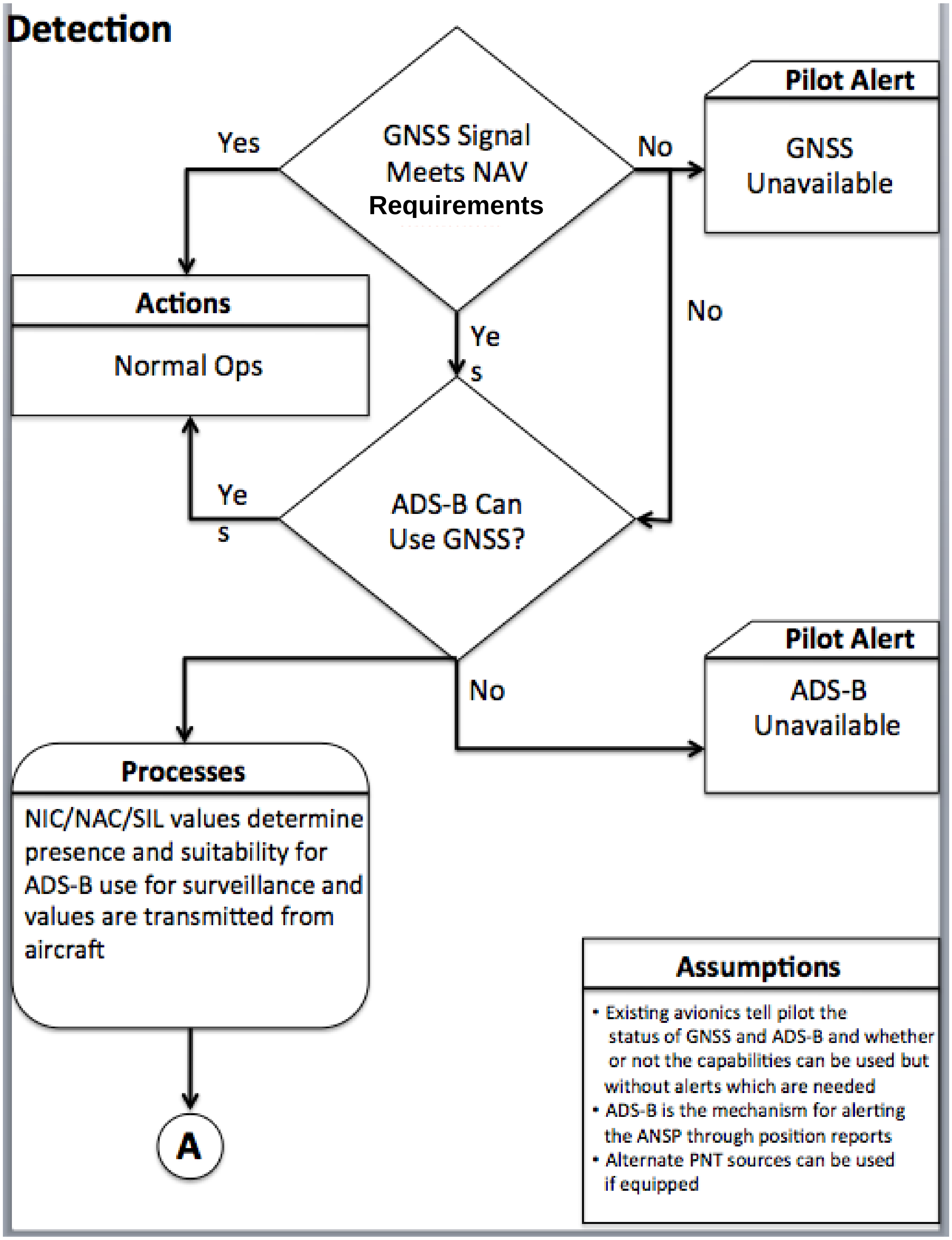


Process Overview

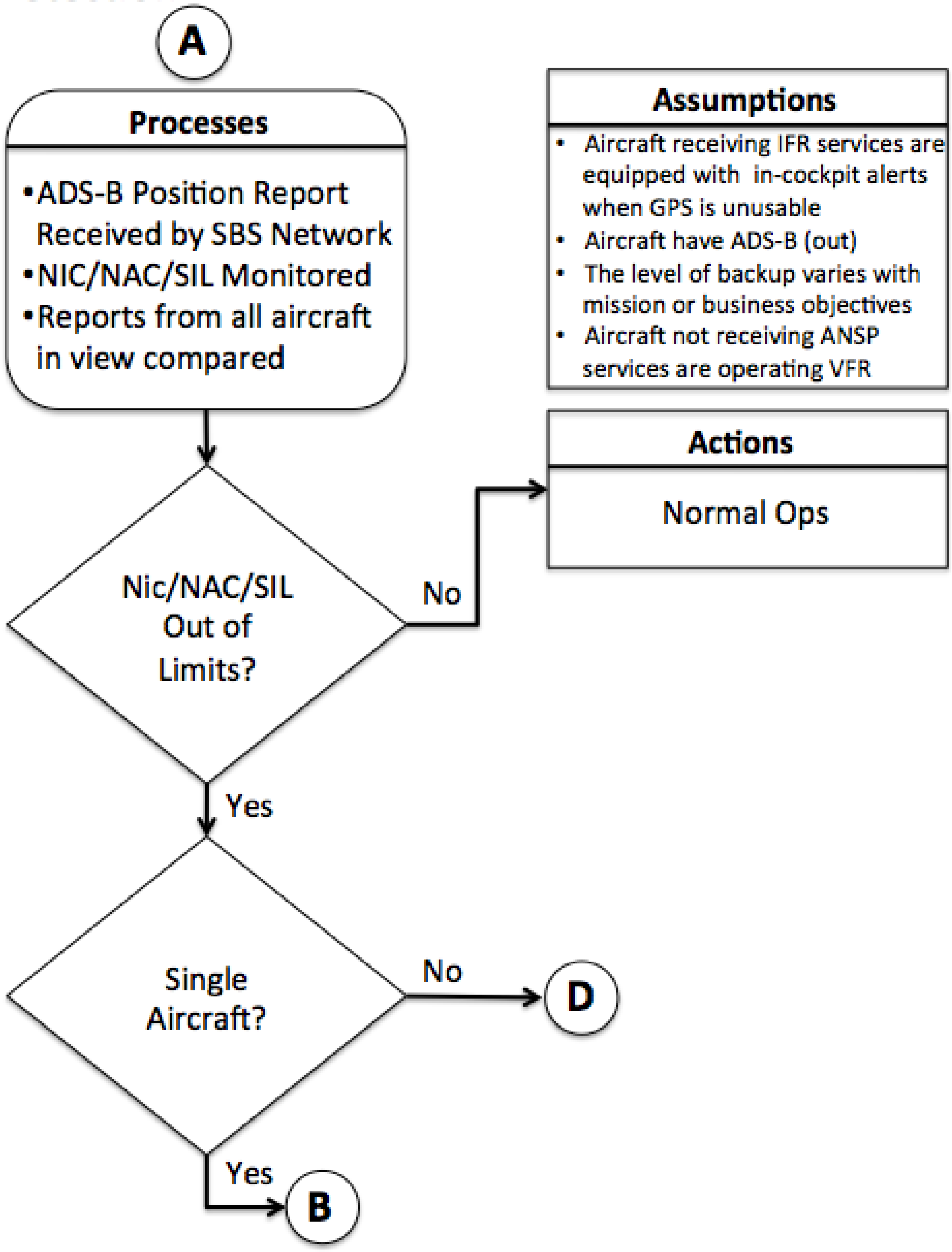
Avionics + Cockpit Alert = Pilot Action

Pilot Action is either pre-defined for GPS Inop or provided by ANSP

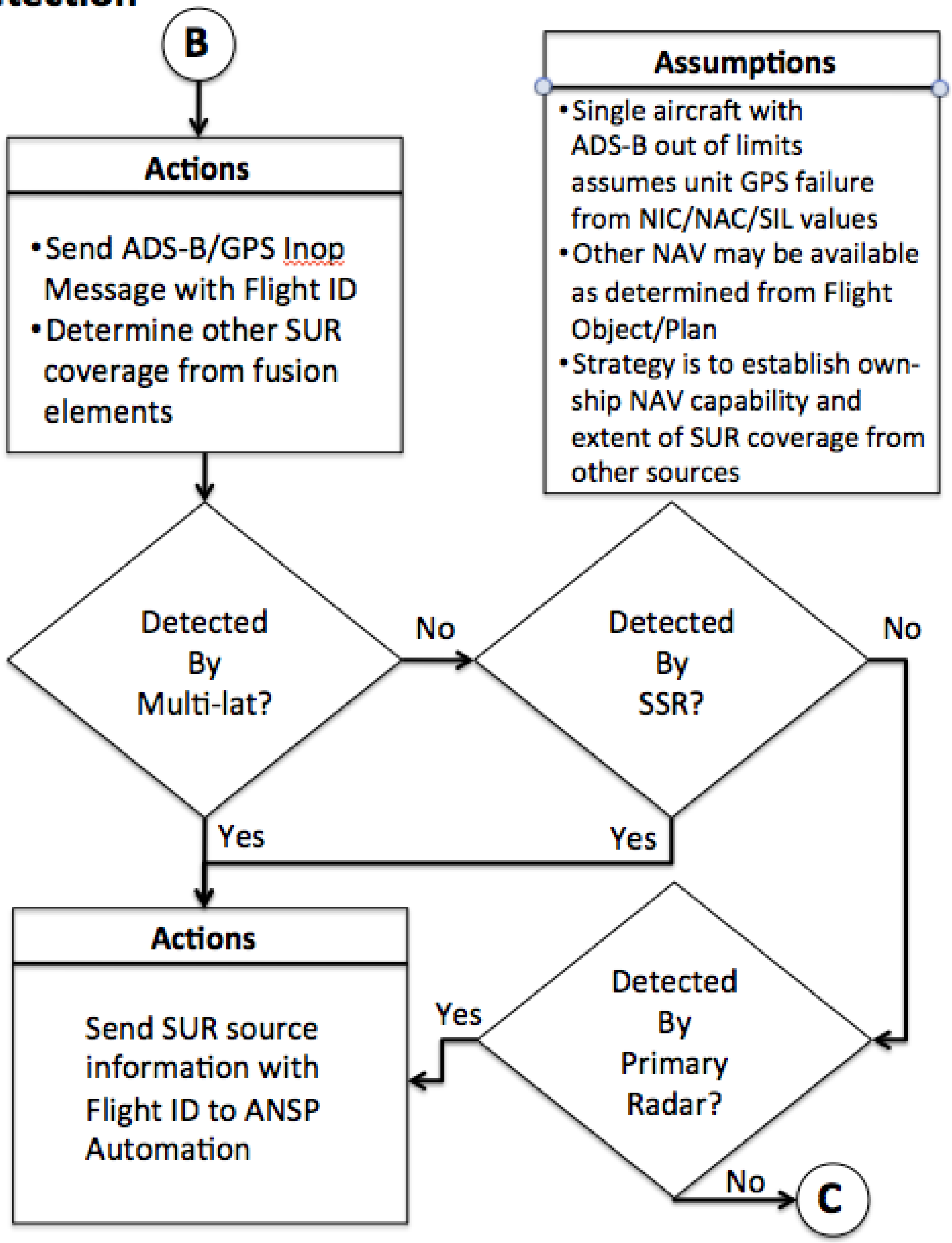



Detection
GNSS Signal Meets NAV Requirements
Yes
No
Pilot Alert
GNSS Unavailable
Actions
Normal Ops
Ye s
No
ADS-B Can Use GNSS?
Ye s
No
Pilot Alert
ADS-B Unavailable
Processes
NIC/NAC/SIL values determine presence and suitability for ADS-B use for surveillance and values are transmitted from aircraft
A
Assumptions
• Existing avionics tell pilot the status of GNSS and ADS-B and whether or not the capabilities can be used but without alerts which are needed
• ADS-B is the mechanism for alerting the ANSP through position reports
• Alternate PNT sources can be used if equipped

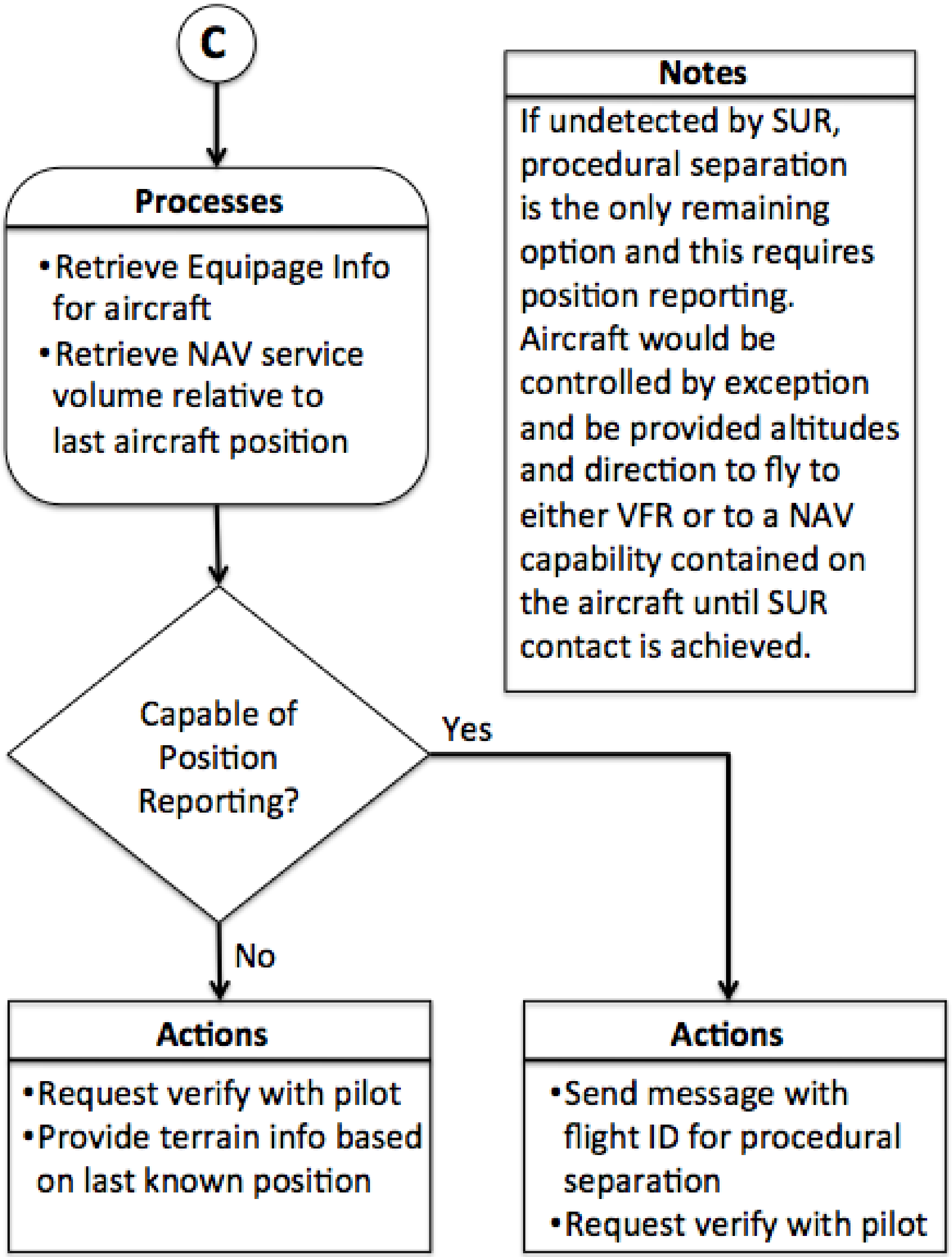
Detection


A
Processes
•ADS-B Position Report Received by SBS Network
•NIC/NAC/SIL Monitored
•Reports from all aircraft in view compared
Assumptions
• Aircraft receiving IFR services are equipped with in-cockpit alerts when GPS is unusable
• Aircraft have ADS-B (out)
• The level of backup varies with mission or business objectives
• Aircraft not receiving ANSP services are operating VFR
Actions
Normal Ops
Nic/NAC/SIL Out of Limits?
No
Yes
Single Aircraft?
No
D
Yes
B

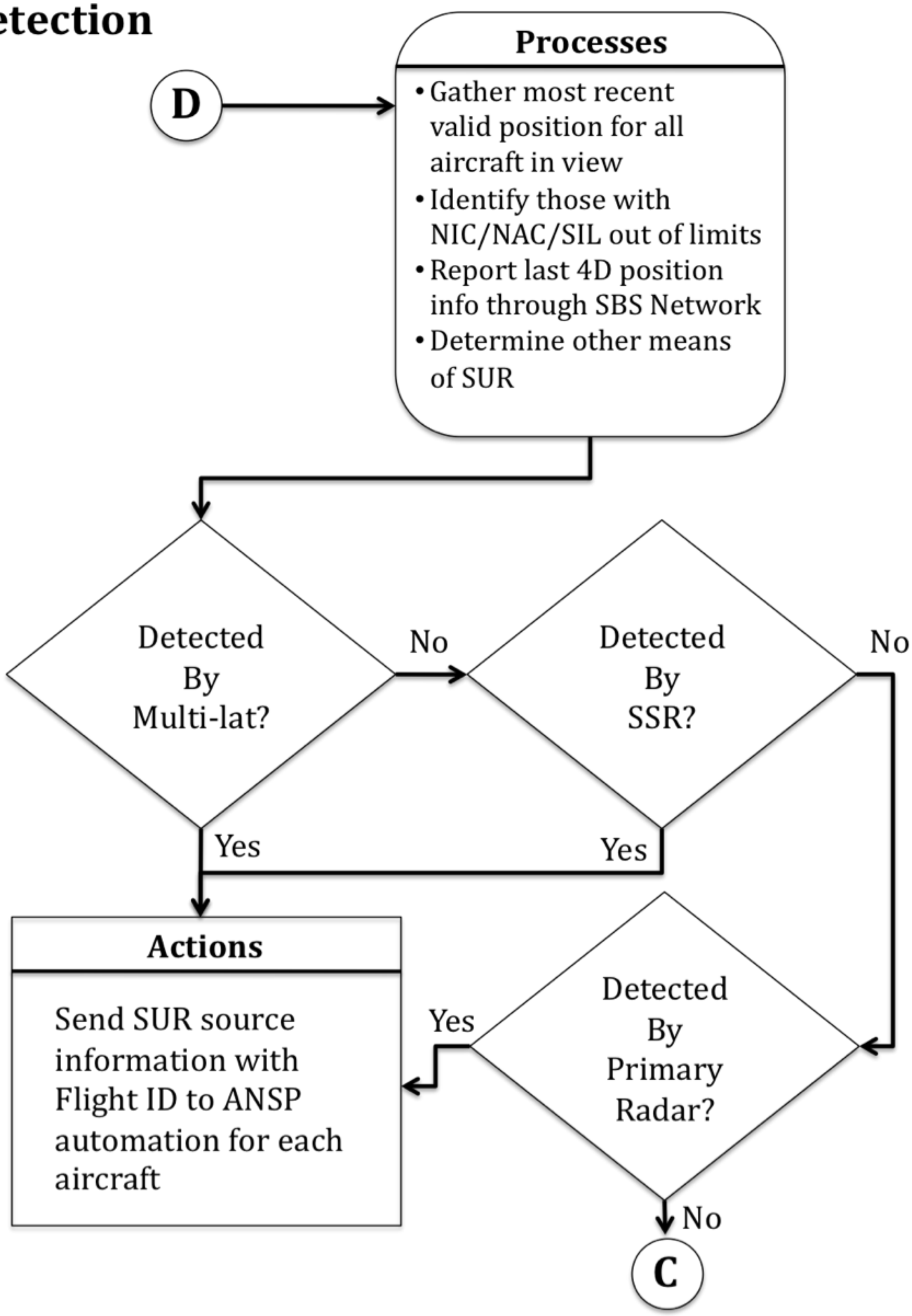
Detection


B
Actions
• Send ADS-B/GPS Inop Message with Flight ID
• Determine other SUR coverage from fusion elements
Assumptions
• Single aircraft with ADS-B out of limits assumes unit GPS failure from NIC/NAC/SIL values
• Other NAV may be available as determined from Flight Object/Plan
• Strategy is to establish own-ship NAV capability and extent of SUR coverage from other sources
Detected By Multi-lat?
No
Detected By SSR?
No
Yes
Yes
Actions
Send SUR source information with Flight ID to ANSP Automation
Yes
Detected By Primary Radar?
No
C

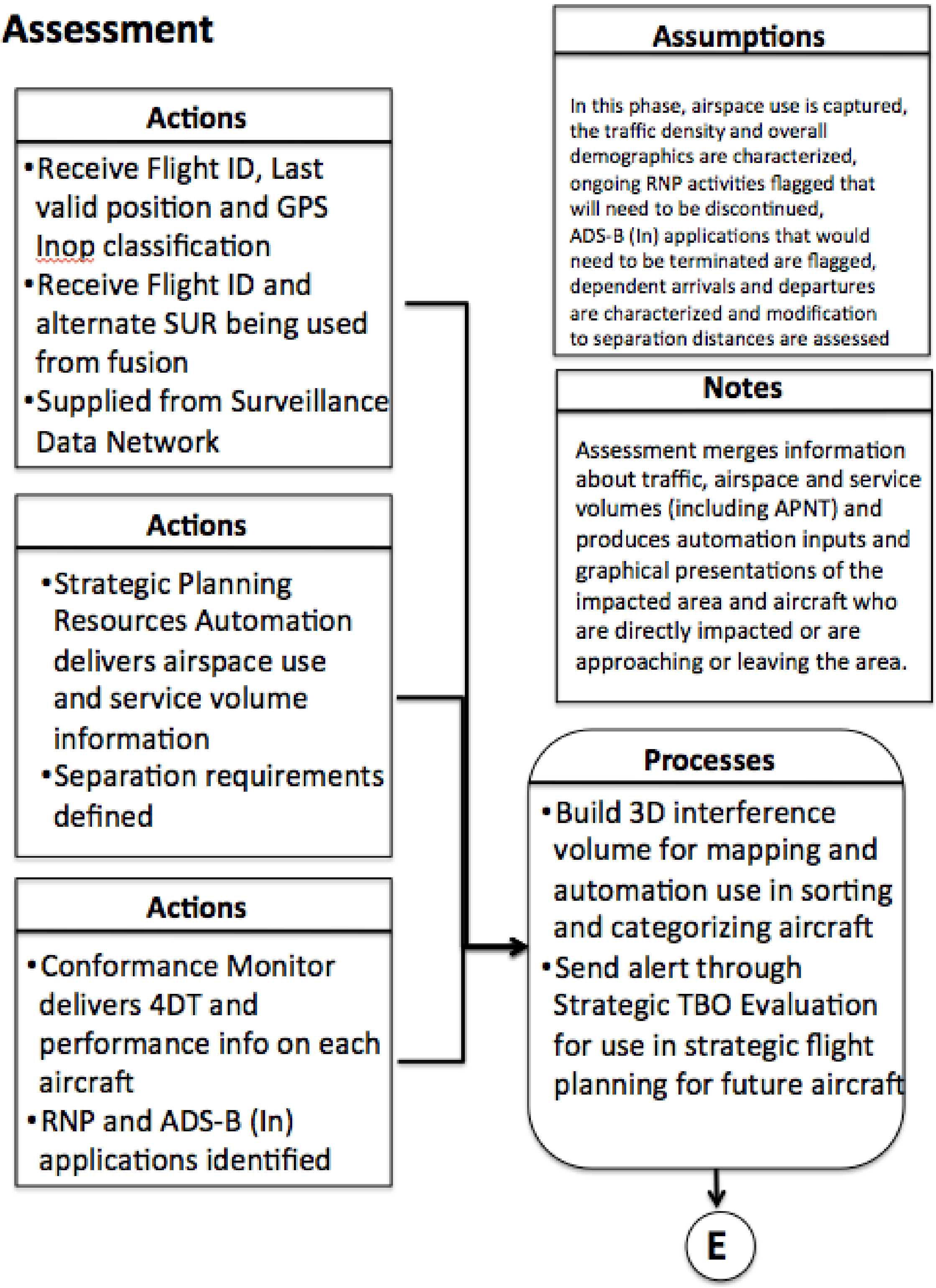
Detection


C
Processes
•Retrieve Equipage Info for aircraft
•Retrieve NAV service volume relative to last aircraft position
Notes
If undetected by SUR, procedural separation is the only remaining option and this requires position reporting. Aircraft would be controlled by exception and be provided altitudes and direction to fly to either VFR or to a NAV capability contained on the aircraft until SUR contact is achieved.
Capable of Position Reporting?
Yes
No
Actions
•Request verify with pilot
•Provide terrain info based on last known position
Actions
•Send message with flight ID for procedural separation
•Request verify with pilot

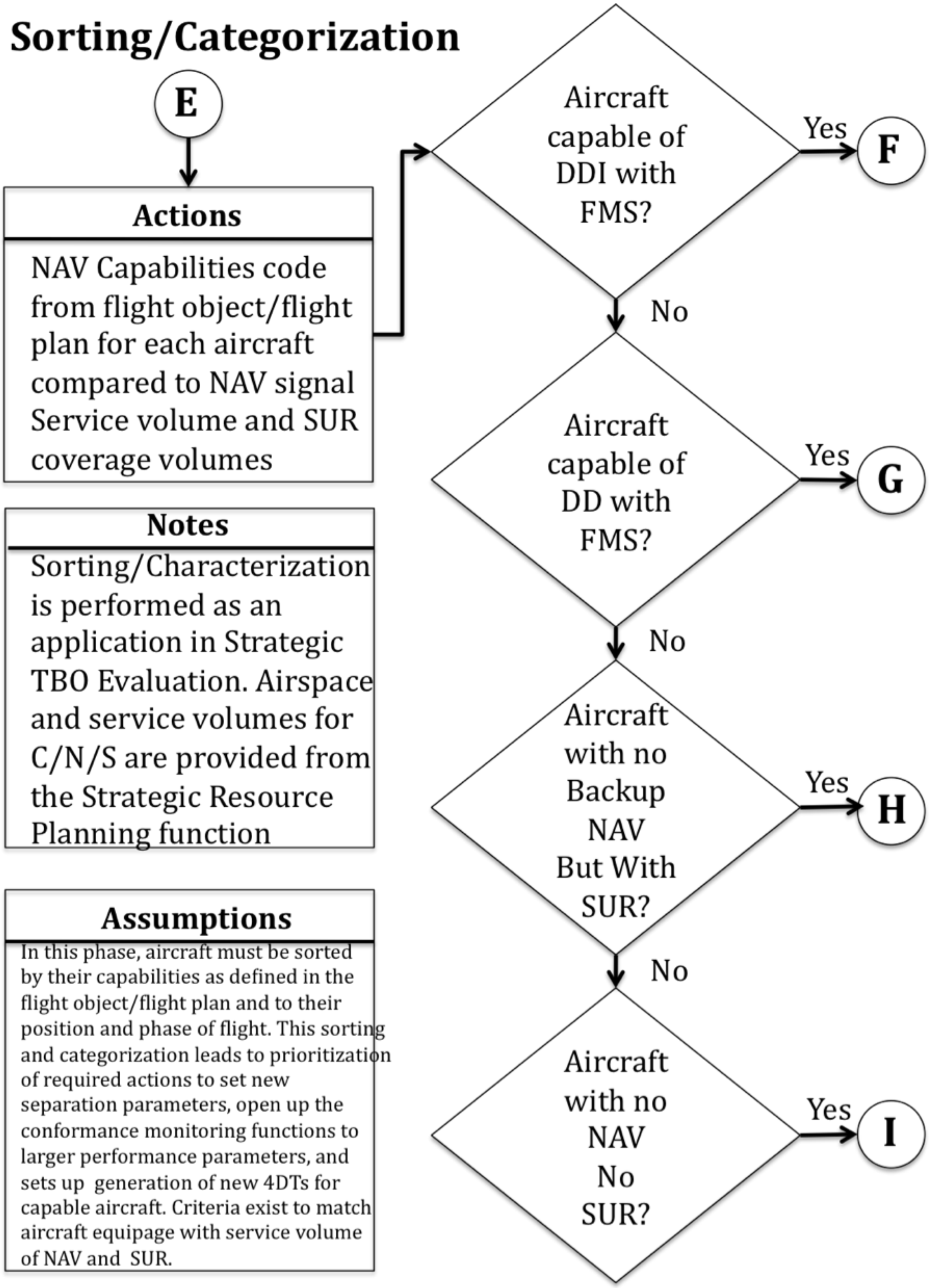
Detection


Processes
• Gather most recent valid position for all aircraft in view
• Identify those with NIC/NAC/SIL out of limits
• Report last 4D position info through SBS Network
• Determine other means of SUR
D
Detected By Multi-lat?
No
Detected By SSR?
No
Yes
Yes
Actions
Send SUR source information with Flight ID to ANSP automation for each aircraft
Yes
Detected By Primary Radar?
No
C

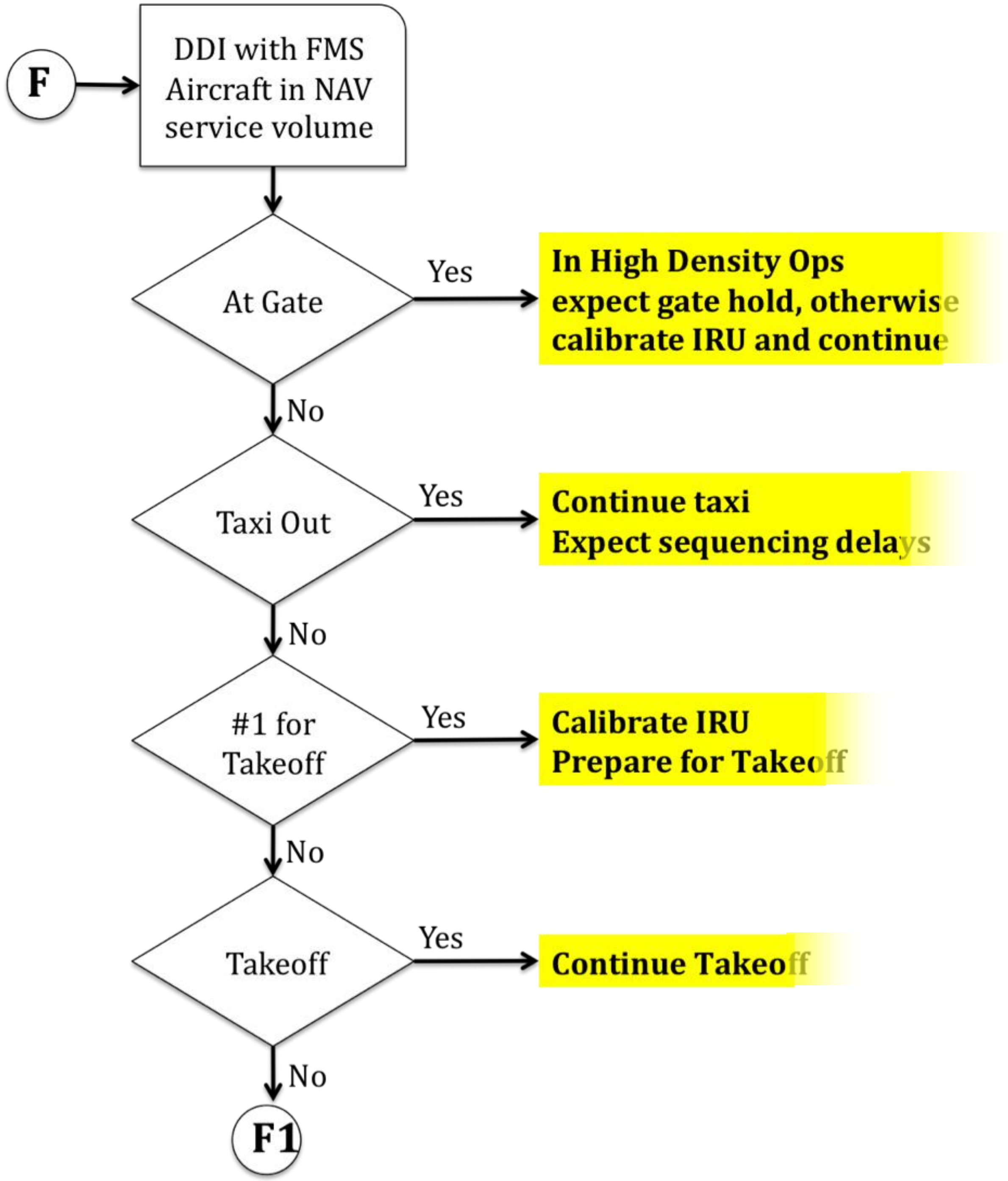
Assessment


Actions
•Receive Flight ID, Last valid position and GPS Inop classification
•Receive Flight ID and alternate SUR being used from fusion
•Supplied from Surveillance Data Network
Actions
•Strategic Planning Resources Automation delivers airspace use and service volume information
•Separation requirements defined
Actions
•Conformance Monitor delivers 4DT and performance info on each aircraft
•RNP and ADS-B (In) applications identified
Assumptions
In this phase, airspace use is captured, the traffic density and overall demographics are characterized, ongoing RNP activities flagged that will need to be discontinued, ADS-B (In) applications that would need to be terminated are flagged, dependent arrivals and departures are characterized and modification to separation distances are assessed
Notes
Assessment merges information about traffic, airspace and service volumes (including APNT) and produces automation inputs and graphical presentations of the impacted area and aircraft who are directly impacted or are approaching or leaving the area.
Processes
•Build 3D interference volume for mapping and automation use in sorting and categorizing aircraft
•Send alert through Strategic TBO Evaluation for use in strategic flight planning for future aircraft
E

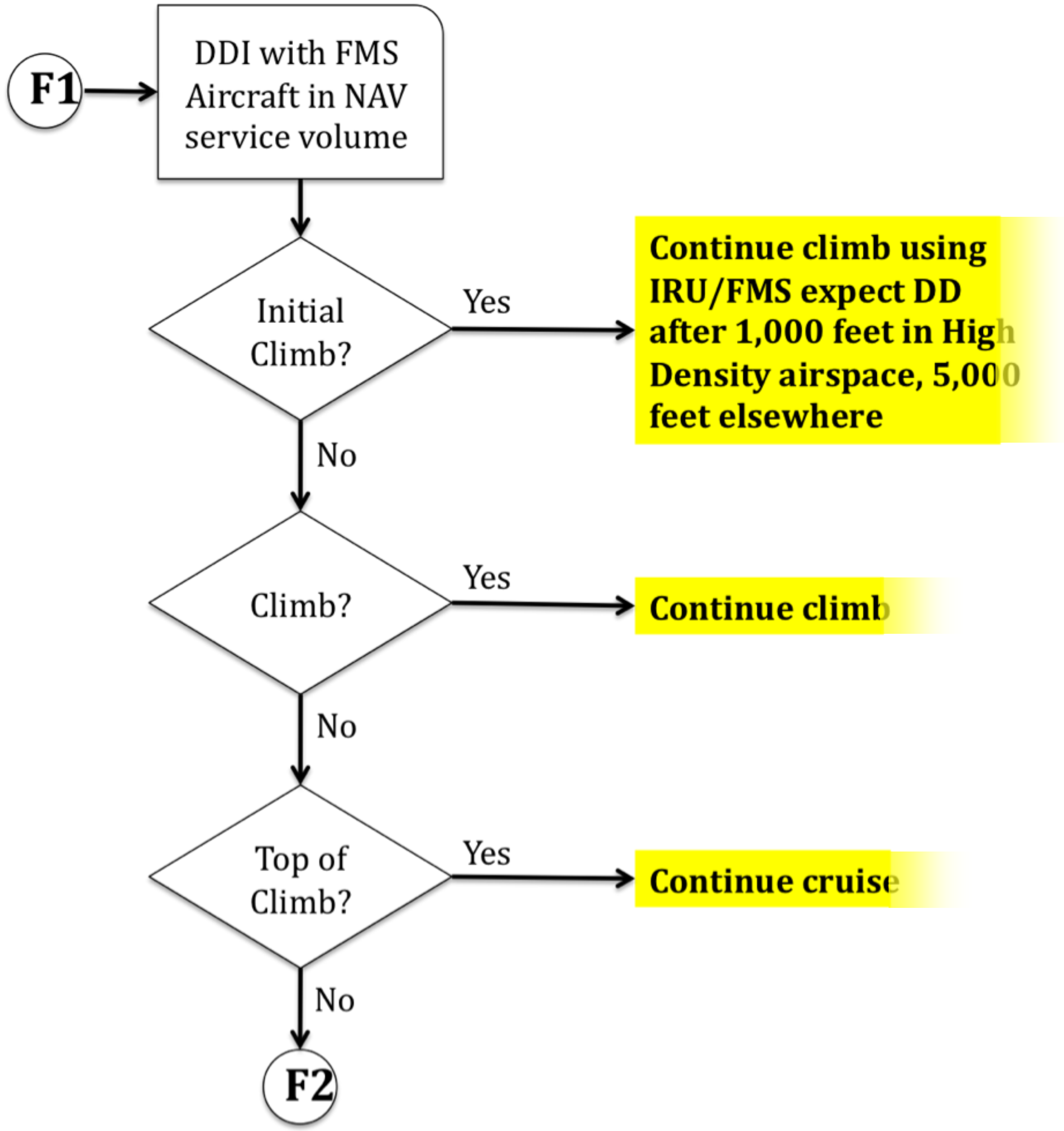
Sorting/Categorization



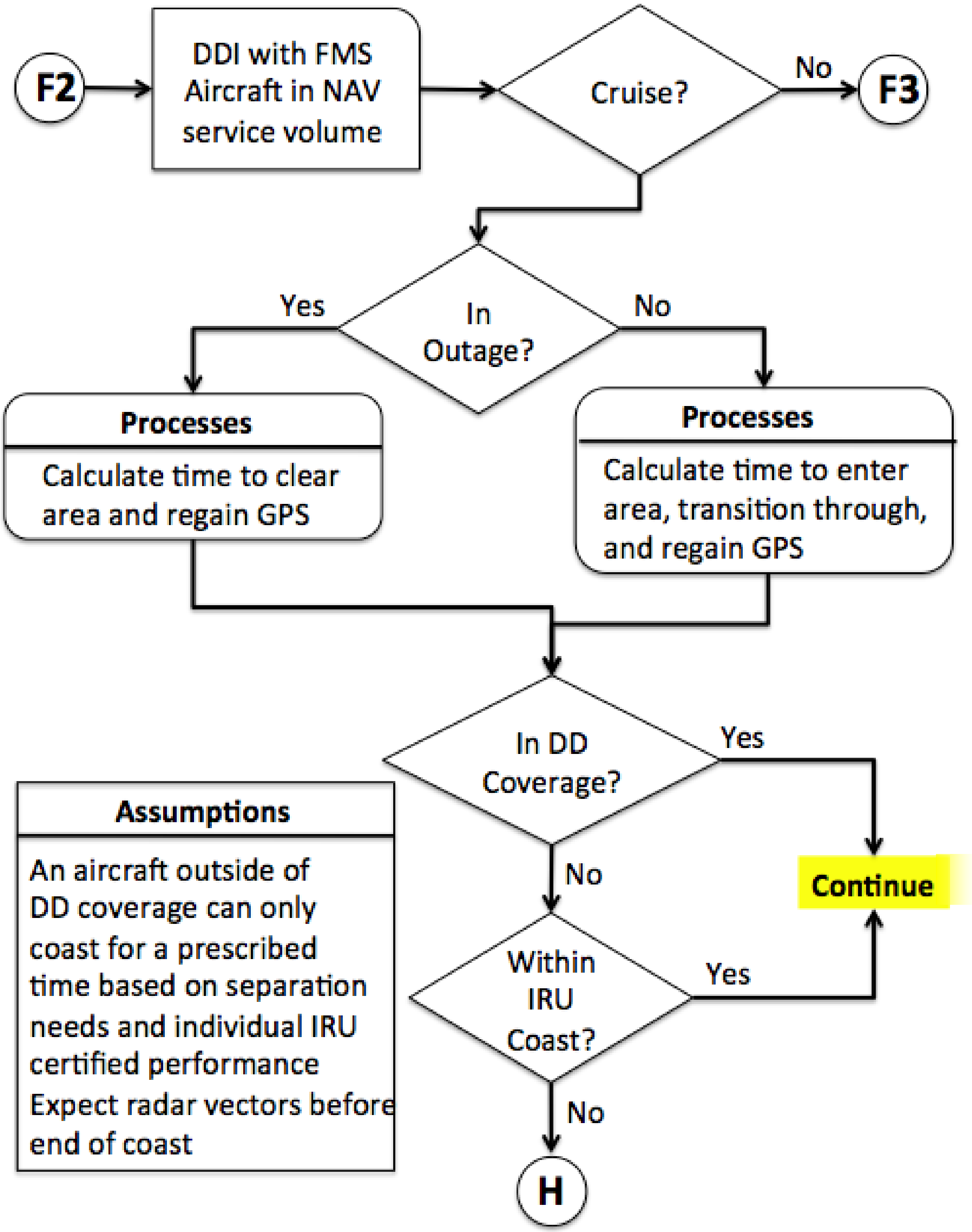
Sorting/Categorization



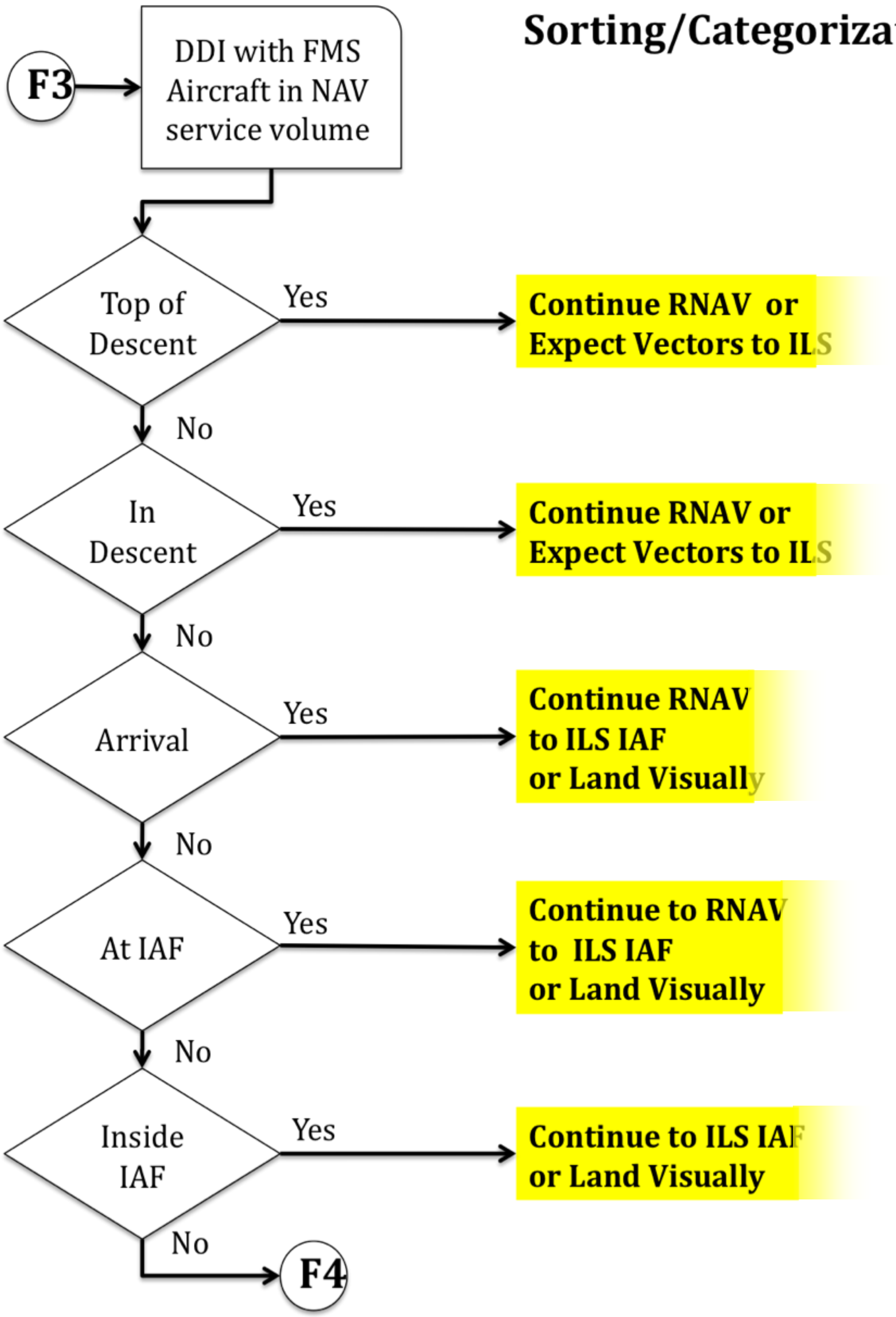
Sorting/Categorization



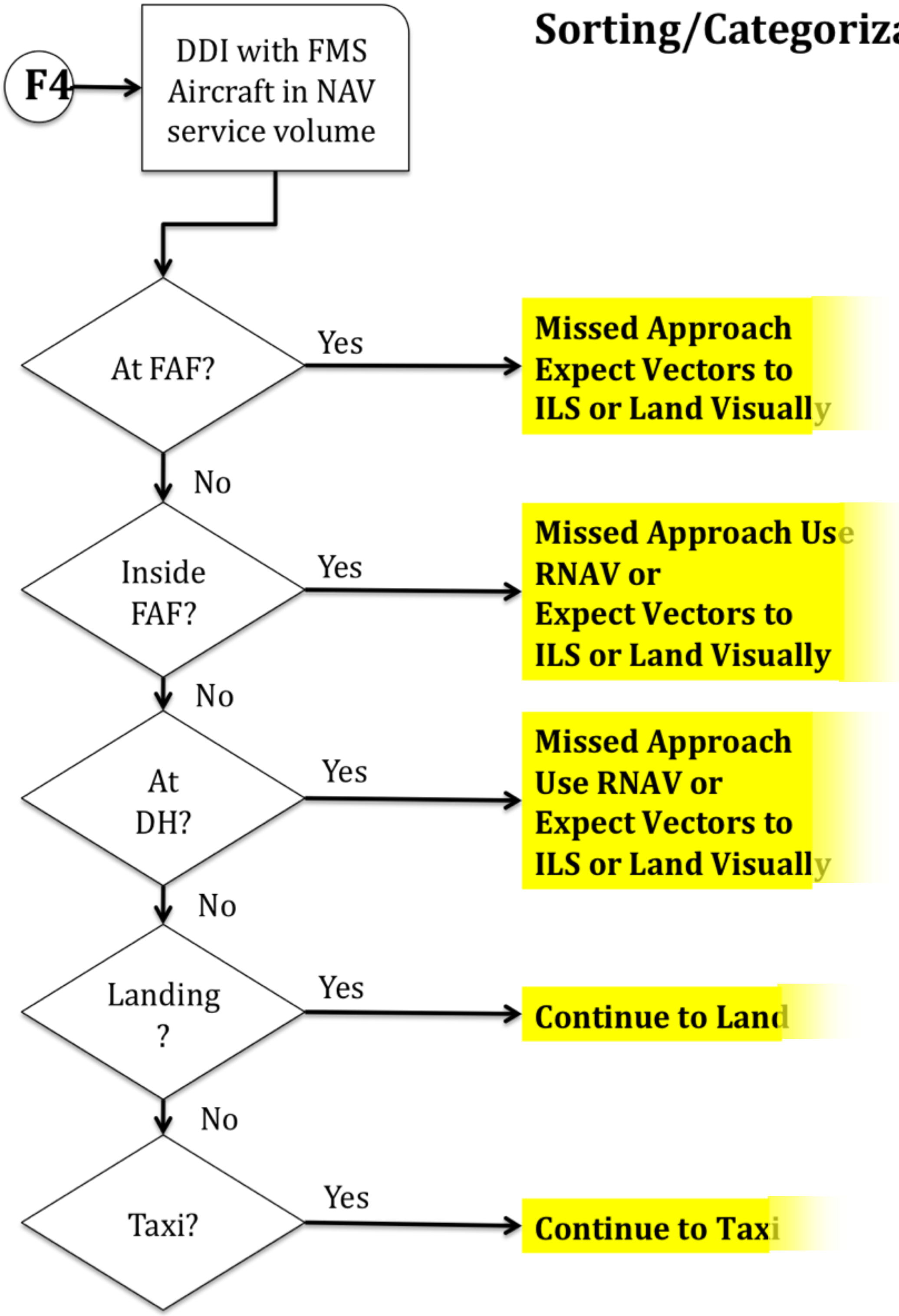
Sorting/Categorization



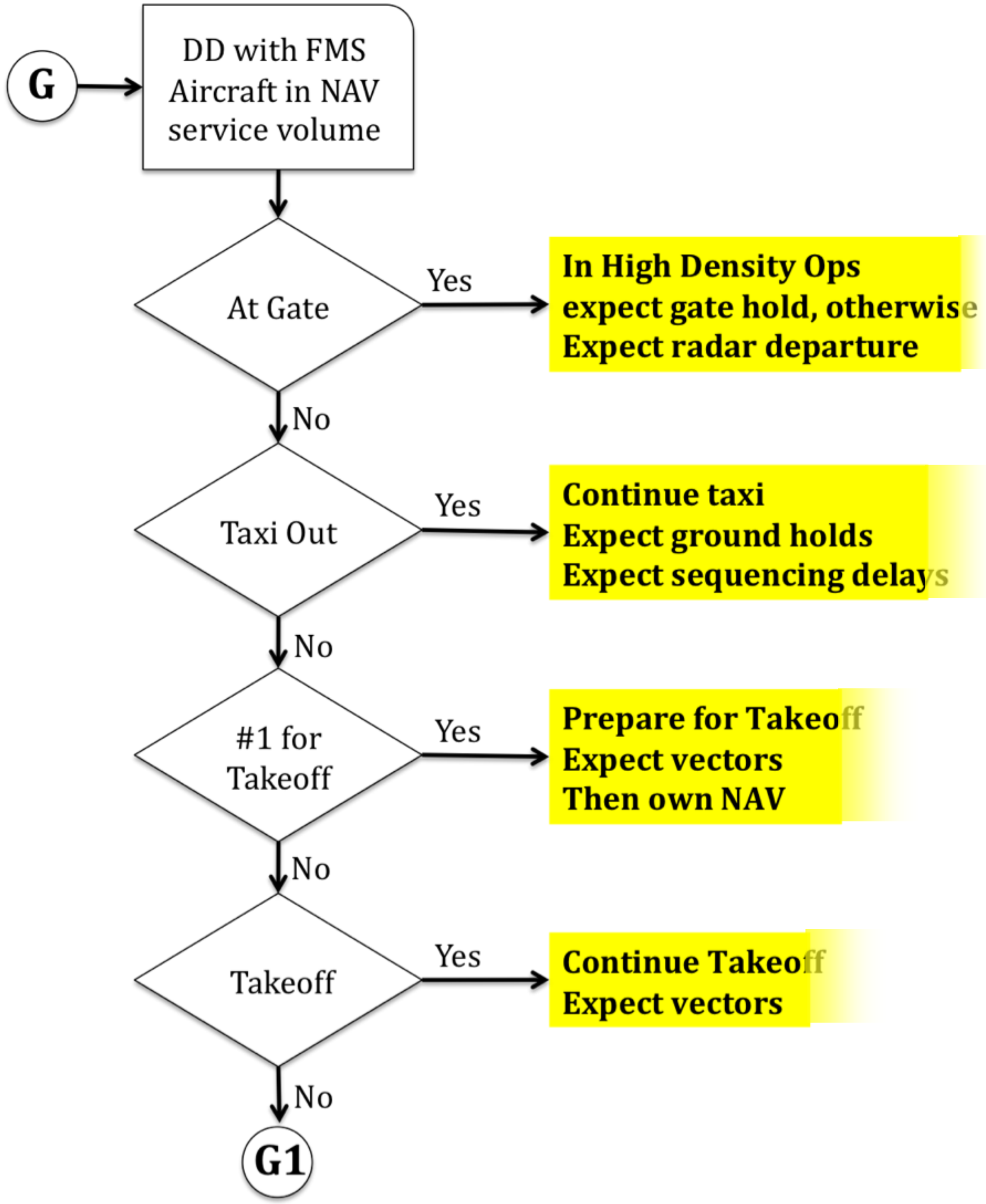
Sorting/Categorization



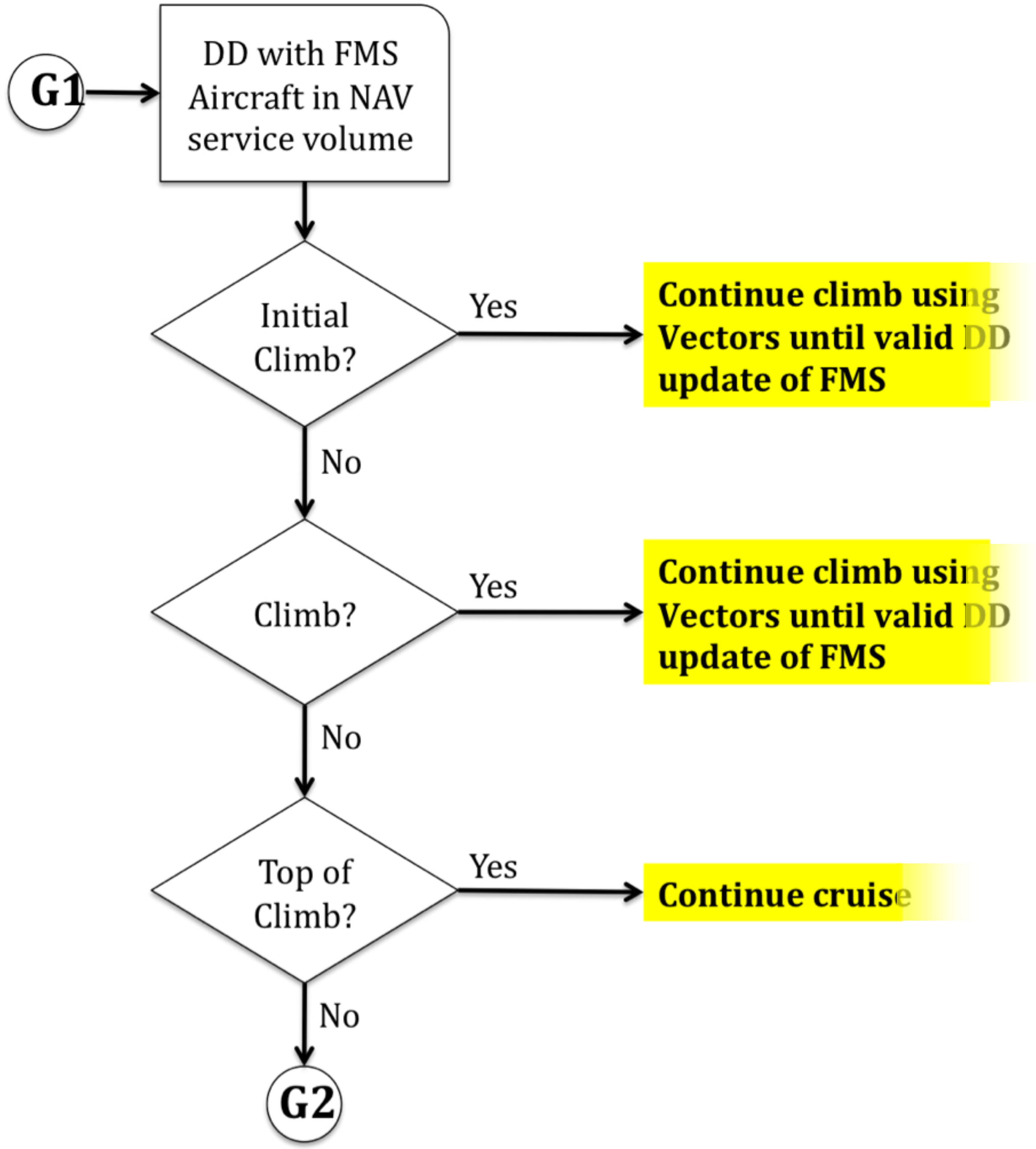
Sorting/Categorization

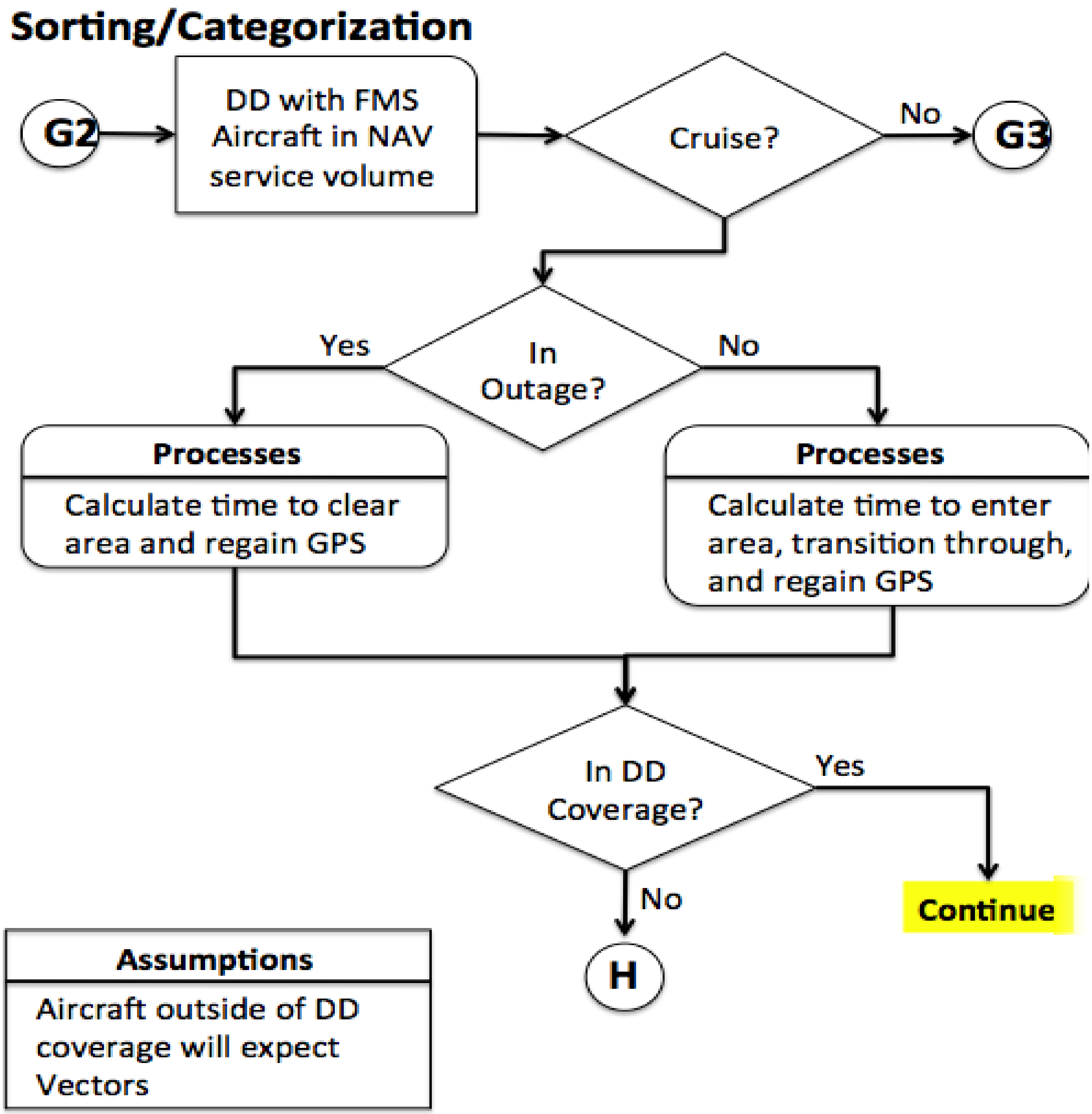


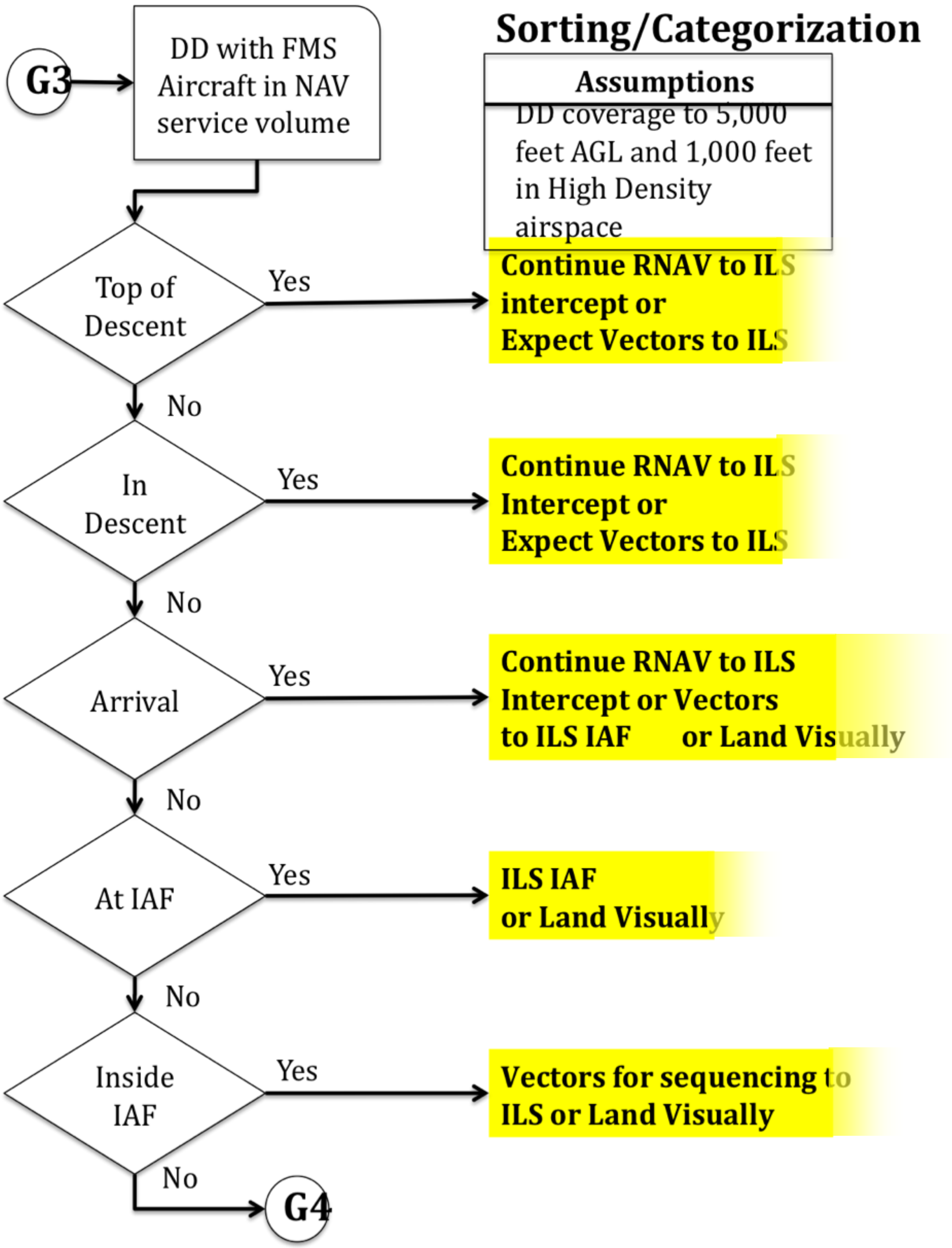
Sorting/Categorization



Sorting/Categorization



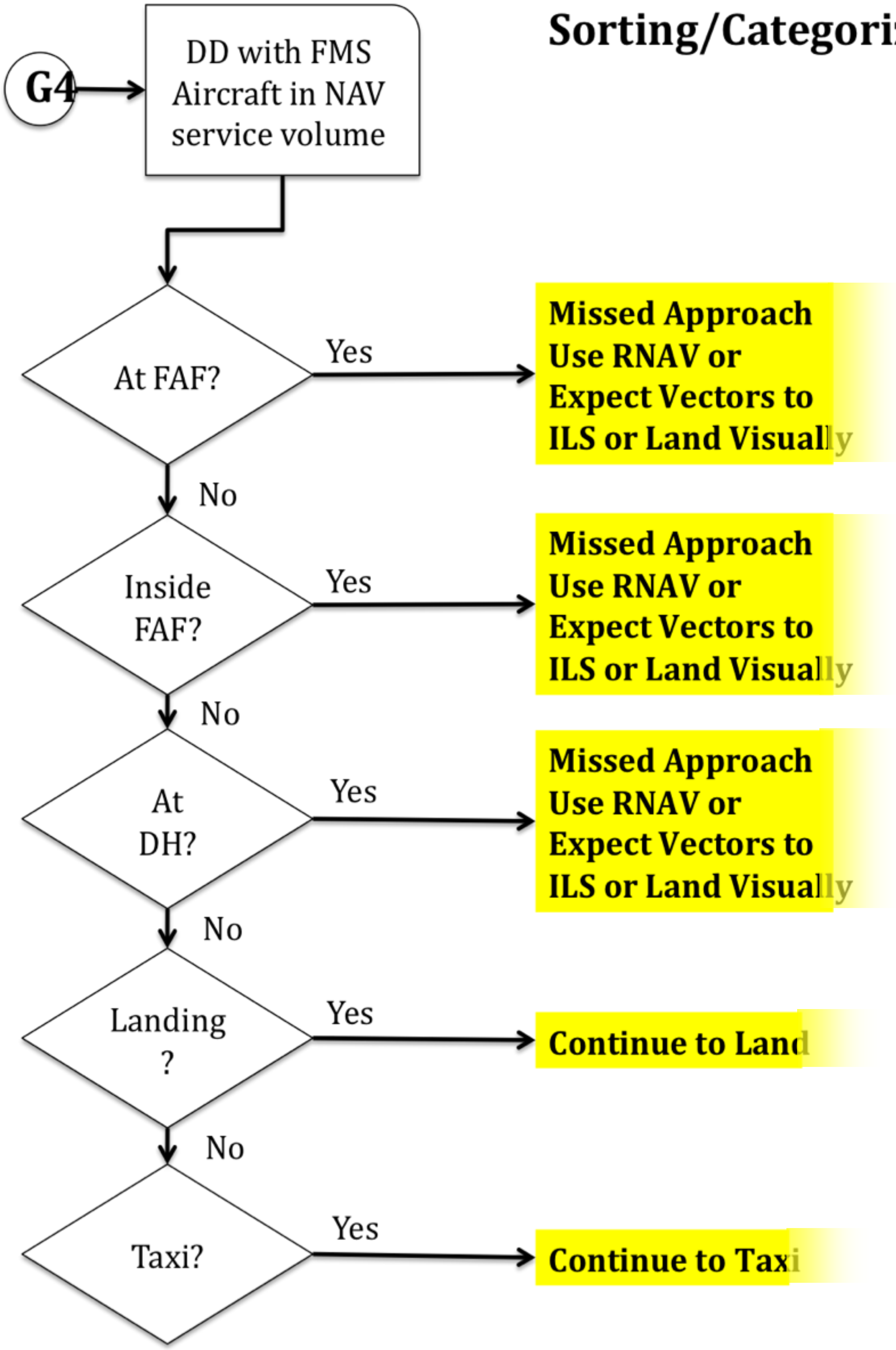

Sorting/Categorization
G2
DD with FMS Aircraft in NAV service volume
Cruise?
No
G3
In Outage?
Yes
No
Processes
Calculate time to clear area and regain GPS
Processes
Calculate time to enter area, transition through, and regain GPS
In DD Coverage?
Yes
Continue
No
H
Assumptions
Aircraft outside of DD coverage will expect Vectors


Sorting/Categorization
Assumptions
DD coverage to 5,000 feet AGL and 1,000 feet in High Density airspace
G3
DD with FMS Aircraft in NAV service volume
Top of Descent
Yes
Continue RNAV to ILS intercept or Expect Vectors to ILS
No
In Descent
Yes
Continue RNAV to ILS Intercept or Expect Vectors to ILS
No
Arrival
Yes
Continue RNAV to ILS Intercept or Vectors to ILS IAF or Land Visually
No
At IAF
Yes
ILS IAF or Land Visually
No
Inside IAF
Yes
Vectors for sequencing to ILS or Land Visually
No
G4

ILS Intercept Issue

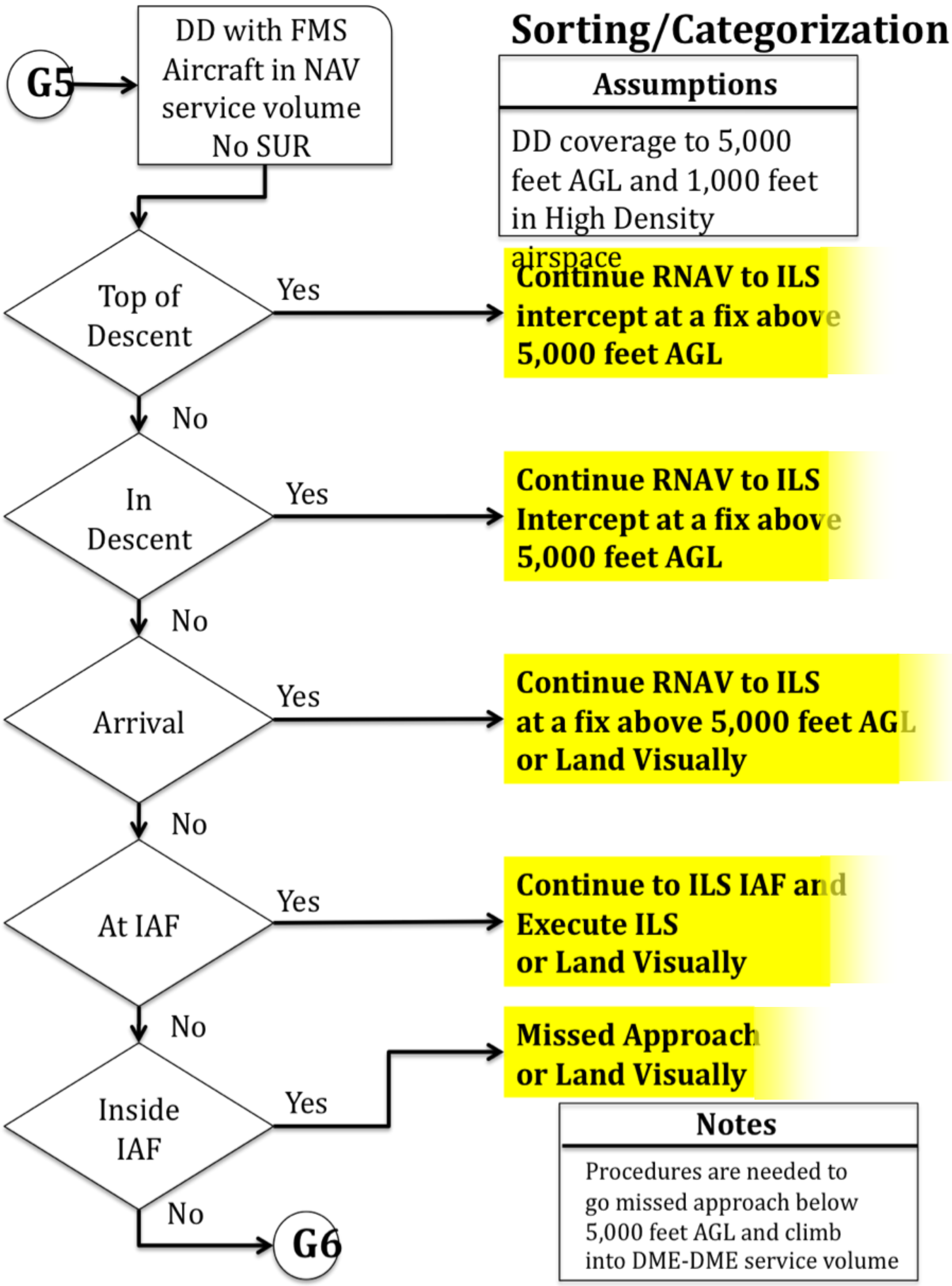
- With ILS as the landing aid backup for recovery of aircraft, DME-DME coverage service volume is an issue relative to the intercept altitude for the ILS Localizer. With a floor of the DME-DME service volume at 5,000 feet AGL, the aircraft must be in coverage for the FMS to resolve the intercept
- At larger airports, this service volume is extended downward to 1,000 feet
- Procedures will be needed to support RNAV to ILS intercept with sufficient geometry of the DME stations to allow use for the maneuver

Sorting/Categorization



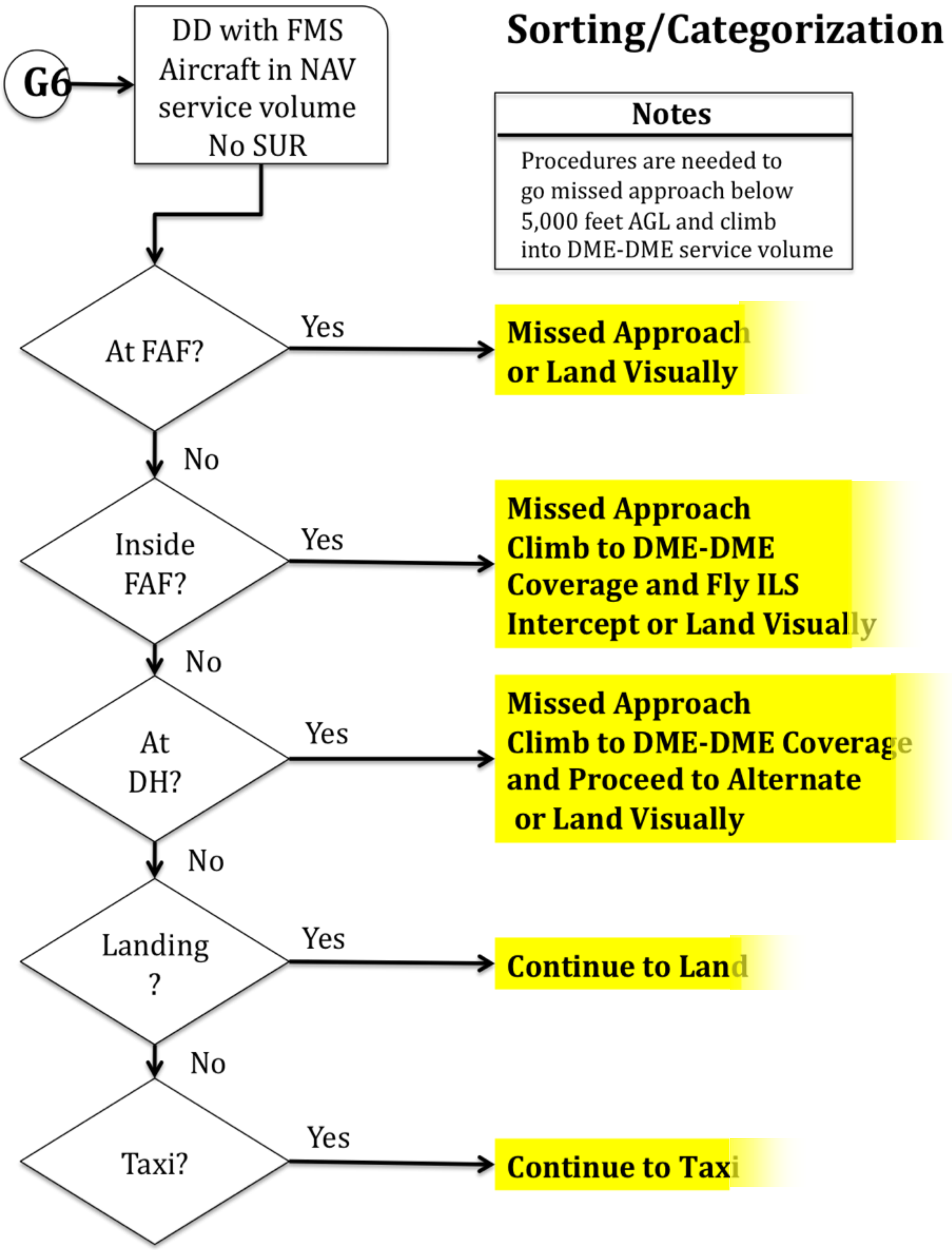
Lack of Surveillance for Vectors

- There is a case where the aircraft has DME-DME (likely to 18,000 feet for en route and 5,000 feet AGL for arrival and approach) but passes into a no surveillance environment due to mountainous terrain
- This problem precludes the use of vectors to an ILS and presents an en route vectoring option below the floor of the DME-DME coverage if not detected by surveillance
- The aircraft in DME-DME coverage is capable of position reporting and use of procedural separation



Sorting/Categorization
Assumptions
DD coverage to 5,000 feet AGL and 1,000 feet in High Density airspace
G5
DD with FMS Aircraft in NAV service volume No SUR
Top of Descent
Yes
Continue RNAV to ILS intercept at a fix above 5,000 feet AGL
No
In Descent
Yes
Continue RNAV to ILS Intercept at a fix above 5,000 feet AGL
No
Arrival
Yes
Continue RNAV to ILS at a fix above 5,000 feet AGL or Land Visually
No
At IAF
Yes
Continue to ILS IAF and Execute ILS or Land Visually
No
Inside IAF
Yes
Missed Approach or Land Visually
No
G6
Notes
Procedures are needed to go missed approach below 5,000 feet AGL and climb into DME-DME service volume

Sorting/Categorization



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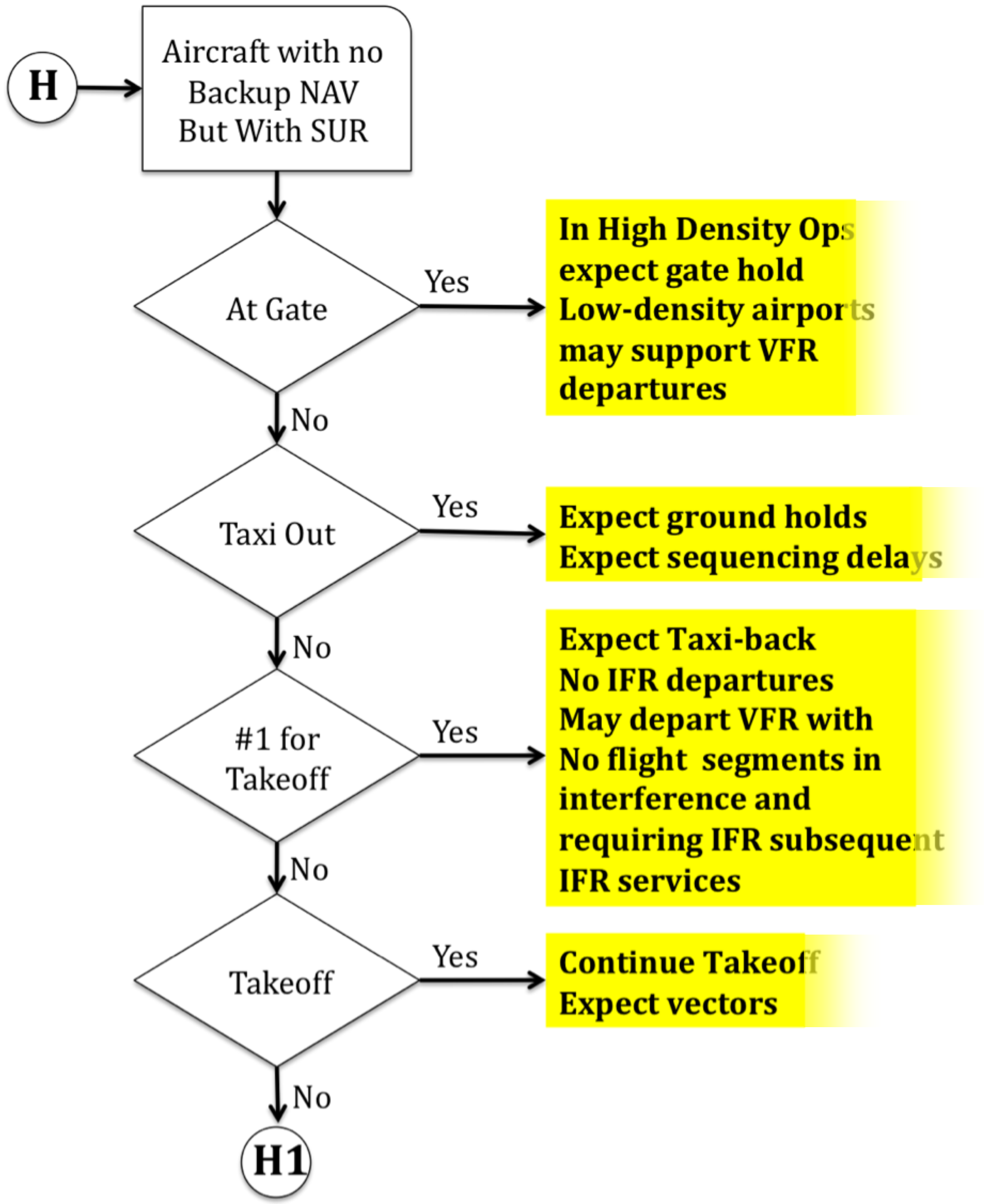
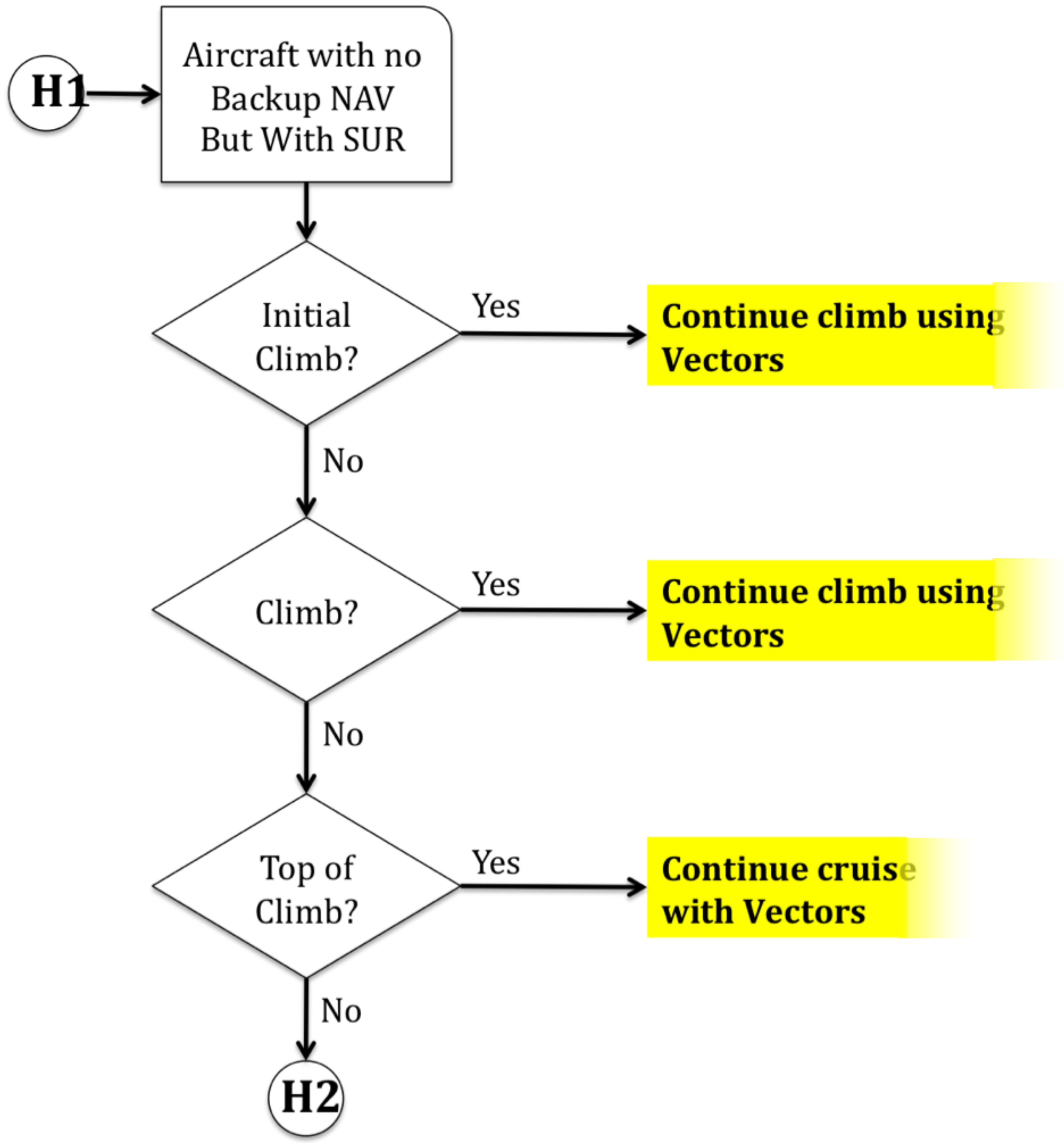
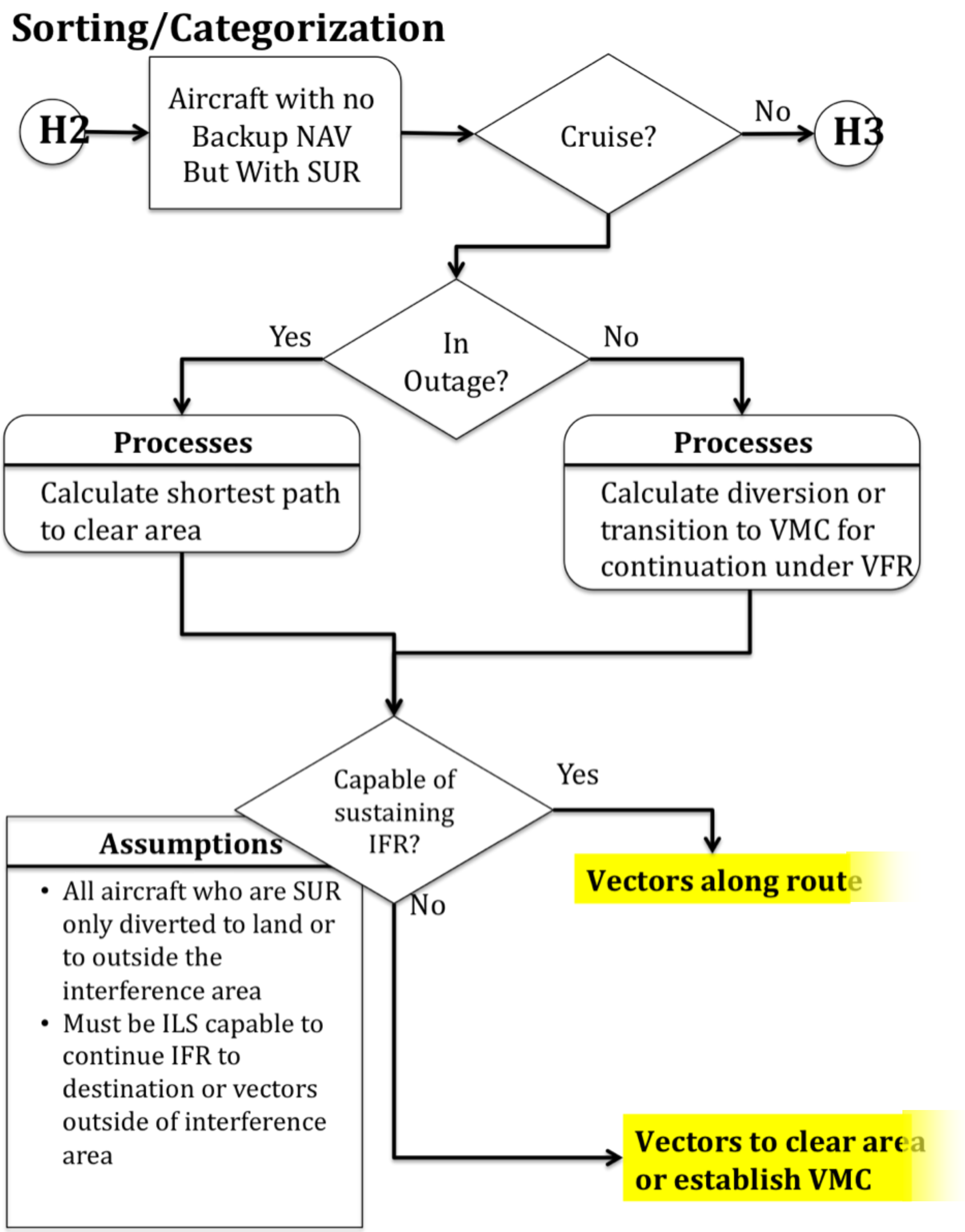
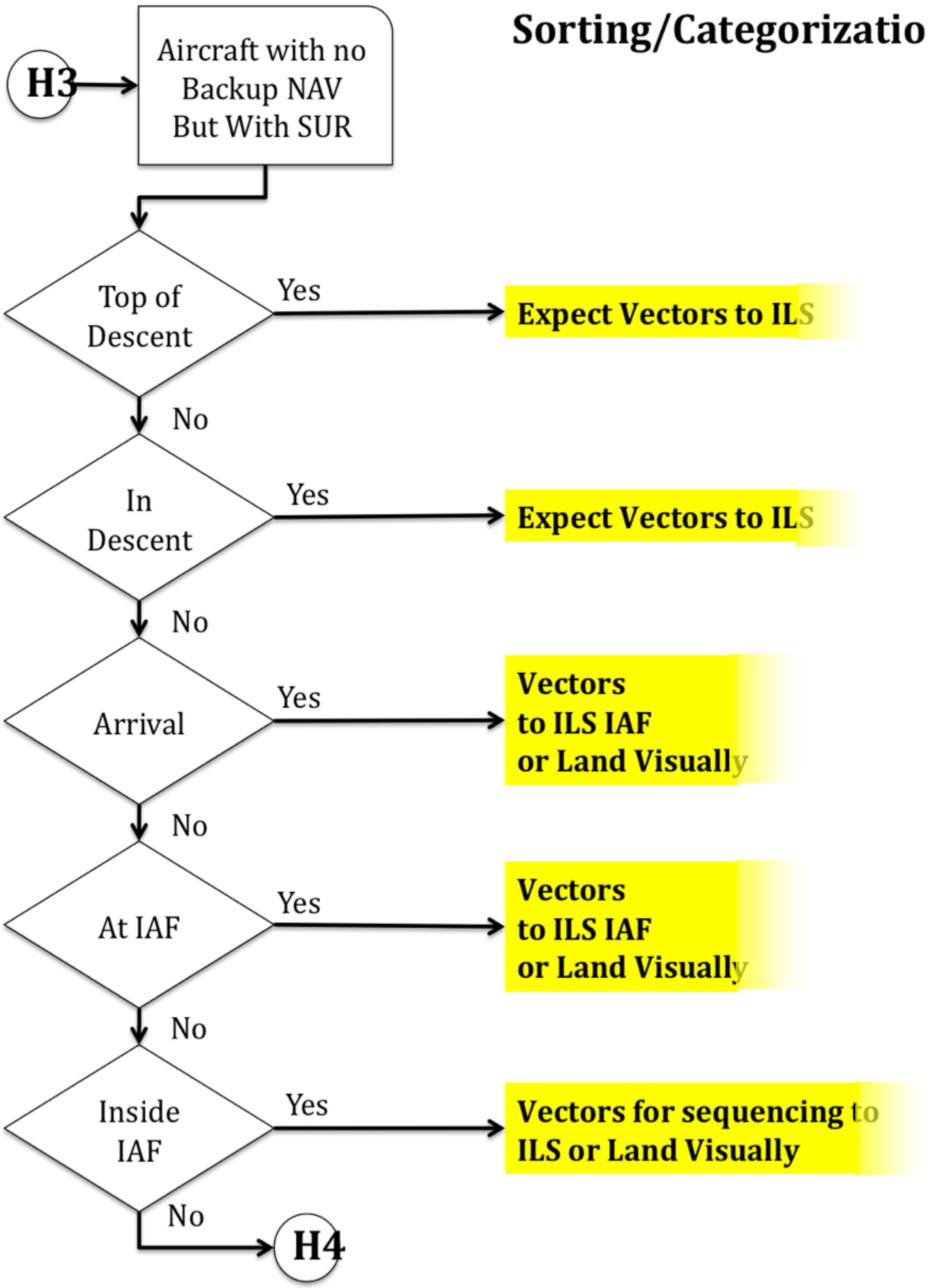


Sorting/Categorization

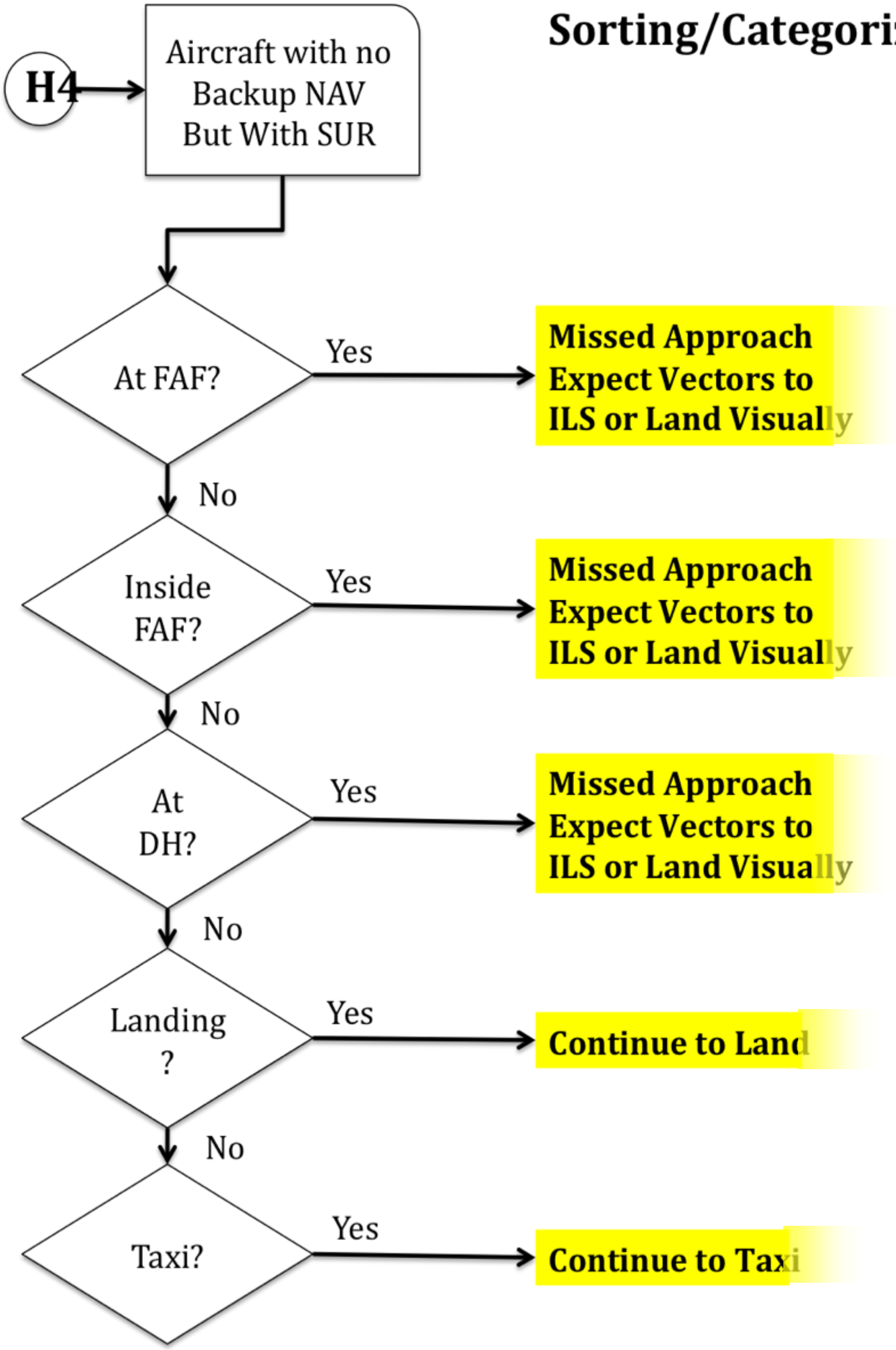



Sorting/Categorization
H2
Aircraft with no Backup NAV But With SUR
Cruise?
No
H3
Yes
In Outage?
No
Processes
Calculate shortest path to clear area
Processes
Calculate diversion or transition to VMC for continuation under VFR
Capable of sustaining IFR?
Yes
Vectors along route
No
Assumptions
• All aircraft who are SUR only diverted to land or to outside the interference area
• Must be ILS capable to continue IFR to destination or vectors outside of interference area
Vectors to clear area or establish VMC

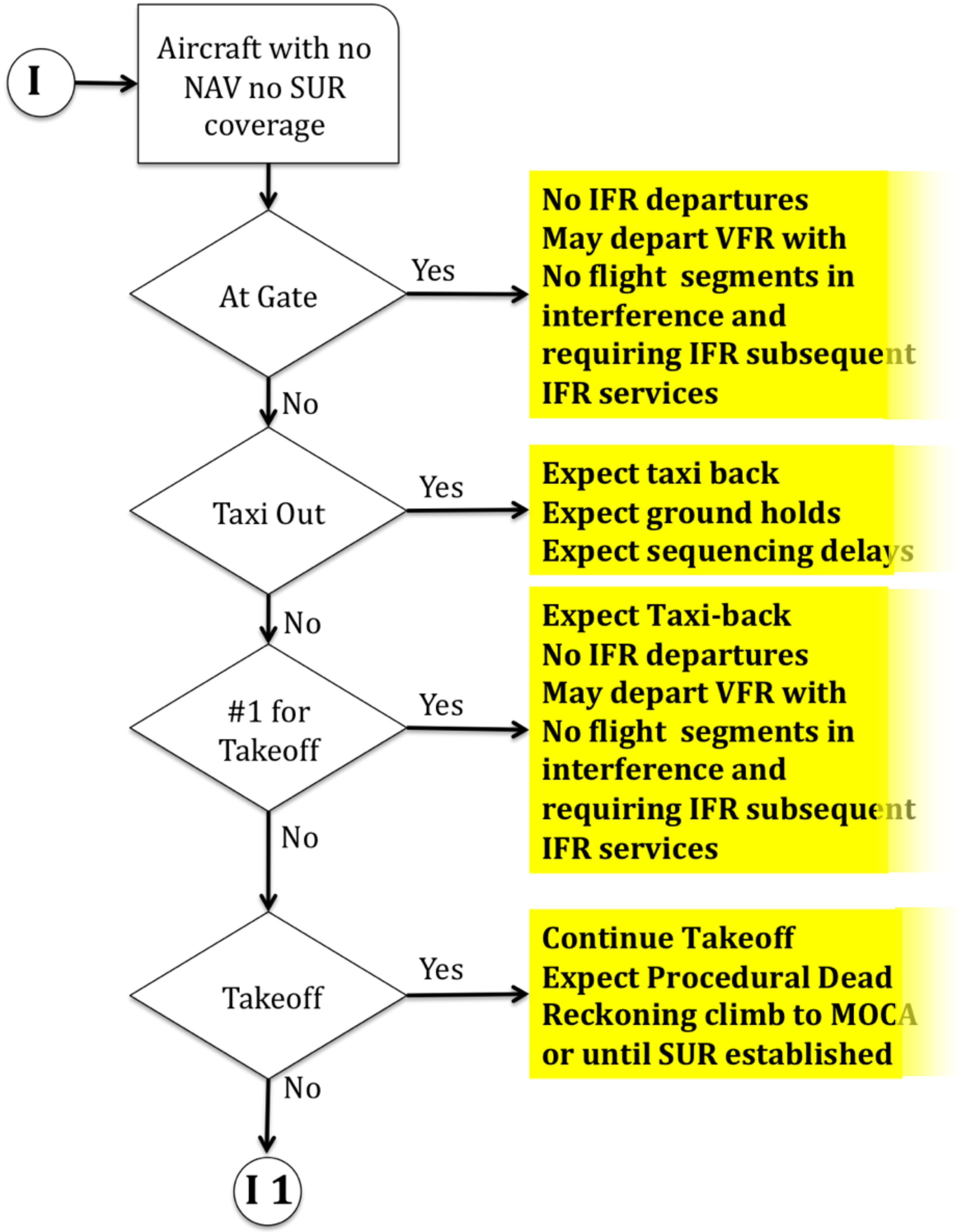
Sorting/Categorization



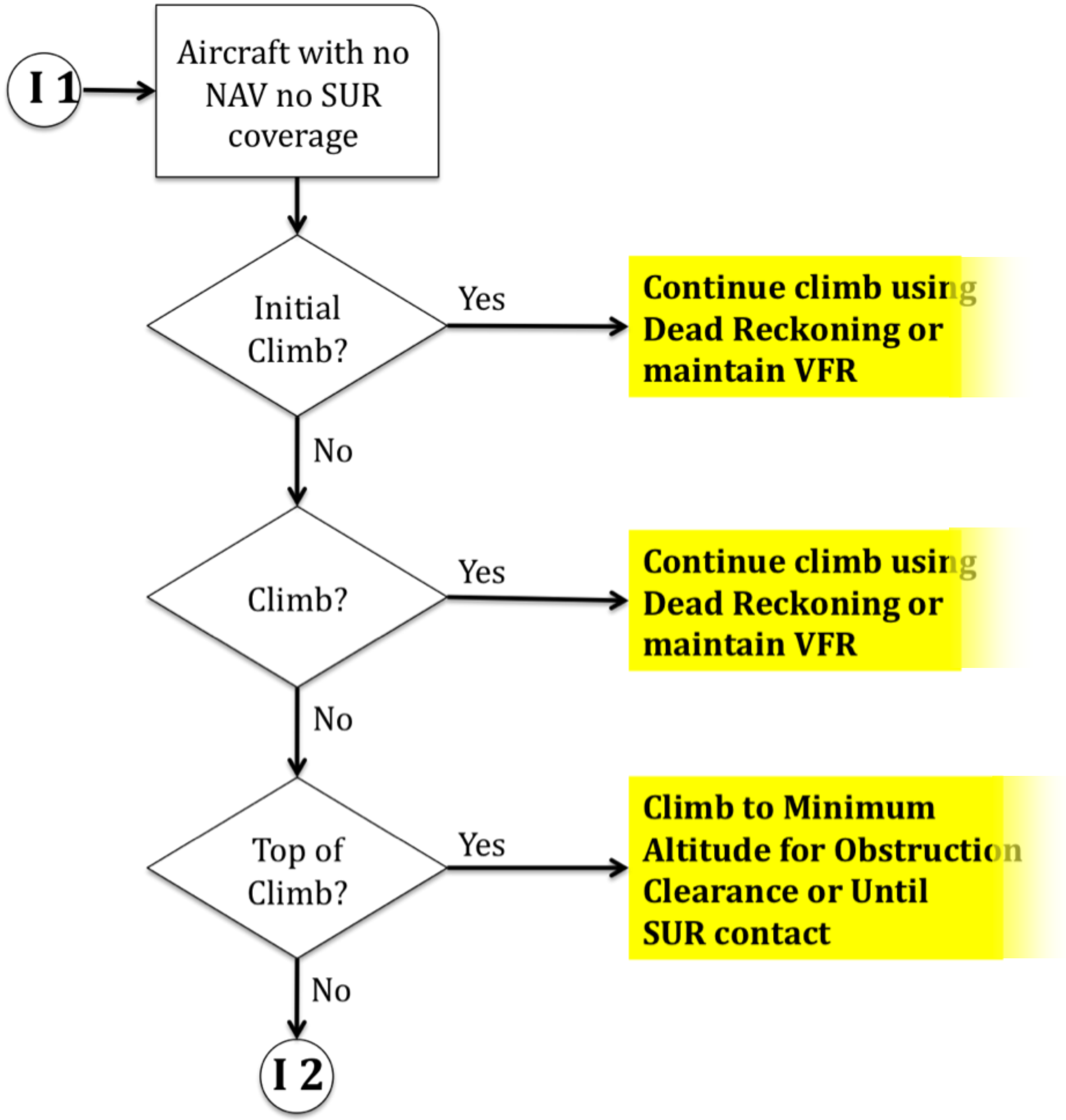
Sorting/Categorization

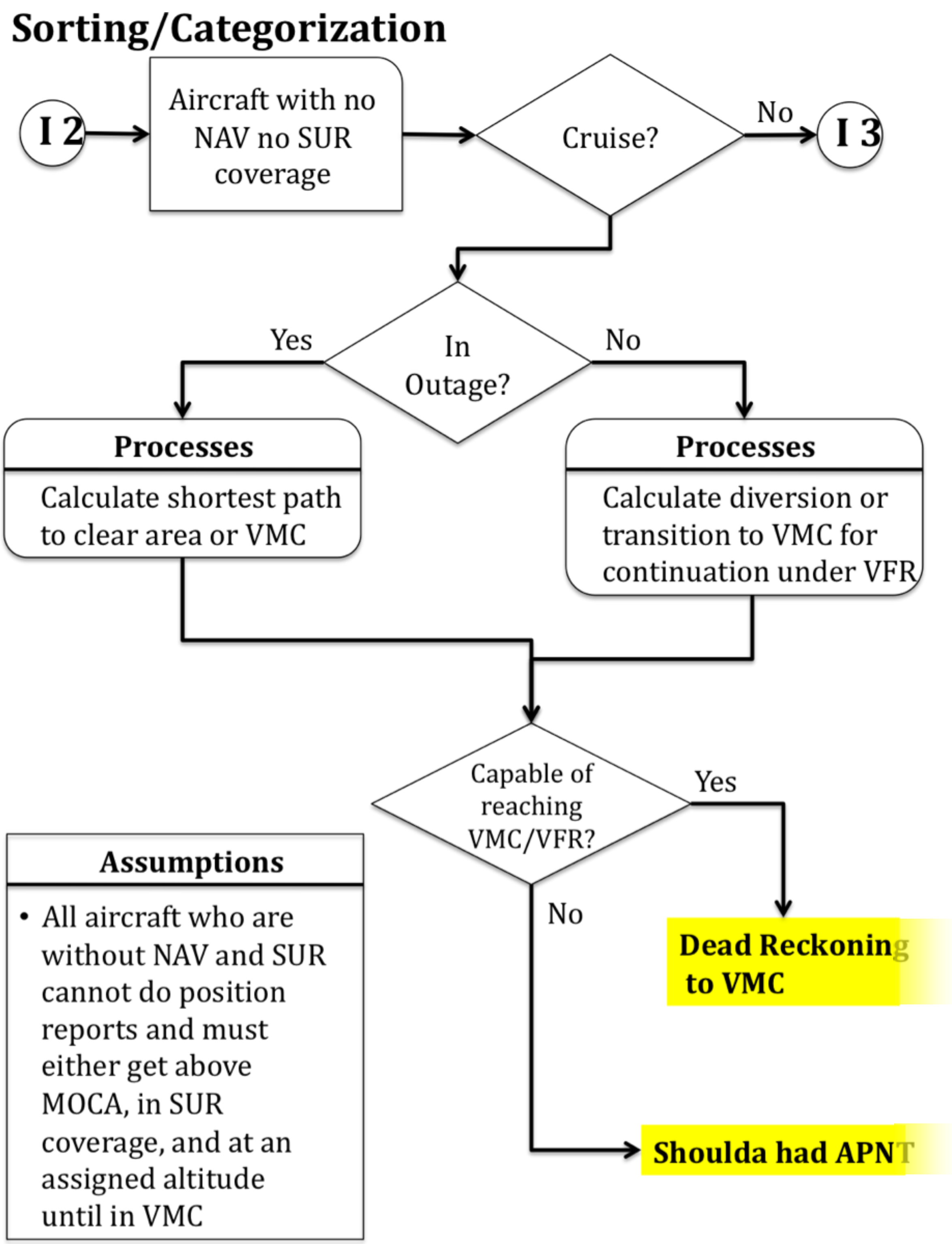


Sorting/Categorization



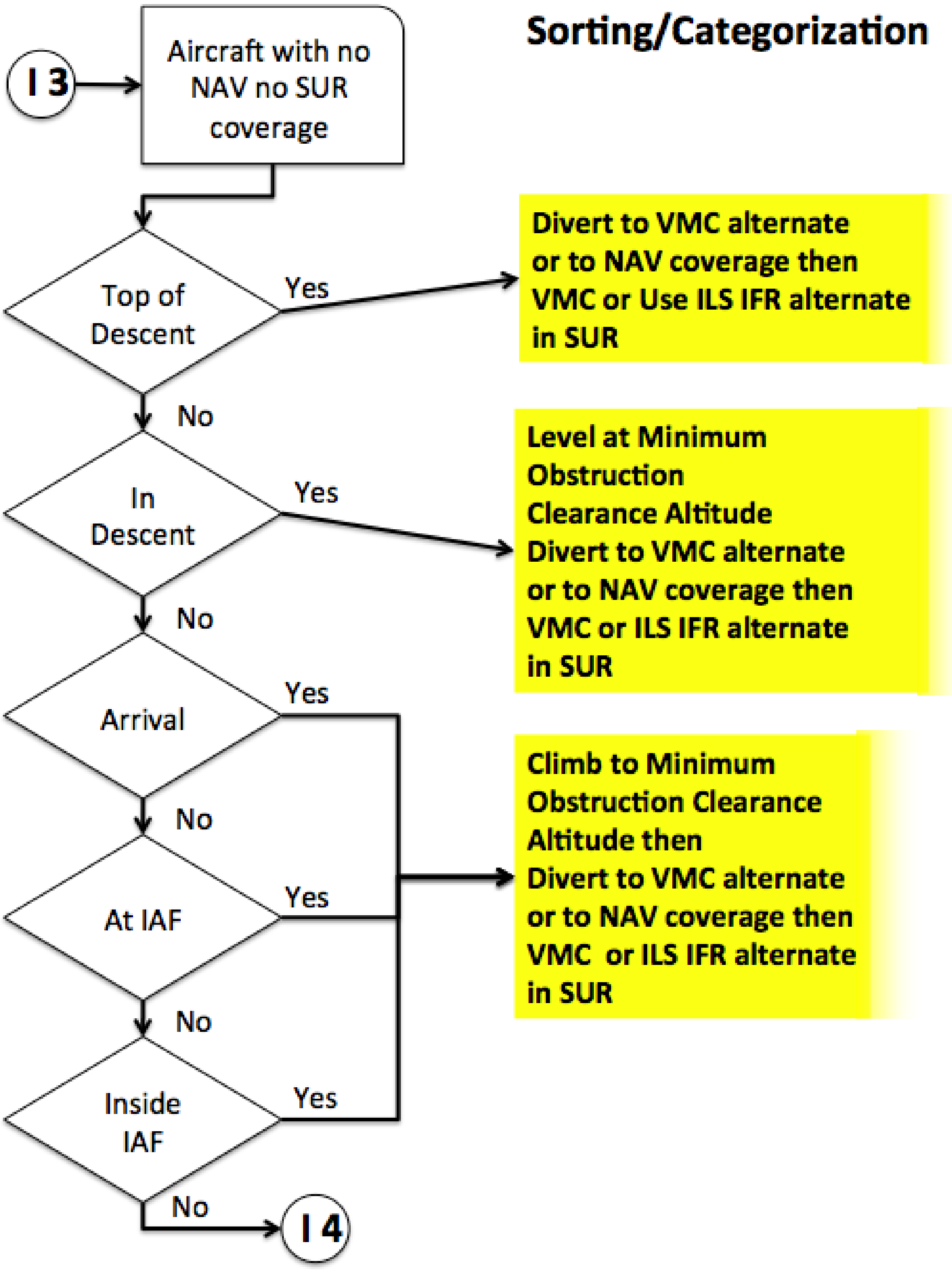
Sorting/Categorization



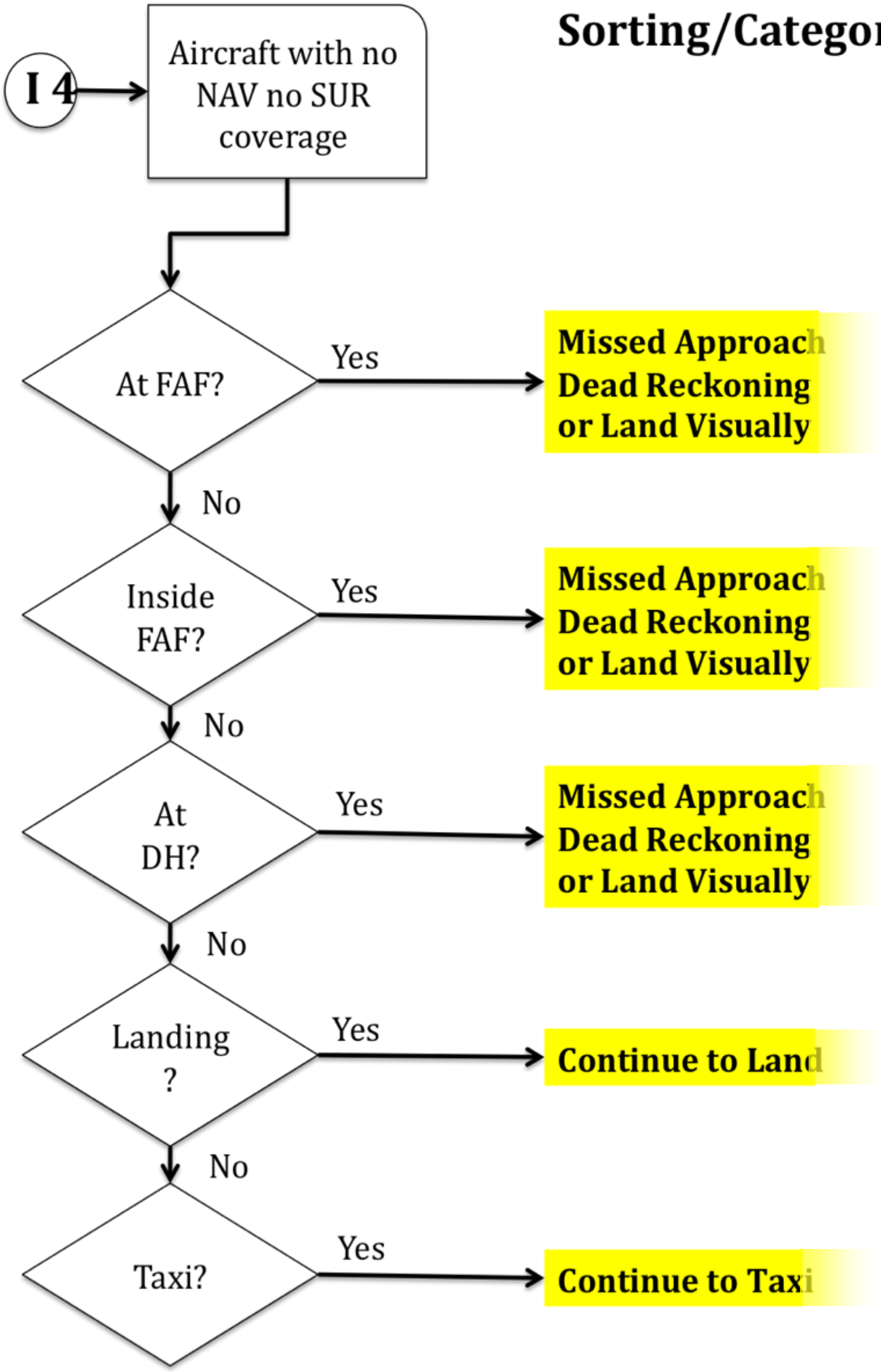


Sorting/Categorization
I 2
Aircraft with no NAV no SUR coverage
Cruise?
No
I 3
In Outage?
Yes
No
Processes
Calculate shortest path to clear area or VMC
Processes
Calculate diversion or transition to VMC for continuation under VFR
Capable of reaching VMC/VFR?
Yes
No
Dead Reckoning to VMC
Shoulda had APNT
Assumptions
• All aircraft who are without NAV and SUR cannot do position reports and must either get above MOCA, in SUR coverage, and at an assigned altitude until in VMC

Sorting/Categorization



Sorting/Categorization



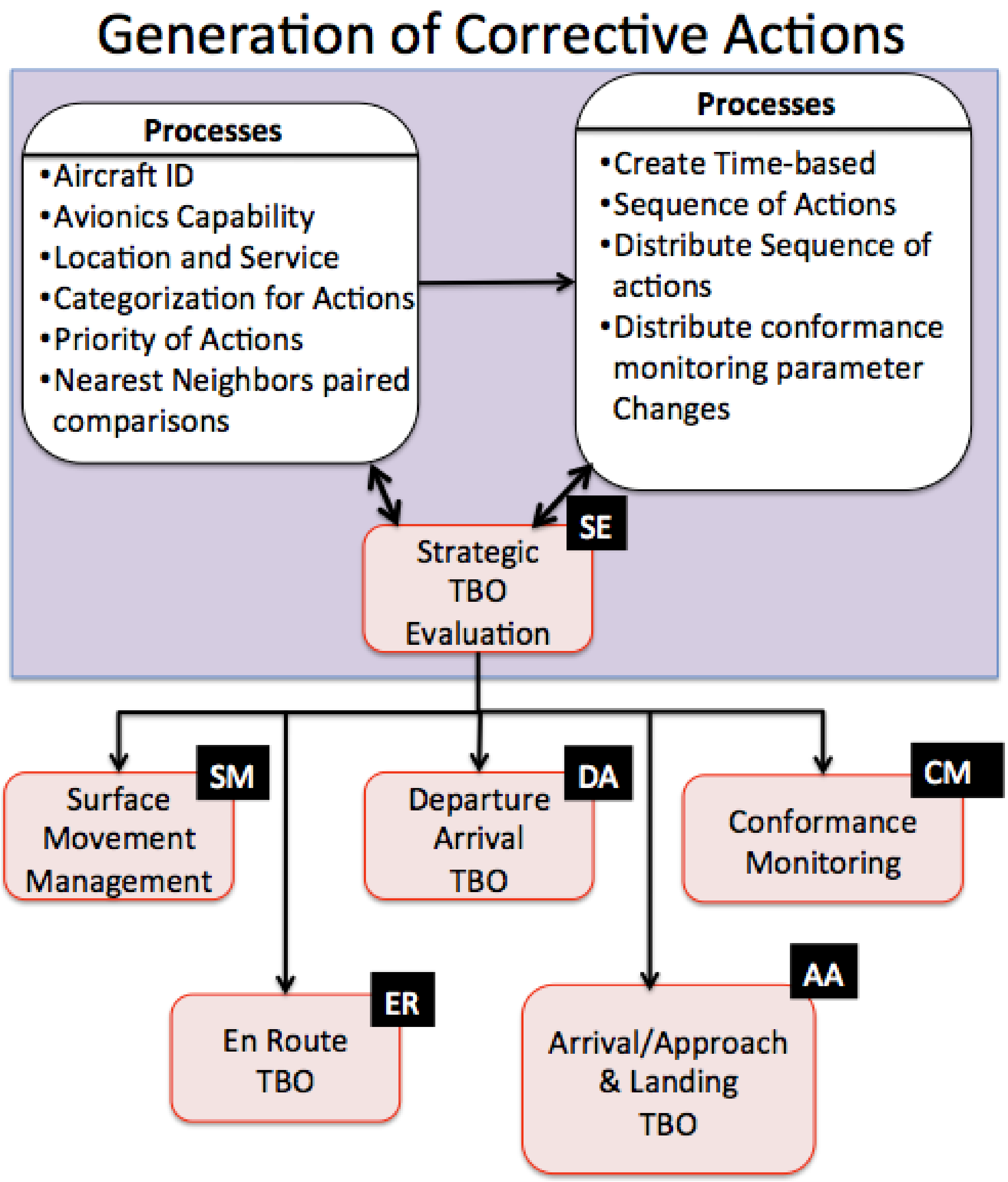
Automation Actions to Resolve GNSS Outages

At the moment of interference, the NIC-NAC-SIL detected within the surveillance data network show multiple aircraft with outages. This condition triggers development of a sequence of corrective actions that are time-based for implementation. The Strategic TBO Evaluation Services posts corrective actions to the air traffic controller's interface and can generate bulk data messages.

With significantly greater traffic volume in NextGen, automation performs the sequencing and separation activities.

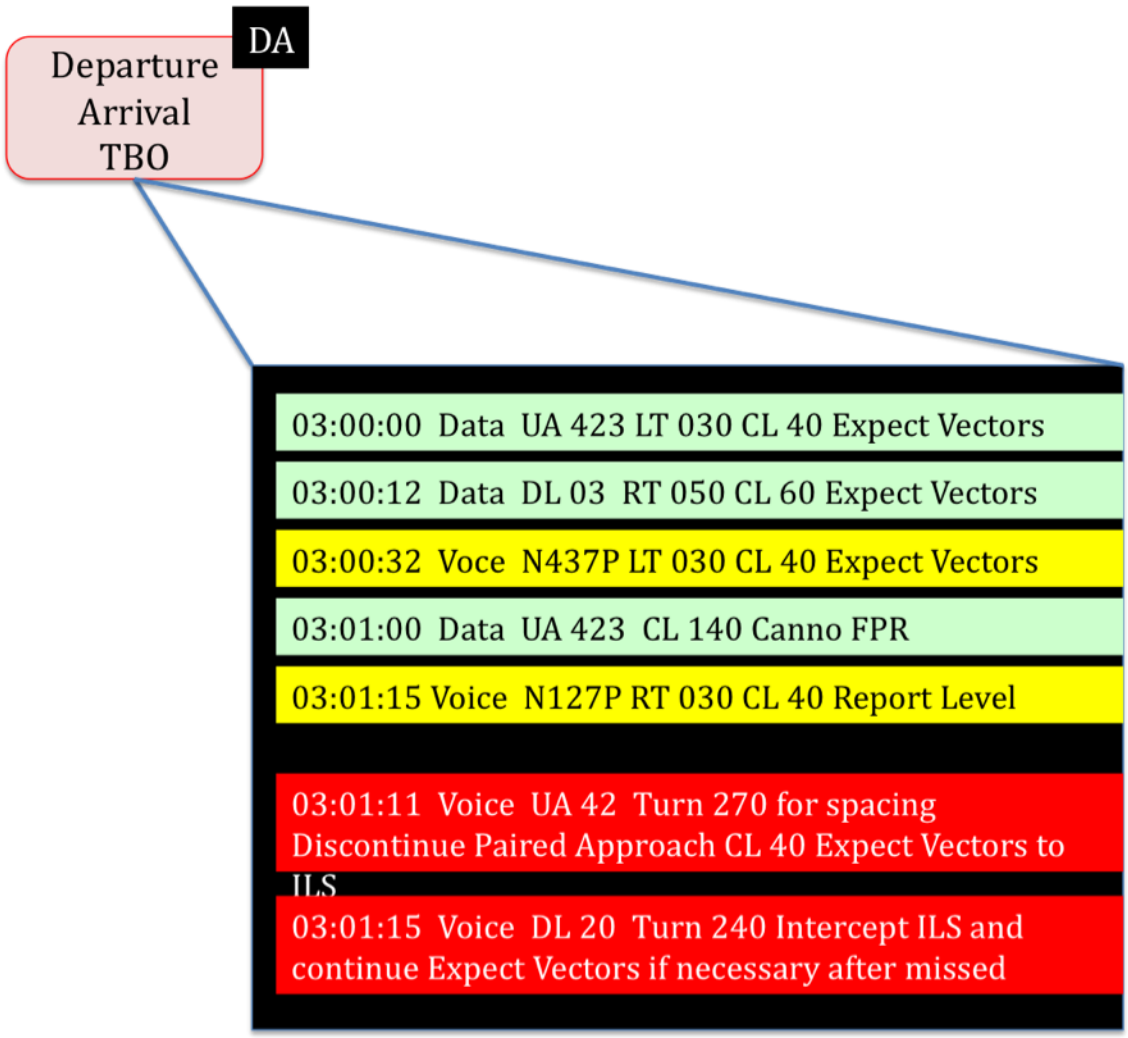
Prioritization for Handling Aircraft

- Aircraft inside final approach fix
- Discontinuance of ADS-B (In) applications to diverge traffic
- No NAV outside of SUR coverage
- Aircraft on Takeoff with No NAV inside of SUR coverage
- No NAV inside of SUR coverage approaching a turning waypoint
- Vectors to ILS for aircraft on arrivals
- Vectors on course for departures without NAV
- Vectors to establish 5-mile separation
- Clearances to increase oceanic separation distances
- Balance of actions are time-dependent conflict resolution – most handled strategically



Generation of Corrective Actions
Processes
•Aircraft ID
•Avionics Capability
•Location and Service
•Categorization for Actions
•Priority of Actions
•Nearest Neighbors paired comparisons
Processes
•Create Time-based
•Sequence of Actions
•Distribute Sequence of actions
•Distribute conformance monitoring parameter Changes
Strategic TBO Evaluation
SE
Surface Movement Management
SM
Departure Arrival TBO
DA
Conformance Monitoring
CM
En Route TBO
ER
Arrival/Approach & Landing TBO
AA

Representative Implementation



Green is automatic data message

Yellow is a voice message (synthesized or actual)

Red is required separation message (Voice or data)

Appendix D Scenario Aircraft Equipage

Sunset Air 42 and 20

Type: Boeing 737-1000

Manufacture: 2019

Avionics:

Dual Analog Voice

Dual Digital Data Links

FMS – NextGen capable with 4DT and Single RTA

Dual Inertial Reference Unit

Autothrottles and autoland

Conflict Detection and Resolution package capable of self-separation, merging and spacing

ILS (Cat II/III)

VOR

DME-DME

GNSS with SBAS and GBAS, RAIM

Dual Transponder

Dual TCAS

Electronic Flight Bag and field of view Guidance Display with surface moving maps

1090 ADS-B In

RNAV RNP 0.11 capable

Dual Enhanced Vision with Heads Up Displays

Weather Radar

West Air 134

Type: Boeing 737-800

Manufacture: 2015

Avionics:

Dual Analog Voice

Dual Digital Data Links

FMS – NextGen capable with 4DT and Single RTA

Dual Inertial Reference Unit

Auto throttles and auto land

Conflict Detection and Resolution package capable of self-separation, merging and spacing

ILS (Cat II/III)

VOR

DME-DME

GNSS with SBAS and GBAS, RAIM

Dual Transponder

Dual TCAS

Electronic Flight Bag and field of view Guidance Display with surface moving maps

1090 ADS-B In

RNAV RNP 0.11 capable

Dual Enhanced Vision with Heads Up displays

Weather Radar

Ariba 151

Type: Airbus A-320

Manufacture: 2001

Avionics:

Dual Analog Voice

Dual Digital Data Link

FMS

Inertial Reference Unit

ILS (Cat II/III)

VOR

DME-DME

GNSS with SBAS

Dual Transponder

Dual TCAS

Electronic Flight Bag with surface moving maps

1090 ADS-B Out

RNAV RNP 0.11 capable

N72MD

Type: Socata TBM 850 Turboprop

Manufacture: 2011

Avionics:

Dual Analog Voice

Dual Digital data link

Mode S Transponder with TAS

Dual GNSS with SBAS with RAIM

1090 ADS-B In with CDTI and TIS-B (no FIS-B)

Satellite delivered weather and flight information

Autopilot capable of 3D – no auto-throttle connectivity

Dual ILS (CAT I) with VOR

RNP 0.3 with radius to fix upgrade

Glass cockpit with Electronic Flight Bag functions including self-separation tools

Automated pilot assistant

N73842

Type: Cessna 172

Manufacture: 2008

Avionics: Garmin G1000 suite

Dual Analog Voice

Mode S Transponder

Dual GNSS with SBAS with RAIM

1090 ADS-B Out with CDTI and TIS-B (no FIS-B)

Satellite delivered weather and flight information

Autopilot capable of altitude and airspeed

Dual ILS (CAT I) with VOR

RNP 0.3 with radius to fix upgrade

Glass cockpit with Multifunction Display

Appendix E – List of Acronyms

2 D	Two-Dimensional
3 D	Three-Dimensional
3DT	Three-Dimensional Trajectory (surface operations)
4-D	Four-Dimensional
4DT	Four-Dimensional Trajectory
ADS-B	Automated Dependent Surveillance – Broadcast
ANSP	Air Navigation Service Provider
AOC	Airline Operational Control
APNT	Alternative Positioning, Navigation and Timing
ASDE-X	Airport Surface Detection Equipment – Model X
ATM	Air Traffic Management
CATM	Collaborative Air Traffic Management
CDA	Continuous Descent Arrival
CDR	Conflict Detection and Resolution
CFR	Code of Federal Regulations
CONOPS	Concept of Operations
CSPO	Closely-Spaced Parallel Operations
CTA	Controlled Time of Arrival
DME	Distance Measuring Equipment
DOT	Department of Transportation
EFB	Electronic Flight Bag
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FL	Flight Level
FMA	Friedman Memorial Airport, Hailey, Idaho
FMS	Flight Management System
GBAS	Ground-Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSPD	Homeland Security Presidential Directive
Hz	Hertz
I-CNS	Integrated Communications, Navigation and Surveillance
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRU	Inertial reference unit
JPDO	Joint Planning and Development Office
MIA	Miami International Airport
MOCA	Minimum Obstruction Clearance Altitude
MON	Minimum Operating Network
NAC	Navigation Accuracy Category
NAS	National Airspace System

NDB	Non-Directional Radio Beacon
NextGen	Next-Generation Air Transportation System
NGIP	NextGen Implementation Plan
NIC	Navigation Integrity Category
nm	Nautical Miles
OPC	Optimized Profile Climb
OPD	Optimized Profile Descent
OSED	Operational Systems Environment Description
PBN	Performance Based Navigation
PFD	Primary Flight Display
PHX	Phoenix International Airport (Sky Harbor)
PIREP	Pilot Report
PNT	Positioning, Navigation and Time
RA	Resolution Advisory
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTM	Required Time(s) of Merge
RTP	Required Time Performance
SAAAR	Special Aircraft and Aircrew Authorization Required
SAS	Single Authoritative Source
SBAS	Satellite-Based Augmentation System
SID	Standard Instrument Departure
SIL	Surveillance Integrity Level
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Route
TA	Tailored Arrival
TACAN	Tactical Air Navigation
TAS	Traffic Advisory System
TBO	Trajectory-Based Operations
TCAS	Traffic Collision Avoidance System
TRACON	Terminal Air Traffic Control Facility
UAS	Unmanned Aerial Systems
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Radio Range

Appendix F. 2018 to 2025 Operational Capabilities and Enablers

ID	Name	Planning IOC	Description	Enablers
OI-0343	Reduced Separation - High Density En Route, 3-mile	2019	Three-mile separation procedures are applied to new airspace based on Required Surveillance Performance (RSP). This assumes a homogeneous environment (e.g., 3-mile separation becomes the "default" in some airspace). In the future, this constraint may be eliminated through the use of advanced surveillance techniques or technologies, e.g., ADS-B, modern radar processing technologies and/or the use of appropriate RSP procedures and technologies. Expected use: high density integrated arrival/departure flows, and transition from En Route into high density terminal airspace.	
OI-0350	Flexible Routing	2019	Equipped aircraft are not restricted to pre-defined routes except when Air Navigation Service Provider (ANSP) requires more structure. Aircraft may execute a desired route using existing fixed waypoints or other route coordinates. Aircraft may change that route at any time within the confines of proper separation management and coordination of route changes with ANSP through data or voice communications. Air-ground data exchange mechanisms will maintain route awareness with relevant ANSP facilities. The ANSP uses ground-based decision support tools (e.g., conflict probe) to maintain separation of aircraft flying on flexible routes. Structure is imposed as needed for congestion management. This supports the ability for operators to fly wherever desired;	EN-1210: Air - Ground Data Exchange - Clearance and Instructions Services - En Route Group 2(2018) EN-1224: Air - Ground Data Exchange – Flight Position Intent Services – Multi Domain(2018)

ID	Name	Planning IOC	Description	Enablers
			operators can file any route desired except where demand requires that structure be imposed.	
OI-0406	NAS Wide Sector Demand Prediction and Resource Planning	2019	National Airspace System (NAS) resource and Collaborative Decision Making (CDM) data are combined in one integrated decision support tool. Strategic management of resources (e.g., airspace, sectors, personnel, facilities, NAS systems) meet changes in systemic demand due to increases in air traffic, seasonality, or city pair business case decisions. Resources are proactively adjusted and assigned based on projections of shifting demand. The Air Navigation Service Provider (ANSP) and stakeholders use decision management systems to achieve consensus once NAS-wide modeling efforts are accomplished and analyzed. Strategic long-term planning with dynamic and flexible airspace and airports minimizes adverse impacts to users. Changes are modeled against various solutions to mitigate adverse impacts. Traffic management strategic change decision support tools model and	EN-0003: 4D Flight Plan Management Decision Support - Level 2 EN-0036:(2018) Airspace/Capacity/Flow Contingency Management Decision Support - Level 2 Limited (2018) EN-0037: Trajectory Management Decision Support - Level 2(2018) EN-2020: NextGen 4-D Weather Cube Information - Level 2 Adaptive Control/Enhanced Forecasts(2018)

ID	Name	Planning IOC	Description	Enablers
			analyze the effect of a change and develop trend analysis for validation of the planning process. Some of these tools are automated system-to-system while others require the human-centric collaborative decision process. ANSP is responsible for managing the NAS; the CDM process results in consensus among the stakeholders about proposed resolutions	
OI-0317	Near Zero Ceiling/Visibility Airport Access	2020	Near Zero Ceiling/Visibility Airport Access is available where needed through a combination of complementary airborne and ground functionality to aid the pilot in approach guidance and acquisition of the runway environment for safe operations. Near zero ceiling/visibility approaches are available for all suitably equipped users through a combination of complementary airborne and ground equipage. Implementation may involve on-board synthetic and enhanced vision systems, and Ground-Based Augmentation Systems (GBAS), and low-cost runway/taxiway lighting.	EN-2020: NextGen 4D Weather Cube Information - Level 2 Adaptive Control/Enhanced Forecasts (2018)

ID	**Name**	**Planning IOC**	**Description**	**Enablers**
OI-0341	Limited Simultaneous Runway Occupancy	2020	Runway capacity is increased through the allowance of multiple aircraft on the runway for specific situations. Expected use: One aircraft can land while another one is exiting to a taxiway, one aircraft can enter the runway while another aircraft is departing. This operation is routinely used by the military to enable expeditious movement of traffic but does require close cooperation and knowledge of the pilots involved with the operation. One way to enable this operation is by the use and transmission of precision surveillance, very accurate prediction and adherence to 4-Dimensional Trajectory (4DT) (air and ground) and easily accomplished escape procedures. This Operational Improvement requires a Policy Decision. This is highly controversial, but would be transformational and depending on how it is implemented could have a significant impact on runway capacity.	EN-0037: Trajectory Management Decision Support - Level 2(2018)
OI-0360	Automation-Assisted Trajectory Negotiation	2020	Trajectory management is enhanced by automated assistance to negotiate with properly equipped aircraft operators. Human Air Navigation Service Providers (ANSPs) are responsible for separation management, supported by automation. Four-Dimensional Trajectories (4DTs) are negotiated between the ground-based automation and the operator, which may be the pilot, a Unmanned Aircraft System (UAS) operator, or perhaps even Flight Operations Center (FOC) personnel, who would then relay information to the aircraft. This will enable higher density of operations thus higher capacity as well as decrease human errors in	EN-0017: Trajectory Negotiation - Level 3 Automation-Assisted 4DTs(2018) EN-0038: Separation Management Decision Support - Level 2(2018) EN-1210: Air - Ground Data Exchange - Clearance and Instructions Services - En Route Group 2(2018)

ID	Name	Planning IOC	Description	Enablers
			trajectory negotiation and entry.	
OI-0403	Wake Turbulence Mitigation: Arrivals - Dynamic Wind Procedures	2020	Arrival spacing and separation rules are dynamically adjusted to accommodate wake drift and decay. Longitudinal departure spacing is dynamically adjusted based on ground-based wind measurements, aircraft type and algorithms to predict wake drift and decay. Dynamic adjustments are made when favorable wind conditions are forecast to persist for perhaps a half hour or more. Controller automation is enhanced to provide controllers with dynamic spacing and separation information that may include a larger matrix of separation standards than the current 4x4 matrix, with more specific pair-wise spacing requirements within and between aircraft types.	EN-2020: NextGen 4-D Weather Cube Information - Level 2 Adaptive Control/Enhanced Forecasts (2018)

ID	Name	Planning IOC	Description	Enablers
OI-0410	Automated Virtual Towers	2020	At non-towered, multiple-runway airports and small airports in metroplex environments, Automated Virtual Towers (AVTs) increase Instrument Meteorological Conditions (IMC) throughput and provide basic Visual Flight Rule (VFR) services. AVTs operate autonomously with separation functions (terrain, obstructions, aircraft, wake turbulence, etc.) provided either by ground automation or through aircraft-based conflict detection/resolution algorithms. Benefits can be realized not only in the areas of capacity and Air Navigation Service Provider (ANSP) productivity, but also cost avoidance for not building towers. Once AVTs are developed for IMC operations, they can also provide basic Visual Meteorological Conditions (VMC) safety benefits for traffic operating at non-towered airports	
OI-3106	Increased International Cooperation for Aviation Safety	2020	The development and implementation of safer practices and safer systems is encouraged worldwide through international participation. Specifically, increased participation in international aviation is encouraged, as is the development of international aviation development partnerships. Provide support for the execution of the International Civil Aviation Organization (ICAO) Global Aviation Safety Roadmap and the associated implementation plan.	

ID	Name	Planning IOC	Description	Enablers
OI-3107	Improved Safety Across Air Transportation System Boundaries	2020	The safety of inter-modal and international operations is improved by harmonization of standards, regulations and procedures, and improvements in their implementation. The safety of dangerous goods handling for air transportation is improved through inter-modal and international harmonization of standards.	
OI-3108	Improved SMS Standards and Effectiveness	2020	Following implementation of the National Safety Management System (SMS) Standard by the Joint Planning and Development Office (JPDO) members and the organizations they oversee, continuous improvement of the processes, tools, and procedures associated with safety management is undertaken to ensure that safety is also continuously improved.	EN-3101: Safety Policy Effectiveness (2018) EN-3102: Safety Risk Management Processes and Tools(2018) EN-3103: Safety Assurance Processes and Tools(2018) EN-3104: Safety Promotion Practices(2018)
OI-3109	Increased Safety Information Sharing and Analysis Scope and Effectiveness	2020	Following the creation of the Aviation Safety Information Analysis and Sharing (ASIAS) environment and the integration of existing analytical tools within it, improvements will be made to the environment and the analytical capabilities. Expansion of the ASIAS environment to include additional data sources, combined with action that improve data security, quality, and scope will provide continuous improvement of the ASIAS environment. Improvements in the analytical techniques and tools used to extract information from the various data sources will continuously improve the understanding of the data and its	EN-3103: Safety Assurance Processes and Tools (2018) EN-3106: Increase Confidence in Analytical Results(2018)

ID	Name	Planning IOC	Description	Enablers
			implications.	
OI-5002	Improved Strategic Management of Existing Infrastructure (Airside)	2020		
OI-5003	Improved Strategic Management of Existing Infrastructure (Landside)	2020		
OI-5110	Advanced Winter Weather Operations - Level 2	2020	During winter weather, aircraft and airport movement surfaces are anti-iced/deiced more efficiently through resource management and new ground-based technology. Deicing/anti-icing fluids and methods are more effective with less environmental impact. Collection methods capture spent fluids for recycling.	EN-5016: Ice-Resistant Pavement Surfaces (2018) EN-5020: Advanced De-Icing/Anti-Ice Fluids (2018) EN-5217: Airport Winter Operations Resource Management System - Level 2 (2018)
OI-6021	Environmentally and Energy Favorable Terminal Operations - Level 2	2020		

ID	Name	Planning IOC	Description	Enablers
OI-6022	Environmentally and Energy Favorable En Route Operations - Level 2	2020		
OI-4107	Improved Passenger Checkpoint Screening - Level 2	2021		
OI-4521	Integrated Command/Control for Security Incident Response and Recovery	2021		
OI-6023	Implement NextGen Environmental Engine and Aircraft Technologies - Level 2	2021	Further enable reductions in aircraft noise, emissions, and fuel consumption by incorporating Next-Generation improvements in aircraft engine and airframe technologies, alternative fuels, and national airspace system infrastructure optimization.	
OI-0339	Integrated Arrival/Departure and Surface Traffic Management for Metroplex	2022	Metroplex traffic flow is more effectively managed through terminal area and surface scheduling automation for increased regional capacity. Metroplex planners at major terminal areas optimize arrival/departure and surface scheduling for increased regional capacity. Trajectory-based operations is a key element of super-density procedures, allowing the Air Navigation Service Provider (ANSP) to maximize access for all traffic, while adhering to the principle of giving advantage to those aircraft with advanced capabilities that support the air traffic management system. Metroplex trajectory management assigns each arriving aircraft to an	EN-0009: Integrated Trajectory/Separation Management – Terminal (2022)

ID	Name	Planning IOC	Description	Enablers
			appropriate runway, arrival stream, and place in sequence.	
OI-0359	Self-Separation Airspace - Oceanic	2022	Oceanic user efficiency and Air Navigation Service Provider (ANSP) productivity are improved through self-separation operations in designated oceanic airspace for capable aircraft. Aircraft-to-aircraft separation is delegated to the flight deck in designated airspace, such as on designated oceanic tracks, for capable aircraft with Automatic Dependent Surveillance-Broadcast (ADS-B) and onboard conflict detection and alerting.	

ID	Name	Planning IOC	Description	Enablers
OI-0362	Self-Separation Airspace Operations	2022	In self-separation airspace, capable aircraft are responsible for separating themselves from one another, and the Air Navigation Service Provider (ANSP) provides no separation services, enabling preferred operator routing with increased ANSP productivity. Research will determine whether the ANSP will provide any traffic flow management services within self-separation airspace. Aircraft must meet equipage requirements to enter self-separation airspace, including transmission of trajectory intent information through cooperative surveillance. Transition into self-separation airspace includes an explicit hand-off and acceptance of separation responsibility by the aircraft. Transition into ANSP-managed airspace is facilitated through assigned waypoints with Controlled Time of Arrivals (CTAs), allowing the ANSP to sequence and schedule entry into congested airspace, and self-separating aircraft are responsible for meeting assigned CTAs. Self-separating aircraft execute standardized algorithms to detect and provide resolutions to conflicts. Right-of-way rules determine which aircraft should maneuver to maintain separation when a conflict is predicted. Contingency procedures ensure safe separation in the event of failures and operational errors.	EN-1504: Cooperative Surveillance - ADS-B IN/TIS-B/FIS-B Level 3(2020)EN-0032: Avionics - Airborne Self-Separation (2022)EN-1208: Air - Ground Data Exchange – Clearance and Instruction Services – Tower Group 3(2022)EN-1211: Air - Ground Data Exchange - Clearance and Instructions Services - En Route Group 3(2022)EN-1214: Air - Ground Data Exchange – Clearance and Instructions Services – TRACON Group 3(2022)EN-1225: Air - Ground Data Exchange – Delegated Separation Services – Multi Domain(2022)

ID	Name	Planning IOC	Description	Enablers
OI-2022	Net-Enabled Common Weather Information - Level 3 Full NextGen	2022	This improvement provides the full capability that supports the NextGen concept of operations to assimilate weather in decision-making for all area of operations and completes the replacement of today's patchwork of conflicting sources of weather observations and forecasts. The information will be provided at the correct accuracy, resolution, update frequency, geographic scale, etc., required to enact the end-state NextGen concept of operation. This final level includes the use of unmanned aerial vehicles used as observation platforms and more advanced predictive model improvements.	EN-2030: NextGen 4-D Weather Cube Information - Level 3 Full NextGen(2022)
OI-4202	Reduced Threat from Unauthorized Persons Entering Airport - Level 2 LEO Integration	2022		
OI-5008	Advanced Weather Capability for Airside Facilities	2022	Airside facilities are open during severe weather conditions. Technology, systems, and procedures support airport operators in more effectively keeping airside facilities open and fully functional during severe conditions. This includes the proactive scheduling of maintenance and weather-response activities such as clearing runways of snow and ice. During thunderstorms, ramp closures due to lightning occur less frequently and have a shorter duration with weather forecasts, lightning detection, and/or lightning deflection. Delays and congestion that occur due to inclement weather and non-nominal airfield conditions are reduced.	EN-5209: Airside Resource Management System - Level 2(2020) EN-2682: Methodologies and Algorithms for Weather Assimilation into Decision-Making - Level 3(2021) EN-2030: NextGen 4-D Weather Cube Information - Level 3 Full NextGen(2022)

ID	Name	Planning IOC	Description	Enablers
OI-0365	Advanced Management of Airspace for Special Use	2023	Access to airspace is enhanced through more advanced automated real-time scheduling and dynamic status updates of Temporary Flight Restrictions (TFR) and SUA. This facilitates daily negotiations between the Air Navigation Service Provider (ANSP) and military operators to determine an effective strategy that meets military operational requirements while minimizing the impact on traffic flows. Military operators may release Special Use Airspace (SUA) to the ANSP and or agree to adjust boundaries or the time of use to accommodate other users, thereby optimizing the use of airspace resources whenever the airspace is not required to satisfy military airspace requirements/operations. These negotiations and active management will allow the military and the ANSP to update schedules and provide dynamic availability of the airspace for other users. The philosophy for airspace restrictions is to provide the maximum available airspace to all users at all times, meet national security needs via priority 4DT reservations, and facilitate immediate user notification of real-time requests for restricted or SUA. Airspace boundaries may still be chosen from a set of fixed configurations, or it may be adjusted dynamically.	EN-2682: Methodologies and Algorithms for Weather Assimilation into Decision-Making - Level 3(2021)EN-0180: Airspace/Capacity/Flow Contingency Management Decision Support - Level 3 Dynamic (2022)EN-2030: NextGen 4-D Weather Cube Information - Level 3 Full NextGen (2022)

ID	Name	Planning IOC	Description	Enablers
OI-0366	Dynamic Airspace Reclassification	2023	Airspace is dynamically reclassified to meet demand requirements and minimize impacts of adverse weather. Reclassification is executed by providing real-time airspace classification to users during preflight and airborne operations. Temporary Flight Restrictions (TFR) and Special Use Airspace (SUA) when not required by the military are factored into the dynamic reclassification process. An example of reclassification is changing the designation of airspace from "Classic" to "Trajectory-Based Operations (TBO)" for a particular time period. Aircraft will be required to achieve the appropriate level of navigation performance. This may be a routinely scheduled change or it may be made dynamically in response to forecast demand. This would require the development of rules and operational procedures for reclassification as well as the preconfigured airspace classifications. This Operational Improvement affects flight planning, and may affect aircraft already airborne.	EN-2682: Methodologies and Algorithms for Weather Assimilation into Decision-Making - Level 3(2021) EN-0180: Airspace/Capacity/Flow Contingency Management Decision Support - Level 3 Dynamic (2022) EN-2030: NextGen 4-D Weather Cube Information - Level 3 Full NextGen (2022)

ID	Name	Planning IOC	Description	Enablers
OI-0368	Flow Corridors - Level 2 Dynamic	2024	High density En Route dynamic flow corridors accommodate aircraft that are capable of self-separation traveling on similar wind-efficient routes or through airspace restricted by convective weather cells, Special Use Airspace (SUA), or overall congestion. Dynamic high-density flow corridors are defined daily and shifted throughout the flight day to avoid severe weather regions and airspace restrictions (e.g., SUA) or take advantage of favorable winds. Dynamic corridor entry and exit points are also defined. This extends static flow corridor technology (see OI-0361) via dynamic airspace design capabilities to provide more En Route capacity to trajectory-based aircraft when the available airspace is restricted. Real-time information on corridor location, and logistics and procedures for dynamically relocating a corridor while it is in effect must be developed. If corridor use is to be widespread, techniques for merging, diverging, and crossing corridors may also be required. Implementation decision required to determine if this is feasible and cost effective.	EN-2682: Methodologies and Algorithms for Weather Assimilation into Decision-Making - Level 3(2021)EN-0180: Airspace/Capacity/Flow Contingency Management Decision Support - Level 3 Dynamic (2022)EN-2030: NextGen 4-D Weather Cube Information - Level 3 Full

ID	Name	Planning IOC	Description	Enablers
OI-0369	Automated Negotiation/Separation Management	2024	Trajectory management is enhanced by automated negotiation of Four-Dimensional Trajectories (4DTs) between properly equipped aircraft and ground automation for separation management. All aircraft in Trajectory-Based Operations (TBO) airspace must be equipped for this function. The ANSP Separation Management function is fully automated, and separation responsibility is delegated to automation. For specified operations, tasks are delegated to the flight crew to take advantage of aircraft capabilities. To manage separation, Air Navigation Service Provider (ANSP) automation negotiates short-term, conflict-driven updates to the 4DT agreements with the aircraft. This will enable higher density of operations thus higher capacity as well as a decrease in human errors in trajectory negotiation and entry. This Operational Improvement requires a Policy/Implementation Decision to determine appropriate roles/responsibilities allocated between humans/automation and air/ground.	EN-0018: Trajectory Negotiation - Level 4 Automated 4DTs(2020) EN-0032: Avionics - Airborne Self-Separation (2022)

ID	Name	Planning IOC	Description	Enablers
OI-0340	Near-Zero-Visibility Surface Operations	2025	Aircraft and ground vehicle movement on airports in near-zero/zero visibility conditions is guided by technology such as moving map displays, Cockpit Display of Traffic Information (CDTI), enhanced vision sensors, synthetic vision systems, Automatic Dependent Surveillance-Broadcast (ADS-B) (for flight vehicles), and a Ground Support Equipment (GSE) Cooperative Surveillance System (CSS) (for ground vehicles). Requires all present aircraft and ground vehicles to have cooperative surveillance (i.e., ADS-B out). Cost/benefit analysis will determine visibility goal to support. Research issue/policy question: responsibility for all aspects of separation for operator vs. Air Navigation Service Provider (ANSP) and humans vs. automation	EN-2682: Methodologies and Algorithms for Weather Assimilation into Decision-Making - Level 3(2021) EN-2030: NextGen 4D Weather Cube Information - Level 3 Full NextGen (2022) EN-1512: Integrated Surveillance Information Service Level 4(2025)
OI-0348	Reduce Separation - High Density Terminal, Less Than 3-miles	2025	Metroplex airspace capacity is increased through implementing separation standards of less than 3 miles between high navigation precision arrival and departure routes. This Operational Improvement increases metroplex airspace capacity and supports super density airport operations by implementing separation standards for inter-aircraft separations of less than 3 miles. Arrival/departure routes with lower Required Navigation Performance (RNP) values (e.g., RNP<1 nm) are defined with less than 3 miles lateral separation between routes, subject to wake vortex constraints, enabling the use of more routes in a given airspace. This may require airborne lateral separation between routes. Enhanced Required Surveillance Performance (RSP) is required. This requires a Policy	EN-1208: Air - Ground Data Exchange – Clearance and Instruction Services – Tower Group 3(2022)EN-1214: Air - Ground Data Exchange – Clearance and Instructions Services – TRACON Group 3(2022)EN-1101: Enhanced NextGen PNT Services (2025)

ID	Name	Planning IOC	Description	Enablers
			Decision to determine what RNP values to require based on performance benefit versus equipage requirements and operational considerations. Expected use: high-density terminal and transition airspace.	
OI-0363	Delegated Separation - Complex Procedures	2025	In Air Navigation Service Provider (ANSP)-managed airspace, the ANSP delegates separation responsibilities to capable aircraft to improve operator routing, enhance operational efficiency, or increase ANSP productivity. This Operational Improvement involves more complex delegated separation responsibilities that may be supported in ANSP-managed En Route and transition airspace. After early concept exploration and feasibility research, an implementation decision will be made by 2015 to determine whether it is cost beneficial to develop additional delegated separation responsibilities in ANSP-managed airspace beyond those covered in OI-0356 taking advantage of advanced airborne technologies, such as conflict detection and alerting.	EN-0009: Integrated Trajectory/Separation Management – Terminal (2022) EN-0032: Avionics - Airborne Self-Separation(2022) EN-1225: Air - Ground Data Exchange – Delegated Separation Services – Multi Domain(2022)

ID	Name	Planning IOC	Description	Enablers
OI-0370	Trajectory-Based Management - Full Gate-To-Gate	2025	All aircraft operating in high-density airspace are managed by Four Dimensional Trajectory (4DT) in En Route climb, cruise, descent, and airport surface phases of the flight. This is the end state 4DT-based capability. This would require the ability to calculate, negotiate, and perform conformance monitoring by Air Navigation Service Providers (ANSPs) including the integration of separation assurance and traffic management time constraints (e.g., runway times of arrival, gate times of arrival). This will be enabled by the trajectory exchange through electronic data communications, as well as many new surface automation and 3D (x, y, and time) trajectory operations. In high-density or high-complexity airspace, precise 4DTs will be used, dramatically reducing the uncertainty of an aircraft's future flight path, in terms of predicted spatial position (latitude, longitude, and altitude) and times along points in its path. This enhances the capacity and throughput of the airspace to accommodate high levels of demand. In trajectory-based airspace, differing types of operations are conducted with performance-based services applied based on the anticipated traffic characteristics. User preferences are accommodated to the greatest extent possible, and trajectories are constrained only to the extent required to accommodate demand or other national concerns, such as security or safety.	EN-0018: Trajectory Negotiation - Level 4 Automated 4DTs(2020) EN-0180: Airspace/Capacity/Flow Contingency Management Decision Support - Level 3 Dynamic (2022)
OI-3103	Improved Safety of Operational Decision Making	2025		

ID	Name	Planning IOC	Description	Enablers
OI-3104	Enhanced Safety of Airborne Systems	2025	Safety requirements are integrated into the development and implementation of NextGen advancements for aircraft, to maintain or improve safety as changes are introduced. The reliability and airworthiness of aircraft is improved at the sub-system level; vehicle systems health management is improved at the sub-system and system level. The reliability and accuracy of operational information sourced from vehicle systems is improved. Aircraft conformance to more stringent operational requirements is improved, and aircraft system contributions to crash survivability are enhanced.	
OI-3105	Enhanced Safety of Ground-based Systems	2025		
OI-4502	Integrated Flight Risk Management and Risk Mitigation - Level 2 Dynamic	2025		
OI-4512	Improved Security Restricted Airspace Planning/Management - Level 3 Flight Risk	2025		
OI-5004	New Airside Airport Infrastructure	2025	New airside airport infrastructure is developed to support aviation growth in a safe, secure, efficient, and environmentally compatible/sustainable manner. Environmental sustainability goals include (1) providing environmental protection that supports and sustains aviation growth and (2) reducing environmental constraints on	EN-5032: Streamlined Airport Development Processes (2020)

ID	Name	Planning IOC	Description	Enablers
			adding airport capacity.	
OI-5005	New Landside Airport Infrastructure	2025	New landside airport infrastructure is developed to support aviation growth in a safe, secure, efficient, and environmentally compatible/sustainable manner. Environmental sustainability goals include (1) providing environmental protection that supports and sustains aviation growth, (2) reducing environmental constraints on adding airport capacity, and (3) incorporating mass transit and intermodal connections regionally in support of flight operations.	EN-5032: Streamlined Airport Development Processes (2020)
OI-5110	Advanced Winter Weather Operations - Level 3	2025	During winter weather, aircraft are anti-iced/deiced more efficiently through resource management systems. Icing holdover times are incorporated into 4DT in order to facilitate departure queuing and enhance safety. Clearing of airport movement surfaces of frozen precipitation is also enhanced through detailed weather information and improved utilization of airport equipment.	

Appendix G. Summary Table of Performance

	Precision-based Navigation, ADS-B Surveillance and Timing Performance In Support of Trajectory-based Operations							
	Navigation		**Surveillance**			**Positioning**		**Time Performance**
	($\geq$99.0% Availability)		($\geq$99.9% Availability)			GNSS PNT		RTP[1]
	Accuracy	Containment	Separation	NACp	NIC	(99.0 - 99.999%)		
Flight Operation	(95%)	(10^{-7})		(95%)	(10^{-7})			
Taxi-out	Visual	Visual	Visual	0.05 nm (8)[2]	0.6 nm (6)[2]	GNSS		(+/-) 1 minute
Low-vis (300-600 RVR)	1m	3m	1,200 feet[3]	121 m (8)	0.2 nm (7)	GNSS	GBAS	(+/-) 3 minutes[4]
Low-vis (<300 RVR)	1m	3m	1,200 feet	121 m (8)	0.2 nm (7)	GNSS	GBAS	(+/-) 3 minutes
Takeoff	Visual	Visual	Visual	0.05 nm (8)	0.6 nm (6)	GNSS		(+5/-15) minutes
High Density Airport	Visual	Visual	Visual	0.05 nm (8)	0.6 nm (6)	GNSS		(+/-) 1 minute
Low-vis (300-600 RVR)[5]	1m	3m	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS	GBAS	(+/-) 3 minutes[4]
Low-vis (<300 RVR)	1m	3m	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS	GBAS	(+/-) 3 minutes[4]
Climb to Cleanup[6]	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+/-) 1 minute
Departure/Climb	1 nm	2 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+5/-15) minutes
Top of Climb	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+5/-15) minutes
High Density Airspace	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+1/-5) minutes
Top of Climb	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+1/-5) minutes
Top of Climb (Merge)	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS		(+/-) 1 minute[7]
Cruise[8]	10 nm	20 nm	20 nm	0.1 nm (7)	1 nm (5)	GNSS		(+/-) 2-5 minutes
	4 nm	8 nm	10 nm	0.1 nm (7)	1 nm (5)	GNSS		(+/-) 2-5 minutes
	2 nm	4 nm	5 nm	<308 m (7)	<1 nm (5)	GNSS		(+/-) 2-5 minutes
High Density Airspace	1 nm	2 nm	3 nm[15]	<92.6 m (8)	<0.2 nm (7)	GNSS		(+/-) 1-3 minutes
Top of Descent	2 nm	4 nm	5 nm	<308 m (7)	<1 nm (5)	GNSS		(+/-) 3 minutes
High Density Airspace	1 nm	2 nm	3 nm	<92.6 m (8)	<0.2 nm (7)	GNSS		(+1/-3) minutes
Arrival	1 nm	2 nm	3 nm	<308 m (7)	<1 nm (5)	GNSS		(+/-) 3 minutes
High Density Airspace	0.3 nm	0.6 nm	3 nm	<92.6 m (8)	<0.2 nm (7)	GNSS	GBAS	(+/-) 30 seconds
Approach								(+/-) 30 seconds
Initial Approach Fix								(+/-) 30 seconds
Final Approach Fix								(+/-) 20 seconds
Runway Threshold								(+/-) 20 seconds
High Density Airports								
Metering Fix								(+/-) 12-18 seconds
Initial Approach Fix								(+/-) 20 seconds
Stable Approach Point[9]								(+/-) 3-4 seconds
Final Approach Fix								(+/-) 3-4 seconds
Runway Threshold								(+/-) 3-4 seconds
Single Runway								
LNAV	0.3 nm	0.6 nm	3 nm	0.05 nm (8)	0.6 nm (6)	GNSS	SBAS	
RNP (AR)	0.3-0.1 nm[14]	0.3-0.1 nm[14]	3 nm	TBD[10]	TBD	GNSS	SBAS	
LPV	16m/4m	40m/50m	3 nm	TBD	TBD	GNSS	SBAS	
LPV-200	16m/4m	40m/35m	3 nm	TBD	TBD	GNSS	SBAS	
GLS Cat-I	16m/4m	40m/10m	3 nm	TBD	TBD	GNSS	GBAS	
GLS Cat-III	16m/4m	40m/10m	3 nm	TBD	TBD	GNSS	GBAS	
High Density Airports								
Parallel Runways[11]								
> 4,300 feet Separation	0.3 nm	0.6 nm	2 nm IPA[12]	0.05 nm (8)	0.6 nm (6)	GNSS	SBAS	
3,400 - 4,300 feet	16m/4m	40m/10m	2 nm IPA	121 m (8)	0.2 nm (7)	GNSS	SBAS	
2,500 - 3,400 feet	16m/4m	40m/10m	2 nm IPA	121 m (8)	0.2 nm (7)	GNSS	GBAS	
1,600 - 2,500 feet	16m/4m	40m/10m	2.5 nm DPA	TBD	TBD	GNSS	GBAS	
750 - 1,600 feet	16m/4m	40m/10m	2.5 nm DPA	TBD	TBD	GNSS	GBAS	
Taxi-in	Visual	Visual	Visual	0.05 nm (8)	0.6 nm (6)	GNSS		(+/-) 3 minutes
Low-vis (300-600 RVR)	1m	3m	1,200 feet	121 m (8)	0.2 nm (7)	GNSS	GBAS	(+/-) 3 minutes
Low-vis (<300 RVR)	1m	3m	1,200 feet	121 m (8)	0.2 nm (7)	GNSS	GBAS	(+/-) 3 minutes

Notes:
1. Required Time Performance (RTP) has been created by the JPDO TBO Study Team to represent performance goals until confirmed by research and represents a range of time values.
2. Navigation Accuracy Category for Position (NACp) and Navigation Integrity Category (NIC) values provided Surveillance Integrity Level (SIL) in ( ).
3. Requires research. Assumes 20 nm/hour taxi speed and being able to detect another aircraft/vehicle by ADS-B and stopping to avoid collision.
4. In low-vis conditions, capacity is reduced and RTP increases to compensate for slower surface movement.
5. Centerline guidance required for takeoff roll.
Operations <300 RVR are expected to be possible with enhanced vision that produces the equivalent of 300 RVR visibility.
6. Flight segment used to transition from liftoff to start of climb route where gear and flaps are retracted.
7. Increased precision in RTP required to merge into an overhead flow.
8. Includes oceanic and offshore operations.
9. Stable approach point is where the aircraft is fully configured and slowed to appropriate speed and the pilot is prepared to land. In TBO, this is a point where time changes are not made.
10. Surveillance values dependent on research to mirror ADS-B In requirements for the procedure
11. TBO envisions 2,500 feet lateral runway separation to be an independent arrival stream and any less runway spacing is a dependent arrival stream between the two runways
12. Independent Parallel Approach (IPA); Dependent Parallel Approach (DPA)
13. Operational requirements are defined for total system accuracy, which is dominated by flight technical error and position accuracy for the operation is negligible.
14. Containment for RNP AR is specified as a total system requirement; value is representative of current approvals.
15. Assessment of approval for 3 nm separation for NACp 92.6 m and NIC <0.2 nm not yet completed (August 2011)

Appendix H. Summary Interference Impacts to Operational Improvements

The following tables present two sets of NextGen Operational Improvements (OI). The first are those mid-term OIs the FAA has accepted as part of the NextGen effort. The second is a listing of OIs from the JPDO's Joint Planning Environment. Both sets are extractions from a larger set of OIs, but these represent the OIs that are navigation and positioning dependent. The description of the OI is the title for that OI. Next is the impact of an interference event on that OI. This has been scaled to show the impact. A "1" (red) means that the OI would not be possible in the presence of interference. A "2" (yellow) represents a condition where the OI could be partially used. A "3" (green) means the OI is unaffected by the interference. The last column provides what the APNT would do to mitigate the impact.

FAA OI	Description	Impact	APNT Use (Rationale)
101102	Provide Full Flight Plan Constraint Evaluation with Feedback	2	Provides position that enables users to fly planned routings and limit constraints, continued dispatch possible
102123	ADS-B Separation	1	Provides position to data processing systems for controller display to continue lower separation minima, especially in non-radar airspace.
102138	Expanded Radar-like Services to Secondary Airports	1	Provides position in mountainous areas where radar coverage is limited for both navigation and surveillance
102146	Flexible Routing	2	Maintains RNP capabilities to continue 4DT operations and continue use of optimized routings
102148	Self-Separation Airspace Operations	1	Enables preferred operator routing
102149	Delegated Separation - Complex Procedures	1	Provides position for conflict detection and alerting
104122	Integrated Arrival/Departure Airspace Management	2	Provides position to continue RNP and RNAV operations while maintaining 3nm separation standards
104123	Time Based Metering Using RNAV and RNP Route Assignments	1	Provides position to continue RNP and RNAV operations while maintaining 3nm separation standards
104126	Trajectory-Based Management - Gate-To-Gate	1	Provides position in high density airspace to allow 4DT operations to continue in en route, climb, cruise and descent
107115	Low Visibility/Ceiling Takeoff Operations	2	Provides position for a transition from localizer guidance to climb navigation for turning procedures (SIDS)
107116	Low Visibility/Ceiling Departure Operations	2	Provides position for RNP/RNAV SIDS to enable aircraft to avoid hazards and maintain a safe buffer from hazards
107117	Low Visibility/Ceiling Approach Operations	2	Will provide position to enable navigation to navigate to ILS final approach course and missed approach procedures

FAA OI	Description	Impact	APNT Use (Rationale)
108105	Flow Corridors - Level 1 Static	1	Provides position for ADS-B and onboard conflict reporting capabilities for self separation operations
108106	Flow Corridors - Level 2 Dynamic	1	Provides position for ADS-B and onboard conflict reporting capabilities for self separation operations that shift for wind or weather conditions
108209	Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigation Performance (RNP)	2	Provides position to continue RNAV and RNP to continue more efficient aircraft trajectories for repeatable and predictable navigation
109311	Environmentally and Energy Favorable En route Operations	2	Enables continued operations to minimize fuel burn, emissions, and noise
109312	Environmentally and Energy Favorable En route Operations – Enhanced	2	Enables continued operations to minimize fuel burn, emissions, and noise
109313	Environmentally and Energy Favorable Terminal Operations	2	Optimize aircraft arrival, departure, and surface operations to reduce emissions, fuel burn, and noise through the use of environmentally friendly procedures
109314	Environmentally and Favorable Terminal Operations – Enhanced	2	Optimize aircraft arrival, departure, and surface operations to reduce emissions, fuel burn, and noise through the use of environmentally friendly procedures
109405	Business Continuity Services	2	Leverages the HSPD-7 policy for Federal departments to provide business continuity of services for critical ATM services to include: automation, surveillance, weather, voice and data communications
0303	Traffic Management Initiatives with Flight Specific Trajectories	1	Provides information to the ANSP when APNT is in use to identify GPS system area outages
0306	Provide Interactive Flight Planning from Anywhere	2	Provides position to airborne and ground automation to continue the capability to exchange flight planning information and negotiate flight trajectory agreement amendments
0307	Integrated Arrival/Departure Airspace Management	1	Provides position to continue RNP and RNAV operations while maintaining 3nm separation standards
0309	Use Optimized Profile Descent	1	Enables aircraft to remain on original flight plan to include the most economical point in which to begin a descent using the most economical power

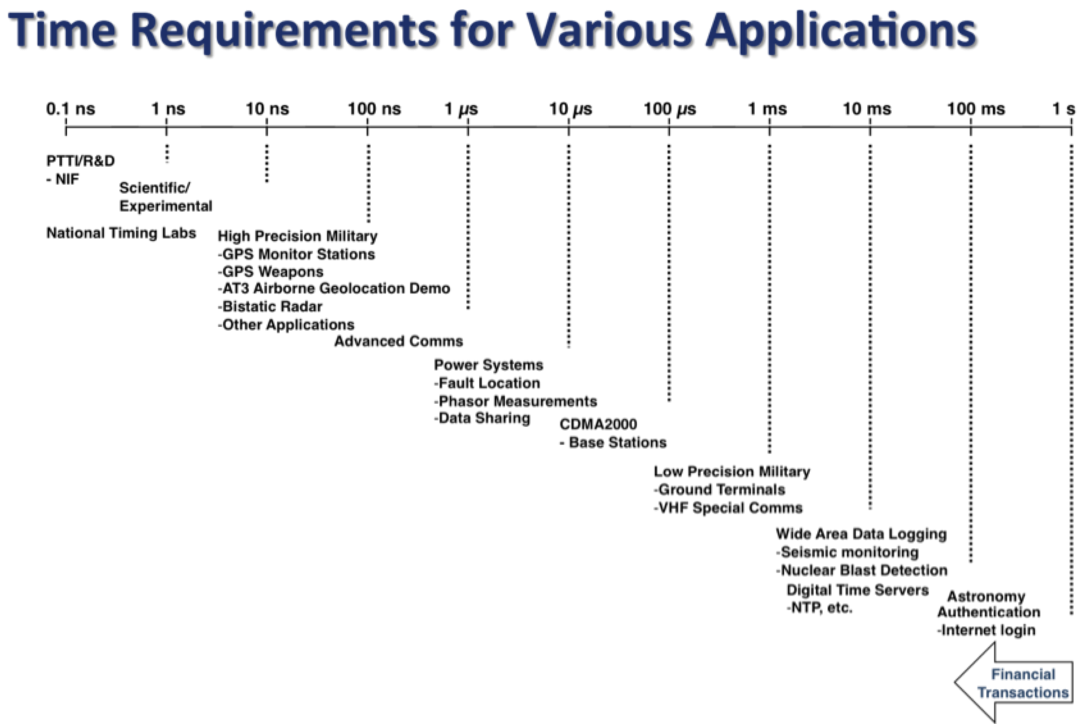
JPDO OI	Description	Impact	APNT Use (Rationale)
0310	Improved GA Access to Traverse Terminal Areas	1	Provides position to GA aircraft for ADS-B positioning for more direct routing through busy terminal area airspace
0311	Increased Capacity and Efficiency Using RNAV and RNP	1	Provides position to continue RNAV and RNP to continue more efficient aircraft trajectories for repeatable and predictable navigation
0316	Enhanced Visual Separation for Successive Approaches	1	Provides equipped aircraft position for onboard traffic display for enhanced out the window OTW approaches
0318	Arrival Time-Based Metering - Controller Advisories	1	Provides position to controllers to decrease the uncertainty in delivery to terminal boundaries to reduce bunching of aircraft into the terminal area
0325	Time-Based Metering Using RNAV and RNP Route Assignments	1	Provides position to continue RNP and RNAV operations while maintaining 3nm separation
0326	Airborne Merging and Spacing - Single Runway	1	Provides position for special use airspace areas to allow use of unused airspace to efficiently manage flight trajectory operations
0329	Airborne Merging and Spacing with OPD	1	Provides position for aircraft to remain on planned trajectory and continue Optimized Profile Descents while merging and spacing to optimize use of airspace
0330	Time-Based and Metered Routes with OPD	1	Provide position to ground based automation to provide conflict free time based metering solutions
0334	Independent Converging Approaches in IMC	2	Provides position to equipped aircraft onboard displays and alerting systems for independent converging runways to continue VMC departure and arrival rates
0337	Flow Corridors - Level 1 Static	1	Provides position for high density corridors to continue self separation procedures
0338	Efficient Metroplex Merging and Spacing	2	Provides position to ANSP automation and decision support tools
0339	Integrated Arrival/Departure and Surface Traffic Management for Metroplex	2	Provides position to update Metroplex scheduling automation to optimize runway and surface movement
0343	Reduced Horizontal Separation Standards, En Route - 3 Miles	1	Provides required performance criteria to continue 3 mile separation standards in larger areas of airspace
0346	Improved Management of Airspace for Special Use	2	Provides position for UAS aircraft, military operations and the ANSP decision support tools
0347	ADS-B Separation	1	Provides position to data processing systems for controller display and to continue lower separation minima

JPDO OI	Description	Impact	APNT Use (Rationale)
0349	Automation Support for Mixed Environments	2	Provides position to ANSP automation to safely manage the anticipated increases in complexity and volumes of traffic
0350	Flexible Routing	2	Provides position for routes based on RNP to continue using minor changes in the route to continue preferred routes to optimize fuel savings without coordination with the ANSP
0351	Flexible Airspace Management	1	Provides position to the ANSP so that different facilities may see navigation source for consideration redefining airspace sector boundaries to balance sector workloads
0355	Delegated Responsibility for Horizontal Separation (Lateral and Longitudinal): Terminal	1	Provides position between equipped aircraft to continue safe aircraft-to-aircraft separation
0356	Delegated Separation - Pair-Wise Maneuvers	1	Provides position to continue delegated separation
0360	Automation-Assisted Trajectory Negotiation and Conflict Resolution	1	Provides position to decision support tools to identify conflicts/complexity/density conditions to provide alternatives
0362	Self-Separation Airspace Operations	1	Provides position to ADS-B for self separation
0363	Delegated Separation - Complex Procedures	1	Provides position for equipped aircraft for merging, passing or crossing of other traffic
0365	Advanced Management of Airspace for Special Use	2	Provides position for 4DT procedures when airspace is available to all users
0366	Dynamic Airspace Performance Designation	2	Provides navigation capability to provide 4DT performance as required airspace use
0368	Flow Corridors - Level 2 Dynamic	1	Provides position to ADS-B for self separation, conflict detection and altering
0369	Automated Negotiation/Separation Management	1	Provides position to ANSP Separation Management to update 4DT agreements
0370	Trajectory-Based Management - Gate-To-Gate	1	Provides position to calculate and negotiate 4DT adjustments of individual aircraft trajectories
0406	NAS Wide Sector Demand Prediction and Resource Planning	2	Provides status of navigation systems when APNT is in use to adjust airspace configurations and allow identification of available navigation resources
0408	Provide Full Flight Plan Constraint Evaluation with Feedback	2	Provides position that enables users to fly routings and limit constraints
3004	Improved Operational Processes Using the Safety Management System (SMS)	3	Provides a mitigating option to safely operate aircraft and will align with the SMS process

JPDO OI	Description	Impact	APNT Use (Rationale)
3102	Improved Safety for NextGen Evolution	3	Alternate Position, Navigation, and Time provides a safety benefit by supporting automated systems to mitigate hazards more quickly
3103	Improved Safety of Operational Decision Making	3	Provides position for better situational awareness for all stakeholders by interfacing with ANSP automation
3104	Enhanced Safety of Airborne Systems	3	Provides position for reliable accurate operational information
4600	Reduced Threat of Aircraft and UAS Destruction or Used as a Weapon	1	Provides position to UAS aircraft to avoid interference disruptions that may result in the loss of control through Jamming or Spoofing
4601	External Aircraft/UAS Threat Protection	1	Provides position to UAS aircraft to avoid interference disruptions that may result in the loss of control through Jamming or Spoofing
6005	Environmentally and Energy Favorable En Route Operations - Level 1	2	Provides navigation capability to remain on planned optimized route to reduce emissions, fuel burn and noise
6008	Environmentally and Energy Favorable Terminal Operations - Level 1	2	Provides navigation capability to remain on planned optimized route to reduce emissions, fuel burn and noise
6021	Environmentally and Energy Favorable Terminal Operations - Level 2	2	Provides navigation capability to remain on planned optimized route to reduce emissions, fuel burn and noise
6022	Environmentally and Energy Favorable En Route Operations - Level 2	2	Provides navigation capability to remain on planned optimized route to reduce emissions, fuel burn and noise

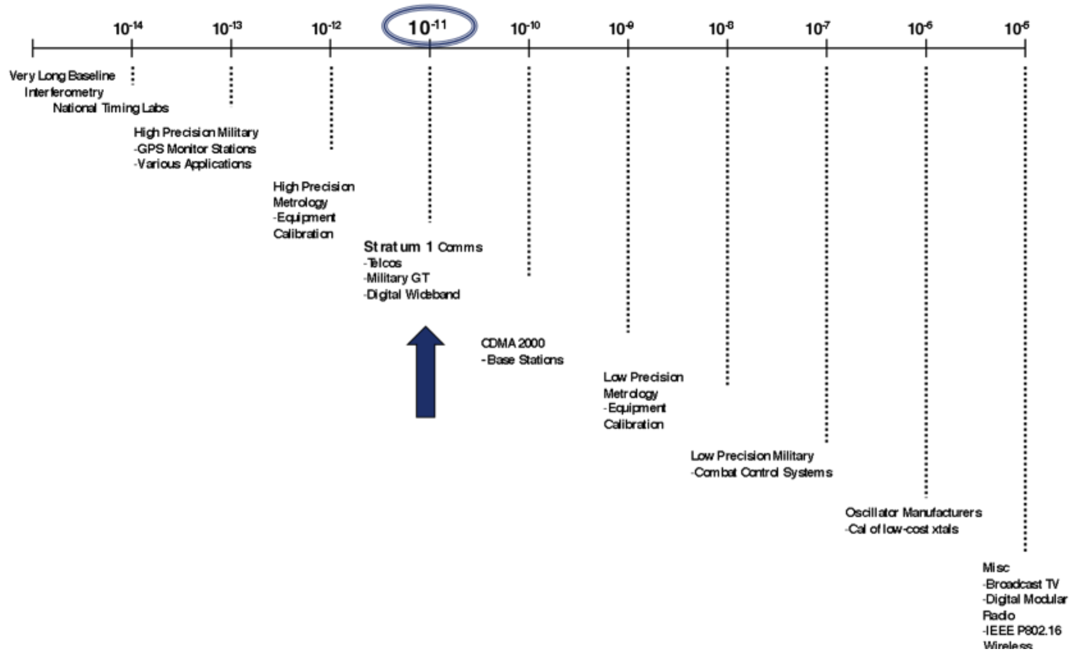
Appendix I. Time Requirements

The following summarized time and frequency performance for various NAS capabilities and is provided as reference to the need for Time. Note that GPS is in the 10 nanosecond range.



It is not just the precision of time, but how time drifts with frequency changes. STRATUM 1 frequency stability is also needed.

Frequency Requirements for Various Apps



Current NAS Precise Time Requirements