European GNSS Contingency/ Reversion Handbook for PBN Operations

PBN HANDBOOK No. 6

SUPPORTING EUROPEAN AVIATION

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This document is one of a series of inter-related PBN publications, each of which can be used independently. Handbooks 1 & 3 are mainly aimed at ATM/operational audiences, whilst the EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114) and Handbook No 4 primarily target Infrastructure Managers. Handbooks 5 & 6, provide the link between the two audiences on subjects of shared importance.

This document is Handbook No 6.

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DOCUMENT CONTROL

The following table records the complete history of the successive editions of the present document.

		DRAFT	
Edition Number	**Edition Date**	**Reason for Change**	**Pages Affected**
0.1 Draft	Q1/2018	Creation of the document	All
0.2 Draft	Q3/2018	Revision of document	All
0.3 Draft	Q1/2019	Revision of document following NSG Webex 26 November 2018	All
0.4 Draft	Q2/2019	Revision of document following Q1/2019 consultation with APDSG, NETOPS, & Internal CNS Unit (DECMA/NM)	All
1.0 Draft	Q4/2019	Revision of document following the stakeholders consultation workshop	All
Draft Ed. 1	Q1/2020	Revision of document following the consultation with NSG and APDSG. Submission to NETOPS and JCSP for approval.	All
Draft Ed. 1	Q1/2020	Document revision after NETOPS/26 (27FEB2020) with updates accommodate info from questionnaire and APDSG feedback.	Chapter 4
Edition 1 ***Published***	22 July 2020	Finalised document; approved by NETOPS & JCSP.	ALL
Edition 1.1 ***Published***	17 June 2021	Removal of PCP IR and replacement with CP1; editorial changes needed plus one substantive change to Sample Scenario 1	Various & Chapter 4, para 4.4, Scenario 1

EXECUTIVE SUMMARY

Context

As the EU regulation related to PBN clearly indicates that GNSS is to become the primary navigation infrastructure over the next decade, this document sets out what States need to consider if the signals from primary infrastructure are degraded or lost. (See EC Regulation No 1048 of 2018 (PBN IR)). Article 6 of the PBN IR requires ANSPs to ensure the availability of contingency measures in the event of GNSS failure, or failure of other means needed to enable PBN Operations. Related SESAR research also identified a need for guidance material for ANSPs on how to develop a minimum operational network [MON] of VOR/DME.
This document has been produced under the auspices of the Navigation Steering Group (NSG), which reports to both the Network Operations Team (NETOPS) and the Joint CNS Stakeholder Platform (JCSP)/ Communication, Navigation and Surveillance Team (CNS-T).

Purpose

This document addresses the topic of GNSS Reversion/Contingency in the context of PBN operations in all flight phases. For completeness, GBAS operations are included in the Scenarios in Chapter 4, as this is also a GNSS-based system used on final approach. The main emphasis of this document, however, is placed on terminal and extended terminal operations in a surveillance environment. Operations in a non-ATS surveillance environment are also covered.

This document is not intended to be a definitive guide to contingency operations for PBN. Rather, it provides planning considerations through explanatory text and the use of two sample contingency scenarios. This is provided as a 'starter pack' for ANSPs and regulators to assist in their deliberations when planning contingency operations for GNSS reversion. In context, the expression ANSPs is used to cover regulated parties of the PBN IR i.e. air traffic management/air navigation services and operators of aerodromes.

It serves as a bridge document between existing EUROCONTROL guidance material already published to support Airspace Planners and Infrastructure Planners implementing PBN. This document is deliberately not detailed: it seeks rather to enhance understanding on the shared challenge of providing for GNSS contingency/reversion.

Scope & Timelines

The first obligation on ANSPs stemming from the PBN IR was due in December 2020 with a second obligation set for 2024. By 2030, this regulation requires GNSS to be the main positioning source for PBN. Because single-frequency single-constellation (SF-SC) i.e. GPS L1, will be the most prevalent form of GNSS positioning expected to be used up to and beyond 2030, **dual-frequency multi-constellation (DF-MC) is out of this document's scope.** As such, the loss of one of both frequencies or one out of several constellations is not covered in this document.

The Annex 10, Vol I definition of GNSS explains that the term includes all core constellations, augmentation systems, aircraft receivers and integrity monitoring. However, because of the time-period covered by *this* document, when the expression GNSS is used in *this* document, it refers only to the GPS core constellation and/or SBAS, depending on the context. In many cases, the explicit terms GPS or SBAS are used.

In February 2020, results were compiled from an on-line GNSS Reversion survey conducted by Eurocontrol's navigation experts. This survey targeted European air traffic controllers who answered anonymously. Results show that 86 % or more respondents either did not have or were not aware of GNSS contingency procedures to use of GNSS becomes unusable.

Recommendations:

Considering the above, ANSPs are strongly encouraged to undertake an awareness campaign on GNSS contingency. Furthermore, ANSPs are encouraged to develop Reversion Scenarios and associated Contingency Procedures in the event of GNSS being unusable in order to ensure compliance with Articles 3-6 of the PBN IR to meet applications specified for the three step target dates of 2020, 2024 and 2030 described in Article 7 of the PBN IR.

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ABBREVIATIONS

4D	4-dimensional
ADS-B	Automatic Dependent Surveillance- Broadcast
A-PNT	Alternative Positioning Navigation and Timing
APV	Approach Procedure with Vertical Guidance
APV-Baro	Approach Procedure with Vertical Guidance with Barometric Vertical Guidance
APV-SBAS	Approach Procedure with Vertical Guidance with Satellite Based Augmentation
AR	Authorisation Required
B-RNAV	Basic Area Navigation (RNAV 5)
CS-ACNS	Certification Specification for Airborne CNS
D/D	DME/DME
D/D/I	DME/DME/IRU
DME	Distance Measuring Equipment
EGNOS	European Geostationary Navigation Overlay Service
FAS	Final Approach Segment
FL	Flight Level
FMS	Flight Management System
FRT	Fixed-Radius Transition
GBAS	Ground Based Augmentation System
GNSS	Global Satellite Navigation System
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IRE	Instrument Runway End
IRU	Inertial Reference Unit
PALS	Precision Approach and Landing System
LOA	Letter of Acceptance
LNAV	Lateral Navigation
LNAV/VNAV	Lateral Navigation/Vertical Navigation
LP	Localizer Performance
LPV	Localizer Performance with Vertical guidance
MASPS	Minimum Aviation System Performance Standards
MC	Multi Constellation
MF	Multi Frequency
MLS	Microwave Landing System
MoC	Means of Compliance
MON	Minimum Operational Network
MOPS	Minimum Operational Performance Standards
NAV	Navigation
NAVAID	Navigation Aid
NM	Nautical Mile
NPA	Non Precision Approach
NPR	Noise Preferential Routes
NSA	National Supervisory Authority
PA	Precision Approach

PANS	Procedures for Air Navigation Services
PBN	Performance-Based Navigation
PBN SG	Performance-Based Navigation Study Group
PIRG	Planning and Implementation Regional Group
P-RNAV	Precision Area Navigation (≈ RNAV 1)
PRB	Performance Review Body
PRC	Performance Review Commission
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radius to Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP APCH	Required Navigation Performance Approach
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
SARPS	Standards And Recommended Practices
SBAS	Satellite Based Augmentation System
SID	Standard Instrument Departure
SIS	Signal In Space
SPA	Specific Approval
SPI	Surveillance Performance and Interoperability
STAR	Standard Instrument Arrival Route
TACAN	Tactical Air Navigation System
TBO	Trajectory Based Operations
TMA	Terminal Control Area
TOAC	Time of Arrival Control
TPO	Tactical Parallel Offset
TSO	Technical Standard Order
US	United States
VOR	Very-High Frequency (VHF) Omni-directional Radio Range
VORTAC	Very-High Frequency (VHF) Omni-directional Radio Range/Tactical Air Navigation System
VNAV	Vertical Navigation
WG	Working Group
xLS	Precision landing system such as ILS, GLS, MLS

DOCUMENT REFERENCES

This document is related to existing publications shown below.

Official Title	*Short title used for reference in this document*
European Airspace Concept Handbook for PBN Implementation, Eurocontrol, Handbook No 1, Edition 4	*Airspace Concept Handbook {No.1}*
Eurocontrol Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114).	*RNAV 1 Infrastructure Assessment {Guidelines}*
European PBN Route Spacing Handbook, Eurocontrol, Handbook No 3, Edition 1,	*Route Spacing Handbook {No.3}*
European Navaid Infrastructure Planning Handbook, including Minimum Operational Network (MON), Eurocontrol, Handbook No 4, Edition 1	*Infrastructure Planning Handbook {No.4}*
European PBN implementation and Transition Planning Handbook, Eurocontrol, Handbook No 5, Edition 2	*PBN Implementation Handbook {No.5}*
ICAO Annex 10, Volume I Radio Navigation Aids , Seventh Edition, July 2018	*Annex 10*
ICAO Annex 11, Air Traffic Services	*Annex 11*
ICAO PANS-ATM, Doc 4444	*PANS-ATM*
Performance-based Navigation Manual, ICAO, Edition 5	*PBN Manual*
EUR RNP APCH Guidance Material	*EUR ICAO DOC 025*
CNS evolution roadmap and strategy (Deliverable D2.1.020 of SESAR 2020 project PJ14 EECNS)	*CNS Evolution Roadmap*
Report on the Real-Time Simulation on RNP Reversion, 15.3.1.D12 (2012)	*Budapest Simulation*

1. CONTEXT

1.1 Regulatory Context

EU Regulatory provisions require that ANSPs publish RNAV and RNP procedures in Member States of the European Union and in those States where European ANSP/ATSP provide a service. (See Commission Implementing Regulation (EU) 2018/1048, known as the PBN IR). A summary of the regulatory requirements detailed in the PBN IR is shown below.

Table 1-1: Snapshot of EU PBN Reglatory requirements

PBN IR Article 4 & 7 Applicability with AUR.2005		Applies 03/12/2020	Applies 25/01/2024	Applies 06/06/2030
Art 4	Transition Plan *(or significant updates)* approved *(living document)*[1]	X[1]	X[1]	X[1]
AUR.2005 1/2/3	RNP APCH at IREs without Precision Approach (PA)	X		
	RNP APCH at all IREs (with PA)		X	
AUR.2005 4/5	RNAV 1 or RNP 1 (+ RF if required) SID and STAR - one per IRE		X	
	RNAV 1 or RNP 1 (+RF if required) for all SID and STARs			X
AUR.2005 6	RNAV 5 ATS Routes (excl. SIDs/STARs) at and above FL150[2]	X		
	RNAV 5 ATS Routes (excl. SIDs/STARs) below FL150		X	
AUR.2005 7	Helicopter RNP 0.3 or RNAV 1 or RNP 1 (+RF if required) SID/STAR - one per IRE		X	
	Helicopter RNP 0.3 or RNAV 1 or RNP 1 (+RF if required) for all SID/STAR			X
	Helicopter RNP 0.3 or RNAV 1 or RNP 1 ATS Routes (excl. SIDs/STARs) below FL150		X	

*Note 1 - The transition plan will have several iterations; Article 4 requires that the draft/significant updates to the plan must be approved by the competent authority **early enough** to provide sufficient time for the ANSPs to meet the identified implementation date. (Sufficient time would include accounting for the AIRAC cycle dates, publication and regulatory approval and compliance with other national requirements - see the PBN Portal for an example of the implementation scheduling and time required: https://pbnportal.eu/epbn/main/PBN-Tools/Planning-Estimation.html). The planned implementation dates detailed in the transition plans should be commensurate with the target date obligations.*

Note 2 - CP 1 requires FRA to be implemented with two milestones: 2022 & 2025. FRA is associated with RNAV 5 through the ICAO EUR requirement for RNAV 5 published in ICAO Doc 7030. (CP 1's revised FRA requirements replace previous requirements in the PCP IR).

Table updated February 2021

Note: Before Common Project One (CP1) referred to in Note 2, above, there was a PCP IR (Pilot Common Project Implementing Regulation [EU] No 716/2014) that also regulated PBN implementation. This PCP IR has been superseded by CP1 and no longer addresses PBN or, by implication, the navigation infrastructure.

The first obligation on ANSPs stemming from the PBN IR was in December 2020, with a gradual migration to a full PBN environment with GNSS as the main positioning source for PBN by 2030.

Because the main point of focus of the PBN IR is the implementation of very specific navigation applications (Table, above), it is easy to miss the step-change introduced by this regulation. In order to understand its significance *within the context of this document,* a recap of PBN and PBN Positioning is provided before deciphering the Regulatory Step change in the context of Contingency.

1.2 PBN Positioning

Cross Reference: European Airspace Concept Handbook No 1, Activity 6, Enablers, Constraints and ATM CNS Assumptions, page 21.

The PBN Concept is comprised of three elements:

- The Navigation Specification (which provides the certification/operational standards for the RNAV or RNP application)
- The Navaid Infrastructure (which provides the positioning for the required RNAV or RNP specification)

- The Navigation Application which is the use of the Navigation Specification and Infrastructure together in the form of Routes, SIDS/STARs and Instrument Approach Procedures

Whilst PBN relies on the use of an area navigation (RNAV) system for navigation, positioning is provided to an aircraft's RNAV system by any of the following means, which may be used in combination:

(i) The space-based Navaid Infrastructure (GNSS, in this case, **GPS & SBAS**);

(ii) Ground-based Navaids (DME/DME, VOR/DME); or

(iii) An on-board inertial reference system which is usually updated periodically by the space- or ground-based infrastructure.

Each PBN Specification states which positioning source may be used. The table below shows those navigation specifications required by the PBN regulations, and the positioning aids that *must* or *may* be used.

*Table 1-2 Positioning Sources (**R**equired/**O**ptional) for the EU Regulation Navigation Specifications*

	GPS	IRS	DME/DME	DME/DME/ IRU	VOR/DME
RNAV 5	O	O	O	O	O
RNAV 1	O		O	O	
RNP 1	R		O	O	
RNP APCH (LNAV and LNAV/VNAV)	R				
RNP APCH (LPV)	R With SBAS				
RNP AR APCH	R	R			
RNP 0.3 (Helicopters)	R				

Note 1 –For RNP AR Operations where the performance requirement is less than 0.3NM in the Approach or less than 1NM in the missed approach, an IRS is required.

Note 2 – For RNP 1, DME/DME may be used for reversion if authorised by the State.

From an ATM and Pilot operational perspective – several 'guarantees' ensure that operations along a published PBN flight path will meet the navigation performance required for the intended PBN operation. One of these is the quality of the positioning provided to the area navigation system used for the PBN operation.

As Navaid Infrastructure Managers are generally responsible for the Navaids, they must ensure that quality positioning information is provided to the aircraft sensors feeding the on-board area navigation system with the aim of contributing to safe PBN operations. Being 'responsible' for ground-based Navaids is relatively straightforward in that a particular ANSP in a State ensures maintenance and calibration of their Navaid installations. In contrast, for GPS the situation is more 'complex' because the (positioning) service is provided by an external authority, namely, the US Department of Defence. (In the future, the EU will be the providing authority for Galileo). The European SBAS, EGNOS, on the other hand, is provided by a certified ANSP, the ESSP. In the case of either GPS or EGNOS, the infrastructure manager is concerned with knowing that GPS or EGNOS is working, when it cannot be used and ensuring that vulnerabilities are properly mitigated.

It is critically important to safe operations, that ATM and Infrastructure work together closely to ensure that an appropriate level of positioning is provided for PBN operations. This allows the Infrastructure manager to assess the MON (minimum operational network) of the ground-based Navaids, to be provided.

1.3 Regulatory (and Positioning) step-change

Cross Reference: Airspace Concept Handbook No. 1, Activities 6 & 7, Enablers, Constraints and ATM CNS Assumptions, page 21 et seq.

Cross Reference: Route Spacing Handbook No.3, Chapter 1.

Extensive use is still made of vectoring in today's operations. A transition period is envisaged *from* the current mix of vectoring, conventional and RNAV ATS Routes or SID/STARs and operations based on a mix of ground-based and space-based infrastructure *to* a total PBN environment, predicated primarily on GNSS by 2030. This total PBN environment will be predicated on either RNAV or RNP operations, which are reliant on GNSS as the primary positioning source, with minimal conventional routes or radar vectoring maintained as contingency operations.

> **What are strategically de-conflicted procedures?**
>
> *Because PBN allows SIDs/STARs to be placed (almost) anywhere, airspace designers lay out PBN flight paths so as to ensure that the aircraft operating on those paths will be 'automatically' separated from each other. This is a great PBN benefit.*

This transition towards the new 'norm' scheduled for June 2030 affects several PBN stakeholders, including:

- **Air traffic controllers** who will need to adapt to controlling traffic less tactically (less vectoring) and rely more on the strategic de-confliction of pre-defined routes published in the airspace structure. (See *EUROCONTROL Route Spacing Handbook)*.
- **Procedure designers** who may need to use different obstacle criteria when designing procedures.
- **ATC system managers,** who will be potentially affected by the need to generate adaptations to their systems should an implementation safety case demonstrate the need for controllers to be informed of GNSS being unusable within an area, with location and dimensions known.
- **Infrastructure managers** who will place GNSS at the 'centre' of the infrastructure stage – and ensure that there are adequate ground-based Navaids to support operations through the transition through to the end state *and* to support contingency operations in both instances, should the need arise.

The step-change triggered by the PBN regulation should not be under-estimated in terms of GPS being placed at the centre of the positioning stage. What this 'position shift' means is that GNSS becoming unusable could have considerable impact, given that it is to become central to PBN, and is also used for some Communication and Surveillance applications (e.g., time stamping and ADS-B surveillance, respectively). This means that **contingency procedures** are needed in the case of GNSS being unusable which would require a **reversion from GNSS.**

1.4 Summary

This chapter has provided a snapshot of the regulatory requirements, highlighted the resulting step-change, and provided a refresher on the significance of GNSS positioning for PBN operations particularly in light of the step change triggered by the PBN regulatory instruments and because GNSS is a shared 'resource', also used by some surveillance and communication services. The next Chapter discusses the impact of GNSS becoming unusable.

2. GPS 'UNUSABLE' - A SIMPLIFIED PERSPECTIVE

2.1 Operational snapshot

At an operational level, there is a need for pilots and controllers to have unambiguous and simple procedures to deal with the situation when GNSS becomes unusable. The interplay between GNSS becoming unusable, Operational Impact and Contingency Procedures to mitigate the impact must be self-evident.

2.1.1 Pilot Procedures

Pilots have an **Aircraft Operations Manual** specific for each aircraft and this document details normal and abnormal operational procedures, with explanations provided. In flight, however, pilots use the **Quick Reference Handbook** (QRH) which contains in-flight procedures to be used in the event of abnormal or emergency situations. Quick Reference Handbooks include procedures related to GPS position degradation. On an RNP APCH, this information is readily provided and usually results in a go-around.

Most pilots would be made aware of a GPS no longer being usable by some indication in the cockpit. Manufacturers determine the avionics interface and decide how obvious this information is made. When becoming aware of that GPS is unusable, a pilot is more likely to suspect a faulty receiver than a constellation problem, unless multiple receivers indicate a failure. Essentially, if the aircraft is unable to achieve the performance required of the navigation specification, the pilot will know this and inform ATC.

If GPS fails, most avionics with alternative navigation means, would automatically default down to IRU with radio updating (e.g. DME/DME) or the pilot can ask for vectoring if navigation becomes impossible. (Note that the step down and positioning source substitution depends on the avionics fit). In those avionics interfaces where the pilot is informed that GPS is lost, the pilot will be likely to communicate this to ATC (depending on company procedure) even if the aircraft is capable of navigating and achieving the required performance.

This difference in avionics suites and pilot procedures is something that needs to be managed when controllers develop their local contingency operations and also when these are developed for the Network. It is important to remember that when GPS becomes unusable, this can affect multiple systems including *navigation* and *communication* (e.g. message timing) and some *surveillance and other systems* e.g. ADS-B, TAWS – See Appendix A.

Industry provides AOs with awareness information on how the avionics deals with a GPS outage by publicizing operating instructions and additional awareness material for flight crew. This information could be applicable to a single model or to a family of aircraft; an example of this would be Airbus's In-service Information.

2.1.2 ATC Procedures

When controllers are trained and receive their ratings, they are required to be familiar with contingency procedures developed for their Units. These procedures can be detailed in local instructions/regulations for a particular unit and can cater for a variety of abnormal situations such as radar failures, a blocked runway, particular maintenance routines or severe weather. An additional abnormal situation would need to be added to such contingency measures to cater for cases when GPS is unusable.

In the past, some ATC units provided a panel indication of the status of NAVAIDS. A RED light indicated unusable, and GREEN indicated usable. So if a particular VOR was unserviceable, it would show a red light, and the controllers would know not to issue any clearance that relied on the use of that VOR. As the number of SIDS/STARS have increased to over a 100 at some major airports, the situation has become more complex. With PBN, the controller also needs to know whether GNSS is usable and the scale and duration of the period when it is not usable. Currently, this information will reach the controller *either* through NOTAM, pilot reports (see 2.1.1, above) or if advantage is taken of airborne equipment such as ADS-B and integrated into information that is usable by ATC. Any such technological solution would require development.

When information that the GPS is unusable is available, the controller should inform the pilot who would then decide which approach to conduct as an alternative, or whether or not diversion to another aerodrome is required. Ideally, the supervisory chain should be provided with information on GPS outage and, when appropriate, decide that the GPS is unusable for operations in a given volume of airspace. Such information should be disseminated to working positions. Appropriate contingency procedures should be in place for such occurrences. When the GPS is unusable, the controller should not –

a. **Clear an aircraft for an RNP APCH:** An RNP APCH *requires* GPS. If EGNOS is not working the pilot knows that the aircraft cannot fly an RNP APCH to LPV minima.
b. **Clear an aircraft for a procedure which is authorised using GPS position only.** Here the reference is to PBN SID/STAR, ATS or free routes which have been published/predicated *only* on GPS, either because there is no available DME infrastructure or because the use of available DMEs is not suitable.
c. **Clear a GPS only equipped aircraft for a procedure which is authorised using GPS or DME position.** This is only possible if the controller is provided with accurate equipage information extracted from the items 10 and 18 of the filed flight plan and its associated update messages.

Normally, ATM systems have a H24 technical monitoring and alerting function. With radar and radio equipment, the status of most critical elements is displayed directly on the Controller Working Positions. As regards ground-Navaids, when only these are used, simple status indicators may be made available to the controller e.g. RED (indicating a Navaid outage) or GREEN (indicating that the Navaid is working). The 'orange' case (where only some aircraft are affected) does not exist with ground-Navaids.

The orange case, does, however, exist with GPS which is why outage indicators may be more complex. With the orange case, a limited number of aircraft may be impacted. While some ATCU provide information to the controller that there is a GPS outage, this is not standardised. Awareness of the outage is further complicated because often the 'orange' case will prevail; dealing with the 'Orange' case would be a challenge. In the case of GPS outage, how the GPS signal-in-space is monitored and how alerting will occur is yet to be decided, as is, how the information could be delivered to the Operational Units (e.g. verbal, HMI support etc.)

The alerting procedure warning that a NAV system should not be used is usually relayed from the Technical supervisor to the Operations supervisor who updates the Controller Working Position's supplemental screens. The delay in this process is usually minimum, so automation may be not necessary, unless there is such a requirement.

2.2 SUMMARY

To achieve the level of simplicity and clarity for both pilot and ATC procedures, PBN airspace design, procedure design and infrastructure planning have to be done coherently and completely – and the complicated facets of GPS being unusable and its impact, understood properly. These aspects and considerations are covered in the remainder of this document.

3. CONSIDERATIONS REGARDING GPS 'UNUSABLE' – COMPLEX ISSUES

3.1 INTRODUCTION

The key goal of the PBN IR is to have an exclusive PBN environment based primarily on GPS for positioning by 2030. With GPS central to these end-state PBN operations, GPS being unusable could have significant impact. This impact may be equally significant if SBAS becomes unusable.

But to understand GPS being unusable and its impact, it is important *first* to ensure that the vocabulary associated with this discussion is understood by the two communities targeted by this Handbook, namely Controllers/Airspace Designers and Infrastructure Managers. For this reason, this Chapter first ensures a common understanding of the terms used by the various communities, then discusses GPS being unusable and mitigation before looking at its impact.

3.2 THE VOCABULARY CHALLENGE

The primary goal of GNSS Contingency/Reversion is to ensure the safety of continued operations.

A challenge facing both Controllers and Infrastructure Managers as regards contingency/reversion relates to vocabulary used by each community. Both specialists use different terms, often for the same thing, with the added complexity that few of these terms are defined by ICAO. Examples of these multiple terms are shown in bold in the text which follows. Yet, despite the absence of formal definition in many cases, it is considered useful to understand the 'generic' intent/meaning of these words when used.

ATM Vocabulary

The ATM community speaks of ***contingency****,* with PANS-ATM having a Chapter dedicated to ***contingency procedures****.* Operational controllers are heard using expressions such as *contingencies*, *back up*, *fall back, reversion (plan B!)*. The generic meaning to be attributed to this variety of informal terms is that due to some 'issue', ATM operations cannot continue normally and controllers have to do something 'different'. Reasons for these issues causing 'non-normal' situations can include equipment failure such as a glide path inoperative; partial or total surveillance system failure; depressurisation experienced by an aircraft; hijack or aircraft's loss of navigation function. Often, ***contingency*** has a negative impact on traffic flow i.e. causing less runway or sector throughput or reduced air traffic flow rate. In this Handbook, in an ATM context, the term ***contingency*** and ***contingency procedures*** will be used to the maximum extent possible.

Infrastructure

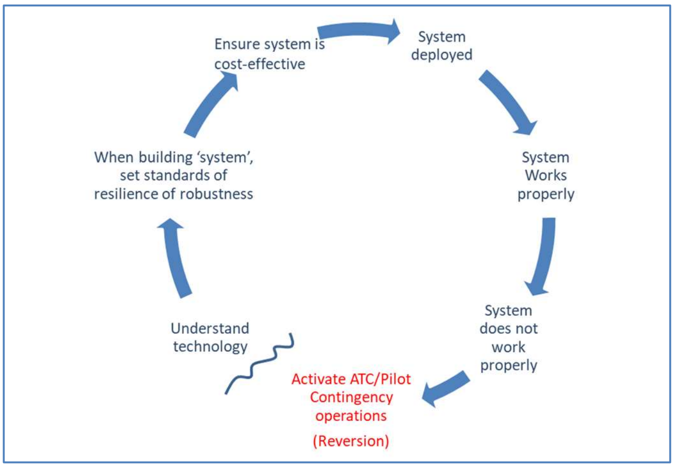
The Infrastructure community has its own collection of terms, many of which are not formally defined. To understand these, it is useful to recall that the link between PBN and the Navaid Infrastructure is that the Navaid Infrastructure provides a positioning service to the aircraft on PBN procedures. The Navaid Infrastructure is split into space-based infrastructure (GNSS, which includes GPS and Glonass, BeiDou, Galileo in the future, as well as SBAS and GBAS) and ground-based Navaid infrastructure which includes terrestrial Navaids such as DME, VOR, ILS, where DME/DME can provide positioning for RNAV 1 and RNAV 5, and VOR/DME can provide positioning for RNAV 5 *only*. Conventional navigation relies only on the use of ground-based Navaids.

Within the context of *contingency/reversion*, infrastructure managers use the expression ***Reversion*** to refer to the need to '*revert'* from a primary positioning system (e.g., GNSS) to the '*backup'* system (e.g. DME/DME) when the primary system cannot be used. The increasing use of GNSS for PBN has introduced a considerable range of vocabulary related to total GNSS non-availability or its partially availability.

- Alternative Position, Navigation and Timing (**A-PNT**) is a commonly accepted term used to refer to what *alternatives to GNSS* are available when GNSS cannot be used to provide positioning for PBN or timing for other applications. Thus, one alternative to GNSS for RNAV 1 or RNAV 5 is typically DME/DME, and for RNAV 5, VOR/DME is possible. (Strictly speaking, these alternatives are not A-PNT because no *timing* is provided; however, the term P-N-T tends to be used to define alternatives not as joint requirements).

- The expression **VOR/MON** (VOR Minimum Operational Network), whilst not limited to the reversion context, has grown in profile because of the consequences of extensive GNSS use. **VOR/MON** relates to the minimum (number of) VORs needed in an airspace to service both normal and reversion operations. (This notion of 'MON' is occasionally extended to **VOR/DME MON and DME MON)**.
- Because GNSS is vulnerable to certain **threats**, infrastructure managers seek to understand ***GNSS vulnerability.*** This can be due to a constellation weakness, radio frequency interference (***RFI***) or Ionospheric Interference (linked to space weather). **RFI** can be caused by (intentional) ***spoofing*** or ***jamming*** or (unintentional) equipment failure or radio operator error. There is a need to ***mitigate GNSS vulnerability****:* whilst key mitigations are achieved by placing more demands on the system (ensuring *technical* ***resilience*** *and* ***robustness*****),** there is also certain reliance on (operational ATM/Flight crew) ***contingency procedures*** to maintain an acceptable level of safety. **RFI is of greatest significance to Contingency Procedures for GNSS reversion, as RFI is the most likely cause of GNSS being unusable.**

Figure 3-1: Simplistic depiction of contingency/reversion



Despite attempts to create a shared (ATM/Infrastructure) understanding, readers may not be familiar with related terms used in other publications. The table below provides an 'equivalency' between terms used in this document and 'other' documents.

Expression used in this document,	**ICAO source reference**	*'Equivalent' term used in other publications.*
Reference Scenario	ICAO PBN Manual; ICAO Airspace Design Manual;	*Baseline Operating Environment*
Future Airspace Concept	ICAO PBN Manual; ICAO Airspace Design Manual;	*Target Operating Environment*
Airspace Concept Evolution Plan	Derived from ICAO PBN Manual; ICAO Airspace Design Manual;	*Operational Environment Evolution Plan*
Ground-Based Infrastructure	ICAO PBN Manual; ICAO Airspace Design Manual; Annex 10.	*Terrestrial infrastructure*

3.2.1 Clarifying 'ATS Surveillance'.

This document makes frequent use of the expression 'ATS surveillance' (or more simply 'Surveillance'). In context, the following ICAO definitions from PANS-ATM Doc 4444 are replicated so as to avoid misunderstanding as to what is meant by the expression.

ATS surveillance service. A term used to indicate a service provided directly by means of an ATS surveillance system.

ATS surveillance system. A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.

Note.— A comparable ground-based system is one that has been demonstrated, by comparative assessment or other methodology, to have a level of safety and performance equal to or better than monopulse SSR.

The second definition makes it obvious that ADS-C is *not* included in the definition of ATS Surveillance by ICAO (nor the notion of 'Surveillance' in this document), even though the expression ADS-C stands for Automated Dependent *Surveillance* – Contract.

3.2.2 Operating environment, and its evolution

Each operating environment, particularly as regards terminal operations, is distinctly different. This is partly to do with the uniqueness of each airport and its geography, and greatly influenced by cultural decision-making process and historical legacy. Contingency procedures are tailor made for a particular operating environment, which can also be distinctive as regards the combination of C-N-S enablers, ATM tools available, fleet capability or the Navaid infrastructure available for PBN operations.

An operating environment is not static; it evolves over time. A green-field airport of the 1970s can become a high-density airport hub in 2020 with surveillance and a high-end equipped fleet. It therefore makes sense that the operating environment and its evolution affect contingency procedures.

3.2.3 What is meant by 'GPS unusable'?

In the technical world, there is a difference between a GPS outage (no signal), GPS unreliable (there is a signal but it cannot be relied on) and GPS being unusable (this could be due to an outage or GPS being unreliable due to interference). Why GPS becomes unusable is of particular relevance to technical personnel. i.e. Radio Frequency Interference or some other reason). In the operational context, however, controllers enter the picture at the 'a postieri' stage i.e. once the problem with GPS has already occurred. The controller may notice aircraft deviating from the track centreline, or receive pilot reports of either "GPS Primary Lost" or "Unable RNP", for example. The on-board avionics determines whether or not GPS is unusable, however, on-board avionics vary considerably in their positioning 'logic' and the way they alert the flight crew. Whilst some FMS may announce "GPS primary lost" when GPS is no longer usable, other FMS will leave the flight crew ignorant of the GPS status, if the aircraft is able to maintain RNP operations.

In essence, the performance criteria of most technical equipment comes into play (accuracy, integrity, continuity and functionality). The usability or not of GPS as decided by the equipment, depends on its 'programming' and its 'logic' – and it must meet a particular standard – but if a population of aircraft in a particular area is reporting GPS outage/loss of GPS or Unable RNP, this would be a strong indication that the GPS is unusable.

3.2.4 Duration

Because Contingency measures are concerned with keeping operations safe when some element of the system 'fails', the period of time for which GNSS is unusable (the duration) is particularly important to operational Controllers and Pilots (even though it is difficult to determine the probability of this 'unusable' status occurring). In a Eurocontrol survey on GNSS reversion, controllers indicated that they would like to know the dimensions of the affected area if there is an outage of long duration. More specifically, they wanted to know which sectors would be impacted during a long duration outage.

Expressions such as 'short', 'medium' and 'long' periods of unusable GNSS are used in the context of GNSS reversion/contingency, but they have no common meaning. To avoid ambiguity in the context of this Handbook, therefore, the following attributes are given such expressions:

- Short (period) = is one of 2 hours or less
- Medium (period) = between 2 hours and 1-2 days
- Long (period) = > 2 days to 1 week
- Extended (period) > 1 week

These (nominal) explanations of duration are only intended to serve as a shorthand in this Handbook. As can be seen in Appendix 2, the question of 'duration' was of relevance in the Budapest RNP 1 simulations run in 2014. This study also showed that determination of GPS being unusable was challenging.

Given the increasing reliance on GPS and its vulnerabilities, the element of outage duration is of considerable significance.

3.2.5 Area

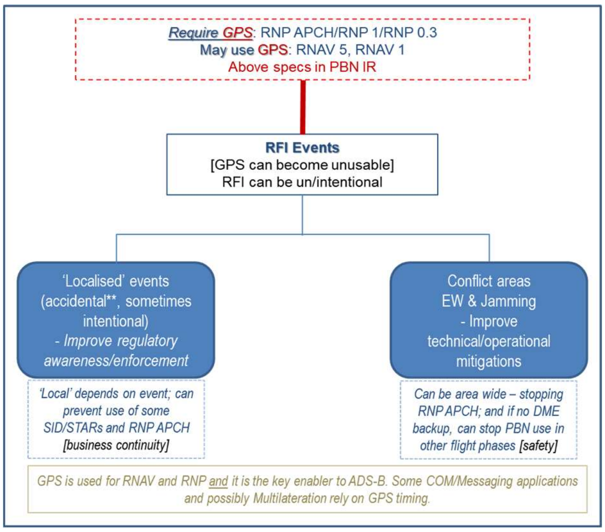
Inasmuch as GNSS can be unusable for a variety of durations, the area in which GNSS can be unusable, can also vary. Some areas of where GNSS cannot be used are localised e.g. in the direct vicinity of an approach flight path, whilst others can cover areas of different dimensons, and in extreme cases, very wide areas.

3.3 GNSS 'UNUSABLE' – MITIGATION - CONTINGENCY

GPS and its augmentations are vulnerable, and such vulnerability must be mitigated either by requiring systems to be more resilient and robust, or by depending on ***contingency procedures*** which, in turn, may rely on alternative positioning sources or COM and/or Surveillance to ensure **GNSS reversion** in order to maintain an acceptable level of safety.

Contingency procedures are the purview of operational ATM/Flight crew. For our purposes, the diagram below focuses on RFI as it is the most likely cause of GPS outage in terminal and extended terminal operations.

Figure 3-2: GNSS Outage (Radio Frequency Interference or RFI)



RFI can cause GPS to become unusable, whether the source of RFI is intentional or unintentional.

If one considers the PBN positioning information discussed in para. 1.2, it becomes evident that GPS being unusable can seriously impact the availability of positioning for PBN operations. As the diagram (right) re-states, certain navigation specification *require* GPS for positioning, and depending on the nature of the 'unusable' status – it's location area and duration, the impact and mitigations can be vary.

Appendix 1 to this document provides a Tabulated view of the impact of a GPS being unusable. There are two tables, one dealing with the impact on airborne equipment, the other on ground equipment. Each Table is divided into three columns, the third being of greatest operational interest to controllers and pilots as it identifies the Operational Impact and potential Mitigations.

3.3.1 Regulatory Impact

The Commission regulation requires PBN to become the norm in all flight phases and GPS to become the central position source by 2030; conventional procedures and ground-based navigation aids will take second place over time.

Airspace Concept evolution

Operationally, the shift to PBN makes it possible to design **strategically de-conflicted** SIDs/STARs or ATS Routes (in the en route network below Free Route Airspace). This may result in significantly less vectoring by 2030 [*European Airspace Concept Handbook, No 1*]. Moreover, RNAV 1/RNP 1 navigation specifications used in an independent surveillance environment provide the possibility to reduce the lateral spacing between routes; by 2030, ANSPs could have implemented a system of strategically de-conflicted ATS Routes in extended terminal areas. [*European Airspace Concept Handbook No. 1*]

As regards Infrastructure Managers, because PBN flight paths can be placed anywhere[1] (obstacles permitting), the **infrastructure managers must know where these PBN flight paths will be placed so that effective positioning coverage is made available along the flight paths for both nominal and contingency operations.** [*Infrastructure Planning Handbook No.4*].

Over time, GNSS supplants conventional Navaids as the primary positioning source.

Operationally, during normal operations, primary reliance on GNSS for positioning is of little relevance to the controller outside the final approach; in reality, the controller is mostly unaware of which positioning source is being used. If GNSS becomes unusable locally or over a wider area, the controller could most likely receive reports and need to know that the aircraft can continue to navigate i.e. that alternative positioning is provided e.g. using DME/DME for RNAV 1. In the Budapest Simulations it was found useful for the controllers to have an indication on their surveillance display as to which aircraft could continue navigation without GNSS[2].

For Infrastructure Managers, the shift to GNSS as the primary positioning source is significant: *first,* GNSS vulnerability mitigation increases in importance; *second*, it heralds a change to the evolution of the ground-based Navaid infrastructure.

As regards the *first*, the infrastructure manager needs to be fully aware of GNSS interference events, their causes and their impact.

Regarding the *second,* there is a change to the *extent* of the required ground-based Navaid infrastructure i.e. what **MON** is needed to provide the required **A-PNT** (see para. 3.2).

Because GNSS becomes the primary positioning source by 2030, ground-based Navaids to support normal operations are less needed over time. Ground-based Navaids must provide for GNSS reversion: a cost-effective ground-based infrastructure providing adequate **redundancy** must be available in the event of a GPS being unusable to meet the levels of safety (and business continuity) required during contingency.

- Ground-based Navaid Infrastructure optimisation, rationalisation and decommission opportunities change i.e. 'how much' ground-based Navaid infrastructure is needed provides opportunities to streamline and potentially save costs.
- Ground-based Navaid Infrastructure investment decisions are affected, as are equipment life-cycles which impact upon maintenance and replacement schedules.

What is 'Redundancy'?

When DME is an approved sensor for an RNAV 1 SID/STAR, the infrastructure manager will ensure adequate redundancy i.e. that two independent DME pairs can provide positioning anywhere along the flight path. When there is a common DME in those two DME pairs, this is called limited redundancy. When there is only one DME pair providing positioning, there is no redundancy. In such a case, either of the DME stations in the pair become a critical Navaid.

[1] *This simplified statement is provided generically and is not entirely accurate. It alludes to the fact that GNSS positioning is 'usually' available everywhere thus giving total freedom in route design (which was not the case with ground-based Navaids). However, there are places where GNSS cannot be used.*

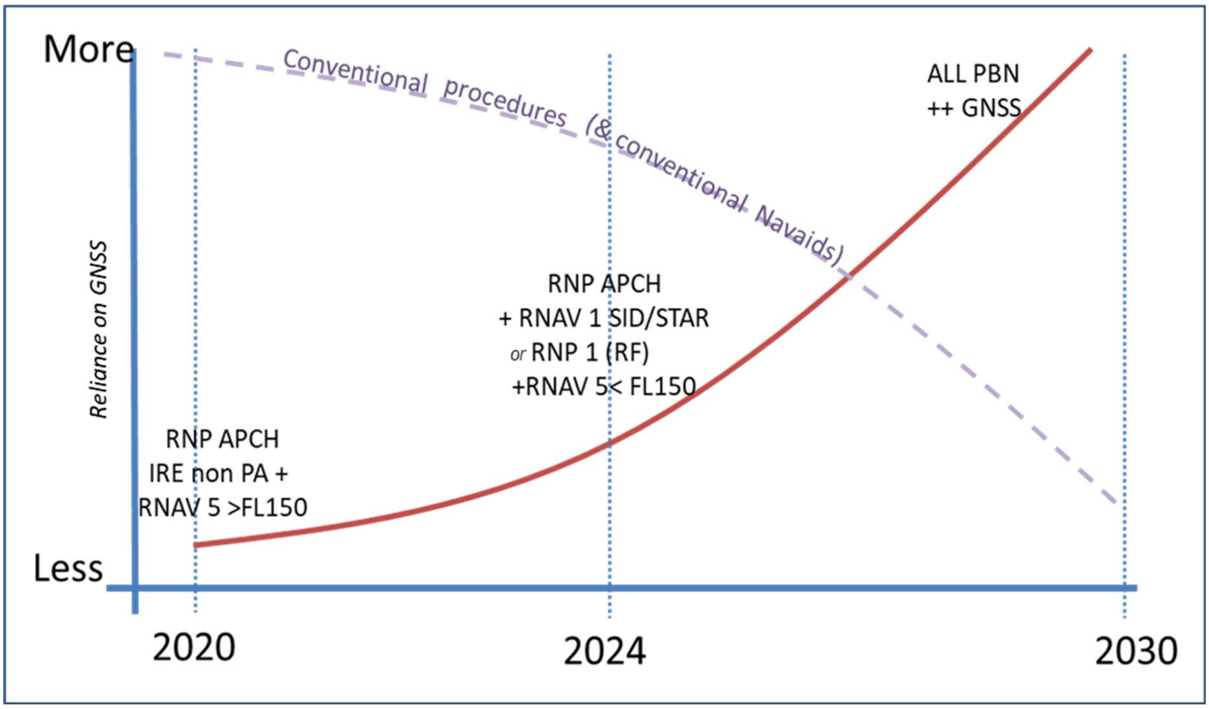
[2] *An automated solution requiring updates to the SDPS or FDPS would not be cost effective. Should the ATM System provide for manual 'flagging', the controller could then 'mark' a target thus passing on the information when the transfer of control and communication occurs. However, this (less expensive) solution could increase RTF and the workload for the initial controller 'marking' the target(s).*

3.3.2 *Impact of the operating environment's evolution over Time*

Notably, however, the PBN regulation is incremental in the demands it makes for PBN implementation, and the central position to be played by GPS. The 'All PBN' in the picture below is the point at which GNSS is likely to be the central positioning player. At this point, there is also likely to have the greatest density of closely spaced strategically de-conflicted PBN routes in an airspace.

Assuming an ANSP followed the letter of the regulation, then in 2020, GPS or SBAS being unusable would only have a direct and distinct impact an aircraft flying an RNP APCH. This impact would increase to maximum by 2024 when all Instrument Runway Ends are to have RNP APCHs with three lines of minima especially if ILS CAT I have been rationalised at airports with only this level of ILS. Across the network, the equivalent level of impact would probably only be reached in 2030. But nothing prevents ANSPs implementing faster than required by regulation – and their graphs could look slightly different.

Figure 3-3: Incremental Requirements of PBN Regulations



The key message of this diagram is that the GPS being unusable will have a different impact depending on *when* (which year) in terms of regulation, the problem occurs and how dependent the fleet operating in the fleet is on GNSS alone. The 'timing criterion' i.e. the 'when', is not the only factor as others also play a role as becomes evident below.

Impact of the Duration and Area in which GPS is unusable.

The dimensions of the area in which GNSS is unusable, the duration of this non availability and the density/kind of traffic are some of the key *factors* determining the impact and the mitigations used. The latter may require the activation of **contingency procedures.** The combination of *factors* is so extensive, that a few examples are provided to give an idea of the consideration needed when developing contingency and reversion.

Example 1: GNSS Unusable over an extended area such as the RFI events experienced in the eastern Mediterranean over several months in 2018. In this case, cockpit indications vary e.g. "GPS Primary Lost" message in Airbus aircraft – source EVAIR or there may be a position disagreement (between FMS 1 and FMS 2, ranging from 2 to 25NM – source ICAO) and terrain warnings with (unnecessary) pull-up requests. In some reported cases, there have been simultaneous events on multiple CNS frequencies (GPS L1 and on or near the 1090 MHz SSR frequency). In general, these events have, thus far, been considered an operational nuisance without significant impact, however, when losing some CNS capabilities (especially over water), safety margins may be reduced and additional problems could increase risk. In this case, however, most of the aircraft operating in the area where the GNSS was unusable for an extended period, were exposed to this GNSS status for a less than two hours. Furthermore, these air transport aircraft operating in the area have IRS to support position determination. As a consequence, the impact was mainly of nuisance value.

Example 2: GNSS Unusable 'locally' - such as experienced by major European TMAs with high density traffic or the uncoordinated use of drone jammers. Often these events occur through carelessness or use of personal privacy devices - PPD (truckers not wanting to be tracked), and in some cases, due to 'controlled' testing of military equipment. Even 'unusable' status of short duration could cause RNP APCHs to be abandoned and possibly cause diversions. The scale of the impact would be different in 2020 than in 2024. Some SID/STARs may also be disabled, where either the SID/STAR is predicated only on GPS or the aircraft positioning capability is limited to GPS. Again, the scale of the impact would depend on when along the evolutionary timeline this problem occurs i.e. 2021 vs. 2028? Longer periods of GPS being unusable would extend the impact and may cause flow control measures to be introduced as aircraft are managed manually by Vectoring. (Note, that in the case of RNP APCH to LPV minima being prevalent at an airport, the loss of SBAS could also induce go-arounds or diversions in some instances).

Example 3. GNSS is Unusable over a 'Wide Area for a medium duration in medium/high density airspace: - such as those tested in the Budapest RNP simulations in 2014. In these scenarios say in 2030, several aircraft operating across a number of sectors could report that GPS is unusable, which means that exposure to GNSS being unusable by each aircraft could be extensive. Of key importance to the controller in the Budapest Simulations was knowing which aircraft needed navigational assistance and which did not. (The former were those who had no other positioning means). Whilst these controllers had the benefit of tailor-made procedures, with an indication on the Surveillance Display showing which aircraft needed navigational assistance, the increased workload caused controllers' to question whether they could sustain working 'manually' for more than 1.5 to 2 hours. Furthermore, a network wide impact was anticipated whereby the network manager could be required to reduce the flows of air traffic to acceptable levels for the ATC centres. Thus this kind of scenario could affect traffic throughput, e.g. by preventing access for aircraft with GNSS as the only PBN position sensor, and seriously impact upon business continuity. As regards the evolutionary timeline, if this scenario played out in 2020 in some of the terminal areas where RNAV 1 is already implemented with significant reliance on GPS, the impact could be significant.

Example 4: GNSS is Unusable over a Wide Area for an Extended Duration: Society has a high dependency on GPS (which includes a variety of systems used across a multitude of sectors in society such as power plants, rail networks, financial services, distribution plants, mobile telephone systems, internet). While a short- or medium-term loss of GPS would have a certain impact on aviation through its effect on CNS, should the GPS be unusable for a long-duration, the societal impact could be significant and will probably necessitate national strategic decision making.

3.3.3 Contingency/Reversion for RNAV 1/RNP 1 SIDS/STARs

Cross Reference: European Airspace Concept Handbook No.1, Activity 7, Airspace Design – Routes & Holds, page 22.

When developing a Future Airspace Concept, ATM needs to establish how to continue safe operations in the event of GNSS no longer being usable for RNAV 1/RNP 1 SIDS/STARs. Here, ATM *contingency* operations could be drawn from a variety of means available to ensure the safe flow of traffic (which is the prime objective). For example:

- Can a surveillance service with a communication service compensate for the GNSS being unusable, giving vectoring instructions; or
- Can procedural control based on ATM Procedures and Communication be used; or
- Can current operations continue to be flown using RNAV 1 based on DME/DME positioning (**A-PNT**) and/or whether the traffic flow rate needs to be reduced.

In determining the 'right' scenario for the contingency operations to be developed, **it is crucial that the package of contingency procedures for an *entire* ATM operation are looked at together. For example:**

- if only ADS-B is used for surveillance in a particular area, it would be pointless to define contingency procedures based on surveillance if the GPS fails, as ADS-B is reliant on the GPS position from the aircraft and therefore the surveillance system will not be available either;
- if severe weather is known to be frequent in a particular area, the contingency operations for severe weather and those of reversion from RNAV1/RNP 1 should be considered together.

Therefore, **Contingency scenarios** are developed for different types of operating environments to permit operations to continue safely. These scenarios are also tested and validated.

Cross Reference: European Airspace Concept Handbook No.1, Activity 11, Airspace Concept Validation, page 29.

Infrastructure Managers are often squeezed between what ATC needs for contingency operations and other drivers such as cost savings (to reduce the infrastructure), spectrum pressure (to use the aviation frequency bands for other purposes) or performance targets (to optimise the infrastructure). This does not suggest that safety should be adjusted to business needs, but rather that the contingency/performance balancing process should not compromise acceptable levels of safety (which may be achieved in various ways).

It is therefore critical that ATM and Infrastructure Managers work *together* on topics related to both normal operations and contingency operations. This is a fundamental premise of successful PBN implementation.

3.4 Summary

This chapter has explained a variety of terminology, detailed positioning requirements and looked at the impact of European PBN regulatory requirements. The key conclusion to be reached is that successful contingency scenarios can only be built by ATM and Infrastructure Managers working together.

It is evident that ATM has to plan Contingency Scenarios, and the Infrastructure Mangers have to plan what reversion infrastructure will be available to support such contingency. It is therefore critical that ATM clearly communicates its requirements to the Navaid Infrastructure Manager to permit the infrastructure to be right-sized and to ensure the safety of the operational environment.

The *European Airspace Concept Handbook No.1* discusses contingency as part of the development of the Future Airspace Concept. Similarly, the *Infrastructure Planning Handbook No.4,* provides guidance to Infrastructure Managers.

4. SCENARIOS FOR GNSS CONTINGENCY / REVERSION

This Chapter is divided into two parts:

- Part I, Contingency Considerations, provides questions which could be used by the ANSP and its stakeholders when developing the airspace concept which *must* include contingency procedures. After this, the notion of CNS-trade-offs is introduced to avoid PBN implementation teams forgetting that CNS/ATM is one system and different parts of it can be used (traded-off) to ensure overall system safety.
- Part II, Scenario Examples, provides two examples of airspace concepts with their contingency operations. The significant differences in Europe in terms of varying levels of complexity and density have determined the scope of these Scenarios and their granularity. The examples are generic, aimed at providing ANSPs with a starter-pack when considering GNSS reversion and associated contingency procedure development in their environment.

Note: Appendix II provides the reader with two anonymised examples of GNSS interference which local contingency plans have addressed with operational and technical mitigations.

Part I
Contingency Considerations

4.1 Introduction

Currently, Air Traffic Controllers and Infrastructure Managers have quite different perspectives on ATM in general: where the controller sees and thinks almost exclusively about the *operations* and *associated* procedures, the Infrastructure Manager things of ATM in terms of technology, and how well it needs to work and its cost. Different perspectives also extend to the positioning source used by aircraft operating along flight paths. In a PBN environment, the controller is mostly unaware which positioning source is being used, a view which is more confined than that of Infrastructure Managers, procedure designers and airline operators.

The Table in Chapter 1 shows that by 2030, a full PBN implementation environment, based primarily on GNSS positioning, will be the norm. In terminal and extended terminal airspace, the premise is that systemised and strategically de-conflicted RNAV 1 SIDs and STARs (as a minimum) will be increasingly the norm, along with other PBN navigation specifications in other flight phases as well as those catering for helicopters.

Key Point

Clearly, the PBN IR increasingly makes GNSS the primary positioning source for a total PBN normal operating environment by 2030. Therefore, reliance on GNSS will be greater than ever before. In the 2020-2030 decade, GNSS means *single-frequency, single constellation* GNSS i.e. GPS, as DF-MC is unlikely to be widely available across the fleet. [See Appendix 1 for system reliance on GPS].

This change in preferred positioning source for PBN supports the premise that European terminal/extended terminal PBN routes will be systemised and strategically de-conflicted.

Together, these realities make it crucial for ANSPs to ensure that contingency operations are possible in the event of a GNSS outage. A non-GNSS *reversion* infrastructure must be available and usable by the airspace user.

Given the above, this chapter provides generic scenarios looking at the decade 2020 to 2030, for which ANSPs will need to develop different 'grades' of contingency scenarios depending on the extent of PBN implementation. These scenarios aim to provide guidance and examples for ANSPs to consider and assess their own reversion scenarios and the impact of a loss of GPS. Each ANSP should develop scenarios based on their own operational capabilities, CNS support arrangements, and operational requirements to determine the resilience of their ATM system to loss of GNSS. A rigorous analysis of both airborne and ground components is required by the ANSP.

The different levels/grades of contingency scenarios developed by ANSPs will probably evolve due to the increasing demand made on PBN between 2024 and 2030. Furthermore, the fact that terminal operations are not homogenous means that considerable differences in contingency operations can exist for different locations in the same period. Simply put, contingency procedures for Arlanda could be expected to be more complex than those for Kiruna.

As the starting point for ANSP reflection, Part I provides a series of questions which should be considered when determining contingency operations.

Naturally, this list is non-exhaustive and generic; local implementation characteristics dictate that ANSPs will add many more of their own questions. It would be ideal that once this GNSS contingency 'thinking' evolves more fully, that these questions are shared, for example, on the PBN portal, for the general benefit of the PBN community.

4.2 Considerations for planning Contingency Operations

A. Probability of a GNSS outage

- **What are the threats?**
    - Space weather – ionospheric blackout
    - Interference – Unintentional (mitigate by policing and education), intentional or malicious interference – impact area? (refer to attachments)
    - Constellation Outage – what and how long? (Examples are: GLONASS in 2014 (navigation data issue); GPS in 2016 (timing issue), Galileo 2019 (navigation data issue). Would the outage impact more than aviation? What would be the level of societal impact?

> **TIP:**
>
> *This is a complex question without easy answers. Fortunately, many ANSPs share experiences especially at EUROCONTROL stakeholder meetings. Surveillance colleagues can also assist, especially where ADS-B is used – they may be collecting data on ADS-B degradation experienced in some areas, which is usually due to GNSS signal loss. EVAIR data, and later, the e-PBN portal, can provide information.*

B. How wide and/or how long is the impacted area likely to be?

- **Area**
    - Approach, terminal, ACC, an FIR, all National airspace?
    - Awareness of outage? – How (see Section 2)
    - Knowledge of airspace impacted. (How will the controller know?)

> **TIP:**
>
> *A GNSS outage can be local (affect an airport) or affect a wider area. An outage area will seldom, if ever, follow the lines of a controlled airspace boundary! In some cases, cooperation between neighbours and groups of States may be needed (See European Airspace Concept Handbook for PBN Implementation Handbook No 1,) which encourages a team approach. The question regarding area outage also has no easy answers, and it is this and other uncertainties that makes GNSS outage/contingency a complex planning issue for controllers and Infrastructure managers alike. Therefore it is imperative to be creative – yet realistic – in scenario development.*
>
> *Some ATC systems are capable of flagging which aircraft only have GNSS navigation. And this will affect the capacity and management of the traffic during contingency operations.*

- **Time**
  - Short duration – up to one hour?
  - Longer duration – in hours or days – again societal impact?

> **TIP:**
>
> *A longer outage does not automatically mean a bigger challenge in terms of contingency. The traffic density, complexity and reliance on GNSS in the operations are key determining factors. For example, if an area has Radar Surveillance and there is a GNSS outage, the navigation of some aircraft may be affected (those that carry only GNSS), but the surveillance service is still available and these aircraft can be radar vectored. There is a view that a long term outage would cause a significant societal impact and affect various transport modes, banking transactions, traffic lights ….. This is why, GNSS contingency planning is not only a local concern, but it concerns neighbours and beyond. As such, planning must be coordinated with the Network Manager as it may affect capacity and flow control measures.*

C. What systems can be impacted by the loss of GPS in terms of CNS?

- **Airborne**
  - Navigation – Position (if single sensor)
  - Communication – Time desync, CPDLC, SATCOM antenna steerage
  - Surveillance –ADS-B
  - Ancillary safety – TWAS/EGPWS, geometric altimetry, synthetic vision loss, combined vision systems degraded.
  - In case of accident – loss of ELT leading to impact on SAR.
- **Ground**
  - Navigation – GBAS
  - Surveillance – ADS, possible time desync of MLAT, multi-sensor tracking
  - Communication – De-syncing of time stamp (CPDLC)

*Note: Refer to **Appendix 1** for more detailed info on loss of services*

D. List the ATM/CNS systems still available following GPS unusable

> **TIP:**
>
> *The specific characteristics of local installations are key here, which is why it is important when determining the impact of a GNSS outage. This is evident from Appendix 1 hence the strongly worded caveat at the beginning of the Appendix. Cooperation between all system engineers working on the Infrastructure is crucial; **a CNS/ATM System team should address GNSS reversion together.***

E. What is the impact on current operations?

- How many aircraft require navigation assistance in the form of vectoring due to GNSS loss?
  - What is the impact on sector capacity?
- Safety implications e.g. must spacing between routes be adapted – immediately or after a certain period?

- What percentage of aircraft will need to land, cannot take off due to loss of signal?
- Are flow control measures needed because, for example, capacity is to be reduced or airport access must be limited?
- Is ATM or flight efficiency affected?
- Is there an environmental impact in previously unaffected areas (e.g. noise exposure change; visual intrusion due to holding)?
- Additional considerations – Loss of Situational Awareness (SA), workload increase

Key Point

The primary question of interest to ANSPs, Airlines and Regulators, is the impact of a GNSS outage on Safety and Capacity. It is possible that the impact on safety will require capacity to be reduced. A choice can be made by the ANSP, to provide the kind of reversion infrastructure (and ATM system) that results in a seamless continuation of operation when one system goes off and another takes its place. Such a choice may require significant investment by the ANSP. A good example of this was the uninterrupted back-up power supplies that were introduced several decades ago. Today, the operational controller barely notices when the main power supply goes off because there is near 'invisible' switch-over to an alternative supply of electricity. (Though the controller will be informed that the operation is now on backup power). Contingency planning affects all stakeholders – and can call for investment from a variety of stakeholders depending on the strategic (contingency) objectives decided between the ANSP and its stakeholders. As such, investment may also have to be made by the Airspace User, to equip, for example, with DME/DME to cater for contingency operations. If the AU elects not to do so (or cannot do so), this could affect their business continuity, as they may not be able to operate without GNSS.

These realities again demonstrate why GNSS reversion and Contingency Procedures are a joint effort between all stakeholders including ANSPs in general, airspace users, controllers and engineers.

F. What level of service is to be provided during contingency operations?

This strategic question concerns all stakeholders, which could be dictated by State policy through the Regulator, and several layers of decision making which include the ANSP, the airspace users down to operational personnel. At a simple level, a decision could be made to shut down operations if there is a GNSS outage – this solution might be 'safe' but extremely unlikely and unacceptable in terms of business continuity. This is why this top level question 'what level of service is to be provided during contingency operations' is of critical importance. Whilst the questions which preceded it deal with understanding the landscape of the fleet and operations, this question marks the beginning of GNSS contingency planning.

- Define requirements on Capacity, Efficiency and/or Access whilst maintaining required safety levels. (what is the pressure to continue operations)
    - Full operations? *(This could require considerable investment, see next point)*
    - Limited Operations? (*This could require negotiation between stakeholders, see next inset)*
    - No operations? Get all aircraft safely on the ground. *(This would be 'absolutely' safe, but there would be no 'zero' business continuity)*

G. How does the ANSP maintain the desired level of operations?

- **Can full operations be maintained without loss of safety?**
    - If Yes.
        - Is there a time constraint?
        - Is the infrastructure sufficiently robust to support further degradation? (e.g. time desynchronization of systems, continuity of service provided by backup infrastructure).

- If No.
  - Determine the acceptable level of operations and ensure a suitable match between the infrastructure, airborne equipage, airspace user needs and ANSP decision making.

THE BUDAPEST SIMULATIONS AND ROUTE SPACING STUDIES

The GNSS Reversion RTS, held in 2014, showed that for a period of 1 ½ hours the controllers could maintain the same capacity in an airspace where 20% of the traffic had GNSS only for positioning and the DME infrastructure allowed reversion from RNP 1 to RNAV 1. The European Route Spacing Handbook (No. 3) shows that the navigation positioning does not degrade to the extent that it affects the spacing between routes as long as there is an appropriate DME infrastructure and aircraft are suitably equipped. Key to this is that the routes and procedures are correctly designed (see the European Airspace Concept Handbook for PBN Implementation (No.1)), which explains that having an airspace design based on solid assumptions is key i.e. the right information must be available regarding the available infrastructure ***and*** *the contingency procedures must be coherent with the available infrastructure.*

The Budapest Simulation also showed that the longer the GNSS outage continued, the greater the exposure to risk became because of the increased controller workload that could not be safely maintained. A way of ensuring the maintenance of safety levels over (a longer) time could be, for example, to ground aircraft without D/D/I – but this would impact their business continuity, whilst maintaining the system safety levels.

If an ANSP concludes that there will be a loss of capacity of X% in Sectors A-B-C during a GNSS outage, then the capacity impact of ANSP contingency plans for GNSS outage must be communicated to the Network Manager as this will affect overall demand and capacity balancing across the network.

H. WHAT IS THE CONTINGENCY OPERATIONS CONCEPT?

- Alternative operations?
- Aerodrome capacity implications in the event of diversion or reduced operations

TIP:

The European Airspace Concept Handbook for PBN Implementation (No. 1) explains how an airspace concept is developed. When developing the airspace concept both normal and contingency operations must be catered for. This means, that a separate standalone airspace concept is not developed in isolation but as part of the main airspace concept development. This point is being re-emphasised in the 2020 update to the Handbook No 1. Contingency operations may require contingency routes (and/or holding patterns) to be used/created, or specific ATM contingency operations procedures to be promulgated. Alternatively, aircraft may need to divert, or execute visual approaches.

I. WHAT CURRENT INFRASTRUCTURE EXISTS TO ENABLE CONTINGENCY OPERATIONS?

- Is the infrastructure sufficient to meet the declared safety and capacity levels for contingency operations within the airspace concept?
- If not, what is required?
  - Ground infrastructure:
    - Additional NAVAIDs?
    - Alternative surveillance available

- Airborne infrastructure:
  - Are aircraft fitted with alternative equipment? (fleet analysis).
  - Additional equipment for reversion - weight
  - Retrofit?
  - Use of inertial – if fitted

J. Cost Benefit Analysis considerations

- ANSPs – Spreading of an asset's costs over time; controller licencing and training;
  - *Benefits:* airspace capacity and maintained safety levels; business continuity.
- AOs – Retrofit, certification and pilot recurrent training;
  - *Benefits:* business continuity; access to airspace and airports.

K. Supplementary Considerations for pilots and controllers

- Operational awareness of degraded environment.
- Ability to demonstrate required competency in managing contingency procedures; this may require extensive/intensive recurrent training to avoid deskilling.
- Flight crew awareness of the impact of GPS outage on the specific aircraft type and the corresponding operational procedures.
- If appropriate, provide supplemental local training to controllers for contingency operations.
  - Do the controllers and pilots hold appropriate licences for the contingency environment? (See Tip).
- Maintenance of skill sets for the contingency environment, e.g:
  - Controller - procedural control, radar vectoring.
  - Pilot - flying NDB or VOR conventional procedures.
- For ab-initio and practising controllers and pilots, is the appropriate training in place for the contingency environment?

> **Tip:**
>
> *The contingency operations envisaged by the ANSP must match the ATC licence endorsements, the aircraft certification, and the flight crew licencing privileges. If procedural control is required for contingency operations, the controllers must be licenced for procedural control and their recurrent training must be ensured.*
>
> *If the contingency operation is based on conventional infrastructure, the aircraft must have the appropriate avionics and the pilots must be competent to fly the conventional procedures. This competency should be maintained through recurrent training.*

4.3 Trade-offs in Contingency Scenario Planning

Cross Reference: European Airspace Concept Handbook No. 1, Activity 6, Enablers, Constraints and ATM CNS Assumptions, page 21. See also, PBN Manual, Volume I, Part A, Chapters 1-3.

No CNS enabler single-handedly resolves all an aircraft's technical challenges in flight. Whilst Communication, Navigation and Surveillance have historically been 'separated', primarily for safety and historical reasons, together with the on-board avionics and flight crew, the safety of flight has been assured. The separation of C-N-S system is changing: as these systems evolve, they are increasingly relying on **GNSS**.

PBN discussions show that GNSS is used by several CNS systems, e.g. time-stamping of data transfers in message sets (COM), synchronisation of surveillance data processors (SUR), in some systems, Data Link (communication) timing (COM). These systems often have back-up timing sources or other reversion means. For back-up timing sources, GNSS being unusable becomes important if the duration is such that a significant clock drift occurs causing de-synchronisation. So even this simple example given above shows that **GNSS is a common point, a shared resource for Communication, Navigation and Surveillance and that a GNSS being unusable has the potential to disrupt operations depending on how much GNSS provides the backbone of various C-N-S elements**.

In terms of *navigation,* the European fleet and Navaid Infrastructure is well equipped: Europe is fortunate to have a rich DME infrastructure and over 90% of the ECAC fleet is equipped with DME/DME RNAV capability[3]. Indeed, in major European hubs, 98% of the fleet is equipped with DME/DME positioning capability[3]. What this suggests is that most aircraft can maintain 'normal' navigation for a reasonable time after GNSS becomes unusable – though of course, this statement is not absolute.

Operationally, and when providing for CNS-redundancy to cater for GNSS outage, it is important to remember that trade-offs between ATM and C-N-S are possible. For example, capacity could be reduced during a GNSS outage e.g. because X% of the fleet cannot continue to 'self' navigate and the controller's extra radar vectoring workload must be limited. Here the 'load' brought about by the GNSS outage has been 'traded' or moved to another part of the total system: one technology has failed and to mitigate this, capacity is reduced to manage the controllers' increased workload. Trade-offs are usually decided during contingency planning as part of the airspace concept development (see Handbook No 1); they aim to guarantee safety, but these can be pressurised due to conflicting interests in business continuity, investment decisions, training and cost.

The diagram below attempts to show how different decisions (trade-offs within the system) can be taken for a single scenario (see High Level Scenario A with two Contingency Options with different choices made).

Having considered a complex set of questions and introduced the notion of trade-offs that permeate the development of contingency procedure development and infrastructure provision, this chapter goes on to examines two generic scenarios developed for contingency operations.

Figure 4-1: CNS Trade-offs

Read rows from LEFT to RIGHT	Nav Performance	*Risk*	*Mitigation of Risk*
NORMAL OPR	RNP 1 Operations using GNSS	Acceptable level of risk included.	Radar environment; ATC tools; procedures; Airspace Design.
GNSS UNUSABLE			↓ CONTINGENCY OPTIONS ↓
High Level Scenario A *(rich DME/DME Infrastructure)*	GNSS loss impacts the entire fleet but in different ways: 20% of fleet loses NAV capability (because they only have GNSS positioning); 80% continue RNAV 1 operations using D/D/I, for which they are certified.	Increased exposure to risk as 20% of fleet need ATC assistance. (See *Budapest Simulation and Route Spacing Studies,* above)	#1 Accept all aircraft and manage by Radar vectoring those without D/D, Increased RTF and ATCO workload; training required (i.e. cost). Network Manager may be impacted.
			#2 Radar vector or divert ac unable to navigate. Deny further access to non-D/D ac. Manage airspace through ATFCM Measures (Demand and Capacity balancing). Increased workload for Network Management and FMPs
High Level Scenario B *(rich DME/DME Infrastructure)*	GNSS loss impacts the entire fleet but all aircraft are certified for D/D/I and so can continue to navigate using RNAV 1	Loss of on-board performance monitoring and alerting although lateral navigation performance minimally affected.	Increased Radar Monitoring, workload and training required (i.e. cost). May require Route adherence monitoring (RAM) (cost).

TLS Met

[3] *Fleet assessments based on Flight Plan Data extracted from the CNS dashboard, and fleet analyses undertaken for the Route Spacing studies included in the Route Spacing Handbook No. 3.*

Part 2
Scenario Examples

4.4 Scenarios 1 & 2: Continental Terminal and Extended Terminal

Scenario 1 correlates to airport & terminal/operating environments characterised by high-density traffic and/or high-complexity post 2030, when all aircraft will be operating on PBN procedures.

Scenario 2 correlates approximately to other airports & terminal/operating environments catering to commercial air traffic. This scenario considers that some but not all of the procedures are already compliant with the PBN Implementing Regulation in the 2024-2030 timeframe.

Both Scenarios start by showing what is available and used during **Normal Operations (NML)**: i.e. what Infrastructure is available and which Navigation Applications are in use based (also) on the fleet equipage and other capabilities. The **NML** scenarios also show what route spacing is applied, what separation minima are used based on which surveillance system and how communication is achieved.

Both **Reversion/Contingency (REV) Scenarios** are then shown, noting the unavailability of GNSS. Under the Infrastructure those CNS elements which are 'lost' due to the GNSS outage are struck out and, consequently, those 'Normal' navigation applications which have been impacted by the infrastructure loss are also struck out. The remaining available infrastructure/capabilities without GNSS are then able to support contingency procedures once the considerations raised in the rest of Part I have been addressed.

These examples are not complete because they cannot be: their formulation is intended to assist ANSPs in thinking through the possible contingency scenarios which could be developed.

Although the PBN-IR foresees three specific timeframes for the deployment of PBN within the terminal airspace, only two environments are considered and reflected in Scenarios 1 and 2: a high density, core ECAC terminal airspace complying with the PBN-IR c. 2030 where PBN operations are the norm, and, a lower density TMA complying with the PBN-IR based on Conventional as well as RNAV 1 SIDs and STARs in the period 2024-2030.

It should be noted that some European airports have implemented RNAV 1 SIDs/STARs already, which makes them fully compliant with both the 2024 and 2030 PBN regulatory requirements for PBN SIDS/STARs. However, as of 2021, very RNP 1 SIDs and STARs have been deployed across Europe.

Consequently, in 2021, GNSS being unusable for an airport having RNAV 1 SIDS/STARS based only on GNSS, would be the same as for this same airport having all RNAV 1 SIDs/STARs based only on GNSS by 2030. This must be kept in mind when looking at the scenarios.

Reading the Scenarios and decoding the 'shorthand' used

Although extensive use is made of the word 'assumption' in the scenarios developed in this Part, when the development of the airspace concept is underway, which includes contingency procedures, the available technology and fleet equipage would be known and not assumed. This is dealt with in the European Airspace Concept Handbook for PBN Implementation (Handbook No 1)

Scenario descriptions start by showing available technology (infrastructure/avionics) followed by the supported Airspace Concept and operations. This technology-based view is preferred because these scenarios deal with loss of a part of the infrastructure which then impacts upon operations.

The two Scenarios are ordered as NORMAL OPERATIONS and a corresponding REVERSION Scenario.

In the REVERSION scenario:

— Struck out red text e.g. ~~GNSS,~~ indicates that the {struck-out} technology cannot be used and that as a consequence, the {struck out} navigation function (e.g. ~~RF~~) or navigation specification (e.g. ~~RNP 0.3~~) or particular route spacing (~~e.g. 5 NM~~) cannot be used either given the remaining CNS enablers without GNSS.

— Red text written in italics, e.g. *RF,* means that it is considered probable that there would be significant impact in the short or medium term, thus requiring consideration when planning contingency procedures.

— Highlight text indicates what may need to be made available to accommodate contingency operations/reversion.

Explanatory notes are provided in the Reversion Scenarios.

This document and the scenario descriptions have taken account of the fact that referring to terminal operations having different levels of complexity or density often generates debate, particularly as some low-density operations can have extremely high complexity due to lacking equipage, staffing issues, terrain challenges etc.
As such, in this document these terms are generalised and are intentionally not defined, but parallels or equivalencies are roughly drawn.

4.4.1 Scenario 1: correlates to airport & terminal /operating environments characterised by high-density traffic and/or high-complexity post 2030

The airport and the associated terminal/extended terminal operations described in this Scenario is fully compliant with the PBN-IR when all aircraft will be operating on PBN procedures as of June 2030.

NORMAL OPERATIONS (NML) – GNSS IS AVAILABLE

AVAILABLE NAVAID INFRASTRUCTURE

The following *assumptions* are made in this scenario regarding the Navaid Infrastructure such as:

- GPS is available for use in all phases of flight
- There is good DME/DME and VOR/DME coverage down to Minimum Vectoring Altitude (MVA) to support TMA and approach operations
- The airport uses SBAS or/and GBAS systems as a default to support the approach operations down to CAT I.
- The airport has ILS on some runway ends. This supports approach operations for aircraft non-equipped with SBAS/GBAS and supports low visibility operations (LVO) down to CAT IIIB.

Note: Currently, precision approaches with an DA/DH below 200 feet are not included in the PBN IR, which also excludes GBAS operations. Nevertheless, the GBAS is being certified to provide for CAT II/III operations and can be a replacement to ILS. It also provides other benefits as one system can serve multiple runway ends and there are no critical or sensitive areas for low visibility operations, such as exist with ILS Cat II/III. Several mainline Airbus and Boeing aircraft types operating at busy European airports are equipped with GBAS. As such Frankfurt has already installed the GBAS system and in the future other busy European airports may do so, in the context of ILS rationalisation and future operations based exclusively in GNSS technologies. Therefore, GBAS is included in the scenario.

Sc. 1 – **NML**

FLEET POSITIONING CAPABILITIES FOR PBN

Mindful that all pilots operating in this Scenario hold the necessary EASA PBN privileges, the following *assumptions* are made on the aircraft equipage/certification of the operating fleet:

- All aircraft are equipped with single frequency GPS receivers primarily employing RAIM for integrity.
- At least 90% of the aircraft are equipped with DME/DME (and some with VOR/DME) for area navigation capability.
- The majority of aircraft are equipped with inertial systems (INS/IRS/IRU).
- 20% of the aircraft are equipped with SBAS/GBAS
- All aircraft are equipped with and certified to use ILS.
- All aircraft are certified for RNAV 5 operations using either VOR/DME or DME/DME or GPS.
- All aircraft are certified for RNAV 1 operations based on GPS and 90% of this aircraft fleet are certified for RNAV 1 operations based on DME/DME with or without IRU.
- Some aircraft are certified for RNP 1 with the use of RF outside the final approach segment.
- All aircraft are certified for RNP APCH operations to LNAV.
- The majority of aircraft for RNP APCH operations with LNAV/VNAV minima.
- 20% of the aircraft are certified for RNP APCH operations to LPV minima or SBAS CAT 1/GBAS CAT I.

Communication and Surveillance Means

The following *assumptions* are made regarding the SUR and COM infrastructure of the scenario TMA and airport.

- Non-cooperative surveillance (primary radar) available at the airport.
- At least 2 independent cooperative ATS surveillance systems are available, one of which is MSSR.
- ADS-B is available.
- Controllers use VHF Voice as the primary communication means with multiple frequencies.
- Data Link is available.

Timing

It is assumed that the ground systems used in the scenario airport have independent stable timing source that can be used in case of GPS loss. Some ground systems may suffer time synchronization issues when GPS is unusable for a long time.

It is assumed that on-board the majority of the aircraft, the C-N-S systems rely primarily on GPS for position and timing. Some back-up source for both navigation and timing is available; however, should GNSS be unusable for long periods, significant clock drifts could occur.

Note: This topic is covered in greater detail in Appendix 1

ATC Tools

The *assumption* in this scenario is that there are no additional controller support tools developed for GNSS reversion.

Sc. 1 – **NML**

NAV APPLICATIONS ENABLING THE AIRSPACE CONCEPT

The ATS surveillance capability is independent and enables a 5NM separation minima en route and 3NM separation minima in terminal airspace operations.

Above FL305 there is Free Route Airspace in accordance with AF#3 of the [EU] 2021/116 (CP 1 IR). RNAV 5 is the performance required by ICAO EUR Doc 7030, Regional Supplementary Procedures.

For all ATS Routes excluding SIDS/STARs, RNAV 5 is mandated, EU 2018/1048 (PBN IR).

All helicopter operations are based on RNP 0.3.

For the SID/STARs:

- Some SIDS/STARs are published as RNP 1 with Radius to Fix (RF) transitions where required.
- Most SIDS/STARs are published as RNAV 1 with Fly-by transitions only.
- For RNP 1 routes the spacing of 5NM is used for straight and turning segments, where RF is required.
- For RNAV 1 routes the spacing of 5NM is used for straight segments only, with increased spacing at the turn.
- A single conventional procedure based on VOR/DME is available to comply with Article 6 of the PBN IR, Contingency Measures.

For the Approach, RNP approaches are main landing mode:

- RNP APCH procedures are published with LNAV, LNAV/VNAV and LPV minima.
- RNP AR APCH procedures are published specifically for Mode 1 parallel approach operations.
- Precision approach procedures are published to CAT I minima for ILS, GBAS and SBAS.
- Precision approach procedures are published to CAT II/IIIB with ILS.
- When parallel approach operations are in use in Mode 1 (independent) they are enabled by RNP AR APCH or ILS or GBAS.

The missed approach is based on the following:

- RNAV 1 based on DME/DME for the RNP APCH, ILS, and GBAS approach.
- RNP AR extraction achieved using DME/DME and inertial systems.

Note: It is expected that the primary reason for the missed approach is the loss of GPS signal.

Sc. 1 – **NML**

Tabular Summary of Normal Scenario 1

NORMAL INFRASTRUCTURE	
Available Navaid Infrastructure	GPS; SBAS/GBAS ; DME/DME; VOR/DME; ILS
Fleet Positioning Capability for PBN and PA	GPS + D/D > 90% + VOR/DME ; ILS ; SBAS/GBAS 20%
Surveillance Sensors Used	PSR; MULTIPLE SSR; with ADS-B or MLAT
Communication Service Used	Voice; Data Link (CPDLC)
Timing for On-Board Systems	Independent + GPS synchronised
Timing for Ground Systems	Independent + GPS synchronised
NORMAL OPERATIONS (ENR + SID/STAR)	
NAV Applications enabling Airspace Concept:	RNAV 5 (ATS Routes + FRA); RNP 1 + RF (some SID/STAR); RNAV 1 (most SID/STAR); RNP 0.3 (All Heli);
Airspace Concept	PBN enabled FRA above FL 305; ATS Straight and turning parallel routes incl. SID/STARs and non-parallel routes; crossing; Helicopter Routes.
Route Configuration (spacing; interaction; turn)	5 NM on straight and turning RNP 1 route segments with RF req. 5 NM on straight segments between RNAV 1 routes;
Applicable Separation Minima	3 NM in terminal operations; 5NM en route operations;
NORMAL OPERATIONS (Approach)	
Final Approach Segment Applications	RNAV 1 or RNP 1 (using RF) STAR transitioning to any of the following approaches: RNP APCH (LNAV/VNAV; LPV; LNAV); GBAS; RNP AR APCH; ILS;
Approach Operating Concept	RNP approaches are main landing mode. ILS or GBAS for CAT II/III
Multiple Runway Operation	Parallel Approach Operations (Mode 1 Independent)
Missed Approach Guidance	RNP APCH – based on RNAV 1 RNP AR APCH – based on AR extraction D/D + inertial. GBAS approaches – based on RNAV 1 ILS – based on RNAV 1
Separation Minima	2.5 NM longitudinal on Final Approach Segment where 3 NM used as Separation Minima for terminal operations.

Sc. 1 – REV

Reversion Scenario 1: In the event of GNSS being unusable in normal operations

The controllers received multiple radio transmissions from pilots informing them that the aircraft was "unable RNP" or "GPS primary lost" and aircraft were deviating from their assigned ATS routes. It was recognized that GPS was unusable, and the assumption was that this was a wide area loss of signal, therefore contingency measures needed to be implemented in accordance with the agreed reversion plan.

This reversion plan has assessed the following questions.

How were the controllers informed about the outage?

Through RTF

Outage has occurred, how long will it continue?

Assumption: longer than 1 hour

What part of the airspace is impacted by the outage?

Wide area outage impacting all phases of flight and ground systems.

What systems are impacted by the loss of GPS?

- The ground and space systems reliant on GPS (ADS-B, SBAS, GBAS)
- The airborne capability in all phases of flight.

List systems which are still available following GPS unusable

The C-N-S infrastructure remaining is

- DME/DME and VOR/DME with coverage down to Minimum Vectoring Altitude (MVA)
- ILS on some runway ends that support CAT I operations and low visibility operations (LVO) down to CAT IIIB.
- Non-cooperative surveillance (primary radar) available at the airport.
- At least 2 independent cooperative systems are initially still available, one of which is MSSR.
- Controllers use VHF Voice communication as primary communication with multiple frequencies.
- The Data Link is initially still available.
- Time synchronization may be an issue for MLAT, surveillance sensor fusion and Data Link for long period of GPS unusable.

Explanation: Gaps not covered by SSR must be known. If no gaps, impact of ADS-B non-availability negligible. However, if some SSR surveillance gaps are filled by ADS-B, these areas would lose surveillance cover and alternative procedures needed. Some MLAT ground-station clocks are synchronised by GPS – so in longer term outages, MLAT availability may be affected.

ATC Tools

No loss off controller support tool functionalities is expected.

Sc. 1 – REV

REVERSION INFRASTRUCTURE	
Available Navaid Infrastructure	~~GPS~~; ~~SBAS/GBAS~~ ; DME/DME; VOR/DME; ILS
Fleet Positioning Capability for PBN	~~GPS~~ + D/D > 90% + VOR/DME ; ILS; ~~SBAS/GBAS 20%~~
Surveillance Sensors Used	PSR; MULTIPLE SSR; with ~~ADS-B~~ or MLAT
Communication Service Used	Voice; ~~Data Link (CPDLC)~~
Data Link Explanation: Whilst Data Link may not be lost immediately, it can be lost in the longer term if the outrage timing is extended.	
Timing for On-Board Systems	Independent ~~+ GPS synchronised~~
Timing for Ground Systems	Independent ~~+ GPS synchronised~~

Operational impact on current operations

- Percentage of aircraft impacted by loss of signal: 100%, however the reversion fleet capability is:
    - 90% of aircraft fleet can continue RNAV 1 operations based on DME/DME with or without IRU and 10% can only follow conventional procedures or navigate conventionally.
    - If the State has authorised the use of DME/DME for RNP 1 with RF, those aircraft certified to operate on RNP 1 SIDS/STARs using DME/DME will continue to operate normally.
    - Those RNP 1 + RF aircraft unable to support on-board-performance monitoring and alerting with DME/DME, could continue operations on the RNP 1 SIDS/STARs using RNAV 1 with the RF function. *This is the working assumption in Scenario 1 contingency operations.*
    - All aircraft can continue RNAV 5 operations using either VOR/DME or DME/DME.
    - The majority of aircraft are equipped with inertial systems (INS/IRS/IRU).
    - All aircraft can execute ILS approaches.

- Reduction in capacity efficiency or access
    - Above FL305 in the FRA there is minimal impact, given that full infrastructure coverage of the airspace is available by VOR/DME or DME/DME in support of RNAV 5.
    - For all en route flight levels below FL305, RNAV 5 is mandated on all ATS Routes and there is minimal impact providing full coverage of the airspace by VOR/DME or DME/DME.
    - No RNP 0.3 helicopter operations are possible.

For the SID/STARs:

- RNP 1 operations may still be possible for some aircraft; however, special conditions may apply to the DME infrastructure. For the majority of aircraft, on board performance monitoring and alerting (OBPMA) will not be available. Those aircraft can still provide a ±1 NM performance along the RNP 1 SID/STAR, provided they are in the coverage and availability of the DME/DME infrastructure.
- SID/STAR published as RNAV 1 are still flyable provided within the coverage and availability of DME/DME.
- Published contingency procedure based on VOR/DME and/or Radar Vectoring is available.
- RF functionality is not lost with GPS unavailability. Therefore, the RNP 1 routes the spacing of 5NM may be maintained for straight and turning segments, where RF is required, provided there is an alternative way of monitoring the integrity of the aircraft's performance along the routes.
- For RNAV 1 routes the spacing of 5NM can be maintained for straight segments only.

Sc. 1 – **REV**

For the Approach, all RNP approaches and GBAS are lost. Operations that can continue are:

- Precision approach procedures published to CAT I minima for ILS.
- Precision approach procedures published to CAT II/IIIB for ILS.
- Parallel approach operations in Mode 1 (independent) are still possible with ILS.

The ILS missed approach is based on RNAV 1, provided within the coverage and availability of DME/DME.

- Safety implications
  - Controller workload
  - Potential loss of separation due to loss of OBPMA

Can normal operations be maintained?

No, loss of RNP, some aircraft unable to navigate and possible problems with ground systems and time desynchronization.

What level of service in a degraded environment is required?

As close as possible to normal operations

What contingency operations are included in the airspace concept?

All operations in the en route are unaffected and maintained with RNAV 5 providing full coverage of the airspace by VOR/DME or DME/DME.

Helicopter operations will be RNAV 1 provided the aircraft has a DME/DME capability and within the coverage of the ground infrastructure. Helicopters which are GPS only will have to maintain VFR.

For the SID/STARs:

- All SIDs/STARs provided they are within the coverage and availability of the DME infrastructure will be treated as RNAV 1 ATS routes. Where 5 NM route spacing is applied in the turning segments, special consideration is to be given to the monitoring and integrity of the aircraft’s performance.
- For those aircraft unable to accept a clearance along these ATS routes, ATC will handle the aircraft conventionally. Consideration should be given to controller workload and capacity reduced in the event of unacceptable levels of traffic.

Sc. 1 – REV

CONTINGENCY OPERATIONS (ENR & SID/STAR GNSS REVERSION)	
Applications which can continue in Airspace:	RNAV 5 (ATS Routes + FRA); ~~RNP 1~~ + RF (some of SID/STAR); RNAV 1 (majority of SID/STAR); ~~RNP 0.3~~ (All Heli); Published contingency procedures based on conventional navigation.
Applications Explanation: (i) For reversions of short duration, RNAV 1 with/without RF could substitute for 90% of the fleet and RNAV 1 for other routes; though 10% of the fleet would require vectoring or continue on the published conventional (contingency) procedure. For reversion to DME/DME operations, special conditions may apply to the infrastructure (see PBN Handbook No 4)	
Airspace Concept *(revisions to mitigate impact)*	PBN enabled FRA above FL 305; ATS Straight and *turning parallel routes* incl SID/STARs (all now RNAV 1) and non-parallel routes; crossing; Helicopter *Routes – go VFR?* A single Conventional SID/STAR for contingency;
Airspace Explanation: (i) For short-term outage, relevant turning parallel routes can be maintained or radar vectoring or the contingency conventional procedure may be used. Note to reduce controller workload, controller support tools such as RAM (Route Adherence Monitoring) may mitigate loss of OBPMA (ii) Helicopter routes based on RNAV 1 D/D needed, but for helicopters without D/D, a separate conventional contingency procedure needed.	
Spacing between proximate PBN SID/STAR	5 NM on straight segments between RNP 1 routes (now operated by RNAV 1 aircraft) **
*Spacing Explanation: As 90+% of fleet can continue with D/D RNAV 1, and given the potential route spacings published in the EUROCONTROL Route Spacing Handbook No.3, continuation of this spacing likely, subject to a safety assessment. 10% of the fleet will require Vectoring or on the conventional contingency procedure. **RF capability would remain for RNP 1 aircraft capable of DME/DME, which have now reverted to RNAV 1. Nevertheless, as most of the aircraft are not RF equipped, additional controller monitoring is needed on turns.*	
Applicable Separation Minima	3 NM in Terminal and Extended Terminal (Or other due to contingency operation); 5NM in en route.

For the Approach:

- Precision approach is supported down to CAT IIIB minima with ILS.
- Runways without ILS can only be approached visually.
- Parallel approach operations will be conducted by radar vectoring to final approach.

The ILS missed approach is based on RNAV 1 provided within the coverage and availability of DME/DME.

CONTINGENCY OPERATIONS (Approach GNSS REVERSION)	
Final Approach Segment Applications which can continue	~~RNP APCH LNAV/VNAV; LPV; LNAV; GBAS; RNP AR APCH;~~ ILS; VOR/DME; Visual Approach;
Applications Explanation: Only ILS available as well as VOR/DME in extremis. Visual Approaches also possible in VMC.	
Approach Operating Concept *(revisions to mitigate impact)*	~~RNP approaches are main landing mode.~~ ILS or ~~GBAS~~ for CAT I/II/III
Airspace Explanation: Runway throughput may need to be changed	
Multiple Runway Operation (*revisions?)*	Parallel Approach Operations (Mode 1 Independent) can continue onto the ILS final approach track preceded by radar vectoring or an RNAV 1 STAR.
Missed Approach guidance *(revision?)*	~~**RNP APCH~~ - based on RNAV 1 ~~**RNP AR APCH~~ based on AR extraction D/D+ inertial. ~~** GBAS approaches~~ based on RNAV 1 ILS – ~~based on RNP 1~~ RNAV 1
Separation Minima	2.5NM longitudinal on Final Approach Segment
*Explanation: ** Missed approach included to accommodate aircraft on the approach when GPS becomes unusable.*	

Sc. 1 – REV

What current infrastructure exists to enable degraded operations?

It is assumed that the ANSP has undertaken its assessment and created a robust contingency infrastructure to support the contingency airspace concept.

Supplementary Considerations for pilots and controllers:

- Awareness of degraded environment

  This scenario is based on the assumptions that:

  - The controllers have been informed by flight crew that there are issues with the GPS signal.
  - These radio calls come from a wide area and it has been assessed that this is impacting across the whole airspace of responsibility.
  - This information regarding the degradation of GPS performance has been passed to supervisors, who in turn ensure that all controllers are aware of the situation.
  - The information was shared with the Network Manager.
  - A NOTAM is issued.

  Considerations should be given to how the outage is identified and how the information is disseminated to all the actors. The automated analysis of ADS-B reports can quickly provide an indication on the size of the area impacted when the GPS signal is lost.

- Awareness of required reversion procedures

  The assumption is that the contingency procedures are published in the unit's local operating instructions. The controllers are appropriately trained for both normal and contingency operations and hold the correct licences.

  Consideration should be given to how the controller can identify which aircraft can no longer navigate due to the loss of GNSS and require ATC assistance. Furthermore, with the loss of OBPMA the ANSP may consider additional support tools such as Route Adherence Monitor (RAM) to assist the controller to monitor the accuracy of the aircrafts' navigation performance. The GNSS reversion real time simulation report of 2014 provides thoughts on such support tools and details can be found in SESAR document 15.3.1 D12.

- Flight crew awareness of the impact of GPS outage on the specific aircraft type and the corresponding operational procedures. The assumption is that the flight crew have been appropriately trained and hold PBN privileges for both normal and contingency operations.

  Consideration should be given to the maintenance of the ability to fly conventional procedures and this can be undertaken in recurrent simulator training.

- Do the controllers and pilots hold appropriate licences for the contingency environment?

  Yes

- Maintenance of skill sets for the contingency environment, e.g:

  The controllers will need to be proficient in radar vectoring for contingency operations. This skills set is to be maintained; this can be done in ATC simulations.

  The pilots will need to be proficient in identifying and communicating a GPS outage and should be capable to fly the contingency operations. This can be maintained through recurrent simulator training.

- For ab-initio controllers and pilots, is the appropriate training in place for the contingency environment?

  Consideration should be given to controllers and pilots who have never operated in a conventional environment. Appropriate training and simulation should be made available and the controllers are to be appropriately licenced for contingency operations.

Sc. 1 – REV

Tabular Summary of Reversion Scenario 1

REVERSION INFRASTRUCTURE	
Available Navaid Infrastructure	~~GPS~~; ~~SBAS/GBAS~~ ; DME/DME; VOR/DME; ILS
Fleet Positioning Capability for PBN	~~GPS~~ + D/D > 90% + VOR/DME (10% can only do conventional); ILS; ~~SBAS/GBAS 20%~~
Surveillance Sensors Used	PSR; MULTIPLE SSR; with ~~ADS-B~~ or MLAT
Communication Service Used	Voice; ~~Data Link~~
Explanation: Whilst Data Link & MLAT may not be lost immediately, time de-synchronisation may occur in the longer term.	
Timing for On-Board Systems	Independent ~~+ GPS synchronised~~
Timing for Ground Systems	Independent ~~+ GPS synchronised~~

CONTINGENCY OPERATIONS (ENR & SID/STAR GNSS REVERSION)	
Applications which can continue in Airspace:	RNAV 5 (ATS Routes + FRA); ~~RNP 1~~ + RF (some of SID/STAR); RNAV 1 (majority of SID/STAR); ~~RNP 0.3~~ (All Heli); Published contingency procedures based on conventional navigation.
Applications Explanation: (i) For reversions of short duration, RNAV 1 with/without RF could substitute for 90% of the fleet and RNAV 1 for other routes; though 10% of the fleet would require vectoring or continue on the published conventional (contingency) procedure. For reversion to DME/DME operations, special conditions may apply to the infrastructure (refer to Infrastructure Planning Handbook No 4)	
Airspace Concept *(revisions to mitigate impact)*	PBN enabled FRA above FL 305; ATS Straight and *turning parallel routes* incl SID/STARs (all now RNAV 1) and non-parallel routes; crossing; Helicopter *Routes – go VFR?* A single Conventional SID/STAR for contingency.
Airspace Explanation: (i) For short-term outage, relevant turning parallel routes can be maintained or radar vectoring or the contingency conventional procedure may be used. Note to reduce controller workload, controller support tools such as RAM (Route Adherence Monitoring) may mitigate loss of OBPMA (ii) Helicopter routes based on RNAV 1 D/D needed, but for helicopters without D/D, a conventional contingency procedure needed.	
Spacing between proximate PBN SID/STAR	5 NM on straight segments between RNP 1 routes (now operated by RNAV 1 aircraft) **
*Spacing Explanation: As 90+% of fleet can continue with D/D RNAV 1, and given the potential route spacings published in the EUROCONTROL Route Spacing Handbook No. 3, continuation of this spacing likely, subject to a safety assessment. 10% of the fleet will require Vectoring or continue on the conventional contingency procedure. **RF capability would remain for RNP 1 aircraft capable of DME/DME, which have now reverted to RNAV 1. Nevertheless, as most of the aircraft are not RF equipped, additional controller monitoring is needed on turns.*	
Applicable Separation Minima	3 NM in Terminal and Extended Terminal (Or other due to contingency operation); 5NM in en route.

Sc. 1 – REV

CONTINGENCY OPERATIONS (Approach GNSS REVERSION)	
Final Approach Segment Applications which can continue	~~RNP APCH LNAV/VNAV; LPV; LNAV; GBAS; RNP AR APCH;~~ ILS; VOR/DME; Visual Approach;
Applications Explanation: Only ILS available as well as VOR/DME in extremis. Visual Approaches also possible in VMC.	
Approach Operating Concept *(revisions to mitigate impact)*	~~RNP approaches are main landing mode.~~ ILS or ~~GBAS~~ for CAT I/II/III
Airspace Explanation: Runway throughput may need to be changed	
Multiple Runway Operation (*revisions?)*	Parallel Approach Operations (Mode 1 Independent) can continue onto the ILS final approach track preceded by radar vectoring or an RNAV 1 STAR.
Explanation:	
Missed Approach guidance *(revision?)*	~~**RNP APCH~~ - based on RNAV 1 ~~**RNP AR APCH –~~based on AR extraction D/D+ inertial ~~** GBAS approaches~~ based on RNAV 1 ILS – ~~based on RNP 1~~ RNAV 1
Separation Minima	2.5NM longitudinal on Final Approach Segment
*Explanation: ** Missed approach included to accommodate aircraft on the approach when GPS becomes unusable.*	

4.4.2 Scenario 2: correlates to airports & terminal/operating environments catering to commercial air traffic where some but not all of the procedures are already compliant with the PBN Implementing Regulation covering the 2024-2030 timeframe.

The airport and the associated terminal and extended terminal operations that are described in this scenario correspond to a low/medium density TMA and airport complying with the PBN-IR.

NORMAL OPERATIONS (NML) – GNSS IS AVAILABLE

AVAILABLE NAVAID INFRASTRUCTURE

The following *assumptions* are made in this scenario regarding the Navaid Infrastructure such as:

- GPS is available for use in all phases of flight.
- There is DME/DME coverage down to MVA however, there are not enough DMEs to provide redundant coverage, making the DMEs critical to support RNAV 1 operations.
- There is adequate VOR/DME coverage down to Minimum Vectoring Altitude (MVA) to support conventional SIDs/STARs and RNAV 5 in the TMA and also to support conventional approach operations.
- Single NDB situated on the airport.
- The airport uses ILS CAT I as a default to support precision approach operations. The airport is within the footprint of LPV200 and SBAS CAT I procedures are published.

FLEET POSITIONING CAPABILITY FOR PBN

Mindful that all pilots operating in this Scenario hold the necessary EASA PBN privileges, the following *assumptions* are made on the aircraft equipage/certification of the operating fleet:

- All aircraft are equipped with single frequency GPS receivers primarily employing RAIM for integrity.
- All aircraft are equipped with VOR/DME for area navigation capability.
- At least 90% of the aircraft are equipped with DME/DME for area navigation capability.
- The majority of aircraft are equipped with inertial systems (INS/IRS/IRU).
- 25% of the aircraft are equipped with SBAS.
- All aircraft are equipped with and certified to use ILS.
- All aircraft are certified for RNAV 5 operations using either VOR/DME or DME/DME or GPS.
- All aircraft are certified for RNAV 1 operations based on GPS and 90% of this aircraft fleet is certified for RNAV 1 operations based on DME/DME with or without IRU.
- All aircraft are certified for RNP APCH operations to LNAV.
- The majority of aircraft are certified for RNP APCH operations with LNAV/VNAV minima.
- 25% of the aircraft are certified for RNP APCH operations to LPV minima including SBAS CAT 1.

Communication and Surveillance Means

The following *assumptions* are made regarding the SUR and COM infrastructure of the scenario TMA and airport.

- Two independent cooperative systems are available: MSSR and ADS-B.
- Controllers use VHF Voice as the primary communication means with multiple frequencies.

Sc. 2 - **NML**

Timing

The surveillance tracker uses GPS timing to ensure valid surveillance data. If GPS time is lost the system follows the Network Time Protocol (NTP) which defines a hierarchy of timing default; there is the possibility of time desynchronization.

It is assumed that on-board the majority of the aircraft, the C-N-S systems rely primarily on GPS for position and timing. Some back-up source for both navigation and timing is available, however for a long period of time of GNSS being unusable large clock drifts may occur.

Note: This topic is covered in greater detail in Appendix 1

ATC Tools

The *assumption* in this scenario is that there are no additional controller support tools developed for GNSS reversion.

NAV APPLICATIONS ENABLING THE AIRSPACE CONCEPT

The surveillance capability is independent and enables a 5NM separation minima en route and 3NM separation minima in terminal airspace operations.

For en route

- Above FL305 there is Free Route Airspace in accordance with AF#3 of the [EU] 2021/116 (CP 1 IR). RNAV 5 is the performance required by ICAO EUR Doc 7030, Regional Supplementary Procedures.
- For all ATS Routes excluding SIDS/STARs, RNAV 5 is mandated in accordance with EU 2018/1048 (PBN IR).

For the terminal area:

- The majority of the SID/STARs published as RNAV 1.
- Several ATS routes and SID/STARs are based on conventional navigation.
- For RNAV 1 routes the spacing of 5NM is used for straight segments. For turns, wider spacing is used.
  Note: this is a mixed operating environment with Conventional and RNAV 1 SIDS/STARs
- All helicopter operations are based on RNP 0.3.

For the Approach, RNP approaches are the main landing mode:

- RNP APCH procedures are published with LNAV, LNAV/VNAV and LPV minima.
- Precision approach procedures are published to CAT I minima for ILS and SBAS.
- Conventional VOR/DME and NDB procedures are published for contingency operations only.

The missed approach is based on following:

- Conventional based on VOR/DME for the RNP APCH approach and ILS

Sc. 2 - **NML**

NORMAL INFRASTRUCTURE	
Available Navaid Infrastructure	GPS; DME/DME; VOR/DME; NDB; SBAS
Fleet Positioning Capability for PBN	GPS + D/D > 90% + VOR/DME + NDB ; SBAS 25% + ILS
Surveillance Sensors Used	MSSR and ADS-B
Communication Service Used	VHF Voice;
Timing for On-Board Systems	Independent + GPS synchronised
Timing for Ground Systems	GPS synchronised with NTP
NORMAL OPERATIONS (ENR and SIDs/STARs)	
NAV Applications enabling Airspace Concept:	RNAV 5 (ATS Routes & FRA); RNAV 1 (Some SID/STAR); Conventional SIDs/STARs; RNP 0.3 (All Heli);
Airspace Concept	PBN enabled FRA above FL 305; ATS Straight parallel routes including SID/STARs and non-parallel routes; crossing;
Spacing between proximate PBN SID/STAR	5 NM on straight segments, wider spacing on turns due to fly-by transitions;
Applicable Separation Minima	3 NM in terminal operations; 5NM en route operations;
NORMAL OPERATIONS (Approach)	
Final Approach Segment Applications	RNP APCH (LNAV/VNAV; LNAV; LPV); ILS;
Approach Operating Concept	RNP approaches and precision approach ILS or SBAS for CAT I
Multiple Runway Operation	Not applicable
Missed Approach guidance	RNP APCH – conventional based on VOR/DME ILS – conventional based on VOR/DME
Separation Minima	3NM longitudinal based on radar separation minima
Explanation: DME infrastructure does not support RNAV 1 for missed approach	

Reversion Scenario 2: In the event of GNSS being unusable in normal operations

A GPS RAIM NOTAM was issued via AUGUR tool (https://www.eurocontrol.int/online-tool/augur) to the National NOTAM office of the scenario airport. For maintenance reasons GPS would not be available the next day, for one to several hours for a wide area affecting TMA and approach operations. The controllers received this information via their NOTAM office. The contingency measures needed to be implemented in accordance with the agreed reversion plan.

This reversion plan has assessed the following questions.

How were the controllers informed about the outage?

Through NOTAM

Outage has occurred, how long will it continue?

Four-to-six-hour outage.

What part of the airspace is impacted by the outage?

Wide area outage impacting all phases of flight and ground systems.

Sc. 2 - REV

What systems are impacted by the loss of GPS?

- The ground and space systems reliant on GPS (ADS-B, SBAS).
- The airborne capability in all phases of flight.

List systems which are still available following GPS unusable

The C-N-S infrastructure remaining is

- DME/DME and VOR/DME with coverage down to Minimum Vectoring Altitude (MVA) and NDB
- ILS supporting CAT I operations
- MSSR - timing stability managed by NTP (Network Timing Protocol)
- Controllers use VHF Voice communication with multiple frequencies.

Explanation: Gaps not covered by SSR must be known. If no gaps, impact of ADS-B non-availability negligible. But if some SSR surveillance gaps are filled by ADS-B, these areas would lose surveillance cover and alternative procedures needed.

ATC Tools

There's not considered to be any loss of controller support tools functionalities.

REVERSION INFRASTRUCTURE	
Available Navaid Infrastructure	~~GPS~~; DME/DME; VOR/DME; NDB; ~~SBAS~~
Fleet Positioning Capability for PBN	~~GPS~~ + D/D > 90% + VOR/DME + NDB; ~~SBAS 25%~~ + ILS
Surveillance Sensors Used	MSSR; ~~with ADS-B~~
Communication Service Used	VHF Voice;
Timing for On-Board Systems	Independent ~~+ GPS synchronised~~
Timing for Ground Systems	NTP ~~+ GPS synchronised~~

Operational impact on current operations

- <u>Percentage of aircraft impacted by loss of signal</u>: 100%, however the reversion fleet capability is:
  - 90% of aircraft fleet can continue RNAV 1 operations based on DME/DME with or without IRU and 10% can only do conventional procedures.
  - All aircraft can continue RNAV 5 operations using either VOR/DME or DME/DME.
  - The majority of aircraft are equipped with inertial systems (INS/IRS/IRU)
  - All aircraft can execute non precision approaches based on VOR/DME or NDB
  - All aircraft can execute ILS approaches.

- <u>Reduction in capacity, efficiency or access</u>

Above FL305 for Free Route Airspace there is minimal impact providing full coverage of the airspace by VOR/DME or DME/DME which will support RNAV 5.

For all en route flight levels below FL305, RNAV 5 is mandated for ATS Routes and there is minimal impact providing full coverage of the airspace by VOR/DME or DME/DME.

No RNP 0.3 helicopter operations remain possible, Sc. 2 - **REV**

For the SID/STARs:

- Those published as RNAV 1 are still flyable provided they fall within the coverage area of the DME stations and that those DME stations are available.
- Published conventional procedures based on VOR/DME.
- For RNAV 1 routes the spacing of 5NM for straight segments and wider on turns can be maintained.

For the Approach, RNP approaches are lost. Operations that can continue are:

- Precision approach procedures published to CAT I minima for ILS.

The ILS missed approach is based on VOR/DME.

Can normal operations be maintained?

For the majority of aircraft, yes, GPS only aircraft would need to be managed conventionally. RNP 0.3 Helicopter operations cannot be supported.

What level of service in a degraded environment is required?

As close as possible to normal operations

What is the contingency operation airspace concept?

All operations in the en route are unaffected and maintained with RNAV 5 providing full coverage of the airspace by VOR/DME or DME/DME.

Helicopter operations will be RNAV 1 provided the rotorcraft has a DME/DME capability and within the coverage of the ground infrastructure. Helicopters which are GPS only will have to maintain VFR.

For the SID/STARs:

- All SIDs/STARs provided they are within the coverage and availability of the DME infrastructure can be continued as RNAV 1 ATS routes. Where 5 NM route spacing is applied in straight segments, the surveillance tracking time synchronisation should be considered.
- For aircraft unable to accept a clearance along these RNAV 1 ATS routes, ATC will provide clearance on the conventional SIDs/STARs.
- For those aircraft unable to accept either clearance along the ATS routes, ATC will manage the aircraft by radar vectoring. Consideration should be given to controller workload and capacity reduced in the event of unacceptable levels of traffic.

For the Approach

- Precision approach supported down to CAT I minima with ILS
- Non-precision approach enabled by VOR/DME or NDB
- Visual approach operations possible

The ILS missed approach is based on VOR/DME.

Sc. 2 - REV

CONTINGENCY OPERATIONS (ENR and SIDs/STARs GNSS REVERSION)	
Applications which can continue in Airspace:	RNAV 5 (ATS Routes + FRA); RNAV 1 using DME/DME RNAV (Some SID/STAR); Existing Conventional ATS Routes + SID/STAR; ~~-~~ ~~RNP 0.3~~ (All Heli);
Applications Explanation: (i) For reversions of short duration, RNAV 1 could continue though 10% of the fleet that would require vectoring or continue on conventional procedures.	
Airspace Concept *(revisions to mitigate impact)*	PBN enabled FRA above FL 305; ATS Straight routes incl. SID/STARs and non-parallel routes; crossing; Existing + *New** Conventional Routes incl. SID/STAR
*Airspace Explanation: For short-term outage, parallel routes can be maintained. Is the current DME/DME infrastructure robust enough to support RNAV 1 operations? What is the operational impact of the loss of a critical DME? If not, radar vectoring workload could increase. *Are additional conventional procedures required to support contingency operations?*	
Spacing between proximate PBN SID/STAR	5 NM on straight segments, wider spacing on turns due to fly-by transitions;
Spacing Explanation: As 90+% of fleet can continue with D/D RNAV 1, and given the potential route spacings published in the EUROCONTROL Route Spacing Handbook No.3, continuation of this spacing likely, subject to a safety assessment. 10% of the fleet will require Radar Vectoring or clearance on to a conventional procedure.	
Applicable Separation Minima *(revision?)*	*3 NM* **or possible increase due to contingency operation** 5NM en route operations;
CONTINGENCY OPERATIONS (Approach GNSS REVERSION)	
Final Approach Segment Applications which can continue	~~RNP APCH LNAV/VNAV; LNAV; LPV; RNP AR APCH;~~ ILS;
Approach Operating Concept *(revisions to mitigate impact)*	~~RNP approaches are main landing mode.~~ ILS; Conventional (VOR/DME, NDB); Visual Approach;
Airspace Explanation: Runway throughput may need to be changed. VOR/DME and NDB procedures published and Visual Approaches also possible in VMC.	
Missed Approach guidance *(revision?)*	**~~RNP APCH~~ – conventional based on VOR/DME ILS – conventional based on VOR/DME
Separation Minima	3NM longitudinal based on radar separation minima
*Explanation: ** Missed approach included to accommodate aircraft on the approach when GPS becomes unusable. DME infrastructure does not support RNAV 1 for missed approach.*	

Does the current infrastructure enable degraded operations?

Where are the critical DMEs? Is there a justification for additional DME's to be deployed to ensure redundancy?

Supplementary Considerations for pilots and controllers:

- Awareness of degraded environment

  This scenario is based on the assumptions that:

  - The controllers have been informed by the NOTAM office that there are issues with the GPS signal.
  - It has been assessed that this is impacting across the whole airspace of responsibility.
  - This information regarding the degradation of GPS performance has been passed to supervisors, who in turn ensure that all controllers are aware of the situation.
  - The information was shared with the Network Manager.

Sc. 2 - **REV**

Considerations should be given to how the outage is identified and how the information is disseminated to all the actors. The automated analysis of ADS-B reports can quickly provide an indication on the size of the area impacted when the GPS signal is lost.

- Awareness of required reversion procedures

  The assumption is that the contingency procedures are published in the unit's local operating instructions. The controllers are appropriately trained for both normal and contingency operations and hold the correct licences.

  Consideration should be given to how the controller can identify which aircraft can no longer navigate due to the loss of GNSS and require ATC assistance. The ANSP may consider additional support tools such as Route Adherence Monitor (RAM) to assist the controller to monitor the accuracy of the aircrafts' navigation performance. The GNSS reversion real time simulation report of 2014 provides thoughts on such support tools and details can be found in SESAR document 15.3.1 D12.

- Flight crew awareness of the impact of GPS outage on the specific aircraft type and the corresponding operational procedures.

  The assumption is that the flight crew have been appropriately trained and hold PBN privileges for both normal and contingency operations.

  Consideration should be given to the maintenance of the ability to fly conventional procedures and this can be undertaken in recurrent simulator training.

- Do the controllers and pilots hold appropriate licences for the contingency environment?

  Yes

- Maintenance of skill sets for the contingency environment, e.g:

  The controllers will need to be proficient in radar vectoring for contingency operations. This skills set is to be maintained; this can be done in ATC simulations.

  The pilots will need to be proficient in identifying and communicating a GPS outage and should be capable to fly the contingency operations. This can be maintained through regular simulation.

- For ab-initio controllers and pilots, is the appropriate training in place for the contingency environment?

  Consideration should be given to controllers and pilots who have never operated in a conventional environment. Appropriate training and simulation should be made available, and the controllers are to be appropriately licenced for contingency operations.

5. PROCESS FOR CONTINGENCY SCENARIO DEVELOPMENT

Cross Reference: Airspace Concept Handbook No.1, Activities 1-17.
Cross Reference: Infrastructure Planning Handbook No.4, Activities IA-1 to IA-8.

When developing an Airspace Concept, **Activity 6** of the **European Airspace Concept Handbook No.1** makes it clear that the Enablers available to support the airspace design must be identified, as must the constraints to be mitigated, and what assumptions have to be made. What is equally clear, is that when undertaking the Airspace Design, **Activity 7,** the design schema must cater for normal and contingency operations with contingency procedures to match. The Airspace Concept is a total package, and having an ideal operating scenario is not enough. Non-Normal operations must be envisaged and accounted for, therefore Airspace Concept developers should plan Contingency operations as part of the Airspace Concept.

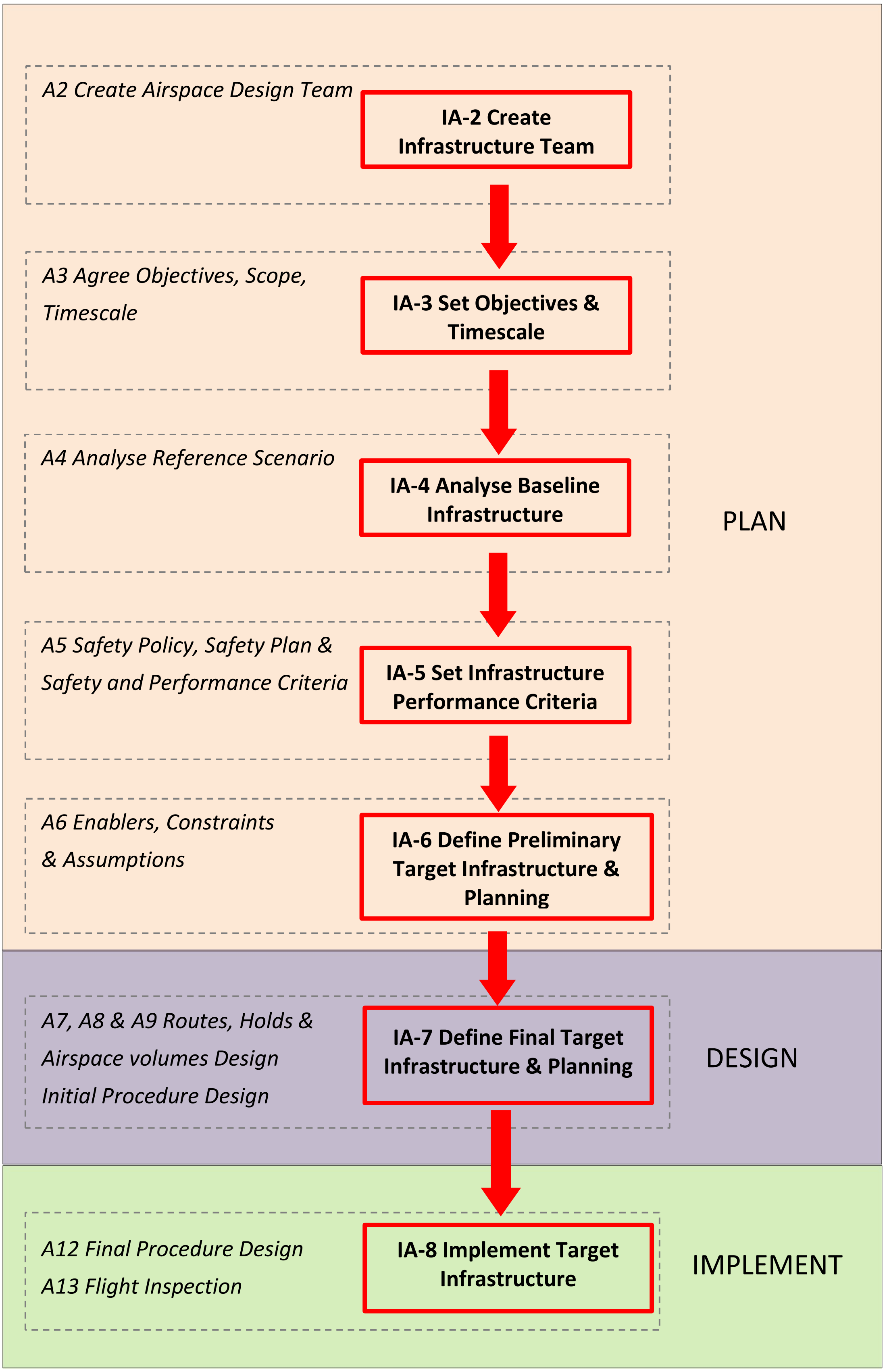
When developing a CNS evolution plan, the Infrastructure Manager has two primary considerations: the first is servicing the ATM requirements of its ANSP, the second is meeting the cost-saving or regulatory targets for Navaid rationalisation/decommissioning. The Infrastructure manager is thus often faced with contradictory pressures, which need to be managed.

In as much as the Airspace Concept developers *must* communicate their airspace evolution plans to the Infrastructure Managers, it is equally important that Airspace Designers and Planners are aware of the strategic evolution of the Navaid Infrastructure. Changes in the Navigation infrastructure may require changes in the operations or airspace design for reasons not connected to ATM requirements e.g. decision not to replace particular VORs at the end of their life cycle could cause conventional STAR/SIDs to be withdrawn or at best, altered. It is quite conceivable that uncoordinated rationalisation decisions could force airspace changes with unintended consequences.

To these ends, the Airspace Design and the Navaid Infrastructure Planning processes should continuously involve exchange of information and this can often cause several iterations before reaching the optimal solution. It is recommended though that these activities are performed in a common framework which is the Airspace Concept Development, therefore the **European Navaid Infrastructure Planning Handbook No.4**, defines the specific activities as part of the Airspace Concept Handbook No.1 activities, see Figure 5-1 and Figure 5-2.

Figure 5-1: Airspace Concept Development Activities

Figure 5-2: Navaid Infrastructure Planning Activities



The following table shows two sets of activities: those from the Airspace Concept Handbook No 1 and the Navaid Infrastructure Planning Handbook No 4. The Table highlights the main Contingency/Reversion considerations required in each Methodology's Activities. These activities, and their Contingency/Reversion considerations shown below, are provided at a more detailed level of granularity in Handbooks 1 and 4.

<table>
<tr><th colspan="2">Airspace Concept Handbook No.1,
Airspace Activities needing ATM contingency considerations</th><th colspan="2">Navaid Infrastructure Planning Handbook No.4,
Infrastructure Activities and corresponding INFRA contingency aspects</th></tr>
<tr><td>Activity 1</td><td>None</td><td>None</td><td>None</td></tr>
<tr><td>Activity 2</td><td>None</td><td>IA-2</td><td>None</td></tr>
<tr><td>Activity 3</td><td>Include contingency in Objective setting</td><td>IA-3</td><td>Set Navaids rationalization targets; identify potential conflicts with contingency objectives</td></tr>
<tr><td>Activity 4</td><td>Include contingency in Reference Scenario Analysis</td><td>IA-4</td><td>Analyse the role in supporting GNSS reversion for Baseline Infrastructure</td></tr>
<tr><td>Activity 5</td><td>Include contingency in Safety Policy, Plan and Performance criteria</td><td>IA-5</td><td>Identify required Infrastructure performance for supporting planned operations, including GNSS reversion, as required by planned contingency operations</td></tr>
<tr><td>Activity 6</td><td>Include in ATM/CNS enablers – though iterations will be needed during activities 7-8-9-10.</td><td>IA-6</td><td>Define preliminary target infrastructure considering required performance and rationalization targets. Iterations may be needed to find the best compromise in case of conflicting requirements (e.g. performance requirements vs rationalization targets)</td></tr>
<tr><td>Activity 7</td><td rowspan="4">During iterations between these activities, contingency operations will be catered for in the design (7), initial procedure design (8), adjustments made for the airspace Volume (9). This could trigger a need for more infrastructure or provide indications as to how C-N-S infrastructure could be rationalised.</td><td rowspan="4">IA-7</td><td rowspan="4">Plan infrastructure evolution considering foreseen nominal and contingency (GNSS reversion) operations. Iterations may be needed to find the best compromise in case of conflicting requirements (e.g. performance requirements vs rationalization targets)</td></tr>
<tr><td>Activity 8</td></tr>
<tr><td>Activity 9</td></tr>
<tr><td>Activity 10</td></tr>
<tr><td>Activity 11</td><td>Include contingency in Concept Validation</td><td>None</td><td>None</td></tr>
<tr><td>Activity 12</td><td>Include contingency in Final Procedure Design</td><td rowspan="2">IA-8</td><td rowspan="2">None (the achieved infrastructure performance to be taken into account in the final procedure/airspace design)</td></tr>
<tr><td>Activity 13</td><td>Include contingency in IFP validation/Flight Inspection.</td></tr>
<tr><td>Activity 14</td><td>Include contingency in ATC System Integration</td><td rowspan="4">None</td><td rowspan="4">None (Airspace Concept activities not directly related with the navigation infrastructure evolution)</td></tr>
<tr><td>Activity 15</td><td>Include in Awareness and Training Material</td></tr>
<tr><td>Activity 16</td><td>Include contingency in implementation</td></tr>
<tr><td>Activity 17</td><td>Include contingency in implementation Review</td></tr>
</table>

For further information on the navigation infrastructure rationalization/optimization activities, refer to the European NAVAID Infrastructure Planning including MON, Handbook No. 4.

6. CONCLUSION

This Handbook has looked at the regulatory context and the operational impact of a loss of GNSS on pilot and controller procedures. The document has then considered how that loss is communicated before looking at how a service provider can mitigate that loss. The Handbook provides two scenarios, which should enable the reader to understand the complexity of the subject. In addition, the Handbook provides a couple of de-identified real use cases.

The development of a future Airspace Concept includes the simultaneous development of contingency procedures for certain outages, one of which is GNSS loss. When developing contingency scenarios within the Airspace Concept, inter-dependencies should be identified particularly when dealing with GNSS which affects so many systems. This will permit multiple system failures to be considered e.g. radar and GNSS failure, or COM and GNSS failure. Whilst redundancies must be provided, care must be taken to ensure that viable shared redundancies are identified (include trade off considerations) to avoid unnecessary cost.

In both normal and contingency operations, a Safety Assessment must be undertaken. However, for the contingency operation, a Cost Benefit Assessment will also need to be considered. The assessment of the additional cost will be subject to the contingency level of service planned. If the contingency operation is just to get the aircraft safely on the ground, a basic level of backup infrastructure may suffice. If the contingency operation is planned to maintain the same level of operations, regardless of the GNSS outage, then clearly a full backup infrastructure probably with redundancy will need to be available.

In February 2020, results were compiled from an on-line GNSS Reversion survey conducted by Eurocontrol's navigation experts. This survey targeted European controllers who answered anonymously. Results show that 86 % or more respondents either did not have or were not aware of GNSS contingency procedures to use of GNSS becomes unusable.

In light of the above, ANSPs are strongly encouraged to undertake an awareness campaign on GNSS contingency. Furthermore, using this Handbook as a 'starter-pack', it is highly recommended that each ANSP undertakes a resilience assessment for the loss of GNSS as a pre-requisite to developing contingency procedures for GNSS reversion. This means that at local level the full impact of GNSS loss is assessed and can be mitigated.

Note: ANSPs is used as a generic term in this document to cover the regulated parties of the PBN IR i.e. air traffic management/air navigation services and operators of aerodromes.

APPENDIX 1 - Impact of GNSS being unusable

NOTE: This is a high level preliminary assessment of a generic nature which seeks to provide understanding for operational staff. It does not purport to be a technically detailed. As such, this brief is a simplified explanation, attempting to make the impact of GPS outage comprehensible to operational staff.

GPS Interference has multiple potential impacts on aircraft systems. However, given the variety of systems operating, the impacts will not be homogenous across all fleets and equipage. In some cases, the GPS signal could be degraded but not completely lost, resulting in decreased position accuracy. The aircraft GPS receiver itself is the main source of position information, which drives aircraft navigation system supporting Required Navigation Performance (RNP) operations and providing position input to different aircraft systems. Some business aircraft are even using GPS as a reference source for aircraft flight control and stability systems. The most common impact is complete loss of GPS reception, which results in loss of GPS position, navigation and time.

TABLE I

Aircraft System using GNSS	*System* Impact of GPS Loss	*Operational* Impact (numbered) & *Mitigations*
1. **GPS receiver**	Loss of GPS signal	GNSS position and time no longer feed other A/C systems. Operational impact and mitigations described below. *(In cases where GPS is stand alone, impact under Item 2 (FMC) is relevant)*
2. **Flight Management Computer (FMC)** *[FMC logic selects the position from one of the GNSS sensor units as the primary update to the FMC position. When GNSS position data is available, radio updating can also occur. If all GNSS data becomes unavailable FMC position will be determined by radio or inertial (IRS) updating. On the ground, the FMC calculates present position based on GNSS data.* *In general, FMC position updates from navigation sensor positions are used in the following priority order: (a) GNSS; (b) two or more DME stations; (c) one VOR with a collocated DME; (d) one localizer and collocated DME; (5e) one localizer (f) IRS only].*	Loss of GPS position input. When available the FMC reverts to IRS and/or radio updating.	FRA/ATS Routes/SIDS & STARs: (**1**) Loss of all positioning information for aircraft having GNSS as the only positioning source for PBN. *These aircraft can revert to dead reckoning or be provided with vectoring (more controller Workload)*. (**2**) Loss of GNSS positioning information for aircraft equipped with multi sensor navigation systems, where other possibilities may be DME/DME, VOR/DME or inertial reference system (IRS) with radio updating (DME/DME, VOR/DME). *These aircraft can continue navigating on respective routes, though some flow regulation may be needed;*
3. **Ground Based Augmentation System (GBAS)** *[GBAS is a ground-based augmentation system used for precision landing. It is a GPS-dependent alternative to ILS, which uses a single GBAS airport ground station to transmit corrected GNSS data to suitably equipped aircraft to enable them to fly a precision approach with much greater flexibility.]*	Loss of GBAS position. (GBAS ground system, can no longer 'augment' the GPS signal).	(**3**) GBAS approaches not possible; may generate missed approaches and increased workload. *Alternative instrument approach procedure, such as ILS, needed. If not available, diversion may be required.*

4. **Satellite Based Augmentation System (SBAS)** *[SBAS supports wide-area or regional augmentation with additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations and take measurements of one or more of the GPS satellites].*	Loss of SBAS position. (The SBAS system can no longer 'augment' the GPS signal.	(**4**) RNP Approaches (LPV) not possible; may generate missed approaches and increased workload. *Alternative instrument approach procedure, such as ILS, needed (RNP Approaches to LNAV or LNAV/VNAV minima not possible due to unavailability of GPS positioning). If not available, diversion may be required.*
5. **Synthetic vision guidance system (SVGS)** *[SVGS provides situational awareness by using terrain, obstacle and other databases. A typical SVGS application uses a set of databases stored on board the aircraft, an image generator computer, and a display. Navigation solution obtained using GNSS and inertial reference systems. SVGS can enable lower minima on different kinds of approach].*	Loss of GNSS position. Loss of synthetic vision display and flight path marker on PFD. GNSS being unusable might affect capability to apply operational credit	(**5**) SVGS becomes unusable. *Alternative instrument approach procedure not SVGS dependent, needed e.g. ILS. If not available, diversion may be required.*
6. **ATC Transponder – Mode S / SSR function**	No impact on independent surveillance positioning function. Some downlinked airborne parameters (e.g. possibly groundspeed, track angle, track angle rate) may be lost or degraded.	Operational impact see Table II.
7. **ATC Transponder – ADS–B function** *[An ADS-B equipped aircraft determines its own position (longitude, latitude, altitude, and time) using GNSS and periodically broadcasts this position and other relevant flight information to ground stations and other aircraft with ADS-B equipment via Mode S ES messages. In the new space based ADS-B applications the ADS-B reports are sent via a satellite link.* *The information can be used by ATC as a complement or replacement for secondary surveillance radar or multilateration, It can also be received by other aircraft to provide situational awareness.]*	Loss of (qualified) position and groundspeed in ADS-B Out data.	Operational impact see Table II.

8. **ADS-B In system**	Loss of ADS-B In application	Safety and capacity reduction. Loss of ADS-B IN functionality for impacted aircraft. If own aircraft is impacted by the outage the ADS-B IN function it is lost for all tracked aircraft. If traffic is impacted by the outage the ADS-B IN function it is lost for impacted traffic.
9. **ACAS**	Loss of ADS-B input to ACAS RF reducing function.	Loss of ***RF reducing functions*** in ACAS systems (**the ACAS function itself is not impacted**). If own aircraft is impacted by the outage the RF reducing function it is lost for all tracked aircraft. If traffic is impacted by the outage the RF reducing function it is lost for impacted traffic.
10.**ADS-C** *ADS-C is intended to provide long distance position tracking, (and weather reporting...) as in transoceanic flight. In this case the messages are sent to a specific ATC centre, via a satellite link.*	Loss of position in ADS-C data.	See Table II
11.**Controller Pilot Data Link Communications (CPDLC)** *CPDLC is a means of communication between controller and pilot, using data link for ATC communication. In continental airspace, VHF is used for message transmission; in oceanic airspace, transmission is via SATCOM (see Item 13, below)*	Loss of GPS *time* input. A local time source would be used for time stamping of CPDLC messages.	(**9**) Potential operational impact: CPDLC unusable due to unreliable time stamp on messages. *Use of voice messages via VHF or HF; Mitigation: increased separation for trans-Atlantic flights if SATCOM are impacted (depending on the operator used for PBCS) ,*
12.**Aircraft communications addressing and reporting system (ACARS)** *[ACARS is a digital datalink system for transmission of short messages between aircraft and ground stations. ACARS messages may be sent using a choice of communication methods, such as VHF or HF, either direct to ground or via satellite. GNSS position reports sent through ACARS enable the operators to track their fleet. The system may be used to transmit ATC messages e.g. to request or provide clearances.]*	Loss of GNSS position input. Aircraft may stop reporting its position through ACARS	(**10**) Potential operational impact, where ACARS used to transmit ATC messages. *Use of voice messages via VHF or HF.*

13.**Satellite communication (SATCOM)** *[SATCOM may be used for transmitting CPDLC and ACARS messages; Geosynchronous satellite networks generally require valid GPS position information to connect the on-board SATCOM terminal to the communication network].*	Loss of GNSS position input. If position is not available, connectivity will not be enabled. Primarily affects system start up on ground or for in-air satellite handoffs.	(**11**) Potential operational impact: transmission of CPDLC messages and position reporting impaired. *Use of voice messages via VHF or HF and apply appropriate separation for trans-Atlantic flights where PBCS is required for strategic separation (NAT), if this area is impacted.*
14.**Attitude and Heading Reference System (AHRS)** *[GNSS, aided by inertial reference systems, can augment AHRS. Very few aircraft have GNSS augmentation to AHRS without inertial].*	Loss of GNSS aiding to AHRS.	(**12**) Where aircraft do not have inertial aiding to AHRS, the loss of GNSS augmentation to the AHRS, can result in degradation of AHRS pitch and roll accuracy with potential downstream effects. *The pilot might require special ATC assistance*
15.**Terrain awareness warning system (TAWS) / Enhanced Ground Proximity Warning System (EGPWS)** *[TAWS/EGWPS positioning information can be generated internally to the TAWS/EGWPS (e.g. GNSS receiver) or acquired by interfacing to other installed avionics on the aircraft (e.g. FMS). An RNAV system may be used as an aeroplane position sensor for the TAWS/EGWPS. Vertical position may come from a barometric source (altimeter) or an air data computer, or from a geometric source, such as GNSS]. TAWS/EGWPS is combined with a digital terrain database, on-board computers compare current location with a database of the Earth's terrain].*	Loss of GNSS position input. If GNSS is lost it will affect the TAWS (EGPWS) function in some aircraft, while in other the TAWS (EGPWS) function will use IRS with radio updating as position input instead of GNSS.	(**13**) Unusable TAWS/EGPWS in some cases; possibly reduced situational awareness for equipped aircraft, depending on how the system is integrated in the aircraft. *The pilot might require special ATC assistance and/or rerouting to avoid operations in terrain rich areas.*
16.**Emergency locator transmitter/beacon (ELT/B)** *[GNSS position data integrated into the distress signals transmitted by certain ELTs, improving the quality of information when searching for aircraft in distress. ELTs transmit signals at 406 MHz to a global network of 12 satellites.]*	No GNSS position input for ELT.	(**14**) No direct operational impact but this could result in larger search radius where search operations are activated. *No Mitigation.*
17.**Digital Flight Data Recorders (DFDR)** *[Certain aircraft are required by regulations to carry a data recorder to aid in accident investigation. GNSS provides location data and clock signal timestamps. DFDR operates during all phases of flight (take off, departure, en route, arrival, landing, and taxiing].*	Loss of GNSS position and time. Some aircraft may use IRS with radio updating as position input instead of GNSS and a local time source for time stamps	(**15**) No direct operational impact but in case of an accident the investigation may be hampered. *No Mitigation*

The GPS signals are used as well by some of the ground CNS systems. The next table shows that the main impact of a GPS outage on these systems is the loss of the main time synchronisation source. Note that the impact on GPS augmentation systems (GBAS & SBAS) is included in the first table.

TABLE II

Ground System using GNSS	*System* Impact of GPS Loss	*Operational* Impact (numbered) & *Mitigations*
18.**Dependent Surveillance sensors ADS-C** *ADS-C is intended to provide long distance position tracking, (and weather reporting...) as in transoceanic flight. In this case the messages are sent to a specific ATC centre, via a satellite link.*	Loss of ADS-C position data	*(**8**) In ADS-C surveillance only areas (e.g. oceanic or remote areas): Loss of surveillance* *Mitigation: Procedural control without surveillance.*
19. **Dependent Surveillance sensors ADS–B** *[An ADS-B equipped aircraft determines its own position (latitude, longitude, altitude, and time) using GNSS and periodically broadcasts this position and other relevant flight information to ground stations and other aircraft with ADS-B equipment via Mode S ES messages. In the new space based ADS-B applications the ADS-B reports are sent via a satellite link.* *The information can be used by ATC as a complement or replacement for secondary surveillance radar or multilateration, It can also be received by other aircraft to provide situational awareness.]*	Loss of ADS-B position data	(**7**) In complex environment with multiple surveillance sources: No or limited operational impact, possibly followed by airspace capacity/regulation. *Mitigation: Multi sensor tracking including Independent (or Primary) Surveillance sources.* *(**8**) In ADS-B surveillance only areas (e.g. oceanic or remote areas or in low density TMAs or airports with relatively low traffic levels): Loss of surveillance* *Mitigation: Procedural control without surveillance.*
20. **Multilateration sensors** *Multilateration (MLAT) is the process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from an aircraft to three or more receivers. In order to locate the aircraft with sufficient accuracy, the multilateration receivers need be synchronised in time with nanoseconds precision, therefore GPS timing is used.*	Loss of GPS time synchronisation. Revert to back-up time source if available (e.g. ref. transmitter or local clocks)	(**6**) Impact depends on system design and range from no direct impact to degraded or limited function, surveillance is still provided in degraded/time limited mode. Possible longer-term capacity regulations. Mitigation: *Back-up timing sources will enable continued operation, possibly time limited. Multi sensor tracking* Secondary effects may include loss or degradation of downlinked airborne parameters (e.g. groundspeed). *Mitigation: Surveillance tracking deriving the data*

21.**Radar sensors** *[Time service provided by GPS constellation and in the future by GNSS in general is used in radar application to synchronise the internal clocks used to timestamp the information in order to let the ATM system know when the aircraft position was calculated and compare with its own timing to accept or reject the plot.]*	Loss of GPS time synchronisation. Revert to local time source or non-time synchronised service (depending on the system architecture and alternate time sources). For long duration outages (days/weeks) the MRT can be impaired.	(**6**) No direct impact on core function, surveillance is still provided in degraded/time limited mode. Possible longer-term capacity regulations. Mitigation: *Back-up timing sources will enable continued operation, possibly time limited.* Multi sensor tracking Secondary effects may include loss or degradation of downlinked airborne parameters (e.g. groundspeed). *Mitigation: Surveillance tracking deriving the data*
22.**Multi Sensor Tracking systems**	Sensors: Loss of synchronised GPS time for one or more surveillance data sensor. Tracking system: (own timing sensor tbd)	Impact depend on which source is impacted and the extent of the impact. The impact can range from no or limited track performance degradation to loss of input from one or more sensors, which may reduce coverage and performance.

APPENDIX 2 – Examples of internal ANSP procedures in case of GPS interference (de-identified)

Example #1

GPS interferences checklist for ATM Unit

Target

Define required actions and limitations when experience GPS Interferences.

General Information

The Survey Unit (governmental company), have many stations around the country to track satellite signal, also they operate information center (open 24/7) that can share information about which of the station experience GPS interferences, what is the severity of the interferences and sometimes also what are the sources for the interferences

Method

1. When GPS interferences activities are about to start immediately:
    a. RNP Procedures for the effected RWY are not authorized;
    b. No limitation for RNAV1/2/5 Procedures and Routes;
    c. Stop transmit via ATIS about RNP procedures in use.
2. When GPS interferences activities are known well in advance:
    a. AIS office will publish a NOTAM sharing all the information about upcoming GPS interferences;
    b. the notification will include areas and time table of the GPS interferences;
3. When GPS interferences start without any notification:
    a. if detected by the air traffic controller -
        i. the current APCH will be changed to a conventional or RNP that is not effected by the GPS interferences;
        ii. notify to the other adjacent units;
        iii. Contact Survey Unit to receive more information about the source of the GPS interferences;
        iv. Contact the military for more information;
        v. Rules 1a, 1b and 1c are applicable.
    b. if declared by Pilot –
        i. Verify with more than one source and/or aircraft in the vicinity for the probability of GPS interferences;
        ii. if more than one source and/or aircraft are experiencing GPS interferences -
        iii. The current APCH will be changed to a conventional or RNP that is not effected by the GPS interferences;
        iv. Notify to the other adjacent units;
        v. Contact Survey Unit to receive more information about the source of the GPS interferences;
        vi. Contact the military for more information;

vii. Rules 1a, 1b and 1c are applicable

4. Resume normal operation:
    a. when the time table for the GPS interferences is over;
    b. Input from the military or from Survey Unit that there are no longer GPS interferences in the area of interest.
    c. After reasonable time that aircrafts are reporting that they no longer experiencing GPS interference, head of shift can determent to resume normal operation.

Example #2

Checklist of tasks for detection, reporting and removal of GNSS interferences.

The following table collect the tasks that should have to be performed after a GNSS interference (that affects to Air Operations) has been detected, in order to eliminate the interference.

The following tasks have been defined in order to serve as a guidance and verification material, to the GNSS interference removal process.

TASK	RESPONSABLE
A. DETECTION AND INTERNAL NOTIFICATION	
1. Compilation of all the information associated with the interference report through different sources: • Regional ATS. • Regional Engineering. • Regional Security/Safety. • GNSS interference receivers (GPS L1).	Satellite Navigation Department
2. Notification of the interference to the National Spectrum protection authority according to the internal procedures.	Telecommunications Department
3. Coordination and notification with other internal units: • Operations Directorate. • Systems Directorate. • Regional Directorate. • ATM development division. • H24 Network Monitoring and Control Centre. • Regional Safety division. • Communication directorate.	Air Navigation Directorate
4. Notification to the ANSP General Director	Air Navigation Directorate
B. INTERNAL PROCEDURES ACTIVATION	
1. Analysis of the availability and/or requirement for the flight verification/inspection aircraft. Assessment of the necessity to perform verification/inspection flights to localize the interference.	Flight Verification Unit
2. Analysis of the availability and/or requirement for portable GNSS interference detection equipment in order to perform site GNSS measures.	Satellite Navigation Department
3. Analysis of the Operational impact and possible procedures activation.	Air Navigation Directorate Operations Directorate Regional Air Navigation Directorate H24 Network Monitoring and Control Centre
4. Analysis on the need to publish a NOTAM and publication.	Air Navigation Directorate Operations Directorate Regional Air Navigation Directorate AIS

TASK	RESPONSABLE
5. Analysis of the flights trajectories and aircraft type affected by the loss of GPS signal (route deviation) through radar tracks and ADS-B data.	Surveillance and Navigation Departments Regional Safety division
6. Analysis on the need to activate ATIS messages.	Air Navigation Directorate Operations Directorate
7. Analysis of GNSS interference, GPS and EGNOS systems status through the following sources: • GPS and EGNOS signal status (NANUs, RAIM, etc.). • Ground GPS signal validation. • GNSS interference receivers. • Space weather information. Ionosphere activity	Satellite Navigation Department
8. Deployment of ground equipment in order to locate the interference.	Satellite Navigation Department
C. COORDINATION WITH EXTERNAL UNITS	
1. Notification to the Airport Manager of the affected airport.	H24 Network Monitoring and Control Centre
2. Notification to the National Supervisory Authority and the Civil Aviation Authority and Transport Ministry.	Air Navigation Directorate
3. Coordination with Airlines.	Air Navigation Directorate
4. Notification to the National Ministry of Defence.	Air Navigation Directorate
5. Notification to the National Security Authority.	Security and Safety division
D. RESOURCES/COORDINATIONS ACTIVATION FOR THE DETECTION OF THE INTERFERENCE SOURCE	
1. Coordination with Space stakeholders capable of emitting radiation: • Space industry. • National Space Agency.	Surveillance and Navigation Departments
2. Coordination with the National Authorities: Ministry of Defence, Security Authority	Air Navigation Directorate
3. Coordination with National Meteo Agency.	Air Navigation Directorate
4. Coordination with Satellite service providers and GNSS Centres: • GSA/ESSP. • GNSS Service Centre.	Satellite Navigation Department
5. Turn off possible internal interference systems (PSR, etc.)	Air Navigation Directorate Systems Directorate
6. Coordination with other companies.	Satellite Navigation Department

TASK	RESPONSABLE
7. Analysis of the interference environment with the telecommunications authority.	Satellite Navigation Department Telecommunications Department
E. ACTIONS TO BE PERFORMED AFTER THE MITIGATION OF THE INTERFERENCE ORIGIN	
1. Flight inspection to verify that the interference has been removed, if needed.	Flight Verification Unit
2. Elaboration and distribution of final technical report to the interested parties.	Satellite Navigation Department
3. Elaboration and distribution of the final operational report to the interested parties.	Operations Directorate
4. Removal of NOTAMS and/or ATIS messages.	AIS Regional Air Navigation Directorate
5. Notification of the GNSS Interference resolution to the interested parties.	Air Navigation Directorate
6. Interference signals monitoring (H24), in order to verify the removal of the interference source.	Satellite Navigation Department
7. Elaboration of detailed technical reports and lessons learned.	Satellite Navigation Department

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