EUROCONTROL

European Navaid Infrastructure Planning Handbook including Minimum Operational Network (MON)

PBN HANDBOOK No. 4

SUPPORTING EUROPEAN AVIATION

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NETWORK MANAGER

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 4.

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DOCUMENT CONTROL

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EXECUTIVE SUMMARY

Context

This document is intended to respond to needs arising from EU regulation related to PBN which give a clear signal that GNSS is to become the primary navigation infrastructure for PBN by 2030 (See EC Regulation EU 2018/1048 (PBN IR)). Until 2030, the vast majority of the airspace users will only have a single frequency, single constellation receiver (SF-SC) using the US NAVSTAR Global Positioning System (GPS). As such, consideration must be given to the possible loss of this signal and how to maintain ATM operations using only ground-based Navaids. GNSS vulnerability will consistently need to be mitigated: 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) procedures to maintain an acceptable level of safety. This applies equally to SF-SC or DF-MC (dual-frequency multi-constellation) environments.

The infrastructure provides positioning for PBN operations. Whatever the positioning source used – be it satellite or ground-based Navaids, two criteria must be fulfilled: (i) aircraft's navigation sensor must match the navigation infrastructure available; (ii) the aircraft must be certified and crew must be authorised for the intended PBN operation.

Purpose

The aim of this document is to encourage infrastructure planners to work with their airspace and procedure design colleagues to enable and achieve PBN implementation for both normal and contingency operations. The importance of considering both normal *and* contingency operations is stressed in two PBN Handbooks:

- the *European Airspace Planning Handbook for PBN Implementation, Handbook No 1*, whose activities are frequently cross-referenced in this handbook;
- the *European GNSS Contingency/Reversion Handbook, Handbook No 6*, which provides a thinking-pack for ANSPs when developing their contingency procedures and reversion infrastructure in the event of GNSS outage.

Together, Handbooks 1 and 6 explain the *operational* need for both a ground-based Navaid infrastructure and its Minimum Operational Network (MON). In turn, this Handbook, No 4, provides the 'how to' package related to infrastructure evolution and creation of a MON.

Terminology

In the context of this handbook, ***Minimum Operational Network (MON)*** refers to the minimum Navaid infrastructure needed to provide the required level of (ATM/ANS) service for both normal and contingency operations (See Handbook 6).

In the context of this handbook, the term ***evolution*** refers to all changes to the Navaid infrastructure including ***decommissioning***, ***optimisation*** or ***deployment***. The words ***decommissioning*** and ***rationalisation*** may be used interchangeably as regards the ground-based Navaid infrastructure. ***Optimisation***, on the other hand, has a distinct nuance of cost-effective improvement of the infrastructure.

The terms ***terrestrial navigation infrastructure*** and ***ground-based navigation infrastructure*** are both commonly used in different international fora. Within this document the terms are inter-changeably used and from the perspective of PBN operations, there is no difference between the two terms. Furthermore, if 'conventional' is linked with either term (i.e. conventional ground-based navigation infrastructure) then this expression excludes any GNSS elements in that infrastructure. Within this document the expression 'conventional' will not be regularly repeated and whenever either the words terrestrial or ground-based appear in front of the word Navaids or infrastructure, this explicitly excludes any GNSS element (*Note: GNSS elements cover core constellations as well as any augmentation system).*

Scope

Given the above, the scope of this book is limited to the EU regulatory environment and does not purport to cover all aspects of Navaid infrastructure planning. Furthermore, given that 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 dual frequencies or one out of several constellations is not considered in the context of Navaid infrastructure planning in this document.

Recommendations:

ANSPs should plan the evolution of their Navaid Infrastructure. This plan should be frequently updated and considered as a living document.

ANSPs are encouraged to work in partnership with the national authorities in undertaking the evolution of their Navaid Infrastructure 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.

TABLE OF CONTENTS

1. CONTEXT 11

1.1 Global context - ICAO 11

1.2 EU Regulatory Context 12

1.3 ATM/CNS Context 13

2. NAVAID EVOLUTION STRATEGIES 16

2.1 Introduction 16

2.2 ICAO Strategy 16

2.3 European Strategy 20

3. FACTORS INFLUENCING NAVAID INFRASTRUCTURE EVOLUTION 22

3.1 Infrastructure Management Challenges 22

3.2 Cost Benefit Analysis (CBA) 26

3.3 Conclusion 26

4. PROCESSES FOR NAVAID INFRASTRUCTURE EVOLUTION 27

4.1 Introduction 27

4.2 Infrastructure Planning 27

4.3 Summary 29

5. INFRASTRUCTURE PLANNING METHODOLOGY 30

5.1 Airspace Concept Development 30

5.2 Infrastructure Planning Activities 31

5.3 PBN Transition Plans 40

6. CONCLUSION 41

ATTACHMENTS:

Att. A: Operational/Technical Terrestrial Navaid Considerations supporting IA-6 43

Att. B: General Considerations supporting IA-6 47

ABBREVIATIONS

ADF	Automatic Direction Finding
ADS-B	Automatic Dependent Surveillance- Broadcast
AIP	Aeronautical Information Publication
AMC	Acceptable Means of Compliance
ANC	Air Navigation Conference
ANSP	Air Navigation Service Provider
A-PNT	Alternative Position, 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
ATM	Air Traffic Management
ATSEP	Air Traffic Safety Electronic Personnel
AR	Authorisation Required
ASBU	Aviation System Block Upgrade
AU	Airspace User
CBA	Cost Benefit Analysis
CCC	Common Core Content
CDM	Collaborative Decision Making
CNS	Communications, Navigation and Surveillance
CP1	Common Project One
CS-ACNS	Certification Specification for Airborne CNS
D/D	DME/DME
DF	Dual Frequency
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
EC	European Commission
ED	European Document (EUROCAE)
EGNOS	European Geostationary Navigation Overlay Service
EU	European Union
FAS	Final Approach Segment
FL	Flight Level
FMG	Frequency Management Group
FMS	Flight Management System
GANP	Global Air Navigation Plan
GBAS	Ground Based Augmentation System
GLS	GNSS Landing System
GM	Guidance Material
GNSS	Global Satellite Navigation System
GPS	Global Positioning System
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
INS	Inertial Navigation System
IR	Implementing Regulation
IRE	Instrument Runway End

IRS	Inertial Reference System
IRU	Inertial Reference Unit
LNAV	Lateral Navigation
LNAV/VNAV	Lateral Navigation/Vertical Navigation
LOA	Letter of Acceptance
LOC	Localizer
LP	Localizer Performance
LRU	Line Replaceable Unit
LVO	Low Visibility Operations
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
MSSR	Monopulse Secondary Surveillance Radar
NAV	Navigation
NAVAID	Navigation Aid
NDB	Non Direction Beacon
NM	Nautical Mile
NPA	Non Precision Approach
NSA	National Supervisory Authority
OEM	Original Equipment Manufacturer
PA	Precision Approach
PANS	Procedures for Air Navigation Services
PBN	Performance-Based Navigation
PBNSG	Performance-Based Navigation Study Group
PCP	Pilot Common Project
QoS	Quality of Service
RAFT	Radio Frequency Function Group (EUROCONTROL)
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP APCH	Required Navigation Performance Approach
SARPS	Standards And Recommended Practices
SBAS	Satellite Based Augmentation System
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
SIS	Signal In Space
STAR	Standard Instrument Arrival Route
TACAN	Tactical Air Navigation System
TMA	Terminal Control Area
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
xLS	Precision landing system such as ILS, GLS, MLS

DOCUMENT REFERENCES

Document Full Title	Short title used in document text
European Airspace Concept Handbook for PBN Implementation, PBN Handbook No 1	*Airspace Concept Handbook*
European GNSS Contingency/Reversion for PBN Operations, PBN Handbook No 6	*GNSS Reversion Handbook*
European Route Spacing Handbook, PBN Handbook No 3	*Route Spacing Handbook*
Eurocontrol Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114).	*RNAV 1 Infrastructure Guidance*
Eurocontrol, Common Core Content Initial Training, Eurocontrol – SPEC – 132.	*ATSEP CCC*
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*
ICAO Manual on Testing of Radio Navigation Aids, Doc 8071, Volume I.	*Doc 8071*
ICAO Performance-based Navigation Manual, ICAO, Doc 9613, Edition 4, 2013	*PBN Manual*
ICAO EUR Doc 011, Frequency Management Manual	*Frequency Management Manual*
ICAO EUR DOC 015, European Guidance Material on Managing Building Restricted Areas.	*EUR DOC 015*
EUR RNP APCH Guidance Material (EUR DOC 025)	*EUR DOC 025*
Rationalisation Planning for ECAC, SESAR D.2.3, SESAR 1, Project 15.3.2	*Project 15.3.2*
CNS evolution roadmap and strategy (Deliverable D2.1.020 of SESAR 2020 project PJ14 EECNS)	*CNS Evolution Roadmap*

1. CONTEXT

1.1 Global context - ICAO

1.1.1 Global Air Navigation Plan (GANP)

The Global Air Navigation Plan (Doc 9750) is described as *"ICAO's highest air navigation strategic document and the plan to drive the evolution of the global air navigation system, in line with the Global Air Traffic Management Operational Concept (GATMOC, Doc 9854) and the Manual on Air Traffic Management System Requirements (Doc 9882)".*

To this end, the current GANP is structured as a rolling, 15-year strategic methodology that leverages existing technologies and anticipates future developments based on State/industry agreed operational objectives. The foreseen evolution of the navigation applications and supporting technologies is organized in "Aviation System Block Upgrades" (ASBU), i.e. six-year time increments that started in 2013 and continues through 2031 and beyond. The main declared objective of this structured approach is to *"provide a basis for sound investment strategies and generate commitment from States, equipment manufacturers, operators and service providers."*

This ICAO document includes, in Appendix 5, the Technology Roadmaps defined to support of the evolution of the navigation applications. The following extract from this Appendix describes the high-level ICAO vision regarding the future role of the terrestrial navigation infrastructure.

Future terrestrial infrastructure requirements

The GANP has the objective of a future harmonized global navigation capability based on area navigation (RNAV) and performance-based navigation (PBN) supported by the global navigation satellite system (GNSS).

The optimistic planning that was considered at the time of the Eleventh Air Navigation Conference (2003) for all aircraft to be equipped with GNSS capability and for other GNSS constellations to be available, together with dual frequency and multi-constellation avionics capability being carried by aircraft have not been realized.

The current single frequency GNSS capability provides the most accurate source of positioning that is available on a global basis. With suitable augmentation, as standardized within Annexes, single frequency GNSS has the capability to support all phases of flight. The current GNSS has an extremely high availability, although it does not have adequate resilience to a number of vulnerabilities, most notably radio frequency interference and solar events causing ionospheric disturbances.

Until a solution to ensure adequate GNSS resilience is available, it is essential that a terrestrial navigation infrastructure, suitably dimensioned to be capable of maintaining safety and continuity of aircraft operations, be provided.

1.1.2 Air Navigation Conferences (ANC)

ANC 12

The vulnerabilities of GNSS and the need for mitigation planning were further addressed at the ICAO Twelfth Air Navigation Conference. The Conference adopted the following Recommendations in this respect, published in ICAO Doc 10007:

Recommendation 6/8 – Planning for mitigation of global navigation satellite system vulnerabilities

That States:

a) Assess the likelihood and effects of global navigation satellite system vulnerabilities in their airspace and apply, as necessary, recognized and available mitigation methods;

….

f) where it is determined that terrestrial aids are needed as part of a mitigation strategy, give priority to retention of distance measuring equipment (DME) in support of inertial navigation system (INS)/DME or DME/DME area navigation, and of instrument landing system at selected runways.

Recommendation 6/10 – Rationalization of terrestrial navigation aids

That, in planning for the implementation of performance-based navigation, States should:

a) assess the opportunity for realizing economic benefits by reducing the number of navigation aids through the implementation of performance-based navigation;

b) ensure that an adequate terrestrial navigation and air traffic management infrastructure remains available to mitigate the potential loss of global navigation satellite system service in their airspace; and

c) align performance-based navigation implementation plans with navigation aid replacement cycles, where feasible, to maximize cost savings by avoiding unnecessary infrastructure investment.

ANC 13

In addition, ANC/13 has highlighted the need for CNS spectrum protection and access.

Recommendation 2.2 / 1 - Long-term evolution of CNS systems and frequency spectrum access

That States:

a) engage in the spectrum regulatory process to ensure the continued necessary access to and protection of safety-critical aeronautical CNS systems;

b) ensure through the implementation of a safety oversight programme that the designated competent authorities are involved in safety case assessments of the radio frequency environment so as to adequately protect the operational availability of aeronautical CNS systems;

1.2 EU Regulatory Context

In accordance with the ICAO strategy, EU Regulatory provisions require that ANSPs implement RNAV and RNP procedures in Member States of the European Union and in those States where European ANSP/ATSP provide a service. The regulation that defines these requirements is the Commission Implementing Regulation (EU) 2018/1048, known as the PBN IR[1] supplemented by Acceptable Means of Compliance and Guidance Material through EASA ED Decision 2018/013/R.

These regulatory requirements drive the planning of the evolution of navigation applications in all phases of flight and the associated airspace changes. Therefore, the requirements have been summarised in the *Airspace Concept Handbook* and in the *GNSS Reversion Handbook* as shown in Table 1-1.

The Commission regulation requires PBN operations to become the norm in all flight phases in a stepped approach starting 2020 for completion by June 2030. As this transition takes place, GNSS becomes the 'central' positioning source with ground-based Navaids relegated to a secondary role.

As regards the future role of the terrestrial infrastructure, the key provision is included in Article 6 (Contingency measures) of the PBN IR:

"Providers of ATM/ANS shall take the necessary measures to ensure that they remain capable of providing their services through other means where, for unexpected reasons beyond their control, GNSS or other methods used for performance-based navigation are no longer available, making it impossible for them to provide their services in accordance with Article 3. ***Those measures shall include, in particular, retaining a network of conventional navigation aids*** *and related surveillance and communications infrastructure."*

Although the main purpose of this handbook is to support the navigation infrastructure planning for PBN implementation, it is also necessary to consider non-PBN operations and related Navaid use. This aspect is **also addressed in the PBN IR**, as regards landing systems. In this respect, the regulation sets an exception to the general rule of PBN being the 'norm' for Low Visibility Operations (LVO) CAT II/III which can be supported by Instrument Landing Systems (ILS); PBN cannot support LVOs. *(Note: Standards and Recommended Practices (SARPS) were published for Ground-Based Augmentation Systems (GBAS) CAT II/III in Nov 2018; however, the current version of EU 965/2012 does not include GBAS as a LVO system. This may change when this regulation (AirOps) is*

[1] *Previously the PCP IR (Pilot Common Project Implementing Regulation [EU] No 716/2014) also regulated PBN implementation. This regulation has been superseded by Common Project One (CP1) that no longer addresses PBN or, by implication, its infrastructure.*

reviewed. The potential inclusion of GBAS to support CAT II/III in the future is also implied by the inclusion of GLS in ED Decision 2018/013/R GM2 Article 4, Transitional Measures paragraph (d) to the PBN IR).

In a nutshell, this required transition towards PBN applications increasingly supported by GNSS as the primary navigation sensor affects several PBN stakeholders, including:

- Air traffic controllers who will need to adapt to controlling traffic using less vectoring and increased monitoring of aircraft performance on the strategically de-conflicted PBN routes published in the airspace structure. (See *Route Spacing Handbook*). At the same time, air traffic controllers have to be aware of the risk of GNSS outages, the contingency procedures to be applied in this case and maintain the appropriate skills to manage the contingency. For example, in areas with no terrestrial Navaid infrastructure support, if a GNSS outage occurs then controllers could manage the traffic either by radar vectoring and/or procedural control (see *GNSS Reversion Handbook*).
- Procedure designers who need to consider the ground-based Navaid infrastructure from a different angle when designing instrument flight procedures. First, when considering Navaids for both normal and contingency PBN operations (which are underpinned by area navigation techniques) the procedure designer will be aware that the infrastructure's primary goal becomes the provision of a navigation performance 'mesh' in support of RNAV procedures. This contrasts to the way in which the Navaid infrastructure supports conventional (point-to-point) operations. Second, terrestrial Navaids will evolve to become the 'backup' for GNSS.
- ATC Operation managers who will be potentially affected by the need to generate adaptations to their procedures and/or systems should an implementation safety case demonstrate the need for controllers to be informed of the area outage, its location and dimensions.
- 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 to the end state and to support contingency operations in both instances, should the need arise.

Table 1-1: Summary of the PBN Implementation Regulation

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).

1.3 ATM/CNS Context

A holistic ATM/CNS view in the context of PBN implementation is given in the *GNSS Reversion Handbook*. That Handbook addresses GNSS Reversion/Contingency in the context of PBN operations in all flight phases, with the main emphasis on terminal and extended terminal operations in a surveillance environment. The document provides planning considerations through explanatory text and the use of sample contingency scenarios. The purpose of the *GNSS Reversion Handbook* is to serve as a 'bridging' document between guidance material published to support Airspace Planners and Infrastructure Planners implementing PBN.

The document emphasizes the need for planning the GNSS contingency operations together with the introduction of PBN operations and provides a series of generic considerations to be made when defining the reversion scenarios. The *GNSS Reversion Handbook* highlights the increasing level of interdependency on the GNSS signal in CNS and draws attention to the fact that a loss of GNSS signal impacts more than just the navigation elements; aircraft functions are also potentially impacted as well as ground-systems reliant for example, on the GNSS timing for synchronisation. For more details, see Figure 1-1 and Figure 1-2 and also refer to *Appendix 1* in Handbook No. 6.

The *GNSS Reversion Handbook* at Chapter 5 shows the Airspace Design and the Navaid Infrastructure Planning methodologies side-by-side which suggests that they run as mirror images and in parallel. The reality of the interaction between the two methodologies is more complex: exchange of pertinent information is crucial between the Airspace Design and Infrastructure Optimisation Teams, and these exchanges are often executed over several iterations to find the optimal solution. If the *Airspace Concept Handbook* methodology is used by the ANSP, it is recommended that the activities be performed within a common framework agreed between airspace and infrastructure colleagues. Chapter 5 of this handbook (*Navaid Infrastructure & MON Handbook*) builds on the recommendation in the *Airspace Concept Handbook*, and provides the mapping between the activities outlined in the two documents. Further details on the relationship and interactions between these two methodologies are found in Chapter 5.

Figure 1-1: GNSS Vulnerablities

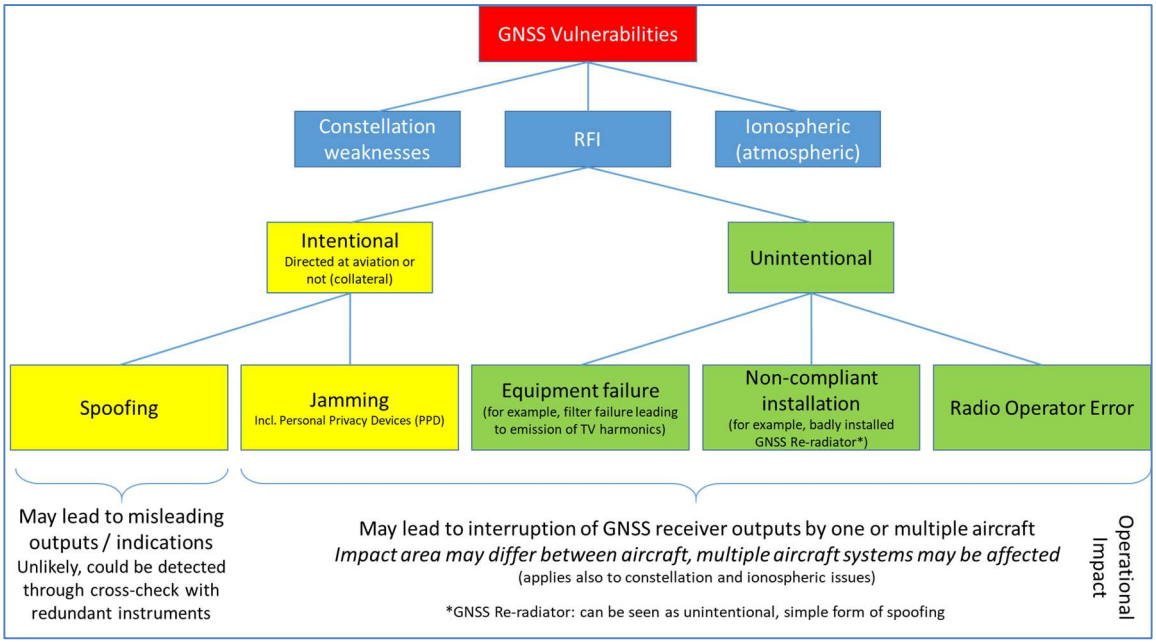
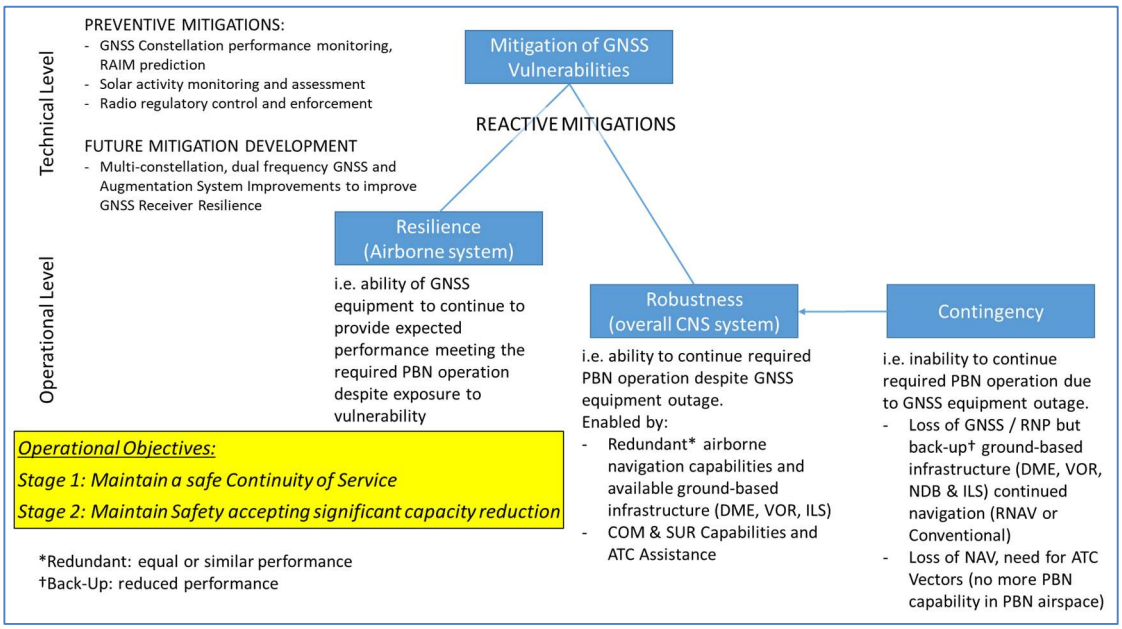


Figure 1-2: Vulnerability Mitigations – terminology *



**Note: Most of these terms are not defined by ICAO but commonly used in GNSS fora in Europe. Guidance on the development of a GNSS mitigation plan is located in the GNSS Manual, ICAO Doc. 9849, Appendix F.*

2. NAVAID EVOLUTION STRATEGIES

2.1 Introduction

The evolution of the navigation infrastructure in European countries is based on various factors. Two of these have been alluded to in the previous section highlighting the international (ICAO) context and the European regulation which are generally driven by operational ATM needs (including PBN Implementation). There are also other drivers such as **international** and **national** strategies (regarding spectrum and frequency availability, for example). The pressures on the L-band are well-known; this is a highly sought after part of the frequency spectrum particularly for the evolution of future telecommunications and entertainment systems (See ANC/13, Recommendation 2.2/1 which deals with the need for spectrum protection). Furthermore, **industrial interests**, altered **geo-political situations** and **unforeseen events** can (suddenly) cause a significant change to a defined and agreed infrastructure strategy which has driven the evolution thus far.

These factors are mentioned as a reminder to infrastructure managers that Navaid Infrastructure Evolution planning cannot be absolute, and that it is probably a reasonable strategy to have alternative 'scenarios' available to cater for the unexpected. Whilst this chapter elaborates the international and European Infrastructure strategies, both of which are underpinned (mainly) by ATM operational need, it is useful to remember that these are not the only influencing factors determining the evolution of these strategies.

2.2 ICAO Strategy

The overview of the Global and the European context given in the previous sections shows that in general, the role of the ground-based Navaids will evolve towards providing a reversion for GNSS and supporting contingency operations in case of GNSS becoming unusable. This evolution offers the opportunity for the rationalization of some of the terrestrial infrastructure and retaining only a **Minimum Operational Network** (**MON**) which is designed to efficiently provide reversion service.

However, each Navaid can fulfil different operational roles irrespective of the availability of ATS Surveillance:

- During <u>normal ATM operations</u>, ground-based Navaids support
  - PBN applications as a primary positioning source;
  - PBN applications as a secondary positioning source to GNSS
  - Conventional procedures (e.g. either in an environment where there are no PBN procedures; or to accommodate non-PBN capable aircraft.)
- During <u>ATM contingency operations</u>, ground-based Navaids support
  - PBN applications as a back up positioning source due to GNSS outage;
  - Conventional procedures as a means of reversion during a GNSS outage;

In order to plan the evolution of the navigation infrastructure, it is important for an ANSP to have a thorough picture of the type of operations that can be supported by each type of terrestrial Navaid. This understanding will enable the ANSP to develop both an optimisation and *decommissioning* plan of Navaids as well as a coordinated evolution to a reversionary terrestrial infrastructure.

Table 2-1 identifies which ground-based Navaid support which PBN specification. The navigation specifications performance requirements determine which positioning source/sensor (e.g. navigation aid and/or aircraft integration with IRU, inertial reference unit) can be used. The on-board navigation sensors must match the infrastructure in such a way as to achieve the prescribed navigation performance within the coverage area of the Navaid infrastructure.

Where there are sensor options for a particular Navigation Specification, one or more of the identified sensors may be fitted to meet the navigation performance. The operator makes the choice of sensor(s). In a multi-sensor fit, generally, the aircraft's navigation computer makes use of the highest performing

positioning source and then 'steps down' if that source is no longer available. An IRU may be integrated in the avionics to improve performance and continuity of the operation. This is evident in the varieties of FMS software logic in positioning determination. For example, with a multi-sensor FMS, the order of (positioning) precedence could be: GNSS updating the IRU > D/D updating the IRU > V/D updating the IRU > IRU coasting. (Where reliance is placed upon IRS, some aircraft systems will revert to VOR/DME-based navigation before reverting to inertial coasting. The impact of VOR radial accuracy, when the VOR is within 40 NM from the route and there is insufficient DME/DME NAVAID infrastructure, must be evaluated by the ANSP to ensure that it does not affect aircraft position accuracy. One means of minimising the VOR's influence on inertial position is for RNAV systems to exclude VORs greater than 40 NM from the aircraft.

*Table 2-1: Navaid Infrastructure (**R**equired/**O**ptional) supporting PBN applications*

	GNSS	DME/DME	VOR/DME	Note
RNAV 10[1]	O			*IRU optional*
RNAV 5[1]	O	O	O	*IRU optional*
RNAV 2[1] & 1[1]	O	O		
RNP 4	R			
RNP 2	R	TBD[2]		
RNP 1	R	TBD[2]		
ADVANCED RNP	R	O[2]		
RNP APCH[3]	R			
RNP AR[4]	R			*IRU optional.*
RNP 0.3	R			

Note 1: Infrastructure must match on-board equipage

Note 2: TBD (To be determined) The use of DME/DME for this navigation specification requires a specific State authorization. EUROCAE WGs 107 and 85 are in the process of determining potential European standards for the use of DME/DME for RNP applications (infrastructure/avionics respectively).

Note 3: Conventional navigation can provide guidance on the missed approach, and exceptionally, this may be supported by NDB.

Note 4: IRU required where the lateral navigation accuracy is less than 0.3 NM in the approach phase and less than 1 NM in the missed approach.

Annex 10 Attachment H defines a global *"Strategy for rationalization of conventional radio navigation aids and evolution toward supporting performance based navigation".* The objective of Attachment H is to provide guidance to the States for both the rationalization and reversion of the terrestrial Navaid infrastructure. The recommendations included in this high-level strategy are based on the residual roles foreseen for each type of Navaid to support PBN operations and/or conventional procedures.

Furthermore, consideration of this strategy should be given when deciding investments into new facilities or on facility renewals. As this strategy is highly relevant to the objectives of this handbook, key points of this strategy are included below, contextualised for the European region.

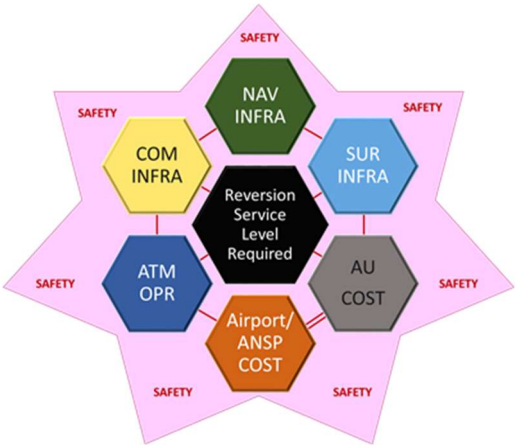
Note that the considerations and the evolution strategy included in ICAO Annex 10, Volume I, Attachment H are intended to be globally applicable. The high-level strategy for the European region is addressed in section 2.3

Table 2-2: Summary of Attachment H, contextualised for EUR region

Note: In the context of Attachment H, the term "network" refers only to navigation facilities assessed on a regional scale, and it does not refer to a network of routes or a particular airspace design.

	ROLE IN PBN **(providing an adequate infrastructure is available, where applicable)**	**OPPORTUNITIES AND SOLUTIONS** **(Residual roles – PBN/conventional)**
NDB	NDB has no role in PBN. Exceptionally it may be used for conventional guidance of a PBN missed approach. This operation is not encouraged.	If NDBs are used to define PBN ATS Routes they should be replaced by RNAV waypoints. Non—Precision Approaches based on NDB should be replaced by RNP APCH. Similarly, if NDBs are used as ILS locators associated with an RNAV procedure intercept, RNAV Waypoints should replace these. ***CONCLUSION:*** *Rationalize NDB and associated conventional procedures.*
VOR	VOR has a limited role in PBN supporting one navigation application only, viz. RNAV 5, which is primarily used in en route. The PBN IR requires RNAV 5 for all en route ATS routes (excluding SIDS/STARs) by 2024.	The opportunity arises to rationalise some VORs providing cost savings. Introduction of new VORs is not encouraged, but existing ones may be needed to support reversion operations; enhance situational awareness in terminal operations; provide limited inertial updating if D/D not available; exceptionally to be used for NPAs if no other option is available; to support aircraft only able to navigate conventionally (this may include state aircraft) up to June 2030; and support procedural separation. . ***CONCLUSION:*** *Rationalize VOR and associated conventional procedures. From a European perspective, this rationalisation should, if possible, aim to facilitate DME channel assignment (estimates are that a decrease up to 50% of facilities could be possible in some countries). Plan for a minimum number of VORs to support conventional navigation guidance in case of GNSS loss.*
DME	DME/DME supports RNAV 5, RNAV 2 and RNAV 1 navigation specifications. DME/DME is the most suitable terrestrial Navaid for PBN for appropriately equipped aircraft. States are encouraged to plan the evolution of their DME infrastructure by considering the following:	DME/DME provides a fully redundant capability to GNSS for RNAV applications, and a suitable reversionary capability to RNAV 1 for RNP applications requiring a lateral accuracy performance of ±1 NM (95%), providing there is an adequate DME infrastructure. Many DMEs are co-located with VORs which creates certain limitations. When VORs are decommissioned, this can be an opportunity to optimise the DME network. In such instances, to save costs or to improve DME/DME performance, DME's can be re-located (ideally with other CNS assets) if a co-located VOR is withdrawn. To be operationally robust, efficient DME network design should fill gaps and provide DME/DME coverage as low as possible without requiring more investment unless needed for safety reasons. (Other solutions such as requiring on-board IRU, reliance on ATS surveillance and/or military TACANS may be viable alternatives). Cross-border use of DME facilities is encouraged supported by the necessary authorisations and/or agreements. Deployment of new DME stations should avoid that part of the frequency spectrum close to the GNSS L5/E5 band (1 164 – 1 215 MHz). ***CONCLUSION:*** *The application of the above principles should enable uniformity of DME deployment across the European region; the overall number of DMEs is not expected to change significantly. That said, in areas of high DME station concentration, the number of DME stations could reduce. These reductions could provide the opportunity for an increase of DME stations in areas of low DME density or to support terrain*

		challenged environments. It is recognized that in some areas, the provision of D/D navigation is not possible or practical, such as at very low altitudes, in terrain-constrained environments, or on small islands, archipelagos, remote areas and airspace over the water. Finally, it is possible that in some countries there could be an increase in the number of DMEs to support A-PNT. *Note: Some FMS may exclude the use of ILS-associated DMEs. Consequently, it is not possible to ensure consistent D/D service is available to all D/D-equipped users based on ILS-associated DMEs. Therefore, those facilities should not be planned in the provision of such D/D service (regardless of whether they are published in the en-route section of the AIP), without an appropriate fleet assessment. Further guidance is provided in the RNAV 1 Infrastructure Guidance.*
Aircraft Capabilities	Aircraft must be fitted with sensors that match the navigation infrastructure.	If aircraft are not certified with GNSS for PBN operations then an alternative navigation solution is required. Terrestrial navigation aids can support either conventional procedures or a PBN application permitting their use: (i.e. D/D enables RNAV 1/2/5, VOR/DME enables RNAV 5 only). When all AUs are certified with GNSS for PBN operations, a reversion 'back-up' of terrestrial navigation aids provides one means to mitigate GNSS outages (other mitigations could be radar surveillance or, in the future, A-PNT) – See *GNSS Reversion Handbook*. ***CONCLUSION**: It may not be possible or cost-efficient for some AUs to equip with multiple navigation sensors such as DME/DME and/or INS/IRU avionics. Therefore, awareness of the AUs' sensors and associated PBN capabilities is required for infrastructure planning – which is why the Airspace Concept Handbook emphasises multi-disciplinary PBN implementation and Activity 6 of that Handbook goes into considerable detail regarding fleet equipage and Infrastructure matching. This handbook shows how an* Airspace Design Team *(which includes infrastructure planners) uses flight-planning data to analyse the current fleet capability.*
Reversion	The Navaid Infrastructure's evolution must accommodate both normal and reversion ATM operations. *Note: In high-density airspace, it is considered impractical to provide an alternate, conventional back-up route network, once the transition to a fully PBN-based route network has been achieved.*	A Navaid infrastructure must be provided to ensure the safety of operations. Additionally, the level of service to be provided during operations determines the extent of the infrastructure needed; this is especially the case in a reversion scenario. A balance is needed between the **cost** of the infrastructure, the **benefits** of the selected level of service/business continuity and the apportionment of the financial burden between airborne (equipage) and ground (infrastructure, which may require changes across C-N-S). In exceptional cases, it may not be possible or financially viable to provide a reversion service e.g. terrain rich environments, which may force a termination of service. Leveraging airspace user capabilities, such as INS/IRS, as well as other capabilities (e.g. COM/SUR service coverage and ATC capabilities) must be considered to the maximum extent practicable. However, common mode failures must be considered. In some airspaces, it may not be possible to cater for all airspace user equipage levels and, as a consequence, some airspace users may become subject to operational restrictions. **Example of Reversion choice:** Some States with a high traffic density environment have identified DME/DME as their main PBN

Figure 2-1: The Reversion mozaic	
	reversion capability (providing either a fully redundant or a degraded level of performance). These States may also plan to provide a residual VOR or VOR/DME infrastructure network to cater to users which have a PBN capability exclusively enabled by GNSS or to those without an adequate PBN capability. Operational procedures associated with the use of such reversion capabilities would need to be developed. ***CONCLUSION:*** *The provision of a Navaid Infrastructure for reversionary operations requires safety to be assured and the navigation infrastructure costs to be commensurate with the level of service required.*

Evolution Strategy (from Annex 10, Attachment H)

There is a need to consult aircraft operators and international organizations, and to ensure safety, efficiency and cost-effectiveness of the proposed infrastructure solutions. Based on the above, the global strategy is to:

a) Rationalize NDB and VOR and associated conventional procedures;

b) Align rationalization planning with equipment life cycles and PBN implementation planning;

c) Replace conventional approaches without vertical guidance with vertically guided approaches;

d) Where a terrestrial navigation reversion capability is required, evolve the existing DME infrastructure towards providing a PBN infrastructure complementary to GNSS;

e) Provide a residual capability based on VOR (or VOR/DME, if possible) to cater to airspace users not equipped with suitable DME/DME avionics, where required [For Europe, this is an intermediate step until June 2030]; and

f) Enable each region to develop an implementation strategy for these systems in line with the global strategy.

2.3 European Strategy

The PBN Implementing Regulation indicates that GNSS is to become the primary navigation infrastructure over the next decade (See EC Regulation 2018/ 1048 (PBN IR)). Article 6 of the PBN IR requires ANSP 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 MON of VOR/DME.

EASA's acceptable means of compliance to the PBN IR, also highlights the need to rationalise the Navaid Infrastructure (see Acceptable Means of Compliance and Guidance Material to PBN IR issued by EASA through the ED Decision 2018/013/R). A précis from this document of relevance to the future role of the ground Navaids in a PBN environment is provided below. The Guidance Material has three separate sections covering two topic areas:

Transitional Measures

- Transition Planning
  - Based on operational requirements which will set out the plan for making the change from existing procedures to a PBN environment (with due account taken of aircraft capability), infrastructure managers should decommission as many ground-based facilities as possible having

due regard for the operational needs, the possibility of efficiencies in cross-border situations and contingency requirements. In context, ground-based facilities are NDB, VOR, DME and ILS.

- Navaid Infrastructure
  - In an RNAV 1 environment, either GNSS or D/D can support this application. In the DME case, this could require deployment of more DMEs or the re-location of existing DMEs. However, the PBN regulation has the effect of mandating GNSS on-board aircraft by 2024. This stems from the requirement for RNP APCH to be used at all EASA IREs by 2024. This now generalised fleet equipage of GNSS means that the 'hierarchy' of positioning sources used for RNAV 5 and RNAV 1 used will invariably 'default' to GNSS thereby making the probability of D/D as the primary infrastructure for RNAV 1 extremely unlikely.
  - A specific reversionary NAVAID infrastructure is not required. It is only necessary if a safety assessment so dictates, to ensure the safety of operations under contingency conditions.
  - Retaining a MON of ground-based Navaids (e.g. NDB, VOR, DME and ILS) provides conventional navigation means to non-PBN aircraft during the transition.

Contingency Measures

- GNSS Failure: As GNSS is to become the primary Navaid Infrastructure for PBN, its robustness will be enhanced by dual-frequency multi-constellation capability. Nevertheless, the continued availability of a ground-based Navaid Infrastructure is considered desirable to provide positioning capability in the event of radio frequency interference. For example, ILS maintained at key airports and a minimum network of VOR & DME to permit operations on ATS routes.
- Evaluation of Contingency Infrastructure: the reversion infrastructure is based on safety requirements and the level of service to be provided (this corresponds to the ICAO reversion strategy in Table 2-2, (Summary of Attachment H of Annex 10, Vol 1)). The MON referred to above may enable reversion to RNAV applications or, alternatively, support conventional procedures.

With the wide scale implementation of PBN in all phases of flight, it is foreseen that the Navaid infrastructure will gradually evolve towards a Minimum Operational Network (MON) which can efficiently support the continuation of PBN operations or alternative contingency operations in case GNSS becomes unusable.

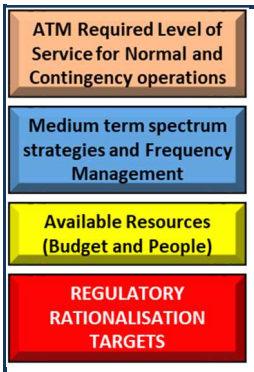
3. FACTORS INFLUENCING NAVAID INFRASTRUCTURE EVOLUTION

3.1 Infrastructure Management Challenges

As explained at the start of Chapter 2, there are a variety of factors and drivers that influence infrastructure management and planning. At global level there are strategic decisions made on spectrum use by the International Telecommunications Union (ITU) who are responsible for the allocation of the spectrum to different technical sectors. For aviation, on a regional basis, ICAO's Frequency Management Groups manage frequency assignment; this affects regional and national strategies and CNS infrastructure decision making.

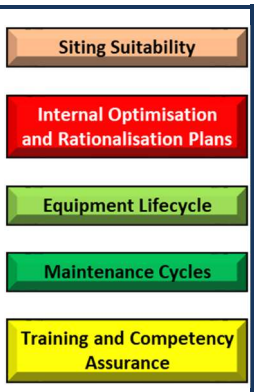
At the level of the Navaid Infrastructure Manager, the management of the infrastructure evolution is a complex process as it has to take into account a number of drivers and constraints (inputs); these can often conflict with each other so efficient trade-offs maybe needed.

The factors influencing infrastructure management can either be: external or internal.



External factors are those over which the infrastructure manager has little influence. These factors are those which stem from the ATM required level of service as well as relevant strategies (e.g. spectrum), available ANSP resources (staff and budget) and regulatory rationalisation targets. Notably, some of these external factors may produce requirements and limitations which are in conflict with each other and an optimum compromise should be sought.

Internal factors are commonly the remit of the infrastructure manager and have technical and financial implications. Primarily, they are comprised of technical limitations, maintenance and evolution activities. These include siting suitability, equipment and maintenance lifecycles, security, training and competency assurance. These factors may constrain how the infrastructure can evolve and are largely associated with cost. "Internal" factors are generally not known to ATM and the AU.



The objective of this chapter is to identify and briefly describe these external and internal factors that impact the infrastructure management decisions.

3.1.1 External Factors

3.1.1.1 Required performance

The purpose of the Navaid infrastructure is to enable certain navigation operations by providing the appropriate signal-in-space. The supported navigation operations can be either conventional or PBN (Area Navigation applications). For each type of application a number of performance requirements are defined for the signal-in space, expressed usually in terms of:

- Accuracy
- Continuity
- Availability
- Integrity

Some of these parameters have a determinant role in achieving the target safety levels and are either defined by the standards (e.g. Annex 10, PBN Manual) or can be derived from these standards. However, in some cases the required level of performance may be also a consequence of the business continuity requirements. During the unavailability of the satellite-based and/or ground based navigation service that enables RNAV operations, due to failures or maintenance, ATC needs to apply contingency operations (e.g. radar vectoring) and may have to reduce the airspace capacity in order to maintain the appropriate safety level. The capacity reduction largely depends on the ATM/CNS environment (traffic density, airspace complexity, type of Surveillance service, etc.). The expected availability and continuity of the navigation service determines the redundancy of the DME/DME coverage (even if DME/DME provides the GNSS backup), and finally the density of ground stations.

'Redundancy'

Redundancy may be operational and/or infrastructure related and should be provided for both normal and contingency operations.

The objective of infrastructure redundancy is determined by the required level of service and this is directly linked to continuity and availability.

The required level of service must be specified for both normal and contingency operations. This will allow ANSPs to provide the most cost-effective infrastructure to achieve the specified required levels of service for both kinds of operations. If the level of service is to be provided by a ground-based infrastructure, adequate redundancy to meet the levels of safety (and business continuity) is needed.

If one Navaid becomes key to supporting a number of instrument flight procedures and its outage means the IFPs cannot be flown, that Navaid becomes 'critical' to the operations concerned. This is a *critical Navaid*.

DME/DME Redundancy

Full redundancy means that two independent DME pairs are available to 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 that pair becomes a *critical Navaid*.

3.1.1.2 Spectrum and Frequency Allocation

Spectrum is a scarce resource, which is in demand across a variety of industries e.g. entertainment, telecommunications and aviation. Furthermore, within the aviation domain there are also competing interests for the same part of the spectrum. The ITU manages spectrum allocation on a global basis.

At regional level, there is significant frequency congestion in Europe particularly in the ILS, VOR and DME bands. In some areas, this makes it practically impossible to assign new VOR or DME channels which then limits any of the opportunities for expansion of the ground-infrastructure. For these reasons, spectrum allocation and frequency management needs to be carefully controlled, and as such, the coordination of aeronautical frequency management is assured via the Frequency Management Group (FMG) and the Radio Frequency Function Group (RAFT).

Spectrum limitations need to be carefully considered in the evolution of the C-N-S infrastructure (See ANC/13, Recommendation 2.2/1).

3.1.1.3 ANSP Resources

It is obvious that within any ANSP, the budget and the human resources allocated to the navigation infrastructure manager are limited. This limitation has a direct impact on the size of the infrastructure that can be operated. When dimensioning the infrastructure network one should remember that the initial investment is not the only cost factor and that the future maintenance costs are always proportional with the investment. Very high service performance requirements may generate high investment and maintenance costs that may exceed a reasonable resources allocation. The infrastructure-associated costs can't always be accurately estimated at the start in a new project. Therefore, it is key that airspace and procedure designers work together with the infrastructure managers during the development of a new airspace concept in order to find the best trade-off between the required navigation service performance and the costs associated with the infrastructure needed to provide the service.

3.1.1.4 Rationalisation Targets

While at the global level the GANP sets out ASBUs, these are not obligatory. At EU level, the European Commission has identified a set of key performance areas and within these, a set of key performance indicators. Cost-efficiency is one of these areas for the ANSP to achieve.

3.1.2 Internal Factors

Internal factors are influenced by technical and financial aspects and a balance must be struck between operational need and infrastructure costs.

3.1.2.1 Equipment Life Cycle

Any technical system has a limited life cycle which, for Navaids, is set generally in-between 15 and 25 years. In some cases, if the system has been carefully maintained, its life can be safely extended over the estimated duration. However, the likelihood of failures increases substantially with the age and has implications on the service quality and maintenance activities and the associated cost. A common practice consists of executing refurbishment works towards the end of the life cycle, which enables the extension of the life time in good operating conditions. One other common practice is to decommission systems of the same type gradually and use components of the early decommissioned facilities as spare parts for the remaining ones.

Different organizations have different acquisition policies when renewing or installing new Navaids. One frequently applied option is to award big contracts, covering a large number of systems in order to minimize the acquisition cost and the administrative overhead of the procurement process and optimize the maintenance activities. A second option, often used by smaller organization is to repeat the procurement process for individual or small lots of systems especially when the number of the existing/needed facilities is low and they are at various stages of their lifecycles.

In any case, the replacement of a Navaid system may require a substantial investment (in particular for VOR) and has to be planned several years in advance. It is very likely that once installed the Navaid will not be decommissioned until the end of its design life (for financial reasons, even if the withdrawal may be possible due to airspace changes). Even if the relocation is possible during the lifetime, this generates additional costs and technical complexities. While the relocation of DMEs is, in general, less complex and can be considered for the network optimization, the relocation of VOR systems should be avoided.

Therefore, in the current context, rationalization should be carefully considered before renewing any system. It is highly recommended that only the facilities identified as future components of the MON are replaced while the life cycle of the other systems is extended until the decommissioning is made possible by the required airspace changes. For this, a clear strategy for the evolution of the ground infrastructure towards a MON configuration has to be defined and implemented by the ANSP organizations.

3.1.2.2 Siting issues and constraints

One important aspect related with the Navaid infrastructure management is the fact that in order to fulfil their operational role, the facilities have to be placed in certain geographical locations.

These locations are not very flexible when it comes to the Navaids that support conventional procedures (rules regarding the relative position to the runways or routes served must be observed). Therefore most of the en-route and TMA VOR/DME systems were originally placed at the intersection of major ATS routes. While these locations were optimal for serving multiple conventional routes, they are in general non-optimal for enabling PBN operations.

For the Navaids that support PBN applications there's a greater flexibility in selecting the location, however, in this case the optimization of the coverage is sought. Therefore, especially in a terrain rich environment, high elevation locations are desirable. While such locations can provide coverage at low altitudes, they also raise technical issues related with the accessibility and the provision of electrical power, which may impact substantially the cost of the civil works and eventually also the maintenance cost. Alternatively, in the sites which provide best coverage and accessibility, non-aviation systems may be already installed (e.g. radio relays, mobile telephone towers/masts) hindering the installation of Navaids.

With the exception of NDBs, all ground Navaids are susceptible to multipath, which may impact the accuracy of the navigation service, to a degree that may render the facility unusable in certain azimuths (sectors). The multipath effect can be produced either by terrain or static or mobile structures such as buildings or aircraft respectively. Therefore, in addition to an optimal coverage, specific siting criteria must be observed when

selecting the location of a Navaid. These criteria include limitations on terrain irregularities in the vicinity of the facility, but also the "Building Restricted Areas" (*EUR DOC 015*).

Having in mind the complexity introduced by high altitude and/or remote sites in terms of installation and maintenance, installing/preserving sites with less optimal coverage performances but easily accessible can be more efficient in some cases, even if the overall size of the network is slightly increased.

Conversely, selecting a site which places facilities very close to inhabited or industrial areas may create difficulties over time. These occupied areas may expand and the pressure on the infringement of the 'building restricted' areas may keep increasing.

One other potential issue refers to the sites which are not owned by the ANSP. It is possible that some systems have to be installed on leased property. In such cases the lease agreement duration should be set at least for the system design life. The threat with leased properties is that at the end of the lease agreement an extension is not accepted by the owner or by the ANSP as the new contract conditions are unreasonable.

The constraints and potential issues described above should be considered when evolving the ground infrastructure in context of PBN implementation, which may be seen as an opportunity to decommission or relocate facilities with siting related issues, especially at the end of their life cycle.

If additional systems are required (e.g. DMEs), the installation in existing CNS sites should be considered. Although compatibility issues may arise, notably with systems using the same frequency band (e.g. MSSR, ADS-B) in general these issues can be overcome with appropriate technical solutions.

3.1.2.3 Maintenance activities

Unlike several decades ago, today the majority of the Navaids facilities are unmanned. Current technologies permit remote monitoring and control and have reached a reliability level which makes unnecessary the 24/7 presence of technicians on site. There are exceptions which apply mainly to remote facilities, difficult to access especially during winter, potentially co-located with COM and/or SUR systems. Nevertheless, regular checks and preventive maintenance works are still required. In addition, intervention teams have to be organized for troubleshooting the systems in case of failures.

The main resources required for the maintenance activities are:

<u>Staff (Air Traffic Safety Electronics Personnel)</u>

The technical staff that executes preventive maintenance, troubleshoots and adjusts the Navaids must have adequate qualifications, for the tasks to be executed and for the type and model of equipment to be serviced. To obtain these qualifications the personnel have to be trained in accordance with the existing European and national regulations and specifications. The training programme must include the topics identified in the *ATSEP CCC* and Regulation (EU) 2017/373 Annex XIII (Part-PERS) but also courses provided by the OEMs, specific for each equipment model. Therefore, the size and qualifications of the maintenance teams have to be adapted to and evolve together with the infrastructure operated by the navigation services provider.
The impact of the infrastructure changes on the required maintenance staff should always be considered in the project planning.

<u>Spare parts and materials</u>

For minimising the repair time, the systems have in general a modular design, based on Line Replaceable Units (LRU) which can be easily changed when faulty. A minimum stock of spare LRUs is usually ordered together with the new systems. The size of this stock depends on the number of systems purchased and the maintenance organization (e.g. centralised or distributed). In general, the acquisition of multiple systems (compared to individual system contracts) permits a more efficient management of the spare parts.

The cost of the maintenance activities represent a high percentage of the overall cost of the navigation service provision. While the optimization of the cost of these activities is always recommended, it should not be forgotten that the allocated resources will reflect and impact on the quality of the service (QoS). The resources allocated and the organization of the maintenance activities have to be aligned with the required performance of the navigation services (e.g. required availability and continuity of service).

3.1.2.4 Flight Inspection

Flight inspection is the ultimate method of checking if the navigation service is compliant with the applicable requirements. This test has to be performed on a regular basis, at intervals which depend on the system type and criticality. Because these inspections are executed by specialized companies using dedicated aircraft, on board systems and specially trained pilots and engineers, the associated cost is substantial and may add significant weight to the overall budget allocated to maintenance. Therefore, this cost should not be overlooked when estimating the overall maintenance cost.

It should be noted that specific flight inspection procedures may be needed for DME's that support RNAV procedures, e.g. flight inspection following supported SID's/STAR's, especially when the predicted coverage using simulation tools is marginal.

3.2 Cost Benefit Analysis (CBA)

Cost-effectiveness is a critical internal factor, which is why a 'living' cost-benefit analysis (CBA) is undertaken throughout the duration of an airspace design project and associated infrastructure optimisation project. In the Airspace Concept development, the CBA includes costs such as fleet equipage, procedure design, publication as well as giving consideration to infrastructure costs across CNS. Simplistically one could say that the airspace change provides benefits with some cost, whereas the infrastructure is primarily about cost, which is why a balance must be struck between the cost and the operational needs and associated benefits. Rigorous cost-effectiveness analysis is essential because a CBA may show that anticipated cost savings cannot be realised e.g. the commissioning of new DMEs may not be cost effective when balanced against the expected benefits of the planned airspace change.

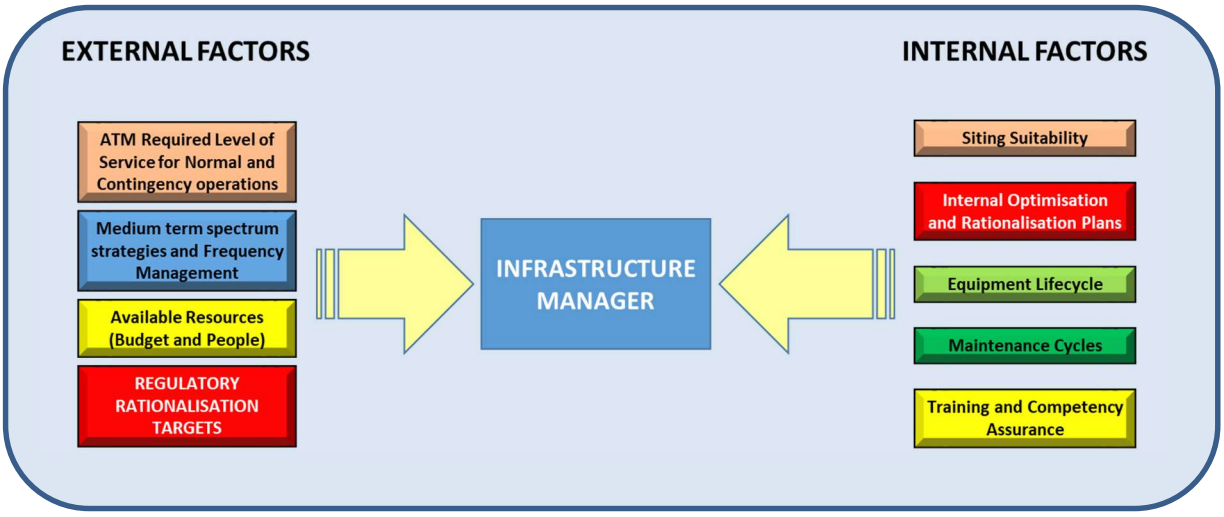
3.3 Conclusion

This Chapter has sought to identify and describe external and internal factors that impact the infrastructure management decisions. It has built on the drivers that influence infrastructure management and planning at different levels (global, regional, national).

Detail has been provided regarding external and internal factors influencing infrastructure planning (see Figure 3-1, below). How these external and internal factors are dealt with by Infrastructure Managers is discussed in the next Chapter.

Finally, this chapter has emphasised the importance of rigorous and iterative cost-benefit analyses when planning to optimise the Navaid infrastructure.

Figure 3-1: Factors Influencing Navaid Infrastructure Evolution



4. PROCESSES FOR NAVAID INFRASTRUCTURE EVOLUTION

4.1 Introduction

PBN was placed as ICAO's top priority in the GANP (ICAO DOC 9750, 4th Ed. 2013). Consequently, expectation arose that extensive use would be made of PBN and GNSS, which would be embraced by all stakeholders. This was expected to give rise to opportunities for infrastructure rationalisation as some Navaids would become redundant.

By the time the GANP was updated to the 5th Edition (2016), it had become evident that the expected evolution of the Navaid Infrastructure had not been significant. It had therefore become clear that exclusively adopting a 'reactive' approach to infrastructure planning is not efficient. Consequently, the GANP identified a top-down and bottom-up approach to infrastructure planning. (Further updates to the GANP are electronically available on the ICAO web site).

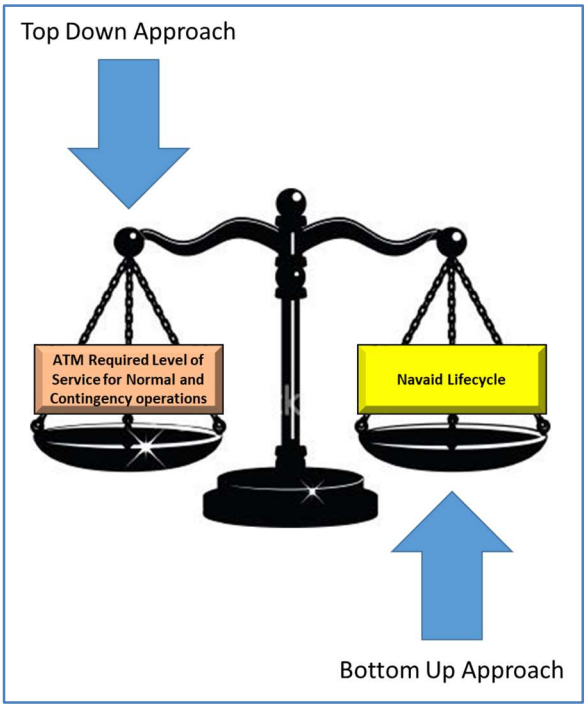
This chapter addresses the external and internal factors influencing infrastructure planning identified in the previous chapter. It explains the two ICAO derived approaches that can be taken to balancing these factors when planning the infrastructure evolution.

4.2 Infrastructure Planning

Infrastructure planning (which is part of the overall infrastructure management process) consists of the installation of new facilities as well as decommissioning old facilities taking account of internal and external factors described in Chapter 3 .

As highlighted previously, with the wide scale implementation of PBN in all phases of flight, the role of the ground Navaids evolves towards providing a backup infrastructure to GNSS which will become the primary navigation enabler. In this context an opportunity arises for **optimising** the overall infrastructure and consequently, **rationalising** ground-based Navaids. Exceptionally a need may arise for **deploying** new Navaids. The evolution of the infrastructure needs special consideration. The two approaches that can be taken for the infrastructure **evolution** in relation with the PBN implementation have been described in Appendix 5 of the fifth edition of the GANP. A simplified depiction is shown below.

Figure 4-1: The GANP's Top-Down & Bottom-Up Processes



The ICAO GANP 5th Edition identified a ***top-down*** and ***bottom-up*** approach to infrastructure planning. The ***top-down*** **approach** is one where infrastructure evolution is driven almost exclusively by ATM operational requirements thus placing the infrastructure manager in a 'reactive' role. The ***bottom-up*** approach has the infrastructure manager playing a pro-active role: here the infrastructure manager aims to influence the airspace concept with the objective of infrastructure optimisation and realising cost-efficiencies. In this approach, infrastructure optimisation acts as a catalyst for airspace change by avoiding the need to renew the infrastructure at the end of equipment lifecycle.

4.2.1 Potential Consequences of the Top-Down Process

This type of process in which the infrastructure planning is driven only by the operational needs could lead to inefficient investments (e.g replacement of Navaids which may be needed only for several years) or delay the infrastructure rationalization. Generally, this would mean a less cost-effective rationalisation plan.

4.2.2 Potential Consequences of the Bottom-Up Process

The justification for this approach arises from the consideration that the greatest economic benefits from rationalization come from avoiding the replacement of Navaids at the end of their lifecycle. Therefore, rationalization efforts would be most efficient if directed to address those Navaids that have reached the end of the lifecycle, with priority on those facilities with maintenance issues (e.g. remote sites, high outage rates, high maintenance cost). This should be done on the basis of an analysis aimed at identifying rationalization opportunities, evaluating the necessary route changes and ascertaining whether a prioritised PBN implementation on the affected routes would be more cost effective than the replacement of the facilities. The analysis should also take into account other uses of the infrastructure beyond those promulgated in the AIP (e.g. to meet the needs of State operators, to support aircraft operators' contingency procedures, etc).

This process may carry more weight when resources limitation targets have been set for the infrastructure operation, which require the rationalization and optimization of the Navaids network and the maintenance activities.

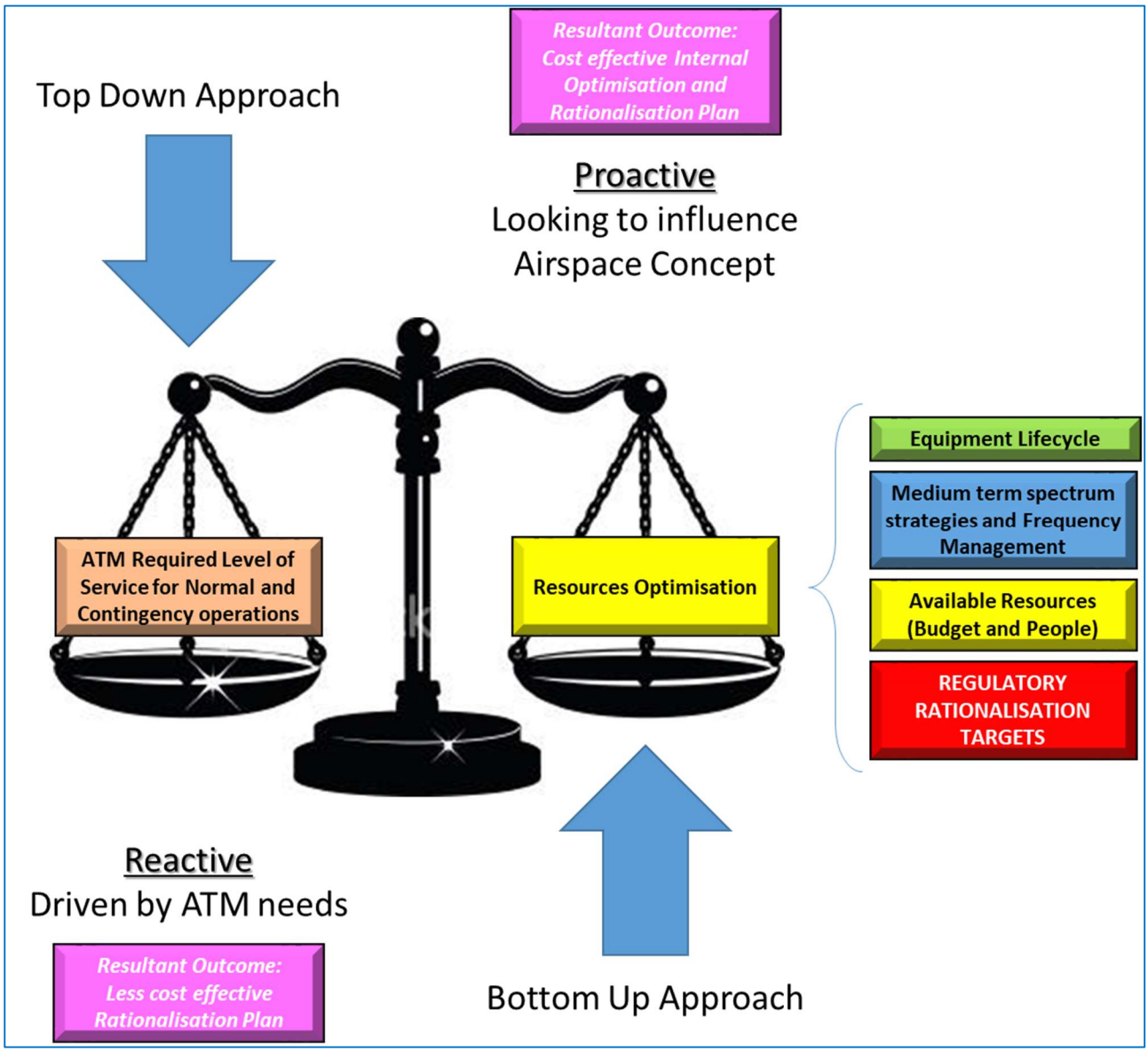
4.2.3 Use of the two processes

In most instances a "combined" approach should provide the best outcome i.e. the top-down and bottom-up processes are used in tandem to complement each other. An example of combined approach may be that in a certain FIR the Top-Down approach is followed as a general strategy, but in particular airspaces (e.g. a certain TMA) the PBN implementation is planned and implemented based on a Bottom-Up approach, considering the priorities of the infrastructure. Nevertheless, the connectivity between these two airspaces means that the top-down and bottom-up approaches in the relevant airspaces would need to be fully aligned and treated in a complementary manner.

It is expected, that only on rare occasions, would just *one* of these approaches (top-down or bottom up) be used.

However, it should be noted that the definition of an overall Airspace Concept for the full PBN implementation is still required even in the Bottom-Up scenario and that the infrastructure changes cannot be implemented unless coordinated with the necessary airspace changes.

Figure 4-2: Complementary Top-Down and Bottom Up Processes



4.3 Summary

This section has highlighted and compared two approaches to Navaid infrastructure evolution: the ***top-down*** and ***bottom-up*** approaches. The former tends to be more reactive in terms of infrastructure planning and consequently results in a less cost-efficient rationalisation plan. The latter is more pro-active and enables more cost-efficiencies. In reality, the two approaches should be used in a complementary manner when implementing PBN, and consistency between the two approaches must be assured.

The next chapter of this handbook gives an overview of the specific activities required in the Methodology for planning and implementing the infrastructure evolution.

5. INFRASTRUCTURE PLANNING METHODOLOGY

5.1 Airspace Concept Development

The *European Airspace Concept Handbook for PBN Implementation,* (Handbook No 1) provides generic guidance on how to develop the airspace elements of an Airspace Concept in the context of PBN.

An Airspace Concept describes the intended operations within an airspace. Airspace Concepts are developed to satisfy strategic objectives such as safety, capacity or flight efficiency. Given the nature of these strategic objectives the Airspace Concept development, is driven by operational requirements.
It is important to note that **Airspace Concepts include details of the practical organisation of the airspace and its operations as well as the CNS/ATM assumptions on which it is based.**

The sequence of activities defined by the *Airspace Concept Handbook* are depicted in the following picture.

Figure 5-1: Airspace Concept Development Activities

Some of these activities make direct reference to the coordination needed between the airspace design and procedure design and the infrastructure planning. In context, the relevant activities to infrastructure planning are:

- *Activity 6, PBN Assumptions & Enablers*
- *Activity 7, Airspace Design - Routes & Holds*
- *Activity 8, Initial Procedure Design*

Whilst the above three activities from the *Airspace Concept Handbook* make a direct reference to infrastructure planning, this does not mean that other airspace activities exclude the infrastructure. **The basic principal is that in matters affecting the infrastructure the airspace planners must work with Infrastructure managers, both of whom may have their own pressures and/or priorities.** In keeping with this general principal, infrastructure planners must be included in the wider airspace team and be aware of airspace changes or plans (as per Activity 2 of the *Airspace Concept Handbook*). Similarly, airspace planners need to be made aware of infrastructure evolution plans including, for example, renewal of Navaids at end of life.

Although airspace developments and infrastructure evolution may not be fully synchronised, the two areas must be coherent and relevant and timely information between them must be exchanged. Airspace developers need to appreciate that infrastructure planners sometimes need to consider other facts such as the external and internal factors in Chapter 3, and the constraints of the bottom up approach in Chapter 4.

Whilst the airspace concept development and infrastructure planning are separate methodologies, several of the activities of the two methodologies have a direct connection. Given that Airspace Concept development uses a holistic approach, the methodology for infrastructure planning provided in this Chapter uses a comparable holistic framework.

This Handbook (No. 4) is comprised of a methodology containing a sequence of Activities for a navigation infrastructure planning; this mirrors a similar methodology described in the *Airspace Concept Handbook* (No 1). The two methodologies allow for mapping between the activities and this may enable the seamless integration of infrastructure planning within the development of that airspace concept.

The *Airspace Concept Handbook* stresses several characteristics related to planning.

*Airspace Concept development relies on sound planning and **iterative** processes. Planning begins before starting the Airspace Design, Validation and Implementation. **Planning** needs to be an in-depth (and therefore, quite a lengthy) process because sound preparation is one of the pre-requisites to successful Airspace Concept development. Careful consideration is needed in terms of what needs to be done and the organising of the necessary time and resources to do it. **Iteration** is the other key to any Airspace Concept development: development of an Airspace Concept is not a linear process but relies on several iterations and refinement moving backwards and forwards between some of the 17 activities. (see Airspace Concept Handbook, Chapter 2)*

These characteristics apply equally to the infrastructure planning methodology and its associated activities.

5.2 Infrastructure Planning Activities

For the reasons explained above, in this document the activities specific to Infrastructure Planning methodology are referenced to the corresponding Airspace Concept Development activities. Infrastructure planning and implementation activities can be related to more than one airspace concept activity; there is not a direct one-to-one relationship between the numbered activities. Nevertheless, in most instances, the final phase of the airspace concept development (i.e. implementation) can only occur once the relevant Navaid Infrastructure has been agreed and implemented.

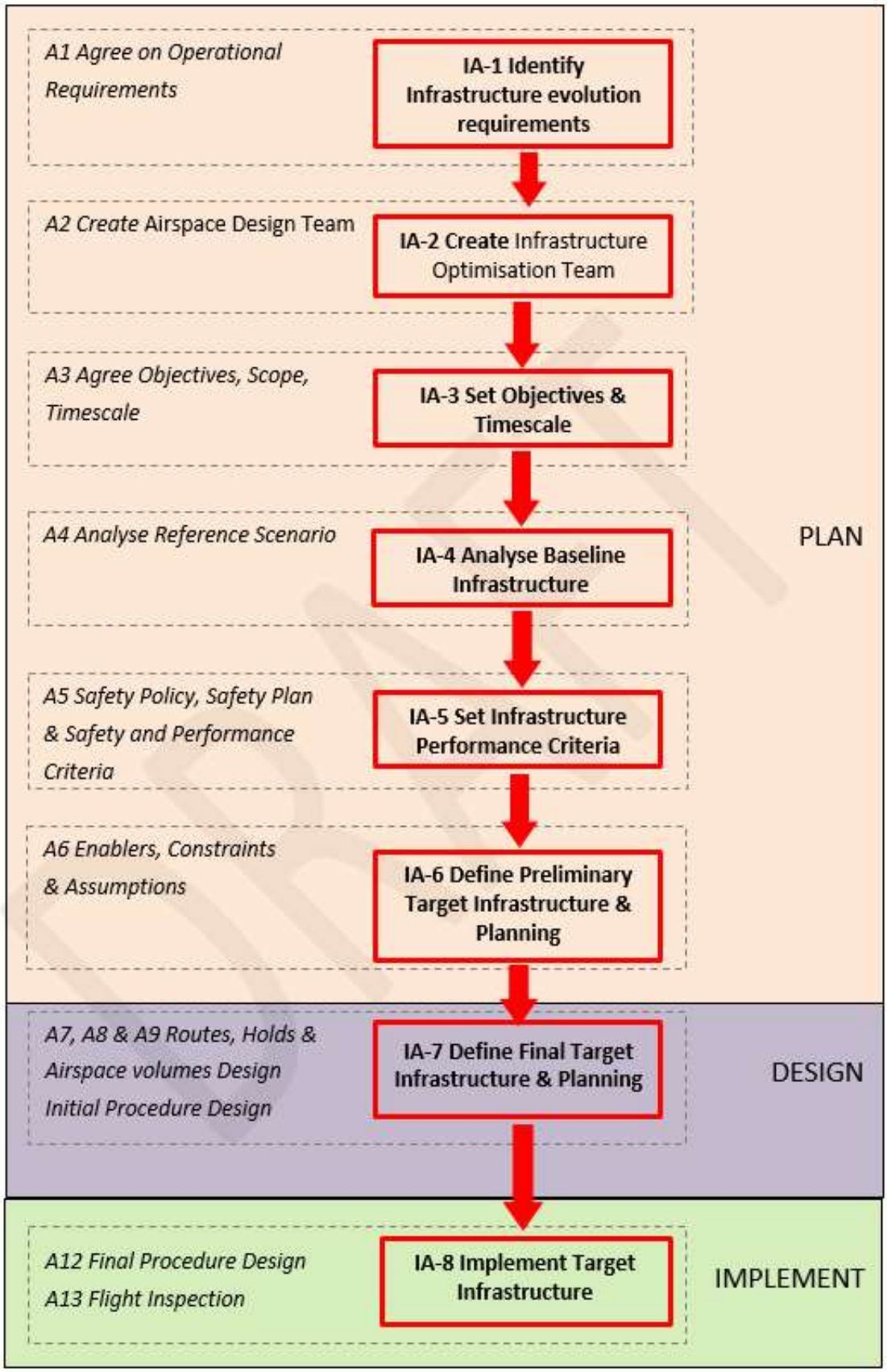
The infrastructure specific activities designators have an additional "I" for differentiation.

Figure 5-2 shows that the two methodologies for Airspace Concept Development for PBN Implementation and Navaid Infrastructure Planning are each comprised of activities which are similar in name. Although the two sets of activities of these methodologies appear side by side, this should not be interpreted that the timelines of these activities will be parallel or occur at the same time. Some INFRA activities could take place prior to the associated Airspace activity, some may need to take place after the associated Airspace activity. In some instances, the INFRA activities can occur when there is no airspace change in progress, in other cases; the two methodologies may be applied at similar times. The absolute synchronised timing of the activities of the two methodologies is neither realistic nor likely.

*Although the activities are presented in a linear manner, there are **iterations** that take place in both methodologies and may also occur across the two methodologies.*

Figure 5-2- Infrastructure Optimization Activities

(With PBN Airspace Concept Handbook No. 1 activities shown on the left)



5.2.1 IA-1 Identify Infrastructure evolution requirements

Whether developing airspace or evolving a Navaid infrastructure, high-level objectives are needed.

The initial phase of the infrastructure project identifies all high-level objectives pertaining to the evolution of the Navaid infrastructure. These objectives include:

- *Internal*, e.g. cost savings, optimization of maintenance activities (avoid difficult sites), systems life cycle (avoid replacement).
- *External*, e.g. ICAO and European high-level targets on the terrestrial Navaids evolution and any specific regulations.

At this stage, the high-level strategic objectives are **cost-effectiveness** whilst ensuring **safety** and these are independent of ATM requirements.

In the *Airspace Concept Handbook*, Activity 1 also begins with high-level objectives known as Operational Requirements which are derived from strategic objectives such as safety, capacity and cost effectiveness. In this context, operational requirements refer to high-level ATM operational objectives such as the addition of a new runway in a terminal area, reduction of aircraft noise over a residential area or allowing operations at an airport during low visibility conditions.

In the infrastructure management context the "Operational Requirements" has a different meaning; it generally refers to coverage and performance requirements for the navigation service. (These type of requirements are addressed in Activity 6 – PBN Assumptions and Enablers of the *Airspace Concept Handbook;* this corresponds to IA-6 below).

Activity IA-1 is at the high-level stage. No technical requirements are set yet, and there is no consideration, as yet, concerning ATM requirements.

5.2.2 IA-2 Create Infrastructure Optimisation Team

The planning and implementation of infrastructure changes are complex activities which require some specific skills and expertise. Therefore these activities have to be executed with the contribution of different experts. This team of experts is generally coordinated by the person in charge of the infrastructure planning or another nominated expert. The specific capabilities required by the experts include the ability to:

- Assess the current state of Navaids and of the possibilities to extend their life time;
- Simulate the coverage provided by the network (e.g. DME/DME, VOR/DME) using specific software tools such as DEMETER;
- Execute site surveys and analyse their suitability for installation of Navaids;
- Write or contribute to the development of necessary reports (e.g. technical specifications for procurement, technical analysis, feasibility studies, safety assessments);
- Coordinate with the appropriate regulatory and oversight authority;
- Coordinate with the military and look for synergies;
- Manage the dismantling and/or relocation of existing facilities or installation of new facilities;

In general, most of the members of the team will not consistently work on the infrastructure optimization project, but will be called upon when needed. (These experts are usually doing other day-to-day tasks). However the availability of the required expertise within the organization has to be analysed by the team leader, together with the possibilities to allocate effort from identified experts. When some specific expertise is not available in-house, the services could also be contracted (in which case potential contractors should be identified). In smaller organizations, where the necessary expertise cannot be made available, the option of "turn key" projects can be considered, in which case the Infrastructure Optimisation Team plays mainly a planning and coordination role.

In the *Airspace Concept Handbook*, Activity 2 defines an Airspace Design Team to which certain members of the Infrastructure Optimisation Team need to be assigned to ensure coherency between airspace plans and the supporting navigation infrastructure (though this applies equally to other infrastructures).

5.2.3 IA-3 Set Infrastructure Objectives & Timescale

IA-3 may set specific infrastructure objectives in accordance with the high-level requirements (which may be constraints) identified by IA-1. These objectives are most likely to be independent from the ATM objectives. Examples of IA-3 infrastructure objectives could include: decommissioning of a certain facility (e.g. for maintenance reasons), reducing the size of the infrastructure (by a certain percentage or number of facilities) evolving to a MON. The timeframe for implementing these changes is also defined.

Although the infrastructure objectives are still independent from the ATM objectives, it is important that the Airspace Design Team objectives and infrastructure objectives are defined and exchanged between the two teams with the aim of enabling awareness on both sides and facilitating the harmonisation in the next phases.

It is important to highlight that the infrastructure specific objectives (bottom-up approach) are not intended to override the ATM requirements (top-down approach). Understanding the objectives of the airspace concept should allow the Infrastructure Optimisation Team to anticipate if new Navaids will need to be deployed (or relocated) to support the airspace concept. Nevertheless, the infrastructure requirements can only start to be finalised after completion of Airspace activities 7 to 9 i.e. once the design or routes and holds and airspace volumes together with initial procedures design has been completed through a series of iterations. The members of the infrastructure team participating in the Airspace Design Team must ensure that the Infrastructure Optimisation objectives do not conflict with the needs of the airspace concept.

The involvement of the infrastructure personnel within the Airspace Design Team will ensure collaborative work and coherent project completion. **Uncoordinated decommissioning of Navaids can negatively affect airspace capacity and possibly impact on the safety of operations.** This could then negate the anticipated short-term benefits of infrastructure rationalization. Therefore, the airspace interface to the Infrastructure optimisation project must also ensure that the airspace needs are not compromised.

5.2.4 IA-4 Analyse Baseline Infrastructure

IA-4 aims to create the comprehensive record of the existing navigation infrastructure and the operational role of each facility in the existing airspace design. Although Analysis of the Reference Scenario Activity 4 in the *Airspace Concept Handbook* can be executed at the same time as IA-4 should there be an implementation project in progress, it is preferable that airspace Activity 4 (Analysis of the Reference Scenario) take place before IA-4 in order to provide inputs to IA-4.

The Reference Operational Scenario from Activity 4 provides input on current PBN or conventional operations in all phases of flight utilising ground-based Navaids. Operations include instrument flight procedures (e.g. ATS routes, arrival, departure and approach procedures) and free routeing, which is extensively used in the upper en route airspace.

While this information can be retrieved from the AIP by the Infrastructure Optimisation Team, effort should not be duplicated if the Airspace Design Team is undertaking an analysis of the Airspace Reference Scenario at the same time. In this case, common information should be used by the airspace and Infrastructure teams. Using reliable and realistic inputs and other Navaids specific information, the output expected from IA-4 is a description of the Baseline Infrastructure, including as a minimum:

a) **A Full inventory of the existing Navaids and the operating parameters** (e.g. frequency/channel, coordinates, DOC max. range and height, DME antenna height, etc)

b) Identification of all **operational roles associated with each Navaid** (routes and procedures supported).

Whilst the information at (a), above, is generally available across a series of different documents (e.g. AIP or ICAO EUR Table COM 3) and accessible to NAV departments of any ANSP, the information related to (b) is not as comprehensively documented. However, by examining published RNAV procedures and routes, the information can be compiled deductively except for any critical Navaid which will be identified (see IA-6).

It is recommended that all information ((a) and (b)) is centralised in an easily accessible format.

Understanding the operational roles of the Navaids is essential to estimating the operational impact of an infrastructure change, which is why the technical department must acquire full awareness of each Navaid's role. This is usually done by enlisting the assistance of the Airspace Design Team who may provide complementary information, such as -

- Procedure designers have a comprehensive understanding of Navaid use for operational purposes. Nevertheless, there is no guarantee that aircraft avionics will limit themselves to using the Navaids identified for a particular PBN procedure.
- ATM operations know which Navaids are used for separation minima (e.g. NDB, VOR for the application of procedural lateral separation).

Therefore, the identified roles of each Navaid have to be confirmed by the Airspace Design Team and, if necessary, supplemented by additional operational information. As such, the exchange of information between the two teams is key for an accurate description of the Baseline Infrastructure, and some iterations of IA-4 may be needed for refining this description.

The culmination of Airspace Activity 4 and IA-4 is to identify those navigation which are currently pertinent to operations and to provide a first impression as to which Navaids could *potentially* be decommissioned. However, final confirmation of which Navaids can be decommissioned can only occur after Airspace Activities 7-13 (a new validated airspace design based on PBN).

The preliminary inputs to the CBA will evolve out of this activity as it identifies the cost of the baseline.

5.2.5 IA-5 Set Infrastructure Performance Criteria

The key performance criteria are set at the strategic level (see IA-1) and refined by the Infrastructure Optimisation Team. Standard criteria for infrastructure evolution are ensuring that the Navaid infrastructure contribution to ATM operations enhances **safety** in the most **cost effective** manner possible. Other performance criteria can be defined and refined by the Infrastructure Optimisation Team depending on the drivers for the project. These could include reducing VHF frequency congestion by decommissioning certain VORs *or* reducing the overall number of Navaids (reflected in cost-effectiveness and frequency use). These criteria must be coherent with the Activity 3 of the *Airspace Concept Handbook*, related to setting Objectives, Scope and Timescales as well as Activity 5 of the Airspace Concept Development. Activity 5 is expected to set the overall safety and performance criteria that will drive the airspace design, in order to comply with the regulator's Safety Policy. (*Note that in an operational context, performance criteria can include capacity, environmental performance, ATCO workload, runway throughput etc.)*. Infrastructure performance criteria must cater for the **targeted level of service** for both **normal** and **contingency/reversion operations** for all stakeholders both civil and military**.** For example, GNSS loss causing the total loss of navigation capability in a certain airspace may represent a hazard with high impact on safety, therefore reversion means must be provided, at least for a minimum percentage of aircraft.

Operationally, the targeted level of service is normally set by Safety and ATM experts and the metrics used may not be directly applicable to the navigation infrastructure. Therefore the infrastructure experts should acquire an appreciation of the operational safety and performance criteria so as to 'translate' these into infrastructure specific safety and performance criteria to meet the required operational level of service. Two examples of the interplay between infrastructure specific criteria and operational performance criteria are provided:

- *Infrastructure specific performance criteria* are **accuracy** with appropriate **availability**, **continuity** and **integrity**. These criteria could be different for different types of operations (e.g. requirements for supporting RNP 1 reversion may be more stringent than for supporting RNAV 1; missed approach requirements for RNP AR are more stringent than for RNP APCH).
- *Operational specific performance criteria*, such as the continued provision of Category I precision approach may 'translate' into identifying a need for the continuation of ILS Cat I at certain airports.

Such criteria will be driven by safety and or capacity considerations and will have an impact on **cost-effectiveness** of the infrastructure optimisation. This will feed into the cost-benefit analysis as it identifies possible requirements on the Navaid Infrastructure.

Having performance targets clearly identified is key for the infrastructure planners, because they are one of the main "external" factors that impact the design of the ground Navaids network.

As highlighted in Chapter 4, in some situations the infrastructure optimization process may become the driver for airspace changes (bottom-up approach). When this happens, the coordination between Airspace Activities 3 and 5 and IA-5 may be reversed, meaning that the infrastructure level of service are proposed by the infrastructure optimisation team to the Airspace Design Team.

In all cases, these performance targets need to be defined, coordinated with the regulator, and considered in the safety assessments before any infrastructure change is implemented.

5.2.6 IA-6 Define Preliminary Target Infrastructure & Planning

IA-6 is the final activity of the planning phase and will be coherent with Infrastructure Baseline of IA-4 (linked to the ATM/CNS Assumptions inherent in Activity 6) and closely coordinated with Activities 7-8-9 of the Airspace Concept Development. Once the initial design of the airspace is complete, the Infrastructure Optimisation Team together with the procedure designer can do a preliminary identification of the Navaids on which the future concept would rely. At the same time, the Infrastructure Optimisation Team could undertake a **preparatory cost-benefit analysis** of the desired infrastructure and identify any issues and limitations. Often, in the engineering design context IA-6 corresponds to a Feasibility Study whose output may provide feedback to the Airspace Design Team and cause adjustments to their conceptual airspace design. Differently put, a two-way exchange of possibilities is needed between the two teams, typically facilitated by the procedure designer. The finalisation of the Navaid infrastructure will take place in IA-7, which occurs after airspace concept validation.

Airspace Activities 7-8-9 are iterative processes, which see the Airspace Design Team undertake the conceptual airspace design for the first time. RNAV or RNP routes are placed, spaced and crossing points selected and this occurs independently of the available infrastructure or too much attention being paid to constraints. The idea is to allow a freethinking of airspace optimisation. Part of the route placement iterations are refined with the help of the procedure designer, and at the end of these multiple iterations, it is possible for the Infrastructure Optimisation Team to have an idea where the Navaid coverage is likely to be required. This is a typical **top-down** approach. However, the output of the feasibility study may indicate where Navaid coverage cannot or would not be supported due to cost. This then could limit where certain routes could be placed. This is a typical **bottom-up approach.** (*See below, where another facet of the bottom-up approach is presented).*

In a nutshell, the main inputs needed for this analysis by the infrastructure planners regarding the ATM Concept assumptions are:

- What type of service is expected (e.g. DME/DME, VOR/DME, which would typically refer to reversion operations in a PBN environment);
- What type of navigation applications have to be enabled (e.g. RNAV 5, RNAV 1, RNP 1, conventional);
- In which geographic area the infrastructure coverage is required (aerodromes and airspace volumes).

The inputs should not only cover the PBN implementation changes, but should also identify the changes regarding the conventional applications. In accordance with the PBN-IR it is not expected that new conventional routes and procedures will be designed, however, some of the existing ones may be maintained for contingency purposes. Therefore, Airspace Activities 7-8-9 are expected to clearly identify the conventional routes, SIDs/STARs, and approach procedures that will be withdrawn/maintained and the associated timelines.

When planning the evolution of the Navaids network, the infrastructure planners should also consider the **bottom-up** approach and thus take into account any infrastructure constraints identified in IA-3 and the findings of the baseline infrastructure analysis (IA-4). In particular, the following main factors are taken into consideration:

- Infrastructure rationalization objectives
- Systems at the end of the lifecycle (priority for decommissioning or replacement if retained)
- Facilities with maintenance issues (relocation or decommissioning to be considered)
  - Remote sites with difficult access
  - Land issues
  - Building Restriction Area issues

One other category of inputs to be considered is the performance criteria identified in IA-5. While in Activity 5 / IA-5 a generic set of target performance requirements are generally identified, in this phase these have to be clearly defined for each particular airspace on the basis of the intended normal and contingency operations. These performance requirements will drive the definition of the technical specification for individual Navaids and the design of the infrastructure network.

Starting from the inputs and the considerations described above, a preliminary infrastructure configuration can be defined together with the implementation timelines. As stated before, the two sets of requirements, corresponding to the top-down and bottom-up approaches can have different maturity levels and moreover can often be in contradiction, in which case several iterations may be needed between Activities 7-8-9/ IA-6 before arriving to an acceptable compromise. In any case, at this stage the overall target infrastructure configuration is still in a preliminary state, which will need refining in IA-7 taking into account the concrete airspace/procedure design validated in Activity 11.

Since each type of terrestrial Navaid may enable only certain types of operations, the applicable airspace requirements could be defined slightly differently. Therefore, the following Table provides a limited overview and further details for each terrestrial Navaid are provided in Attachment A.

Table 5-1: Overview of Operational Considerations for terrestrial Navaids

	Operational Roles	Navigation Performance	Specific Limitations
DME	**PBN**: This can be used in all phases of flight except final approach. On the missed approach it can be used for extraction.	**PBN**: Can support a position estimation for RNAV 5 and RNAV 1 (and 2 NM) operations. This enables operations in FRA, RNAV 5 ATS Routes and RNAV 1 SIDS/STARs.	**PBN**[1]: Minimum range of 3NM and maximum range of 160 NM for RNAV 1; Below 40° above the horizon as viewed from the DME facility; geometric limitations between DME pairs of 30° to 150°;
	CONV: Paired with a VOR, ILS or NDB, it can support conventional operations as described below. Stand-alone it can enable the flying of DME arcs.	**CONV**: Can provide range when co-located with a VOR, NDB or ILS.	[**CONV**: See Annex 10].
VOR	**PBN**: This can be used in the en route phase of flight and arrival segment of an IFP. On the missed approach it can be used for extraction of an RNP APCH.	**PBN**: Can support a position estimation for RNAV 5. This enables operations in FRA and on RNAV 5 ATS Routes.	**PBN**[2,3.] Maximum range of conventional VOR typically 60 NM; Doppler VOR, typically 75 NM.
	CONV: Paired (or not) with a DME can support en route operations and SIDS/STARs and NPA and intercept to the ILS or missed approach.	**CONV**: Can provide bearing information and enable homing to a beacon. When co-located with a DME, range and bearing information is available.	[**CONV**: See Annex 10].

NDB	**PBN**: Exceptionally, can be used for extraction on the missed approach for RNP APCH. *This operation is not encouraged.* **CONV**: Can support en route operations and ATS Routes, SIDS/STARs and NPAs. *This is not encouraged.* NDB may be paired with a DME.	**PBN**: None **CONV**: Can enable homing to a beacon. When co-located with a DME, ranging information is also available.	**PBN**: N/A [**CONV**: See Annex 10].
ILS	**PBN**: ILS is not a PBN infrastructure. However, exceptionally for challenging environments, ILS has been used for hybrid approaches with RNP AR APCH. e.g. Innsbruck. **CONV**: Supports Precision Approach and NPAs for LOC only approaches. Can be co-located with DME, to provide range information.	**PBN**: None **CONV**: Provides lateral and vertical path guidance for precision approach, and can provide lateral path guidance for NPAs.	**PBN**: N/A [**CONV**: See Annex 10].

1. *Details provided in RNAV 1 Infrastructure Guidance and ICAO PBN Manual, Doc 9613.*
2. *ICAO PBN Manual, Doc 9613.*
3. *If a State wished to use a VOR in excess of the typical ranges stated, then an implementation safety assessment based on a flight inspection demonstration may enable such non-standard use, subject to approval by the competent authority.*

In addition, there are a number of Generic Considerations for defining and planning the target infrastructure. These are detailed in Attachment B, and listed below:

- Top-down vs Bottom-up approach
- Support of multiple applications
- Redundancy
- Critical Navaids
- Cross-border Navaids
- Military Navaids
- Assessment methodologies
- Additional Guidance and Information material
- Software Tools
- Spectrum

IA-6 is a lengthy and comprehensive activity for the Infrastructure Optimisation Team. Rigorous and in-depth analysis is essential if the Infrastructure is to be deployed in a cost-effective manner. The finalisation of this activity will provide a mature set of factors for consideration in the cost-benefit analysis (CBA)

5.2.7 IA-7 Define Final Target Infrastructure & Planning

Defining the final target infrastructure will take into account and possibly refine the work undertaken in IA-6 and be closely coordinated with the *Airspace Concept Handbook* Activities 7-9 as well as the output from Activity 10. Once the Airspace Concept has been validated (Activity 11), the final target infrastructure and associated CBA can be confirmed. Ideally, once the preliminary target infrastructure has been planned (IA-6 completed), it would be beneficial if Activities 10 and 11 of the *Airspace Concept Handbook* do not result in substantial changes to the preliminary Navaid Infrastructure and its associated CBA; any changes could

significantly delay PBN implementation. Substantive changes could include an alteration to the commissioning or re-location of a Navaid or even a reversal of a planned decommissioning.

At this stage, final target infrastructure planning (IA-7) must confirm that the required coverage and redundancy expected from the preliminary target Navaid infrastructure (IA-6) meets the validated airspace concept. In addition, the final target infrastructure planning (IA-7) must confirm that the foreseen costs are reasonably balanced against the benefits of the validated airspace concept. Here again, it would be unusual for a gross discrepancy to be uncovered at this late stage in the project.

If this occurs, iterations may be needed between IA-6 and IA-7 as well as airspace Activities 7-11 – which may, in turn, have an impact on the validated airspace concept.

The *Airspace Concept Handbook* has a placeholder, after Activity 11, for a **Project Checkpoint.** This is the point in the overall project where the validation is complete, but before making the final commitment, the Airspace Design Team revisits the project's performance and safety targets set in Activity 5, and asks itself whether these are met and whether this project remains cost-effective and useful. It can be helpful to have 'external' parties helping in the evaluation of the **Project Checkpoint.**

A similar **Project Checkpoint** should be made at this stage of the infrastructure project, driven by the CBA. The output of this INFRA Project Checkpoint should be provided to the Airspace Design Team for input into the Airspace Project Checkpoint. This exchange between the two project checkpoints would be of maximum value where the two projects (one airspace and one infrastructure) had reached their respective Checkpoints similar times.

There are two expected outputs of IA-7

- a final target infrastructure than can support the normal/contingency operations of the validated Airspace Concept.
- an implementation plan for the target infrastructure changes should also be defined, in coordination with the airspace changes planning. Planning should include changes in the size, organization and professional training of the maintenance personnel.

Planning coordination is essential since airspace changes relying on any new systems (e.g. new DMEs) cannot be implemented until these systems are operational. In addition, the conventional Navaids included in the rationalization plan should not be decommissioned before the supported routes and procedures are withdrawn.

5.2.8 IA-8 Implement Target Infrastructure

This step represents the execution of the optimisation plan which includes all planned actions and activities of the associated project.

In the commissioning of new Navaids, it is possible that during flight inspection the performance achieved by the new facilities does not meet what was expected and predicted by the evaluation tools. This may occur when the actual site does not fully comply with the conditions associated with siting a specific Navaid. As such, the commissioning flight inspection may detect either unexpected coverage limitations or errors out of tolerance in some sectors (e.g. due to multipath), which may have an impact on the airspace concept. If this is the case, then the instrument flight procedures design may need to be adjusted. This iteration would result in minor adjustments and not a requirement to revalidate the complete airspace concept. Safety permitting, the mitigation of the Navaid performance limitations by the refinement of procedure design is preferable to re-siting a Navaid, which involves substantial cost and delays.

Where facilities are to be decommissioned, all procedures and operations (whether conventional or PBN) based on that navigation aid must have been withdrawn and removed from the State's AIP before decommissioning starts. Furthermore, sites of decommissioned Navaids may require reconditioning, notably before ending a lease contract. For systems which require significant civil works (e.g. DVORs), the cost of the reconditioning, which is not negligible, should have been foreseen.

Once the target Navaid infrastructure has been fully deployed, any new Navaids would be added into **maintenance cycles**. Furthermore, the Infrastructure Optimisation Team will continuously **review** and

monitor the totality of the infrastructure (which includes GNSS) to ensure that the performance criteria (e.g. accuracy, continuity and availability) meet the quality of service required by the airspace concept. This is similar to Activity 17 of the *Airspace Concept Handbook*, which takes an overall review to see that the performance and safety targets are being met.

If after implementation, unforeseen events occur which may compromise the achievement of the performance requirements; the Infrastructure Optimisation Team should identify potential mitigations to ensure safe and efficient operations.

Navigation Aids cannot be decommissioned before all dependent procedures have been withdrawn and all references in the AIP have been adapted.

5.3 PBN Transition Plans

One of the outputs of IA-7 is a (project) implementation plan which may cover the:

- PBN Transition Plan required by Article 4 of the PBN IR (as regards AUR PBN 2005 and Articles 3 & 5); or
- PBN Implementation Plan required by ICAO Assembly Resolution 37-11.

The European *PBN Transition and Implementation Planning Handbook* (PBN Handbook No.5) provides guidance to States and ANSPs on how to develop a PBN implementation and Transition plan and suggests what such a plan could contain. The examples and templates encourage stakeholders to identify the airspace changes and also the supporting infrastructure (see Part B, ANSP requirements, Section 5 Operational Requirements and PBN Implementation Objectives). Moreover, in Part B, ANSP requirements, Section 7 Transition Plan it is also recommended that the plans for infrastructure rationalization are included in the transition plan.

The stakeholders should also consider planned new facilities in the transition plans.

6. CONCLUSION

This handbook has explained the need to carefully plan the Infrastructure Optimisation process and has provided a supporting methodology. Throughout the methodology is an underlying emphasis on the importance of consultation with all stakeholders and this includes the military. Furthermore, as optimisation becomes increasingly important, synergies must be found between different infrastructure providers and where shared use can be made of civil/military infrastructure this should be encouraged supposed by the appropriate letters of agreement and/or authorisation.

Key elements to be noted include:

- Safety and a balance between cost and benefit drive Navaid optimisation projects.
- Infrastructure planning is multi-faceted, considerations should be top-down, bottom-up, external and internal and should view operations from en route to the approach phase of flight and vice versa.
- The development of the infrastructure plan should be methodical and there will be a series of iterations.
- Navaid Infrastructure Evolution should be considered together with:
  - ATM operations.
  - Communication and Surveillance infrastructures as trade-off solutions could be found to enhance cost-effectiveness and optimise the use of available frequencies.
  - Military needs and facilities to maximise potential trade-offs and cost sharing.
- Considerations should be given to cross-border navigation facilities to ensure maximum cost-effectiveness and efficiency (e.g.. frequency use) to provide the same level of service.
- Redundancy plays a role in both normal and contingency operations; technical and operational redundancies are two sides of the same coin. The ATM community commonly knows operational redundancy as contingency procedures. This provides robustness and resilience for the airspace concept.

States and ANSPs are encouraged to develop an **infrastructure optimisation plan** and make provision for a MON. The relevant (PBN) parts of the infrastructure optimisation plans should be included in the PBN IR Transition Plan as required by Articles 4 to 6 of the PBN IR and its associated Guidance Material. Furthermore, Article 4 of the PBN IR requires that the PBN Transition Plan be consulted with various parties. This consultation process has been refined through an arrangement provided by the Network Manager's CDM processes.

ATTACHMENT A: OPERATIONAL/TECHNICAL TERRESTRIAL NAVAID CONSIDERATIONS SUPPORTING IA-6

(Define Preliminary Target Infrastructure and Planning)

The strategic direction provided by the PBN IR is that GNSS will become the main positioning sensor for PBN operations by 2030. **Whatever the positioning source used, two criteria are to be fulfilled: (i) the on-board navigation sensor must match the infrastructure available; (ii) the aircraft must be certified and crew must be authorised for the intended operation**. Nevertheless, the GM provided for EU Regulation 2018/1048 acknowledges that some identified navigation applications (e.g. RNAV 5 and RNAV 1) can be supported by only ground-based navigation aids. However, the requirement for all aircraft to be capable of RNP APCH by January 2024 implicitly requires all aircraft to be GNSS equipped because this is the only identified sensor for RNP APCH. (See Chapter 2).

This means, that in most instances, conventional ground-based Navaids are likely to play a reversionary role. The desired level of availability and continuity of service from these Navaids drives the size of the MON of ground-based Navaids. The size the MON has an impact on cost. But cost is not the only determining factor, there may be other strategic drivers which impact the level of service and therefore the MON. The impact of choices made for reversionary operations, could result in different ATC contingency levels of operation: For example, full coverage of DME/DME or VOR/DME would mean that the relevant PBN operations continue normally with no negative impact e.g capacity or efficiency. Limiting the coverage could mean certain ATS Routes or SIDS/STARs may no longer be available during contingency operations as there is no effective positioning source.

Exceptionally, where aircraft are not GNSS equipped, an aircraft may undertake RNAV operations using DME/DME or VOR/DME, but this would be unusual.

Since each type of Navaid may enable only certain types of operations, the applicable airspace requirements can be defined slightly different. This Attachment provides some more detailed considerations for each type of Navaid listed in Table 5-1.

A.1 DME Considerations

Operational roles

In accordance with the future operational roles described in ICAO Annex 10, Attachment H and in the AMC/GM to PBN-IR, DME may be used to enable both PBN applications and conventional application (in both cases primarily as a GNSS backup). Therefore, in IA-6 all these applications have to be identified, for all phases of flight. At this stage, only the preliminary ATS route network and procedures will be available, allowing preliminary requirements to be defined in terms of the airspace volumes served for potential PBN applications in en-route and TMA. These volumes should be defined by boundaries: **horizontally** (e.g. FIR, TMA) and **vertically** (e.g. the minimum and maximum altitude).

PBN: DME/DME enables the following specifications: RNAV 5, RNAV 1 (which serves also as RNP 1 reversion) and does not support RNP APCH. However, where authorized by the State it can support RNP 1 and if applicable, it can support RNP AR missed approach.

CONV: A minimum set of conventional procedures enabled by ILS/DME, VOR/DME and NDB/DME may be maintained. For these types of procedure, DME is not the main enabler; therefore, the operational requirements for DME will result mainly from the analysis of the operational roles of ILS, VOR and NDB.

Consequently, the following minimum set of considerations is recommended when identifying the future operational roles of the DME network:

<u>En route & TMA</u>

Identify where DME/DME is needed to support:

- RNAV 5 operations in FRA or ATS routes, in ENR airspace volumes;
- RNAV 1 operations (SIDs/STARs) in terminal airspace volumes;
- RNP 1 ***reversion*** operations (actually RNAV 1, SIDs/STARs) terminal airspace volumes;

- Conventional ATS Routes incl. SIDS/STARS in en route or terminal airspace volumes, where DMEs are co-located with VORs;

Approach and landing

Identify where DME is required, as a co-located facility, to support:

- The intercept, approach or missed approach of conventional approach procedures.

In conclusion, this set of considerations is aimed at answering the following key question:

What type of operation requires DME or DME/DME and where is this coverage needed?

DME performance

PBN: In future, the main role of DME is to support reversion for PBN operations in case of GNSS failure. Therefore, the main objective should be the definition of the DME/DME performance in the airspace volumes where PBN operations are to continue.

The DME/DME performance requirements can be defined in terms of accuracy, integrity, continuity and availability of the navigation service. This performance level should be defined for each airspace volume served based on the type of application to be supported considering the general targets identified in A5/I-A5 and also the business continuity objectives set by the airspace concept. While the required navigation accuracy generates constraints on the geometry of the DME/DME pairs, it should be noted that the RNAV navigation specifications do not include integrity requirements for the DME/DME signal in space. However, the expected continuity and availability of service will determine the required DME/DME coverage redundancy. *RNAV 1 Infrastructure Guidance* provides guidance for the use of DME/DME for RNAV 1 operations. For RNP 1 reversion, specific considerations, including integrity requirements, will be addressed in the *EUROCAE MASPS for "DME Infrastructure supporting PBN Positioning"*. For example, additional integrity requirements on the DME ground transponder may be included.

CONV: Performance requirements associated with defined conventional procedures will result from the VOR, NDB and ILS considerations.

In conclusion, this set of considerations has answered the following question:

What is the required performance of the DME (DME/DME) signal-in-space?

A.2 VOR considerations

Operational roles

PBN: In special situations, notably where DME/DME coverage is not available, the use of VOR/DME for supporting en-route RNAV 5 operations may also be considered. As for DME, for RNAV 5 applications in en-route and the arrival phase, the requirements can be defined in terms of airspace volumes served.

CONV: The main residual operational role of the VOR in context of the PBN IR is to allow the operation of non-PBN capable aircraft during the transition to PBN, as well as providing alternative means of navigation during contingency operations. (The only permitted conventional role for VOR/DME after June 2030 will be to support contingency operations). This role may be envisaged both for en-route/TMA and for approach operations. In addition, the conventional routes and procedures based on VOR(/DME) that are to be maintained should be identified.

The analysis concerning VOR's operational role should consider all the other potential residual roles described in ICAO Annex 10 Attachment H. The following minimum set of considerations is recommended.

En route & TMA

Identify where VOR (/DME) is needed to support:

- RNAV 5 operations in FRA or on ATS routes;
- Conventional ATS routes defined by VOR/DME which are required to be maintained;

- the operations of State aircraft or aircraft of lower capabilities on ATS Routes;
- the provision of:
    - Navigation, cross-checking and situational awareness (e.g. during contingency operations, in support of radar vectoring or to avoid airspace infringements) within an airspace volume.
    - procedural separation within an airspace volume;

Approach and landing

Identify where VOR(/DME) is required to support:

- Conventional instrument approach procedures that will be maintained or potentially redesigned. The analysis should consider the aerodromes which are designated as alternates for major aerodromes and/or for aerodromes where only RNP APCH procedures are foreseen;
- ILS IAP (LOC intercept and; avoid premature automatic flight control system arming for ILS intercept);
- Missed Approach Operations;

In conclusion, this set of considerations is aimed at answering the following key question:

Which VOR(/DME) stations will no longer be needed to support either en route, terminal or approach and landing operations?

VOR/DME performance

PBN: The VOR/DME performance requirements can also be defined in terms of accuracy, continuity and availability of the navigation service. The RNAV 5 specification provides typical maximum ranges for the use of different VORs (note that a minimum integrity baseline is not defined for the VOR/DME signal in space to enable RNAV 5 or conventional applications). For airspace volumes where VOR/DME coverage is to support RNAV 5 applications, the required navigation accuracy may determine a maximum usable range for each facility. At the same time, the required continuity and availability of service will have a direct impact on the coverage redundancy. The continuity and availability requirements for VOR/DME signal-in-space should also take into account the general performance requirements identified in A5/I-A5 and any business continuity objectives set in the airspace concept.

CONV: For existing conventional route segments and procedures, it may be that the required performance is already met. These route segments and procedures are defined by particular facilities. Therefore, the main objective is to identify the VOR(/DME) facilities that have to be maintained.

In conclusion, this set of considerations has answered the following question:

Which VORs must be maintained and which can be decommissioned?

A.3 NDBs

Operational roles

NDBs do not support PBN operations and their use as en-route navigation terminal area or approach aids is generally considered obsolete. An increasing number of aircraft no longer provide an ADF capability on-board. Therefore the retention of NDB based ATS routes and procedures is not recommended. However, if a need for NDBs is identified in the airspace concept, the reason for this must be fully explored and justified. Additionally, the required facilities (including co-located DMEs) should be identified.

The above would answer the following question:

Are there any NDBs which cannot be decommissioned?

A.4 ILS

Operational roles

ILS is not a PBN Infrastructure. The AMC/GM of the PBN IR foresees that ILS will remain the primary means of navigation in low visibility operations (CAT II/III).

PBN: For normal operations, RNP APCH to three lines of minima are to be implemented at all IRE by January 2024. RNP APCH to LPV minima may replace ILS CAT I precision approach provided that the appropriate SBAS coverage is locally available. Both ICAO DOC 9992 *(Manual on the use of PBN in Airspace Design)* and the *European Airspace Concept Handbook, No 1* require extensive analysis of fleet equipage prior to making implementation decisions.

CO-LOCATED ILS/DMEs: Most ILS facilities are co-located with DME. These facilities are generally not included in the RNAV infrastructure assessments, because some RNAV systems do not use them for area navigation (mainly because some of these facilities have intentional offsets). In addition, consideration should be given to the DME facility not transmitting omni-directionally. Furthermore, the DME could be switched off when the ILS is not in use. However, recent surveys have shown that more modern RNAV systems use ILS coupled DMEs and that the exclusion of these DMEs for the area navigation solution applies only to a relatively low number of aircraft. The possibility to add these DME facilities to support RNAV operations could be considered, following an analysis of the fleet equipage and changes in the operational management of these ILS/DME facilities. For further guidance see *RNAV 1 Infrastructure Guidance* which addresses the RNAV 1 Infrastructure assessment and future *EUROCAE MASPS for DME Infrastructure supporting PBN Positioning*.

Consequently, the evolution of the ILS/DME network has to be considered when planning the evolution of the overall DME network.

CONV: ILS supports precision approaches and NPAs for LOC only approaches by providing lateral and or vertical guidance and can be used to support low visibility operations.

Decommissioning opportunities:

In Europe, PBN IR requires all the IREs to offer RNP APCH to three lines of minima by January 2024. Generally,

a) Some IREs have CAT II/III ILS (these also enable CAT I capability);
b) Some IREs have ILS CAT I only;
c) The remaining IREs offer NPAs (based on LOC only, or VOR or NDB).

Rationalisation opportunities exist at **(b),** but are influenced by the geographic location of IREs at **(a)** and contingency service levels to be provided. Where CAT II/III facilities are not in close proximity, a strategic decision will need to be made on the continuing provision of ILS CAT I. Where all approaches are based on GNSS (i.e. RNP APCH or GBAS), the loss of that signal will impact on the type of approach that remains. Therefore, the decision will be driven by safety, capacity and efficiency requirements, as well as business continuity.

This set of considerations would answer the following questions:

What precision approach level of service is required for contingency operations?
What is the ILS CAT I MON requirement?

ATTACHMENT B: GENERAL CONSIDERATIONS SUPPORTING IA-6

(Define Preliminary Target Infrastructure and Planning)

In addition to Attachment A, there are a number of generic considerations for defining and planning the target Navaid infrastructure. These considerations are amplified below.

B.1 Top-down vs Bottom-up approach

Two infrastructure evolution approaches can be followed:

- Top-down approach, in which the infrastructure changes are driven by the airspace changes
- Bottom-up approach, in which the window of opportunity for the infrastructure rationalization drive the planning of the airspace changes

These two approaches are not mutually exclusive: it is recommended that they should be used together in a coordinated and coherent manner through multiple iterations. For example, while the top-down approach may be considered to be the general framework for the implementation of a new airspace concept, the bottom up approach may set specific infrastructure priorities that could equally influence the planning of the airspace concept (e.g. the placement of SIDS/STARs to multiple airports). This reality emphasises the need for the Airspace Design Team and Infrastructure Optimisation Teams to work collaboratively.

B.2 Support of multiple applications

Whenever possible the facilities should fulfil multiple operational roles. This is an important consideration especially for the DME's co-located with maintained VOR or ILS facilities. These systems will continue to support specific conventional procedures, but at the same time, they should also be considered for the support of RNAV applications.

B.3 Redundancy

A cost-effective ground-based infrastructure providing adequate **redundancy** must be available to meet the levels of safety (and business continuity) required during normal and contingency operations in both a conventional and PBN environment.

Redundancy may be *operational* and/or *infrastructure* related. *Operational redundancy* is commonly known to ATM as *Contingency procedures*.

Typical infrastructure considerations can be:

- How many ground-based Navaids are needed to streamline the infrastructure and potentially save costs i.e. what are the opportunities for ground-based Navaid Infrastructure optimisation, rationalisation/decommission changes.
- What level of investment is required for the target ground-based Navaid Infrastructure. This investment will take into account the equipment lifecycle, maintenance and replacement schedules.

B.4 Critical Navaids

The use of ground-based Navaids should be optimised to support multiple operations including instrument flight procedures. This could be more cost effective, could increase the efficiency of the ground infrastructure and could facilitate Navaid decommissioning. However, in so doing, a facility may become the key Navaid for a number of procedures making that Navaid 'critical' for the instrument flight procedures concerned; this is referred to as a critical Navaid. The outage of a critical Navaid can have a major impact on capacity and/or accessibility. To protect for the loss of that Navaid, a safe contingency procedure must be planned, this could be an alternative instrument flight procedure based on different Navaids (and possibly to a different runway), a diversion or the use of radar vectoring.

Maintenance activities on critical Navaids could seriously impact operations. Therefore, the out-of-service time will need to be minimised and planned taking into account the traffic loads.

The reliance upon critical Navaids should be carefully assessed taking into account the impact on operations. When developing alternative contingency procedures fleet equipage must be considered.

B.5 Cross-border Navaids

Excessive signal-in-space redundancy should be avoided by considering the use of cross-border Navaids whenever possible. In this case, a service agreement should be put in place between the responsible ANSPs, in order to ensure the timely exchange of information regarding the operational status (incl. NOTAMS), planned maintenance activities, decommissioning/renewal plans, etc. Best practice suggests that these cross-border Navaids be published in the appropriate sections of the AIP of each State involved.

B.6 Military Navaids

Military TACtical Air Navigation (TACAN) can provide civil aviation with range information similar to DME. The use of fixed-location TACANS is recommended; however, the use of mobile TACANs must not be considered. The use of a specific TACAN facility for civil aviation should be authorised by the competent authority, who would assure that the facility meets Annex 10 DME standards and is listed in the State's AIP. As with cross-border Navaids, service agreement between the ANSP and the Military should be put in place.

B.7 Assessment methodologies

B.2 refers to the use of the same facility for different operational roles. Many systems in use can support applications in en-route, TMA and even approach and landing procedures. This aspect becomes a key factor when developing a (MON) of Navaids. However, it is possible that several configurations of the MON could support the same Airspace Concept. These configurations could depend on the analysis methodology used.

In general, it seems more practical to start the **assessment from the approach to the en route phase of flight** because terrain impacts on the signal coverage and Navaids are specifically linked to instrument flight procedures. The assessment approach steps can be defined as identifying the:

- facilities needed to support conventional operations at individual airports and in terminal areas;
- additional Navaids required to support PBN operations at individual airports and in terminal areas;
- any additional facilities that may be needed to fill any RNAV coverage or redundancy gaps (VOR/DME or DME/DME) in en route airspace.

Alternatively, it is possible to start the **assessment from the en route to the approach phase of flight**. Some of the VOR/DME facilities installed at airports are not at an appropriate location to efficiently support terminal or en route applications (e.g. due to line of sight blanking due to terrain). In addition, the Airspace Concept may be flexible as regards the approach applications, i.e. the need for maintaining conventional approach operations at a number of airports is identified, but there is flexibility in the selection of these airports. In this case it may be more efficient to *first* determine which aerodrome VOR/DME's provide the best TMA coverage, build the en route and terminal ATS route structure (including SIDS/STARs) based on these facilities, and at the end determine if any additional terminal facilities are needed to enable approach applications.

Whichever approach is used, the Infrastructure Optimisation Team and the Airspace Design Team need to collaborate so that the most efficient infrastructure can be provided to achieve the desired operations.

B.8 Additional Guidance and Information material

It should be borne in mind that specific standards and/or guidance materials are available to support the infrastructure assessment process. This is certainly the case with regard to the DME infrastructure: detailed information is available in the *RNAV 1 Infrastructure Guidance.* Additional guidance for enabling RNP 1 reversion is expected in the future *EUROCAE MASPS for DME Infrastructure supporting PBN Positioning*.

Other material of relevance, depending on the planning activity in progress, includes the *GNSS Reversion Handbook,* and ICAO *Doc 8071.*

B.9 Software Tools

The infrastructure rationalization/optimization process is substantially facilitated by the use of specific software tools. One of the available tools is DEMETER whose design is based on the criteria for the RNAV 1

application based on the *RNAV 1 Infrastructure Guidance*. This tool can also support the assessment of the DME/DME and VOR/DME infrastructure for RNAV 5 applications.

It should be noted that there are similar assessment tools available on the market. However, DEMETER is provided free of charge to the EUROCONTROL member States and certain categories of stakeholders such as CAA, Military and ANSP.

B.10 Spectrum

Mindful of ANC/13, recommendation 2.2/1, Spectrum protection must be assured.

Due to DME's primary role as backup to GNSS for PBN applications, it is possible that in some areas the need for additional DME stations will be identified. However, the high frequency congestion currently limits the number of new DME channel assignments available (notably in core Europe). Therefore, new facilities should be considered only where absolutely necessary. The possibility of extending the current Designated Operational Coverage (DOC)[2] of existing facilities can also be investigated in order to avoid the need for new facilities. Both the request for DOC extension or a new frequency assignment should be coordinated with the neighbouring States ahead of time, and an agreement should be obtained before planning the implementation. The Frequency assignment planning criteria for the aeronautical frequency bands are defined in EUR DOC 011. ICAO's Regional Frequency Management Group (FMG) and the EUROCONTROL NM Radio Frequency Function Group (RAFT) facilitate inter-State coordination and monitor the compatibility of assignments.

[2] *In the context of this Attachment, DOC is concerned with the management of the frequency protection volume to avoid interference between frequency assignments. Within the DOC, the ANSP provides 'assurance' that the Navaid is meeting Annex 10 obligations.*

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