CNS infrastructure evolution opportunities

An economic assessment on behalf of the CNS Advisory Group

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EDITION HISTORY

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V0.4	28-Dec-2020	EUROCONTROL	Clean up of previous version. Main improvements addressed: - Grammatical suggestions all accepted. - Deletion of comments that have been accepted or are not relevant any longer. - Full update of latest values. - Full review and improvements to Chapter on Sensitivity Analysis.
V0.5	04-Jan-2021	EUROCONTROL	Clean up of previous versions and further improvements: - Now Mix 2 from CP2 is considered from the beginning in the Optimal Mix. - Further improvements to Chapter 6 Risk Analysis. Reviewed in line with EU Guidelines.
V0.6	14-Jan-2021	EUROCONTROL	Further improvements following comments received: - Back to split between Ratio 1 and Ratio 1 as in the original CP2. - General update of the tables and figures to match the new results.- Further updates: - SUR: augmentation of MON to 150 units. - NAV: further improvements.
V0.7	22-Feb-2021	EUROCONTROL	Updates addressing comments provided by Advisory Group in coordination meetings of 26 and 29 of January 2021. Main improvements include: - Executive Summary rewritten. - Inclusion of COM related savings. - Extension of Sensitivity Analysis to consider cost inputs. - Inclusion of relevant comments on V.06 received from CNS AG reviewers.
V1.0	22-Apr-21	EUROCONTROL	Final version after discussion within CNS Advisory Group. Executive Summary updated following Section 5 of CNS Advisory Group Report V6.3.

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1 Executive Summary

This document is the outcome of an economic assessment initially developed by EUROCONTROL/NM on behalf of the CNS Advisory Group, and further refined based upon the Group's comments. The assessment estimates the potential net savings coming from rationalising current CNS infrastructure within the European ATM Network. Building upon previous economic assessments – themselves based on substantial stakeholder involvement, it consolidates results for the SES and ECAC Areas over the period 2021-2040 and considers the latest Regulatory Developments and the CNS roadmap in the ATM Master Plan. However, the assessment does not quantify all potential net savings enabled by the introduction of new CNS technologies during the 2021-2040 period. For example, savings related to ILS decommissioning enabled by the introduction of SBAS and GBAS are not evaluated as it is too soon to estimate those savings reliably.

The assessment is the work of CNS and economic experts, whose analysis has incorporated the most recently available data about the numbers of CNS facilities currently deployed.

Instead of considering a patchwork of National CNS MONs (Minimal Operational Networks), a European perspective has been applied which recognises that facilities located in a State can provide services in neighbouring States. Therefore, this assessment gives a first estimate of the potential cumulative benefits to be realised through decommissioning unnecessarily redundant CNS infrastructure across the pan-European ATM network.

It must be stressed that the assumptions about the reduced number of facilities in the CNS MONs that were used to estimate potential savings are based on theoretical scenarios for decommissioning that remain to be assessed – and eventually modified – by civil and military stakeholders and authorities outside the Advisory Group. Therefore, the CNS MONs that have been considered in this assessment do not necessarily correspond to the rationalisation elements of the CNS evolution plan that, as proposed in the recommendations of this report, should be endorsed by stakeholders.

As indicated in recommendation 2 of the CNS Advisory Group Report, the provision of pan-European CNS services through satellites and sharing processed data across borders will enable the rationalisation of nationally operated terrestrial CNS systems.

Three reference dates are used for the initial results, namely 2024 (end of SES RP3), 2030 and 2040

There are immediate quick wins available…

The report shows that, for the SES Area, there are immediate potential savings of roughly €139 million for RP3 (€132 million in NPV). To put things in perspective, this is approximately equivalent to savings of up to 3.3% of the CNS joint total costs for the SES Charging Zones forecasted for RP3.

… Which demonstrate the strategic value of this initiative to realise the SESAR ambition

By 2030, the expected savings for the SES Area grow steadily reaching an aggregated nominal value of €543 million or €478 million discounted. Extending the period of study up to 2040, we would be reaching nominal savings of €1.4 billion or €1.1 billion discounted. Linking with the SESAR Performance Ambition envisaged in the Master Plan, the calculated savings would contribute to reducing the ANS cost by approximately €6 per flight in 2035.

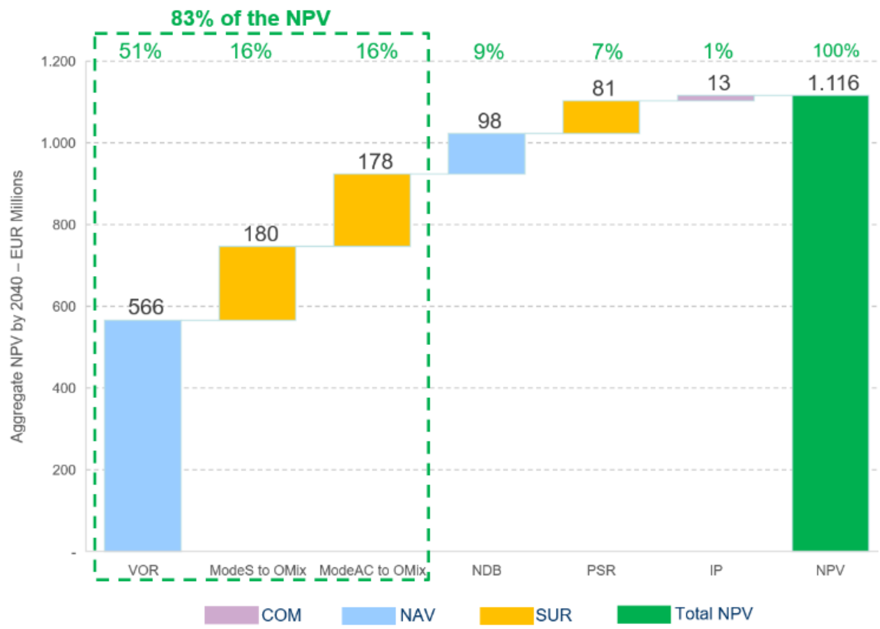
For the ECAC Area, the nominal savings reach almost €1.8 billion at the end of 2040 or €1.4 billion in NPV.

Area (Savings in €M)	In RP3		By 2030		By 2040	
	Nominal	NPV	Nominal	NPV	Nominal	NPV
SES	139	132	543	478	1 409	1 116
ECAC	177	168	655	578	1 776	1 405

VOR decommission and SUR optimisation driving the biggest part of the savings

Ground Navigation and Surveillance infrastructure is owned by civil and military ANSPs and is based on technologies developed specifically for ATM. ATC communications rely, in many cases, on more recent technologies delivered by commercial communication organisations with applications wider than ATC, and thus ANSPs have benefitted from a faster evolution of that infrastructure, which remains by and large up-to-date. The direct CNS infrastructure-related savings available to ANSPs from CNS rationalisation are thus predominantly for Navigation and Surveillance. The savings in the communication domain coming from the use of internet protocols based network technologies for ground/ground communications, are comparatively very small.

For the SES Area, three types of equipment drive the generation of savings. VOR, SSR Mode A/C and Mode S jointly account for €924 million (83%) of the projected total NPV.



Potential size of the Minimal Operational Networks (MONs)

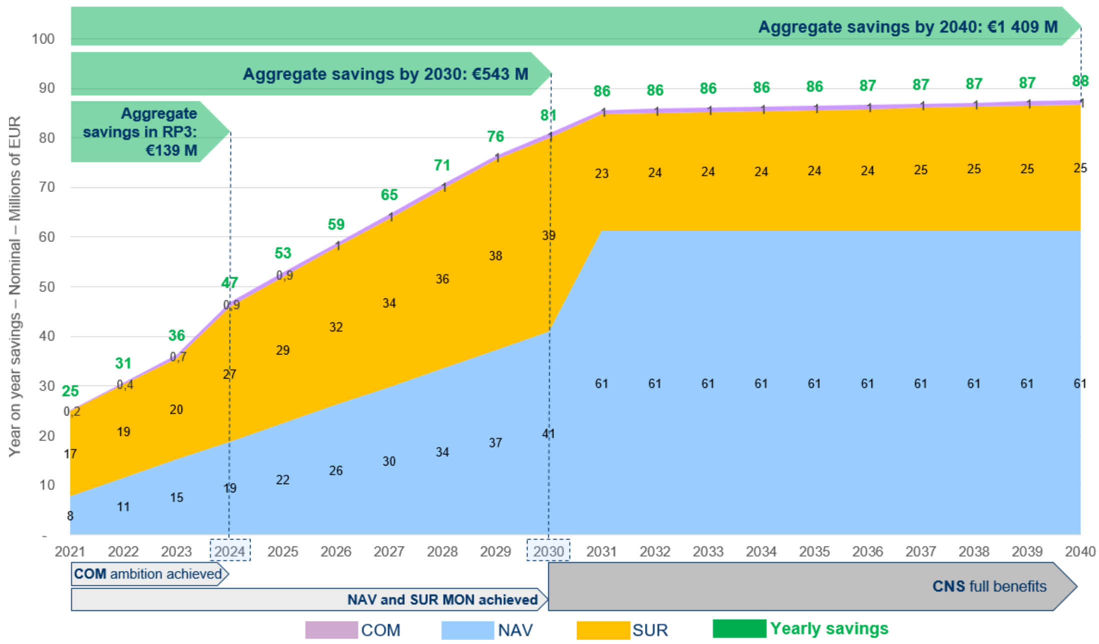
This analysis has concentrated on civil-owned assets only. The table below shows the number of facilities currently in the Navigation and Surveillance networks, as well as how many facilities would be retained in the future theoretical Navigation and Surveillance MONs. At this stage, the work has remained location-agnostic, such that the analysis has estimated the rationalisation potential without assessing the practical consequences of decommissioning specific facilities. Such assessments would be undertaken by the service providers and national authorities to which Network Manager could provide support as necessary to understand the implications of decommissioning decisions at local and network level. Detailed plans for the infrastructure optimisation will have to be defined taking into account these assessments.

SES Area	NAVIGATION		SURVEILLANCE				
Facility (Units)	NDB	VOR	Mode AC	Mode S	PSR	WAM/ADS-B	ADS-B
Current Network	806	586	100	205	130	856	109
Future MON	81	273	0	150	110	1 293	275

Three key characteristics over time…

The evolution of nominal yearly savings for the SES Area shows three different characteristics:

- The rationalisation target for Communication infrastructure would be achieved by the end of RP3.
- From 2021 to end 2030 we have a steeply rising rate of savings driven by the retirement of Navigation assets and the optimisation of the Surveillance network.
- Finally from the beginning of 2031 onwards we have achieved the Navigation and Surveillance Minimal Operational Networks (MONs). The MONs are fully operational such that the total savings increase only slightly by retiring the remaining PSR stations that have reached the end of their operating lives.



Results are robust notwithstanding worst-case tests…

This study also includes a sensitivity analysis in which a number of additional tests have been undertaken to cater for uncertainty in the results and scenarios. These indicate that the project risk is low. Even using the most pessimistic combination of scenarios and inputs suggested by CNS infrastructure experts, the final Net Present Value of the proposed initiative remains strongly positive.

2 Introduction

There have been numerous studies into the costs and benefits of introducing new C, N and S infrastructure to replace existing equipment. While the operational benefits may be clear, there is often a long transition period in which existing and future systems are in place, reducing the long-term benefits. Ground infrastructure may be wholly owned and operated by ANSPs or contracted on a build, operate and maintain basis, with ownership remaining with a commercial organisation. On the other hand, there is some infrastructure which is provided free of charge to the aviation industry, such as Global Navigation Satellite System (GNSS) signals for position, time and navigation, whose infrastructure is controlled by State-backed organisations. In some cases, the existing airborne equipage may constrain significant rationalisation. Furthermore, for national security and military reasons in particular, there are sovereignty issues that may override reliance on C, N and S equipment physically located in neighbouring countries, which can lead to an apparent over-supply of infrastructure. The current crisis may, however, provide renewed impetus for the National Authorities to reassess optimising the deployment of equipment.

The analyses presented here into the potential for Navigation and Surveillance optimisation in the Single European Sky (SES) and European Civil Conference (ECAC) Areas are based on contributions to the CP2 study [1] carried out by SESAR in the context of PCP follow-up. The data provided in this paper builds upon work developed and agreed by all the SESAR PJ20 partners, including EUROCONTROL, as a proposal for CP2. This baseline has been adapted to reflect a wider scope and take into account updates in the meantime. This initial assessment has been prepared as a contribution to the work of the European Commission's CNS Advisory Group. It should serve as a basis for discussions within the group and stakeholders, the findings of which will influence the completion of this assessment in support of the Advisory Group's final report.

2.1 COM

The ATM communication infrastructure has already been considerably rationalised, mainly on the ground with the implementation of NewPENS. ATM Applications like X.500-based AMHS messaging replaced all AFTN/CIDIN segments and are now almost all operating on NewPENS, whereas other applications (FMTP/OLDI, voice, datalink etc…) are migrating gradually (30% up to now). There are nevertheless potential extra savings that could be achieved by migrating more G/G communication currently carried by international leased lines.

It should nevertheless be underlined that NewPENS requires a dual core to meet the ATM availability requirements for G/G voice, without which some ANSPs may hesitate to migrate their voice infrastructure to NewPENS. This upgrade is under study and is expected to be implemented shortly as the former E1 technology is becoming obsolete, hence not maintained anymore by telecommunication operators.

A quick win could be to accelerate the implementation of Voice over IP (VoIP) for the Ground–Ground communications or the usage of gateways to convert the former E1/2 protocols to VoIP PENS. The migration to the VoIP would potentially allow an optimisation of the VHF stations (not yet analysed) while delivering operational cost savings and supporting new ATC capabilities (remote control for instance). However, this migration and the associated benefits would take some time as only 10 to 15% of the G/G voice communications are performed using VoIP.

2.2 NAV

The implementation of Performance-Based Navigation (PBN) on a wide scale in all phases of flight is well under way and is itself a prerequisite for CNS rationalisation, in particular that of the ground-based navigation aids (navaids). This is because PBN procedures are enabled by GNSS as the primary navigation means. While some of the ground systems can also support PBN operations (e.g. DME), the role of the ground-based navigation infrastructure will evolve towards providing a reversion capability for GNSS and supporting contingency operations in the case of GNSS becoming unusable. This offers the opportunity to rationalise some of the terrestrial infrastructure while retaining a Minimal Operational Network.

It is foreseen that a network of Distance Measuring Equipment (DMEs - used for DME/DME navigation) will provide the main GNSS backup in en-route and terminal areas, with VHF Omnidirectional Range (VORs) complementing this where needed. The rationalization potential for the DME network is therefore very limited; but, the size of the VOR network could be substantially reduced. The Non-directional Beacons (NDBs) cannot support PBN applications and may play only a minor role, if any, for GNSS contingency operations. Thus, an almost total decommissioning of NDBs can be considered.

Instrument Landing Systems (ILS) will continue to support Precision Approach procedures where required for safety, capacity or business continuity reasons, remaining the main enabler for low visibility operations (Category (CAT) II/III). A gradual decommissioning of ILS CAT I facilities may be envisaged following the implementation of RNP APCH (Required Navigation Performance Approach) enabled by SBAS and GBAS procedures, but this depends upon a significant majority of the fleet being equipped with Satellite and Ground-Based Augmentation Systems (SBAS/GBAS). Considering the current low equipage rates, in particular for the mainline fleet, it is too soon to estimate reliably the ILS decommissioning potential. It is recommended that the analysis of the ILS decommissioning opportunities is done airport by airport, supported by detailed fleet and operational environment assessments.

The PBN IR [2] and the PCP IR [3] define a clear roadmap for the implementation of the different types of PBN applications. A summary of the requirements defined by these EU regulations is provided in Figure 1 below.

PBN IR Article 4 & 7 Applicability with AUR.2005 and with PCP IR *(AF#1 and AF#3[3])*		Applies 03/12/2020	Applies 01/01/2022	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), including IREs at PCP airports			X[4]	
AF#1	RNP 1 + RF SID and STAR at PCP airports[2]			X[2]	
AUR.2005 4/5	RNAV 1 or RNP 1 (+ RF) SID and STAR - one per IRE			X	
	RNAV 1 or RNP 1 (+RF) for all SID and STARs				X
AUR.2005 6	RNAV 5 ATS Routes (excl. SIDs/STARs) at and above FL150	X			
	RNAV 5 ATS Routes (excl. SIDs/STARs) below FL150			X	
AF#3	Free Routes Airspace above FL310 (with FUA)		X[3]		
AUR.2005 7	Helicopter RNP 0.3 (or RNAV 1/RNP 1 (+RF)) SID/STAR - one per IRE			X	
	Helicopter RNP 0.3 (or RNAV 1/RNP 1 (+RF)) for all SID/STAR				X
	Helicopter RNP 0.3 or RNAV 1/RNP 1 ATS Routes (excl. SIDs/STARs) at and above FL150	X			
	Helicopter RNP 0.3 or RNAV 1/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 prior to it being implemented. The obligations in the transition plans would need to be commensurate with the target date obligations.

Note 2 - The PCP IR AF#1 has an implementation date of 1 Jan 2024, which could be expected to be aligned with the AIRAC cycle in the future.

Note 3 - Free Routes Airspace (PCP IR AF#3) is associated with RNAV 5 as the requirement for RNAV 5 is published in ICAO Doc 7030. [Free Route Airspace is distinguished from Direct Route Airspace, which should have been implemented as of January 2018].

Note 4 – At the CANSO/EASA joint meeting of 4th June 2020, it was clarified that both PA and NPA IREs at PCP airports are to be covered by RNP APCH by 2024.

Figure 1: PBN Applicability Roadmap

Recently, Single Sky Committee 77 adopted Common Project 1 (CP1) implementing regulation that will repeal and replace the PCP IR. CP1 does not include sub-ATM Functionality on PBN, therefore when this new regulation enters into force, the PBN IR will be the only regulation on PBN.

In accordance with the PBN IR, the first priority implementations are RNP APCH procedures at Instrument Runway Ends without Precision Approach, and RNAV (Area Navigation) applications at upper flight levels. Following the European-wide 1998 mandate for Basic RNAV (now known as RNAV 5) [4], RNAV 5 routes have already been implemented in European airspace above FL 150 and even above lower flight levels in some Flight Information Regions. The publication of helicopter routes above FL150 is used only in special situations (implemented so far by one State only).

The implementation status and planning information for RNP APCH approaches is summarised in Figure 2 (extracted from the NM report to the NSA Coordination Platform for SES implementation) [5].

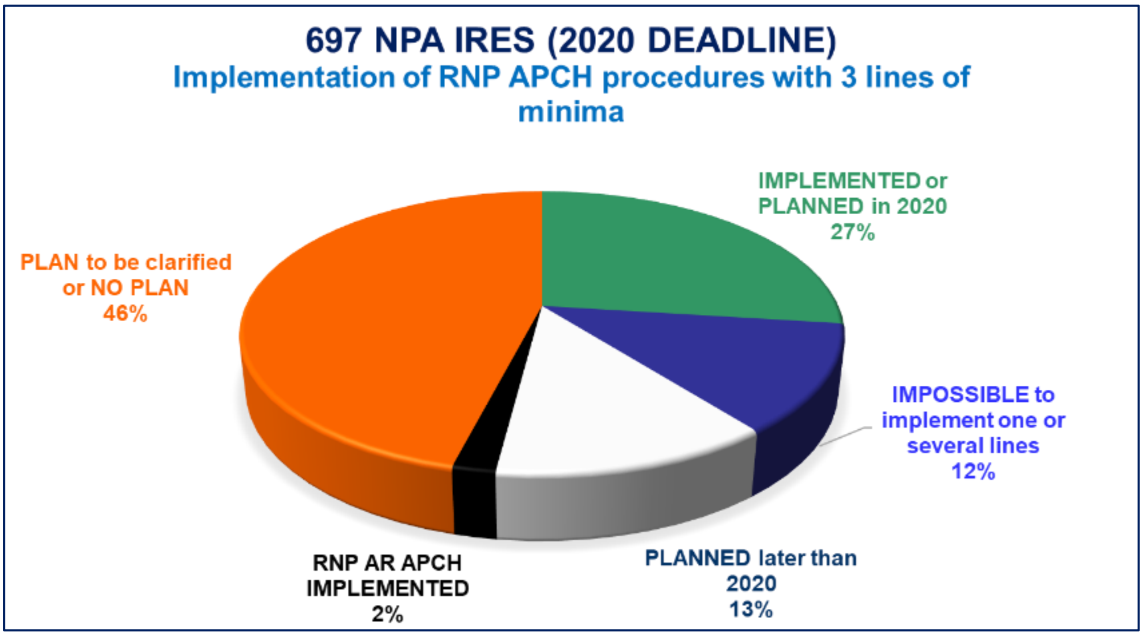


Figure 2: RNP APCH Implementation Status

The implementation of PBN applications is also required for all en route and terminal area applications. Due to the later implementation deadline, the coordination process between States and NM is still in an early phase, therefore accurate planning statistics are not yet available.

2.3 SUR

The Surveillance system in Europe has been in continuous evolution and modernisation over the last 20 years with the implementation of Secondary Surveillance Radar (SSR) Mode S radars, followed by Multilateration (MLAT) systems and Automatic Dependent Surveillance – Broadcast (ADS-B), as well as the associated on-board equipment.

Surveillance sensors currently deployed in Europe for terminal and en route operations include Primary Surveillance Radar (PSR), SSR Mode A/C, Mode S, Multilateration systems and ADS-B, as outlined below:

- The number of civil and military Primary Surveillance Radars (PSR) in Europe, supporting Air Traffic Control, is estimated to be more than 200 (including 60 En-Route);
- The number of legacy SSR Mode A/C radars operating in Europe is still quite high, at around 200; this includes civil radars in the EU, Norway and Switzerland (as well as a number of military radars). They are generally at the end of their operational lives and their operation also has a significant negative impact on the 1030/1090 MHz Radio Frequency spectrum, due to the outdated interrogation/reply techniques. Their decommissioning should be a priority;
- The number of SSR Mode S radars (civil and military) in Europe is around 500;
- Dozens of Multilateration (MLAT) systems (consisting of ADS-B stations) are currently in operation. Amongst the many European States that have implemented them, more than 10 States have country-wide coverage;
- More than 1000 ADS-B ground stations have been deployed by civil European ANSPs over the last several years. This was mostly driven by the implementation of MLAT/ADS-B systems and Mode S radars with ADS-B functionality, but also includes standalone ADS-B systems. This has established a very extensive and continuously expanding ADS-B coverage. Moreover, space-based ADS-B is also operational since 2019, aiming at global surveillance coverage of air traffic including oceanic and remote areas for the first time.

Further details on the current SUR infrastructure are provided in Annex C.

The inputs from the above sensors are processed by Surveillance Data Processing systems and the output tracks are provided to air traffic control officers and the ATM systems.

Data sharing agreements between neighbouring ANSPs or between civil and military authorities have been established in many cases but not in all.

The evolution of the ground Surveillance infrastructure in Europe has enabled advanced capabilities but has also created a significant potential for optimisation of the infrastructure.

3 Motivation for optimisation

3.1 Optimisation strategy for COM

Although the possibilities for further rationalisation of the current COM infrastructure are limited, there is still some limited scope for additional operating savings in the G/G setup. It is envisaged that the migration away from leased analogue and digital lines onto New PENS could bring savings in the range of 10-20% annually.

Aviation is among the last users of leased lines and the X.25 standard protocol suite for packet-switched data communication in Wide Area Networks (WAN). X.25 was standardised in the 1970s and mostly felt out of use by 2015 as most users moved to Internet Protocol (IP) systems instead.

Approximately 20% of international Flight Message Transfer Protocol / On Line Data Interchange (FMTP/OLDI) communications are routed using X.25; around 30% use New PENS and the rest is over leased lines or via bridges between national networks. In total there are in excess of 200 connections for FMTP/OLDI applications in ECAC. X.25-related costs are becoming a higher burden due to obsolescence of the equipment and the need to stock old equipment as a parts store. It is proposed to accelerate the migration of all of the remaining forty-one X25 lines except for a residual number to be kept for non-EU and non-ECAC interfaces. It is also proposed to migrate all 117 leased lines to NewPENS – under the assumption of the availability of a dual core for PENS.

Two thirds of the 682 operational voice network's lines are analogue and, as these are being gradually phased out by the Communication Service Providers (CSPs), these communication lines are very expensive to operate. Savings are expected by switching all voice communications to Voice over Internet Protocol (VoIP). That will require a replacement of the ANSPs' Voice Communication Systems (VCS) which constitutes a huge investment, as upgrading the VCS will be very expensive. While waiting for the full implementation of the new VoIP, the maintenance of the former G/G voice communication technologies (such as E1 for instance) is extremely expensive. It is therefore proposed to migrate part of these lines to an IP network such as NewPENS via specific voice gateways developed by Industry. Under the assumption that one third of these former lines could be migrated onto an IP network, savings in OPEX could be expected. Such a migration would require special attention and studies to avoid the creation of single points of failure for the safety-critical G/G voice communications.

3.2 Optimisation strategy for NAV

In the context of PBN becoming the norm in all phases of flight, a gradual decommissioning of a substantial number of VORs and almost all NDBs can be envisaged. This would lead to a Minimal Operational Network of VORs – the "VOR MON."

This evolution of the ground-based navigation infrastructure is fully aligned with the considerations and recommendations included in ICAO ANNEX 10, Vol I Attachment H - Strategy For Rationalization Of Conventional Radio Navigation Aids and Evolution Toward Supporting Performance-Based Navigation [6]. A similar evolution of the USA's ground navigation infrastructure is also foreseen (according to current FAA Navigation Programs).

A detailed analysis of the coverage and PBN performance ensured by the navaids infrastructure was conducted in SESAR 1, in project 15.3.2. [7] . The analysis focused on the support of PBN applications, but has considered the use of navaids for conventional applications as well. The rationalization and optimization potential was also assessed in this context. The term “potential” was used to recognize that it is not possible to know about all the various residual operational roles of each VOR in a local airspace context.

The SESAR assessment estimated the Minimal size of the VOR MON at approximately 300 facilities out of the 748 currently in operation ECAC-wide (586 in the SES area). The study was done at a high level, based on a generic set of criteria that addressed mainly the coverage for en route operations and high density Terminal Manoeuvring Areas (TMA’s – the airspace around and above airports or groups of airports). However, the goal was also to ensure that the capability of the residual VOR network to support terminal and final approach operations at a maximum number of airports would be retained. Therefore, as a general rule, the retention of VOR facilities installed at - or in the vicinity of - airports, was favoured, focussing decommissioning on remote facilities, used only for en route operations. The assessment also assumed a generalised shared use of cross-border navaids.

The selection of VORs that will be part of the MON has to be done in close correlation with the development of the Airspace Concept that supports PBN implementation and should involve the military at national and cross border discussions. Detailed considerations and recommendations regarding the coordination between the Airspace Concept development and the Navaids infrastructure planning are included in the following EUROCONTROL PBN Handbooks:

- PBN Handbook No.1 – European Airspace Concept Handbook for PBN Implementation [8]
- PBN Handbook No.4 – European NAVAID Infrastructure Planning Handbook, Including MON [9].
- PBN Handbook No.6 – European GNSS Contingency/Reversion Handbook for PBN Operations [10].

A full consideration of all local operational needs is almost certain to increase the size of the VOR MON compared to the estimation in SESAR project 15.3.2. Consequently, it is estimated that up to 400 VORs can be decommissioned in the 2021-2030 timeframe, leading to a VOR MON of 350 facilities as a minimum across ECAC. This significant downsizing of the VOR network would bring substantial cost savings through the avoidance of replacement costs (CAPEX) and related operational costs (OPEX).

Given that many ANSPs have preferred to retain VORs in operation that have already been fully amortized, these should be targeted for rapid decommissioning to realise early cost savings.

It should be noted though that the decommissioning has a cost as well. Removing all references to a specific VOR from all aeronautical charts and redesigning the associated procedures is a prerequisite for rationalization and this has associated costs. Moreover, completely dismantling and removing a VOR (including the counterpoise for a Doppler VOR), and returning the site to its initial state requires civil works that may be substantial.

Due to the dependency on airspace and flight procedure changes, the decommissioning of navaids has to be carefully planned, well in advance of the foreseen date. Some factors that may delay the process are listed below:

- The decommissioning of any VOR facility requires a specific safety assessment and regulatory approval for the airspace/procedure design changes needed to compensate for current operational use of the facility;
- There is a limited number of qualified procedure designers such that their availability is now on the critical path for airspace/procedure changes with the consequence that publication of modified or new procedures could be delayed; and
- Changes to ATS routes or instrument procedures often require a lengthy public and industry (aircraft operator) consultation process, and may become the main delay factor for implementation.

The PBN IR requires that national PBN implementation planning is described and maintained by States in a “Transition Plan”, to be coordinated with the Network Manager. It should also include the planning for the evolution of the navigation infrastructure that a number of States have already defined in their detailed infrastructure plans. In order to facilitate coordination at network level, all States are encouraged to plan changes in their CNS infrastructure in line with their PBN implementation planning, and to exchange that information with neighbouring States and the Network Manager. In particular, States are encouraged to use the PBN Transition Plans as a means to coordinate the evolution of the navigation infrastructure.

3.3 Optimisation strategy for SUR

The optimisation process should be consistent with the CNS Roadmap of the SESAR ATM Master Plan [12], targeting a Surveillance architecture, with cost and spectrum efficiency, composed of ADS-B and a Minimal Operational Network including Mode S radars and Multilateration systems. The use of a passive technique, such as ADS-B, as part of the SUR target architecture will significantly improve frequency congestion in the 1030/1090 MHz spectrum by reducing over-interrogation of airborne equipment. This improves the efficiency and sustainability of the SUR architecture, which in turn leads to operational and additional economic benefits.

In the light of the above and earlier work on the subject, the SUR sensor optimisation strategy should aim at:

- Reduction in the number of PSR, SSR Mode A/C/S radars;
- Shift towards sensor types with lower cost, i.e. MLAT/ADS-B or ADS-B only; and
- Expansion of the sharing practices between the stakeholders (cross-border, civil-military, network level-local level).

The EU Regulation SPI IR [13] lays down the foundation for the optimisation process, as it includes provisions for two key pillars of the process, namely the SUR performance and the SUR interoperability.

For the *airborne* side, the SPI IR mandates equipage which is compatible with all possible types of ground cooperative Surveillance sensors used by ANSPs.

For the *ground* side, the SPI IR foresees that the ANSPs shall ensure that, before putting into service their SUR systems, they are implementing the most efficient deployment solutions taking into account the local operating environments, constraints and needs as well as airspace users’ capabilities.

In support of the efficient deployment solution targeted in the SPI IR, the EASA AMC/GM – Acceptable Means of Compliance (AMC) and Guidance Material (GM) [14] for the SPI IR foresees that before commissioning a new or modified surveillance system, air navigation service providers (ANSPs) should develop a business case to demonstrate that the proposed surveillance system is the most effective solution that safely supports the required operations and among other elements considers efficiency issues (e.g. through-life cost (TLC) and the 1030/1090 MHz radio frequencies (RF) band usage).

There is an important interdependency of optimisation with the evolution of ADS-B airborne equipage and ground operations. Whereas ADS-B operations can start with low ADS-B equipage rates, the optimisation of Surveillance infrastructure using ADS-B needs almost the entire fleet of aircraft operating in a specific airspace to be fully equipped. The sensor mix used to replace ageing radars will be more cost-efficient and spectrum efficient after the milestone of full airborne equipage, which will thus accelerate the transition to an optimised SUR infrastructure.

Currently, about 90% of the total (EU and non-EU) fleet (performing ~85% of the flights) operating in Europe and subject to the SPI IR are equipped with the appropriate ADS-B version (v2).

The target of full ADS-B airborne equipage for the SPI IR is expected by 2023-25 (see Figure 3 below depicting the European fleet equipage and the EUROCONTROL CNS web pages presenting the most recent status). The planned airborne equipage rate for the total (EU and non-EU) fleet subject to the SPI IR will be higher than indicated in Figure 3, because the non-EU fleet operating in Europe is mostly long-haul and therefore better equipped.

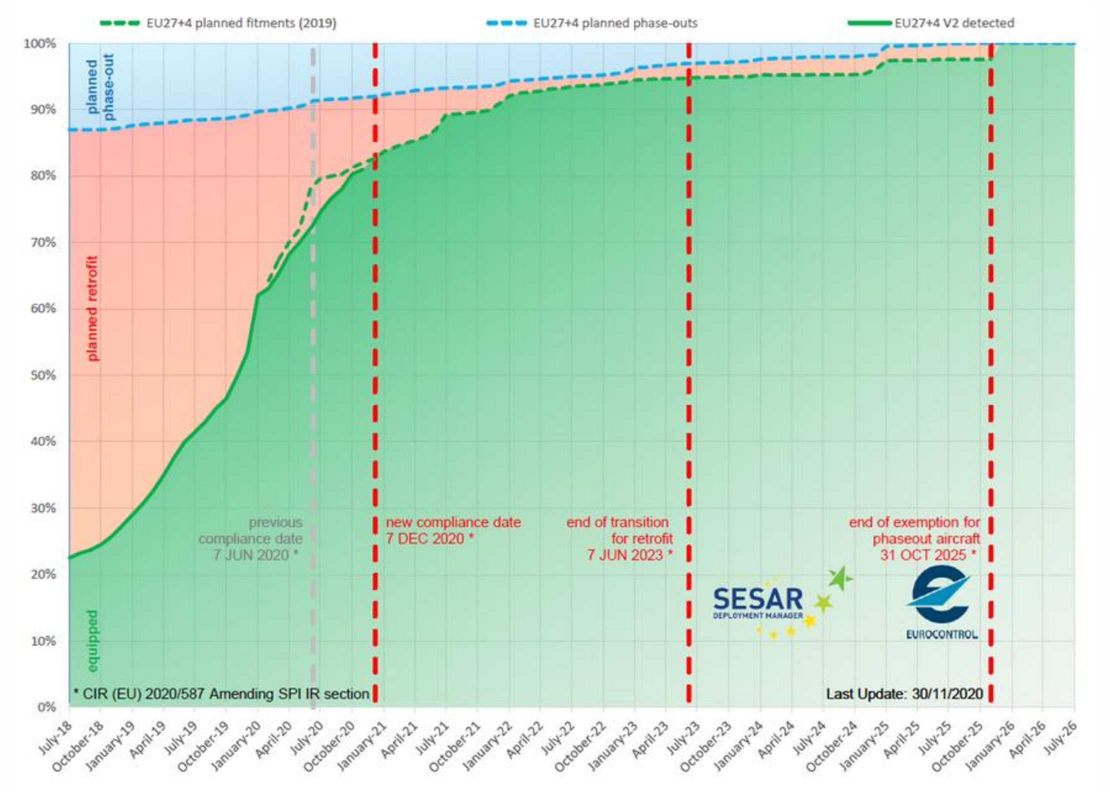


Figure 3: ADS-B airborne equipage rate of European fleet

Regarding the ground side, as described above, ADS-B stations are widely deployed in Europe. Moreover, ADS-B is currently used operationally in around 25% of the airspace operated by European ANSPs. Based on recent feedback from ANSPs, ADS-B operations will further grow in the next years, thus widening the airspace in which ADS-

B can be used towards optimisation of the sensor mix. This evolution is clearly visible in Figure 4. The areas in green show where ADS-B is in operation, and those in yellow indicate that ADS-B coverage is available.

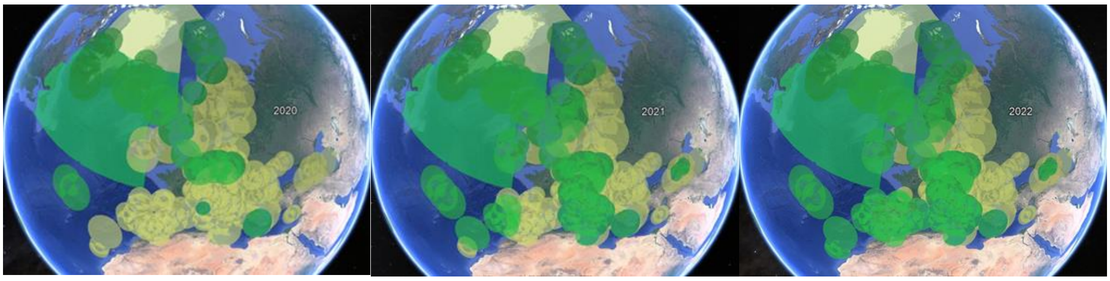


Figure 4: ADS-B ground implementation progress in 2020-22

The trend towards full ADS-B coverage and integration in ATM systems will continue steadily, as all new sensors deployed include ADS-B capabilities (Mode S/ADS-B, WAM/ADS-B).

The ADS-B component of the target architecture is therefore expected to be widely available operationally in the ground systems by 2023-25. Consequently, the emphasis of the optimisation work should be put on the fast transition towards a SUR Minimal Operating Network, as envisaged by the Master Plan [12].

In addition to the timing of the ADS-B airborne equipage and ground integration, the optimisation process depends on the extent of using best practices and resolving constraints.

Best practices that could be used in SUR infrastructure optimisation include:

- Most efficient use of civilian air traffic control Primary Surveillance Radars, by comparing the use cases and clarifying the applicability of SUR standards;
- Inclusion of ADS-B as a functionality in new Mode S radar procurement, as well as to simplify/reduce the cost of Multilateration systems;
- System sharing, e.g. common infrastructure (sensors and/or processing systems) supporting both civil and military;
- Split cost between different users (e.g. civil and military), regarding different types of sensors (non-cooperative SUR, cooperative SUR); and
- Sharing of Surveillance information cross-border, between civil and military or between Network level and local level (e.g. for the latter case, on incoming traffic from neighbouring airspace).

The constraints that have to be addressed in the process of infrastructure optimisation include the following:

- Mixed (equipped/non-equipped) ADS-B traffic
    - There are SPI IR clauses allowing non-equipage of some aircraft (e.g. with CoA before 1995, some State aircraft). Provisions have to be considered with ANSPs to minimise/eliminate the impact of such aircraft in the SUR infrastructure optimisation process. A harmonised approach reflected in AIP was elaborated in consultation with the stakeholders.
    - The SPI IR scope regarding ADS-B includes IFR/GAT aircraft above a threshold of 5.7t or 250 knots. This means that even after achieving full equipage of the SPI IR mandated fleet, there will be lower-end aircraft using Surveillance services which will not be equipped with ADS-B, typically flying at lower altitudes. Addressing this constraint will increase the optimisation potential in lower altitude airspace (e.g. TMA

radars), reduce the remaining number of radars in the MON and unlock the associated additional benefits.

- Performance in the case of data sharing. Systems are tuned, tested and validated for a specific environment and their use by another ANSP raises issues regarding ensuring performance of the shared data in the area of responsibility of other ANSPs. Resolving this issue will allow a much wider use of SUR data and optimisation of the infrastructure. The available SUR standards and the use of performance monitoring can support convergence and seamless operations in this respect. Collaborative work is necessary to realise this to a full extent.
- Liability in the case of data sharing, for which, as above, the SUR standards and performance monitoring can support mitigation.
- 1030/1090 MHz RF band congestion, which reduces the detection range of SUR systems and consequently leads to additional infrastructure deployed. It is important to use the 1030/1090 RF monitoring to identify hot spots and implement actions to address the problem. Relevant best practices include improved configuration of radars and active Multilateration systems, use of passive surveillance (i.e. ADS-B), composite surveillance, radar clustering, efficient sharing of Downlinked Aircraft Parameters (DAPs), improvements of Airborne Collision Avoidance Systems (ACAS), etc.

Due to the multiple factors driving the optimisation process and their interdependencies, the process will be greatly improved by a close collaboration of all involved stakeholders. Such a collaborative activity will identify and maximise the use of best practices and address the constraints efficiently and effectively, in order to accelerate the optimisation process and increase the benefits.

The basis used in the economic assessment in Chapter 5 is the CP2 study on CNS rationalisation (which addressed Mode A/C radars only) [1]. This is extended with additional optimisation objectives for Mode S and PSR.

4 Scenario assumptions

In this section we describe the main characteristics of the scenarios envisaged and whose expected savings have been quantified in Chapter 5. A short description of the main assumptions is provided in this section; a full description can be found in Annexes A and C.

4.1 Geographical Scope

Two geographical scopes are considered and evaluated throughout the study. First, we study the Member States (MS) subject to the Single European Sky (SES) Area's legislative framework, namely the EU27, Norway and Switzerland. Second, we analyse the European Civil Aviation Conference (ECAC) Area. A complete list of the MS within the SES and ECAC areas is provided in Annex D.

4.2 Timeline considered

We have analysed the 20 year period between 2021 and 2040. The reason to choose this is twofold: firstly, it is in full alignment with the SESAR Vision as described in the SESAR European ATM Master Plan [12]; and secondly, most of the CNS assets considered have a lifecycle of around 20 years. We consider that a fair assessment needs to address the normally expected operating life of the assets.

In our quantification of savings, special attention is given to the aggregated savings at three points in time:

1. End 2024, to provide the savings that could possibly be achieved by the end of RP3. Please note that our analysis for this case will cover the period 2021 to 2024, whereas RP3 covers 2020 to 2024.
2. End 2030, as the period of applicability of the next RP is currently not known.
3. End 2040 to consider the total expected contribution to the SESAR Vision.

4.3 Asset ownership

In this study, only the assets under civil ownership are considered. Military registered units have not been included in the scope but in section 6.1.1 – Decommissioning potential - MON Sizes – a potential limitation in decommissioning a minor number of units that have a dual civil and military use is considered.

4.4 Communication Scenario

The COM business case is driven by savings in operating costs via the migration from ageing technologies to more cost efficient and modern solutions. Considering the optimisation strategy designed in Chapter 3.1, the following scenario is envisaged for COM. Figure 5 below explains in a graphical way.

- Migration ambition:
    - All X.25 lines are migrated to NewPENS except for 10 lines which are kept for Non-EU and Non-ECAC interfaces.
    - All lease lines are migrated to NewPENS.
- Migration rate:
    - 25% of the ambition every year so the transition period is 4 full years. Full benefits reach as of beginning of 2025.

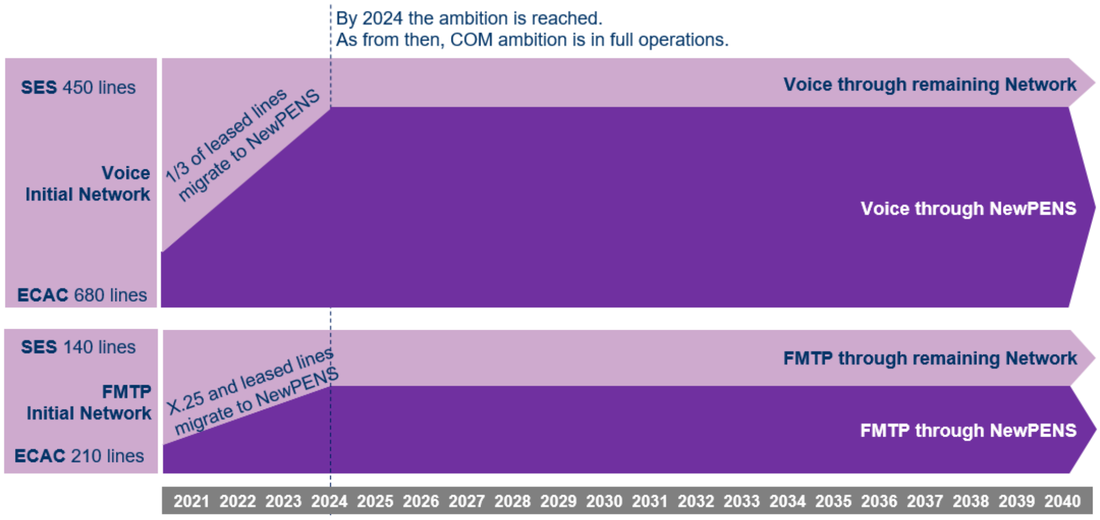


Figure 5: Communication scenario

4.5 Navigation Scenario

The NAV business case is based on the cost savings generated by decommissioning redundant assets, in this case terrestrial navigation aids (or "navaids"). This is a pure 'rationalisation' of the existing network. Given the optimisation strategy presented in Chapter 3.2, we propose the following scenario for NAV, as summarised in Figure 6 below.

- Decommission ambition:
  - 90% of the existing NDB Network (725 units in SES and 1 005 units in ECAC) will be decommissioned by 2030.
  - 53% of the current VOR Network (313 units in SES and 400 units in ECAC) will be decommissioned by 2030.
  - Neither the NDB nor the VOR units will be replaced by any other type of navaid.
- Decommission rate: linear decommission rate based on the ambition and the expected operating life of the assets.
  - Roughly 9% of the initial NDB units are decommissioned per year during 10 years.
  - Around 9% of the initial VOR units are decommissioned per year during 10 years.
- Minimal Operational Network (MON):
  - Approximately 81 (SES) or 112 (ECAC) of the currently deployed NDB units are retained.
  - In the order of 273 (SES) or 348 (ECAC) of the currently deployed VOR units are retained.

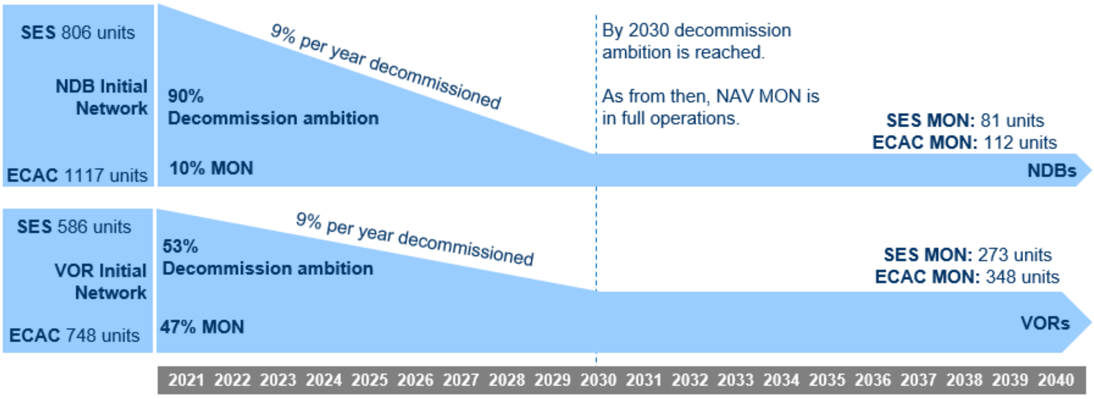


Figure 6: Navigation scenario

4.6 Surveillance Scenario

The SUR business case relies on a slightly different approach. On the one hand, all the Mode A/C stations and a number of the Mode S stations will be decommissioned and replaced by a combination (the 'Mix') of surveillance sensors with lower operating costs and improved spectrum efficiency.

The 'Mix' is based on the CP2 proposal [1] and consists of two different replacement ratios in line with the SPI IR:

- A first replacement ratio for the first three years (before "full" SPI IR equipage).
- A second replacement ratio when "full" SPI IR equipage is attained.

On the other hand, a number of PSRs will go through a pure 'rationalisation' of their Network as will be the case for NDBs and VORs.

In line with the optimisation strategy described in Chapter 3.3, the scenario described below and depicted in Figure 6 is modelled in this assessment.

- Mode A/C radars: 100% decommissioned by 2030 and replaced with a cost and spectrum efficient SUR sensor mix
- Mode S radars: 50% decommissioned by 2030 and replaced with a cost and spectrum efficient SUR sensor mix
- Primary Surveillance Radar (PSR): 15% of the decommissioned PSRs are not renewed.

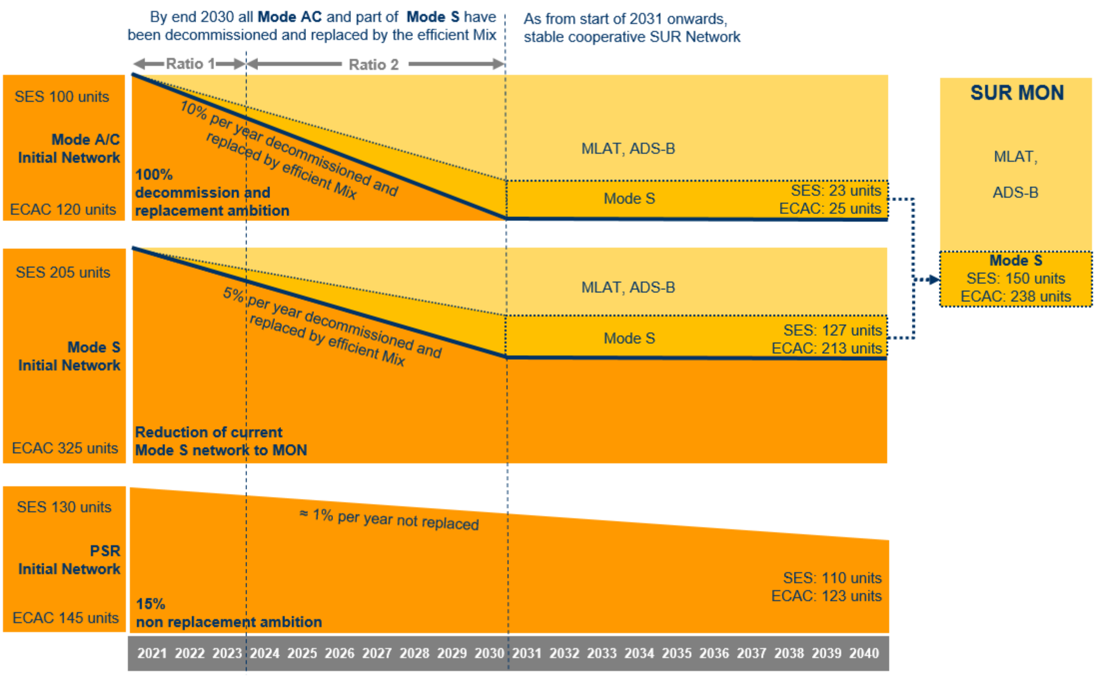


Figure 7: Surveillance scenario

This scenario will facilitate the transition towards the target SUR architecture including ADS-B and a Minimal Operational Network consisting of MLAT in TMAs and most of en-route, complemented by Mode S in major TMAs and for limited required gap filling en-route. PSR will be retained in major TMAs, if needed. This target architecture also assumes a sustainable 1030/1090 MHz environment, with optimal use of interrogators and ground-ground data sharing (clusters, passive acquisition, DAPs) etc.

4.7 Costs

The COM costs have been provided by EUROCONTROL NM experts. The NAV and SUR cost data have been extracted from the original CP2 Report [1]. The cost data were validated at the time through extensive stakeholder consultation inside dedicated working groups in SESAR PJ20 [12]. The stakeholders consulted represented ANSPs, Airspace Users and NM notably. Airports and the Military were also involved. For this new analysis, we have maintained the same cost values.

The ANSPs would bear the vast majority of the costs associated with the optimisation. However, they will also be the direct beneficiaries of the improvements. In our economic modelling, we consider up to 4 types of different cost components, as summarised in Table 1.

Concept	Comment
Capital Expenditure (CAPEX)	This is typically the cost of replacing an old unit by a new one to perform the same job. Here we would also consider the renewal of sensors that have achieved the end of their life.
Operating Expenditure (OPEX)	The yearly operating costs of keeping in full operating conditions the NAV and SUR assets.
Decommissioning costs	This is the cost of decommissioning one asset and returning the land to its 'original state' if necessary.
Sunk costs	We assume some NAV and SUR units might disappear before their End of Life (EOL). In other words, stakeholders may decommission

	units they have not fully 'amortised'. This would appear as a 'financial loss' in stakeholders' accounts because the value of the assets has not yet been written-off. Importantly, this is not a cash outflow but a financial consideration.

Table 1: Cost elements considered

A summary of the cost values – rounded – is presented in Table 2. Further details are provided in Annexes A, B and C.

Domain	Units	CAPEX (K€)	OPEX (K€)
COM	FMTP X.25 International lines	Not considered	7
	FMTP Other International leased lines		5
	Voice leased lines		15
NAV	NDB	75	7.5
	VOR	1 000	100
	Decommissioning	30% of CAPEX	Not applicable
SUR	PSR	3 700	220
	SSR Mode A/C/S	1 900	180
	MLAT (incl. 6 stations)	720	95
	ADS-B (incl. 2 stations)	150	32
	Decommissioning	17% of CAPEX	Not applicable

Table 2: Costs per CNS domain – Rounded values

The modelling did not include any airborne equipage costs, since the cost of equipping Commercial Air Transport is practically sunk, as the vast majority of the fleet is already equipped, both for NAV and SUR (ref. sections 3.2 and 3.3 above).

4.8 Benefits

Whereas in many economic assessments the benefits of an initiative are calculated as an inflow of cash, we have to think in different terms. The 'benefits' of CNS optimisation are the 'avoided costs', because at the end of the period the number of assets to be deployed and operated is reduced, thus reducing the costs of the service. Additionally, for Mode A/C and Mode S we will substitute the technologies with a more cost-efficient Mix.

In Chapter 5, the expected savings that would be obtained from NAV and SUR optimisation are calculated. The 'savings' are calculated as the net result of the concepts in Table 3 below. The savings are considered against maintaining the current assets in today's network.

Sign	Concept	Comment
+	Avoided CAPEX	Investments that would not be necessary any more as a result of implementing an optimisation strategy.
+	Avoided OPEX	The operating costs of units we have decommissioned would no longer be incurred.
-	Decommissioning costs	Decommissioning costs are treated as a reduction of savings.

-	Sunk costs	The time at which some CNS units will be decommissioned is assessed and assumptions are made on the possible sunk costs incurred.
=	Net 'savings'	The net of the 4 concepts above

Table 3: Calculation of savings

5 Expected savings

This chapter presents the expected savings from the scenarios envisaged in Chapter 4. Results are provided for two different scopes: the SES and ECAC Areas. Here, the estimated savings are provided. This is setting the inputs at the most reasonable values according to the information provided by CNS infrastructure experts. Any slight differences in the sums of values can be explained by the rounding of decimals.

5.1 SES Area

Table 4 below presents the expected aggregated savings at SES level of the proposed optimisation. Values are provided in undiscounted (nominal) and discounted (NPV using 2% as discount rate) terms.

EUR millions	In RP3		By 2030		By 2040	
	Nominal terms	NPV	Nominal terms	NPV	Nominal terms	NPV
COM	**2**	**2**	**8**	**7**	**16**	**13**
NAV	**53**	**50**	**243**	**213**	**856**	**665**
NDB	8	7	36	32	127	98
VOR	45	43	207	181	729	566
SUR	**84**	**79**	**292**	**259**	**536**	**438**
Mode AC	35	33	125	111	216	178
Mode S	36	34	127	112	218	180
PSR	13	13	40	36	102	81
TOTAL	**139**	**132**	**543**	**478**	**1 409**	**1 116**

Table 4: Aggregated savings per period per category – SES Area

In the short term, for the entire RP3 period, savings of €139 million can be expected. In real terms, this is translated into a Net Present Value (NPV) of roughly €132 million.

Considering 10 years ahead, savings almost quadruple. By the end of 2030, the aggregated savings are expected to amount to €543 million in nominal value or €478 million discounted.

Looking in the long term up to year 2040 – to be aligned with the SESAR ATM Master Plan Vision [12] – we calculate savings in the order of €1.4 billion in nominal terms which represents a NPV of around €1.1 billion.

Figure 8 below allows to study the breakdown of NPV savings per type of equipment by 2040.

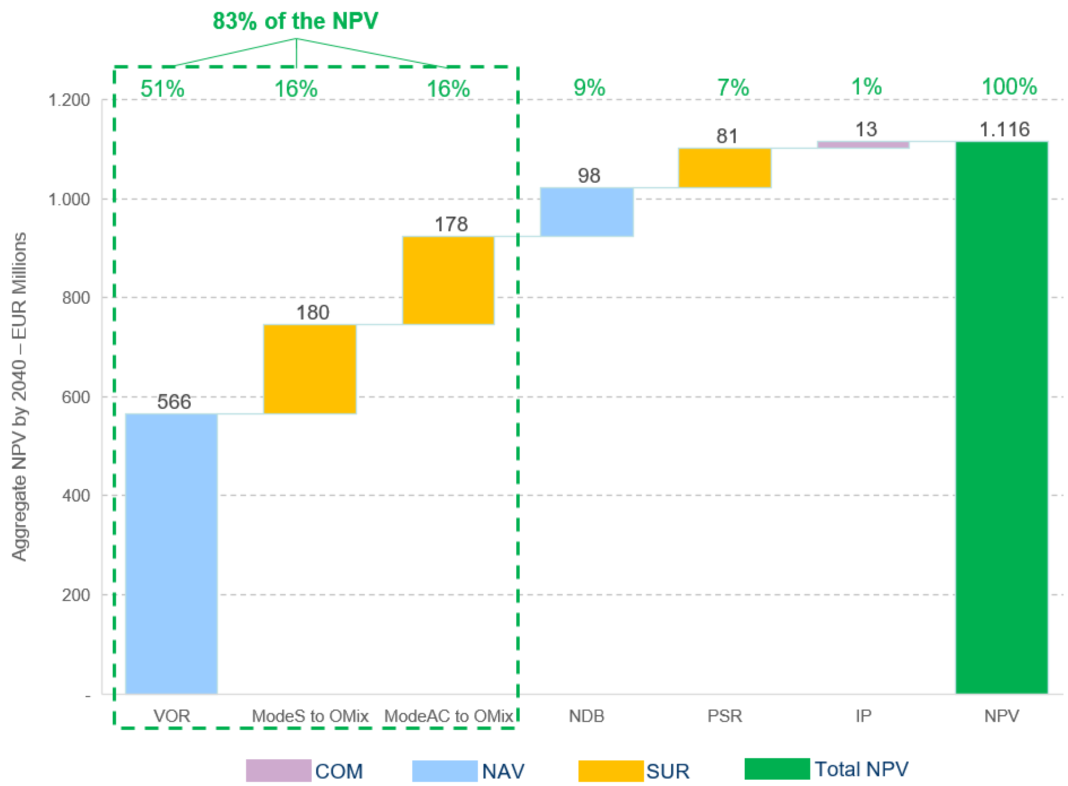


Figure 8: NPV by 2040 – Breakdown per technology – SES Area

Three types of equipment drive the generation of savings. VOR, Mode S and Mode A/C jointly amount for €924 million (83%) of the projected total NPV savings by 2040. Their relative importance remains quite constant for the whole time period.

The evolution of yearly savings for the SES area can be better understood by looking at Figure 9 below.

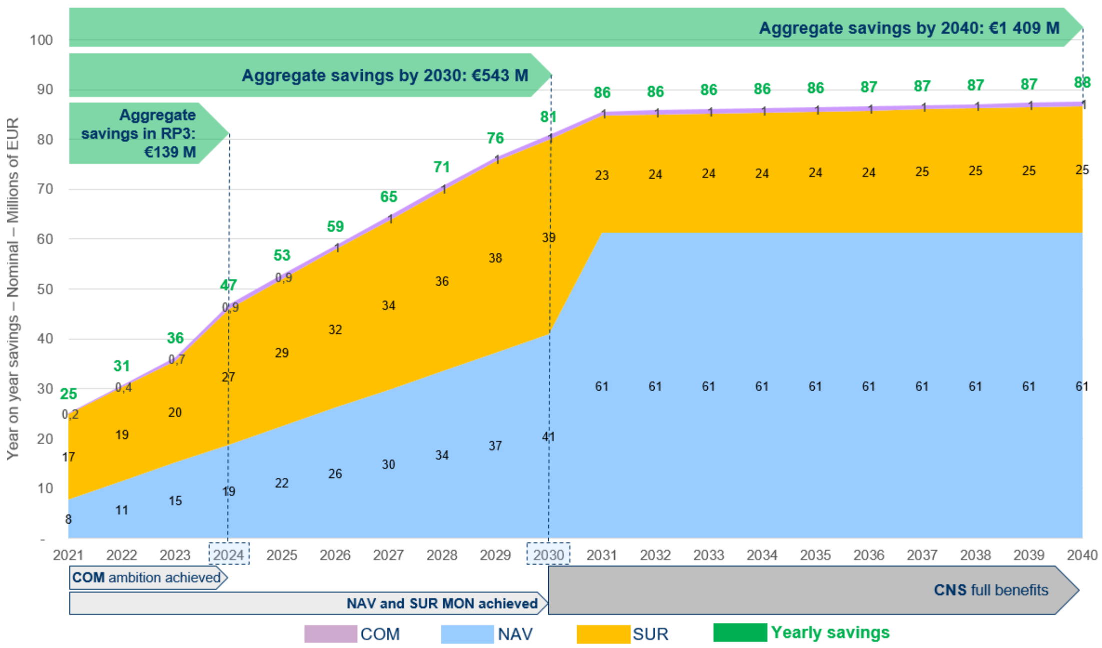


Figure 9: Yearly savings per year per category – SES Area

The figure shows a linear ramp-up of benefits for the whole period of study as we have used a linear decommission and replacement strategy. Four performances can be identified from our modelling assumptions:

- By the end of RP3, the COM ambition is achieved.
- From 2021 to end 2030 we have a steeply rising rate of savings driven by the retirement of NAV assets and the replacement of Mode A/C and Mode S receivers by the Optimal Mix.
- We observe an increase in the rate of savings in 2024 as we move from the first SUR replacement ratio to the second – which is more cost efficient – as envisaged in CP2.
- Finally from the beginning of 2031 onwards we have only small increases in annual savings. The NAV and SUR MONs are fully operational and we increase the total savings only slightly by retiring the remaining targeted PSR stations.

Studying the split between CAPEX and OPEX gives an understanding of what the implications for the Performance Scheme will be, as shown in Table 5 below.

EUR Millions – Nominal values	In RP3	By 2030	By 2040
COM	**2**	**8**	**16**
COM CAPEX	-	-	-
COM OPEX	2	8	16
NAV	**53**	**243**	**856**
NAV CAPEX	31	78	323
NAV OPEX	22	165	533
SUR	**84**	**292**	**536**
SUR CAPEX	74	206	236
SUR OPEX	10	87	300
TOTAL	**139**	**543**	**1 409**
CAPEX Sub-Total	105	283	559
OPEX Sub-Total	37	259	847
CAPEX	75%	52%	40%
OPEX	25%	48%	60%

Table 5: Aggregated nominal savings per period per cost type – SES Area

By the end of RP3, three quarters of the savings come from avoided capital expenditure. As time advances, their relative importance switches from CAPEX to OPEX savings. We see that by the end of 2030, savings in operating costs catch-up with CAPEX savings, to represent close to an equal split of the total savings. By 2040, the relative importance of the OPEX savings supersedes that of CAPEX as all our new assets have been deployed and they are fully operational. In Chapter 6.1.1 we show how changes in the speed of deployment impact the savings.

This is consistent with the logic that in the first years we mostly avoid renewal of unnecessary NAV and SUR assets and thereafter increasingly enjoy the operating savings associated with these removals and the switch to a more cost efficient SUR sensor mix.

5.2 ECAC Area

Similarly to the SES Area, Table 6 below calculates the expected savings for the ECAC Area.

EUR millions	In RP3		By 2030		By 2040	
	Nominal terms	NPV	Nominal terms	NPV	Nominal terms	NPV
COM	**3**	**3**	**11**	**10**	**25**	**20**
NAV	**69**	**65**	**314**	**275**	**1 107**	**859**
NDB	11	10	50	44	176	136
VOR	58	55	264	232	931	723
SUR	**105**	**100**	**329**	**292**	**662**	**525**
Mode AC	40	38	133	118	228	188
Mode S	51	48	151	135	303	247
PSR	15	14	45	40	113	90
TOTAL	**177**	**168**	**655**	**578**	**1 776**	**1 405**

Table 6: Aggregated savings per period per category – ECAC Area

By 2024, ECAC could benefit from savings of €177 million in nominal terms. Considering the end of 2030, the aggregated savings would reach around € 655 million. Discounting the values at 2% would result in savings of €168 and €578 million in real terms respectively. In the long term, we foresee savings of almost €1.8 billion in nominal terms or around €1.4 billion in real terms.

6 Risk assessment

In this chapter, the impact of a number of deviations from our 'most-likely' assumptions is analysed. We follow a series of steps in the assessment of the project risk as recommended by the EU Guidelines for CBAs of investment projects [15].

The scope of this chapter is limited to the SES Area. Unless otherwise stated, the values provided are discounted, so referring to the NPV.

Numbers in green text represent an increase in the savings compared to the most likely input considered in Chapter 5. Alternatively, numbers in red signify a decrease in savings. Any slight differences in the sums of values can be explained by the rounding of decimals.

6.1 Sensitivity analysis

Sensitivity analysis helps to identify the variables whose variations have a significant impact on the project's economic performance. The assessment is following *ceteris paribus* conditions; that is, only changing one parameter at a time and determining the effect of that change in the value of the final NPV.

Through expert review and exchanges within the Advisory Group, four main areas of uncertainty have been identified. The following sub-sections analyse the potential impact in the expected NPV from deviations in our initial most-likely assumptions.

6.1.1 Decommissioning potential - MON Sizes

Although based on extensive research performed in SESAR 1 [7] and having gone through a consultation process in CP2 [1], the decommissioning ambitions considered for the NAV and SUR domains come from a high-level network view. The CNS Advisory Group stressed that details about individual facilities would be reserved for a future CNS Evolution Plan and the local plans that complement it. In order to facilitate such planning, an analysis of different MON sizes for NAV and SUR is provided. Changes in the COM domain have so little impact that they have not been studied here.

The examination of different MON sizes for NAV is equally key for the inclusion of the Military needs. Although only civil-owned assets have been considered in the scope – section 4.3 – military experts highlighted that a limited number of civil owned units are also used by the military when needed. In parallel, there is a rather small number of units published for civil use but collocated with military radars. The military should not be impacted by the SUR MON as the Optimisation strategy is based on maintaining the same radar equivalence. In Table 7 we analyse a range of MON sizes proposed by operational experts to cater for uncertainty.

- The 'Low' scenario is considered to sufficiently cover the possible specific local constraints. Reviewers have referred to (non-exhaustively) local airspace redesign, needs of specific stakeholders, military constraints and other cross-border issues not considered in the SESAR VOR MON assessment [7]. For the SUR domain, the Low and the 'Most-likely' options are merged. This is because the 'Most-likely' option is already considered as conservative as indicated by operational experts.
- The 'High' scenario studies the potential of more ambitious decommissioning as suggested by some reviewers, particularly the NAV domain experts

NPV in € M	In RP3			By 2030			By 2040		
Ambition target	Low	Most likely	High	Low	Most likely	High	Low	Most likely	High
COM		**2**			**7**			**13**	
NAV	**34 (↓16)**	**50**	**56 (↑6)**	**145 (↓68)**	**213**	**237 (↑24)**	**453 (↓212)**	**665**	**739 (↑75)**
NDB	75%	90%	95%	75%	90%	95%	75%	90%	95%
	6 (↓1)	7	8 (↑1)	26 (↓5)	32	33 (↑2)	82 (↓16)	98	104 (↑5)
VOR	35%	53%	60%	40%	53%	60%	40%	53%	60%
	28 (↓15)	43	48 (↑5)	119 (↓63)	181	204 (↑22)	371 (↓196)	566	635 (↑69)
SUR	27%		51%	27%		51%	27%		51%
	79		**-**	**259**		**260 (↑1)**	**438**		**514 (↑76)**
NPV	**116 (↓16)**	**132**	**137 (↑6)**	**410 (↓68)**	**478**	**504 (↑25)**	**904 (↓212)**	**1 116**	**1 266 (↑150)**

Table 7: Variations of decommission ambitions

The sensitivity analysis shows that changes in the decommissioning ambition for NAV and SUR assets generate different outcomes. Whereas the impact on NAV-related savings is observable from the first year of our study, the differences in SUR-linked savings appear only from 2030. As we maintain the same annual decommissioning rates in both, the Most likely and High ambition scenarios, we need more years to reach the MON in the High ambition scenario. This paradox is explained in the subsequent section.

In the Low ambition scenario, the NPV is only impacted by changes in the NAV MON. VORs have a considerably larger relative impact than NDBs, remaining consistent with the results shown in Figure 8 (above). The Low case reduces the NPV of the study by €212 million, of which €196 million is due to the lower VOR reduction ambition.

In the High option, NAV and SUR have a comparable effect in absolute terms by 2040. Both domains contribute further potential savings of approximately €75 million each, increasing the overall NPV by €150 million.

6.1.2 Timing - Speed of the deployment of the Optimal Mix in SUR

The results for the most-likely scenarios are provided in Table 4 and are based on the assumption that the SUR network will be optimised by decommissioning exclusively the units at the end of their life, thus under a constant linear rate for the whole period. However, we are interested in studying if it is worth changing the "speed" of rationalisation of SUR radars during the first three years. We only consider changes in the decommissioning rate for Mode A/C and Mode S facilities. PSR radars are excluded from this analysis.

By accelerating the optimisation of the network, on the one hand, we will incur some sunk costs in the short term in the expectation that the mid-to-long term benefits of more years of operating cost savings will deliver a higher net result. On the other hand, we might suffer from a reduced coordination among the involved stakeholders and that will slow down the decommissioning rate. This will bring a reduction in the expected savings.

We define a set of possible options in Table 8 below. The optimisation rate is varied in the first three years and kept linear (as in Chapter 4.6) until the targeted MON is reached. We compare two slowdown options – Severe and Moderate – and one acceleration option – Modest – against the linear option.

SSR Type	Option	Concept	Change in decommission rate from 2021 to 2023	Linear rate from 2024 to 2040
Mode AC	Slowdown Severe	Decommission ambition as a % of the initial network	10%	90%
		Units decommissioned in the period	10 units of which 7 are retired and 3 replaced by Mode S	90 units of which 72 are retired and 18 replaced by Mode S
	Slowdown Moderate	Decommission ambition as a % of the initial network	20%	80%
		Units decommissioned in the period	21 units of which 14 are retired and 6 replaced by Mode S	80 units of which 64 are retired and 16 replaced by Mode S
	Linear	Decommission ambition as a % of the initial network	30%	70%
		Units decommissioned in the period	30 units of which 21 are retired and 9 replaced by Mode S	70 units of which 56 are retired and 14 replaced by Mode S
	Acceleration Modest	Decommission ambition as a % of the initial network	40%	60%
		Units decommissioned in the period	40 units of which 28 are retired and 12 replaced by Mode S	60 units of which 56 are retired and 12 replaced by Mode S
Mode S	Slowdown Severe	Decommission ambition as a % of the initial network	5%	95%
		Units decommissioned in the period	10 units of which 7 are retired and 3 replaced by Mode S	86 units of which 69 are retired and 17 replaced by Mode S
	Slowdown Moderate	Decommission ambition as a % of the initial network	10%	90%
		Units decommissioned in the period	21 units of which 15 are retired and 6 replaced by Mode S	79 units of which 63 are retired and 16 replaced by Mode S
	Linear	Decommission ambition as a % of the initial network	15%	85%
		Units decommissioned in the period	31 units of which 22 are retired and 9 replaced by Mode S	71 units of which 57 are retired and 14 replaced by Mode S
	Acceleration Modest	Decommission ambition as a % of the initial network	30%	70%
		Units decommissioned in the period	62 units of which 44 are retired and 18 replaced by Mode S	45 units of which 36 are retired and 9 replaced by Mode S

Table 8: Variation of the speed of deployment in SUR – Assumptions

The importance of an adequate optimisation rate is easily understood when looking at the SUR Network evolution in Figure 10 and the impact in the NPV savings as shown in Table 9.

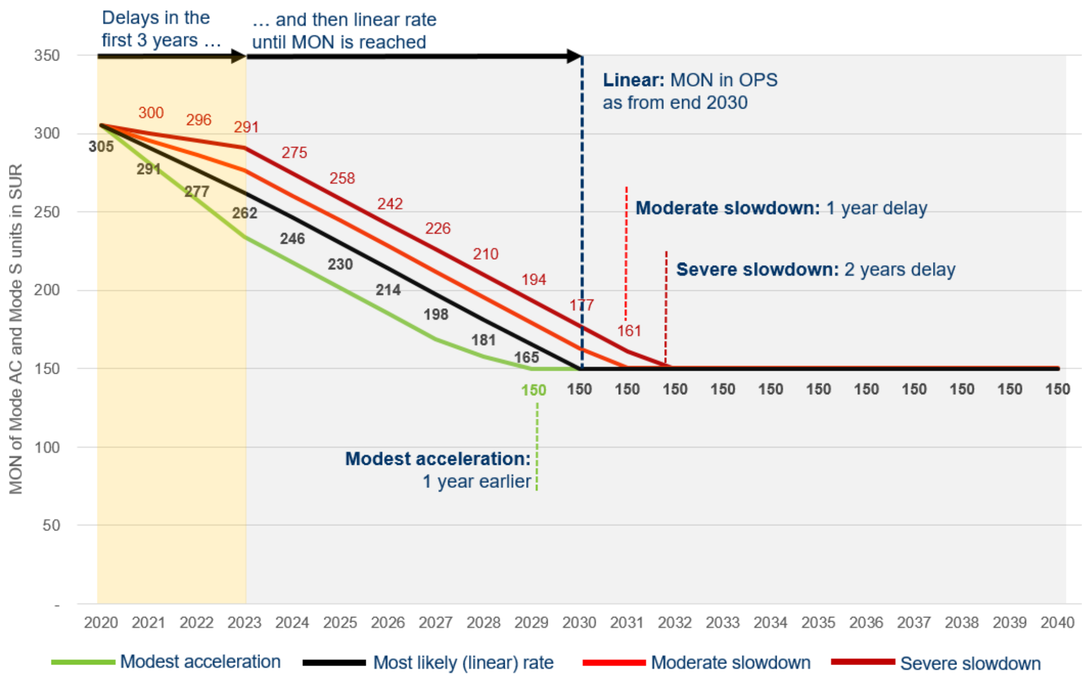


Figure 10: Delays in SUR replacement – Network evolution

Lower deployment rates delay the year in which the MON is achieved. The Moderate Slowdown means a delay of one year in completing the MON. A Severe Slowdown is translated into two years of delay in completing the MON. The Modest Acceleration is comparable to achieving the MON one year earlier. Table 9 below shows the aggregate NPV savings in key years reflecting the cost risks of deviating from the most-likely case considered.

NPV in € M	In RP3	By 2030	By 2040
Severe slowdown	99 (↓33)	432 (↓46)	1 098 (↓18)
Moderate slowdown	115 (↓16)	456 (↓23)	1 108 (↓8)
Linear	**132**	**478**	**1 116**
Modest acceleration	139 (↑8)	480 (↑1)	1 116 (↓0.2)

Table 9: Variation of the speed of deployment in SUR – Impact in NPV savings

In the presence of delays, the NPV is reduced in all circumstances. The later we reach the MON, the later we will enjoy the lower potential savings. In RP3, delays could lead to a reduction of up to €33 M in the potential savings. By 2040, the final NPV would be around €18 M lower.

The acceleration case increases the NPV by the end of RP3 (up by €8 million) but ends up reducing it marginally by 2040 (decrease of €0.2 million). Initially, this could seem counter-intuitive but the explanation lies in the first replacement ratio considered for the first three years – to be consistent with SPI IR – before “full” SPI IR equipage. The ratio before ‘full’ equipage is less efficient than the ratio ‘after’ and – by accelerating – we end up in the long term with a MON which is equivalent in terms of Mode S units but is larger in MLAT/ADS-B and smaller in ADS-B only facilities, i.e. the acceleration results in a higher ratio of MLAT/ADS-B and a smaller ratio of ADS-B only in the total accumulated replacement mix.

The economically efficient option would be to accelerate the SUR optimisation only after 'full' equipage.

6.1.3 Cost inputs

Given that this Economic Perspective's objective is to estimate the range of potential cost savings, an additional sensitivity analysis of the cost inputs of rationalised assets has been conducted, in response to feedback from the CNS Advisory Group. The overall results are presented in Table 10. Changes of up to ±10% in the cost data inputs vary the NPV by almost the same percentages.

NPV in € M	In RP3			By 2030			By 2040		
	10% lower	Most likely	10% higher	10% lower	Most likely	10% higher	10% lower	Most likely	10% higher
COM	**-**	**2**	**-**	**-**	**7**	**-**	**-**	**13**	**-**
NAV	**45 (↓5)**	**50**	**55 (↑5)**	**192 (↓21)**	**213**	**234 (↑21)**	**598 (↓66)**	**665**	**731 (↑66)**
NDB	7 (↓1)	7	8 (↑1)	28 (↓3)	32	35 (↑3)	88 (↓10)	98	108 (↑10)
VOR	39 (↓4)	43	47 (↑4)	163 (↓18)	181	200 (↑18)	510 (↓57)	566	623 (↑57)
SUR	**71 (↓8)**	**79**	**87 (↑8)**	**233 (↓26)**	**259**	**285 (↑26)**	**394 (↓44)**	**438**	**482 (↑44)**
Mode AC	30 (↓3)	33	36 (↑3)	100 (↓11)	111	122 (↑11)	160 (↓18)	178	196 (↑18)
Mode S	30 (↓3)	34	37 (↑3)	101 (↓11)	112	124 (↑11)	162 (↓18)	180	198 (↑18)
PSR	11 (↓1)	13	14 (↑1)	32 (↓4)	36	39 (↑4)	73 (↓8)	81	89 (↑8)
TOTAL	**119 (↓13)**	**132**	**145 (↑13)**	**431 (↓47)**	**478**	**526 (↑47)**	**1 006 (↓110)**	**1 116**	**1 226 (↑110)**

Table 10: Variations in the cost inputs – Impact in NPV savings

6.1.4 Economic and Financial methodology topics

For the results presented in Chapter 5 – Expected savings – we have purposely considered a number of conservative financial assumptions, namely that there will be a series of sunk costs for those CNS assets to be decommissioned that have not yet been written off in ANSPs' accounts. A 2% discount rate was agreed internally with the Advisory Group reviewers. In this section, we assess what is the impact in the NPV of changes in these parameters.

6.1.4.1 Absence of sunk costs for NAV

CNS experts involved in the work suggest a large part of the navaids network is reaching its end of life soon, so there are reasons to believe the sunk costs would be lower than we have assumed in Chapter 5. In this sub-section we analyse what would be the increase in the NPV savings if (i) we were to optimise the decommissioning planning so that we would only dismantle fully written-off assets; or if (ii) the sunk costs would be very limited because assets are at their end of life (EOL). Table 11 below captures the expected NPV.

NPV in € M	In RP3		By 2030		By 2040	
	With sunk	Without sunk	With sunk	Without sunk	With sunk	Without sunk
NAV	**50**	**72** (↑22)	**213**	**264** (↑51)	**665**	**716** (↑51)
NDB	7	11 (↑3)	32	39 (↑8)	98	106 (↑8)
VOR	43	61 (↑19)	181	225 (↑44)	566	610 (↑44)
NPV	**132**	**153** (↑22)	**478**	**530** (↑51)	**1 116**	**1 168** (↑51)

Table 11: Elimination of sunk costs

The results show that adequate coordination to remove assets that have already reached their EOL is valued at an NPV of €22 million in RP3 and €51 million by 2040.

6.1.4.2 Choice of Discount Rate

The results provided in Chapter 5 – Expected savings – are based on a discount rate of 2%, which is less than that proposed by European Institutions such as the EU Commission [15] or the European Investment Bank [16]. The reason for this choice lies in the specific nature of the CNS Rationalisation initiative. The EU CBA Guidelines address investment projects where a risk premium is usually considered. The value of the CNS Rationalisation is generated by cost reductions coupled with the fact that no new investments are needed. Considering this fundamental difference, the internal reviewers for the ECO Perspective decided to use a reduced discount rate of 2%.

In Table 12 we show the reduction of NPV when using this higher discount rate of 4% in alignment with the EU CBA Guidelines [15]. This would reduce the NPV at the end of RP3 by €7 million and by €218 million by 2040.

NPV in € M	In RP3		By 2030		By 2040	
Discount rate	2%	4%	2%	4%	2%	4%
NPV	**132**	**125 (↓7)**	**478**	**424 (↓55)**	**1 116**	**898 (↓218)**

Table 12: Variation of the discount rate – Impact in NPV savings

6.1.5 Criticality analysis

We can identify if any of the variables analysed in the sensitivity analysis are '*critical*' to the economic performance of the project, as defined in the EU Guidelines for CBAs of investment projects [15]. The guidelines suggest that '*critical*' variables are those in which a variation of ±1 % in the value adopted in the 'Most-likely' case gives rise to a variation of more than 1 % in the value of the NPV. This '*criticality*' definition is not easily applicable to all the variables in our model but the limitation can be overcome by proposing equivalent tests.

Table 13 below shows that none of the variables analysed in this chapter is '*critical*' to the NPV of the project. This reinforces the idea that our project risk is low - small changes to our inputs do not translate into big changes in the calculated NPV.

Percentage impact in NPV		By 2040	
Variable	Comments	Variation of NPV due to ± 1% variation in input	Critically judgement
MON size	When MON of NAV and SUR are reduced by 78% - considering jointly NAV and SUR units – NPV increases only by 13%.	+ 0.2	Not critical
Speed of deployment of 'Optimal Mix'	MON is achieved in 10 years in Most Likely option so 1 year delay is a variation of 1/10 = 10% of the input. Criticality would mean 1 year delay is more than ±10% of the NPV	Slowdown: (-) 0.6% Acceleration: (-) 0.7%	Not critical
Cost inputs	When costs are varied by ±1%, NPV is impacted by a ±0.9881%.	± 0.9881%	Not critical (but quite close)
Sunk cost for NAV assets	In our modelling we consider sunk costs are present or absent. We cannot directly check a change of a ±1% variation in the 'absence' or 'presence' of sunk costs. We propose to study alternatively a reduction of -1% in the sunk cost when it is present.	(-) 0.1%	Not critical

Table 13: Criticality analysis – SES Area

6.1.6 Tornado diagram analysis

Finally, we can conclude our sensitivity analysis by providing a standard 'Tornado' diagram to show the relative influence of all the variables tested. Figure 11 below shows that – within the input values we tested – the MON size is the most important variable in the final NPV by 2040. It can reduce the NPV by €212 million or increase it by up to €150 million. Deviations from the cost data inputs are the second in importance with a symmetric impact in the NPV of ± €110 million. The absence of sunk costs in NAV and the speed of deployment of the 'Optimal Mix' in SUR have the lowest impacts.

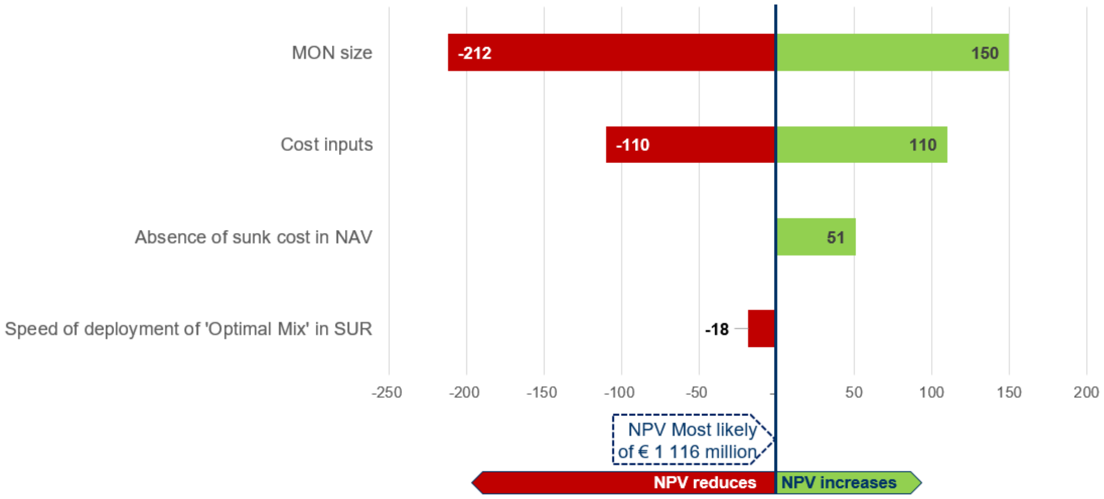


Figure 11: Impact of each variable in NPV by 2040 – SES Area

6.2 Scenario analysis

Finally, we can also complete our analysis studying the impact of combinations – pessimistic or optimistic - of our key variables. Here we will deliberately break the *ceteris paribus* assumption in order to change more than one variable at a time. When we set all the input parameters to those values that reduce the overall savings, we will refer to the 'Lowest NPV' value. Conversely, when we consider the input choices that increase the overall savings, we will refer to the 'Highest NPV' option. This type of analysis, presented in Table 14 below, gives an idea of what would be the minimum and maximum savings we could expect from any combination of the variables studied in our sensitivity analysis.

For the 'Lowest NPV' we consider:

- The lowest decommissioning potential which means the biggest MON size.
- A 'severe slowdown' in the deployment of the 'optimal mix' for SUR.
- The lowest cost inputs.
- Presence of sunk costs in NAV assets.

For the 'Highest NPV' we take:

- The highest decommission potential meaning the smallest MON size.
- The most-likely linear timing for the deployment of the 'optimal mix' for SUR.
- The highest cost inputs.
- No presence of sunk costs in NAV assets.

NPV in €M	In RP3			By 2030			By 2040		
Scenario	Lowest	Most likely	Highest	Lowest	Most likely	Highest	Lowest	Most likely	Highest
COM	2			7			13		
NAV	31 (↓19)	50	79 (↑29)	131 (↓82)	213	291 (↑78)	407 (↓257)	665	788 (↑123)
SUR	42 (↓37)	79	87 (↑8)	191 (↓68)	259	286 (↑27)	378 (↓60)	438	565 (↑127)
NPV	75 (↓57)	132	169 (↑37)	328 (↓150)	478	584 (↑105)	799 (↓317)	1 116	1 366 (↑250)

Table 14: Lowest and highest bounds for NPV

Under the most pessimistic combination of inputs, we would expect an NPV of at least €75 million in the RP3 period rising to minimum savings of €328 million out to 2030 and roughly €800 million by 2040. Switching to the most favourable assumptions and scenarios, we would achieve a NPV of a maximum of €169 million by the end of RP3 growing to €584 million at the end of 2030 and €1 366 million by 2040.

Figure 12 summarises graphically the lowest and highest bounds where the expected NPV would fall. We can conclude that the project risk is low. Even using the most pessimistic combination of inputs provided by CNS experts, the final NPV, at €799 million, remains strongly positive.

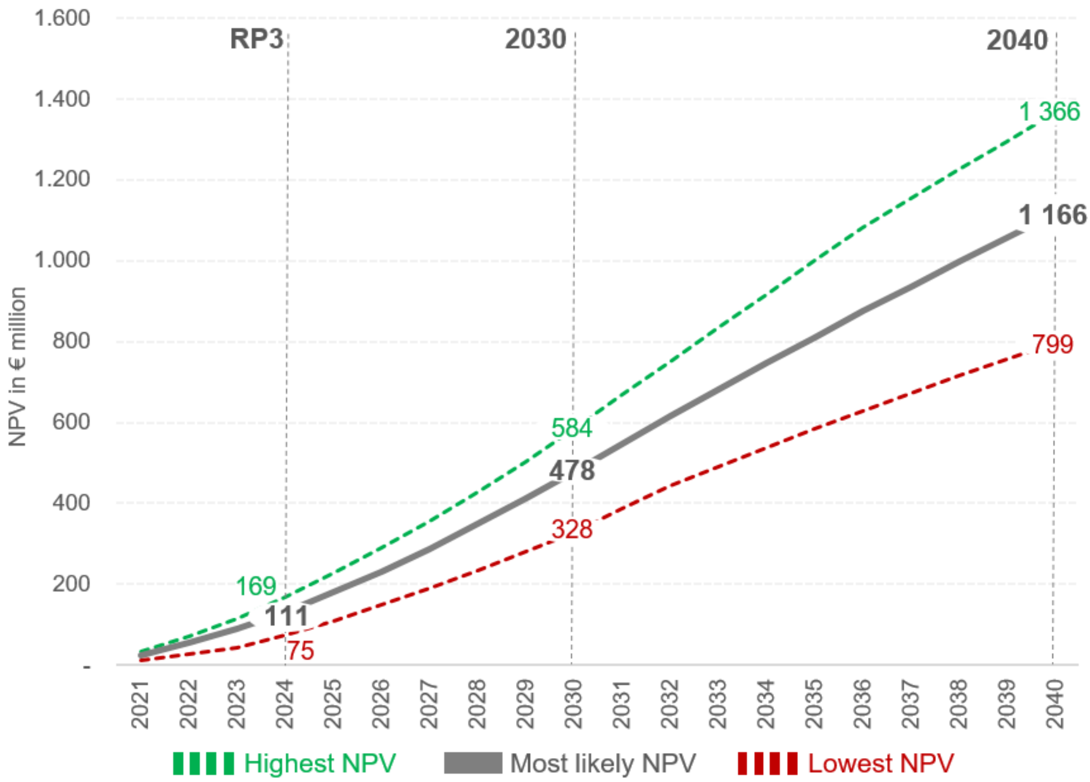


Figure 12: Sensitivity analysis – Lowest and highest bounds for NPV

Appendix

A. Further COM assumptions

The network of COM lines, 2020 values, is shown in Table 15. Data have been approximated.

Domain	Use	Type	ECAC	SES
FMTP	National	X25	6	4
		National Network	18	12
	International	X25	41	27
		Regional Networks	72	47
		NewPENS	51	34
		Others (leased lines)	21	14
	FMTP Total	**FMTP Total**	**209**	**138**
Voice	National	National Networks	10	45
		Leased lines (Analog)	42	189
	International	Analog lines	0	0
		Regional Networks	5	22
		Leased lines (Analog)	40	180
	Voice Total	**Voice Total**	**682**	**450**

Table 15: COM infrastructure in 2020

B. Further NAV assumptions

As per beginning of 2020, Table 16 below shows the approximate size of the Navaids network.

	Area	**EU27+2**	**ECAC**
	ILS	**603**	**813**
	ILS Cat I	401	550
	ILS Cat II/III	202	263
	DME (ILS)	594	807
	GLS	23	23
	DME standalone	158	189
	TACAN standalone	80	102
	VOR standalone	45	46
	VOR/DME	516	675
	VORTAC	25	27
	NDB	806	1117
VOR - VOR standalone + VOR/DME) + VORTAC)	**VOR**	**586**	**748**
DME - (DME standalone + VOR/DME)	**DME**	**674**	**864**
TACAN (TACAN standalone + VORTAC)	**TACAN**	**105**	**129**

Table 16: NAV infrastructure in 2020

C. Further SUR assumptions

Table 17 below shows the approximate size of the Surveillance network in SES and ECAC.

	SES			ECAC		
Type	**CIV**	**MIL**	**TOTAL**	**CIV**	**MIL**	**TOTAL**
PSR	130	>70	>200	>145	>120	>265
Mode AC	100	>80	>180	120	> 80	>200
Mode S	205	170	375	325	210	535
WAM/ADS-B	856		-	926	-	-
ADS-B	109	-	-	133	-	-

Table 17 – SUR infrastructure in 2020

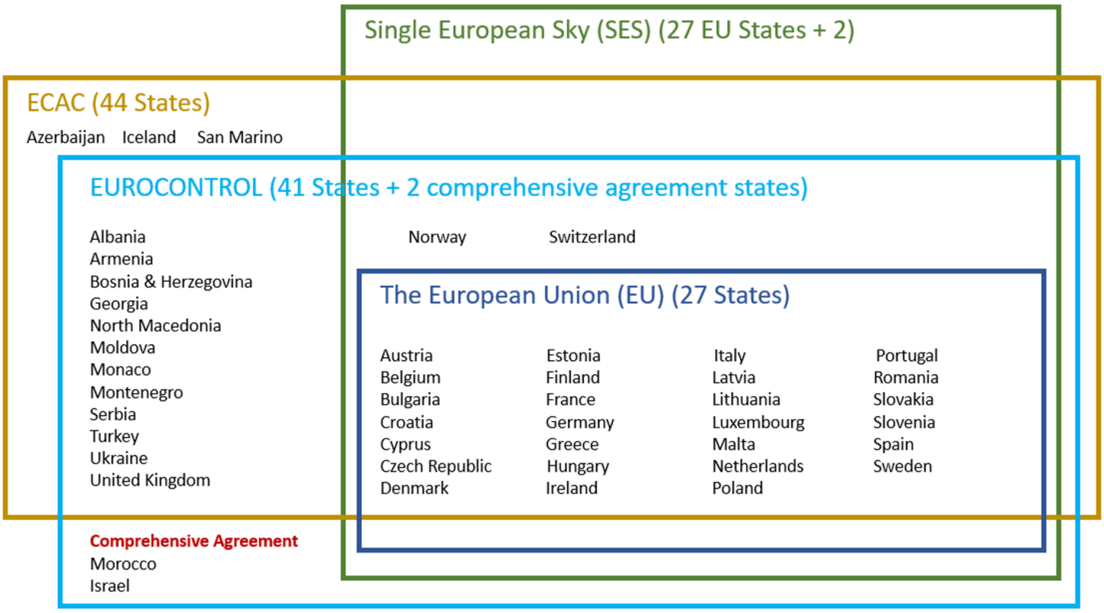
Table 18 below shows full details of the additional assumptions considered for Surveillance units.

	Concept	**Input**	**Comment**
Mode AC	# units	SES: 180 ECAC: 200	Number of units in the network.
Mode AC	Decommission ambition	100%	All Mode AC units would be decommissioned and replaced by the 'Optimal Mix'.
Mode AC	Decommission timeframe	10 years in total	In the first two years 60 units are decommissioned in a first wave. From 2022 onwards, the remaining 140 units are replaced at a rate of 11 per year. Out of the 200 (100%) targeted, 92 are decommissioned up to 2025.
Mode AC	CAPEX	€ 1900K	Per unit cost for deploying a station and making it ready to operate.
Mode AC	OPEX	€ 180K	Per unit per station yearly OPEX in FOC
Mode S	# units	46	Number of units to be installed in the Network.
Mode S	Deployment timeframe	15 years in total	In the first two years 18 units are deployed in a first wave. From 2022 onwards, the remaining 28 units are deployed. Out of the 46 units the Network needs, 24 (around 50%) are installed by 2025.
Mode S	CAPEX	€ 1900K	Per unit cost for deploying a station and be ready to operate.
Mode S	OPEX	€ 180K	Per unit yearly OPEX in FOC
MLAT	# units	72	Number of additional MLAT systems to be installed in the Network.
MLAT	Deployment timeframe	15 years in total	In the first two years 30 systems are deployed in a first wave. From 2022 onwards, the remaining 42 systems are deployed. Out of the 72 systems the Network needs, 24 (52%) are installed by 2025.
MLAT	CAPEX	€ 720K	Per unit cost for deploying a station and be ready to operate.
MLAT	OPEX	€ 95K	Per unit yearly OPEX in FOC
ADS-B	# units	82	Number of additional units to be installed in the Network.
ADS-B	Deployment timeframe	15 years in total	In the first two years 12 units are deployed in a first wave. From 2022 onwards, the remaining 70 units are deployed. Out of the 82 units the Network needs, 56 (68%) are installed by 2025.
ADS-B	CAPEX	€ 150K	Per unit cost for deploying a station and be ready to operate.
ADS-B	OPEX	€ 30K	Per unit yearly OPEX in FOC

Retrofit	CAPEX	€ 5K	The cost of equipping lower-end aircraft (e.g. GA) is estimated to be 5k€ per a/c. This value was not used in this initial version of the study. It could be used in future updates, for a scenario of equipping GA aircraft in order to extend the decommissioning of TMA radars and consequently further reduce the number of radars in the MON.

Table 18 – Cost of SUR units – Further details

D. SES and ECAC Member States



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Abbreviations

Term	Definition
ACAS	Airborne Collision Avoidance Systems
ADS-B	Automatic Dependent Surveillance - Broadcast
CAPEX	Capital Expenditure
CAT	Category (of Precision Approach – I, II or III)
CSP	Communication Service Provider
DAP	Downlinked Aircraft Parameters
DME	Distance Measuring Equipment
ECAC	European Civil Aviation Conference
EOL	End of Life
EU	European Union
FDPS	Flight Data Processing System
FMTP	Flight Message Transfer Protocol
G/G	Ground to Ground
GBAS	Ground-Based Augmentation System(s)
GNSS	Global Navigation Satellite System(s)
ILS	Instrument Landing System
IP	Internet Protocol
MLAT	Multilateration
MON	Minimal Operational Network
MS	Member State(s)
NDB	Non-Directional Beacon
NM	Network Manager
NPV	Net Present Value
OLDI	On Line Data Interchange
OPEX	Operating Expenditure
PENS	Pan European Network Service
PSR	Primary Surveillance Radar
RF	Radio frequency
RNAV	Area Navigation
RNP	Required Navigation Performance
RP2	Second Reference Period
RP3	Third Reference Period
SDM	SESAR Deployment Manager

SBAS	Satellite-Based Augmentation System(s)
SES	Single European Sky
SSR	Secondary Surveillance Radar
TLC	Through-life cost
VCS	Voice Communication System
VOIP	Voice Over Internet Protocol
VOR	Very High Frequency (VHF) Omnidirectional Range
WAM	Wide-Area Multilateration
WAN	Wide-Area Network

Table 19: Abbreviations table

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