

Annex IV to

## **Final Report**

Revision of the SPI Regulation

RMT.0679 – Surveillance, performance and interoperability  
December 2017



# **Regulatory Impact Assessment (RIA) to support the RMT.0679 – Revision of Surveillance Performance and Interoperability**

## **Final Report - Task 1**



18<sup>th</sup> April 2017

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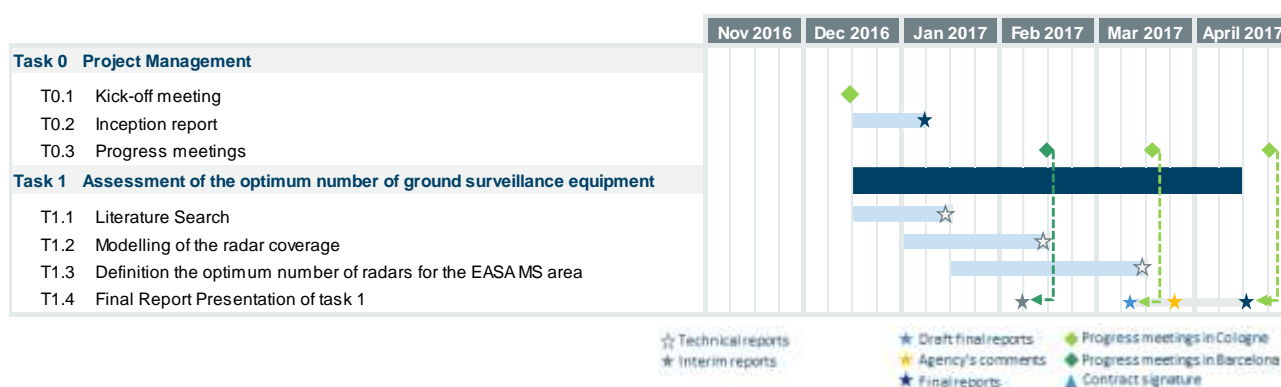


# 1 Introduction

## 1.1 Purpose and scope of the document

The present document is the Final Report of Task 1 of the contract for Regulatory Impact Assessment (RIA) to support the Rule-making Task RMT.0679 “Revision of Surveillance Performance and Interoperability”, under the Multiple Framework Contract “Support to Impact Assessment and Evaluation of EASA rules (ASSESS II)”.

Task 1 aimed at establishing a reliable, traceable and structured model to propose an optimum surveillance deployment in the EASA MS area. The agreed work flow and schedule, as presented below, aimed at producing a comprehensive review of the literature assessing the surveillance rationalisation problem, modelling radar coverage, and based on the preceding two steps, defining the optimum number of radars (or other secondary surveillance infrastructure) in the EASA MS area.



Purpose of the present report is to present the results concerning first three sub-tasks (T1.1, T1.2 and T1.3). Results in this report will also be presented in the Progress Meeting to be held in Barcelona on the 18<sup>th</sup> of April 2017.

## 1.2 Structure of the document

This document gathers the results previously presented in the interim and draft final report of this task, as well as the complete analysis regarding the optimum and current deployment of ground surveillance infrastructure.

The document is structured as follows:

- Section 2 presents the literature review covering the present and past work in terms of ground surveillance infrastructure optimum deployment and rationalisation;
- Section 3 describes the selected airspace surveillance coverage rationale and radar coverage modelling methodology;
- Section 4 provides the results of the analysis regarding optimum and current distribution of surveillance technology;
- Section 5 provides an overview of the next planned steps in the scope of Task 1 of the project

The main differences between the Draft Final Report delivered on March and the present Final Report consist on:

- The description of the terrain elevation algorithm (Section 3.2.5)
- The update of the analysis of results (Section 4) due to the removal of APP stations in the current scenario and the integration of the terrain elevation in both blank sheet and current scenarios

### 1.3 Glossary and definition of terms

Term	Meaning
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ADS-B	Automatic dependent surveillance-broadcast
CNS	Communication, Navigation & Surveillance
GASP	Global Air Navigation Plan (ICAO publication)
GMST	Guidance Material on Comparison of Surveillance Technologies (ICAO publication)
IATA	International Air Transport Association
MLAT	Multilateration
MPSR	Multi-static Primary Surveillance Radar
PSR	Primary Surveillance Radar
PVT	Position, Velocity and Time
SSR	Secondary Surveillance Radar
TMA	Terminal Manoeuvring Area
WAM	Wide Area Multilateration

*Table 1. Glossary and definition of terms*



## 2 Literature Review on Surveillance Deployment Strategies

The first step for Task 1 consists on a literature search in order perform a comprehensive review covering the present and past work in terms of ground surveillance infrastructure optimum deployment and rationalisation.

Main goal of the present search is to ensure that the rationale and the solutions proposed concerning optimization of surveillance infrastructure are relevant and taking advantage of the progress achieved by experts and organisations who have tackled this problem before.

### 2.1 Overview of surveillance technologies

Air traffic controllers need position, heading, speed and time information for the continuous management of all aircraft. To this end, today's air traffic control (ATC) systems do not rely on coverage by one single surveillance source, which directly measure the range and bearing of an aircraft from a ground-based antenna. Instead, a multi-radar picture is presented via the ATC system's display to the controller. This improves the quality of the reported position of the airplane, provides a measure of redundancy, and makes it possible to verify the output of the different radars against others. This verification can also use sensor data from other technologies, such as ADS-B and multilateration.

The following subsections provide a short overview of the main aircraft surveillance technologies currently in use and a comprehensive comparison between them.

#### 2.1.1 Primary surveillance

Primary surveillance does not require any cooperation from the aircraft, as it is active, independent and non-cooperative. Primary surveillance systems are therefore reliable sources providing a strong resilience and a high value in terms of security, and governed by a security-sensitive deployment policy of their own, which remains out of the scope of this project.

The result is a robust capability in the sense that surveillance outage failure modes are limited to those associated with the ground radar system. The single main technology for primary surveillance is the primary surveillance radar:

- The **primary surveillance radar (PSR)** usually comes in the form of a pulse radar. It transmits a continuous high power sequence of pulses. Bearing is measured by the position of the rotating radar antenna when it receives the reflected beam that comes from the body aircraft; and range is measured by the time it takes for the radar to receive the reflected beam.

#### 2.1.2 Secondary surveillance

As opposed to primary surveillance, secondary surveillance is cooperative by definition, since it relies on the collaboration of the aircraft through its on-board transponder. Moreover, different secondary surveillance technologies use dependent or independent techniques, depending on whether they actively interrogate the aircraft's on-board transponder for a response, or whether they passively received broadcasted transmissions. If switched off, it cannot provide surveillance tracking.

Primary surveillance infrastructure is commonly coupled with secondary surveillance working in close cooperation, although most secondary surveillance infrastructure is deployed on a standalone basis. A number of solutions are available and currently under deployment worldwide:

- **Secondary surveillance radar (SSR)** depends on active replies from the aircraft. Unlike primary radar systems that measure only the range and bearing of targets by detecting reflected radio signals, SSR relies on aircraft equipped with a radar transponder, which reply to each interrogation signal by transmitting a response containing encoded data. Its failure modes include the transponder aboard the aircraft.
- **Multilateration & Wide Area Multilateration (MLAT/WAM)** employs a number of ground stations, which are placed in strategic locations around airport, its local terminal area or a wider area that covers the larger surrounding airspace. These units listen for "replies," typically to interrogation signals transmitted from a local SSR or a multilateration station. Since individual aircraft will be at different distances from each of the ground stations, their replies will be received by each station at fractionally different times. Using advanced computer processing techniques, these individual time differences allow

an aircraft's position to be precisely calculated. Multilateration requires no additional avionics equipment, as it uses replies from Mode A, C and S transponders, as well as military IFF and ADS-B transponders.

- **Automatic Dependent Surveillance – Broadcast (ADS-B)** is conceived as a means to monitor and control airplanes at a significantly lower cost regarding ground stations, and with potentially larger coverage than traditional radar technology. ADS-B relies on an aircraft's automatic transmission and/or reception of traffic information to/from other aircraft and to air traffic control. The aircraft position is derived from global navigation satellite system (GNSS) data. It is therefore a means of surveillance both automatic (i. e. not requiring the aircraft crew's operation) and dependant on the aircraft's on-board equipment, the information of which is broadcast through datalink without the need for interrogation by other devices or ground stations, as is the case of secondary radar.

From a safety perspective, this introduces an additional failure mode compared to SSR and MLAT/WAM, through the reliance on the on-board Position, Velocity and Time (PVT) data source. From a surveillance quality perspective, it also means that ADS-B typically provides lower performance compared to SSR and MLAT/WAM since this is limited by the on-board PVT source. Accuracy, defined in [23] as the degree of conformity of the provided value of a data item (in this case, position or velocity) with its actual value at the time when the data item is considered, is an example of this performance decrease. As specified in [13], Mode S SSR provides an accuracy of 3.8m, while ADS-B performance in terms of accuracy is of 7.8m [24].

A number of initiatives are seeking to couple ADS-B technology to space-based communications systems, therefore enhancing coverage limited today to line of sight from ADS-B ground stations.

In terms of transmission content, secondary surveillance technologies rely on a set of standard message typologies, referred to as Modes, which standardise the content of communications between on-board transceivers and ground sensors. Traditionally, SSRs and on-board aircraft transponders have used Modes A and C, catering for limited information. In recent years, Mode S has emerged as an evolution and has been implemented in all secondary surveillance technologies, allowing, for instance, to transmit on-board determined positioning for ADS-B to simpler and lower cost ground stations.

- **Mode S** (Select) establishes selective and addressed interrogations with aircraft within its coverage, whereas traditional SSR stations interrogate all aircraft within their range. Such selective interrogation improves the quality and integrity of the detection, identification and altitude reporting.

### 2.1.3 Comparison of technologies

Table 2 summarizes the technical aspects of the ATS surveillance systems described above:

Type	Independence	Cooperation
<b>PSR</b> Primary surveillance radar	<b>Yes</b> Surveillance data derived by radar	<b>No</b> Does not depend on aircraft equipment
<b>SSR</b> Secondary surveillance radar	<b>Yes</b> aircraft range and azimuth derived by radar	<b>Yes</b> Requires aircraft to have a working SSR transponder
<b>MLAT/WAM</b> Multilateration	<b>Yes</b> Surveillance data derived by ground stations and advanced computer processing	<b>Yes</b> Requires aircraft to have a working Mode A/C transponder as a minimum
<b>ADS-B</b> Automatic dependent surveillance	<b>No</b> Surveillance data provided by aircraft	<b>Yes</b> Requires aircraft to have working ADS-B function

Table 2. Summary surveillance technology

The present analysis is restricted to secondary surveillance technologies – primary surveillance sources are above mentioned for context.

In addition to single surveillance sources, co-mounted surveillance stations are also possible:

- **ADS-B + SSR Mode S:** Various approaches can be considered to integrate an ADS-B receiver into an SSR, and different solutions are available on the market depending on the system manufacturer.
- **ADS-B + WAM:** New systems with both ADS-B and WAM capabilities can be easily achieved as both systems may use the same and single antenna, RF reception and digitisation hardware. A dual functionality of ADS-B and Multilateration ground station is a big advantage. Such a capability is recognized in Eurocae standardization documents such as ED-142. It is recognised that a WAM system may also provide ADS-B data reception and handling capability.

The International Civil Aviation Organization's (ICAO) publication Guidance Material on Comparison of Surveillance Technologies (GMST) [13] provides guidance on surveillance technology selection based on a series of criteria, including:

- Cost
- Market segment mix (nature of aircraft to be subject to surveillance)
- Airspace segregation
- Geography
- Existing telecommunications infrastructure
- Existing surveillance & ATC automation infrastructure
- Required functionality
- Ability to mandate equipage
- Airspace capacity requirements

On the one hand, in the referred document and as recognised by ICAO at ANC11, ADS-B is stated to be the *"technology of the future"* referring also that *"States will work towards its deployment but will consider alternative technology, when cost effective"*.

One other hand, the ICAO GMST document further elaborates in the comparison between SSR and Multilateration ground technology. Such analysis is performed by comparing a distribution of 9 or 7 WAM receivers to an MSSR station. In this short analysis it is assumed that only 9 multilateration ground stations are required to achieve a coverage of 200 NM in accord with a NLR report [12].

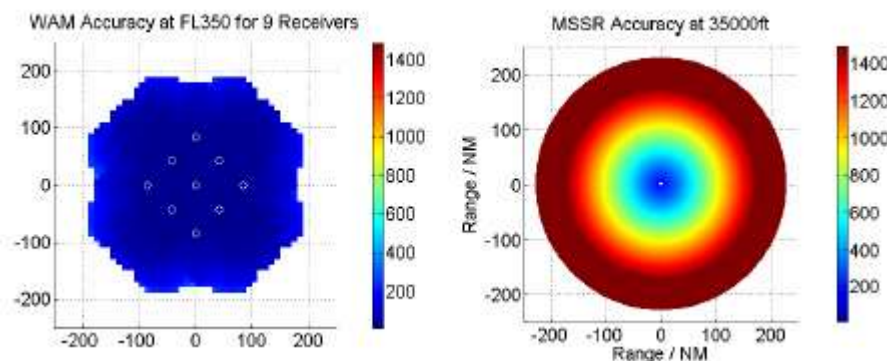


Figure 1. WAM vs. MSSR Accuracy (ft) for En-Route Applications [12]

Main conclusion outlined is that Multilateration is a stronger competitor against radar when the required area of coverage is small. Nonetheless, it is noted that each individual case must be considered because the costs are highly dependent on the environment, cost and infrastructure in the country of deployment. For these types of applications an MLAT system has the potential of providing equivalent or higher levels of service at reduced cost when compared to traditional surveillance radar system. Moreover in hardly accessible areas and/or mountain the surveillance coverage by SSR is economically inconvenient (above all for low altitude coverage).

## 2.2 Global Surveillance Deployment Guidelines

### 2.2.1 ICAO Global Air Navigation Plan

The ICAO Global Air Navigation Plan (GANP, ICAO Doc 9750 [10]) presents a framework for harmonising avionics capabilities and the required ATM ground infrastructure as well as automation. The global building blocks of this framework are the Aviation System Block Upgrades (ASBUs). The ASBUs provide a roadmap to assist ANSPs in the development of their individual strategic plans and investment decisions with a goal of global aviation system interoperability, while allowing ANSPs to advance their air navigation system based on their individual operational requirements.

The ASBUs detailed in the ICAO GANP are supplemented by Communications, Navigation, Surveillance, Avionics and Information Management roadmaps.

The surveillance roadmap indicates which surveillance techniques will be available, and at which point in time, over the next twenty years. It provides an indication of drivers for change and how the different surveillance techniques will be used over time in support of existing operational services and future improvements introduced by the ASBU as well as their timescales. Figure 2 illustrates the diagram of ground-based and surface surveillance enablers and capabilities as mapped in the Surveillance Technology Roadmap.

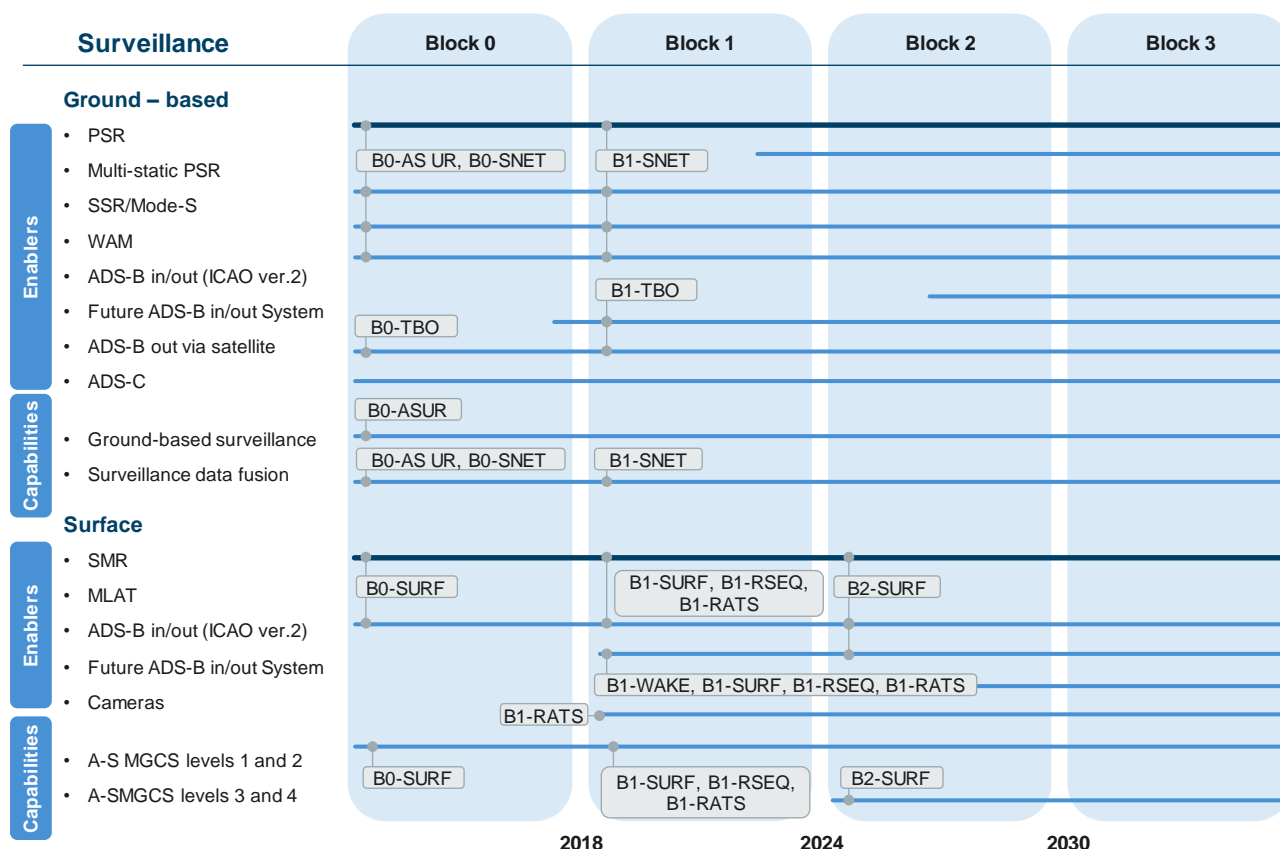


Figure 2. ICAO GASP Technology Surveillance Roadmap - Ground-based and surface surveillance components

The following points are referred in the document concerning the evolution of surveillance technology:

In the Block 0 time frame (from now until 2018):

- **There will be significant deployment of cooperative surveillance systems: ADS-B** (ground- and space-based), **MLAT**, **WAM**.
- Ground processing systems will become increasingly sophisticated as they will need to fuse data from various sources and make increasing use of the data available from aircraft.
- Surveillance data from various sources along with aircraft data will be used to provide basic safety net functions. Surveillance data will also be available for non-separation purposes.

In the Block 1 time frame (2018-2024):

- **Deployment of cooperative surveillance systems will expand.**
- Cooperative surveillance techniques will enhance surface operations.
- Additional safety net functions based on available aircraft data will be developed.
- **It is expected that multi-static primary surveillance radar (MPSR) will be available for ATS use and its deployment will provide significant cost savings.**
- Remote operation of aerodromes and control towers will require remote visual surveillance techniques, e.g. cameras, to provide visual situational awareness.
- This visual situational awareness will be supplemented with graphical overlays such as tracking information, weather data, visual range values and ground light status, etc.

In the Block 2 time frame (2024-2030):

- The twin demands of increased traffic levels and reduced separation will require an improved form of ADS-B.
- Primary surveillance radar will be used less and less as it is replaced by cooperative surveillance techniques.
- Space-based ADS-B is likely to be fully available.

Finally, for Block 3 time frame (2030+), Cooperative surveillance techniques will be dominant as primary surveillance radar (PSR) use will be limited to demanding or specialized applications.

## 2.3 European context

The current European surveillance infrastructure is mainly composed of Mode A/C Secondary Surveillance Radar (SSR), SSR Mode-S and Primary Surveillance Radars (PSRs). However, technological developments such as ADS-B and WAM have reached maturity and are being deployed across Europe. Further details about current ADS-B and WAM implementation across Europe can be found in Section 4.2.3 of this report. In parallel, new performance targets and associated operational requirements are emerging from Single European Sky (SES) and SES ATM Research (SESAR) initiatives. These factors will drive changes to the existing surveillance infrastructure.

### 2.3.1 European ATM Master Plan

Within the framework of the Single European Sky, the European ATM Master Plan represents the highest level planning document driving the implementation of the ATM target concept. It is the main planning tool for defining ATM modernisation and ensuring that the SESAR target concept becomes a reality.

In other words, the European ATM Master Plan re-interprets and expresses the SES high-level targets in the form of SES Strategic Performance Objectives. They provide the more measurable and practical long term guidance that can serve as the basis for R&D (SESAR) and long-term deployment planning.

Amongst others, the European ATM Master Plan provides a comprehensive roadmap for surveillance provision, offering a view the technology and infrastructure required to support the evolving SESAR target concept.

According to the last edition (2015) of the European ATM Master Plan, surveillance provision comprises the availability of ground sensors and surveillance data processing and distribution systems which support 3-mile and 5-mile separation requirements. Future airborne surveillance requirements will essentially be linked with the ability to extract the avionics parameters required to support applications, normally standardised by EUROCAE/RTCA, and to broadcast and receive such information.

The current surveillance infrastructure is mainly composed of secondary surveillance radar (SSR), mono-pulse secondary surveillance radar (MSSR), MSSR Mode-s and primary surveillance radar (PSR). Recent technological developments such as the emergence of automatic dependent surveillance broadcast (ADS-B) and wide-area multilateration (WAM) have reached maturity and are being deployed in many parts of the world including Europe. The European surveillance infrastructure will be provided by a mix of these surveillance techniques.

In addition to ground-based surveillance, satellite based ADS-B will become available as a source for surveillance especially in oceanic and remote areas. ADS-B will also enable the development of new airborne surveillance operational services, including air traffic situational awareness (ATSAW), and airborne separation assistance system (ASAS), such as sequencing and merging and self-separation.



Future airborne applications will require changes in the avionics (ADS-B Out and ADS-B In) to process and display the air situation picture to the pilot. A low-cost ADS-B solution for GA is to be provided.

For airports, a locally-optimised mix of the available technologies, i.e. airport multilateration, surface movement radars and ADS-B, will enable advanced surface movement guidance and control systems (A-SMGCS) and integrated airport operations. This includes the availability of surveillance information on a moving map, using a human-machine interface (HMI) in the cockpit and in surface vehicles.

A rationalised (i.e. cost-efficient and spectrum efficient) ground surveillance infrastructure can be foreseen to be gradually deployed, using the opportunities offered by new technologies. Surveillance data sharing will also contribute to reduce the number of infrastructure elements (e.g. radars) as the information (e.g. surveillance data) can be made available through ground communications networks.

The interrelation of surveillance techniques with communications and navigation will become a reality. The avionics carried on board an aircraft must become a fully integrated element of the surveillance infrastructure. The scope of surveillance systems will extend to embrace an increasingly diverse range of avionic components, such as GNSS, traffic computers and cockpit display systems, as well as transponders. SESAR Solution PJ.14-01-01, as an example, aims at identifying potential technological/functional synergies across the CNS domains to benefit from common system/infrastructure capabilities for both ground and airborne segment.

The future edition of the ATM Master Plan is planned to be released in 2018. The new version will provide inputs for worldwide guidance, specifically for the new edition of ICAO's GANP to be released in 2019. The new edition of the Master Plan will include a Critical Path description for the achievement of proposed objectives and within this activity an "Essential" summary is foreseen to be included regarding CNS rationalisation. Such should define the strategy for CNS in the medium and long term for Europe.

### 2.3.2 SESAR rationalisation strategy

Since 2012, significant progress has been made in completing the R&D activities of the first SJU work programme (SESAR 1). In recognition that the future surveillance infrastructure is to be leaner and more efficient in respect of a number of key performance indicators, the WP15.04.01 project aimed to detail a methodology that promotes a rationalisation and adaptation to the Surveillance Infrastructure.

The WP15.04.01 final report [5] summarises the drivers for change that are foreseen to influence the European surveillance infrastructure and proposes a roadmap of how the changes will influence the evolution of the infrastructure. The roadmap can be used as a contributor when considering means for rationalisation of an ANSPs surveillance infrastructure or when assessing the surveillance specific aspects of higher-level strategic documents such as the 'European ATM Master Plan' and the 'Strategic Guidance in Support of the Execution of the ATM Master Plan' and for compiling an ANSPs local surveillance plans.

The rationale behind the roadmap is to present the evolution of a surveillance infrastructure capable of meeting the requirements stemming from SESAR and known and predicted changes to the operational requirements.

The target is met by "combining a layer of ADS-B with a layer of secondary surveillance (provided either by SSR Mode S or WAM). Primary radar coverage will also be available, where required (e.g. for safety or security reasons), either by classic (mono-static) PSR or possibly in the form of multi-static PSR (MSPSR)."

The surveillance roadmap proposed details the foreseen availability of surveillance techniques and how they will be deployed within Europe over the next 20 years. It shows the evolution of the different surveillance techniques which may be used to support different surveillance applications used within TMA and En-Route airspace including ground based surveillance of aircraft and airborne surveillance of other aircraft.

The key objectives the roadmap is designed to achieve include:

- The retention or deployment of a ground surveillance infrastructure supporting safety performance requirements
  - Achieved through the development (if necessary) and deployment of modern surveillance systems such as Mode S, WAM, ADS-B Out and MSPSR.
  - Ground based surveillance in en-route and terminal areas with continuity of service being provided by at least 2 parallel layers of cooperative surveillance. Towards the end of Phase 1

(Today until 2020) it is anticipated that ADS-B RAD type applications will form a ‘stand-alone’ layer of surveillance to replace a single layer of cooperative surveillance. Where there is a need for non-cooperative surveillance to address safety or security concerns, it would initially be met by conventional PSRs although once developed and validated it could be fulfilled by Multi-static PSR (MSPSR) – where siting and system constraints support a technical and financially viable solution. The local surveillance infrastructure would be an optimal mix of the techniques to meet local requirements.

- In general, the optimal mix of the various surveillance techniques depends on the local environment, operational needs and business case from an overall ATM Network viewpoint. This will allow a smooth transition path from short term (radar like) surveillance system in a mixed equipage environment to the future high performance, rationalized and interoperable surveillance system.
- The deployment of Wide Area Multilateration system (WAM) provides surveillance in volumes of airspace not suited to the use of conventional surveillance systems as well as supporting the future evolution towards ADS-B. WAM ground station receivers can, and often do, incorporate ADS-B ES receiver functionality as a stand-alone channel. In 2012 EUROCAE WG51 SG 4 was established to support the exploitation of the synergies and potential benefits of merging the two techniques, cross sharing of data and common utilisation of hardware. The deployment of an infrastructure based upon a composite ADS-B/WAM configuration thus provides an independent position of the aircraft based upon multilateration techniques and also a dependent position based upon ADS-B ES.
- Rather than providing the principal source of surveillance data for separation services independent non-cooperative surveillance is foreseen to continue to provide safety mitigation against intrusion by aircraft that are not equipped with SSR transponders or experiencing an avionic failure.
- To enable the SESAR objectives for airborne surveillance including an improved situational awareness by aircrew of aircraft in their proximity and a phased introduction of ASAS applications,
  - Achieved through the widespread deployment of ADS-B Out and ADS-B In.
- To support a cost-efficient RF Spectrum strategy for surveillance including the long-term viability of the 1090 MHz datalink, thus obviating the need for a costly and technically complex second data link
  - Achieved through a rationalisation of the surveillance infrastructure and the introduction of spectrum efficient mechanisms supporting ACAS and airborne and ground-based surveillance.
- To ensure the availability of surveillance techniques that support a reduction in the cost of providing surveillance services.
  - Achieved through data sharing and the deployment of cost-efficient surveillance techniques.

In 2014, in recognition of the need for sustained R&D investment, the mandate of the SJU was extended and SESAR 2020 was launched. This latest programme addresses further several key areas of ATM, as well as new challenges, changing markets and the need for continuous and coordinated investment.

According to [14], in SESAR 2020 the following solutions will continue investigating optimum surveillance deployment:

- **SESAR Solution PJ.14-01-01:** CNS environment evolution - This SESAR Solution aims at identifying potential technological/functional synergies across the communication, navigation and surveillance domains to benefit from common system/infrastructure capabilities for both ground and airborne segment. The goal is to evaluate and define evolutionary steps towards an efficient and reliable integrated CNS provision. This project will produce a feasibility study for ground and airborne segment optimization
- **Solution PJ.14-04-02:** Surveillance Performance Monitoring
- **SESAR Solution PJ.14-04-03:** New use and evolution of Cooperative and Non-Cooperative Surveillance.

### 2.3.3 EUROCONTROL standards and surveillance modernisation

ICAO documentation specifies accuracy and latency requirements to apply 5 NM or 3 NM ATS surveillance separation minima. In general, however, more detailed surveillance performance requirements are specified at the regional or national level, such as the following documents that detail ATM system and performance requirements for the application of ATS surveillance separation and services:

- EUROCONTROL Standard Document for Radar Surveillance in En-Route Airspace and Major Terminal Areas. This document, published in 1997, sets out the prescriptive requirement for ANSPs to maintain duplicate SSR radar coverage in en-route airspace (supporting application of 5 NM separation) and to maintain duplicate SSR coverage and single PSR coverage in major terminal areas (supporting application 3 NM separation).
- EUROCONTROL Specification for ATM Surveillance System Performance (ESASSP): This document, consisting of two volumes, provides performance requirements for ATM surveillance systems when supporting 3 NM and 5 NM separation applications.

Currently, EUROCONTROL's Surveillance Modernisation Unit activities focus on promoting performance-based modernisation and the rationalisation of the European ATM Network's surveillance.

It covers both ground surveillance (such as SSR, ADS-B and WAM) as well as airborne surveillance applications. It supports short-term implementation as well as longer-term SESAR projects. It works actively to ensure global interoperability.

According to EUROCONTROL [16], significant modernisation of the European surveillance infrastructure has taken place over recent years, addressing both surveillance applications and infrastructure. A rapid transition from radars-only to multiple types of sensors is in progress, including the implementation of dozens of multilateration systems and over 750 ADS-B ground stations in about 25 European States. Surveillance modernisation in Europe follows two paths:

- Implementation of ADS-B sole means or with multilateration in non-radar airspace, using current (certified) equipment on thousands of aircraft.
- Implementation of Multilateration/ADS-B systems in radar airspace, in which multilateration is used first, to be followed by the additional use of ADS-B. The latter requires enhanced ADS-B avionics and will be driven by the SPIR EU Regulation No 1207/2011 and its ongoing amendment.

## 2.4 European Regulation – Update of SPI IR and industry position

The European Commission has published Regulations laying down requirements for the performance and the interoperability of surveillance for the Single European Sky. These regulations are the following:

- Commission Implementing Regulation (EU) No 1207/2011, published on 22/11/2011;
- Commission Implementing Regulation (EU) No 1028/2014, published on 26/09/2014, amending EU Regulation 1207/2011.

These regulations are based on the EC Airspace Regulation No 551/2004 and explicitly stipulate mandatory milestones comprising the implementation of ADS-B airborne capability on new-build aircraft and the upgrading and retrofitting of such equipment in previous-build examples.

They also apply to all aircraft conducting flights as IFR/GAT and cover the different segments in civil and state aircraft, ranging from light vehicles to high performance, high MTOM aircraft. Nevertheless, such regulations may be subject to additional provisions under local mandates in order to extend ADS-B applicability to a wider fleet.





*Figure 3 - SPI IR implementation timeline for ADS-B across aircraft types*

**Registered civil aircrafts** operating IFR/GAT in Europe and with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots are required to carry and operate ADS-B 1090MHZ Extended Squitter (ES) capabilities. The applicability dates for this requirement are:

- 8 June 2016 for “new” aircraft, i.e. aircraft with an individual certificate of airworthiness first issued on or after 8 June 2016
- 7 June 2020 for aircraft with an individual certificate of airworthiness first issued before 8 June 2016

These applicability dates may be modified through the revision of the SPI Regulation that is currently being performed under the RMT.0679.

**All fixed wing transport-type State** aircraft operating IFR/GAT in Europe and with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots are required to carry and operate ADS-B 1090MHZ Extended Squitter (ES) capabilities by 7 June 2020.

Certification of an aircraft against EASA Certification Specification and Acceptable Means of Compliance for Airborne Communications, Navigation and Surveillance (CS-ACNS) is a mean for an aircraft operator to demonstrate that the aircraft complies with the Commission Implementing Regulations. CN-ACNS are the main element of the soft law accompanying the SPI IR. This piece of regulation includes the ETSO standards of the data sources which qualify for ADS-B.

It is to be noted that in addition to the requirements related to airborne surveillance systems outlined above, the Regulations also include requirements for the ground-based surveillance systems, surveillance data processing systems, and ground-to-ground communications systems used for distribution of surveillance data.

## 2.4.1 Background

Commission Implementing Regulation (EU) No 1207/2011 of 22 November 2011 is considered a significant enabler for improved surveillance performance and increased safety in the European ATM network, and while it addresses both air and ground environment, most of the specific obligations are addressed to operators of aircrafts.

During SSC53 meeting, and building on the outcome of the SPI Workshop of 7 March 2014, the Commission presented a two-step approach for the needed revision of the SPI Regulation. This two-step approach consisted:

- **Step 1:** to change the airborne requirements of the Regulation in order to gain time for the review of the scope and impact of the Regulation. This was achieved concretely by amending Regulation (EU) No 1207/2011 and “pushing back” the main application dates for the airborne equipment:
  - Move the “forward” fit date for Annex II Part B and Part C : from 8 January 2015 to 8 June 2016
  - Move the “retrofit” date for Annex II Part B and Part C (including for state aircraft where relevant) : from 7 December 2017 to 7 June 2020
- **Step 2 :** to “review” and “re-assess” the scope and expected impacts (including cost/benefits) of the regulation:
  - The review would notably look elements such as a possible extension of the mandate of the regulation to other aircraft types (and notably General Aviation), on the clarifications of the exemption conditions, on a clarification and possible review of the obligations of the ANSP's, on the introduction of monitoring and deployment provisions, and other additional legal clarifications.
  - The review should be the subject of a new impact assessment (incl. cost/benefit analysis) addressing all possible modifications.
  - The review should also consider possible new required incentives or enforcement means.

As described in the previous section, following the positive opinion of the SSC at its 54th session, the Commission implemented Step 1 of this two-step approach by adopting on 26 September 2014 the Commission Implementing Regulation (EU) 1028/2014.

For Step 2, the Commission tasked the SJU to carry out, as an initial stage of the Step 2 review, a preliminary study, within the remit of the SESAR technical expertise on surveillance and ensuring the

involvement and support of the SJU AU group, to prepare the ground for the needed evolution of Commission Implementing Regulation (EU) No 1207/2011. The focus of this preliminary study analysis was on:

- Building a vision or strategy for the future surveillance capability (using SESAR 15.4.1 D10 deliverable as a baseline)
- Establishing a common understanding of what we want to achieve in the regulation (strategic objectives and scope)
- Establishing a more performance-based approach for the Surveillance regulation.

The SJU concretely proceeded with an initial review of available material, a workshop and consultation with SESAR members involved in surveillance and other stakeholders (especially airspace users) and a consolidation phase of the report.

## 2.4.2 Step 2 - SJU preliminary study

The SJU preliminary study was intended to provide material in support of the way forward for the Step 2 review of the SPI in order to establish a new surveillance regulation that meets the strategic needs of the European ATM system for a surveillance capability which also enables the implementation of improvements in line with the European ATM Master Plan.

It provides a consolidated SESAR input to be considered as a technical basis for the ongoing review of the SPI IR to be carried out by the Commission in 2015.

According to this study, the main drivers for change in the European surveillance infrastructure would be the need to fulfil surveillance performance requirements; the possibility to reduce costs, and the need to address the congestion of 1030/1090 MHz band used for surveillance. This could be achieved by implementing a target surveillance system which would be *"combining a layer of ADS-B with a layer of secondary surveillance provided either by SSR Mode S or WAM"*. Primary radar coverage will also be available, where required (e.g. for safety or security reasons), either by classic (mono-static) PSR or potentially in the form of multi-static PSR (MSPSR) once this is mature. It is also possible that aircraft ADS-B transmissions could be relayed to the ground via satellite. This would provide improved surveillance in Oceanic and Remote areas." This view is confirmed by the SESAR step 2 CONOPS where the future surveillance is described as the following:

*"Surveillance is foreseen to remain a mix of SSR Mode S, Wide Area Multilateration (WAM) as independent surveillance, ADS-B Out for dependent surveillance and PSR (including MSPSR) where required for security reason."* More importantly a surveillance infrastructure designed and implemented at the European level rather than national-level deployments could lead to a significant rationalization in cost and spectrum while still delivering the required performance as long as the level of surveillance system performance can be assured. *Any regulatory approach should consider the need to ensure this European level approach.*

The study finally addresses the main identified regulatory options to support the implementation of such "ideal" surveillance infrastructure:

- Option 1: cancelling (repealing) the SPI Regulation
- Option 2: keeping the SPI Regulation as it is
- Option 3: moving from the current SPI mandate with ADS-B Out to an ADB-In mandate
- Option 4: replacing current "equipment" based mandate to a " 'pockets' of airspace based " mandate
- Option 5: evolve to a "Universal Ground and Aircraft System" mandate, i.e. full ADS-B Out coverage
- Option 6: establish, in addition to any of the previous options, an overarching "Surveillance Performance framework"

Initial feedback from various stakeholders is shared in the study which however falls short of providing specific recommendations on the way forward.

In the light of the previous considerations, the Commission proposed the following actions:

- To organise a stakeholder workshop to present and discuss the outcome of the SJU study (21 April 2015)
- On the basis of the SJU SPI study and the outcome of the planned workshop, to launch the new regulatory process (NPA under EASA) for the revision/update of the SPI Regulation

### 2.4.3 RMT.0679

During the debates at the workshop held by the Commission (21 April 2015), it was evident that building an efficient surveillance network is of paramount importance for the safety and efficiency of the single European sky. As a result several key areas have been identified which form the basis of what **RMT.0679** rulemaking task should address. These key areas that need to be addressed are:

- Performance: surveillance systems and infrastructure need to ensure that surveillance capability can continue to fulfil its role as the operational environment evolves in line with the 'European ATM Master Plan 2015'. The system performance needs to reflect the services being provided.
- Spectrum protection/rationalisation: ATM is required to improve the manner in which the radio frequency (RF) spectrum currently assigned to it is managed and used.
- Cost rationalisation: keeping the costs to a minimum and maximising the benefits is a key consideration, the use of systems with lower procurement and maintenance costs could result in significant savings if deployed in a coherent manner.
- Interoperability: the interoperability between ground-ground, airborne-ground and airborne-airborne systems needs to be ensured.
- Safety: the required performance whilst maintaining or enhancing safety needs to be ensured.

### 2.4.4 Industry position

The International Air Transport Association (IATA) has stated from as early as 2007 [15] that, where justified by operational and business cases, air traffic control using ground radar surveillance should migrate in some layers to ADS-B (Out). Specifically, IATA supports the following key strategies:

- ADS-B (Out) based on Mode-S Extended Squitter (1090ES) is the preferred surveillance technology to replace or supplement radar
- Airlines continue to equip their aircraft with ADS-B (OUT) capability
- Where justifiable by operational/ business cases - ANSPs should replace ground surveillance radar with ADS-B (OUT)
- New surveillance implementations should prioritize ADS-B OUT or Multilateration - over conventional radar
- ATS ground systems should continue to process valid DO-260 and DO-260A and DO-260B based ADS-B

On the other hand, throughout the regulation update process and upon establishment of RMT.0679, a number of industry representatives have expressed their opinion on the SPI IR.

The **Industry Consulting Body (ICB)** [17] agrees that the target surveillance end-state is best described by the 'Evolution of the Surveillance Infrastructure', the SESAR document that details a technology roadmap leading up to 2030. The target is met by *"combining a layer of ADS-B with a layer of secondary surveillance (provided either by SSR Mode S or WAM). Primary radar coverage will also be available, where required (e.g. for safety or security reasons), either by classic (mono-static) PSR or possibly in the form of multi-static PSR (MSPSR)." The ICB supports this target, whilst acknowledging that re-validation is needed through a detailed cost-benefit analysis and recognising the need to develop a transition plan towards the target. The target does not extend to surface operations.*

ADS-B is deemed by **EAS (Europe Air Sports**, who represents some 650,000 sports and recreational pilots across the European ECAC area) [18] as a *"complementary surveillance means to provide surveillance in remote or mountainous areas without radar coverage"*. In addition, it is stated that *"it has to be considered as a technology which will allow a multi-source surveillance, not as the successor of the PSR and SSR technologies"*. As a result, Mode S transponders will continue to contribute to radar detection and surveillance service.

The position paper published by **EBAA, ECOGAS, ERAC, GAMA, and IAOPA** [19] emphasizes the need to clarify ANSP obligations. In order to assure ADS-B equipage can achieve all of the potential benefits, a cohesive ground implementation is required. It is stated that *"ANSPs must implement ADS-B by 2018 within the current mandate, to support an expectation that the ground infrastructure must be working and in place before aircraft are required to carry this equipment"*. It is critically important that in doing this, ADS-B is integrated into the air traffic management process and a uniform and integrated level of ADS-B ground coverage is already in place across Europe.

To assure ANSPs can meet obligations vis-à-vis a uniform and integrated level of ADS-B ground coverage across Europe, the by EBAA, ECOGAS, ERAC, GAMA, and IAOPA position paper reinforces that it would be appropriate to include a detailed review of implantation as the next steps in the SPI plan are reviewed. This review should also address the surveillance responsibilities and rules depending on use within both controlled and uncontrolled airspace.

## 2.5 Conclusions

As mentioned at the beginning of the present section, the main goal of the present literature search is to ensure that the rationale and the solutions proposed concerning optimization of surveillance infrastructure are relevant and taking advantage of the progress achieved by experts and organisations who have tackled this problem before.

In summary, there is a worldwide trend, and a strong agreement in Europe in particular, to recommend an optimum combination of different surveillance technologies as part of a coherent, safe and cost-efficient surveillance strategy. Perhaps the best specific proposal is that put forward by the European ATM community through SESAR, recommending a mix of secondary cooperative surveillance in the form of a continuous airspace user-dependent layer of ADS-B, complemented by an additional layer of independent Mode S SSR or WAM. This combination of two cooperative surveillance layers is to be supplemented, where necessary, with a layer of independent surveillance composed of PSR or multi-static PSR.



Figure 4. SESAR Surveillance infrastructure strategy [11]

The main motivation for such combination, to be applied in both en-route and terminal airspace, resides in the need to leverage the strengths of each asset, while at the same time make up for their shortcomings:

- Secondary surveillance is cooperative by definition, since it requires, at least, an aircraft's identification via its on-board transponder.
  - This renders it complementary to primary surveillance, which does not require any cooperation to obtain a hit, but is blind as to the identity of the hit, something that is only known through identification through cooperative surveillance.
  - Moreover, primary surveillance provides continuous standalone awareness in critical airspace (such as terminal areas or security-critical regions) to make up for the possible loss of aircraft on-board transponder, which would render all secondary surveillance useless.
- In turn, secondary ground surveillance can be made less technically sophisticated, and therefore less costly, by fully relying on the airspace user for position determination and reporting.
  - This sub-class of dependent secondary surveillance, represented by ADS-B, is a cost-effective candidate, attractive for universal deployment even in remote areas with very low traffic.
  - However, it introduces an additional level of vulnerability on top of the transponder through the use of on-board PVT data sources. This means that any two ADS-B stations would be affected by the same malfunction of on-board avionics, failing to provide meaningful redundancy.
  - Moreover, ADS-B's performance is constrained by that of the on-board PVT source, which would typically underperform independent secondary surveillance.
- Other secondary surveillance sources, i.e. SSR and WAM, are not affected by ADS-B's weaknesses, since these are active technologies continuously sending out interrogations which are then responded to by aircraft. In addition, both SSR and WAM rely on themselves to determine the PVT data of the airspace user in question. This is accomplished via multilateration of four or more stations in WAM, and through mechanical steering and time-difference computation in SSR.

- Additionally, the fact that WAM relies on distant ground stations multilaterating the position of any aircraft within range means that a comprehensive network will provide higher redundancy in case of malfunction in one station, as well as the possibility to tailor deployments in mountainous regions so long as four or more stations remain within direct line-of-sight at any time.

In line with the SPI IR regulation for avionics and European surveillance infrastructure guidelines, the need for consideration of a complete ADS-B reception coverage layer is clear. On the other hand, the criterion for selection between SSR Mode S and WAM is more complex. Assuming similar performance by both technologies, several factors might be taken into account:

- SSR systems have formed the backbone of ATC for many years, and SSR Mode S ground stations are now deployed across many European states. Nonetheless, the deployment of such systems has taken place in many areas of Europe, providing surveillance in volumes of airspace where other forms of conventional surveillance were neither viable nor cost effective.
- The analysis performed in ICAO Guidance Material on Comparison of Surveillance Technologies [13] concludes that multilateration is a stronger competitor against radar when the required area of coverage is small
- SESAR P15.04.01 final report indicates that an area in which MLAT/WAM offers a significant advantage over 'rotating' surveillance sensors is the possibility for a much increased update rate. Such functionality is especially beneficial to ATC monitoring manoeuvres during approach.
- MLAT/WAM provides surveillance through a network of small sensors and much easier to install around airports in mountainous areas and even on mountain tops.

As such, the proposed coverage rationale guidelines for the present surveillance infrastructure optimisation analysis are the following:

- As described by international guidelines, all airspace considered in the analysis shall be covered by a layer of ADS-B coverage
- In addition, As described by international guidelines, all airspace considered in the analysis shall be covered by a layer of either SSR Mode S or MLAT/WAM coverage
  - MLAT/WAM shall be the preferred option for the busiest Terminal Manoeuvring Areas (TMAs)
  - MLAT/WAM shall be the preferred option for mountainous regions
  - Where MLAT/WAM is not the preferred option, deployment of SSR Mode S shall be considered

Such proposed assumptions are the key basis for definition of the scenarios of optimum future deployment and rationalisation activities concerning surveillance infrastructure for the present assignment, and as such shall be carefully reviewed and approved by EASA.



### 3 Modelling of Radar Coverage

The analysis of surveillance deployment and coverage in Europe strongly relies on the accurate definition of optimum deployment scenarios and on the development of a an adequate modelling tool portraying Mode S SSRs, MLAT/WAM and ADS-B additive effective coverage, resulting in the compound surveillance coverage in the EASA MS area. The top-level scenarios defined for the present analysis are the following:

1. **Blank sheet scenario:** A “blank sheet” scenario will be assessed, where current surveillance deployment will be disregarded, and a fully new configuration, driven only by efficiency and high-level safety and performance coverage requirements, will be proposed from scratch.
2. **Realistic scenario:** The current surveillance infrastructure deployment in EASA MS area will be modelled, assessing current surveillance redundancy.

Following the literature search previously presented, the present section details the airspace coverage rationale and modelling methodology for the surveillance deployment analysis. Finally, the results of the analysis are presented. As agreed in the project inception report and KOM, the following factors are taken into consideration:

- The analysis performed in this step is at **high strategic level** and at pre-feasibility stage, and shall not be taken as an exact roadmap for deployment, but rather as an acceptable estimate.
- The assumed **surface area covered by each ground station** will be assessed through the typical effective range for acceptable performance – Nominal coverage assumptions are described in section 3.2.
- Additionally, a **single, harmonised and interoperable surveillance framework** will be assumed, thereby eliminating any national boundaries or non-operational considerations which may have constrained the current deployment of ground surveillance, resulting in inefficiencies and high redundancies – States considered in the analysis are listed in section 3.1.2.
- No ground-ground infrastructure and associated costs are considered in the scope of the present analysis.
- No emerging technologies (such as SBAS or space-based ADS-B) are considered in the scope of the present analysis.

#### 3.1 Airspace surveillance coverage rationale

There are a number of key questions to be taken into account when proposing an airspace surveillance coverage rationale at a continental scale. In the present section, the rationale concerning the surveillance technology selected is first described. Then, the geographic scope of the analysis, 2D coverage visualisation and nominal coverage assumptions are detailed. Finally, the rationale for the different scenarios considered is described.

##### 3.1.1 Surveillance technology rationale

Following the conclusions outlined in previous section 2.5, the following surveillance technology rationale for optimisation will be considered for the present surveillance deployment analysis.

- All airspace considered in the analysis shall be ultimately covered by a layer of ADS-B coverage
- In addition all airspace considered in the analysis shall be ultimately covered by a layer of either SSR Mode S or MLAT/WAM coverage
  - MLAT/WAM shall be the preferred option for busiest TMAs
  - MLAT/WAM shall be the preferred option for mountainous regions
  - Where MLAT/WAM is not the preferred option, deployment of SSR Mode S shall be considered
- No co-mounted installations are considered for optimization (ADS-B + SSR, ADS-B + WAM ground stations)
- Primary surveillance coverage is out of the scope of the present analysis and shall therefore not be considered for surveillance infrastructure optimization scenarios

Such proposed assumptions are the key basis for definition of the scenarios of optimum future deployment and rationalisation activities concerning surveillance infrastructure for the present assignment, and as such shall be carefully reviewed and approved by EASA.

### 3.1.2 Geographic scope

The geographic scope of the analysis is restricted to the EASA member states (MS) area. These are listed in Table 3.

Countries considered in surveillance coverage analysis - EASA Member States		
Austria	Norway	Italy
Bulgaria	Portugal	Liechtenstein
Cyprus	Spain	Luxembourg
Denmark	Switzerland	Netherlands
Finland	Belgium	Poland
Germany	Croatia	Romania
Hungary	Czech Republic	Slovenia
Ireland	Estonia	Sweden
Latvia	France	United Kingdom
Lithuania	Greece	
Malta	Iceland	

Table 3. Countries considered in the analysis

More specifically, the analysis targets the land (mainland and insular) within the metropolitan European flight information regions (FIRs), since these are the airspace regions where ATC ultimately requires real time, high performance surveillance data.

However, the analysis is also constrained by the inherent limitations of land-based surveillance infrastructure, i.e. the impossibility to fully cover some airspace regions within the designated FIRs due to the need to base surveillance infrastructure on dry land. This fact hinders the capacity to provide full continuous coverage in some oceanic areas.

Nevertheless, the above limitation exists today through the use of the same technology subject to the same sort of limitations. As a result, the outcome of the analysis is considered valid even if insurmountable surveillance gaps exist in specific oceanic sectors within FIRs. Moreover, it is common practice to use other lower performance surveillance solutions in these areas, such as FANS or other data link communications systems, provided that separations are adequate and significantly greater than in fully ground surveillance-covered sectors.

#### Specific areas – High density TMAs

Part of the defined airspace coverage rationale indicates that “MLAT/WAM shall be the preferred option for busiest TMAs”. In the European ATM Master Plan portal [22], European TMAs listed are classified according to their complexity using as an indicator their 2012 traffic capability as follows:

- Low-Complexity TMAs handle less than 30 movements in peak hour;
- Medium-Complexity TMAs handle between 30 and 60 movements in peak hour;
- High-Complexity TMAs handle more than 60 movements in peak hour.

The following 18 TMA's are a given a score of high-complexity, under no specific order:

- (EBBR) Brussels Approach
- (EDGG) Langen
- (EDMM) Munchen TMA
- (EGCC) Manchester Approach
- (EGSS) Stansted Approach
- (LTBA) Istanbul Approach
- (EGTTTMA) London TMA
- (EHAM) Amsterdam Approach
- (EKCH) Copenhagen Approach
- (ENOS) Oslo TMA
- (LEBL) Barcelona TMA
- (LTBJ) Izmir Approach
- (LEMD) Madrid Approach
- (LFFF) Paris TMA
- (LKPR) Praha Ruzyně Approach
- (LOWW) Wien Approach
- (LTAI) Antalya Approach
- (UKBV) Kyiv Terminal Control

On the other hand, the 2015's Performance Review Report (PRR) [21] published by the Performance Review Commission provides traffic information on the busiest European airports. Figure 5 illustrates average daily traffic at top 30 European airports.

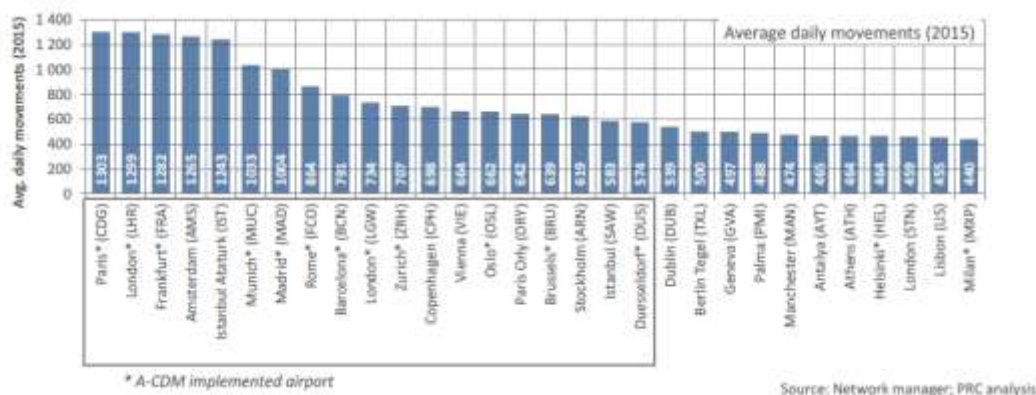


Figure 5. Average daily traffic at top 30 European airports [21]

Through the combination of both above mentioned sources, for the present analysis the following airports and associated TMA are considered as high complexity within EASA Member States to be taken into account for MLAT/WAM deployment:

- Paris TMA (CDG airport)
- London TMA (LHR airport)
- Langen TMA (FRA airport)
- Amsterdam Approach (AMS airport)
- Munich TMA (MUC airport)
- Madrid Approach (MAD airport)
- Rome (FCO airport)
- Barcelona TMA (BCN airport)
- Zurich (ZRH airport)
- Copenhagen Approach (CPH airport)

### Specific areas – Mountainous regions

Part of the defined airspace coverage rationale indicates that “MLAT/WAM shall be the preferred option for mountainous regions”. Europe’s largest mountain ranges are the following:

- Ural Mountains, which form the boundary between Europe and Asia
- Caucasus Mountains, which also separate Europe and Asia
- Carpathian Mountains, a major mountain range in Central and Southern Europe
- Alps, in Central Western Europe
- Apennines, which run through Italy
- Pyrenees, the natural border between France and Spain
- Cantabrian Mountains, which run across northern Spain
- Scandinavian Mountains, a mountain range which runs through the Scandinavian Peninsula, includes the Kjølén mountains
- Dinaric Alps, a mountain range in the Balkans
- Balkan Mountains, a mountain range in central Balkans
- Scottish Highlands (including the Cairngorms) in the United Kingdom

From the above, the following are located within EASA Member States and are chosen to be considered in the analysis as mountainous regions to be taken into account for MLAT/WAM deployment:

- Scandinavian Mountains
- Carpathian Mountains
- Alps
- Pyrenees
- Balkan Mountains

### 3.1.3 Projection considerations

Selection of the 2D environment onto which project surveillance coverage and perform optimum coverage performance is required. A map projection is one of many methods used to represent the 3-dimensional surface of the earth or other round body on a 2-dimensional plane. Due to the large geographic scope of the present analysis, appropriate selection of map projection to work on is of high importance.



After consideration of different options the Mercator projection was selected as a starting point for the analysis, due to its property of angle conservation – as such, circles maintain their circular shape upon 2D projection. In this projection the meridians are equally spaced, parallel vertical lines, and the parallels of latitude are parallel, horizontal straight lines, spaced farther and farther apart as their distance from the Equator increases. An illustration of the Mercator projection is displayed in Figure 6 below.

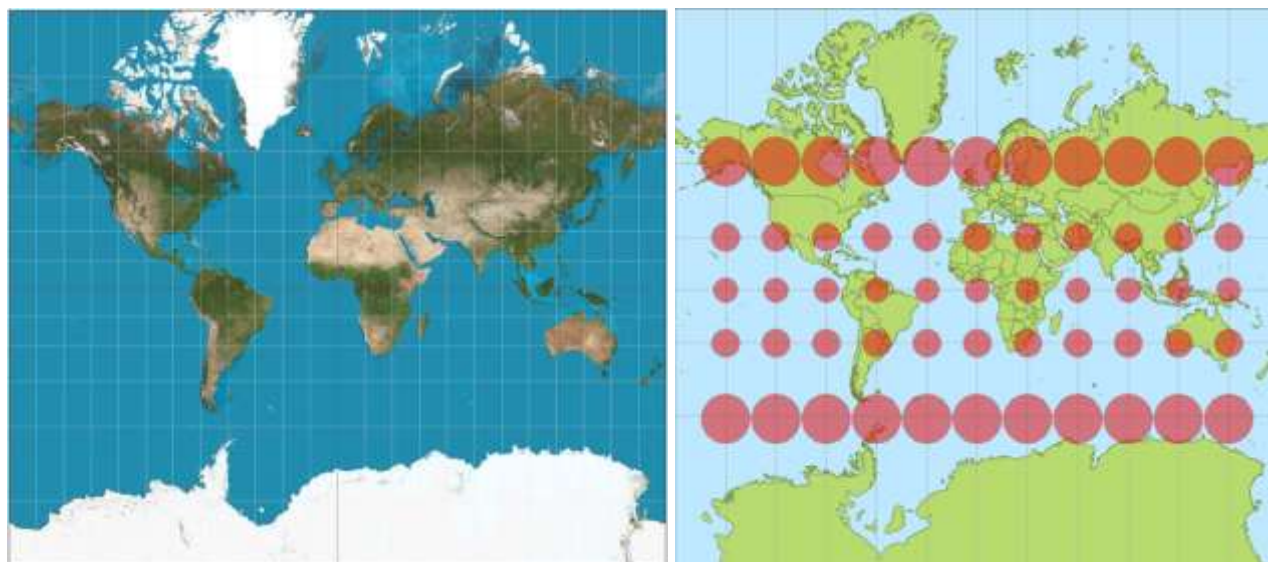


Figure 6. Left: Mercator projection of the world between 82°S and 82°N; Right: Tissot's indicatrices on the Mercator projection, representing a circle of constant radius at different locations [20]

### 3.1.4 Nominal coverage assumptions

When considering nominal coverage assumptions for surveillance infrastructure deployment, one must take into account factors such as the altitude at which the system is installed, the direct line of sight from the considered location and the radiation pattern of the antenna being used. In the scope of the present high-level surveillance coverage analysis, a set of assumptions are outlined to avoid complex considerations:

- One single nominal coverage radius must be assumed for each surveillance type (ADS-B, Mode S SSR, WAM) and flight level (FL180, FL300, FL350) independent of ground station location
- Assumptions must be based on worst case (most conservative) scenario, to ensure full coverage in any case

The following subsections detail the defined assumptions for the different surveillance technology types, based on industry consultation.

#### 3.1.4.1 Mode S SSR

Due to the rotation speed of the radar antenna, the maximum detection range of typical en-route SSR ATS surveillance systems is 463 km (250 NM). To perform initial estimates (worst case) of standard radar coverage range charts (Blake charts) as the one illustrated in Figure 7, and the vertical diagram of the antenna, are used. The worst case is that the antenna is at an altitude below 50m at sea level, so the range is always estimated as "better than" or "greater than", as normally the actual location altitudes higher are and therefore the range is also higher.

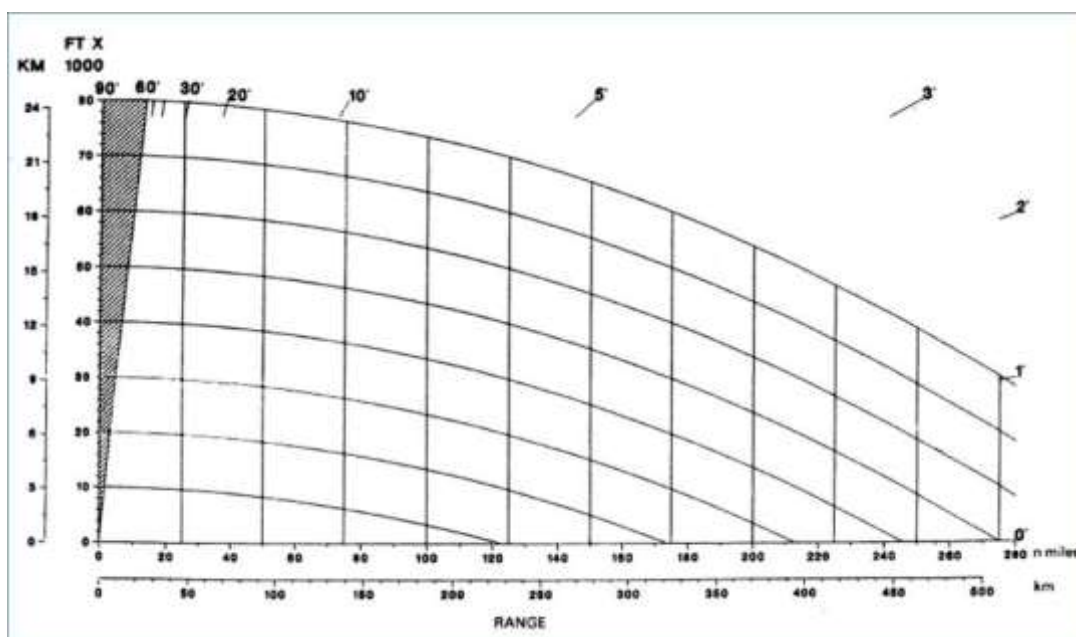


Figure 7. Blake chart of standard SSR antenna

Following the above mentioned rationale, for the case of Mode S SSR technology the analysis is straightforward, as its maximum reach of 256NM is established by ICAO.

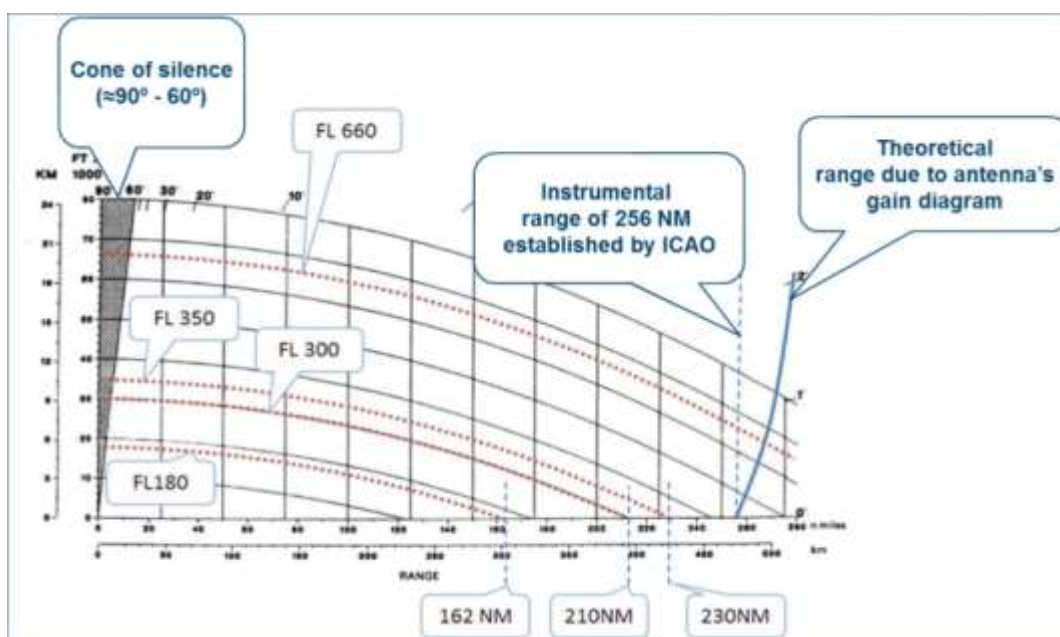


Figure 8. Blake chart of standard SSR antenna - interpretation

The limitations of the SSR at different levels of flight are by direct line of sight and by the cone of silence of the antenna. Final assumed coverage radius is shown in Table 4.

Flight Level	Corresponding coverage radius
FL180	162 NM
FL300	210 NM
FL350	230 NM
=>FL430	256 NM

Table 4. Assumed nominal operating coverage radius of a generic SSR station

### 3.1.4.2 ADS-B

For an ADS-B system, there are no direct line-of-sight limitations at the indicated levels (FL180, FL300 and FL350) and the range is only limited by an estimated operating range of about 150 NM. There is therefore no direct line-of-sight limitation from FL140 on. For lower flight levels, there would be limitation by line of sight (in an obstacle free space).

Flight Level	Corresponding coverage radius
=>FL140	150 NM

Table 5. Assumed nominal operating coverage radius of a generic ADS-B station

### 3.1.4.3 MLAT/WAM

The case of WAM is more particular, since its coverage depends on the deployment topology of the stations, and there is no straightforward “centre” from which to define a nominal coverage radius. The more separate the receiving stations, the greater the range, to the extent that the S/N ratio prevents multilateration of the signals. As a limit of operational coverage one can estimate about 120 NM from the outermost stations (perimeter) of the WAM system. So, as in an ADS-B station (WAM uses ADS-B-like receivers), there are no direct line-of-sight limitations. For flight levels lower than FL100, there would be limitation by line of sight (in an obstacle free space).

Flight Level	Corresponding coverage radius
=>FL100	120 NM external to the deployment of receiving stations

Table 6. Assumed nominal operating coverage radius of a generic WAM station

As the above detailed MLAT/WAM nominal coverage rationale is not straightforward in its application and for simplicity purposes, in the present analysis the assumptions provided by the ICAO GMST document and NLR report [12] are used (see section 2.1). In the mentioned literature it is assumed that an approximate number of 9 multilateration ground stations are required to achieve a coverage of an SSR ground station at FL350. In the present analysis the referred assumption is extrapolated to all flight levels, as no direct line-of-sight limitations are assumed for WAM/MLAT stations.

Flight Level	Corresponding coverage radius
=>FL100	9 stations provide 162 NM coverage radius

Table 7. Assumed nominal operating coverage radius of a 9 generic WAM stations

In both ADS-B and WAM systems, there is one more factor to keep in mind, since high-gain (very directional) antennas can also limit the range at low elevation angles. The values detailed in the previous paragraphs are based on the use omnidirectional antennas of 5.5 dBi of maximum gain.

## 3.1.5 Surveillance scenarios

Taking into consideration the airspace surveillance coverage rationale aspects described in the previous sections, the top-level scenarios defined for the present analysis are the following:

- 1. Blank sheet scenario:** A “blank sheet” scenario will be assessed, where current surveillance deployment will be disregarded, and a fully new configuration, driven only by efficiency and high-level safety and performance coverage requirements, will be proposed from scratch. The result, despite being possibly unrealistic, will come to illustrate the high degree of inefficiencies resulting from fragmentation and duplicities.
- 2. Realistic scenarios:** The current surveillance infrastructure deployment in EASA MS area will be modelled, assessing current surveillance redundancy and coverage.

### 3.1.5.1 Blank sheet scenario

The modelling and posterior analysis of the blank sheet scenario will be performed with the aid of a developed toolset for graphical surveillance coverage modelling (see section 3.2). The developed toolset will allow for automated optimisation of ground station placement, as to ensure optimum distribution throughout the EASA MS area.

The analysis shall take into account requirements for coverage at different flight levels (FL180, FL300, FL350). The lowest (FL180) will be used as the most conservative case when assuring full surveillance coverage. For the blank sheet scenario, such condition implies the following:

- All considered airspace shall have a full ADS-B coverage layer at FL180 (corresponding, as described in section 3.1.4, to an assumed unit coverage radius of 150 NM per ground station)
- In addition, all airspace shall be fully covered by SSR or MLAT/WAM coverage at FL180 (corresponding, as described in section 3.1.4, to an assumed coverage radius of 162 NM per SSR station and per group of 9 MLAT/WAM stations)

In order to obtain the most optimum (lower) number of ground stations following the conditions described above, geometric optimisation for the placement of each ground station must be considered first. From a 2-dimensional point of view, the problem consists on finding the distribution of circles to fully cover a certain area such that the total number of circles is the minimum. Given an area of X by Y, the minimum amount of circles with a fixed given radius R, necessary to fully cover every part of the considered area, is obtained by distributing the said circles in an hexagonal shape. Such distribution is illustrated in Figure 9.

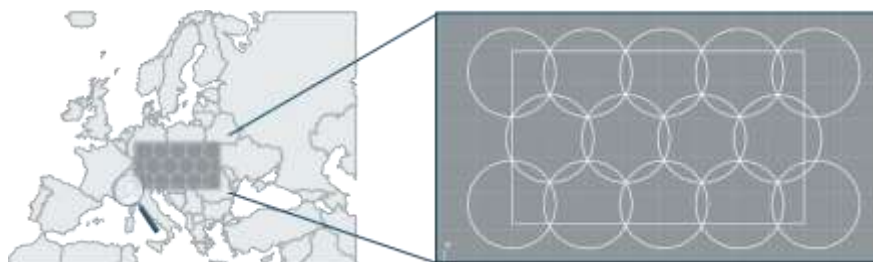


Figure 9. illustration of hexagonal ground station distribution and associated coverage

In the present analysis, however, the geographic scope of the distribution is not 2-dimensional, but 3-dimensional instead as the Earth's surface is being considered. As illustrated in section 3.1.3, when working in a 2D projection of European dimensions the optimal distribution must account for projection deformation. As such, the assumed optimum distribution of each surveillance technology layer (e.g. ADS-B ground stations) follows an hexagonal distribution empirically adapted to comply to projection considerations.

For dependent secondary surveillance layer (ADS-B), only distribution parameter is that of the adapted hexagonal distribution such that the minimum number of ground stations fully covers all considered airspace at FL180. All ground stations are placed in land (no oceanic stations considered). The distribution is performed such that ground stations that fall next to the ocean are placed as close as possible to the corresponding land border, in order to provide maximum oceanic/sea coverage though the deployment of land-based stations. Finally, a single, harmonised and interoperable surveillance framework will be assumed, thereby eliminating any national boundaries.

For the independent secondary surveillance layer (Mode S SSR and MLT/WAM), an additional set of requirements is taken into consideration. The following rationale is followed for the referred layer:

- First, a layer of Mode S SSR ground stations is distributed along all considered area following the adapted hexagonal distribution, as detailed for the ADS-B surveillance layer
- Second, MLAT/WAM sets of stations are placed in the considered high density terminal areas
- Then, MLAT/WAM sets of stations are placed in the considered mountain regions
- Finally, in areas of high redundancy of independent secondary surveillance coverage resulting from the outlined distribution, Mode S SSR ground stations will be removed if deemed appropriate

The analysis of the blank sheet scenario can be found in section 4.



### 3.1.5.2 Realistic scenarios

The current surveillance infrastructure deployment in EASA MS area will be modelled, assessing current surveillance redundancy and coverage. The rationale below is followed:

- The list of currently deployed ground surveillance infrastructure according to the EASA survey (originally based on EUROCONTROL information), containing information relating to ground stations' type, location, year of installation and year of replacement is used as baseline input for the analysis

The specific data provided in this list, as well as the assumptions regarding the current scenario modelling and the corresponding results are described in section 4.

## 3.2 Airspace surveillance coverage modelling

To graphically render the deployment of surveillance infrastructure and the resulting aggregated coverage, an automated toolset has been developed. In order to achieve the most suitable result, first step was to split the software development work into three distinct sequential phases, illustrated in Figure 10 below.



Figure 10. Coverage modelling high-level methodology

First step consists on the definition of the tool requirements, or final goals of the toolset, resulting in a list of software requirement specifications. Secondly, the appropriate selection of programming environment is performed along with the specific design of the end toolset to achieve. Implementation follows through the development of the aimed software set.

### 3.2.1 Definition of requirements

Main objective of the proposed toolset is twofold:

- To support the analysis of the optimum number of ground surveillance structures through a certain degree of automation concerning optimum location for structure deployment
- From a set of input locations, to graphically render the deployment of surveillance infrastructure and the resulting aggregated coverage in an automated manner

Following the defined airspace surveillance coverage rationale, nominal coverage assumptions (see section 3.1.4) and geographic scope of the analysis (see section 3.1.2), the following requirements have been defined for the proposed toolset:

- The tool must be able to determine the estimated number of ground surveillance stations that would be required to optimise the surveillance infrastructure deployment – SSR, ADS-B or MLAT/WAM –, as well as their corresponding locations.
- The optimisation must ensure total coverage on all the EASA MS area, as well as intend to maximise the coverage by placing the ground stations close to the corresponding land border.
- All ground stations shall be placed in land, with no oceanic stations considered.
- The toolset must also allow for intuitive user interaction for manual readjustment of location, addition and deletion of ground stations.
- After manual readjustment the toolset must allow for the retrieval of final number of ground stations, corresponding surveillance type and corresponding location.
- On the other hand, the final toolset must be able to visually represent a list of geographic locations of surveillance equipment received as an input.
- In this representation the coverage of each surveillance equipment must be depicted taking into account the selected flight level of visualization.

- Accounting for the geographic scope of the analysis and coverage rationale, the chosen programming environment must allow for the integration of maps for 2D visualisation and possibility 3D visualization of EASA Member State area.
- Due to limited time and high-level scope of the present analysis, the complexity of the design selected for development must be low enough for the tool to be modelled in a simple and traceable manner.
- The final toolset should take into account in a simplified manner the terrain elevation of the main regions that could imply a significant reduction of surveillance coverage.

### 3.2.2 Design

First step into the design stage is the definition of software environment for the development of the proposed toolset. Upon analysis of different options the following two possibilities:

- AutoCAD and associated Application Programming Interface (API) – AutoCAD is a commercial computer-aided design (CAD) and drafting software application. Other than its worldwide usage across a range of industries, AutoCAD supports a number of APIs for customization and automation. These include AutoLISP, VisualLISP, VBA, .NET
- Google Maps and associated APIs: Google Maps is a web mapping service developed by Google. The Google Maps APIs allow for the embedding of Google Maps onto web pages of outside developers, e.g. using a JavaScript or a Flash interface.

Figure 11 summarizes the key comparison features between the two options for the present analysis. Both applications allow for a certain degree of automation through the use of APIs, necessary to perform the automated coverage modelling and analysis tasks set out in the requirements stage.

On the visualisation side, AutoCAD only allows for the modelling of geometric figures on top of a static background figure; the usage of the Google Maps API on the other hand provides full access to Google's worldwide database of locations within countries and associated information. In addition, using Google Maps allows the designer to perform the calculations directly in 3D, as the API calculates automatically the required projections to represent the results in a map. More concretely, Google Maps uses a variant of the Mercator projection.

Another advantage of the second option is the more intuitive user interaction for non-experienced users. Finally, Google Maps APIs are free for a wide variety of use cases, including the scope of the present analysis, with predictable overage pricing and usage limits for APIs and annual contracts for enterprise deployments.



		
<b>Programming languages</b>	AutoLisp, VisualLisp, VBA, DCL	JavaScript, Flash, HTML
<b>Design workspace</b>	2D	3D with automatic projection
<b>Visualization</b>	Limited flexibility	High flexibility
<b>User interaction</b>	Limited interaction and previous knowledge required	Intuitive user interaction
<b>License</b>	Paid license required	Standard version is free

Figure 11. Comparison between coverage modelling options

Considering the factors described above, Google maps was designated as the preferred software tool for development. Within the available interfaces, the JavaScript API was selected. Figure 12 below illustrates therefore the final defined design of the proposed toolset:

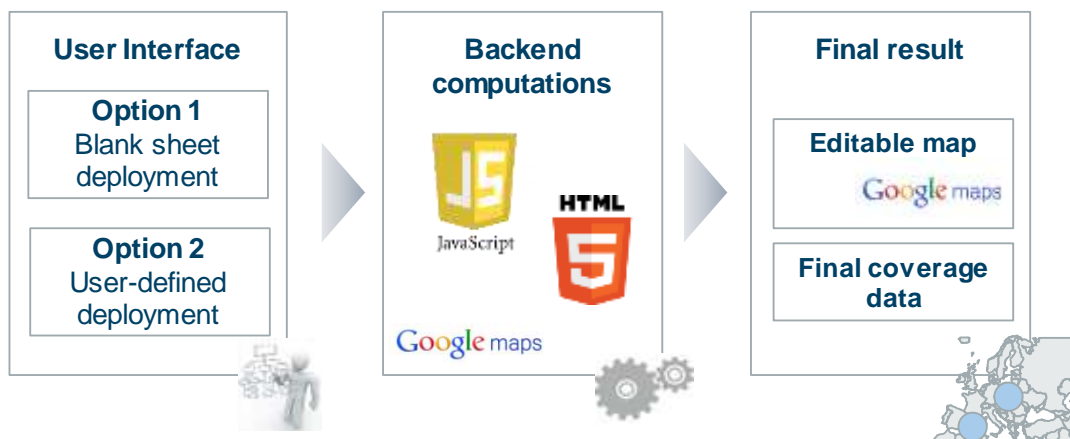


Figure 12. Final coverage modelling and analysis toolset design

The tool will consist of a graphic user interface which will allow the definition of main inputs for modelling and analysis. The tool will include two functionalities:

- **Option 1: Blank sheet deployment of surveillance ground equipment.** This option will instruct the toolset to perform a preliminary optimum distribution of surveillance ground stations. The user will be given the option of using a combination of surveillance technologies according to defined coverage rationale (see section 3.1), using the established nominal coverage assumptions (see section 3.1.4).
- **Option 2: User-defined deployment.** This option allows for the user to upload an input file containing a list of geographic coordinates corresponding to a set of surveillance ground stations and coverage radius at selected flight level.

After user selection of inputs, a set of backend computations will be performed automatically by the toolset using a combination of HTML, JavaScript and the Google Maps API.

Final result will be displayed in an editable map, projected according to Mercator projection as established before. The editable map will display the resulting surveillance coverage and allow for the user to move, add or eliminate ground stations. In addition, the final map will include an option to visualise a data summary with final number of ground stations per type and corresponding geographic coordinates.

### 3.2.3 Implementation: Blank sheet deployment

Figure 13 outlines the implementation logic followed by the tool. Once the user has introduced the required inputs, the tool proceeds to identify the nominal coverage of the ground stations at the selected flight level. Taking this coverage into account, the tool identifies the appropriate location of the ground stations in order to optimise the infrastructure deployment complying with the requirements previously described. The locations are represented in the map, with the corresponding aggregated coverage. The user can then apply modifications on this first proposal by adding, removing, or modifying stations directly in the interactive map. The final optimised deployment, with the total number of stations and the graphical representation of their location and aggregated coverage, is then finally presented.

### Option 1 – Blank sheet deployment of surveillance ground equipment

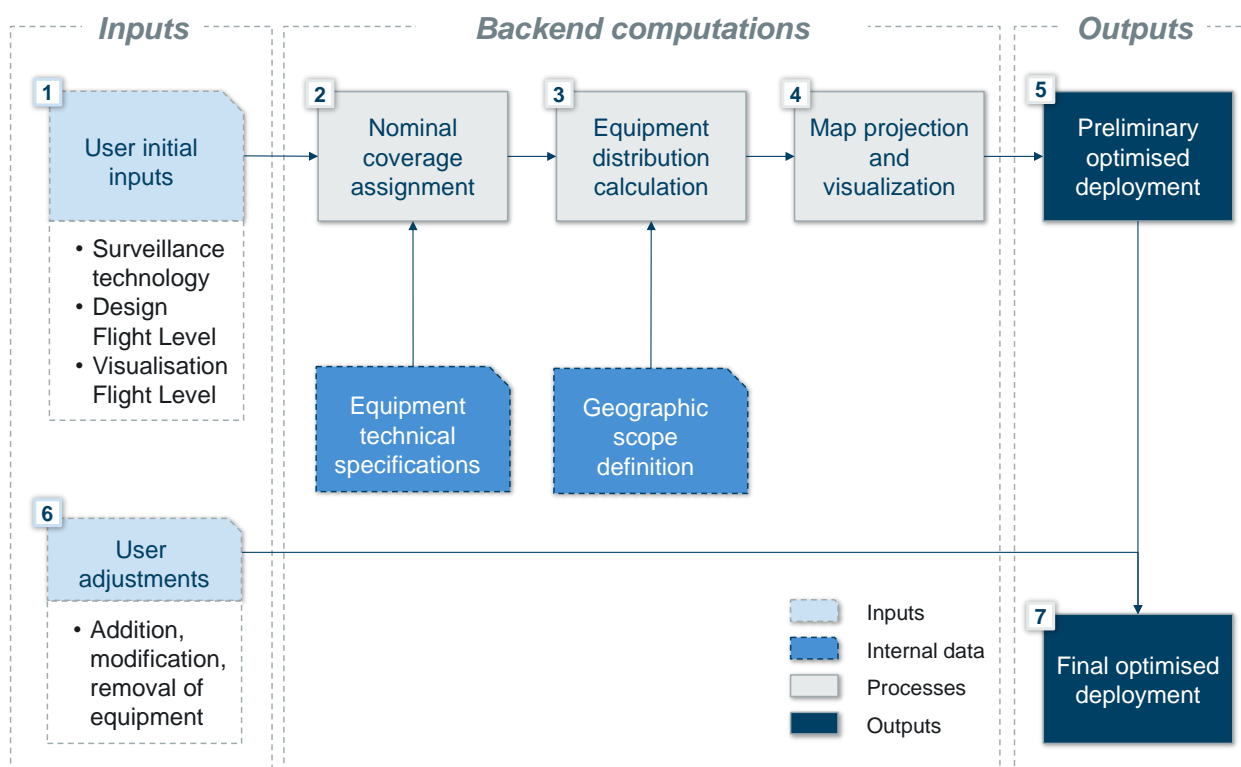


Figure 13. Flowchart for the optimum distribution calculation and representation

#### 3.2.3.1 User initial inputs

As outlined in the software specifications, the user is allowed to provide three different inputs:

- Surveillance technology: three different combinations of ground equipment are available.
  - ADS-B
  - Mode S SSR
  - WAM for mountainous regions and TMAs
- Design Flight Level: the flight level that will determine the location of the equipment. It corresponds to the minimum flight level at which the total coverage must be guaranteed. By default, this FL is set at FL180. Available options are:
  - ADS-B: From FL140
  - SSR: FL180, FL300, FL350, FL430 or higher
  - WAM: From FL100
- Visualisation Flight Level: the flight level that will be depicted in the output map to represent the aggregated coverage. As well as the Design Flight Level, the available options are:
  - ADS-B: From FL140
  - SSR: FL180, FL300, FL350, FL430 or higher
  - WAM: From FL100
  - SSR with WAM: FL180, FL300, FL350, FL430 or higher

#### 3.2.3.2 Nominal coverage assignment

Taking into account the selected design flight level and the equipment technical specifications described in section 3.1.4, the tool assigns the *design nominal coverage* for the selected surveillance technology. This design coverage will be used to calculate the corresponding locations of each equipment unit.

On the other side, taking into account the selected visualisation flight level and the equipment technical specifications described in section 3.1.4, the tool assigns the *visualisation nominal coverage* for the selected



surveillance technology. This design coverage will be used to represent the aggregated coverage in the final map.

### 3.2.3.3 Equipment distribution calculation

The procedure to find the optimum equipment distribution consists of several stages:

- 1) *Calculation of the adjusted hexagonal pattern* described in section 3.1.5. The corresponding distances between each equipment unit is directly dependant of the design nominal coverage previously calculated. Although not represented in the final map, and only for visualisation purposes, the following figure depicts the adjusted hexagonal pattern superposed to the geographic scope.



Figure 14. Adjusted hexagonal pattern (Equipment: Mode S SSR, Design FL: 180)

- 2) *Integration of the hexagonal pattern* to the geographic scope. The tool adapts the hexagonal pattern in order to cover all the EASA Member States area (Figure 15). In this step, only the main land and nearest islands are considered. The implementation logic is depicted in Figure 16. For each latitude, the algorithm identifies the first location inside the geographic scope with lowest longitude, and proceeds to dispose the stations until it reaches the location with highest longitude. Latitude and longitude separations between locations are based on the adjusted hexagonal pattern.

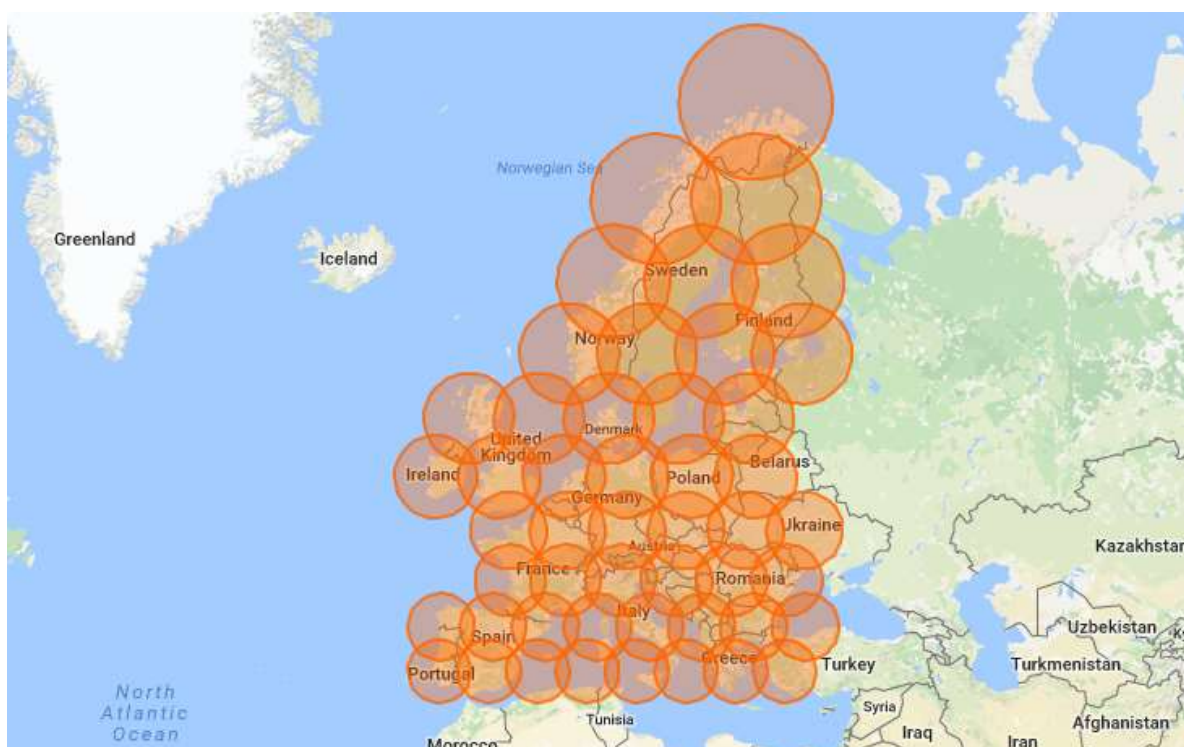


Figure 15. Hexagonal pattern integrated in the geographic scope (Equipment: Mode S SSR, Design FL: 180)

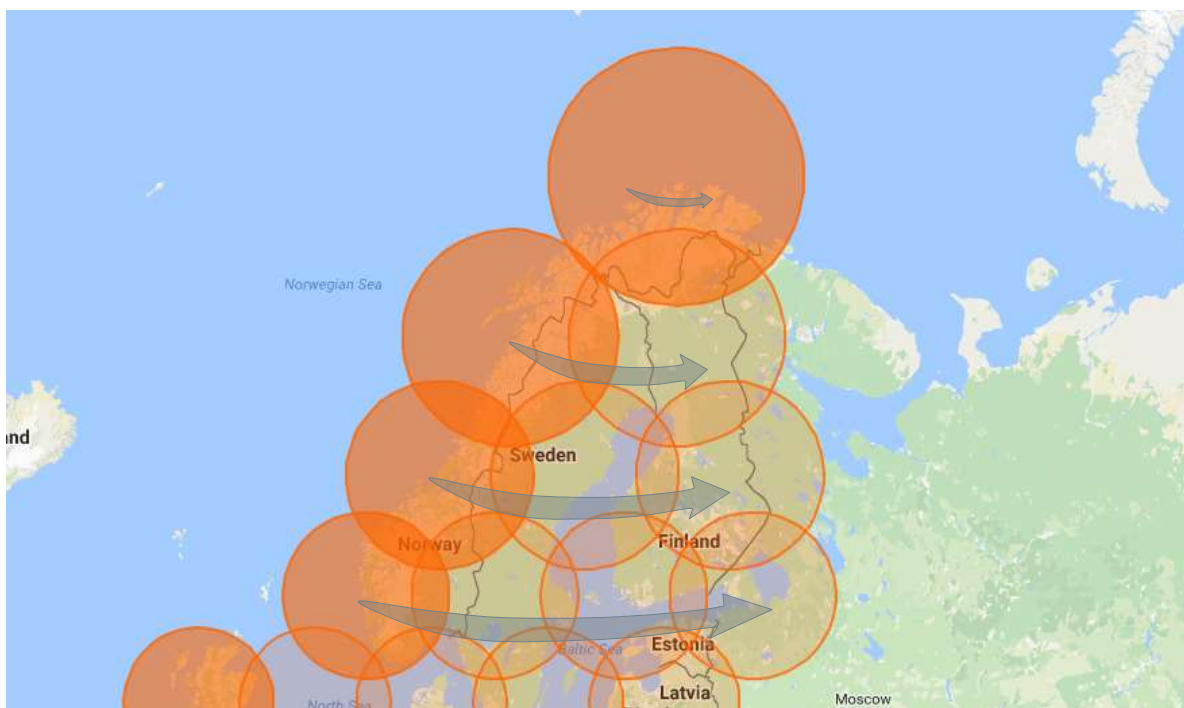


Figure 16. Implementation logic followed to adapt the hexagonal pattern to the geographic scope

- 3) **Location of singular surveillance equipment.** The software has also identified a set of locations where the stations are situated independently of the hexagonal pattern (Figure 17). This is the case of the islands distant to the main land that belong to the EASA Member States WAM stations are also situated individually in the specific areas: high density TMA's and mountainous regions.

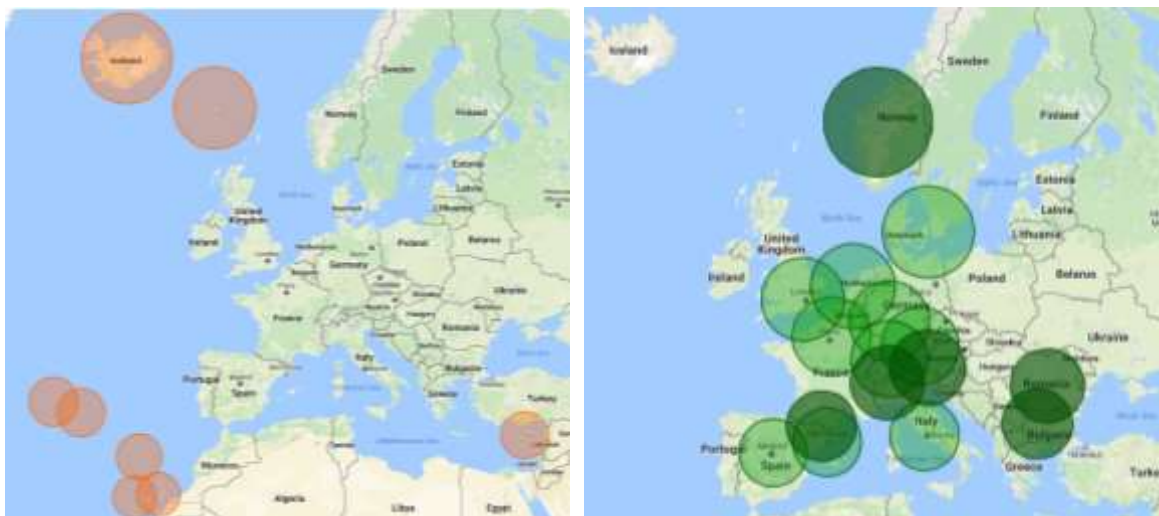


Figure 17. Singular surveillance equipment: stations in distant islands (left) and WAM stations (right)

- 4) Identification of required adjustments. The implementation logic for the main land has followed two fundamental conditions: locations between the longitude and latitude extent of the geographical scope, and separations following the hexagonal pattern. However, this implementation may lead to some misplaced stations. This is the case of the situation depicted in Figure 18, where some stations are required in order to provide coverage to the surrounding islands, but they are currently located in the sea. The software identifies these stations for further manual adjustment of the user.

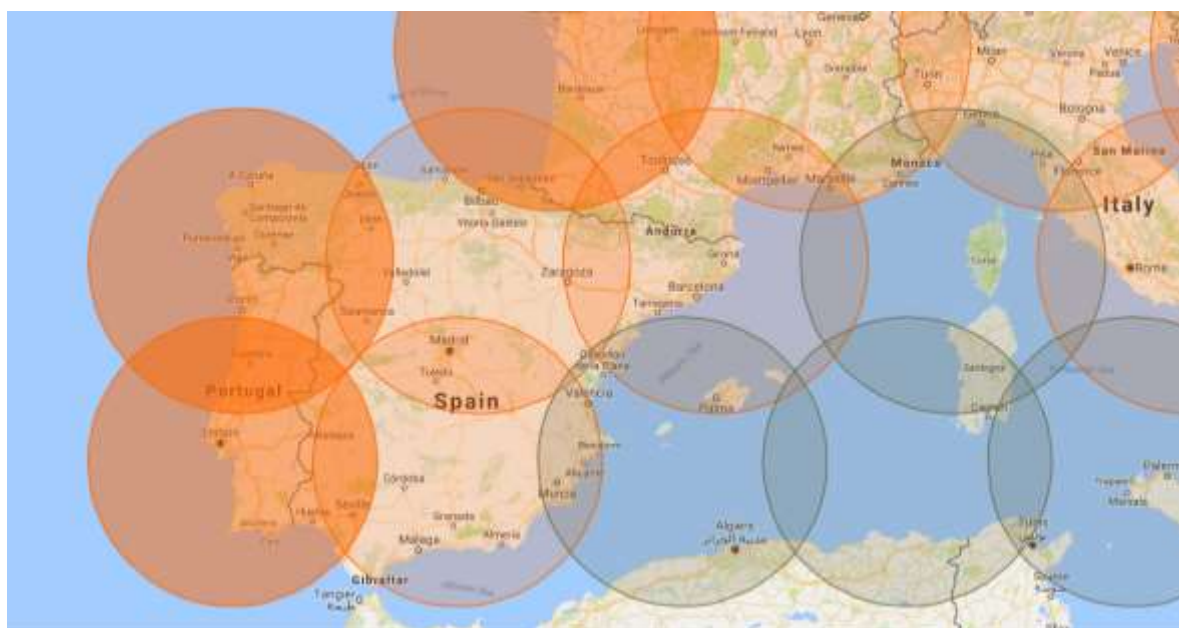


Figure 18. Example of stations that require further manual adjustment

### 3.2.3.4 Map projection and visualization

Once the tool has identified the appropriate location of each station, it proceeds to graphically render them in the map projection provided by Google Maps. As commented before, it uses a variant of the Mercator projection, which preserves angles locally (radar coverages are still depicted as a circle) and the deformation increases with the latitude (high latitude stations are represented with larger circles, although providing the same coverage). This procedure is automatic performed when calling the Google Maps API.



### 3.2.3.5 Preliminary optimised deployment

The preliminary optimisation scenario proposed by the tool is therefore presented to the user. It consists on an interactive map with the proposed locations of the stations, as well as the corresponding coverage. The coverage represented in this map corresponds to the *visualisation* Flight Level introduced by the user, which does not need to be equal to the *design* Flight Level that the software has taken into account to perform the calculations. Ground stations that require manual adjustment by the user are marked in grey.

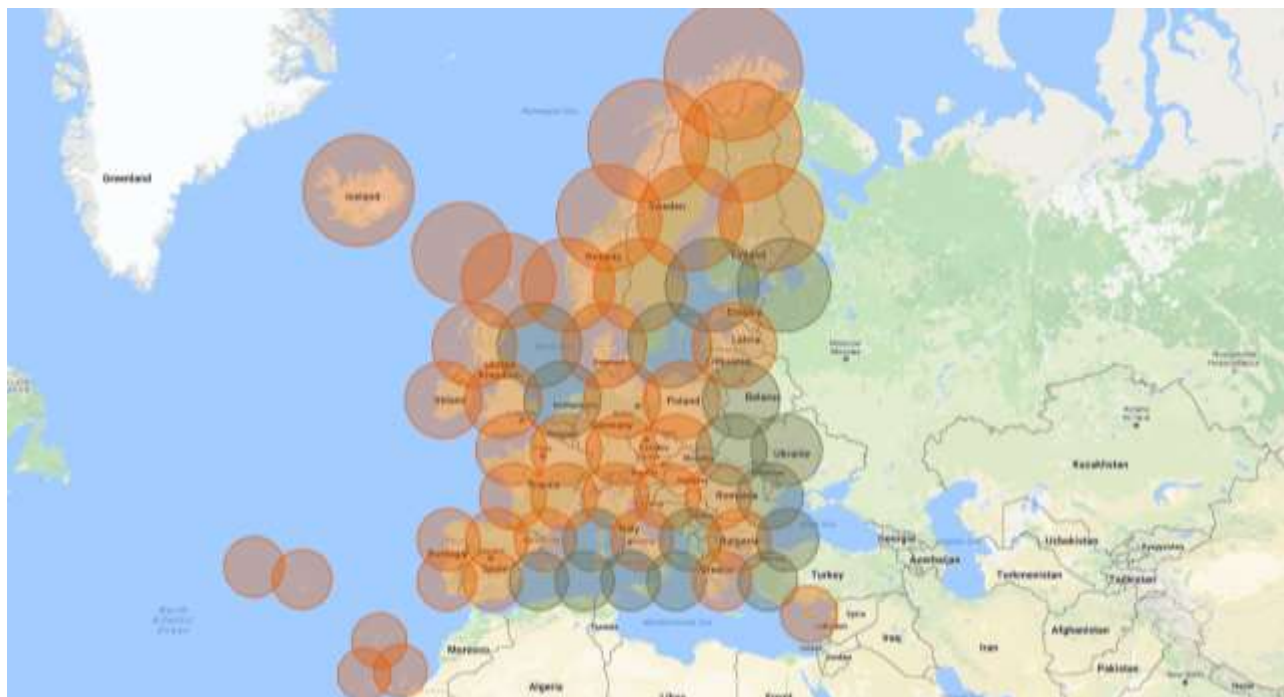


Figure 19. Preliminary optimised deployment proposed by the tool (Equipment: Mode S SSR, Design and vis. FL: 180)

### 3.2.3.6 User adjustments

The interactive map allows the user to perform three different modifications:

- *Modification of the location* of single equipment, by dragging it into the desired location. This is mandatory for the stations located in the sea or outside the scope, which are previously displayed in grey and modified to the corresponding colour when the user has modified the location (Figure 18).
- *Addition of necessary equipment*. It is possible that some areas that should be provided coverage are not appropriately covered in the preliminary proposal, due to the adaptation of the hexagonal pattern. The user is allowed to add new stations by clicking directly into the map.
- *Removal of redundant equipment* or deletion of stations situated outside the geographic scope. The user is also allowed to delete stations which are not considered necessary.

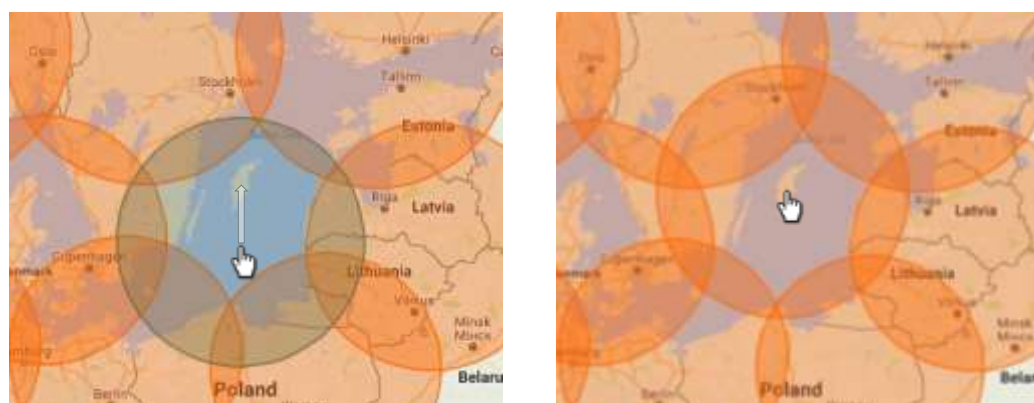


Figure 20. Example of manual adjustment by dragging the station into the appropriate location

### 3.2.3.7 Final optimised deployment

Once the user has introduced the manual adjustments considered necessary, the final optimised deployment is displayed in the map. The software also provides the list of the stations' locations as well as the total number of stations that has been considered necessary.

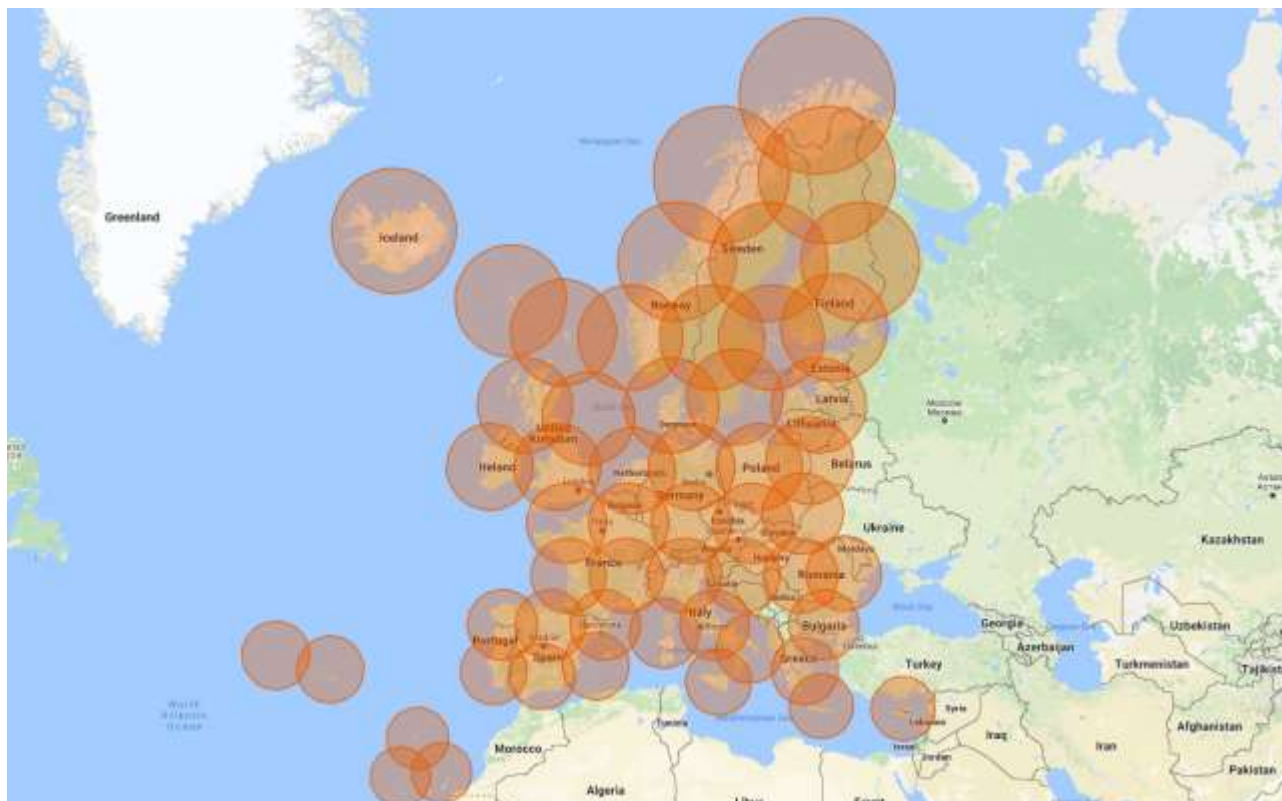


Figure 21. Example of final optimised deployment (Equipment: SSR, Design and visualisation FL: 180)

After the visualisation of the optimised deployment and the corresponding adjustments of the user, the scenario can be exported as a text file containing the location and coverage parameters of each station.

### 3.2.4 Implementation: User-defined deployment

Figure 22 depicts the implementation logic followed by the tool in the user-defined deployment function. It follows a similar procedure than in the Optimum deployment, but eliminating the *Equipment distribution calculation* process, since the distribution is already defined in the input file. In addition, this functionality is provided with coverage and redundancy analysis tools.

The user introduces a text file with the locations and surveillance technology type of each station. It can also set the visualisation flight level of the deployment, since the tool has implemented the coverage assumptions of each surveillance type. It continues by representing the corresponding locations and aggregated coverage in the map, which is also interactive and can receive inputs from the user to add, remove or modify surveillance stations. It also provides indicators on the coverage redundancy in the map, as well as the detection of non-covered areas. Finally, the user is able to export the final deployment as a text file with the same format.

## Option 2 – User-defined deployment of surveillance ground equipment

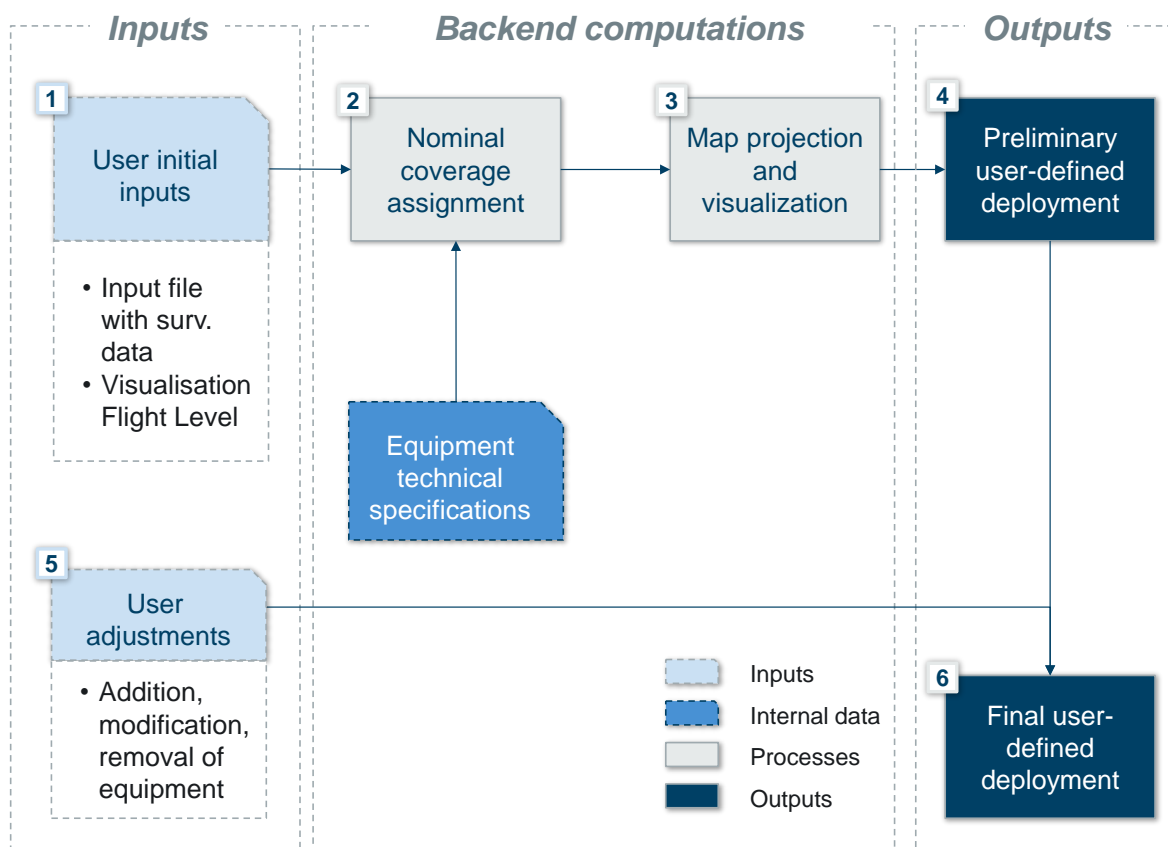


Figure 22. Flowchart for the user-defined distribution calculation and representation

### 3.2.5 Integration of the terrain elevation

The last update of the modelling tool includes the integration of the terrain elevation for the calculation of the ADS-B and SSR surveillance coverage in both Blank sheet and User-defined functionalities.

This functionality introduces a high-level representation of the Pyrenees and the Alps terrain elevation in order to visualize how the coverage of the surveillance stations is reduced. Both mountainous regions are represented as a set of points with constant altitude. The terrain elevation at the location of the surveillance station is not taken into account.

The implementation logic is represented in Figure 23 and is applied to each surveillance station displayed on the map, and for both the Pyrenees and the Alps. It consists on:

- The calculation of the minimum distance between the location of the surveillance station and the corresponding mountainous regions. This distance ( $D_{min}$ ) is then compared to the coverage range of the surveillance station at the selected visualization Flight Level ( $Range_{FL}$ ). If the first one is smaller, it is possible that the station presents interferences due to terrain elevation. Figure 24 represents this situation.
- For the latter group of stations, the minimum altitude at which the station provides coverage at  $D_{min}$  is compared to the elevation of the terrain. If lower, the station coverage is indeed interrupted by the terrain.
- The modified coverage is obtained calculating the intersection between the original coverage and the shape of the mountainous region following a the line-of-sight limitation. Figure 25 and Figure 26 provide two examples of modified coverage.

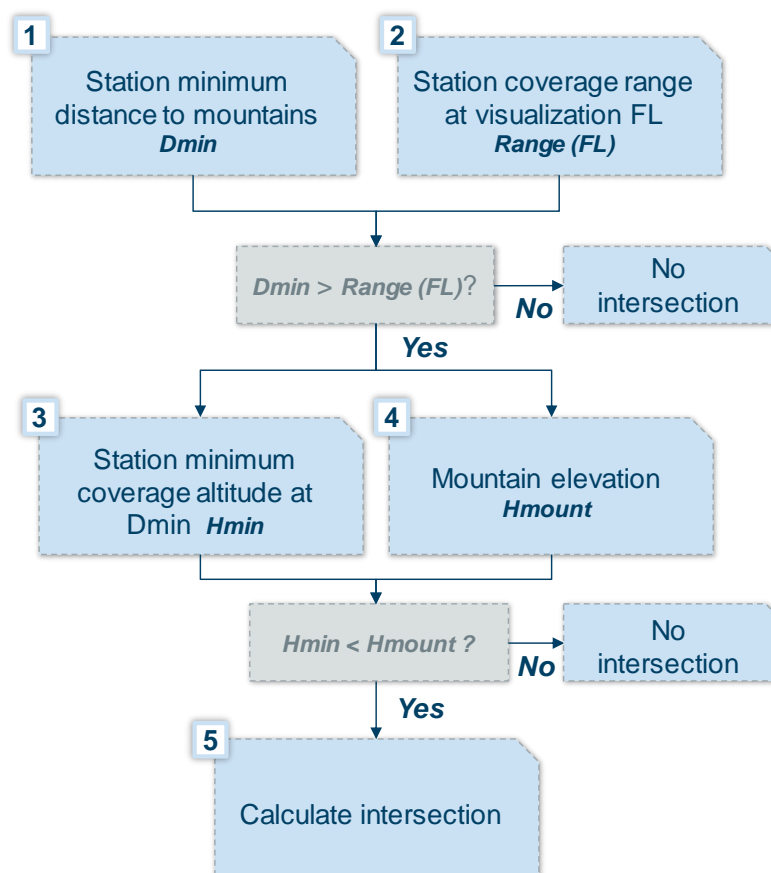


Figure 23. Terrain elevation implementation logic



Figure 24. Comparison of  $D_{min}$  with  $Range(FL)$  in order to identify possible interferences in the radar coverage (left: no interference, right: possible interference)





Figure 25. Modification of the SSR coverage due to the proximity to the Pyrenees



Figure 26. Modification of the ADS-B coverage due to the proximity to the Alps



## 4 Analysis of Results

The current sections presents the results obtained in the analysis of two scenarios that have been described in section 3.1:

- The **blank sheet scenario**: a fully new configuration corresponding to one layer of ADS-B covering all EASA MS area, and another layer of SSR combined with WAM. This scenario has been modelled according to the assumptions described in section 3.1.
- The **current situation** regarding surveillance deployment of SSR, WAM and ADS-B in the EASA MS. This scenario has used as an input the list of currently deployed ground surveillance infrastructure according to the EASA survey, originally based on EUROCONTROL information.

The modelling and analysis toolset developed specifically for this project and described in section 3.2 has been the main support for this assessment, by modelling the deployment of the blank sheet scenario, as well as performing the analysis of both scenarios in terms of locations, coverage and redundancy.

### 4.1 Data validation

Prior to the analysis of the scenarios, the input provided by EASA regarding the current civil ground surveillance infrastructure has been assessed in terms of data quality and completeness, in order to clarify assumptions relating to current situation.

#### 4.1.1 Surveillance data provided by EASA

The information concerning current ground surveillance for EASA Member States was provided by EASA in an Excel data base format. The database contained 652 entries with the following associated information:

- Country
- Name of the location (city, airport, mountain, country)
- Standardised usage (e.g. APP, ENR)
- Ground Surveillance Type
- Year of installation
- Year of replacement
- Sensor type for replacement
- Standardised operational range (NM)
- Standardised operational altitude (FL)
- Number of stations

Following an error analysis, a set of locations have been discarded due to missing data:

- Locations with no specified *Ground Surveillance Type*
- Locations with *Standardised usage* as "N/Op"
- Locations with *Number of stations* as "0" or missing

In addition, locations that do not correspond to the current situation have also been removed:

- Locations with *Year of installation* later than 2017
- Locations with *Year of replacement* previous to 2018
- Locations with *Decommission* set as "-1"

The ground surveillance stations that result from this first filter correspond to the civil ground surveillance infrastructure currently deployed in the EASA Member States. The total number of stations per ground surveillance technology is depicted in Table 8.

Surveillance Technology	Stations
<b>PSR total</b>	<b>147</b>
PSR combined with mode AC	33
PSR combined with mode S	85
PSR Stand alone	29
<b>SSR total</b>	<b>313</b>

Surveillance Technology	Stations
Mode AC	122
Mode S	190
Mode S - Data sharing	1
<b>ADS-B</b>	<b>85</b>
<b>WAM</b>	<b>752</b>
<b>Total</b>	<b>1315</b>

Table 8. Summary of current surveillance infrastructure in EASA Member States

## 4.1.2 Data assumptions

For coherence purposes in the comparison with the blank sheet scenario, a set of stations have also been removed from the previous list of surveillance infrastructure. These stations correspond to:

- Stations with *Ground Surveillance Type* as “PSR stand alone”, since Primary Surveillance Radars are out of the scope of this analysis.
- It is important to clarify that locations with “PSR combined with mode AC” and “PSR combined with mode S” have also been discarded since they have been considered repeated values (the corresponding SSR was already included in an independent row of the file).
- Stations with *Standardised usage* as “SMR”, since *Surface Movement Radars* coverage is limited to the airport.
- Stations with *Standardised usage* as “APP”, since the analysis scope is focused on FL180 and above, considered as the en-route phase of the flight.

In addition, a set of assumptions have been taken into account for coherence purposes:

- Regarding nominal coverage assumptions, all surveillance types have been modelled according to the specifications described in section 3.1. Both Mode AC and S have been modelled as SSRs. WAM stations have been clustered in groups of 9 stations (defined as a WAM “**system**”) with the corresponding coverage described in section 3.1.
- Since the locations did not include the exact position of the equipment, some assumptions have also been taken:
  - Some stations specified the position of the equipment with high precision (e.g. a mountain or an airport)
  - Locations with the name of a city have been assumed to be positioned in the city centre for simplicity;
  - Locations with the name of the country or locations that could not be identified have been assumed to be distributed throughout the country.

## 4.1.3 Surveillance data included in the analysis

Once all these assumptions have been applied, the final data regarding the current situation scenario is summarised in Table 9. One surveillance system equals a single ADS-B or SSR station, or 9 WAM stations. As stated in the previous sections, only civil stations are considered.

Surveillance Technology	Stations	Systems
<b>ADS-B</b>	<b>69</b>	<b>69</b>
<b>SSR</b>	<b>207</b>	<b>207</b>
<b>WAM</b>	<b>657</b>	<b>73</b>
<b>Total</b>	<b>895</b>	<b>349</b>

Table 9. Summary of current surveillance infrastructure included in the analysis

## 4.2 Analysis of results

This sub-section provides the main results of the analysis and comparison of both scenarios regarding the following areas:

- Coverage analysis;
- Number and positioning of the surveillance systems;
- Redundancy analysis;

All numerical and visual results have been directly obtained from the modelling tool.

### 4.2.1 Geographic scope

Figure 27 depicts the geographic scope of the analysis. It is limited to the EASA MS area, covering both mainland and insular areas.

Although the insular areas situated distant to the mainland do not belong to EASA MS corresponding FIRs, since the surveillance equipment situated in these islands is included in the list of current surveillance infrastructure provided by EASA, have also been included in the analysis.



Figure 27. Geographic scope of the analysis: mainland and insular areas of EASA MS

## 4.2.2 Blank sheet scenario

As mentioned before, in the blank sheet scenario current surveillance deployment is disregarded, and a fully new configuration, driven only by efficiency and high-level safety and performance coverage requirements according to the outlined airspace coverage rationale, is assessed.

The results concerning the blank sheet deployment of cooperative surveillance are displayed in incremental steps, corresponding to the modelling stages followed for final representation.

### 4.2.2.1 Scenario coverage analysis

#### 4.2.2.1.1 ADS-B surveillance layer

The blank sheet scenario is composed of two layers, both of them providing total coverage over the entire EASA MS area. The deployment of the first layer, composed entirely by ADS-B stations, is depicted in Figure 28.

As it can be observed, the scenario presents a semi-regular distribution of the locations throughout the mainland, according to the hexagonal pattern that has been applied before adapting the distribution to the geographic scope. Outside the mainland, selected ADS-B stations are deployed in order to cover the insular areas of the MS. Figure 29 includes the ADS-B distribution in the remote islands.

This layer corresponds to a total number of 73 ADS-B stations, including the mainland and insular areas.



Figure 28. Blank sheet scenario ADS-B aggregated coverage (mainland zoom)



Figure 29. Blank sheet scenario ADS-B aggregated coverage (worldwide zoom)

In order to ensure that the ADS-B layer fully covers the entire EASA MS area, Figure 30 presents the aggregated coverage of the layer superposed to the geographic scope that was depicted at the beginning of the section.

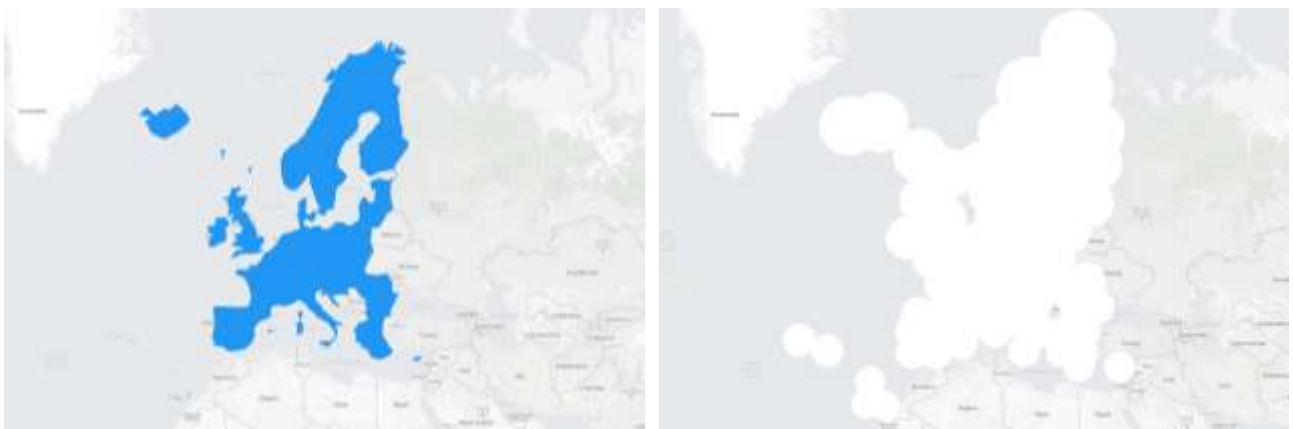


Figure 30. Blank sheet scenario ADS-B aggregated coverage over the geographic scope

#### 4.2.2.1.2 Mode S SSR and MLAT/WAM surveillance layer

The second layer corresponds to an independent surveillance layer composed by a combination of WAM and Mode S SSR stations.

The distribution of WAM ground stations is shown in Figure 31. Placement is performed in the considered high complexity TMAs (busiest airports, in light green) and mountain regions (dark green) detailed in section 3.1.2. A total of 16 sets of MLAT/WAM systems is obtained, each one corresponding to 9 WAM stations.





Figure 31. Blank sheet scenario WAM aggregated coverage

On the other hand, the distribution of the Mode S SSR stations is similar to the deployment of the ADS-B, both based in the hexagonal pattern with the addition of specific locations in the insular areas. However, redundant SSR stations have been removed after combination of SSR and WAM coverage, as depicted in Figure 32.

For this reason, and taking into account that SSR stations provide wider coverage than ADS-B, fewer stations are required: a total of 54 Mode S SSR stations.



Figure 32. Blank sheet scenario Mode S SSR aggregated coverage

Finally, Mode S SSR and MLAT/WAM coverages are combined, resulting in the independent cooperative surveillance layer displayed in Figure 33 with a total of 70 systems (Mode S SSR coverage in orange, WAM coverage in green).



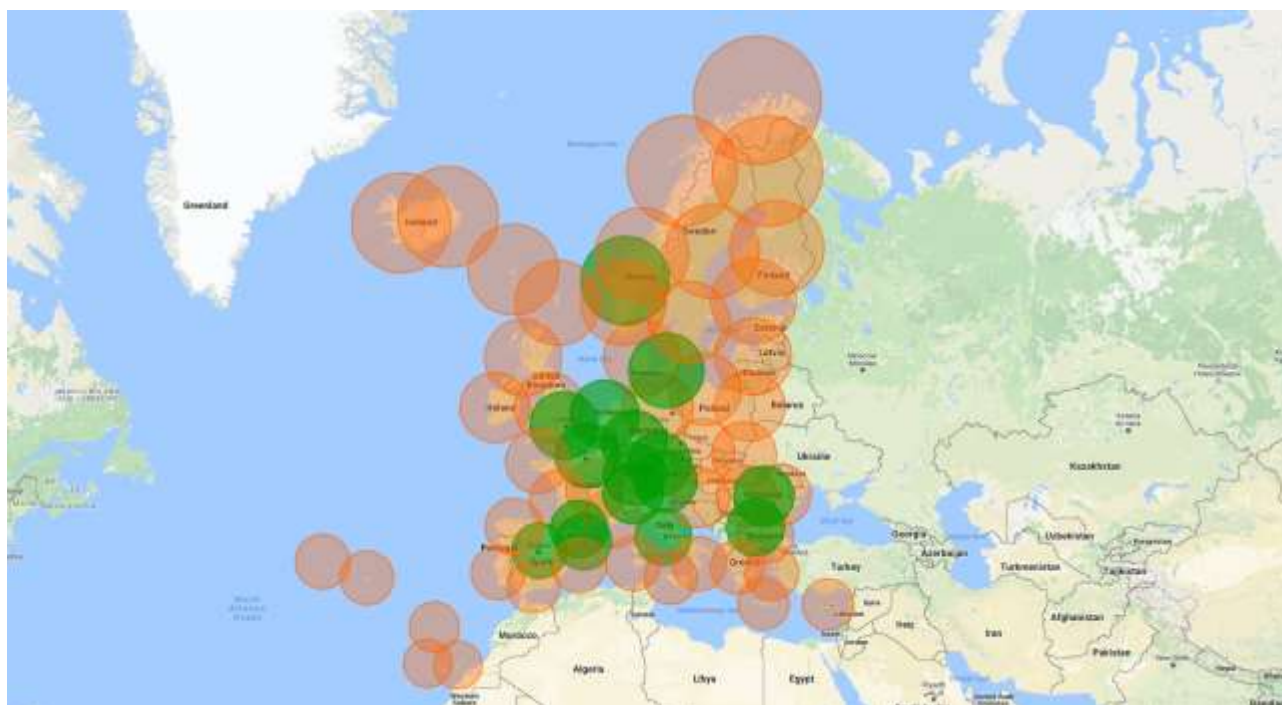


Figure 33. Blank sheet scenario Mode S SSR and WAM layer deployment

In order to ensure that the Mode S SSR and WAM layer fully covers the entire EASA MS area, Figure 34 presents the aggregated coverage of the layer superposed to the geographic scope that was depicted at the beginning of the section.



Figure 34. Blank sheet scenario SSR and WAM layer aggregated coverage over the geographic scope

Finally, Figure 35 and Figure 36 depict the assembled coverage provided in the blank sheet scenario. ADS-B coverage is represented in red, SSR in orange and WAM in green. A total of 143 surveillance systems is required.

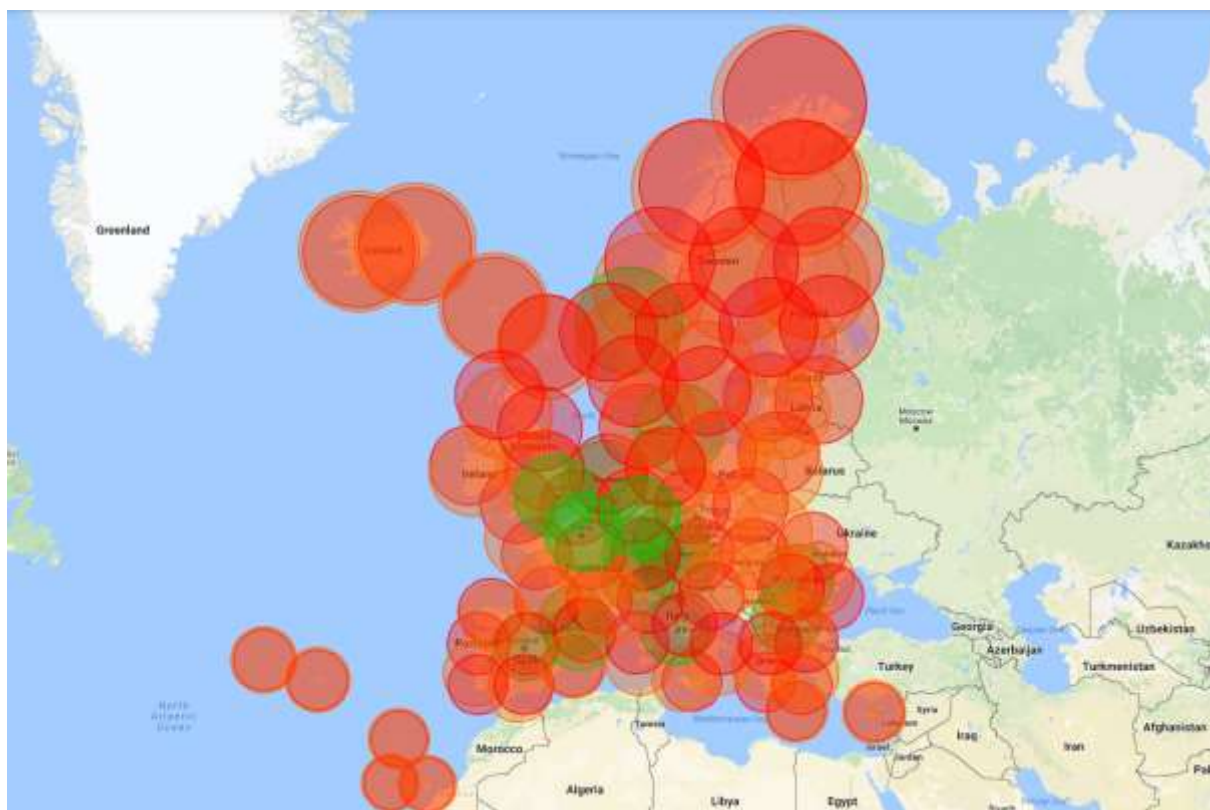


Figure 35. Blank sheet scenario combined ADS-B, Mode S SSR and WAM aggregated coverage (mainland zoom)

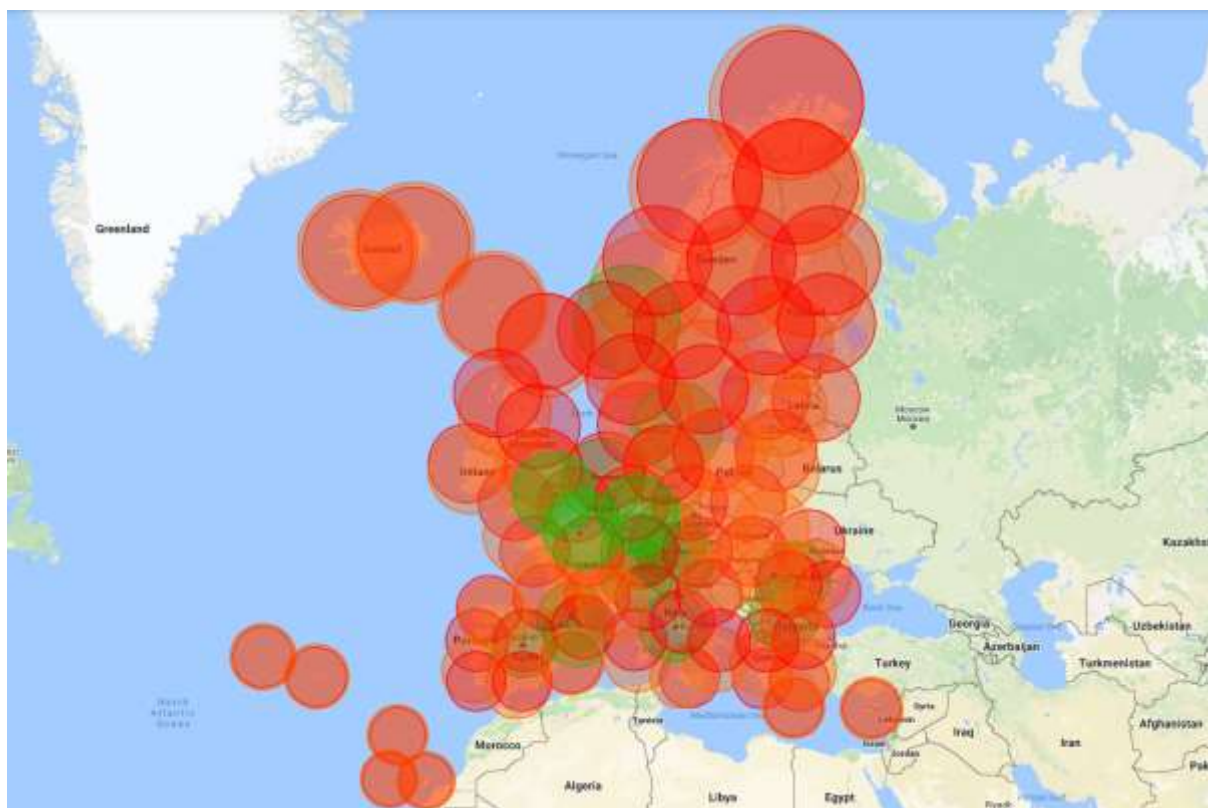


Figure 36. Blank sheet scenario combined ADS-B, Mode S SSR and WAM aggregated coverage (worldwide zoom)

#### 4.2.2.2 Scenario locations analysis

The distribution of all the ground stations that compose the blank sheet scenario is depicted in Figure 37, categorised by technology (red for ADS-B, orange for SSR and green for WAM). Each point corresponds to a single location that can include several surveillance systems.

These figures allow to validate if the modelling assumptions have been successfully implemented. ADS-B and SSR locations have nearby emplacements, since the same pattern has been applied to both technologies. WAM locations are situated in the specific airports that have been considered, as well as the mountainous regions. Most WAM locations have no SSR locations in the surrounding areas, since redundant SSR have been removed. All locations are situated inside the geographic scope; no oceanic locations have been considered. In addition, the locations tend to be emplaced in the coastline in order to maximise the coverage.



Figure 37. Surveillance systems locations in the blank sheet scenario

Figure 38 specifies the number of surveillance systems among the different Member States, classified by type. Most of the States have similar number of ADS-B and SSR stations, in exception of the States where WAM stations have been deployed and redundant SSRs removed.

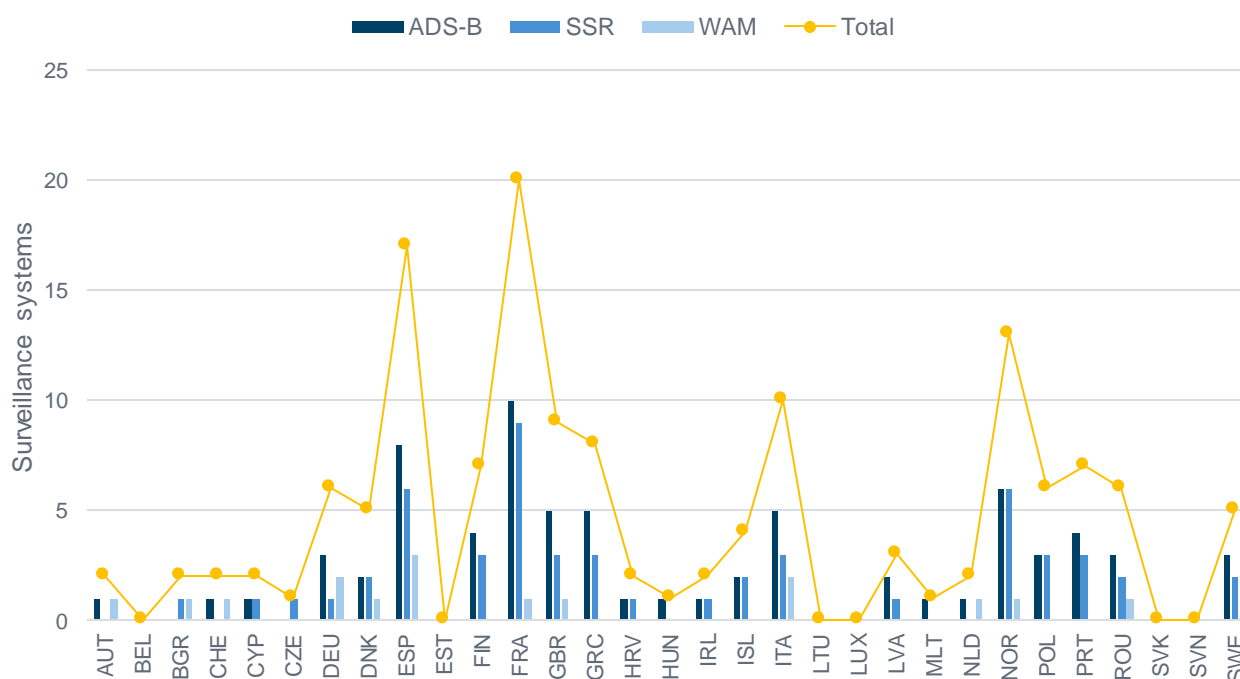


Figure 38. Surveillance systems per country and type in the blank sheet scenario

Since this scenario establishes the deployment of a single, harmonised distribution eliminating any country boundaries, the total number of surveillance systems by country is generally proportional to its extension area. This fact can be observed in Figure 39, where the total surveillance systems by country have been sorted from wider to narrower areas.



Besides of the extension, another relevant fact in the number of surveillance systems of a country is whether it contains insular areas or not. Owning an insular area implies the deployment of minimum two surveillance stations (ADS-B and SSR), even if the area to cover is reduced.

This is the case of the countries marked in blue in Figure 39, which tend to have more stations than the surrounding countries with similar area. France and Spain are the two countries with the highest number of surveillance systems, not only due to its extension but also for owning insular territory.

Italy and the United Kingdom (marked in grey) have also higher number of stations due to their high complexity TMAs and the required WAM systems. Finally, smallest countries do not require to dispose of surveillance stations since coverage is obtained from the stations of the surrounding countries. This is the case of Lithuania, Slovakia, Estonia, Belgium, Slovenia and Luxembourg.

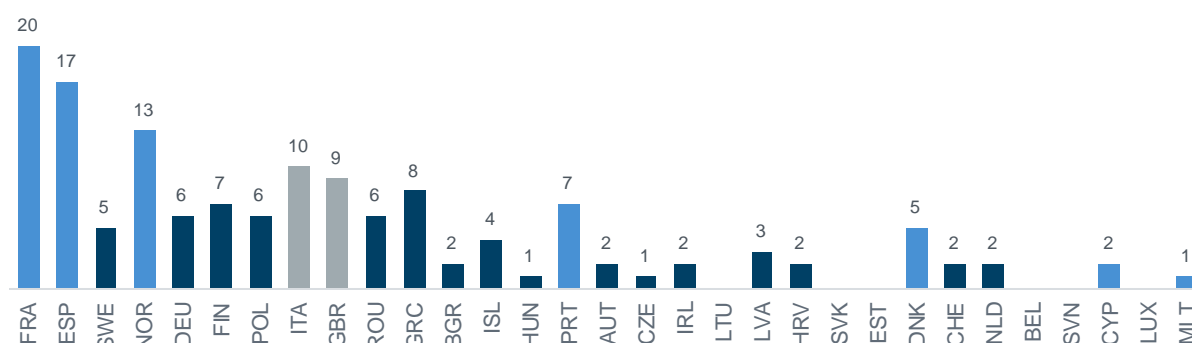


Figure 39. Total surveillance systems by country, sorted by area

#### 4.2.2.3 Scenario redundancy analysis

Figure 40 shows the maximum redundancy that is obtained in the blank sheet scenario, taking into account all the surveillance stations (both dependent and independent layers). Redundancy refers to the maximum number of stations that present overlapped coverage in a single point.

Insular areas reach a maximum redundancy of 4 (i.e. some areas are covered by 4 different stations), due to the proximity of the locations that contain both ADS-B and SSR stations in the same emplacement. Highest redundancy can be found in the mainland, as detailed in Figure 41. Areas with coverage offered by 6 simultaneous stations are encountered due to the integration of the WAM stations.



Figure 40. Blank sheet scenario redundancy (worldwide zoom)

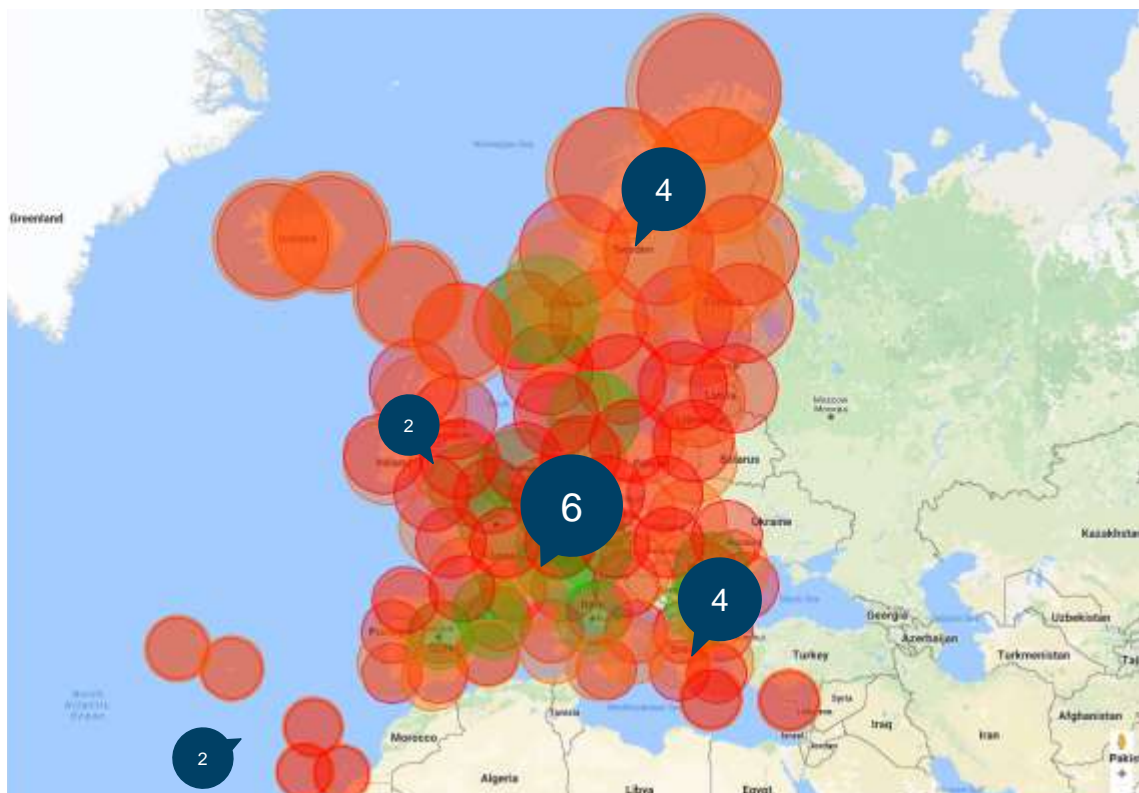


Figure 41. Blank sheet scenario redundancy (mainland zoom)



The segregated redundancy by country and surveillance technology is specified in Figure 42. In line with the number of stations, ADS-B and SSR redundancy is distributed equally among the States. WAM redundancy reaches its maximum (3) in Spain, due to Madrid and Barcelona high complexity TMAs as well as the Pyrenees.

Countries with higher redundancy (6) correspond to the countries with higher number of surveillance systems. This is the case of Germany, Spain, Greece and Italy as depicted in Figure 42. However, France has an important increase in surveillance stations without implying a significant increase in redundancy due to the remote insular areas, which imply an increase in stations but not necessary in redundancy.

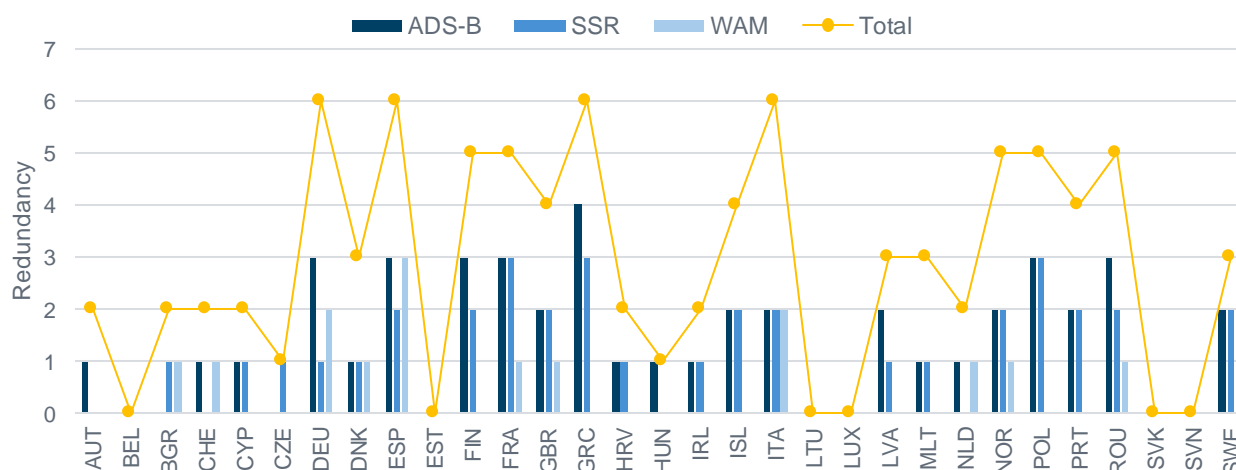


Figure 42. Blank sheet scenario redundancy by country and type

## 4.2.3 Current situation

This subsection presents the results obtained in the analysis of the current surveillance deployment in the EASA MS area, according to the information provided by EASA itself and described in section 4.1. The infrastructure corresponds to the ADS-B, SSR (both Mode A/C and Mode S) and WAM stations that are currently deployed in the EASA MS and offer ENR or APP/ENR service (as 2017).

The corresponding surveillance data has been introduced as an input to the modelling tool, and the aggregated coverage, redundancy and distribution has been obtained and analysed according to the modelling assumptions described in section 3.1.

### 4.2.3.1 Current coverage analysis

The current surveillance deployment aggregated coverage is depicted in Figure 43 and Figure 44. It corresponds to a total of 349 surveillance systems, represented in red (ADS-B), orange (SSR) and green (WAM).

At first sight, the figures reflect a significant increase in the total number of surveillance stations as well as redundancy compared to the blank sheet scenario. For visualisation purposes, stations will be analysed by surveillance technology.

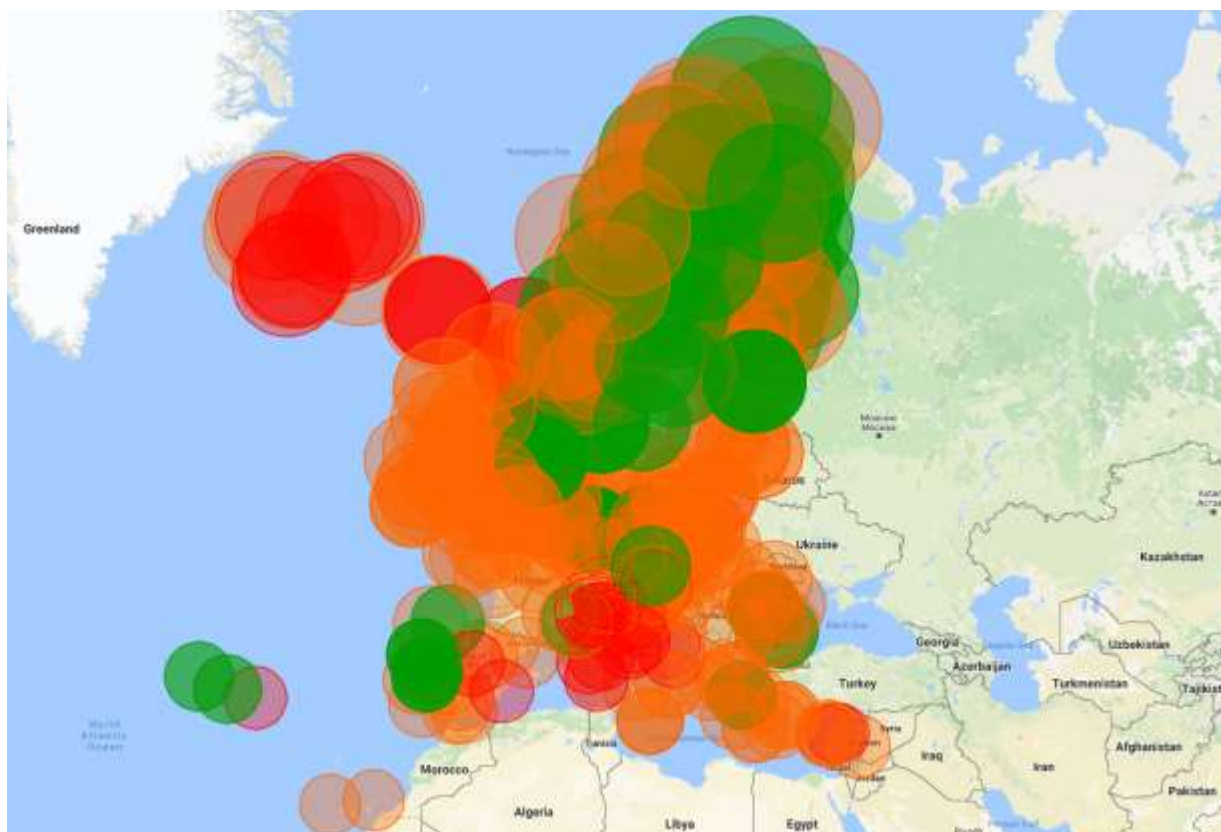


Figure 43. Current ADS-B, SSR and WAM aggregated coverage in the EASA MS (mainland zoom)

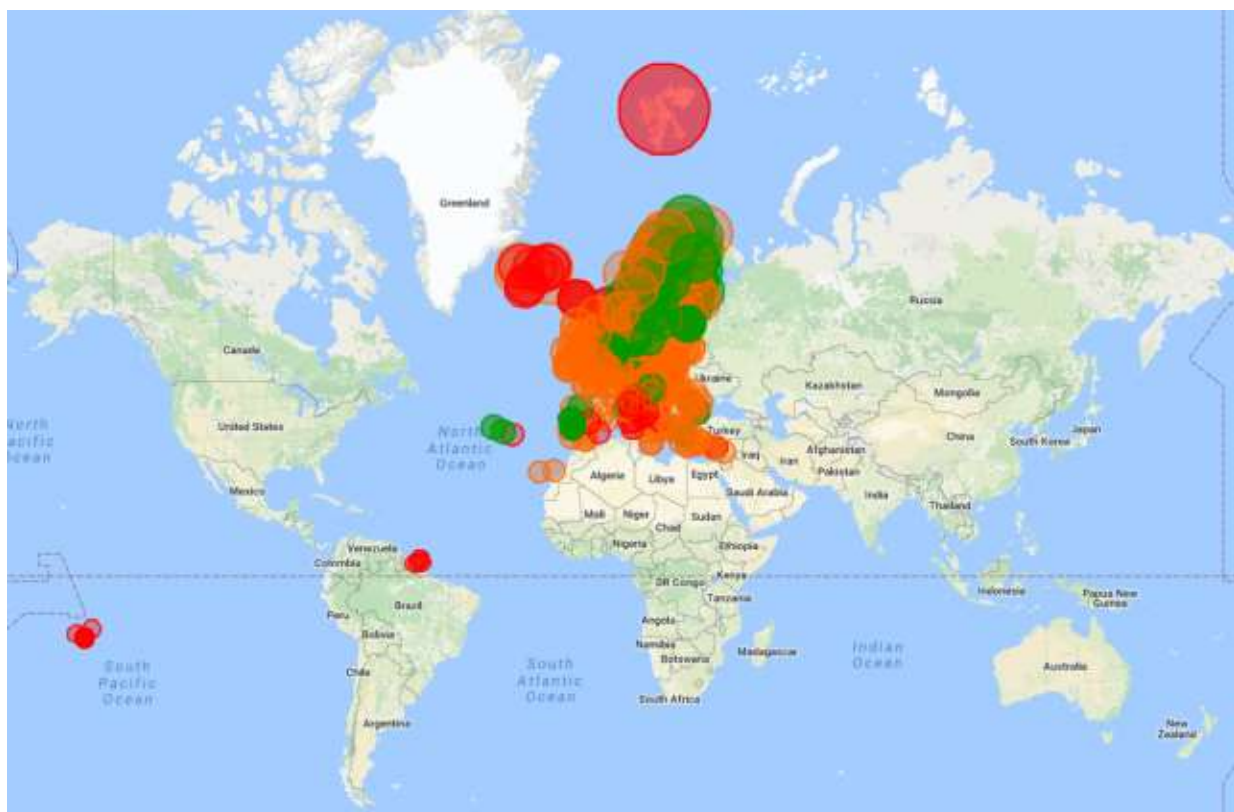


Figure 44. Current ADS-B, SSR and WAM aggregated coverage in the EASA MS (worldwide zoom)

As performed with the blank sheet scenario, total coverage is also verified (Figure 45).



Figure 45. Current aggregated coverage in EASA MS (mainland and worldwide zooms)

#### 4.2.3.1.1 ADS-B surveillance

A total number of 69 ADS-B stations are deployed throughout the area. As depicted in Figure 46, ADS-B coverage is highly focused on specific areas with apparently high redundancy. Remote island are mostly covered with ADS-B stations. This is the case of the French colonies, the Azores, Cyprus, Iceland or the Faroe Islands. The only exception are the Canary islands where SSR stations are deployed. Regarding the mainland, ADS-B is mostly deployed in Italy.



Figure 46. Current ADS-B aggregated coverage in the EASA MS

#### 4.2.3.1.2 Mode A/C and S SSR surveillance

The total number of SSR stations is significantly higher: a total of 207 stations are deployed throughout the area. SSR stations seem to offer complete coverage in all EASA MS area, with exception of some previously mentioned remote islands where ADS-B is deployed.

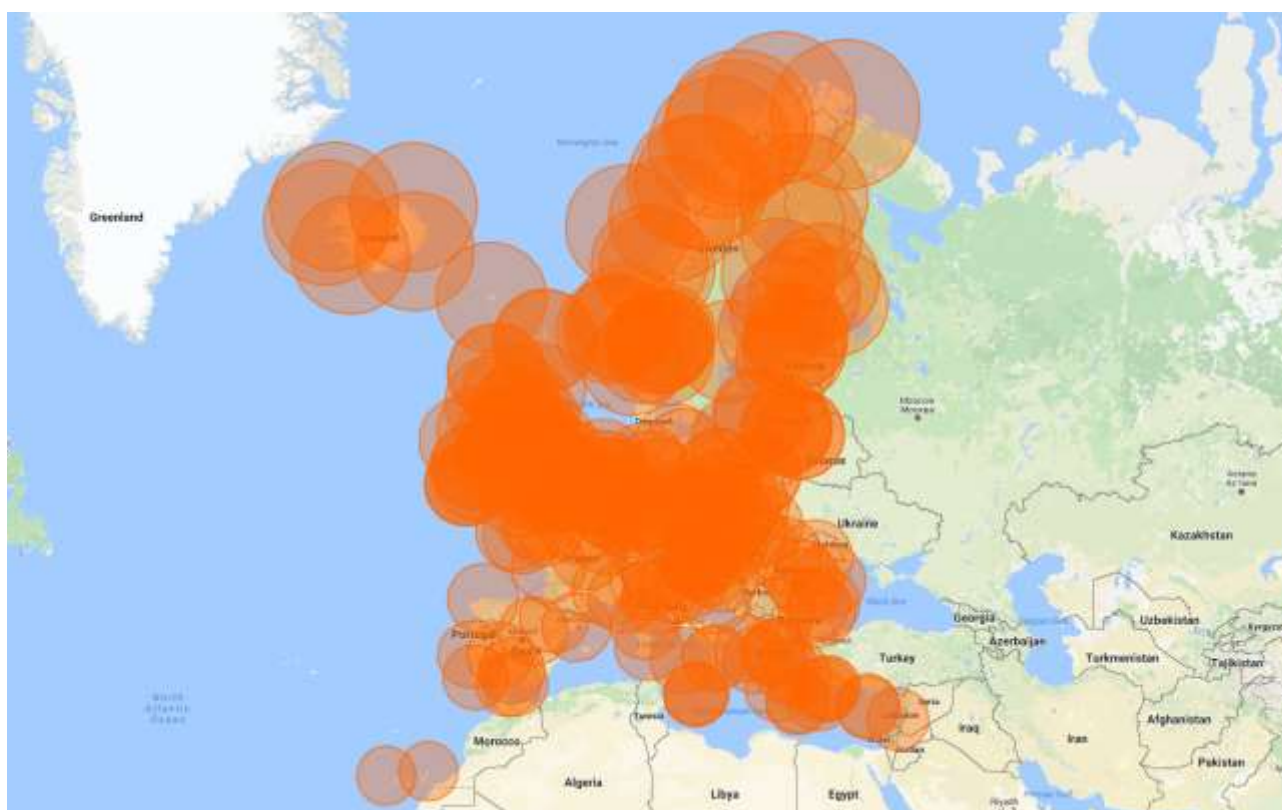


Figure 47. Current SSR aggregated coverage in the EASA MS

#### 4.2.3.1.3 WAM surveillance

Regarding WAM locations, it is important to highlight that several countries were not specified the exact location of the WAM systems. For this reason, it has been assumed that WAM systems were spread along the country. This is the case of Austria, Germany, Finland and Sweden. According to these assumption, Northern European countries as well as Central Europe are provided complete coverage with WAM stations. A total of 73 WAM systems, corresponding to 657 WAM stations (9 per system) have been deployed.



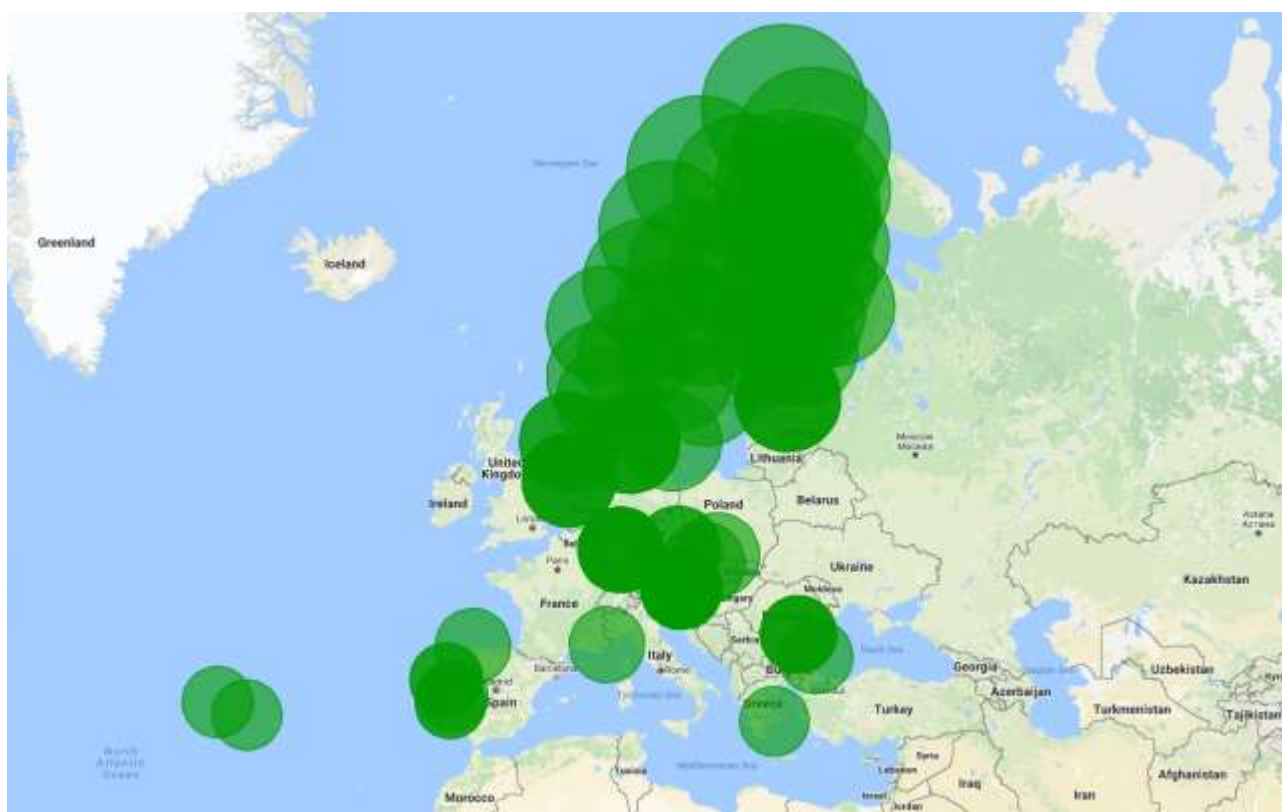


Figure 48. Current WAM aggregated coverage in the EASA MS

#### 4.2.3.2 Current locations analysis

Regarding the emplacement of the stations, Figure 43 depicts how the locations are extended through the entire geographic scope. Areas with higher density of stations are Southern United Kingdom, the Northern Central Europe and the Northern Italy, all corresponding to areas with high-complexity TMAs. On the other side, Southeastern Europe has the lowest density of surveillance equipment since most of its countries do not belong to EASA.

The figure also highlights that several countries tend to locate the stations in the coastline, in order to maximise the sea coverage. This is the case of Iceland, Ireland, Norway, Spain, Italy or Greece.

The technology with highest number of locations is the SSR, which is extended through all the EASA MS area. ADS-B deployment is focused on specific countries, mainly Iceland and Italy, as well as in the French and Norwegian remote insular areas.

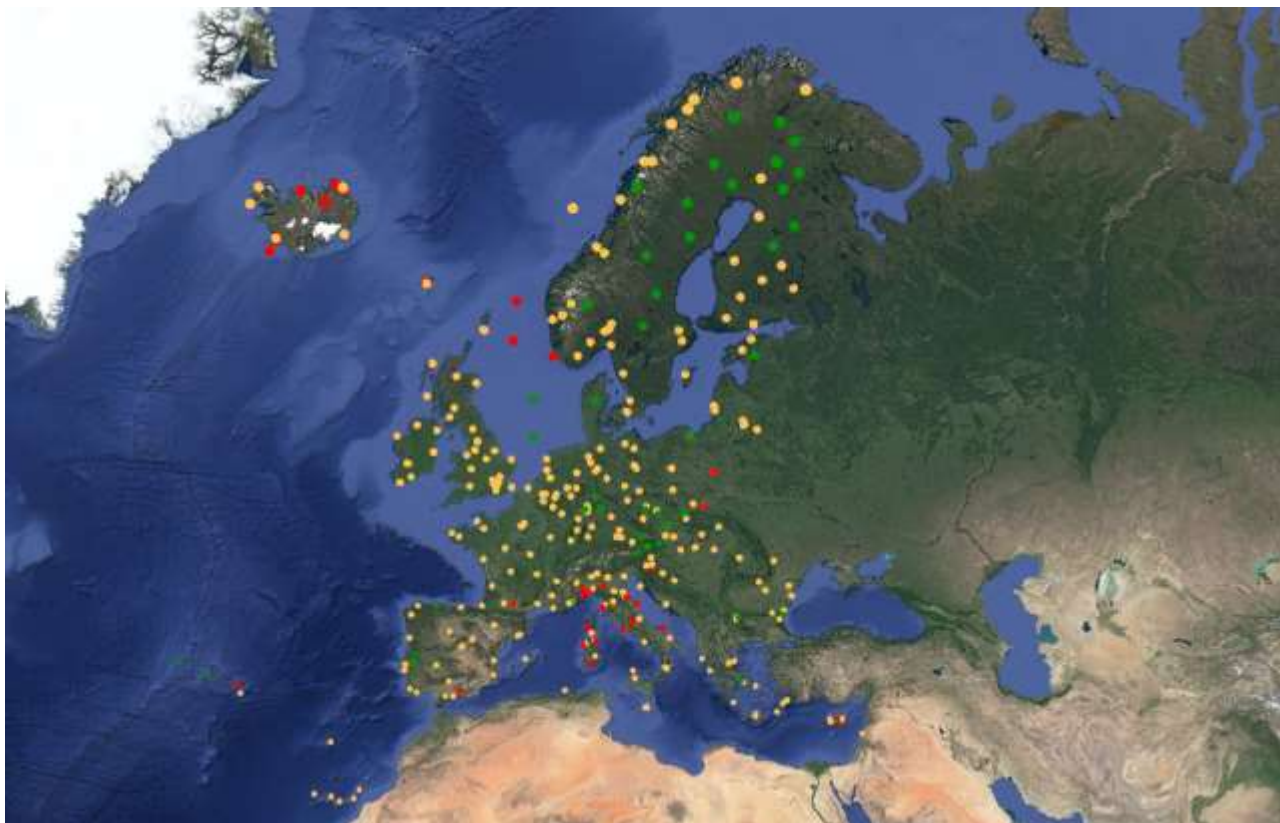


Figure 49. Current surveillance technology locations (zoom mainland)

Figure 50 segregates each surveillance technology by country and type. The country with the highest number of surveillance systems is Norway (45), covering the mainland with SSR and deploying ADS-B stations in the sea oil stations to provide sea coverage in the surrounding area. Italy and France follow the same behaviour: deploying SSRs in the mainland and ADS-B in the insular territory, resulting in a similar number of stations. The United Kingdom, Germany and Spain on the other hand, have also deployed a high number of stations but using SSR technology uniquely.

All 31 States count with SSR stations except the Czech Republic, 11 of them have ADS-B stations and 17 have WAM systems deployed. SSR is the unique surveillance technology deployed in 8 of the States.



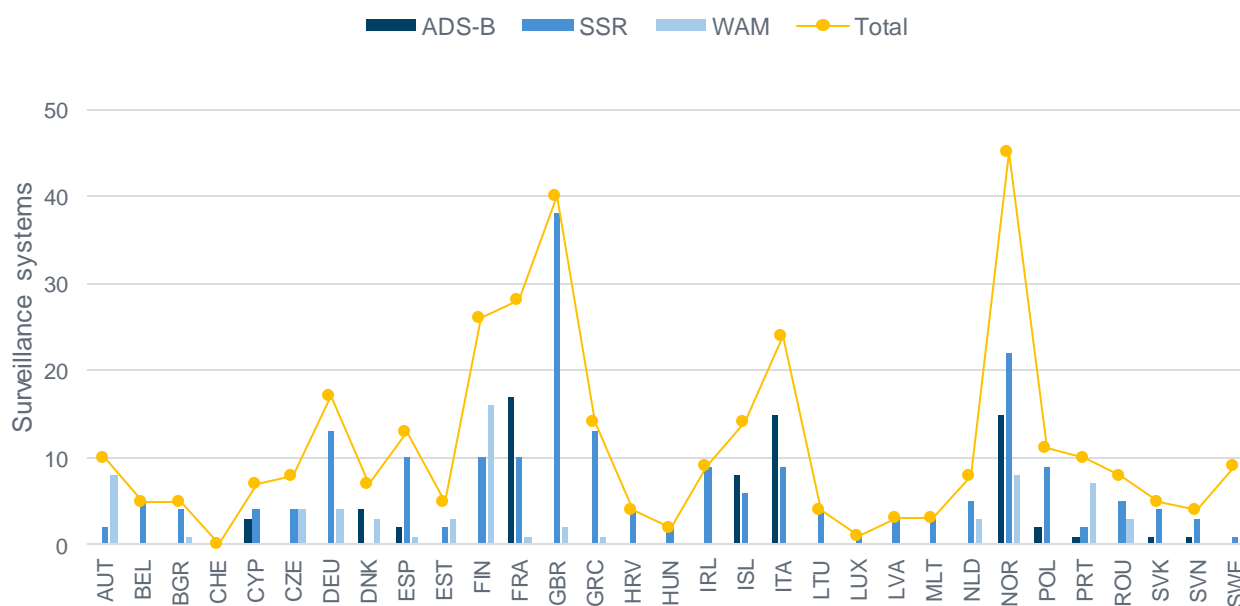


Figure 50. Current situation surveillance systems per country and type

Member State	ADS-B	SSR	WAM	Total
<b>AUT</b>	0	2	8	10
<b>BEL</b>	0	5	0	5
<b>BGR</b>	0	4	1	5
<b>CHE</b>	0	0	0	0
<b>CYP</b>	3	4	0	7
<b>CZE</b>	0	4	4	8
<b>DEU</b>	0	13	4	17
<b>DNK</b>	4	0	3	7
<b>ESP</b>	2	10	1	13
<b>EST</b>	0	2	3	5
<b>FIN</b>	0	10	16	26
<b>FRA</b>	17	10	1	28
<b>GBR</b>	0	38	2	40
<b>GRC</b>	0	13	1	14
<b>HRV</b>	0	4	0	4
<b>HUN</b>	0	2	0	2
<b>IRL</b>	0	9	0	9
<b>ISL</b>	8	6	0	14
<b>ITA</b>	15	9	0	24
<b>LTU</b>	0	4	0	4
<b>LUX</b>	0	1	0	1
<b>LVA</b>	0	3	0	3
<b>MLT</b>	0	3	0	3
<b>NLD</b>	0	5	3	8

Member State	ADS-B	SSR	WAM	Total
<b>NOR</b>	15	22	8	45
<b>POL</b>	2	9	0	11
<b>PRT</b>	1	2	7	10
<b>ROU</b>	0	5	3	8
<b>SVK</b>	1	4	0	5
<b>SVN</b>	1	3	0	4
<b>SWE</b>	0	1	8	9
<b>Total</b>	<b>69</b>	<b>207</b>	<b>73</b>	<b>349</b>

Table 10. Current situation surveillance systems per country and type

#### 4.2.3.3 Current redundancy analysis

Approximate values for coverage redundancy in the current situation are presented in Figure 51 and Figure 52. Among remote islands, highest redundancy can be found in Iceland (13) and the French Polynesia (11). However, the highest redundancy is presented in the main land, reaching a maximum value around 32.

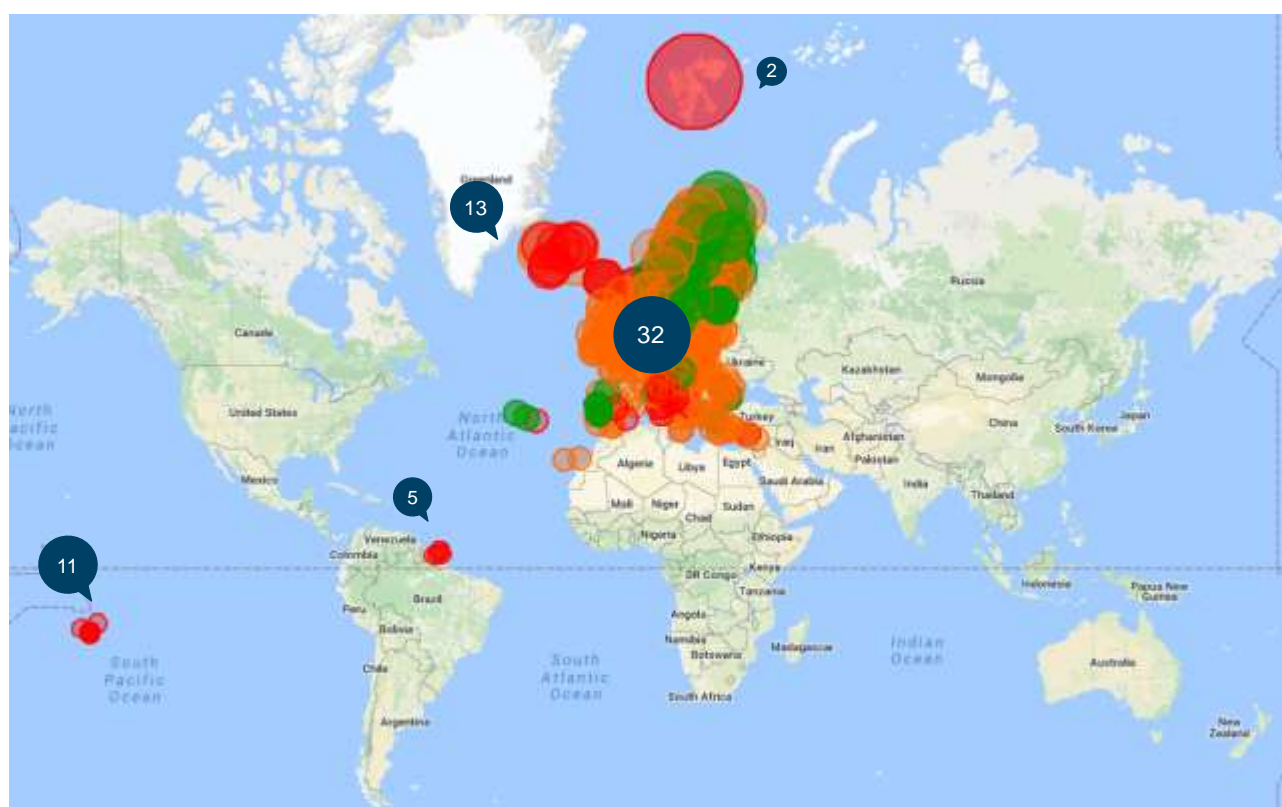


Figure 51. Current surveillance redundancy (worldwide zoom)

Highest redundancy is presented in the United Kingdom, due to the abundant deployment of SSR stations throughout the country. Central Europe, with SSR and WAM coverage, also presents values of redundancy around 30.

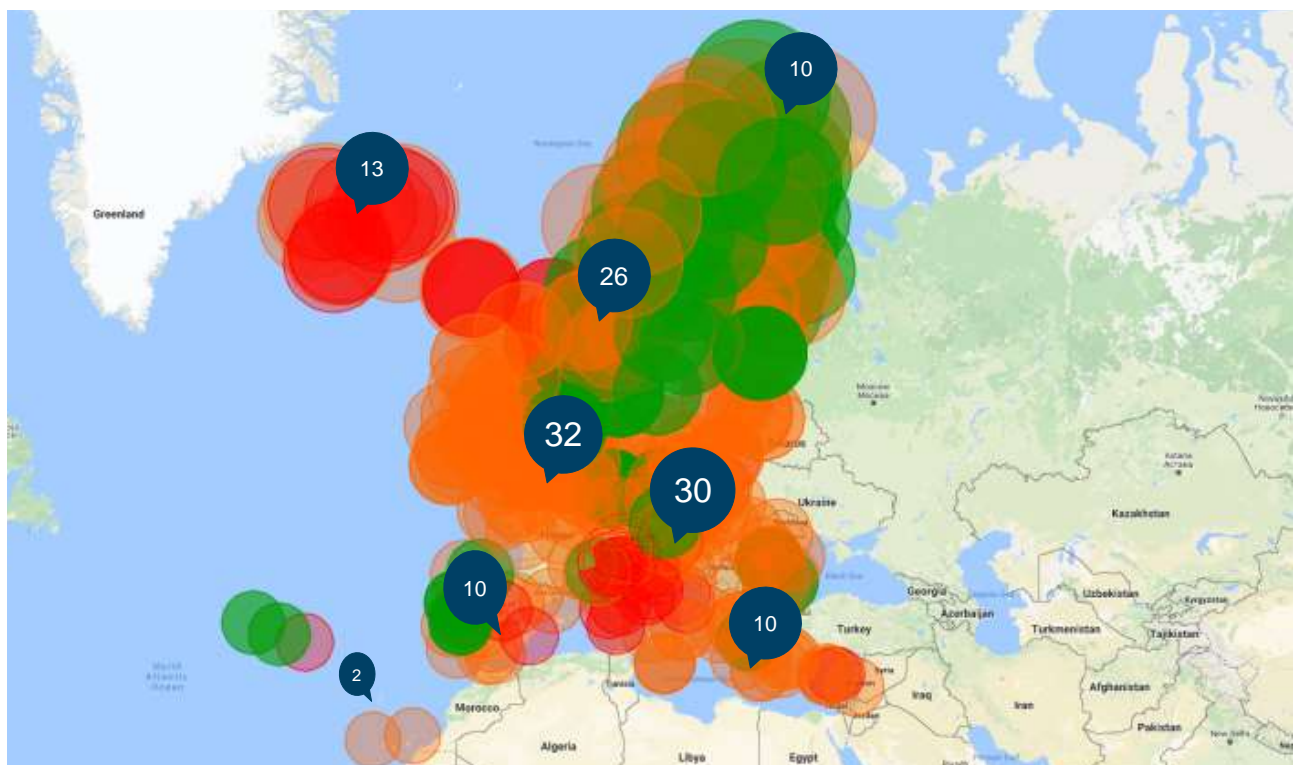


Figure 52. Current surveillance redundancy (mainland zoom)

Segregating by country as depicted in Figure 53, the United Kingdom, Germany and Italy are the countries with highest redundancy provided by the SSR stations. The Northern Europe (Finland and Norway) have also high redundancy due to WAM stations and ADS-B in the latter.

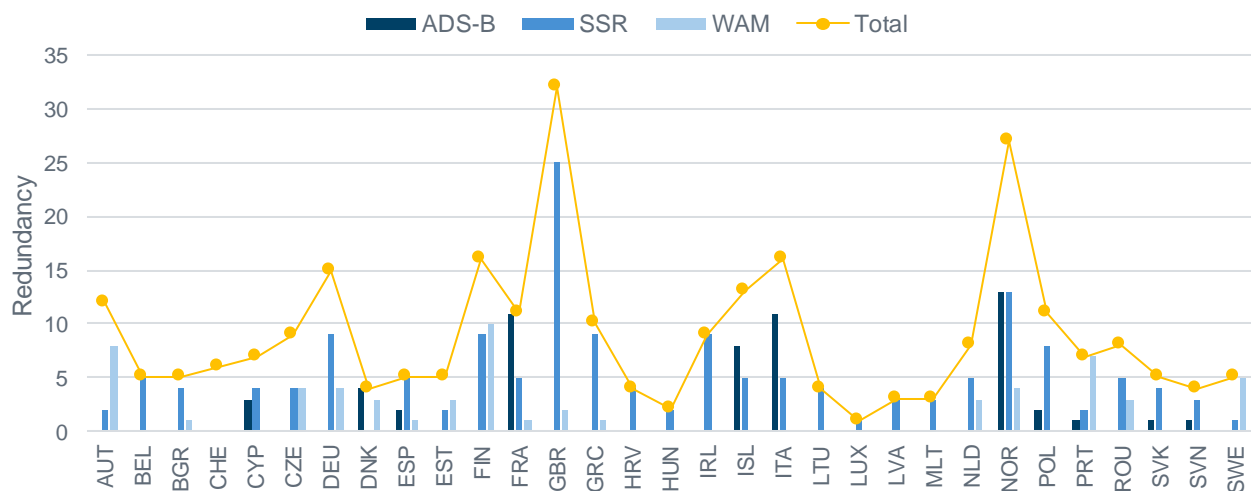


Figure 53. Current redundancy by country and type in EASA MS

#### 4.2.4 Comparison of scenarios

Figure 54 compares the total number of stations in both current and blank sheet scenarios. As it can be observed, the total number of stations in the current situation is around 2.5 times higher than the number of stations required in the blank sheet scenario, leading to the high redundancy situation aforementioned.

Although the number of ADS-B stations is similar in both scenarios, these values cannot be directly compared. In the blank sheet scenario ADS-B deployment aims to provide a full coverage layer in all the EASA MS area, whilst in the current situation ADS-B is located in particular areas.

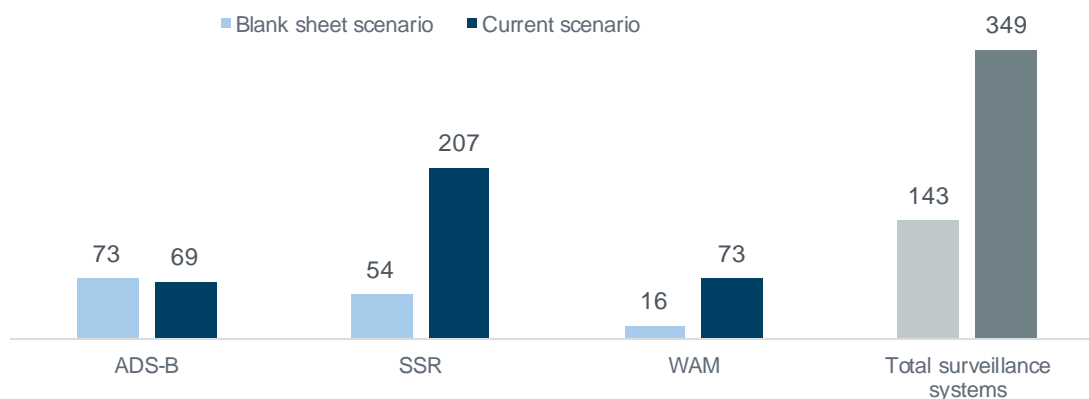


Figure 54. Total number of stations in the current situation and the blank sheet scenario

Figure 55 compares the total surveillance systems in both current and blank sheet scenarios, and depicts the ratio of increase of the systems in the current situation with respect to the blank sheet.

As it can be observed, highest ratios correspond to the countries that in the blank sheet were not provided with any infrastructure, usually small countries. Czech Republic is the case with the highest ratio, going from no stations to 8 (considered as an eight fold increase for simplicity). Belgium, Estonia, Malta or Slovakia are also included in this category.

The United Kingdom, Ireland or Finland also suffer a significant increase (around 4 fold) although in the blank sheet scenario they are provided with several stations. This is due to the high number of SSR that both countries are currently provided. Except 7 countries, all the remaining member states suffer at least a two fold increase compared to the blank sheet scenario.

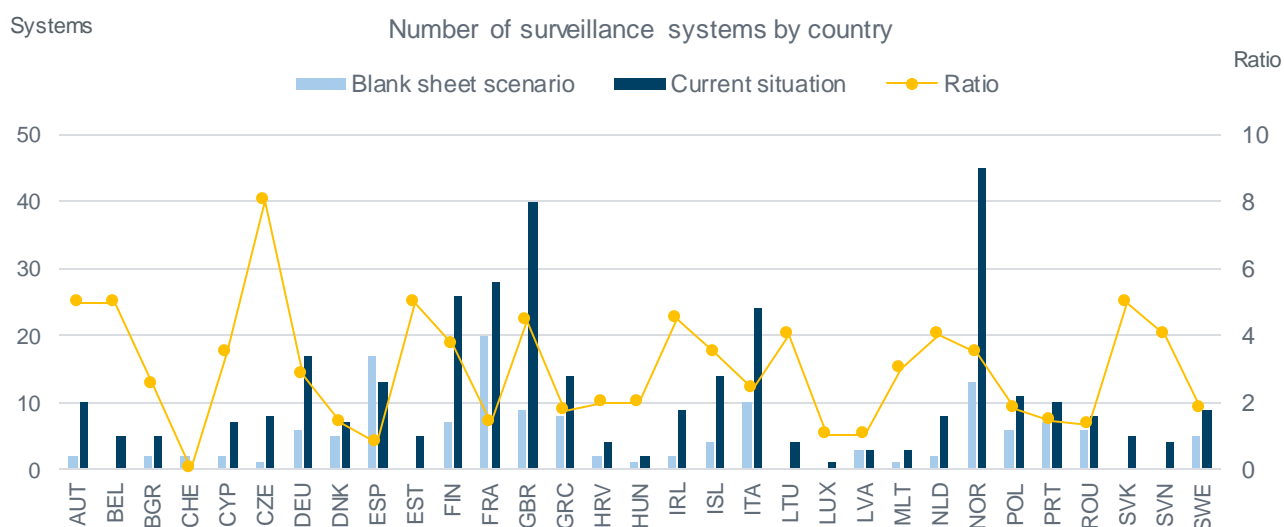


Figure 55. Number of surveillance systems by country in both scenarios

The average redundancy calculated as the arithmetic average of the redundancy per Member State is depicted in the following figure. In the current situation, the average redundancy taking into account all countries is around 9. This is a significant increase compared to the average redundancy in the blank sheet scenario, which is lower than 3.

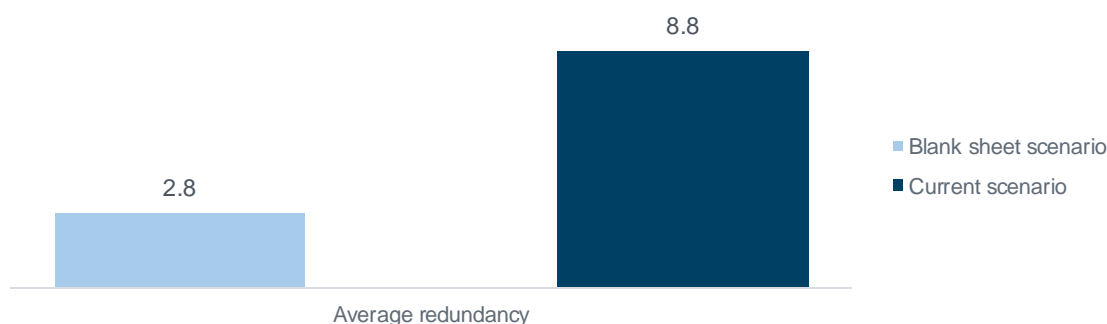


Figure 56. Average redundancy in blank sheet and current scenarios

Finally, a comparison of the increase of redundancy at higher flight levels is presented in Figure 57. Blank sheet redundancy remains at lower values between 6 and 9, whilst in the current situation the redundancy increases until 44 at FL430.

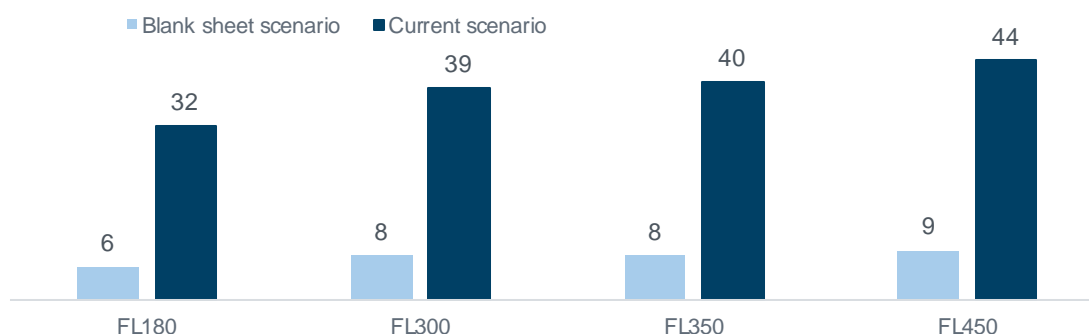


Figure 57. Evolution of redundancy as a function of the flight level

### 4.3 Conclusions of the analysis

The main conclusions of the analysis are summarized below:

- The **blank sheet** scenario eliminates any country boundaries and establishes a single and harmonised deployment with a **total of 149 surveillance systems**, where the total number of systems by country is usually proportional to the extension of the country itself. This deployment allows several countries to eliminate the need of surveillance systems since coverage is obtained from the surrounding countries.
- The maximum **redundancy** in the blank sheet scenario is set as **6** in the areas where WAM coverage is provided. However, the average redundancy in the EASA MS area is around 3.
- On the other hand, the **current situation** highlights an important increase in surveillance technology, suffering around a **twofold increase** (from 143 in the blank sheet to 349 in the current).
- Current coverage **redundancy arises to 32** in the United Kingdom and around 30 in the Central Europe, with an **average value of 9** in all EASA MS area. At higher flight levels, redundancy can increase up to 44.
- **ADS-B** stations are only located in 11 of the 32 EASA Member States, and are mainly deployed in the **insular areas** to cover remote locations. **Italy** is the only mainland country where a significant number of ADS-B stations is deployed. Although the number of stations is similar in the blank sheet scenario, the blank sheet provides full coverage in all the geographic scope.
- The total number of **SSR stations** in the current situation is around **4 times higher** than in the blank sheet, both providing full coverage but in the current situation with an important increase in



redundancy. **WAM** systems are mainly located in the **Northern and Central Europe**, offering partial coverage in 17 of the 32 Member States.

- Most of the countries experience a two fold increase in the total number of surveillance systems compared to the blank sheet scenario.

Surveillance Technology	Blank sheet scenario	Current situation
ADS-B	73 stations	69 stations
SSR	54 stations	207 stations
WAM	16 systems (corresponding to a total of 144 stations)	73 systems (corresponding to a total 657 stations)

Table 11. Summary of surveillance technology stations in both scenarios

Such results may be indicative of non-ideal nominal coverage assumptions for blank sheet scenarios (too optimistic), or of high redundancy of current situation due to operational issues outside of the scope of this analysis, fragmentation in terms of ATM policies, duplicity due to borders, or other non-operational aspects including national security, also outside of the scope of this analysis.

However, although the blank sheet scenario is based on high-level approach, the disparity between both scenarios and the high redundancy of the current deployment is clearly demonstrated. Figure 58 provides the comparison between the location and coverage of both scenarios.

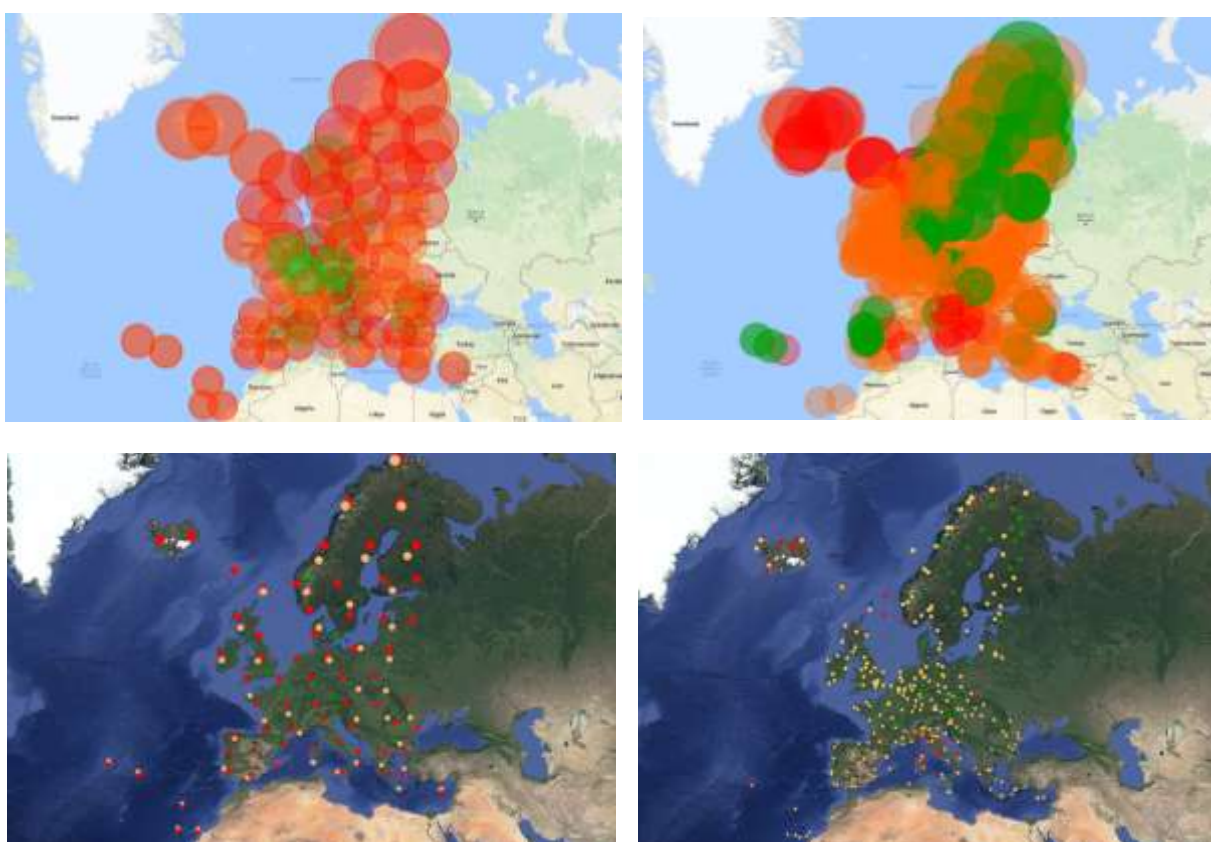
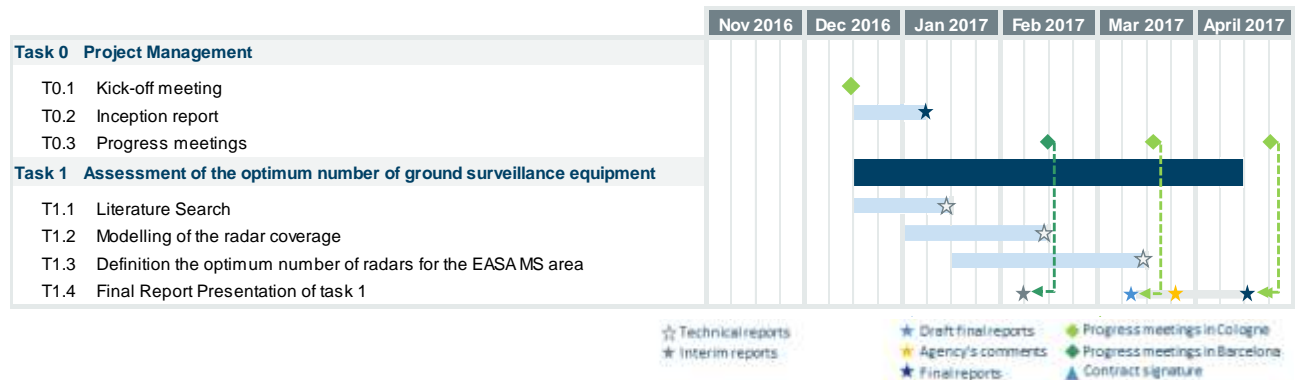


Figure 58. Blank sheet scenario coverage and locations (left) and current coverage and locations (right)

## 5 Next steps

The three subtasks of Task 1 have been assessed in the current date, 4 months after the project kick-off. Task 1 will be closed with the presentation of this report in the third Progress meeting, to be held on the 25<sup>th</sup> of April 2017 in Barcelona. The presentation will gather the last results of the analysis after integrating EASA's feedback, as well as delivering the modelling tool to EASA with all the required implementations.



Next line of actions will focus on the remaining two tasks of the project, which will finish with the ending of the project in mid-June 2017.

ID	Meeting	Location	Date	Duration
KOM	Kick off meeting	Brussels	16 <sup>th</sup> December 2016	1 day
PM1	Progress meeting 1	Barcelona	16 <sup>th</sup> February 2017	1 day
PM2	Progress meeting 2 - Task 1 final report presentation	Cologne	17 <sup>th</sup> March 2017	1 day
PM3	Progress meeting 3 - Task 2 & 3 final reports presentation	Barcelona	25 <sup>th</sup> April 2017	1 day
PM4	Progress meeting 4	Cologne	8 <sup>th</sup> June 2017	1 day

Table 12. Meetings summary

## 6 References

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