DG TREN

GOBAN : GNSS ROADMAP STUDY

FINAL REPORT
CBA ANNEX

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EXECUTIVE SUMMARY

The GOBAN study addresses a number of salient issues of GNSS as sole service, and this annex to the Final Report updates and refines the Cost-benefit Analysis delivered in the Interim Report, and provides a detail background presentation of safety regulation issues.

The approach taken for the economic approach consists in assuming that, without Galileo, there would be too many technical, political and institutional obstacles to the adoption of GNSS as sole service.

Therefore, we have defined a non-Galileo baseline indefinitely prolonging (into the 2015+ target timeframe of this study) the mix of navigation aids (modernised GPS, SBAS, VOR, DME, GBAS, ILS and/or MLS) which is foreseen to be available at the 2010-2015 time horizon.

We have then defined a with-Galileo scenario consisting of: modernised GPS, SBAS, Galileo and GBAS such that GNSS is sole service for aviation.

We performed a differential assessment of costs and benefits between the two scenarios, and we reached the following preliminary conclusions regarding the long term perspective.

For Cat II/III precision landing guidance the main savings obtained from the with-Galileo scenario are:

- the (at least partial) decommissioning of ILS and/or MLS equipment is the main potential long term advantage of the with-Galileo option
- the non-implementation of new ILS at currently non-equipped but fast-expanding airports (that would otherwise require the implementation of Cat II/III precision landing) is also significant, as the alternative “green field” implementation of ILS and/or MLS would be costly
- there are also significant potential savings to be derived from replacing multi-system MMR by multi-frequency multi-constellation GLS-only receivers, when that configuration becomes the “standard fit” on board all new aircraft ; however, this is a very long term (2020+) potential benefit

For en route navigation the main savings are:

- The decommissioning of all the en route VOR/DME infrastructure in high traffic density areas (this applies in Europe and other developed regions),
- The non-deployment or non-replacement of additional VOR/DME infrastructure in lower traffic density areas (this applies in the rest of the world),

For TMA navigation, we expect a number of VOR/DME to be maintained in the foreseeable future as a fall-back means required for IFR NPA operation by those IFR flights conducted on board aircraft with little or no capability for autonomously maintained precision area navigation (General Aviation and commercial transport turbo-prop) and this should have an impact on charging mechanisms; however it should be noted that there is a trend to low-cost computerisation of navigation on board low end aircraft.

We have also identified a number of additional side benefits in terms of availability of more homogeneous and more flexible navigation service, especially for TMA navigation in remote areas.

However, since the safety assessment is made on the basis of classical approaches and ILS-like landing procedures, we have not quantified these side benefits in our CBA, for the sake of consistency between the economic analysis and the safety assessment.

Under all the assumptions described above, cost-benefit analysis of the with-Galileo scenario is positive for airspace users only in that long term perspective, under the condition that the share of the Galileo infrastructure cost to be shouldered by aviation users remains small at all time.

A key assumption in our work is the high availability of GNSS. We have assessed the direct costs of air transport disruption potentially created by an even relatively short interruption of service, and the disorganisation of traffic generated by the triggering of safety-inspired contingency plans would be extremely costly for the air transport industry and its customers.

We have also analysed other potential side benefits derived from the potential integration of CNS functions, and the problems they raise in connection with the safety analysis.

We identified four salient areas of systemic integration:

- The use of aircraft own position reports (through ADS or ADS-B) as a complement or substitute to en route radar-based surveillance ; since the configuration envisaged for GNSS sole service is highly redundant (two independent constellations + augmentation) a NAV-SUR integration strategy making use of that redundancy (by cross-checking and/or hybridising two separately derived GNSS positions) could be developed to reduce the multiplicity of radar coverage for en route navigation ; however, considering (as explained below in the safety analysis section) the difficulty of traffic management in busy TMAs in case of GNSS failure, it is unlikely that TMA radar coverage could be reduced.
- The use of GNSS-derived surveillance in support of airport surface navigation for the implementation of A-SMGCS systems is an alternative to the multiplication of ground-based tracking systems
- The use of GNSS-derived synchronisation for the reconciliation of flight data between the aircraft and the ground is likely to facilitate the implementation of tactical traffic management tools based on 4D trajectory predictions ; the relatively low level of accuracy required makes it relatively easy to maintain a good synchronisation in case of GNSS failure and thus reduces the dependability problem
- By contrast, the use of GNSS-derived time synchronisation in the ground-ground (e.g. in high throughput infrastructure networks) and air-ground communication infrastructure may become a matter of concern because the high accuracy required simultaneously makes the GNSS especially attractive for that function, but also create a potential risk of triple failure degrading simultaneously C, N and S. We recommend to carefully study all the potential indirect dependencies on GNSS created by the current generalisation of GPS synchronisation within general purpose wide area networks (or for synchronising surveillance radars) and their potential impact in the context of CNS integration strategy and conversely to study the benefits of adding the Galileo time as an independent source of synchronisation.

1 INTRODUCTION

1.1 Objective and scope of the study

The objective of this study is to assess the perspective of establishing the GNSS as sole service for aeronautical navigation in all phases of flight, through the introduction of Galileo (to be put in service in 2008), and to determine what the contribution of Galileo can be to that end.

As of today, the notion that GNSS may become the sole external means of aeronautical navigation is met with puzzlement and incredulity. However, addressing all the issues raised by the sole service perspective is the best way to properly assess the complex trade-offs between safety and costs.

Deliberately, the approach of this study is to take a long term perspective (beyond 2015) so as to identify the key aspects of relevance to the decision-making process:

- the operational validation activities that have to be undertaken so as to clarify all the major areas of uncertainty that still exist,
- the tasks that have to be completed and their likely duration and ordering, so as to be able to propose a roadmap towards the sole service end state.

Two main areas have to be explored:

- safety issues raised by the sole service perspective,
- economic issues associated with ground and aircraft equipment cost.

In addition to those two main areas, a number of issues regarding institutional and legal arrangements have to be discussed, and additional incentives to go for sole service have to be appreciated.

The scope of this study is the foreseen technical and operational landscape regarding the aeronautical use of GNSS in 2015+, and the assessment of economic and operational issues on a world-wide basis.

1.2 Content of this annex

This annex provides a Cost-Benefit Analysis based on a world-wide assessment of navigation equipment costs (reflecting also the quantitative benefits expected from the partial or total decommissioning of non-GNSS elements), on the one hand, and the more qualitative advantages yielded by a more continuous and homogeneous service, on the other hand ;

2 COST BENEFIT ANALYSIS

2.1 Approach and methodology

As any navigation system such as INS, DME or GPS, Galileo will be seen and categorised as RNAV equipment contributing to the determination of the position of the aircraft, eventually in combination with other navigation systems. As a consequence, the following characterisation of RNP and RNAV will apply to Galileo.

2.1.1 Concepts of Required Navigation Performance (RNP)

The RNP concept applies to aircraft navigation performance within a defined airspace and it therefore affects, and places requirements upon, both the aircraft and the airspace. RNP is intended to characterise an airspace by means of a statement of the navigation performance accuracy (RNP type) necessary for operations within that airspace. RNP types are identified by a single accuracy value.

From the aircraft perspective, the accuracy value is based on the combination of the navigation sensor error, airborne receiver error, display error and flight technical error. The total system error (TSE) allowed in the individual lateral and longitudinal dimensions must be better than the specified RNP value for 95 per cent of the flight time of any single flight.

From the airspace perspective, the achievement of the navigation performance accuracy value (RNP type), within a defined airspace, requires the provision of a supporting navigation infrastructure. The RNP types can be used by airspace planners to determine airspace utilisation potential and as an input in defining route widths and traffic separation requirements, although RNP by itself is not sufficient basis for setting a separation standard.

Detailed guidance material on the concept and provisions of RNP, how RNP affects the system providers and system users is provided in ICAO Document 9613 - ICAO RNP Manual. This document addresses the use of the RNP Concept in the En-Route phase of flight.

The ICAO Document 9650 (Report on the Special Communications/Operations Divisional Meeting (1995) Appendix A – Description of Proposed Required Navigation Performance (RNP) Concept for Approach, Landing and Landing Operations) addresses the RNP Concept to approach, landing and departure phases of flight. ICAO Document 9650 provides the definition of RNP as “A statement of the navigation performance accuracy, integrity, continuity and availability necessary for the operation within a defined airspace.

The ICAO Document 9613 specifies five types of RNP for general application to en-route operations. These are RNP 1, 4 10, 12.6 and 20. The numerical value indicates the required 95% lateral and longitudinal position accuracy.

RNP 1 - This is envisaged as the RNP type necessary for the most accurate and efficient ATS route operations. It will also provide the most effective support of operations, procedures and airspace management for transition to and from the TMA and the required ATS route. The navigation accuracy achieved by P-RNAV equipped aircraft in EUR airspace equates to RNP 1 but lacks the advanced functionality.

RNP4 / RNP 5 (RNP 5 applies in EUR) - This RNP type will support ATS routes and Airspace Design that are dependent upon the distance between Navaids (VOR/DME). It is the RNP type associated with operations in continental airspace. In Europe, the navigation accuracy of aircraft approved for operations on the existing EUR B-RNAV Route Structure, or of those aircraft without an RNAV capability operating on the remaining conventional routes defined by VOR or VOR/DME, where the VOR facilities are less than 100 NM apart, equates to RNP 5.

RNP 10/ RNP 12.6/ RNP 20 - These types of RNP support lateral and longitudinal separation minima in oceanic airspace and remote areas with limited navigation aids. RNP 20 is the minimum navigation performance considered acceptable to support ATS route operations.

This minimum level of performance is expected to be met by any aircraft in any airspace at any time. At the present time no application of these RNP types is foreseen in EUR.

Future Use of RNP ≤1 - It is anticipated that a navigation performance of RNP ≤1will be required for future TMA Operations in the EUR Region.

[A2.1] We assume that RNP 0.3 is the target value for the RNP level in main TMAs at the time horizon of this study and that RNP 1 will remain the lowest applicable RNP level for en route navigation.

2.1.2 Concept of Area Navigation (RNAV)

Area Navigation (RNAV) is defined as a method of navigation that permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

In general terms, RNAV equipment operates by automatically determining aircraft position, establishing the desired flight-path, and providing path guidance to the next waypoint. The aircraft position is derived from one, or a combination of, input(s) from the following navigation systems:

- INS* or IRS
- VOR/DME
- DME/DME
- LORAN C*
- GNSS (GPS)

2.1.3 Concept of RNP-RNAV

The concept of RNP-RNAV is introduced in the Minimum Aviation System Performance Standards (MASPS) for Required Navigation Performance for Area Navigation (RNP-RNAV), RTCA DO 236A / EUROCAE ED 75 RNP-RNAV. RNP-RNAV combines the accuracy standards laid out in the ICAO RNP Manual (Doc 9613) with specific containment integrity and containment continuity requirements, as well as functional and performance standards for the RNAV system, to achieve a system that can meet future ATM requirements. The functional criteria for RNP-RNAV address the need for the flight paths of participating aircraft to be both predictable and repeatable to the declared levels of accuracy.

The ICAO Obstacle Clearance Panel (OCP) is developing instrument procedure design criteria for RNP-RNAV and the ICAO Safety and Separation Panel is considering the separation criteria for RNP-RNAV. To date, instrument procedure design criteria are only available for RNP 0.3 and route spacing criteria have only been established for RNP4.

In addition, when the ICAO All Weather Operations Panel (AWOP) considered the application of RNP concepts to approach procedures, and to precision approaches in particular, it was decided that vertical navigational accuracy had to be addressed as well as horizontal accuracy. As a result, a range of RNP types were defined from RNP 1 to RNP 0.003/z, where z reflects the requirement for vertical guidance. The GNSSP subsequently proposed a set of values that could be supported by Space Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS). These values are still under review.

At present there is no JAA guidance material to cover the application of RNP-RNAV.

The RNP types that are currently in use or are being considered for use are detailed in the Table below:

RNP Type	Required Accuracy (95% Containment)	Description
0.003/z	± 0.003 NM [± z ft]	Planned for Cat III Precision Approach and Landing including touchdown, landing roll and take-off roll requirements. (ILS, MLS and GBAS)
0.01/15	± 0.01 NM [± 15 ft]	Proposed for Cat II Precision Approach to 100 ft DH (ILS, MLS and GBAS)
0.02/40	± 0.02 NM [± 40 ft]	Proposed for Cat I Precision Approach to 200ft DH (ILS, MLS, GBAS and SBAS).
0.03/50	± 0.03 NM [± 50 ft]	Proposed for RNAV/VNAV Approaches using SBAS.
0.3/125	± 0.3 NM [± 125 ft]	Proposed for RNAV/VNAV Approaches using Barometric inputs or SBAS.
0.3	± 0.3 NM	Supports Initial/Intermediate Approach, 2D RNAV Approach, and Departure. Expected to be the most common application.
0.5	± 0.5 NM	Supports Initial/Intermediate Approach and Departure. Only expected to be used where RNP 0.3 cannot be achieved (poor Navaid infrastructure) and RNP 1 is unacceptable (obstacle rich environment)
1	± 1.0 NM	Supports Arrival, Initial Intermediate Approach and Departure; also envisaged as supporting the most efficient ATS route operations. Equates to PRNAV.
4	± 4.0 NM	Supports ATS routes and airspace based upon limited distances between Navaids. Normally associated with continental airspace but may be used as part of some terminal procedures.
5	± 5.0 NM	An interim type implemented in ECAC airspace to permit the continued operation of existing navigation equipment. Equates to B-RNAV.
10	± 10 NM	Supports reduced lateral and longitudinal separation minima and enhanced operational efficiency in oceanic and remote areas where the availability of navigation aids is limited.
12.6	± 12.6 NM	Supports limited optimised routing in areas with a reduced level of navigation facilities. NAT MNPS

2.1.4 RNAV development in ECAC

2.1.4.1 Basic RNAV (B-RNAV) Operations

B-RNAV was introduced in the EUR airspace in 1998. A Basic RNAV (B-RNAV) capability is currently required for en-route operations in the majority of the airspace of the EUR Region. It is intended that during the period 2002 to 2005, the ATS Route Network of the EUR Region will be made up of B-RNAV Routes for all traffic flows above FL 100.

Detailed Guidance Material on Airworthiness Approval and Operational Criteria for the use of Navigation Systems in European Airspace Designated for Basic RNAV Operations is provided in JAA TGL No. 2(rev 1), setting accuracy, availibility, integrity requirements and functions to be made available to the pilot.

2.1.4.2 Precision RNAV (P-RNAV) Operations

As a further development of the concept of area navigation within the European region, Precision Area Navigation (P-RNAV) is being developed for implementation in terminal airspace, as an interim step, to obtain increased operating capacity together with environmental benefits arising from route flexibility. However, the initial carriage and use of RNAV equipment capable of P-RNAV operations will be optional. This will enable the application of P-RNAV in terminal airspace for suitably equipped aircraft.

The P-RNAV application addresses a navigation performance for track keeping accuracy that equates to RNP1. However it does not satisfy all of the functional aspects of, the Required Navigation Performance (RNP) concept promulgated in ICAO Documents 9613 and 9650. P-RNAV is expected to be progressively replaced by RNP-RNAV operations.

Guidance Material on Approval for Precision RNAV (P-RNAV) Operations in Designated European Airspace is provided in JAA TGL 10. The JAA TGL 10 is based on the assumption that the infrastructure necessary to support and safeguard P-RNAV Operations/Procedures has been provided by the appropriate State Authority.

2.1.5 RNAV development in the USA

The United States Federal Aviation Administration (FAA) Navigation and Landing Transition Strategy plans a migration from navigation based on Victor and Jet Route airway structures to area navigation (RNAV) apart from the airway structures. Satnav provides an RNAV capability. The overall objective of RNAV, whether it be provided by augmented satellite navigation or derived from aircraft flight management systems (FMS), inertial reference systems (IRS), or FMS/IRS in combination, is to remove the restrictions imposed by reliance on ground-based navigation aids.

This change to RNAV opens up more airspace for use by aircraft, increases options for arrivals and departures, and reduces separation requirements—and hence increases capacity—in portions of the airspace. Navigation and landing is migrating to required navigation performance (RNP) operations. Detailed requirements for RNP operations in the US are under development.

As WAAS and LAAS are fielded and users equip, satellite navigation (including GPS/IRS integration for some aircraft) will become the fundamental system used for RNAV operations. Airspace will be converted to an RNAV-based structure, eliminating routes based on the location of ground-based navaids, increasing the diversity of arrivals and departures, and providing approaches with vertical guidance to all runways.

The FAA considers that, in the event of interference to GPS, navigation must revert to other means, as commercial operations must continue uninterrupted. General aviation operators may choose to retain navigation equipment in their aircraft with the ability to continue to navigate, or could avoid flying in the area of interference. General aviation operators that are dependent on Satnav and are operating in instrument weather conditions when a disruption occurs must request radar vectors to reach visual conditions or to fly clear of interference.

Redundant capabilities allow the pilot to continue operating in the presence of interference using the same navigation techniques, with guidance coming from systems other than GPS. The redundant RNAV capabilities that will be supported by the FAA include:

- GPS/IRS
- VOR
- ILS
- DME/DME
- LORAN C, but the feasibility of Loran to provide an RNAV non6precision approach capability is still under evaluation.

2.1.5.1 FAA plans for precision Approach – ILS

The FAA will retain ILS on a reduced number of runways for the more demanding low-visibility cases where interference is occurring. All of the current ILS facilities supporting Category II/III operations 3 will be retained on existing runways and new systems will be added where needed to support Category II/III operations to new runways at delay-constrained airports. New ILS installations will continue until the GPS/LAAS capability can support Category II/III operations at these airports. When that happens, the precision approach infrastructure will be re-assessed based on the GPS signals, power, and receiver robustness available at that time. Any resulting changes to the transition strategy will be published in the Federal Radionavigation Plan.

Approximately 1,275 ILS's are installed throughout the US (including localizer-only installations), with about 700 different airports served in the continental United States.

Approach lights are installed to support most of these ILS's. There are 117 ILS's that provide Category II or Category III service. Until LAAS attains the capability for Category II/III approaches, all of the Category II/III ILS's will be retained and more may need to be added to accommodate new runway operations at larger airports.

Many Category I ILS's will be retained to fulfill precision approach capabilities as a backup to Satnav. Serving as a backup, it is not necessary to retain all ILS's. As airports transition to Satnav approaches, the FAA will decommission ILS's which are not necessary as part of the redundant navigation system and are no longer cost-beneficial to retain. LPV approaches using GPS/WAAS are expected to enable the elimination of a number of ILS units starting in 2010. In these instances, approach lighting will be retained so that the LPV visibility minima are the same as currently available with the ILS. For airports designated as landing locations for redundant or backup capabilities, at least the primary runway (most used in IMC) will retain its ILS. At large capacity-constrained airports, most ILS's will be retained to ensure adequate arrival and departure capacities in the event of interference. Here, pilots will fly either an RNAV or VOR approach to an ILS final, or receive radar vectors. Category I ILS's will not be removed from airports until WAAS or LAAS approaches have been commissioned at those airports.

The number of Category I ILS's in the continental United States will be reduced from the current 933 systems. The FAA will remove excess ILS's at the end of their service life, retain the approach lighting systems, and replace the ILS's with GPS-based approaches augmented either by WAAS or LAAS. At least one ILS will be retained on the primary runway at those airports necessary for recovery of aircraft during an interference event. Pilots landing in areas of GPS interference can fly an RNAV arrival procedure to an ILS final approach segment, receive radar vectors to an ILS final, or fly the published ILS approach.

2.1.5.2 FAA plans for GPS/IRS

The FAA will allow the use of GPS/IRS, but the period of time that RNAV operations can be supported after loss of GPS depends on a number of factors, including the RNP for the operation, the manner in which the systems are integrated, and the aircraft trajectory prior to the loss of GPS. The principle advantage of GPS/IRS as the redundant capability is that it is autonomous in the aircraft and does not rely on any external Navaids.

2.1.5.3 FAA plans for DME/DME

The FAA will retain at least the current network of 930 DME locations to support FMS operations. The FAA may need to expand the DME network to provide a redundant RNAV capability for terminal area operations at major airports. One of the most challenging operations for a redundant service are departure procedures. The coverage of DME at low altitude is not sufficient to guarantee adequate updating of the IRS. Aircraft without IRS integration may experience departure restrictions in the event of interference. Aircraft that integrate IRS may also experience some restrictions.

The FAA will need to evaluate coverage from the surface to approximately 1,000 feet and upgrade the IRS update locations on airports. Users must know performance limits for their individual navigation systems given various updating scenarios. The inability to depart during GPS interference would be for those rare locations where terrain is a factor and radar departures are not available today. While there are published departure procedures for many airports, most departures include a takeoff and climb on runway heading with radar vectors being provided. Radar vectors would continue to provide sufficient redundancy until receiving an update in position from DME during an interference event.

Current plans are to retain full capability for DME/DME navigation in the continental United States. This will include all VORTAC, VOR/DME and ILS/DME. The DME coverage is very dense at en-route altitudes, where pilots are within range of three or more DME's most of the time. However, coverage at lower altitudes is less dense, especially when considering the geometric requirements for DME/DME position solutions. Accordingly, in the future it may be desirable to add some DME's near certain airports to assure adequate DME/DME RNAV capability at lower altitudes. Also, in the future it may be desirable to remove some DME's that produce redundant en route coverage and do not enhance low altitude coverage at airports where DME/DME navigation is used.

2.1.5.4 FAA Plans for VOR

The current VOR service in the continental United States is very dense, even at fairly low altitude. 1,008 VOR's cover the continental United States out of the total 1,033 VOR's in the US. One objective of retaining VOR's is to provide en route coverage at and above 5,000 feet AGL in non-mountainous areas, and to retain existing coverage in mountainous areas to support general aviation in the event of Satnav interference. A second objective of VOR coverage is to provide landing aids at airports, either for a nonprecision approach or for guidance to an ILS approach.

To estimate required coverage for VOR as a backup to Satnav, the 200 busiest airports were selected based on the number of instrument operations. These airports represent approximately 92% of the instrument operations performed in the NAS, and nearly all are served by a radar approach control. A VOR serving each airport was selected and used as the initial basis for a hypothetical list of VOR's to be retained. Over 60 of these airports were not served by a VOR approach, although a VOR was often near the airport and served another airport. A total of 177 existing VOR's were retained to serve the 200 airports and the airspace near them. After selecting the 177 VOR's, additional existing VOR's were added to provide coverage at 5,000 feet AGL. In mountainous areas, nearly all VOR's are to be retained. Where a VOR did not provide a non-precision approach, another nearby VOR was substituted that did provide an approach. In addition, some VOR's were added to enable a non-precision approach (i.e., some non-precision approaches require multiple VOR's). This added 294 VOR's to the hypothetical list of VOR's to be retained, for a total of 471 VOR's.

As the FAA begins to replace existing VOR's that have approached the end of their service life, VOR's in the minimum operating network will be fully replaced. An opportunity exists to relocate VOR's to improve airport coverage, to deal with restrictions imposed due to obstructions that block signals, and to adjust coverage.

The FAA intends to turn off unnecessary Navaids, replace those used as part of the minimum operating network, and provide for both en route backup and the ability to land using a non-precision approach for at least 200 airports. Not every airport needs a backup, since interference is not expected to be US-wide. The FAA plans to begin removal of VOR services in 2010 and complete the transition by 2014.

2.1.5.5 FAA plans for LORAN-C

The FAA and DOT are assessing the capability of Loran to provide an RNAV redundant service. In order to be considered as a viable alternative, Loran will need to provide at least an RNP-0.5 non-precision approach capability. The DOT was expected to make a decision on whether or not to retain Loran by the end of 2002, but discussions between the FAA and the Department of Transportation are still ongoing, so no decision has yet been made.

2.1.5.6 FAA back-up plans for GNSS

A minimum operating network of VOR's and long-range NDB's will be retained in the NAS as a backup capability. Pilots who encounter interference to Satnav will be able to tune a ground-based Navaid, proceed to that Navaid and either continue the flight or land. Efficiency is lost due to requirements to fly from one Navaid to the next. The network of retained VOR's and long-range NDB's are designed to recover aircraft safely, not support a route structure for routine navigation.

Pilots may choose to retain one VOR receiver for use as a backup. The coverage criteria used for the minimum operating network in the continental United States is based on line-of-sight reception from at least one VOR when at 5,000 feet or more above ground level (AGL). To assure safety, the existing VOR structure will be retained in the mountainous terrain of the west, in Alaska and Hawaii, and at offshore locations. For Alaska and certain offshore areas like the Gulf of Mexico, the FAA will also retain and operate the long-range NDB's. Both the VOR and the long-range NDB backups are retained for recovery of aircraft that are caught in an interference event. The network retained is not practical for routine en route navigation, but provides the ability to navigate to an airport VOR and fly a nonprecision approach or intercept an ILS.

The FAA considers that the transition to Satnav for aviation navigation is made possible by the use of GPS, GPS/WAAS and GPS/LAAS. Satnav may be used for all phases of flight including terminal-area navigation (e.g., departure procedures and standard terminal arrival procedures), en route flight, and instrument approach procedures (e.g., nonprecision approaches, approaches with vertical guidance and Category I precision approaches). It is expected that the FAA's LAAS will eventually support Category II and III precision approaches, however, additional research and development will be required before these systems are fielded.

2.1.5.7 FAA timescales

The reduction in the number of VOR's starts slowly in 2010, removing some VOR's that do not support airports and that are in place today to route aircraft along redundant flight paths. Between 2007 and 2012, the FAA replaces those VOR's identified as part of the minimum operating network.

Reduction in the number of Category I ILS's can start in 2010. By this time, WAAS LPV and LAAS procedures will have been available for 5 years. Since at least one ILS is retained at airports supporting the backup strategy, the impact of removal is primarily borne by commercial aviation. The air carriers are migrating to RNAV approaches and expect to use a combination of WAAS and LAAS, and by 2010, the LAAS acquisition contract is in the last year of its option and most of the Category I LAAS units will have been deployed. Many Category I ILS's have exceeded their service life and have had service life extensions. The FAA will need to begin a replacement program for the older ILS units as early as 2005. This replacement will need to focus on those aging ILS's on the primary runway.

Most of the Category II/III ILS's were deployed in the 1990's and, with service life extensions, can continue to operate well past 2015. There is no reduction in Category II/III ILS's until LAAS is able to deliver equivalent service and vulnerability concerns are addressed. The precision approach infrastructure will then be re-assessed based on the GPS signal power and receiver robustness available at that time. A reduction in the number of Category II/III ILS's may then be considered.

2.1.6 Implication of concepts of RNAV and RNP on navigation applications

2.1.6.1 Provision and maintenance of take-off guidance at airports

The increased demand for optimised runway utilisation requires lower take-off and landing minima, which can potentially improve/maintain the runway capacity for operations in low visibility conditions.

Runway guidance is currently provided on Cat III Precision Approach runways by ICAO standardised non-visual systems to approach and landing, i.e. ILS and MLS, which can also be used for departure operations. Runway guidance could also be provided by INS or IRS with update on the runway prior to departure. However, the costs of this equipment are still high.

It is expected that GNSS Ground Based Augmentation Systems (GBAS), as required for Cat III operations, thus providing runway guidance, may become available in the timeframe 2010 - 2015.

The availability of high quality aeronautical data is critical to the successful development of Cat III departure systems. The required enhanced AIS data integrity must be widely available in the timeframe 2005-2010.

2.1.6.2 Provision and maintenance of AWOC (NPA and Cat I/II/III) at airports

The traffic increase will create major constraints in low visibility conditions. This problem will appear at all categories of airports. The number of airports with Cat II/III capabilities is expected to increase in future. Non-precision approaches and Cat I Precision Approach operations will continue to be required at ECAC airports, in particular in medium and low density areas.

NPA procedures based on GNSS and DME/DME are expected to replace many NDB and VOR/DME procedures before 2010. VOR will continue to support non-precision approach operations until 2010. The future enhancements to GNSS for civil use are expected to allow for faster NDB/VOR rationalisation/withdrawal.

ILS Cat I is expected to remain in use until the end of its service life at locations where there is no stringent requirement for upgrading/replacing. It is expected that ILS Cat I will be replaced by GNSS, allowing for decommissioning by 2015.

Cat II/III operations in Europe are currently supported by ILS Cat II/III. Its continued use is recommended as long as economically beneficial and operationally acceptable. Where the levels of service of ILS Cat III cannot be maintained, MLS could be considered as a candidate to replace ILS Cat III in the timeframe 2000-2015. It is expected that GBAS, as required for Cat III operations, may become available in the timeframe 2010 - 2015.

The ILS is likely to be threatened by VHF interference, multipath effects caused by obstacles at and around airports, channel limitations. Frequency issues will become more stringent during the transition period. Frequency allocation cannot be achieved by a simple transfer and, in addition, several systems (ILS, MLS, GBAS) will need to be supported at the same time.

MMR could provide the means for flexible transition. The development of MMR is critical for maintaining full interoperability for landing systems. MMR is already available and progressive implementation of MMR is recommended.

In order to allow the proper continuation of Cat I/II/III operations, to avoid the need for equipping with MLS and to provide a multi-modal cost-effective infrastructure, it is an urgent requirement to initiate NOW all the necessary studies for a safe implementation of GNSS based Cat I/II/III capable systems.

2.1.6.3 RNAV in TMAs

While physical extensions to airports, especially additional runways, may take a long time, changes to TMAs may be made much more quickly. The proposed TMA reorganisation is based on current systems and on the application of RNAV, without major technological changes/advances. RNAV could bring cost savings, as a result of more consistent performance, i.e. improved SIDs/STARs resulting in either noise abatement or reduced track length.

In the period up to 2005, RNAV terminal procedures will be introduced for the use of appropriately equipped aircraft. There will be some new procedures, but in many cases they will overlay conventional procedures.

Between 2005-2010, RNAV could be mandated in selected TMAs, but this will require clearly expressed user requirements, users consultation and positive cost-benefit analyses. The need for additional aircraft equipment will need to be carefully analysed.

The standardisation of RNAV procedures has started and guidance material to support RNAV operations in TMAs is already available. JAA Guidance Material for airworthiness and operational certification for P-RNAV operations is already available (JAA TGL10).

The requirement to provide 5-7 years advance notice of change in requirements may prevent the mandatory use of P-RNAV (RNAV equipment meeting RNP 1 accuracy requirements) in the TMA before 2006 – 2007 and it might be overcome by the requirement to implement RNAV RNP MASPS. Conventional procedures will continue to be provided till then.

Due to significant differences between TMAs, it is important that a CBA is performed prior to setting up a mandatory requirement for RNAV in any TMA. The cost benefit must be demonstrated either by the reduction in infrastructure costs or the ability to effectively increase capacity/economy and/or reduce the environmental impact of operations.

By 2010, RNAV could be mandated in all TMAs. This will be linked with a possible mandate of carriage of RNP 1 RNAV MASPS compliant equipment for en-route operations. RNAV operations in TMAs will require RNP $\leq$ 1 RNAV MASPS compliant equipment. A mandatory requirement for RNP1 operations would also imply a comprehensive DME coverage at lower flight levels and/or appropriate GNSS infrastructure available. Enhanced AIS data integrity must be widely available in the timeframe 2005 - 2010.

Increased use of RNAV will be encouraged throughout the period 2000 - 2010, in order to allow early benefits to capable aircraft. Evidence of achievement of these benefits may provide an incentive for re-equipment by other aircraft operators.

By 2010, the evolution of navigation systems capabilities and supporting infrastructure are expected to reach an RNP1 RNAV baseline. Expected widespread use of RNAV and the availability of RNAV equipment capable of RNP $\leq$ 1 performance in order to satisfy approach and landing criteria may enable the decision to mandate RNP1 RNAV in all ECAC TMAs. Most lower capability aircraft will have been either removed from operations or upgraded by that time.

2.1.6.4 Mandate of RNP 1 RNAV Operations for en-route

In 1998, B-RNAV became mandatory to improve the route structure efficiency. By mid-1998 the vast majority of aircraft operated in the ECAC airspace met the B-RNAV equipage carriage requirements. Still, some States did not implement B-RNAV at all en-route flight levels and operational benefits could not be granted at a maximum possible extent.

One of the constraint in implementing B-RNAV at all flight levels is the provision of supporting infrastructure. Some gaps do exist in the DME coverage in limited areas of Europe at lower flight levels, but this does not justify a general exemption as is the case in certain States.

RNP1 RNAV is expected to enable a reduction in route spacing and separation criteria and consequently give increased system capacity. The mandatory carriage of RNP 1 RNAV MASPS compliant equipment could be requested by 2010.

The studies required for the decision on a mandatory carriage of RNAV RNP 1 MASPS compliant equipment by 2010 (i.e. equipage requirements, safety studies, cost-benefit studies, etc.) are not finalised, but the mandate date will depend on the moment when they will be finalised and accepted, as a 7 years notification period for aircraft operators for the mandatory carriage of RNAV RNP 1 MASPS would be required.

It is possible to require RNP 1 accuracy on a limited basis, for dedicated routes between 2000-2010, where the need for additional capacity is stringent and no other means of providing additional capacity will bring benefits. A comprehensive DME coverage is required, or appropriate GNSS infrastructure, and is expected to be available throughout the timeframe, due to the requirements to enhance coverage to support B-RNAV operations.

Global standards are available for RNP RNAV systems. They relate presently to 2D RNAV but work is underway to extend the standards to longitudinal and vertical (3D) requirements, as well as time (4D). It is expected that they will be available before 2005.

Rationalisation plans for ground navigation aids (VOR, NDB) may apply from 2000 onwards on an opportunity basis. The increase in RNP 1 and even RNP<1 RNAV-equipped aircraft, due to the more stringent demands of terminal airspace operations, may lead to the mandatory requirement for a (baseline) RNP1 RNAV requirement en-route from 2010 onwards. This will allow further rationalisation and the total removal of VORs by 2010.

The DME infrastructure will continue until at least 2015, and will support RNP1 RNAV operations adequately. Multi DME-based RNAV systems, INS/IRS with update and/or GNSS systems will provide the required performance.

2.1.6.5 Advanced Surface Movement Guidance and Control Systems (A-SMGCS)

A-SMGCS are seen as an important factor to increase the capacity and efficiency at airports. Potentially, they can increase arrival and departure rates in poor visibility conditions so that capacity will begin to match that for operations in good visibility conditions.

The use of A-SMGCS may impose additional requirements on the airborne capabilities to support the navigation function and performance. These requirements must be co-ordinated with the requirements for other domains, i.e. communication and surveillance.

The developments for ground operations must be co-ordinated with those for approach and landing operations. Special attention is necessary on the interface of landing operations and ground operations. Improving airport capacity in low visibility conditions is strongly dependent on improving the runway occupancy times, which in turn is dependent on guidance functionality for ground operations.

Detailed technical and operational studies will be required before confirming any additional navigation requirements related to A-SMGCS.

2.1.6.6 Implementation of 4D RNAV Operations

In order to maximise the freedom of movement, efficiency and flexibility of operations and to start enabling a redistribution of tasks between aircraft and ATC, the exploitation of advanced 4D navigation capabilities must be initiated.

By 2015, the “conventional” RNAV operations may not continue to bring the required benefits and the implementation of 4D RNAV operations may be the solution to bring added benefits in terms of capacity and efficiency of operations.

The feasibility of 4D RNAV operations has already been demonstrated, on an experimental basis. Appropriate ATC support tools and datalink will be required to enable the implementation and achieve full operational benefits out of 4D RNAV operations. Research and development activities, followed by the development of appropriate standards must be initiated with due urgency.

Because of the complex nature of the 4D operations, co-ordinated and synchronised development and implementation plans will be required for all the elements of the ATM system. By enabling a further integration between air and ground elements as well as the redistribution of tasks between air and ground, a new approach to the development of the required safety cases must be envisaged.

2.1.7 Implication on ground and on on-board infrastructure

2.1.7.1 Link between navigation Applications and supporting infrastructure

The need for enhanced safety, increased capacity and operational efficiency requires improved navigation performances. An improved navigation performance cannot be achieved without enhanced avionics and additional costs for airborne equipment. Meanwhile, the rationalisation of the navigation infrastructure could bring economies of scale. The following section shows the interaction between the phases of flight, the navigation performance and the supporting infrastructure as well as the potential for infrastructure costs savings.

2.1.7.2 Provision and maintenance of take-off guidance, NPA and Cat I/II/III at airports

Strategic Step	Timeframe	Systems
Provision and maintenance of NPA capabilities	2000-2005	NDB; VOR; DME; GPS+RAIM+conventional back-up; SBAS (expected by the end of period).
Provision and maintenance of take-off guidance and of Cat I/II/III Precision Approaches at airports		ILS Cat I/II/III (continued wide spread use, maintain service level as long as possible); MLS (initial introduction to replace ILS Cat II/III); SBAS (for Cat I, expected by the end of the period); GBAS (expected by the end of the period); MMR.
Provision and maintenance of NPA capabilities	2005-2010	VOR; GPS+RAIM+conventional back-up; SBAS; GBAS.
Provision and maintenance of take-off guidance and of Cat I/II/III Precision Approaches at airports		ILS Cat I/II/III (continued use, maintain service level as long as possible); MLS (further use, replaces ILS Cat II/III as appropriate); SBAS (for Cat I); GBAS; MMR (increased use).

Strategic Step	Timeframe	Systems
Provision and maintenance of NPA capabilities	2010-2015	SBAS; GBAS.
Provision and maintenance of take-off guidance and of Cat I/II/III Precision Approaches at airports		ILS Cat I/II/III (diminishing use, maintain service level as long as possible); MLS (further introduction to replace ILS Cat II/III); SBAS (continued introduction to replace ILS Cat I when appropriate); GBAS (further introduction to replace ILS Cat II/III instead of MLS); MMR (widespread use, with upgrades as required).

2.1.7.3 RNAV in TMAs

Strategic Step	Timeframe	Systems
Provision and maintenance of RNAV SIDs/STARs and holding procedures RNP5 accuracy (B-RNAV) Or RNP1 accuracy (P-RNAV) (optional)	2000-2005	DME/DME; VOR/DME (comprehensive coverage at low levels is required); INS/IRS+ update; GPS+RAIM+conventional back-up; SBAS ; GBAS (expected introduction by the end of the period);
Provision and maintenance of RNAV SIDs/STARs And Holding procedures RNP1 accuracy (P-RNAV) (optional)	2005-2010	DME/DME; VOR/DME; (comprehensive coverage at low levels is required); INS/IRS + update; GPS+RAIM+conventional back-up; SBAS; GBAS.
Mandate of RNAV in selected TMAs RNP1 accuracy (P-RNAV)	2005-2010	DME/DME; VOR/DME (comprehensive coverage at low levels is required); INS/IRS + update; GPS+RAIM+conventional back-up; SBAS; GBAS.
Mandate of RNAV in all TMAs (likely RNP≤1)	2010-2015	DME/DME; INS/IRS + update; GBAS; SBAS;

		RNAV MASPS avionics.
Implementation of 4D RNAV operations	2010-2015	advanced aircraft systems capable of 4D RNAV (MASPS); ATC tools.

2.1.7.4 Requirement for B-RNAV at all en-route flight levels

Strategic Steps	Timeframe	Systems
Requirement for B-RNAV at all flight levels en-route RNP5 accuracy	2000-2005	VOR/DME; DME/DME (to provide adequate infrastructure and to rationalise as appropriate); INS/IRS + update; GPS+RAIM+conventional back-up; SBAS; GBAS (expected introduction towards the end of the period).

2.1.7.5 Mandate of RNP 1 RNAV Operations

Strategic Steps	Timeframe	Systems
Implementation of dedicated RNP1 RNAV routes on an opportunity basis RNP1 accuracy (P-RNAV)	2000-2005	DME/DME (comprehensive coverage required); INS/IRS + update; GPS+RAIM+conventional back-up; SBAS (expected towards the end of the period); GBAS; adequate database integrity.
More widespread introduction of RNP1 RNAV routes RNP1 accuracy (P-RNAV)	2005-2010	DME/DME; INS/IRS+ update; GNSS.
Mandate of RNP1 RNAV operations	2010	RNAV MASPS avionics; DME/DME (comprehensive coverage); INS/IRS+ update; GNSS.

2.1.8 GNSS as sole service

From the above, and subject always to fulfilling the then prevailing RNP requirements, sole service GNSS leads, per phases of flight on a world-wide perspective (always ignoring security issues such as wilful interference over large portion of airspace) to the following requirements.

2.1.8.1 Oceanic areas

For Oceanic operations, en route RNP 10, as the most stringent, will be required in the long run. Long haul aircraft fly such routes. They will be equipped with INS / IRS with GPS up-date, an infrastructure largely sufficient.

2.1.8.2 Remote continental areas

In the absence of more detailed information, the assumption that an infrastructure supporting, as the case may be, RNP4 for en-route and NPA where required would certainly meet all the requirements for such areas. Infrastructure suitable for NPA includes modernised GPS plus SBAS.

An issue for further analysis is: in the absence of INS/IRS and of adequate surveillance infrastructure, are configurations with GPS II/F + RAIM (+ Galileo) sufficient to guarantee RNP 4 ?

2.1.8.3 Dense en route airspace

A performance supporting RNP 1 RNAV requires an infrastructure based on INS/IRS plus update or GNSS. GNSS for RNP 1 RNAV would require more in terms of integrity than GPS + RAIM or baro augmentation. This would mean probably SBAS on top of GPS IIF or GPS IIF plus a network of GBAS (such as the GRAS concept) and/or GPS IIF + Galileo.

2.1.8.4 Terminal areas

An infrastructure based on INS/IRS plus update or GBAS Cat I or SBAS is required in the long run for RNP<1 operations, which should be the norm at a number of complex ECAC locations.

2.1.8.5 NPA

The requirement sits in-between RNP<1 for terminal areas and Precision Approach Cat I and is therefore satisfied by SBAS or GBAS Cat I.

2.1.8.6 Precision Approach Cat I

An infrastructure including GBAS or SBAS is required.

2.1.8.7 Precision Approach CATII/III

An infrastructure including GBAS is required.

2.1.8.8 Take-off guidance

An infrastructure including GBAS or INS/IRS is required.

2.1.8.9 Surface movements and guidance

An infrastructure including GBAS is required.

2.1.9 Galileo's contribution to the establishment of GNSS as sole service

This section analyses the potential contribution of Galileo to foster the adoption of GNSS as sole service.

2.1.9.1 Non-Galileo scenario

Assessing Galileo's contribution to the GNSS Sole service concept, requires that a sensible non-Galileo scenario be defined as a comparison baseline. It would seem to be that SBAS / GBAS on top of GPS would offer the technical capability required for the dense airspace and remote continental areas and INS / IRS plus GPS upgrade would do for Oceanic operations. But this statement remains to be proven.

In the mean time, and for the sake of the CBA, in compliance with the statement that GNSS would become the sole service system for the provision of positioning and timing data, the assumptions taken are as follows:

- GPS block II/F is available, and offers a second civil frequency (L5) permitting automatic ionospheric correction in the receiver and therefore increasing accuracy and availability of the accuracy.
- GBAS is required for Cat III, as there are no indication that the integrity could come from the satellites themselves. However, it is not expected that GBAS Cat III only would be used (ILS plus a limited number of ILS/MLS combinations would be used instead of or concurrently with GBAS Cat III)
- SBAS is available and is economically sustainable, based on the following assumptions:
  - The US are progressing on WAAS;
  - EGNOS has been put under the umbrella of the Galileo Undertaking and is seen as a multi-modal navigation and positioning system, with aviation contributing in the same proportionate manner as for the rest of the Galileo infrastructure;
  - Japan develops MSAS and charges for MSAS are set on the basis of multi-modality;
  - WAAS plus EGNOS plus MSAS together offer world-wide coverage.

(If any of these last two assumptions proved to be wrong, then the attractiveness of SBAS for aviation would drop significantly).

- Cat I landing capability will come from either GBAS Cat I or from SBA (provided that modernised GPS is deployed). It is likely –but not certain- that SBAS will be sufficient at most airports since conventional GPS plus SBAS offers already "near CAT1 capability" and GPS II/F improves the availability of the accuracy. Where local conditions (e.g. mountainous areas) command, GBAS Cat I would be installed on a case by case basis.
- As a consequence, the availability of SBAS on top of GPS II/F would allow for operations over remote continental areas (see 2.1.3.2 above: "Remote Continental Areas").
- As a further consequence, GPS II/F, plus SBAS plus GBAS for Cat II/III plus INS/IRS integrating a GPS-derived position update capability would allow for world-wide operations for all phases of flight.

2.1.9.2 With-Galileo scenario

Galileo potential contribution might be:

- Avoid the deployment of a SBAS infrastructure world-wide, which could prove to be an expensive solution unless SBAS is marketed as a multi-modal product, with aviation paying only a small share of the total cost.
- Reduce the number of places where GBAS Cat I would be required in spite of availability of SBAS, due to geometry (mountains). To the extent such places

would also require Cat II/III, the benefits would accrue only to those airspace users not equipped with, or trained to perform Cat II/III operations.

- Offer “better than SBAS Cat I” landing capability, providing that the potential benefits exceed the cost of the lighting systems.
- Offer aircraft, other than first level aircraft, an alternative to INS/IRS or to SBAS for NPA if SBAS avionics do not come out cheap.
- Reduce the requirements for INS/IRS to two rather than three pieces of equipment for first level aircraft.

The most beneficial contribution form Galileo is to avoid a political debate centred on sovereignty (USA versus rest of the world) and on civil versus military GNSS ownership.

Even where regions would have developed their own SBAS and GBAS systems, such as EGNOS for Europe, GPS dominance could still be seen as excessive and a number of states or groups of states would impose to keep at least one conventional infrastructure (DME or VOR) as back-up. This would seriously impact on the total cost of the navigation infrastructure, both on the ground and in the cockpit.

2.2 Scenarios retained for the Cost-Benefit Analysis

For the sake of comparison, we have looked at the evolution of ground and aircraft equipment over the 2010-2024 time interval for each of our scenarios, assuming that:

[A2-1] the ground equipment in the period 2010-2024 can be extrapolated from today equipment and deployment plans; in the case additional ground navaids are deployed in that period in certain areas, those new navaids deployed up to 2015 would be sufficient to meet the needs of the rest of the period.

[A2-2] In 2010, GNSS-2 could be available for operation.

2.2.1 Non-Galileo Baseline scenario

Based on the preceding outline description of existing plans, our baseline scenario (scenario 1) includes modernised GPS plus GBAS plus SBAS plus one conventional navigation infrastructure as back-up, with the complete corresponding set of equipment on board.

[A2-3] First level aircraft have INS / IRS with a GPS-derived position update capability.

[A2-4] Transition for Cat III ILS to GBAS Cat III will not take place immediately at the beginning of the period, and GBAS Cat I will have been deployed in the mean time.

2.2.2 The GNSS sole service scenario

The GNSS sole service scenario is a scenario set up on modernised GPS plus Galileo plus local GBAS for CAT2/3 operations. SBAS or GBAS for CAT1 will depend on technical requirements versus technical capability of the combination GPS plus Galileo and/or cost/benefit analysis.

[A2-5] First level aircraft have INS/IRS with a GPS-derived position update capability.

2.3 Costs for the ATS Providers

2.3.1 Approach

For conducting the comparison of cash-flows over the whole period we have determined the Net Present Value (NPV) of the various cash-flows identified, all taken at the same year in the comparison period, through the application of a yearly discount rate.

We adopted a standard value of 10 % for that discount rate (since the cash-flow structures of the scenarios are not markedly different, the impact of using a different value of the discount rate is not significant).

In the following, the ground infrastructure costs in the 2010-2024 period are evaluated from the estimation of the costs of renewing (and possibly slightly extending) and maintaining the existing infrastructure. These costs of renewal, extension and maintenance correspond to what is called "replacement value" in the following sections.

That is the reason for sections 2.3.2.1 and 2.3.2.2 to start from the review of the existing infrastructure and to apply to the identified equipment the unit costs for brand new systems, which are presented in the next section.

2.3.2 Ground infrastructure unit costs

The unit costs (in Euro) of the various elements of ground infrastructure are:

	Acquisition	Maintenance (per year)
NDB	40,000	10,000
CVOR	250,000	20,000
DVOR	350,000	20,000
DME	150,000	20,000
Cat I ILS	615,000	100,000
Cat II/III ILS	665,000	200,000

2.3.2.1 En-route and TMA ground infrastructure

The ECAC navigation infrastructure for en-route and TMA operations consists of about 300 DME, 330 C-VOR or D-VOR, 315 collocated VOR/DME and 670 NDBs.

This infrastructure has a replacement value of EUR 305 millions and a maintenance value of EUR 31 millions per annum which, over a period of 15 years, represents a NPV of EUR 260 millions.

The North American navigation infrastructure for en-route and TMA operations consists of 150 VOR, 1810 DME, 980 collocated VOR/DME and 440 NDBs.

This infrastructure has a replacement value of EUR 850 millions and a maintenance value of EUR 85 million per annum which represents, over a period of 15 years, a NPV of EUR 727 million.

The Caribbean and South American infrastructure for en-route and TMA operations consists of about 50 VOR, 40 collocated VOR/DME, and 610 NDBs.

This infrastructure has a replacement value of EUR 52 million and a maintenance value of EUR 8.5 millions per annum which represents, over a period of 15 years, a NPV of EUR 71 million.

For the rest of the world, data are either not available or not robust enough. We recommend the European Community to ensure that a robust data base of world-wide infrastructure is maintained at ICAO level.

[A2-6] We assume that the density of the infrastructure in Asia and Pacific regions is sufficient to cope with existing and future requirements, whereas the infrastructure in place in Africa, China and Russia cannot cope with the requirements of such regions after 2015. Paragraph 2.3.1.3 is an attempt to quantify the additional infrastructure required by that time, so as to cover the further part of the chosen time interval.

2.3.2.2 Aerodrome ground infrastructure

ECAC data come from the EGNOS 1999 CBA study and have been updated after the ICAO ENP of 2001 for the so-called EOIG States. That update also includes the infrastructure of new ECAC Member States: Armenia, Lithuania and Ukraine.

The ECAC navigation infrastructure for precision approach supports the operations of about 390 CAT1 runways and 130 CAT2/3 runways.

This infrastructure has a replacement value of EUR 325 million and a maintenance value of EUR 65 million per annum which, over a period of 15 years, represents a NPV of EUR 540 million.

The North American navigation infrastructure for precision approach supports the operations of about 1,380 runways, consisting of 1250 Cat I runways and 130 Cat II/III runways.

This infrastructure would then have a replacement value of EUR 870 million and a maintenance value of EUR 149 million per annum which represents, over a period of 15 years, a NPV of EUR 1,240 million.

The Caribbean and South American navigation infrastructure for precision approach supports the operations of about 75 Cat I runways and only 4 Cat II/III runways.

This infrastructure has a replacement value of EUR 49 million and a maintenance value of EUR 8 million per annum which represents, over a period of 15 years, a NPV of EUR 69 million.

For the rest of the world, data are either not available or not robust enough.

[A2-7] We assume that the density of the infrastructure in Asia and Pacific regions is sufficient to cope with existing and future requirements, whereas the infrastructure in place in Africa, China and Russia cannot cope with the requirements of such regions around 2015. Paragraph 2.3.1.3 is an attempt to quantify the required infrastructure by that time.

2.3.1.3 Total conventional ground infrastructure around 2015

[A2-8] We assume that the need for en-route and terminal infrastructure would not increase significantly as a function of traffic in areas such as Europe, North America, Caribbean region and South America.

This assumption is too conservative for areas such as Africa, Russia and China. In those areas, the existing network of VOR, DME is not sufficient to meet the requirements of 2015.

[A2-9] We have estimated the total NPV of the infrastructure for the rest of the world at EUR 800 million based on the deployment required by 2015 (this figure 40% of the infrastructure existing today in ECAC plus North America plus Caribbean region and South America).

The world **en-route and terminal navigation** asset would therefore have a replacement value of EUR 1,700 million and a maintenance value of EUR 175 million per annum which, over a period of 15 years, represents a total NPV of EUR 1,475 million. Avoiding the deployment and maintenance of such infrastructure in the future would save a total **NPV of EUR 3,150 million**.

A part of such savings will come from the decommissioning of the NDBs, followed by the rationalisation of the VOR/DME infrastructure (as detailed in Chapter 4.2.3 of the Report), up to a maximum of EUR 2,000 million.

Keeping one conventional navigation infrastructure as back up would maintain a total actual value of EUR 1,100 million if based on VORs and EUR 1,000 million if based on DMEs. As the favoured strategy is to have decommissioned VORs by 2010 in ECAC, replaced by GNSS or DME/DME (as per 2.1.3.1), DME would be the maintained technology.

Concerning aerodrome infrastructure, contrary to En-Route/terminal infrastructure, it is assumed that the requirement for such infrastructure should increase as a function of traffic in areas such as Europe, North America, Caribbean region and South America. The traffic in 2015 being circa twice the traffic of 2002, the number of required CAT 1 runways and the number of required CAT2/3 runways would double. In the absence of specific data, the assumption is made that 50% of the new requirements will be at airports already equipped with CAT1/3 landing capabilities and 50% at airports not already equipped. Not equipped airports add installation costs to the cost of the equipment. We have estimated that the rest of the world would operate a number of 1,120 CAT 1/2/3 runways equal to 30% of the infrastructure then existing in ECAC plus North America plus Caribbean region and South America.

Avoiding the replacement, extension and maintenance of **ILS CATII/III CAT3** in the analysis period (2010-2024) would save a total actual value of **EUR 1,600 million**, at the cost of adding a constellation, as detailed in 2.3.2.2 below plus the cost of adding a network of GBAS CATII/III, as detailed in 2.3.2.4 below.

Avoiding the replacement, extension and maintenance of **ILS CAT1** in the analysis period (2010-2024) would eliminate the need for 4,000 CAT1 runways, saving a total actual value of **EUR 6,400 million**, at the cost of SBAS, as detailed in 2.3.2.3 below.

2.3.3 GNSS infrastructure

2.3.3.1 Cost of GPS

[A2-9] We assume that the GPS, including the expansion to a second civil frequency, is supplied free of charge throughout the period under consideration (2010-2024).

2.3.3.2 Cost of Galileo

[A2-10] Based on figures published by the European Commission, we assume that Galileo development costs are of EUR 3.5 billions and that the running costs are in the order of EUR 200 million per annum.

[A2-11] We assume that aviation share of Galileo as a multi-modal navigation infrastructure capable of Cat I landing is 1% of the total cost. That percentage is derived from the Eurocontrol study “The allocation of GNSS costs” published in June 2000 where it was obtained through the application of a methodology determining the relative weight of each user category for every required level of performance (thus apportioning the cost of the additional equipment needed for that level of performance only to those fractions of the total user population that required it).

This represents for aviation a capital cost of EUR 35 million and running costs of EUR 2 million per annum which over a period of 15 years represents a total NPV of EUR 15 million.

2.3.3.3 Cost of an SBAS infrastructure

The figures available for EGNOS are a total development cost lower than EUR 500 million and running costs around or lower than EUR 35 million per annum. This includes renting 3 GEO-transponders plus the operation and maintenance of ground facilities such as MCCs, RIMS, NLES and central facilities such as EWAN, PACF (Performance Assessment and Check-out Facility), plus the cost of headquarters in charge of managing a multi-modal system. Actual cost would be highly dependent of course of the result of a call for tender for the provision of the service.

[A2-12] We assume that the costs of WAAS and MSAS are of the same order of magnitude then the cost of EGNOS and that they are also passed through to the users.

[A2-13] We assume that aviation share of a multi-modal navigation infrastructure capable of Cat I landing is 1% of the total cost. This is consistent with the assumption made (cf. [A2-11] above) on the multi-modal allocation of GNSS cost.

This represents for the 3 SBAS a capital cost of EUR 15 million and running costs of EUR 2 million per annum which, over a period of 15 years, represents a total NPV of EUR 15 million.

Subject to more detailed analysis or sensitivity analysis, we further assume that **[A2-12]** aviation will have no specific SBAS related costs, as there will be no special route design or approach design for GNSS en route, terminal and Cat I operations (concept of “ILS look alike”).

2.3.3.4 Cost of a GBAS Cat III infrastructure

As of today, there are no standard commercial prices available for GBAS stations. The architecture is simpler than the architecture of an ILS and this should in principle lead to lower prices.

The cost of maintenance would also be lower, owing to a simpler and more compact system architecture (no need for far field monitors, no need for calibration).

[A2-14] However, as no quantitative evidence is available concerning the cost of future GBAS Cat III stations, we (somewhat conservatively) assume that the cost of GBAS Cat III will be the same as the cost of an ILS Cat III.

The capital cost of this infrastructure would be of EUR 200 millions and the maintenance value would be of EUR 30 millions per annum, which, over a period of 15 years, would represent a total NPV of EUR 270 millions.

Major benefits would come from the ability of one GBAS to serve one airport, instead of one runway only. The cost of production, maintenance and operation of the on-board database of the flight critical runway path points is taken into account in 2.4.3 below.

2.3.4 Savings obtained through scenario 1B (GPS + SBAS) against a baseline scenario based on conventional navaids

En-route and terminal infrastructure savings:	EUR	2,150 millions
ILS Cat I infrastructure savings:	EUR	6,410 millions
Additional expenses: SBAS	EUR	– 25 millions
TOTAL SAVINGS OBTAINED THROUGH GNSS-1	**EUR**	**8,535 millions**

2.3.5 Additional savings obtained through scenario 2 (GPS+Galileo)

En route and terminal infrastructure savings (DME)	EUR	1,000 millions
ILS Cat II/III infrastructure savings:	EUR	1,600 millions
Additional expenses: GBAS CAT II/III:	EUR	– 500 million
Cost of Galileo	EUR	– 50 millions
ADDITIONAL SAVINGS OBTAINED THROUGH GNSS-2	**EUR**	**2,050 millions**

The total world-wide savings obtained by the transition from the current pre-GNSS infrastructure to a GNSS-2 sole service scenario are greater than EUR 10 billions.

2.4 Costs for the Aircraft Operators

2.4.1 Approach

The proposed scenarios for future navigation services will have some impact on the costs incurred by the aircraft operators. The costs to be considered are of 2 main types :

- Airborne segment costs : all costs related to the airborne segment adaptation to the scenarios, including equipment, engineering, installation, certification, and associated operating costs.
- ATS charges : they must absorb the costs of the ATS providers as computed in the preceding section 2.3.

The airborne segment costs over the analysis period (2010-2024) have been estimated from fleet forecasts and from a series of navigation equipage assumptions which are the results of investigations and discussions notably with aircraft and avionics manufacturers

2.4.2 Target fleet

As Galileo receivers/functions might be installed in all types of aircraft all over the world, the scope of analysis for this study is the total world-wide fleet.

That fleet can be divided in three main categories :

- First level aircraft : large airliners (Airbus, Boeing, and some aircraft made in CIS)
- Second level aircraft : jets and turboprops, with 40 to 90 seats, mainly regional aircraft and commuters.
- Third level aircraft : mainly General Aviation and Aerial Works

The main sources and assumptions used to estimate the sizes of the different studied fleet segments are presented in the following sections.

2.4.2.1 First level fleet

The first level fleet forecasts used in the present study are directly derived from the air freighters and passenger aircraft forecasts that are published by Airbus in Global Market Forecast 2000-2019, july 2000.

The following assumptions have been made in order to run the financial simulations:

[A2-15] in 2010, Boeing aircraft (except B737) will represent 33% of the world wide fleet.

[A2-16] for each year of the 2010-2024 period, Boeing aircraft (except B737) will represent 33% of the brand new aircraft delivered.

From Airbus statistics and forecasts, it has been observed that the passenger aircraft fleet registered in Europe and the U.S. represented 70% % of the world wide passenger aircraft fleet in 1999 and will represent 66% of the fleet in 2019. From this figure, we have derived the following assumptions :

[A2-17] in 2010, the first level fleet flying in Europe and the U.S.[1] will represent 75% of the world wide fleet in 2010.

[A2-18] between 2010 and 2024, the brand new aircraft that are intended to fly in Europe and the U.S. will represent each year 75% of the brand new aircraft delivered in the world.

[A2-19] in 2010, the first level fleet flying outside Europe and the U.S.[2] will represent 50% of the world wide fleet in 2010.

[A2-20] between 2010 and 2024, the brand new aircraft that are intended to fly outside Europe and the U.S. will represent each year 50% of the brand new aircraft delivered in the world.

2.4.2.2 Second level fleet

The second level fleet has been split in 2 parts, turboprops and regional jets. Then, for each of these parts, figures had to be provided for world wide fleet, European fleet and U.S. fleet.

Turboprops

Statistics on 2001 turboprops fleets in the World, in Europe and in the U.S. have been derived from 2001 Flight International Airliner Census [Flight International 16-22/10/02] with some US aircraft fleet figures extracted from ICAO statistics [Civil Aircraft on Register, digest of statistics No. 481, 1999].

[1] Including aircraft flying both in these regions and other regions of the world
[2] same remark as note 1

The aircraft types that have been considered to estimated the turboprop fleet are the following : ATR 42 and 72, Bombardier DASH 8/100 /200 and /400, Convair 580 600 and 640, De Havilland Dash7, CASA 212 and 235, Embraer 120, Fairchild Dornier 228 and 328, Fairchild Metro, Fokker 27 and 50, Indonesian Aerospace 212 and CN-235, Raytheon Beech 1900C /D, Saab 340 and 2000, Shorts 330 and 360.

Forecasts have been made from 2001 statistics using the following assumptions:

[A2-21] : world wide, European, and US fleets will grow with a yearly rate of 3%.

[A2-22] : removal rate is 4% each year for the 3 studied fleets (world wide, European, and US).

Regional jets

Statistics on 2001 regional jet fleets in the World, in Europe and in the U.S. have been obtained in the same manner as for turboprops.

The aircraft types that have been considered to estimated the regional jet fleet are the following : Jetstream 31/32 and 41, BAE 146, BAE Systems Avro RJ, Embraer 110 135 140 and 145, Fokker 28 70 and 100, Bombardier CRJ /100 /200 and /700.

Forecasts have been made from 2001 statistics using the following assumptions:

[A2-23] : world wide, European, and US fleets will grow with a yearly rate of 5%.

[A2-24] : the removal rate is 4% each year for the 3 studied fleets (world wide, European, and US).

2.4.3 First level aircraft equipment in 2010

The present section aims to identify the navigation equipment systems that would be onboard the first level aircraft just before entering in the period covered by the two scenarios.

This work is not intended to be exhaustive for each type of aircraft; it starts from a particular example and tries to make assumptions on other types of aircraft from the described example.

The example that has been developed in this section concerns Airbus aircraft.

All Airbus aircraft that have been produced since 1995 are RNP 0.3 RNAV certified (in 2D).

RNP 0.15 RNAV certification is expected from 2004 (in 2D).

The Airbus onboard navigation equipment configuration is:

- Inertial Reference Systems (x3) + GPS receivers (x2) as RNAV primary means
- DME-DME systems (2 DME scanners) as backup, with no demonstrated RNAV capability yet (expectations are to reach at least RNP 1 RNAV)
- All Airbus aircraft manufactured after 1998 are systematically MMR equipped.

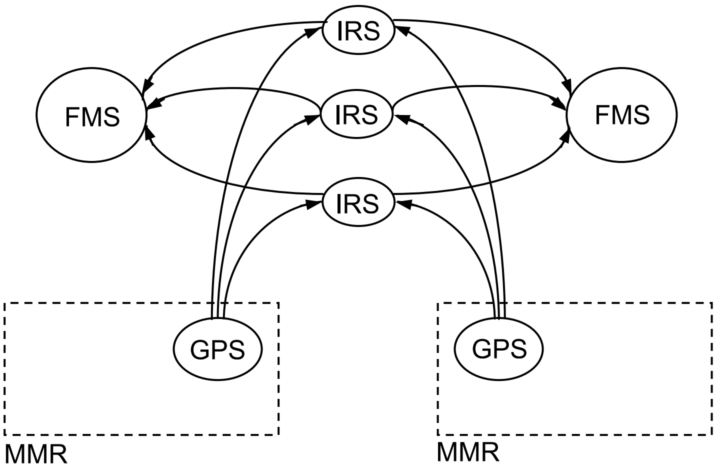

Figure 2-1 : Airbus baseline Navigation system architecture

Concerning Precision Approach, GNSS Landing System is planned to be certified for Cat I in 2005, based on Differential GPS signals only (no use of EGNOS signals). The same type of equipment is also expected to reach Cat II certification around year 2009.

For NPA and areas with specific 3D requirements, it is expected in the medium term to use directly the temperature information with the barometric measurements in the FMS, in order to improve vertical accuracy.

Though EGNOS functions are not clearly planned, Airbus do not preclude to equip its aircraft with EGNOS functions, depending on its performance and costs. However, this would not entail the removal of other airborne navigation equipment.

Boeing would have a very similar policy in terms of navigation equipment.

Independently of any RNAV policy, most of the domestic and international jetliners will be MMR equipped in 2009, because MMR represented an integrated solution to meet various requirements, to cope with different means and to enable flexible transition.

2.4.4 Second level aircraft equipment in 2009-2010

Similarly to the previous section, the present section aims to identify the navigation equipment systems that would be onboard the concerned aircraft just before entering in the period covered by the two scenarios. This section is broken down into 2 parts as regional aircraft fleet is composed of 2 different types of aircraft: turboprops and jets. Each of these parts starts from one particular example and tries to give afterwards some general assumptions on the fleet concerned

Turboprops

The proposed example for turboprops concerns ATR aircraft.

The current ATR fleet is equipped with two main distinct solutions in terms of navigation equipment :

- the old solution based on a GPS stand alone equipment,
- the current solution based on 1 Navigation Processor Unit ("light" FMS with only the navigation function) equipment integrating a GPS module, and connected to a DME scanner (no IRS). Data entry and display is performed through the use of a Cockpit Display Unit (CDU)

Both solutions are B-RNAV capable, but only the NPU based one is expected to meet future requirements, notably RNP < 1 RNAV requirements.

That means that most of ATR aircraft should be fitted with the second solution by 2009-2010, if considering the mandates of the ECAC strategy.

Concerning non precision approach, the present GPS solutions are certified with conventional means in overlay : the GPS data have to be cross-checked with data derived from conventional means. Thus, in case of decommissioning all conventional means, as planned in scenario 2, dual NPU equipment would be required.

As for precision approach, ILS Cat I & Cat II functions are included in the automatic pilot as a baseline (even if not necessarily activated).

It should be noticed that ATR aircraft are not IRS equipped : such systems are still considered expensive and not essential in view of the aircraft range and the flight command type (non-electric).

[A2-25] Except for a few isolated examples due to specific operations or in case of significant reductions in the cost of such equipment, it can be assumed that turboprops will be not be IRS equipped in the next 20 years.

Regional jets

Concerning regional jets, the baseline avionics equipment is globally more advanced than the turboprops one. This can be partly explained from the fact that those jets are derived from business jets that used to be quite well equipped.

As an example, brand new Bombardier aircraft are currently equipped as follows :

- Global Express : dual FMS with dual Cat II autopilots; triple IRS; GPS with option for second sensor; ADF; VOR/ILS; DME.
- Canadair Challenger 604 : dual FMS; dual IRS; dual VHF NAV; dual DME, dual ADF; provision for dual GPS.
- Canadair Regional Jet 700-900 : no detailed information available, but equipment should be similar to equipment of the Global Express of which CRJ is a derivative.

[A2-26] It can be assumed that in the next 8-10 years:

- all regional jets will be equipped with FMS and IRS,
- regional jets will go progressively to MMR based architecture similar to first level aircraft, because MRR is viewed as a valuable integrated solution able to meet various requirements and well adapted to transitions,
- all regional jets will be equipped with at least 1 DME scanner.

2.4.5 GA & AW equipment in 2009-2010

General Aviation is extensively equipped world-wide with VOR and DME receivers.

According to the EGNOS CBA study, the distribution of navigation equipment in the ECAC GA/AW fleet is the following :

	DME scanner			**VOR**			**ADF**		
	0	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Jets			100%			100%		16%	84%
Turboprops	60%	40%			20%	80%		20%	80%
Reciprocal engines	100%			20%	60%	20%	20%	60%	20%
Rotary wings									

As noted in the EGNOS CBA study, it is very difficult to check the exact number of aircraft equipped with GPS as for instance, a huge number of GA pilots use handheld receivers.

[A2-27] It may be reasonably assumed that the part of the fleet that is not yet equipped, i.e. mainly turboprops and reciprocal engines, will be equipped by the beginning of our scenario comparison (2010).

It should be noticed that about 92%-93% of the GA aircraft are operating in accordance with VFR flight rules. In essence any navigation equipment in the cockpit in which the flight is operating in accordance with the VFR rules can only be considered to be an aid to visual navigation, thus from a regulatory standpoint a VFR pilot using GNSS/GPS equipment can only be using it as an aid to his/her visual navigation and therefore the questions of required navigation performance, back up, etc. are largely irrelevant.

However, even though there is a small number of GA IFR movements, these aircraft still have to be able to operate within the system. Most are unlikely to have any form of INS and therefore it seems likely that these operations would need some other kind of independent system such as VOR or DME to be available in the event of a total GNSS loss, unless they can be upgraded with a low-cost INS system or be vectored by the controllers.

2.4.6 Scenario 1 assumptions for aircraft

Scenario 1 is basically the scenario for the 2010-2024 period in which Galileo is not deployed, but in which SBAS and GBAS are operational. Taking into account the current uncertainty on SBAS equipage (for various reasons: notably uncertainty on coverage, cost allocation and charges), two sub-scenarios for scenario 1 have been envisaged in the present study :

- Scenario 1 A : the aviation community has not gone for SBAS in 2005-2010
- Scenario 1 B : the aviation community has gone for SBAS in 2005-2010.

2.4.6.1 First level aircraft

In both variations of scenarios 1, first level aircraft are expected to use DMEs wherever there is sufficient coverage (e.g. ECAC, US) and VOR elsewhere.

[A2-28] It is assumed that aircraft flying in Europe and the US will still be equipped with DME scanners for the whole period of analysis.

The corresponding equipment costs have then to be quantified : investment costs for brand new aircraft from 2010 and operating costs for all aircraft flying in the period of analysis. All investment costs and operating costs addressed in this section together with main assumptions are summarised in 2 tables at the end of the section : one table is dedicated to brand new aircraft produced from 2010, while the other one deals with aircraft produced before 2010 and still flying in the period of analysis.

Scenario 1 indicates also that the VOR infrastructure will be maintained outside Europe and the U.S. : this would have the following consequence on airborne equipment:

[A2-29] : first level aircraft flying outside Europe and the U.S. will still be equipped with VOR receivers.

Concerning GNSS receivers, the interviewed experts from equipment manufacturers plan that "modernised GPS" (GPS IIF) function will be installed onboard between 2010 and 2012. It is foreseen that this will imply to replace the existing GPS modules by new ones, and to change the antennas as well.

[A2-30] : GPS II/F modules and corresponding antennas will be installed in all first level aircraft between year 2010 and year 2012.

Regarding final approach and landing phases, the systems to consider are the following : SBAS, GBAS (GLS), ILS and MLS.

Even if SBAS could enable the equipped aircraft to perform near Cat I approaches, its impact on the first level fleet is relatively low in terms of airborne equipment and associated cost, as it is assumed the following:

[A2-31] : the SBAS function equipage should not prevent aircraft manufacturers to equip their aircraft with ILS and MLS Cat II/III functions, as most first level aircraft are generally Cat II/III equipped.

Besides, as far as the first level fleet is concerned, costs of scenario 1B should not be higher than those of scenario 1A for the following reason : although some manufacturers may put a few additional hardware for it, the SBAS function onboard the aircraft can be considered as a software upgrade to the GNSS module. From discussion with equipment manufacturers, it is assumed that the GNSS module additional cost due to the SBAS software will be negligible, providing that SBAS (EGNOS, WAAS, etc.) are interoperable. Besides, as all GNSS modules are planned to be replaced in the early 2010's, it can be assumed in scenario 1B that the SBAS function (if needed) will be directly integrated in the new GNSS modules to be installed, so that the SBAS function would yield no specific installation costs.

In scenario 1, GLS is not considered as a potential Cat III means, because

[A2-32] : without the use of Galileo to provide redundancy for GPS, GLS will not meet the requirements for Cat III certification.

Nevertheless, as the marginal cost of including a GLS Cat I function in the new GNSS receivers is EUR 5000, it is assumed that :

[A2-33] : the new GNSS receivers that will be installed between 2010-2012 will include a GLS Cat I function.

It results from assumption [A2-32] above that there should be only two Cat III systems available over the period of analysis: ILS and MLS. From discussion with equipment manufacturers, it has been assumed the cheapest one will dominate, which would mean the following:

[A2-34] : ILS will remain the Cat III baseline equipment proposed by aircraft manufacturers for the whole period of analysis, while MLS will be an option.

The MLS option will be taken up on a case by case basis, depending mainly on the equipment of the airports where the aircraft will have to land. Decision will depend on specific business cases carried out by the concerned aircraft operators. No attempt to quantify the costs related to this optional equipment has be made in the present study.

Concerning the airborne architecture, the interviewed experts from equipment manufacturers foresee that :

[A2-35] : all new first level aircraft put into operation from 2010 onwards will be equipped with a dual MMR configuration.

That means that triplex configurations such as those of current Boeing aircraft (except B737) will disappear.

Airborne navigation systems costs per first level aircraft are assumed to be the following over the considered period of analysis :

Cost item	Unit cost (€)	Source	Qty	Remarks
ILS Cat III function (in MMR)	10 000	Discussion with avionics manufacturer	2	Including the corresponding antenna (?)
GPS II F function (in MMR) Integrating or not SBAS software	10 000	Discussion with avionics manufacturer	2	GPS II F will be about 5000 € more costly than the current GPS function SBAS function additional cost is negligible (modernised GPS receiver is already much more complex than current ones)
GLS Cat I function (in the GNSS card)	5 000	Discussion with avionics manufacturer	2	The price considered assumes the function is proposed in the baseline nav equipment.
MLS function	(30 000)**	Discussion with avionics manufacturer	0*	* equipment on a case by case basis; not quantified in the present study

				** price assuming the function is an option
GPS IIF antenna	1 200	Derived from R&C catalogue	2	
MMR/ILS/GPS IIF/GLS + antennas equip. maintenance	3 930	See remark	2	15% of equipment costs
MMR equipment installation	10 000	[INES]	2	100 Hrs at 100 €/Hr
DME scanner equipment	20 000	Discussion with avionics manufacturer	2 or 0	Includes the antenna; only concerns the fleet flying in Europe and the US
DME scanner maintenance	3 000	See remark	2 or 0	15% of equipment costs; only concerns the fleet flying in Europe and the US
DME scanner installation	10 000		2 or 0	Only concerns the fleet flying in Europe and the US; 10 Hrs at 100 €/Hr
VOR/marker beacon receiver	15 000	Discussion with avionics manufacturer	2 or 0	Only concerns the fleet flying outside Europe and the U.S.
VOR airborne equipment maintenance	2 250	See remarks	2 or 0	15% of equipment costs; only concerns the fleet flying outside Europe and the U.S. ; 10 Hrs at 100 €/Hr
VOR airborne equipment installation	10 000		2 or 0	Only concerns the fleet flying outside Europe and the U.S.; includes the antenna price.

Scenario 1 airborne costs for new first level aircraft

Cost item	Unit cost (€)	Source	Qty	Remarks
GPS II F function (in MMR) Integrating or not SBAS software	10 000	Discussion with avionics manufacturer	2 or 3	GPS II F will be about 5000 € more costly than the current GPS function SBAS function additional cost is negligible (modernised GPS receiver is already much more complex than current ones)
GLS Cat I function (in the GNSS card)	5 000	Discussion with avionics manufacturer	2 or 3	The price considered assumes the function is proposed in the baseline nav equipment.
MLS function	(30 000)**	Discussion with avionics manufacturer	0*	* equipment on a case by case basis; not quantified in the present study ** price assuming the function is an option
GPS IIF antenna	1 200	Derived from R&C catalogue	2 or 3	
MMR/ILS/GPS IIF/GLS + antennas equip. maintenance	3 930	See remark	2 or 3	15% of equipment costs (includes ILS equipment maintenance)
GPS IIF/GLS functions integration + GPS IIF antenna installation	7 000	Discussion with avionics manufacturer	2 or 3	
DME scanner maintenance	3 000	See remark	2 or 0	15% of equipment costs; only concerns the fleet flying in Europe and the US
VOR airborne equipment maintenance	2 250	See remarks	2 or 0	15% of equipment costs; only concerns the fleet flying outside Europe and the U.S. ; 10 Hrs at 100 €/Hr

Scenario 1 airborne costs for “old” (pre-2010) first level aircraft

2.4.6.2 Second level aircraft

2.4.6.2.1 Turboprops

In scenario 1, 2 types of conventional navigation means will be maintained in operation in the world: DME in Europe and the U.S. and VOR in the rest of the world. Consequences on the turboprops fleet equipage are assumed to be the following:

[A2-36] turboprops aircraft that fly in Europe and the U.S will still be DME-equipped for the whole 2010-2024 period.

[A2-37] turboprops aircraft that fly outside Europe and the U.S. will still be VOR equipped for the whole 2010-2024 period.

Similarly to the first level fleet, it is expected that turboprops will go for "modernised GPS" some time between 2010 and 2012. This implies replacing the existing GPS receiver by a new one, and also changing the antenna.

[A2-38] GPS II/F receivers and the corresponding antenna will be installed in all turboprop aircraft between 2010 and 2012.

Concerning precision approach system, it is assumed that GPS+SBAS enables near Cat I operations and that, in the early 2010's, "modernised GPS"+SBAS would enable full Cat I operations world-wide.

[A2-39] in scenario 1B, all turboprops will be SBAS equipped from 2010-2012 onwards (with GPS II/F upgrade combined with SBAS functions in a single retrofit operation)

[A2-40] : in scenario 1B, no ILS Cat I equipment would be installed in brand new aircraft from 2010 onwards.

[A2-41] : in scenario 1B, ILS Cat I equipment of the aircraft manufactured before 2010 would still be maintain up to 2016.

Thus, no specific GLS airborne equipment is taken into account in scenario 1B.

In scenario 1A, Cat I capability could be provided by either ILS or GLS. Transition is assumed to take place around 2013.

[A2-42] : in scenario 1A, ILS Cat I equipment would be installed in brand new aircraft up to 2015 for transition reasons. Beyond this year, a similar VHF equipment will still be required to process GLS signals.

Indeed, beyond 2018, assuming GLS would have replaced ILS Cat I systems on the ground side, the airborne segment should still include a VHF receiver and data processing chain similar to the ILS one for processing MLS signals.

[A2-43] : in scenario 1A, all turboprops will be GLS Cat I equipped from 2010 onwards (GPS IIF + GLS functions grouped installation).

Airborne navigation systems costs per turboprop aircraft are assumed to be the following in the period of analysis :

Cost item	Unit cost (€)	Source	Qty	Remarks
GNSS equipment • Scenario 1A : GPS IIF + GLS Cat I functions in NPU • Scenario 1B : GPS IIF function in NPU, integrating SBAS or not	 7 500 5 000	Discussion with avionics manufacturers	1	50% of FL1 equipment costs SBAS function should not increase dramatically the price of the GNSS card, so that even aircraft not flying in the SBAS covered regions will have similar equipment costs.
GPS IIF antenna	1 200	Derived from R&C catalogue	1	
GNSS equip. Maintenance • Scenario 1A • Scenario 1B	 1 305 930	See remarks	1	15% of equipment cost
GNSS equipment installation • Scenario 1A • Scenario 1B	 10 000 3 750	 Discussion with avionics manufacturers See remarks	1	 50 Hrs at 75 €
ILS Cat I (/II) function (or similar equipment necessary to process GLS signals beyond 2020)	10 000	See remarks	0 or 1	No equipment in scenario 1B. ILS or similar equipment required in scenario 1A for the whole period of analysis
ILS Cat I (/II) equipment maintenance	1 500	See remarks	0 or 1	15% of equipment cost
ILS Cat I (/II) function installation	2 500	See remarks	0 or 1	ILS function is included in the autopilot; installation costs mainly concern the antenna; includes the antenna price
DME scanner equipment	10 000	Discussion with avionics manufacturers	0 or 1	Includes the antenna; only concerns the fleet flying in Europe and the US
DME scanner maintenance	1 500	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying in Europe and the US
DME scanner installation	3 750	See remarks	0 or 1	50 Hrs at 75 €; only concerns the fleet flying in Europe and the US
VOR/marker beacon receiver	7 500	Discussion with avionics manufacturers	0 or 1	Only concerns the fleet flying outside Europe and the US
VOR airborne equipment maintenance	1 125	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying outside Europe and the US
VOR airborne equipment installation	3 750	See remarks	0 or 1	50 Hrs at 75 €; only concerns the fleet flying outside Europe and the US; includes the antenna price

Scenario 1 airborne costs for brand new turboprop aircraft

Cost item	Unit cost (€)	Source	Qty	Remarks
GNSS equipment • Scenario 1A :GPS IIF + GLS Cat I functions in NPU • Scenario 1B : GPS IIF function in NPU, integrating SBAS or not	 7 500 5 000	Discussion with avionics manufacturers	1	50% of first level aircraft equipment costs SBAS function should not increase dramatically the price of the GNSS card, so that even aircraft not flying in the SBAS covered regions will have similar equipment costs
GPS IIF antenna	1 200	Derived from R&C catalogue	1	
GNSS equip. Maintenance • Scenario 1A • Scenario 1B	 1 305 930	See remarks	1	15% of equipment cost
GNSS equipment installation • Scenario 1A • Scenario 1B	 12 000 3 750	 Discussion with avionics manufacturer See remarks	1	 Including ILS upgrade for the GLS function 50 Hrs at 75 €
ILS Cat I (/II) equipment maintenance	1 500	See remarks	0 or 1	15% of equipment cost; no maintenance beyond 2016 in scenario 1B
DME scanner maintenance	1 500	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying in Europe and the US
VOR airborne equipment maintenance	1 125	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying outside Europe

Scenario 1 airborne costs for "old" (pre-2010) turboprop aircraft

2.4.6.2.2 Regional jets

As said in section 2.4.4, regional jets avionics will not be very different from the avionics of domestic and international jetliners.

2.4.7 Scenario 2 assumptions

2.4.7.1 First level aircraft

In scenario 2, it is assumed that all DME networks (including the North American and the European ones) are progressively decommissioned :

[A2-44] : in the period of analysis, the airborne DME equipment will be no longer necessary for the first level fleet : brand new aircraft from 2010 will be no longer DME equipped and the equipment of older aircraft will not be maintained anymore.

It should be noticed that the previous assumption may appear quite straightforward with no long transition period but it is a choice in the present exercise not to quantify all the limited side effects in order not to complicate too much the model.

Similarly, the remaining VOR networks outside Europe and the US will be progressively decommissioned.

[A2-45] : in the period of analysis, the airborne VOR equipment will be no longer necessary for the first level fleet: brand new aircraft from 2010 will be no longer VOR equipped and the equipment of older aircraft will not be maintained anymore.

Concerning GNSS equipment, as per scenario 1 aircraft operators are expected to go for GPS IIF between 2010-2012, and it can be reasonably estimated in scenario 2 that manufacturers will offer combined MMR and therefore aircraft operators will directly go for Galileo at the same time, replacing their existing GPS modules by a GPS IIF + Galileo modules (for MMR). Antennas will need to be replaced as well.

Besides, as for precision approach, scenario 2 is based on the progressive replacement of ILS by GBAS systems: GLS should be certified Cat I before 2009, and as the GLS Cat I function mainly consists of a software upgrade in the GNSS module, it can be reasonably assumed that when changing the GNSS module, all first level aircraft operators will equip their fleet with a GPS IIF + Galileo + GLS Cat I module.

[A2-46] : GPS IIF + Galileo + GLS Cat I module and corresponding antenna will be installed in all first level aircraft between year 2010 and year 2012 (GLS would use the ILS antenna).

Using Galileo signals, GLS should reach Cat III certification by year 2015 at the latest. Assuming such a certification could take place around 2013, it could be assumed that GLS Cat III will have fully replaced ILS in 2020. With such a time schedule, the proposed assumptions concerning the airborne segment are the following:

[A2-47] : brand new aircraft will be ILS Cat III equipped up to 2020 for transition reasons. Beyond this year, a similar VHF equipment will still be required anyway to process GLS signals.

[A2-48] : brand new aircraft will be GLS Cat III equipped from 2013. Aircraft produced before that year will be retrofitted with GLS Cat III between 2014 and 2016.

Airborne navigation systems costs per first level aircraft are assumed to be the following in the period of analysis :

Cost item	**Unit cost (€)**	**Source**	**Qty**	**Remarks**
ILS Cat III function (in MMR) (or similar equipment necessary to process GLS signals beyond 2020)	10 000	Discussion with avionics manufacturer	2	Including the corresponding antenna (?)
GPS IIF + Galileo function (in MMR) Integrating or not SBAS software	15 000	Discussion with avionics manufacturer	2	GPS II F + Galileo will be about 10 000 € more costly than the current GPS function SBAS function additional cost is negligible (modernised GPS receiver is already much more complex than current ones)
GLS Cat I function (in the GNSS card)	5 000	Discussion with avionics manufacturer	2	The price considered assumes the function is proposed in the baseline nav equipment.
GLS Cat III function	5 000	Discussion with avionics manufacturer	0 or 2	Available only from 2013
MLS function	(30 000)**	Discussion with avionics manufacturer	0*	* equipment on a case by case basis; not quantified in the present study ** price assuming the function is an option
GPS IIF/Galileo antenna	1 200	Rockwell Collins catalogue	2	
MMR/ILS/GPS IIF/Galileo/ GLS + antennas equip. Maintenance • GLS Cat I only • GLS Cat III	 4 680 5 430	See remark	2	15% of equipment costs
MMR equipment installation	10 000	[INES]	2	100 Hrs at 100 €/Hr

Scenario 2 airborne costs for brand new first level aircraft

Cost item	Unit cost (€)	Source	Qty	Remarks
GPS IIF + Galileo function (in MMR) Integrating or not SBAS software	15 000	Discussion with avionics manufacturer	2 or 3	GPS II F + Galileo will be about 10 000 € more costly than the current GPS function SBAS function additional cost is negligible (modernised GPS receiver is already much more complex than current ones)
GLS Cat I function (in the GNSS card)	5 000	Discussion with avionics manufacturer	2 or 3	The price considered assumes the function is proposed in the baseline nav equipment.
MLS function	(30 000)**	Discussion with avionics manufacturer	0*	* equipment on a case by case basis; not quantified in the present study ** price assuming the function is an option
GPS IIF/Galileo antenna	1 200	Rockwell Collins catalogue	2 or 3	
MMR/ILS/GPS IIF/Galileo/ GLS + antennas equip. Maintenance • GLS Cat I only • GLS Cat III	 4 680 5 430	See remark	2 or 3	15% of equipment costs (includes ILS function maintenance)
GPS IIF/Galileo/GLS functions integration + GPS IIF antenna installation	7 000	Discussion with avionics manufacturer	2 or 3	Retrofit between 2010 and 2012
GLS Cat III function	5 000	Discussion with avionics manufacturer	2 or 3	Retrofit between 2014 and 2016
GLS Cat III function integration	5 000	TBC	2 or 3	Retrofit between 2014 and 2016
GLS Cat III function maintenance	750		2 or 3	15% of equipment costs

Scenario 2 airborne costs for "old" (pre-2010) first level aircraft

2.4.7.2 Second level aircraft

2.4.7.2.1 Turboprops

In scenario 2, VOR and DME networks are supposed to be progressively decommissioned all over the world. Without any conventional means available, it is foreseen that turboprops will require to be fitted with at least dual NPU/GNSS equipment configuration. However, a dual configuration would mean a not cost-beneficial retrofit for the oldest turboprops and it is likely that few turboprops operators will go for such an operation. Thus, the following assumptions have been made :

[A2-49] brand new turboprops (produced from 2010 onwards) will no longer be VOR nor DME equipped.

[A2-50] regarding the aircraft produced before 2010, the part of the fleet flying in Europe and the US will still use the decreasing number of DME stations as long as possible and the corresponding airborne DME equipment will be maintained operational up to the end of the aircraft life. This should have an impact on charging mechanisms (cf. section 2.4.8.3).

[A2-51] regarding the aircraft produced before 2010, the part of the fleet flying outside Europe and the US will still use the decreasing number of VOR stations as long as possible and the corresponding airborne VOR equipment will be maintained operational up to the end of the aircraft life. This should have an impact on charging mechanisms (cf. section 2.4.8.3).

Concerning the avionics architecture, the assumption is the following :

[A2-52] only brand new brand new turboprops (produced from 2010 onwards) will be fitted with a dual NPU/GNSS equipment configuration.

As for "modernised GPS" and Galileo, it is assumed that Galileo will foster the deployment of GLS (notably GLS Cat III) so that :

[A2-53] : all turboprop aircraft all over the world will go for Galileo+GPS2+GLS Cat I receivers/functions between 2010 and 2012 (single equipment for "old" aircraft, dual for brand new ones).

However for transition reasons it is assumed that:

[A2-54] ILS equipment will be installed in brand new aircraft up to 2013. Beyond this date similar equipment will still be installed to receive and process GLS signals.

Airborne navigation systems costs per turboprop aircraft are assumed to be the following in the period of analysis :

Cost item	**Unit cost (€)**	**Source**	**Qty**	**Remarks**
GPS IIF + Galileo+ GLS Cat I card Integrating SBAS or not	10 000	Discussion with avionics manufacturers	2	
GPS IIF/Galileo antenna	1 200	See remark	2	
GNSS equipment maintenance	1 680	See remark	2	15% of equipment cost
GNSS equipment installation	3 750	See remark	2	50 Hrs at 75 €/Hr
NPU/CDU/ACU (additional equipment)	20 300	See remark	1	50% of catalogue price if baseline equipment
NPU/CDU/ACU maintenance	3 045	See remark	1	15% of equipment cost
NPU/CDU/ACU installation	3 750	See remark	1	50 Hrs at 75 €/Hr
ILS Cat I (/II) function (or similar equipment necessary to process GLS signals beyond 2013)	10 000	See remarks	2	Installation of ILS Cat I up to 2013 and similar equipment beyond
ILS Cat I (/II) equipment maintenance	1 500	See remarks	2	15% of equipment cost
ILS Cat I (/II) function installation	2 500	See remarks	2	ILS function is included in the autopilot; installation costs mainly concern the antenna; includes the antenna price

Scenario 2 airborne costs for new turboprop aircraft

Cost item	Unit cost (€)	Source	Qty	Remarks
GPS IIF + Galileo+ GLS Cat I card Integrating SBAS or not	10 000	Discussion with avionics manufacturers	1	Retrofit between 2010 and 2012
GPS IIF/Galileo antenna	1 200	See remark	1	Retrofit between 2010 and 2012
GNSS equipment maintenance	1 680	See remark	1	15% of equipment cost
GNSS equipment installation	3 750	See remark	1	50 Hrs at 75 €/Hr; retrofit between 2010 and 2012
ILS Cat I (/II) equipment (or similar equipment for GLS) maintenance	1 500	See remarks	2	15% of equipment cost
DME scanner maintenance	1 500	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying in Europe and the US
VOR airborne equipment maintenance	1 125	See remarks	0 or 1	15% of equipment cost; only concerns the fleet flying outside Europe

Scenario 2 airborne costs for "old" (pre-2010) turboprop aircraft

2.4.8 ATS charges

2.4.8.1 Existence of transparent cost recovery mechanisms

In countries with a cost recovery mechanism in place, the rationalisation of the navigation infrastructure should have a direct and transparent impact on user charges.

This is in principle the case in ECAC (covered by the Multilateral Agreement on Route Charges), in Canada, in a number of countries of the Far East such as Japan, New Zealand and Australia and of South America which have independent cost recovery mechanisms in place.

This is not the case in the USA, where FAA's budget is covered by fuel taxes. However plans exist to put together cost-related charging mechanisms (eventually as part of corporatisation or privatisation of the FAA).

This is not the case in a number of countries, where the benefits of the rationalisation of the ground infrastructure might not accrue to the aviation community nor to the travelling public.

The European Community should act so that the European citizens can receive the full benefits of the GNSS solutions.

2.4.8.2 ECAC situation concerning cost-recovery mechanisms per phases of flight

In ECAC, the level of charges for en-route is known and is of about EUR 5 billion per annum. Levels of charges for terminal navigation and precision approach however are not precisely known. PRR4 has estimated TN charges at around EUR 1,100 million per annum.

We assume that en-route charges include 2/3 of the cost of the en-route plus TMA ground infrastructure.

We assume that terminal navigation charges include 1/3 of the cost of the en-route plus TMA ground infrastructure plus the cost of the final approach aerodrome facilities (Cat I/II/III landing facilities).

Based on the above assumptions, the annual savings linked to a GNSS sole service reach EUR 30 million for the en-route and EUR 170 million for the terminal and landing phases of flight.

The European Community should act so that the benefits of the GNSS solutions are properly allocated to the actual users of the infrastructure.

2.4.8.3 ECAC situation concerning cost-recovery mechanisms per categories of customers

Charging mechanism do not differentiate categories of users, to take into account the actual utilisation of the ground infrastructure by the different categories of users. In the situation where it would be necessary to maintain a conventional infrastructure to accommodate operators unwilling to equip with INS / IRS, or dual NPU/GNSS the European Commission should consider setting up separate charging mechanisms.

2.4.8.4 ECAC long-term impact on en-route charges

Total en-route charges in ECAC in 2002 should reach about EUR 5 billion.

In order to accommodate a traffic equivalent to twice the traffic of 2002, a new ATM concept based on delegation of separation should have been put together by 2015. The control functions will be of strategic nature, with tactical functions in place only in case of emergency/contingency (see Part 3 of the Report).

The assumption is therefore made that the cost of ATM en-route around 2015 will be similar to the cost of 2002 (in constant EUR) at around EUR 5 billion per annum.

Savings of EUR 30 millions per annum would therefore represent savings of around 0.6% of the en-route cost base recorded at that time.

2.4.8.5 ECAC long term impact on Terminal Navigation charges

Total TN charges in ECAC in 2002 should reach about EUR 1.2 billion. It is unclear if this amount includes the cost of landing capabilities and the situation is probably different from one country to the other.

In order to accommodate a traffic equivalent to twice the traffic of 2002, modifications to the current practices will be put in place. However, they will not go as far as a full delegation of separation to the pilot and should be limited to delegation of spacing responsibility plus major reorganisation of the TMAs, real time sequencing and improved operations under LVP.

The assumption is made that the cost of ATM in ECAC terminal areas will be 50% higher than the cost registered in 2002 (in constant EUR) at around EUR 1.8 billion per annum.

Saving of EUR 20 millions per annum on the conventional terminal infrastructure plus a net value of EUR 150 millions on the aerodrome infrastructure will represent savings of around 10% of the TN cost base recorded at that time.

2.4.8.6 Regions other than ECAC: long term impact on charges

Assuming a cost recovery mechanism in place, similar to the ECAC mechanism, similar cost structures and subject to the limitations identified above, we can consider that the impact would be similar.

2.5 Differential analysis between the 2 scenarios

We have processed the assumptions made on the equipment for the first and second level aircraft, and collated them with the assumptions made on the navigation infrastructure in both scenarios and we have obtained, on a world-wide basis, the following results:

Ground infrastructure: the GNSS-2 scenario combining GPS and Galileo would allow Civil Aviation to save about EUR 2,050 millions with respect to the GNSS-1 scenario, because it would allow for the decommissioning (or non-replacement) of a network of conventional en route navaids and of CAT2/3 landing capabilities.

Avionics: GNSS-2 would save a minimum of EUR 1,050 million, corresponding mainly to the cost of DME scanners (including maintenance) in ECAC and the US, and of VOR systems (including maintenance) in the rest of the world.

Total: The introduction of Galileo as the second independent constellation of GNSS-2 would be the political push permitting to provide some EUR 3 billions world-wide savings for air navigation.

For ECAC alone, the savings brought by GNSS-2 are in the order of EUR 850 millions.

The actual benefits that could be derived from the introduction of Galileo could be larger e.g. through a reduction in the number of required INS/IRS units to two rather than three on certain first level aircraft.

2.6 Identification of additional side benefits

2.6.1 Reduced service interruption for Cat I operations at secondary airports

SBAS CAT1 or GBAS CAT1 will allow to operate CAT1 approaches at runways which are not equipped with CAT1 ILS and where traffic levels do not justify the investment in ILS plus lighting systems.

The EGNOS 1999 CBA had not taken into account – due to lack of time - either the influence of wind on altitude minima or the cost of lighting.

However, benefits accruing from reduced interruptions of traffic at secondary runways are not negligible. This would be even truer as traffic keeps growing and the hubbing concept develops, requiring increasing adherence to tighter schedules.

The cost-benefit analysis had determined discounted savings of EUR 220 million for ECAC countries. Basic assumptions were that:

- 75% of the interruptions would result in delays, at an average cost of EUR 720 per delay;
- 20% would result in re-routings at an average cost of EUR 4060 per re-routing;
- 5% would result in cancellations at an average cost of EUR 5700 per cancellation.

Such assumptions were based on a European environment and should be refined to better reflect the world-wide nature of GNSS.

2.6.2 Decision heights better than Cat I operations

On the assumption (2.1.3.3) that GPS IIF + SBAS offer Cat I landing capability, GPS II F + SBAS (eventually on both frequencies) plus Galileo should offer much better than Cat I landing capability, reducing the existing gap between Cat I and Cat II capability.

The effective impact is unknown and should be subject to a detailed cost-benefit analysis, taking into account local circumstances and other costs, such as avionics costs (database in FMS) and cost of lighting.

2.6.3 Safety benefits

Although it is not possible or desirable to quantify them, the safety benefits linked to the availability of NPA world-wide and of a single and seamless navigation system must be highlighted.

2.6.4 Asset value

A single navigation system on board all aircraft will increase the marketability of the fleet, therefore increasing the asset value of the aircraft and of the operators.

2.7 Conclusion

It results from this CBA analysis that the benefits expected from GNSS are large and mainly relate to the decommissioning (or non-deployment) of ILS (Cat I but also Cat II/III) and in decommissioning the conventional en-route navaids on a world-wide basis.

The main potential contribution of Galileo to obtaining such benefits is, for safety and political reasons, to make possible the decommissioning of one network of ground navaids and of CAT2/3 landing aids.

Other benefits listed above are not quantified at this early stage and should be investigated in detail by the time when Galileo's deployment and its guarantee of service are under way.

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